Version 2

Contaminant Loss Risk Index Tool

Technical Document

Taputapu Tauine Mōrearea Ngaromanga Matū Tāoke

Tuhinga Haungarau

Ministry for the Environment
Manatū Mō Te Taiao

Te Kāwanatanga o Aotearoa
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This Technical Document was updated by the Ministry for the Environment in 2025, to improve clarity and update the document to include new data. The changes were made to reflect decisions made by the Technical Working Group and the changes have been reviewed by members of this group.

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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 to identify 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 (McDowell et al, 2025). The Ministry acknowledges that further work is needed to address limitations and challenges around the assumptions of the data used by 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]

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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:

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

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 at risk of N loss from land 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.

Ministry for the Environment guidance

The Ministry provides three guides to help implement the Risk Index Tool

1. **Contaminant Loss Risk Index Tool: Implementation Guidance for Regulators**
   This guide will help councils understand the potential use of the RIT as an informative tool for regulatory-based decision-making. It provides guidance on the tool's application, including how the RIT should not be used. The guide includes 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.

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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.

2. **Contaminant Loss Risk Index Tool: Understanding Scores and Heatmaps**
   This guide outlines what the different scores and heatmaps show and how they could be used to inform decision-makers. Its audience is councils and tool users.
3. **Contaminant Loss Risk Index Tool: How to Enter and Maintain Your Farm Data and Account**
   This guide provides farmers, growers and nutrient and farm advisors with step-by-step instructions on how to spatially map and block their farm or orchard, enter the required data, and complete the risk assessment.

Introduction

The scientific details of the RIT framework described in this document are implemented to operate as a web-based application with a geographic information system- (GIS-) based graphical 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.

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.

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]

Various risk scores are presented to users. There are aggregated risk scores (totals) and per hectare risk scores (total scores divided by area). Areas of varying risks are also shown to the user in the form of heatmaps based off these scores.

The tool also presents scores as **baseline risk** and **overall 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] The **baseline risk** can also be altered if the user runs additional reports or scenarios which adopt practices or actions which alter the sources and quantities of N. The **overall risk** of N loss is determined by modification of the **baseline risk**, through actions or practices that do not impact the amount of N applied.

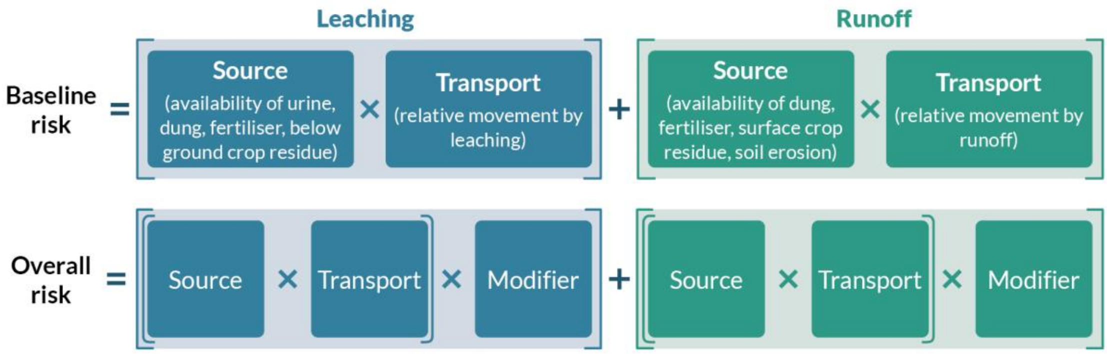
If actions and practices alter sources and the **baseline risk**, we term them mitigations.

If actions and practices act outside of sources and alter the **overall risk**, we term them modifiers (figure 1).

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.

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



In equation form, monthly baseline risk is calculated as:

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

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

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, 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.

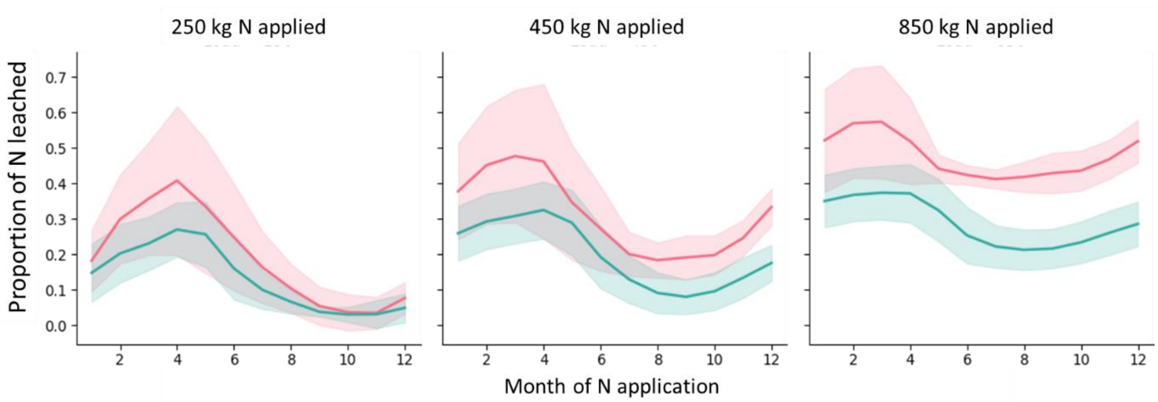
Process to estimate baseline nitrogen-loss risk

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 (Holzworth et al, 2014), 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 is articulated through the Ministry's Risk Index Tool: Phase one implementation guidance.

For each of these blocks there is a matching estimate of the 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.

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 15^{th} of the month divided by 200 (which was the 98^{th} 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 per-hectare risk scores are generated, the risk of N loss cannot be assumed to be – 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).

The combinations modelled in APSIM within and across blocks use:

- 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,

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7 See www.apsim.info for more information.

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

2008; Tait et al, 2006), or corrections to account for gaps around coastlines, from 1978 to 2018 (41 application-years)[9]

- 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
- 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 in 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).

Transport risks are a risk scaling factor (ie, multiplier) rather than the proportion of the source being transported – meaning that the outputs are related to the amount of N lost but cannot be taken as proportionate to the amount of N lost. The RIT output is dimensionless.

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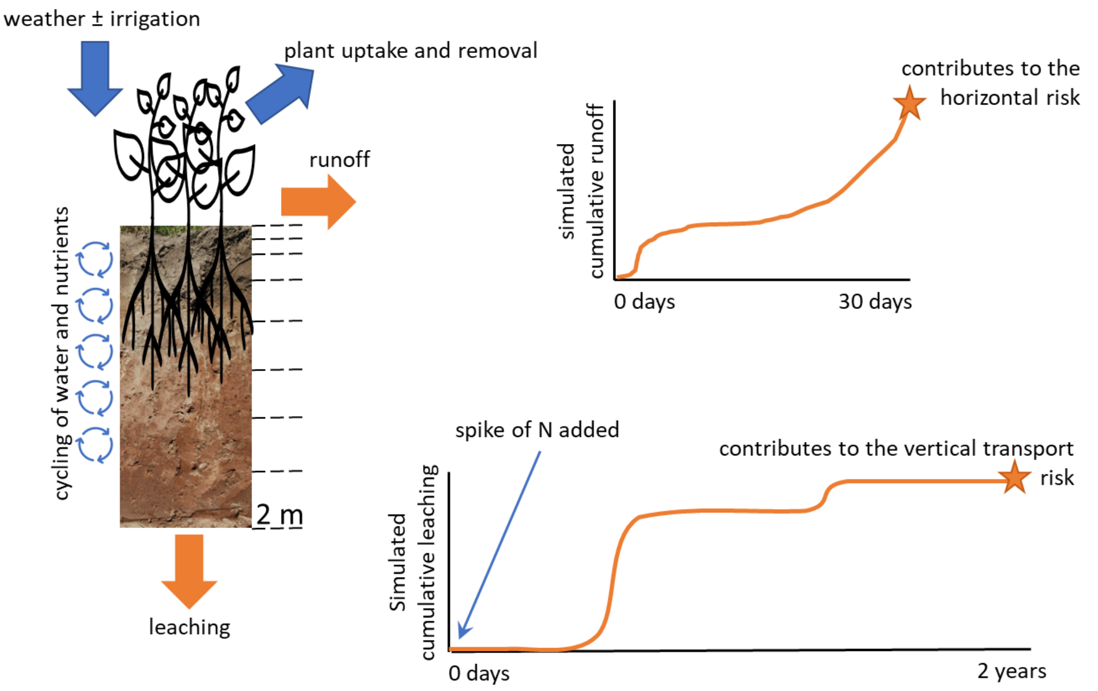
9 It is acknowledged that gaps exist in the VCSN in (primarily) coastal areas. This will be addressed through the RIT back-end calculator functions, using proximate network data.

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

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 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 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 **modifying** runoff and leaching risks after baseline risk has 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 perennial horticulture), flow path (runoff or leaching), and then applied by modifying baseline risk scores to give overall scores.

We term those practices that adjust the risk of N loss after calculating baseline risk as **modifiers**.

If users want to model an adjustment to their baseline risk, they need to run a separate scenario. In this scenario, they alter the sources of their inputs (stock type, quantity, fertiliser use, crop types) which gives them a different baseline risk.

We term practices that alter baseline risk by adjusting the source of N as **mitigations**.

Most changes for mitigations, such as changing fertiliser inputs, or stocking rate (which alters urine and dung N inputs) are determined by user inputs. In the future and after further development users may be able to select mitigations like they currently do for modifiers. For now users will be presented with mitigation options in their reports – the provision of these options will be 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

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[11]. For modifiers, it is assumed the calculation applies them 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 x 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 (see table 2 for an example of its structure and appendix E for the full table). 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.

[11] No modifier is 0 as there will never be no risk, no modifier is 1 as there would be no change to the risk.

Table 2: Example listings for constructed wetlands modified after filtering for enterprise (all excluding forestry) 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 12^{o}C. Excludes highly permeable soils not able to sustain a wetland.	Slope less than 15^{o}, 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 12^{o}C. Excludes highly permeable soils not able to sustain a wetland.	Slope less than 15^{o}, precipitation 800–1,600 mm	R = 0.64, L= 0.82	Tanner et al, 2022; Tanner and Kadlec, 2013; Tanner and Sukias, 2011

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.

Testing 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, Holzworth et al. 2014, or SPASMO, Green et al, 2003) observations for known locations; 58 observations were of total N (TN) and 124 observations were of nitrate-N.

Amongst land uses were 3 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 alone. 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 Nloss 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.

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 Te Ture Whenua (Māori land) than general 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

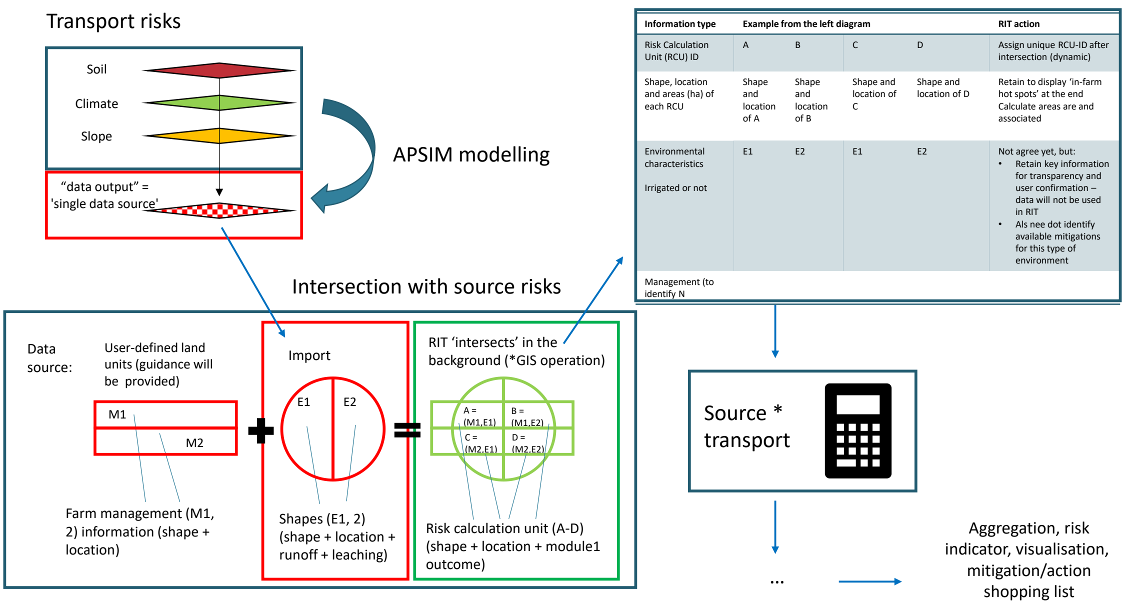
Users block land and enter at the block scale. The underpinning map layer, generated through APSIM modelling, defines the soil type, slope and climate. This layer consists of a mosaic of polygons with consistent soil type, slope and climate data.

The N-loss risk associated with the block-scale user inputs is distributed evenly (ie, by an area-weighted distribution) across the polygons (or risk calculation units) at the soil type by slope by climate by management intersection; see figure 5 for intersection.

Leaching and runoff risks are calculated **separately** but are aggregated to provide total risk scores at the block and farm level. These scores are also divided by area to give a weighted average score (per hectare).

These baseline scores are then adjusted by users selecting modifiers which reduce the risk score. This adjusted score is termed the overall score. This is also presented as an aggregated total and a weighted average (per hectare).

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, a total score (R_{total}, ie, the aggregated score) will be calculated as the sum of the product of risk for each of the spatial units (polygons) (*R_rcu*; ie, soil type by slope by climate intersection intersected to farm block):

$$R_{total} = \sum (R_{rcu} \times Area_{rcu})$$

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 (polygons)

(*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).

To mitigate the risk of the aggregation at block and farm level of overly discounting an area of very high risk from a small fraction of the farm area, the tool produces heatmaps at the polygon level. Two heatmaps are produced using the aggregated and per-hectare scores of each risk calculation unit.

Further, 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).

Within the tool, unproductive land is currently treated as if it were exotic forestry, with erosion and leaching considered to be the only sources of N-loss risk. This is incorrect, unproductive land should be treated as native forest. See appendix C for how erosion risk is calculated. This will be resolved in a future release of the tool.

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 within APSIM and generated a single layer across the country. Increased risks from poorly designed/managed irrigation may be covered as a modifier in a future version.
- 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 N-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).

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Appendix A: Animal nitrogen inputs via urine and faeces

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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:

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

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.

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
Auckland	Milking cows – mature	Oct	10.78	7.89	2.89
Auckland	Milking cows – mature	Nov	10.05	7.36	2.69

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	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
BOP	Milking cows – mature	May	8.89	6.51	2.38
BOP	Milking cows – mature	Jun	7.37	5.39	1.97

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	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
BOP	Breeding bulls	Dec	7.84	5.74	2.1
Canterbury	Milking cows – mature	Jan	12.59	9.22	3.37

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	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
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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
Canterbury	Breeding bulls	Jul	8.93	6.54	2.39
Canterbury	Breeding bulls	Aug	8.77	6.42	2.35

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	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
Gisborne	Breeding bulls	Feb	7.38	5.4	1.98
Gisborne	Breeding bulls	Mar	9.42	6.9	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
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
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

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	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
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†*

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	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
Marlborough	Growing heifers – 0–1	Nov	2.14	1.56	0.57
Marlborough	Growing heifers – 0–1	Dec	2.53	1.85	0.68

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 – 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
Nelson	Growing heifers – 0–1	Jun	4.67	3.42	1.25
Nelson	Growing heifers – 0–1	Jul	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
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
Northland	Growing heifers – 0–1	Jan	2.89	2.12	0.77
Northland	Growing heifers – 0–1	Feb	2.87	2.1	0.77

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	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
Otago	Milking cows – mature	Aug	9.59	7.02	2.57
Otago	Milking cows – mature	Sep	13.53	9.91	3.62

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	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
Southland	Milking cows – mature	Mar	13.77	10.08	3.69
Southland	Milking cows – mature	Apr	11.91	8.72	3.19

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	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
Southland	Breeding bulls	Oct	7.63	5.59	2.04
Southland	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
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
Taranaki	Breeding bulls	May	9.36	6.86	2.51
Taranaki	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
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
Tasman	Growing heifers – 1–2	Dec	5.87	4.3	1.57
Tasman	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
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†*
Waikato	Growing heifers – 1–2	Jul	5.27	3.86	1.41
Waikato	Growing heifers – 1–2	Aug	5.52	4.04	1.48

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	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
Wellington	Growing heifers – 1–2	Feb	6.09	4.46	1.63
Wellington	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
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**
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

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	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

Alpacas

A proxy of mature breeding ewes is adopted for the N contribution from alpaca.

Table A.5: Nitrogen (N) excretion rates for alpaca using breeding ewes as a proxy (2021–22)

Class	Month	Total excreta kg N/head/month	Nitrogen excreted in urine kg N/head	Nitrogen excreted in faeces kg N/head
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

All other livestock

All other livestock equations use the annual N excretion number ($N_{(ex)}$) and distribute the N-loss risk across the months by the number of days in each month (February is always assumed to be 28 days and does not account for leap years). Users enter the number of animals on the property for each month and their distribution across the different blocks.

Outdoor pigs

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

Monthly N_{ex} = head x monthly N_{ex} factor

where:

- monthly N_{ex} — Excreted nitrogen in kilograms per month
- head — Number of animals on the block for the month – **a user-inputted figure**
- monthly N_{ex} factor — Total Nex per head / 365 days x days in the month

Table A.6: Total annual nitrogen (N) excretion rates for outdoor pigs and sows (2021–22)

Pig type	Total N_{ex} (kg N/year/head)
Outdoor pigs	11.05
Outdoor sows	11.05

Table A.7: Estimated monthly nitrogen (N) excretion rates for outdoor pigs and sows (2021–22)

Note: All pigs classes are called outdoor as the tool does not consider indoor pigs and barn litter.

Class	Month	Monthly excreta = kg N/head
Outdoor pigs	Jan	0.938
Outdoor pigs	Feb	0.848
Outdoor pigs	Mar	0.938
Outdoor pigs	Apr	0.908
Outdoor pigs	May	0.938
Outdoor pigs	Jun	0.908
Outdoor pigs	Jul	0.938
Outdoor pigs	Aug	0.938
Outdoor pigs	Sept	0.908
Outdoor pigs	Oct	0.938
Outdoor pigs	Nov	0.908
Outdoor pigs	Dec	0.938
Outdoor sows	Jan	0.938
Outdoor sows	Feb	0.848
Outdoor sows	Mar	0.938
Outdoor sows	Apr	0.908
Outdoor sows	May	0.938
Outdoor sows	Jun	0.908
Outdoor sows	Jul	0.938
Outdoor sows	Aug	0.938
Outdoor sows	Sept	0.908
Outdoor sows	Oct	0.938
Outdoor sows	Nov	0.908
Outdoor sows	Dec	0.938

Note: NZ Pork 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.

The GHG Inventory uses the terms breeding pigs and growing pigs. The RIT continues to use ‘outdoor pigs’ and ‘outdoor sows’ as the tool does not consider barn raised pigs and the removal of barn litter.

Poultry

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

Monthly N_{ex} = head x monthly N_{ex} factor

where:

- monthly N_{ex} Excreted nitrogen in kilograms per month
- head Number of animals on the block for the month – **a user-inputted figure**
- monthly N_{ex} factor Total Nex per head / 365 days x days in the month

Table A.8: Total annual nitrogen (N) excretion rates for outdoor poultry classes (2021–22)

Poultry type	Total N_{ex} (kg N/ year/ head)
Broilers	Total N_{ex} = 0.39
Layers	Total N_{ex} = 0.42
Other (including ducks, turkeys, emus, ostriches)	Total N_{ex} = 0.60

Duck, turkey, emu and ostrich are all assumed to have the same annual N_{ex} number. The Greenhouse Gas Inventory notes the very small national herd size of emu and ostrich. While the N loss for these animals is likely higher, the population size means there is unlikely to be a big impact on scores.

Table A.9: Estimated monthly nitrogen (N) excretion rates for outdoor poultry classes (2021–22)

Note: All poultry classes are called outdoor as the tool does not consider indoor poultry and barn litter.

Class	Month	Monthly excreta = kg N/head
Outdoor broilers	Jan	0.033
Outdoor broilers	Feb	0.030
Outdoor broilers	Mar	0.033
Outdoor broilers	Apr	0.032
Outdoor broilers	May	0.033
Outdoor broilers	Jun	0.032
Outdoor broilers	Jul	0.033
Outdoor broilers	Aug	0.033
Outdoor broilers	Sept	0.032
Outdoor broilers	Oct	0.033
Outdoor broilers	Nov	0.032
Outdoor broilers	Dec	0.033
Outdoor layers	Jan	0.036
Outdoor layers	Feb	0.032
Outdoor layers	Mar	0.036
Outdoor layers	Apr	0.035
Outdoor layers	May	0.036
Outdoor layers	Jun	0.035

Class	Month	Monthly excreta = kg N/head
Outdoor layers	Jul	0.036
Outdoor layers	Aug	0.036
Outdoor layers	Sept	0.035
Outdoor layers	Oct	0.036
Outdoor layers	Nov	0.035
Outdoor layers	Dec	0.036
Outdoor other	Jan	0.051
Outdoor other	Feb	0.046
Outdoor other	Mar	0.051
Outdoor other	Apr	0.049
Outdoor other	May	0.051
Outdoor other	Jun	0.049
Outdoor other	Jul	0.051
Outdoor other	Aug	0.051
Outdoor other	Sept	0.049
Outdoor other	Oct	0.051
Outdoor other	Nov	0.049
Outdoor other	Dec	0.051

Outdoor poultry have been included within the tool at this time but should still be treated with caution. Barn raised poultry have been excluded as further work is required to allow for the removal of barn litter off site. Further, the modifiers that may appear for outdoor poultry may not be appropriate to select due to the way modifiers are filtered. There are no poultry specific modifiers within the tool.

Goats

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

Monthly N_{ex} = head x monthly N_{ex} factor

where:

- monthly N_{ex} Excreted nitrogen in kilograms per month
- head Number of animals on the block for the month – **a user-inputted figure**
- monthly N_{ex} factor Total Nex per head / 365 days x days in the month

Table A.10: Total annual nitrogen (N) excretion rates for goats (2021–22)

Goat type	Total N_{ex} (kg N / year / head)
Dairy	Total N_{ex} = 12.7
Non-dairy	Total N_{ex} = 10.6

Table A.11: Estimated monthly Nitrogen (N) excretion rates for goat classes (2021–22)

Goat Type	Month	Monthly excreta = kg N/month
Goats dairy	Jan	1.079
Goats dairy	Feb	0.974
Goats dairy	Mar	1.079
Goats dairy	Apr	1.044
Goats dairy	May	1.079
Goats dairy	Jun	1.044
Goats dairy	Jul	1.079
Goats dairy	Aug	1.079
Goats dairy	Sept	1.044
Goats dairy	Oct	1.079
Goats dairy	Nov	1.044
Goats dairy	Dec	1.079
Goats non-dairy	Jan	0.900
Goats non-dairy	Feb	0.813
Goats non-dairy	Mar	0.900
Goats non-dairy	Apr	0.871
Goats non-dairy	May	0.900
Goats non-dairy	Jun	0.871
Goats non-dairy	Jul	0.900
Goats non-dairy	Aug	0.900
Goats non-dairy	Sept	0.871
Goats non-dairy	Oct	0.900
Goats non-dairy	Nov	0.871
Goats non-dairy	Dec	0.900

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.

Monthly N_{ex} = head x monthly N_{ex} factor

where:

- monthly N_{ex} Excreted nitrogen in kilograms per month
- head Number of animals on the block for the month – **a user-inputted figure**
- monthly N_{ex} factor Total Nex per head / 365 days x days in the month

Table A.12: Total annual nitrogen (N) excretion rates for horses, mules and asses (2021–22)

Class type	Total N_{ex} (kg N / year /head)
Horses	Total N_{ex} = 25
Mules	Total N_{ex} = 25
Asses	Total N_{ex} = 25

Table A.13: Estimated monthly Nitrogen (N) excretion rates for horses, mules and asses (2021–22)

Class Type	Month	Monthly excreta = kg N/month
Horses	Jan	2.123
Horses	Feb	1.918
Horses	Mar	2.123
Horses	Apr	2.055
Horses	May	2.123
Horses	Jun	2.055
Horses	Jul	2.123
Horses	Aug	2.123
Horses	Sept	2.055
Horses	Oct	2.123
Horses	Nov	2.055
Horses	Dec	2.123
Mules	Jan	2.123
Mules	Feb	1.918
Mules	Mar	2.123
Mules	Apr	2.055
Mules	May	2.123
Mules	Jun	2.055
Mules	Jul	2.123
Mules	Aug	2.123
Mules	Sept	2.055
Mules	Oct	2.123
Mules	Nov	2.055
Mules	Dec	2.123
Asses	Jan	2.123
Asses	Feb	1.918
Asses	Mar	2.123
Asses	Apr	2.055
Asses	May	2.123
Asses	Jun	2.055
Asses	Jul	2.123
Asses	Aug	2.123
Asses	Sept	2.055
Asses	Oct	2.123
Asses	Nov	2.055
Asses	Dec	2.123

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Appendix B: Soil residue nitrogen inputs

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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.

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

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:NAG = 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

Note: 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
Fodder beet	Deep	0.37	NA	0.009	0.13	20	Forage cereal used as proxy (pers comm, TWG 2023)
Sugar beet	Deep	0.37	NA	0.009	0.13	20	Forage cereal used as proxy (pers comm, TWG 2023)
Maize (silage)	Deep	0.37	NA	0.009	0.13	20	Forage cereal used as proxy (pers comm, TWG 2023)
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
Shallots	Shallow	0.80	0.020	0.010	0.11	23	Onions used as proxy (pers comm, TWG 2023)
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*	

Species	Rooting depth	HI	NAGR (kg N/kg DM)	NBG (kg N/kg DM)	DMF residues	C:N	References
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
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:

$N,p = (AG_{DM} \times N_{AG}) + (BG_{DM} \times N_{BG})$ [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.

$GMN = Prodc \times NAG \times 0.8$ [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

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Appendix C: Erosion losses associated with land use and management

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We estimated nitrogen (N) losses at the polygon level from soil 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.

* Some vegetable crops are classed as arable in the tool for erosion losses. The Technical Working Group have assigned crops to a category depending on typical planting practices and explained this as broadacre vs small acre rather than arable vs vegetables.

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

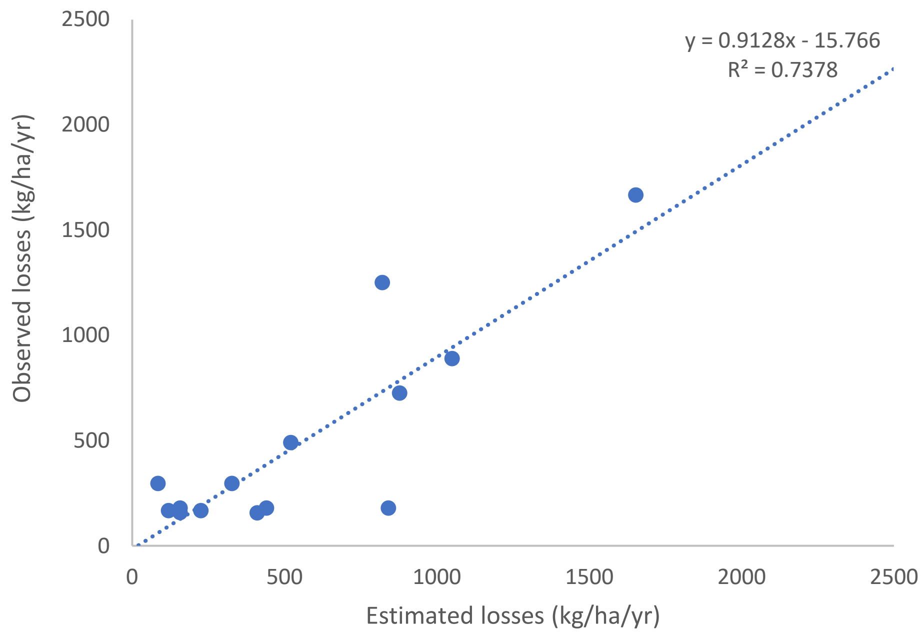
In addition to erosion losses for native and exotic forest, an additional loss of N is added to calculations for native and exotic forestry to reflect leaching losses observed in the field in the long term. These additional losses reflect observations in undisturbed (native forest; 0.7 kg N ha^{-1} yr^{-1}; Drewry, 2018) and a mix of disturbed and undisturbed situations commensurate with the harvesting and growth of exotic forestry (2.4 kg N ha^{-1} yr^{-1}; Davis et al, 2012), but not captured by other risks. Recent research indicates that total annual nitrogen loss from exotic systems is likely to be at least 5.5 kg N ha^{-1} (Davis et al, 2012; Snelder et al, 2023).

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 were exotic forestry.

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

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
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.

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Appendix D: Nitrogen concentrations for common fertilisers and manures

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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: Appendix D

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Appendix E: Mitigations and modifiers

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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). Note: no modifiers use 0 in the calculations as zero risk of N loss is not possible. However, 0 may be shown in the ranges of modifier efficacy which reflect the cited papers. While the risk may indeed be low, risk is never removed completely.

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 class (see table E.1). 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. Ranges of effectiveness are given where appropriate, while the information is for the user to understand possible variations, the number is unable to be changed in the tool.

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

- enterprise type – dairy, deer, sheep, beef, forestry, arable (which includes some vegetable crops), horticulture annual, and horticulture perennial
- 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 as listed in table E.1:

[12] Climate being precipitation.

- riparian filter (value can be true or false)
  - if riparian filter = True; soil composition is relevant for modifier 1 and 2
- riparian buffer (value can be true or false)
  - if riparian buffer = True; soil composition is relevant for modifier 3
  - if riparian buffer = False; soil composition is relevant for modifier 4.

The following logic is used to determine which modifiers to display for each block:

- if any 'dairy' stock type animals are added, then assume the enterprise type is dairy
- if any 'deer' stock type animals are added, then assume the enterprise type is deer
- if any other stock type animals are added, then assume the enterprise type is sheep, and beef
- if 'forestry – native' or 'forestry – exotic' are selected from the predominant block use, then assume the enterprise type is forestry
- if 'horticulture – perennial' is selected from the predominant block use, then assume the enterprise type is perennial horticulture
- if any other block use type is selected from the predominant block use, then assume the enterprise type is arable*.

*There is no modifier that uses arable as a filter currently in the tool. This means that any other block use type will have the 'all (except forestry)' and 'all (except forestry and perennial horticulture)' modifiers presented to the user.

If a user navigates back to input screens and makes changes, clear the previous modifier selections and rerun the logic to display updated options.

Table E.1: Reduction efficiencies (at a block scale) for 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 modifier in the right place and at the right time. 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 in 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 (excluding forestry)	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 (excluding forestry)	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 (excluding forestry)	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 (excluding forestry)	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 (excluding forestry)	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 (excluding forestry)	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 (excluding forestry)	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 (excluding forestry)	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 (excluding forestry)	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 (excluding forestry)	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 (excluding forestry)	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 (excluding forestry)	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 (excluding forestry)	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~~ *Modifier removed from the initial release as it is not working correctly. Interim modifiers 17a and 17b have been implemented. A permanent solution is still required – see note at the bottom of the table.	~~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 forestry and 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~~
17a.	Cropping and cultivation	Catch cropping (system 1) Interim modifier	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. System 1: summer/early autumn and late autumn cropping.	**Modifier**	All (excluding forestry and perennial horticulture)	Leaching			Flat, rolling		0.50 Mar, 0.50 Apr (0.5-0.9)	Horrocks et al, 2021; Malcolm et al, 2020; 2022
17b.	Cropping and cultivation	Catch cropping (system 2) Interim modifier	Typically, short rotation crops with good cool season growth and a deep rooting system that helps to mop up N that would otherwise be	**Modifier**	All (excluding forestry and	Leaching			Flat, rolling		0.80 Jun, 0.80 Jul (0.70-0.90)	Horrocks et al, 2021; Malcolm et al, 2020; 2022

No.	Class	Action	Description	Actioned via	Enterprise filter	Flow path filter	Soil – riparian filter	Soil – riparian buffer	Slope	Rainfall	Modifier (multiply by)	References
			leached. Effectiveness is dependent on when crops are sown in relation to grazing/N loading or harvest. System 2: Winter crops/following winter forage crop grazing.		perennial horticulture)							
18.	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 forestry and perennial horticulture)	Runoff			Flat, rolling		0.70	Daigneault and Elliott, 2017
19.	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 forestry and perennial horticulture)	Runoff			Flat, rolling		0.90	Basher et al, 1997; Basher and Ross, 2002; Dymond, 2010; Horticulture New Zealand, 2010
20.	Cropping and cultivation	Silt traps	Use silt traps to settle out sediment from water before it enters drains.	**Modifier**	All (excluding forestry and perennial horticulture)	Runoff				NA	0.90	Basher et al, 1997; Basher and Ross, 2002; Dymond, 2010; Horticulture New Zealand, 2010
21.	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**	Dairy, deer, sheep and beef	Leaching				NA	0.95	Cruickshank et al, 2009
22.	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
~~23.~~	~~Additives~~	~~Nitrification inhibitors (dicyandiamide, DCD)~~ See note at the bottom of the table.	~~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.~~ This modifier is not selectable in the tool and is currently hidden from view (as of October 2023). This may be reintroduced in the future so has been left in the technical document as of July 2025.	~~**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~~
24.	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

No.	Class	Action	Description	Actioned via	Enterprise filter	Flow path filter	Soil – riparian filter	Soil – riparian buffer	Slope	Rainfall	Modifier (multiply by)	References
25.	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
26.	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 20% reduction of N leaching losses for centre-pivot irrigation-induced leaching.	**Modifier**	All (excluding forestry and perennial horticulture)	Leaching				NA	0.80	Carlton et al, 2019; McDowell, 2017
27.	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 forestry and perennial horticulture)	Runoff				NA	0.80	Houlbrooke et al, 2008; Monaghan et al, 2009
28.	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 should only be selected for arable crops.	**Modifier**	All (excluding forestry and perennial horticulture)	Leaching and runoff			Flat	North Island only	0.86 ± 0.14	Ballantine and Tanner, 2013; McDowell et al, 2012
29.	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
30.	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
31.	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
32.	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

No.	Class	Action	Description	Actioned via	Enterprise filter	Flow path filter	Soil – riparian filter	Soil – riparian buffer	Slope	Rainfall	Modifier (multiply by)	References
33.	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
34.	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

Note:

Modifier 4 has a range presented for the modifier (0.00–0.30). While the referenced literature states complete effectiveness of the modifier (0) this is impossible as there can never be no risk. The decision was made to leave it as 0 to reflect the study but note this is not possible when calculating risk.

Modifier 17, 17a and 17b: The tool does not allow users to enter the details of catch crops. Currently users can only select a modifier. The tool was initially using modifier 17 (now struck through) but this was applying the modifier incorrectly and not a true reflection of catch crop systems. It was agreed with the Technical Working Group to remove it until it could be corrected. A short-term solution is the use of modifiers 17a and 17b which allows users to select two different modifiers for early catch crops vs winter catch crops. This is not a perfect solution nor the permanent fix

It is proposed to allow users to enter catch crop details. Users, when entering crops for each block, will confirm planting date and harvest date for catch crops and the area planted (whole or partial block). The intention is for the tool to then automatically apply the correct risk modifiers for the months of planting and appropriate efficacy. This will only be applied for the appropriate area – ie, if only a part of the block is planted then the risk will be reduced for that portion only.

Modifier 23 has been struck out as per a decision made by the TWG in October 2023 as its use was restricted due to international food safety concerns. It has been left here as it may be reintroduced in a later version.

Table E.2: Mitigation actions, 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 in the right place and at the right time. If actioned via a source mitigation, advice is given on which sources to alter. All refers to all land uses except for forestry.

No.	Class	Action	Description	Actioned via	Enterprise filter	Flow path filter	Soil – riparian filter	Soil – riparian buffer	Slope	Rainfall	References
1.	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) *These crops are not loaded into the tool. Mitigation unavailable.	All (excluding forestry and perennial horticulture)	Leaching				NA	Carey et al, 2017; Malcolm et al, 2014; Maxwell et al, 2019
2.	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 as per appendix A	Dairy, deer, sheep and beef	Leaching				NA	Doole, 2015; McDowell et al, 2013
3.	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 as per appendix A	Dairy, deer, sheep and beef	Leaching				NA	Beukes et al, 2012; Gourley and Weaver, 2012; Silva et al, 1999
4.	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 as per appendix A	Deer, sheep and beef	Leaching				NA	Doole, 2015
5.	Grazing practices	Strategic grazing of cropland gullies	Delaying the grazing of gullies within the catchment until as late as possible in the	Delay source inputs for dung and urine by changing stock	Dairy, deer, sheep and beef	Runoff			Rolling, easy, steep	More than 800 mm	Monaghan et al, 2017

No.	Class	Action	Description	Actioned via	Enterprise filter	Flow path filter	Soil – riparian filter	Soil – riparian buffer	Slope	Rainfall	References
			winter and ensuring soil damage in these areas was minimised when grazing does occur.	numbers and age by month as per appendix A *the tool currently has no consideration of this mitigation, users cannot select anything to say this is happening.							
6.	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 June 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 as per appendix A *the tool currently has no consideration of this mitigation, users cannot select anything to say this is happening.	Dairy	Leaching and runoff				NA	Christensen et al, 2019; De Klein et al, 2017
7.	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	Bryant et al, 2020; de Ruiter et al, 2019; Malcolm et al, 2020;Smith and Monaghan, 2020
8.	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.	Remove source inputs for dung and urine by removing stock in winter months as per appendix A	Dairy	Leaching and runoff				NA	Waikato Regional Council, 2017
9.	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.	Remove source inputs for dung and urine by removing stock in months where cut and carry used as per appendix A *the tool does also allow for harvesting of pasture if you select “crop” “pasture”	Dairy	Leaching and runoff			Flat		Waikato Regional Council, 2017
10.	Effluent management	Better timing of effluent application	Effluent applied outside of winter–early spring.	Alter source inputs for fertiliser N applied by month as per appendix D	Dairy	Leaching and runoff			Flat		Houlbrooke et al, 2008; Monaghan et al, 2010
11.	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		Craggs et al, 2014; Houlbrooke et al 2011
12.	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	Reduce inputs of fertiliser (appendix D) by 630 kg N over property applied in a summer month	Dairy	Leaching			Flat		Houlbrooke et al, 2011; Waikato

No.	Class	Action	Description	Actioned via	Enterprise filter	Flow path filter	Soil – riparian filter	Soil – riparian buffer	Slope	Rainfall	References
			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).								Regional Council, 2017
13.	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 *imported feed is not shown in the tool as a fertiliser type. The tool is not gathering this information.	Dairy, deer, sheep and beef	Leaching and runoff				NA	Beukes et al, 2012; Monaghan et al 2008
14.	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) *the tool currently is not implementing this.	Dairy	Leaching and runoff				NA	Burggraaf et al, 2019; Johnstone et al, 2010
15.	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	De Klein et al, 2017; McDowell, 2009
16.	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 (excluding forestry)	Leaching				NA	Waikato Regional Council, 2017
17.	Forestry	Increasing forested area	Forest area doubled from 12.5% to 25% (on average) with erosion-prone land planted first.	User increases land area. Alter erosion input by modifying soil erosion losses via table C.1 in appendix C. Set monthly fertiliser input (appendix D) to nil	Sheep and beef	Runoff			Rolling, easy, steep		Davis, 2014; Dymond et al, 2016; Larned et al, 2020; McDowell et al, 2021; Monaghan et al, 2021
18.	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 *The tool currently does not do this. There is nowhere for a user to select this as a mitigation.	Deer, sheep and beef	Leaching and runoff			Rolling, easy, steep		Baillie and Neary, 2015; Davis, 2014; Larned et al, 2020

Note:
Mitigations are only entered into the tool by changing the source inputs (stock, crops, fertiliser- including effluent). Some mitigations are currently unavailable within the tool – see the * in the ‘actioned via’ for information on this for each mitigation. As new versions of the tool are produced, we will endeavour to get these into the tool. They will continue to show to users of the tool as recommended options to reduce risk scores in the reports produced.

For many users, they will create their first report to be reflective of their current farm situation – eg, stock numbers, crops, fertiliser use. They can use the scenario function if they want to test what these mitigations will do to their scores if they reduce (or increase) source inputs such as higher or lower stocking rates, different stock or crop types etc.

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Appendix F: Testing

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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

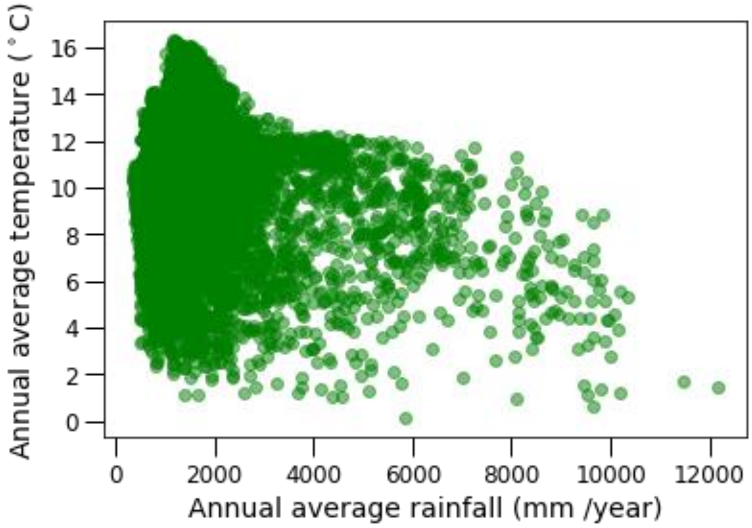
Leaching transport risk was derived from APSIM modelling of the probable leaching of a spike of N applied in any given month leaching below the root zone within two years. Runoff risk was derived from the median amount of runoff simulated by APSIM. The process is described under 'Process to estimate 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.

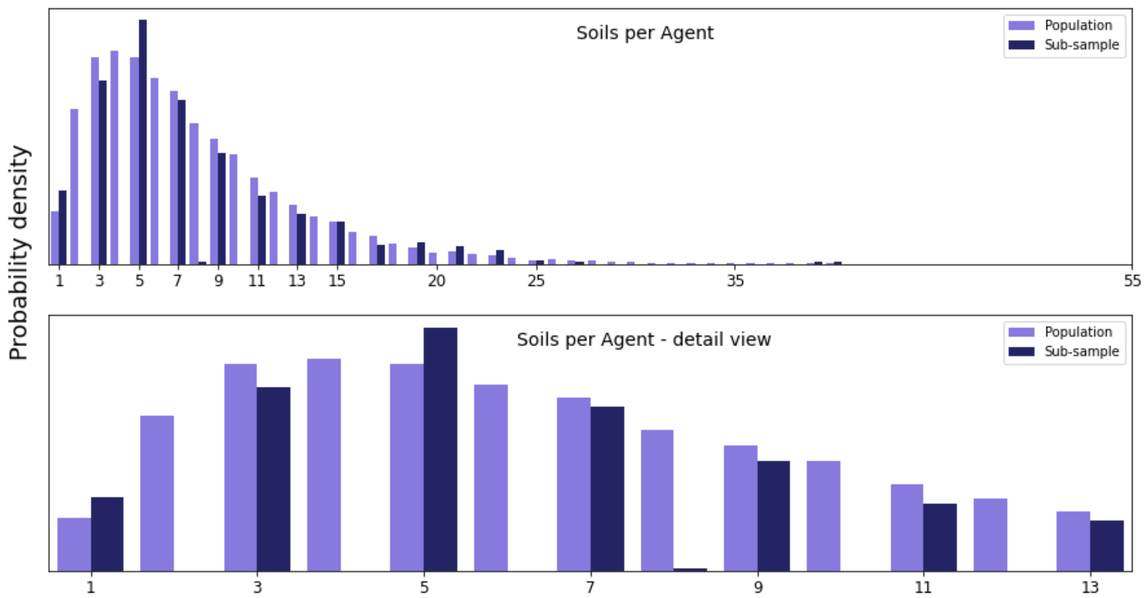
Rainfall (which drives both leaching and runoff transport as well as growing conditions) and air temperature (which drives growth) are known important factors. Preliminary analysis of the full data set showed that a negative relationship existed (figure F.1) between these two variables so the first decision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



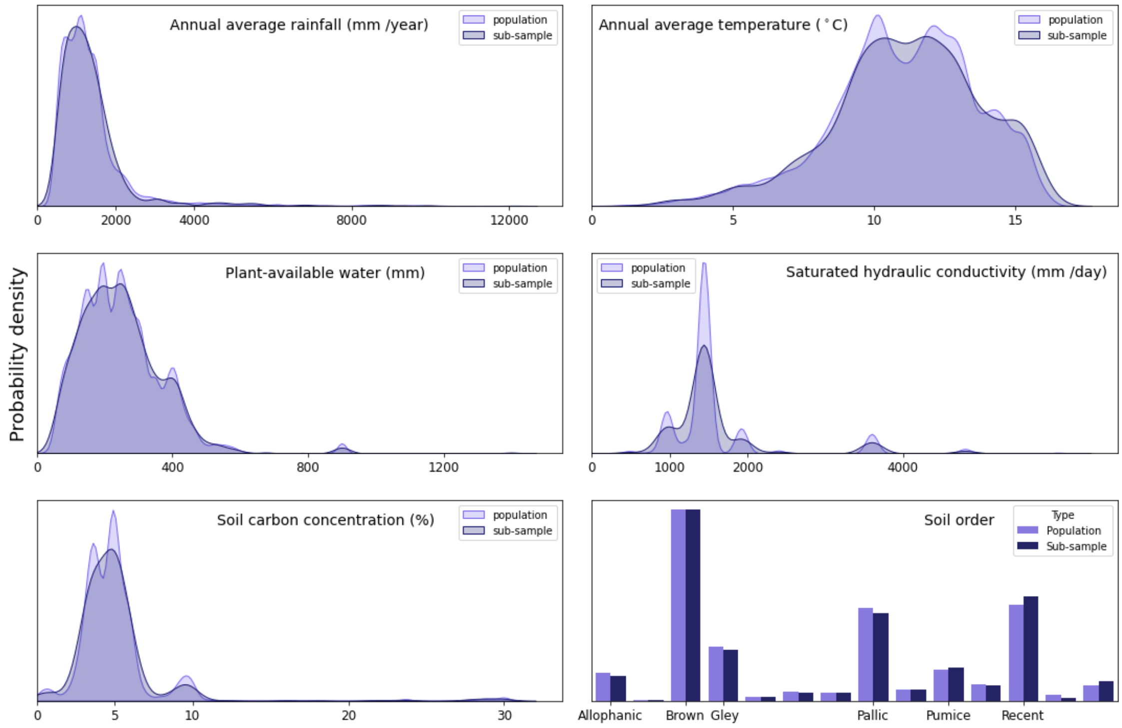
The full data set of 81,710 naturally occurring combinations of weather data (termed 'Agents') and S-Map soil siblings (termed 'Soils') comprised the population. The Agents were ranked (using pandas.DataFrame.rank with method='average') according to annual average rainfall and then all Agent–Soil combinations 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

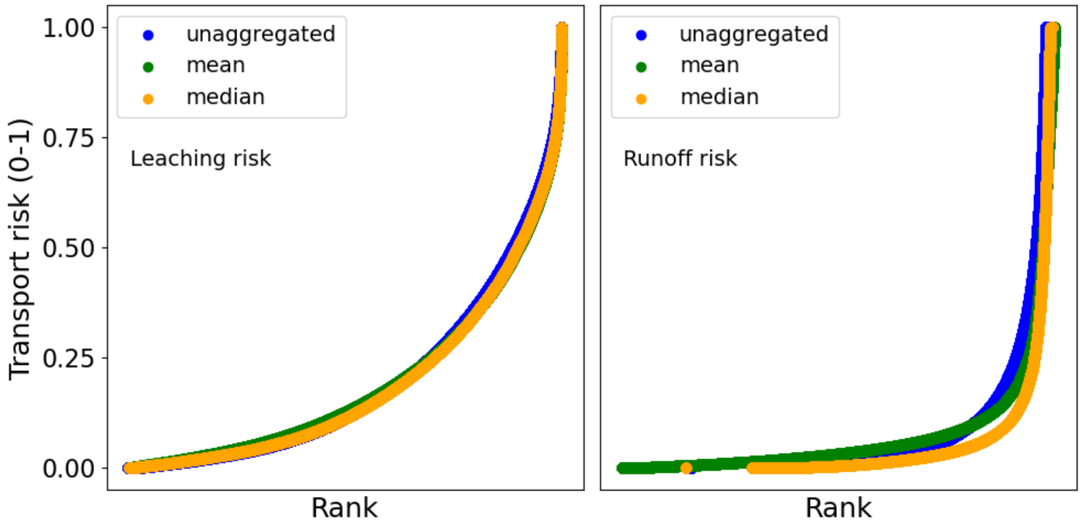


Calculation of transport risks

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.

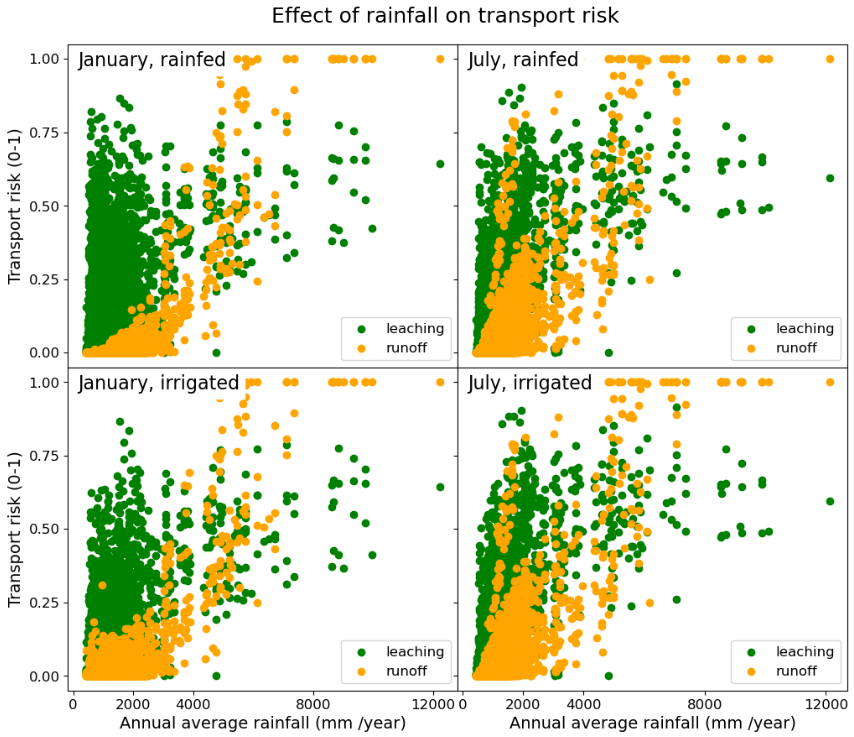
Note, to simplify the language, risks are referred to as, for example, 'in July'. This means the risk of activities in July on leaching in the following two years or runoff in the following 30 days.

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:

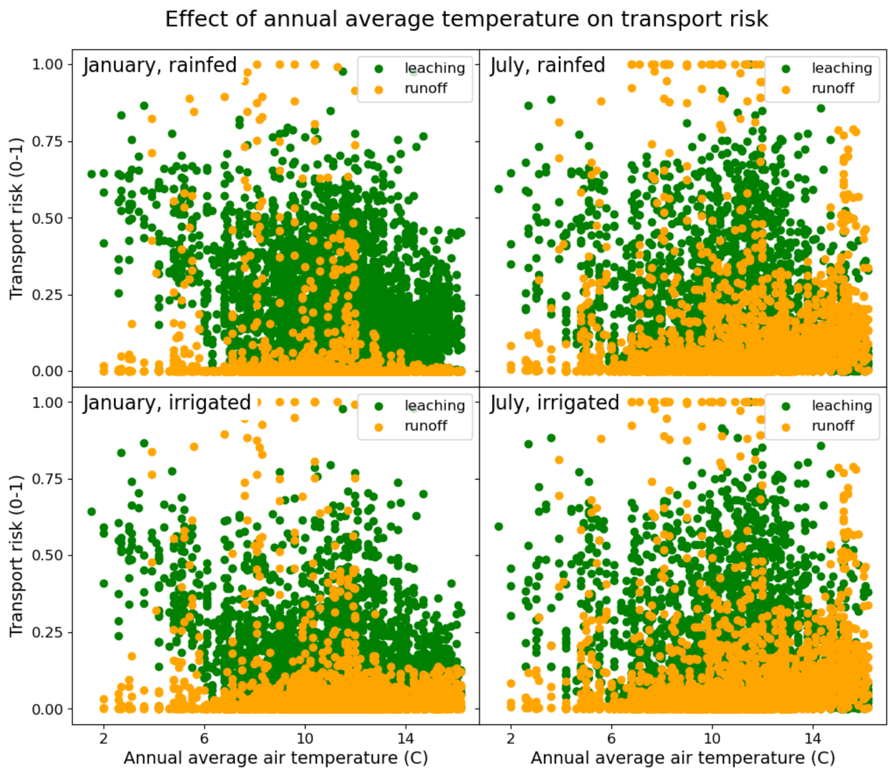
- examining the lower envelope of the data, a general trend was evident for increasing risks with increasing rainfall
- irrigation reduced leaching risk at low-rainfall sites in January (and to a much lesser extent in July), likely because of increased growth and uptake of N
- runoff risk increased with 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



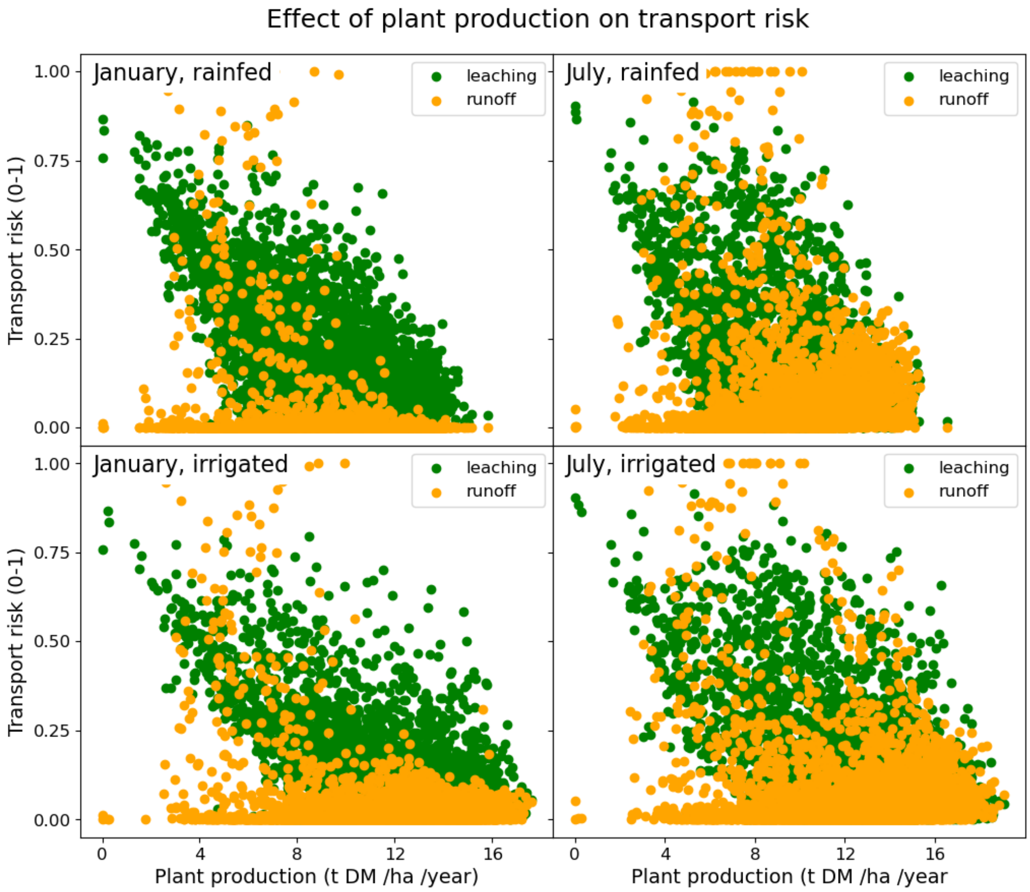
Only minor patterns were observable between air temperature and transport risks (figure F.6) and most of the effects are likely through a secondary driver (plant growth) and the association between air temperature and rainfall.

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

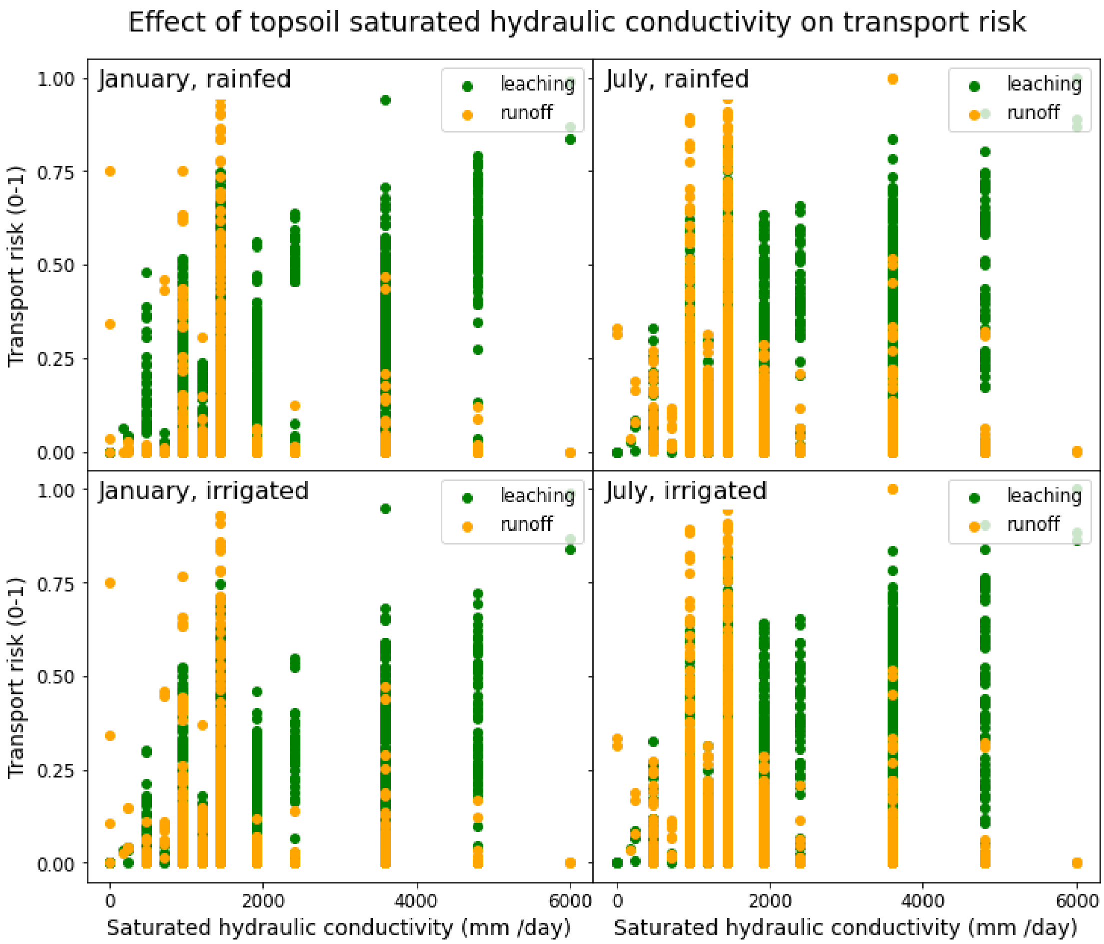


Effect of soil properties on transport risks

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

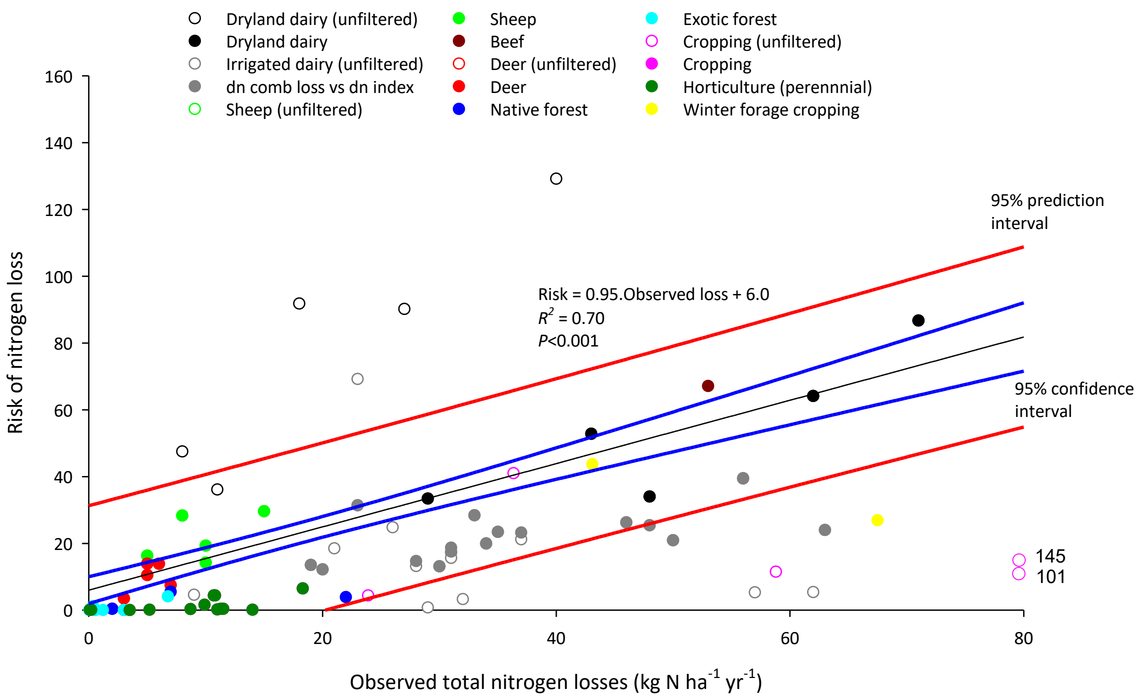
We reinspected our database of observations (n = 155, see Testing of risk' at the start of this report) by land use and flow path, separating measurements of leaching from runoff (inclusive of surface runoff and interflow calculated by difference from evapotranspiration and leaching). Using each observation's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

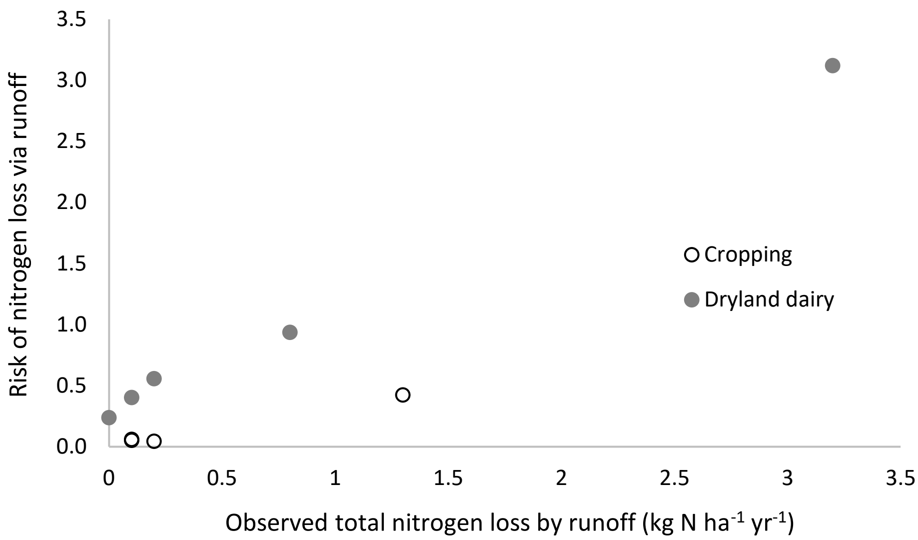
Once filtered, data points largely fell within the 95 per cent prediction interval. We did not assess performance of the risk index using this relationship because the data were not normally distributed.

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.

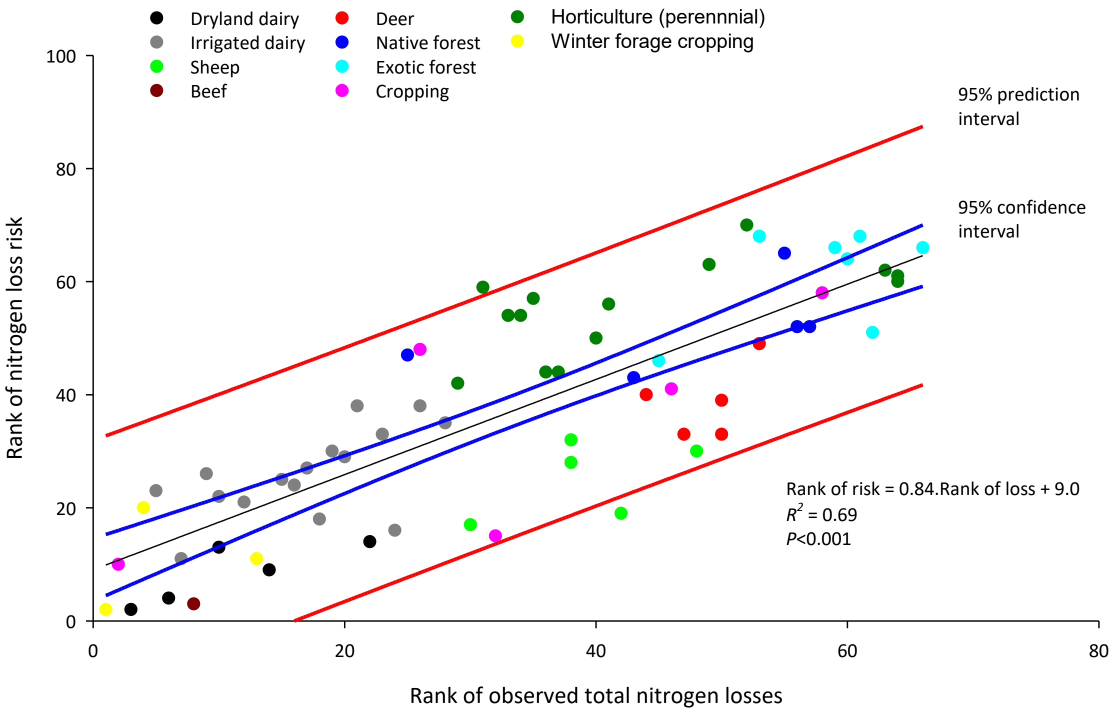
Figure F.10: Plot of filtered observed runoff (alone) nitrogen losses against their corresponding risk values



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).

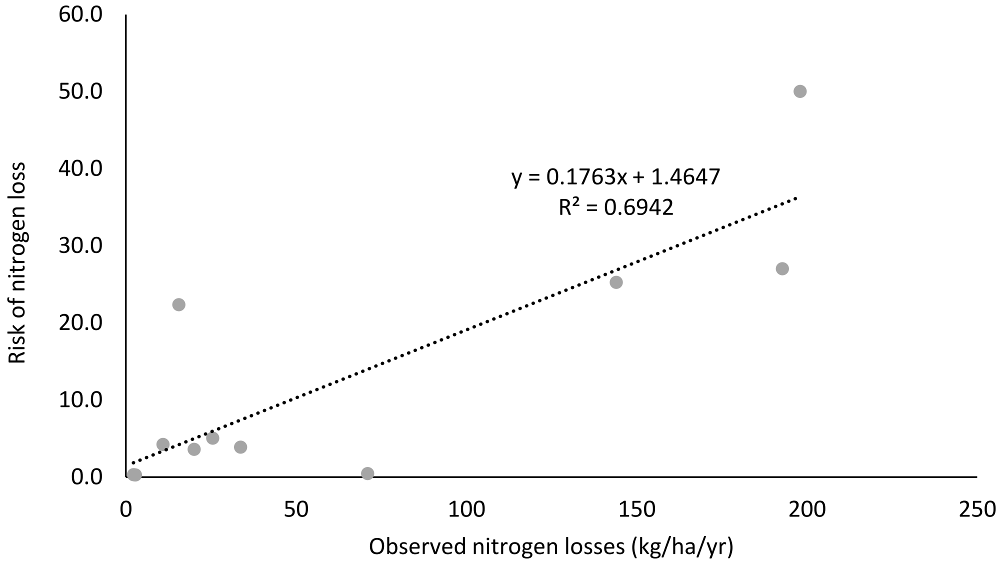
Figure F.11: Plot of the rank (1 = highest) of the risk of nitrogen loss against the rank of observed nitrogen loss



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.

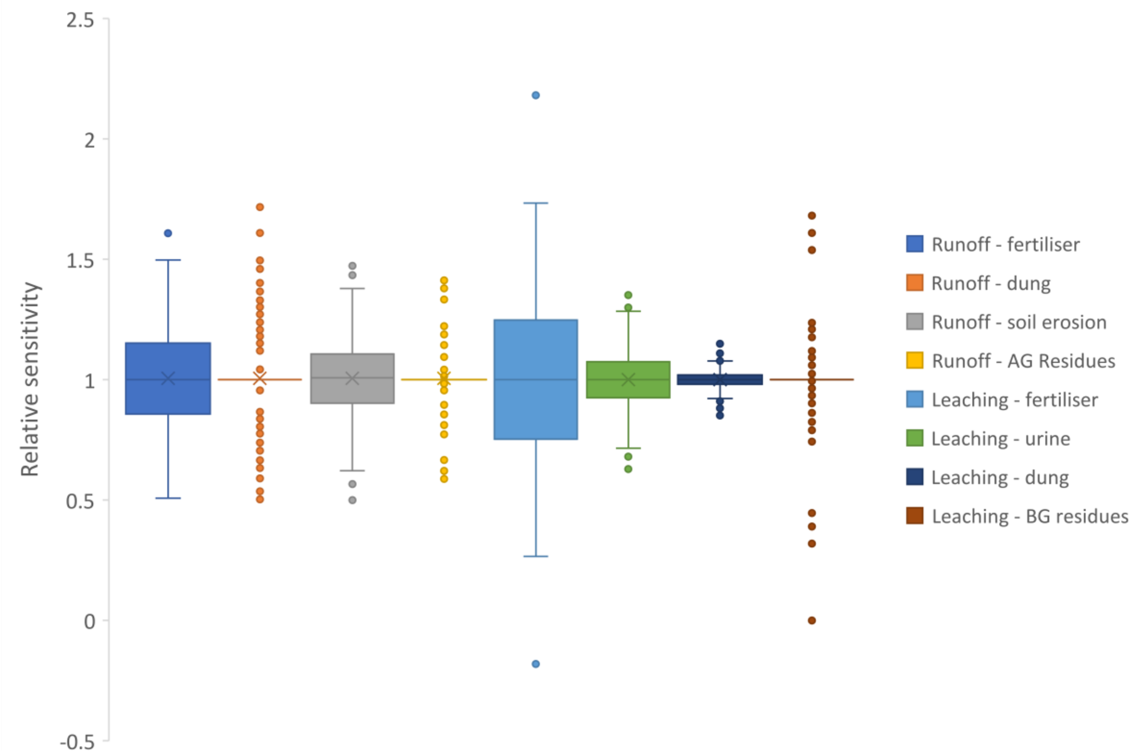
Table F.1: Comparison of observed losses and risk scores over six years of ryegrass–wheat–barley–plantain rotation in mid-Canterbury that was periodically grazed by livestock

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: Appendix F

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

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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). The Chatham Islands has been excluded from the tool at this time.

[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)**

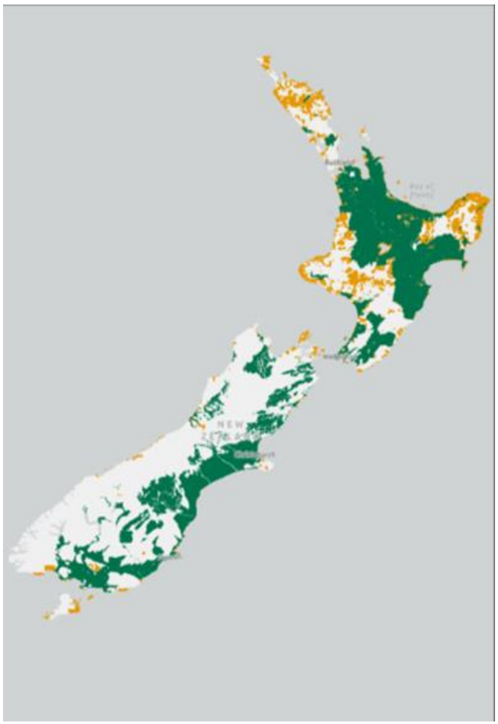

Figure G.2: **Māori land in the Chatham Islands**

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 (now Bioeconomy Science Institute) 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

<table>
<tr><th></th><th></th><th>Rotation 1</th><th>Rotation 2</th><th>Rotation 3</th><th>Rotation 4</th><th>Rotation 5</th></tr>
<tr><th>Year of cycle</th><th>Sowing month (1st day of month)</th><th>Crop in cycle</th><th>Crop in cycle</th><th>Crop in cycle</th><th>Crop in cycle</th><th>Crop in cycle</th></tr>
<tr><td rowspan="12">Year 1</td><td>January</td><td>Barley (cereal grain)</td><td>Barley (cereal grain)</td><td rowspan="2">Fallow</td><td>Barley (cereal grain)</td><td>Pumkin</td></tr>
<tr><td>February</td><td rowspan="6">Cabbage</td><td rowspan="4">Cultivation, fallow, ground prep</td><td rowspan="2">Lettuce</td><td rowspan="4">Cultivation</td></tr>
<tr><td>March</td><td rowspan="4">Lettuce</td></tr>
<tr><td>April</td><td rowspan="5">Fallow, cultivation</td></tr>
<tr><td>May</td></tr>
<tr><td>June</td><td rowspan="7">Onions</td><td rowspan="7">Onions</td></tr>
<tr><td>July</td><td rowspan="2">Fallow</td></tr>
<tr><td>August</td><td rowspan="10">Barley (cereal grain and then incorporated)</td></tr>
<tr><td>September</td><td rowspan="3">Asian greens</td><td rowspan="3">Broccoli</td></tr>
<tr><td>October</td></tr>
<tr><td>November</td></tr>
<tr><td>December</td><td>Fallow</td><td rowspan="6">Oats cover crop</td></tr>
<tr><td rowspan="9">Year 2</td><td>January</td><td rowspan="4">Cultivation, fallow, ground prep</td><td rowspan="3">Spinach</td><td rowspan="4">Cultivation</td></tr>
<tr><td>February</td></tr>
<tr><td>March</td></tr>
<tr><td>April</td><td>Fallow</td></tr>
<tr><td>May</td><td rowspan="5">Potatoes</td><td rowspan="4">Cauliflower</td><td rowspan="5">Potatoes</td></tr>
<tr><td>June</td><td rowspan="4"></td><td rowspan="4">Broccoli</td></tr>
<tr><td>July</td></tr>
<tr><td>August</td></tr>
<tr><td>September</td><td>Fallow</td></tr>
</table>

		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					
Year 3	January			Leeks and spring onions	Fallow	Cultivation
	February		Oats cover crop – incorporated			
	March					Lettuce
	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				

<table>
<tr><th></th><th></th><th>Rotation 1</th><th>Rotation 2</th><th>Rotation 3</th><th>Rotation 4</th><th>Rotation 5</th></tr>
<tr><th>Year of cycle</th><th>Sowing month
(1st day of month)</th><th>Crop in cycle</th><th>Crop in cycle</th><th>Crop in cycle</th><th>Crop in cycle</th><th>Crop in cycle</th></tr>
<tr><td rowspan="5"></td><td>August</td><td rowspan="3"></td><td></td><td rowspan="5">Potatoes</td><td rowspan="3">Broccoli</td><td rowspan="5">Barley (cereal grain)</td></tr>
<tr><td>September</td><td rowspan="3">Broccoli</td></tr>
<tr><td>October</td></tr>
<tr><td>November</td><td rowspan="5">Silver beet</td><td rowspan="4">Fallow, cultivation</td></tr>
<tr><td>December</td><td rowspan="2">Cultivation, fallow, ground prep</td></tr>
<tr><td rowspan="12">Year 5</td><td>January</td><td rowspan="4">Phaecelia (for incorporation)</td><td rowspan="2">Broccoli</td></tr>
<tr><td>February</td><td rowspan="2">Broccoli</td></tr>
<tr><td>March</td><td rowspan="10">Barley (cereal grain)</td><td rowspan="6">Fallow, cultivation</td></tr>
<tr><td>April</td><td rowspan="6">Cabbage</td><td>Fallow</td></tr>
<tr><td>May</td><td rowspan="8">Barley (cereal grain)</td><td rowspan="3">Lettuce</td></tr>
<tr><td>June</td></tr>
<tr><td>July</td></tr>
<tr><td>August</td><td>Fallow</td></tr>
<tr><td>September</td><td rowspan="3">Asian greens</td><td rowspan="4">Pumpkin</td></tr>
<tr><td>October</td><td rowspan="3">Barley (cereal grain)</td></tr>
<tr><td>November</td></tr>
<tr><td>December</td><td>Fallow</td></tr>
</table>

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

<table>
<tr><th>Subfactor</th><th>Equation and/or dataset</th><th>References</th></tr>
<tr><td>R-factor</td><td>Global Rainfall Erosivity Dataset (GloREDa)[14]</td><td>Panagos et al, 2017</td></tr>
<tr><td>LS-factor</td><td>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 (%)</td><td>Morgan, 2009</td></tr>
<tr><td>K-factor</td><td>Fundamental Soil Layer (FSL) for North Island[16] and South Island[17]
$$K = \left[(0.043 \times pH) + \left(\frac{0.62}{OM}\right) + (0.0082 + S) - (0.0062 \times C)\right] \times Si$$
Where:
pH: pH of the soil
OM: organic matter (%)
S: sand content (%)
C: Clay ratio = $\frac{\%\,Clay}{\%Sand + \%Silt}$
Si: silt content = $\%Silt \div 100$</td><td>David, 1988</td></tr>
<tr><td>C-factor (with some P-factor consideration)</td><td>New Zealand Land Cover Database v5.0[18]</td><td>Donovan, 2022</td></tr>
</table>

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.

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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.

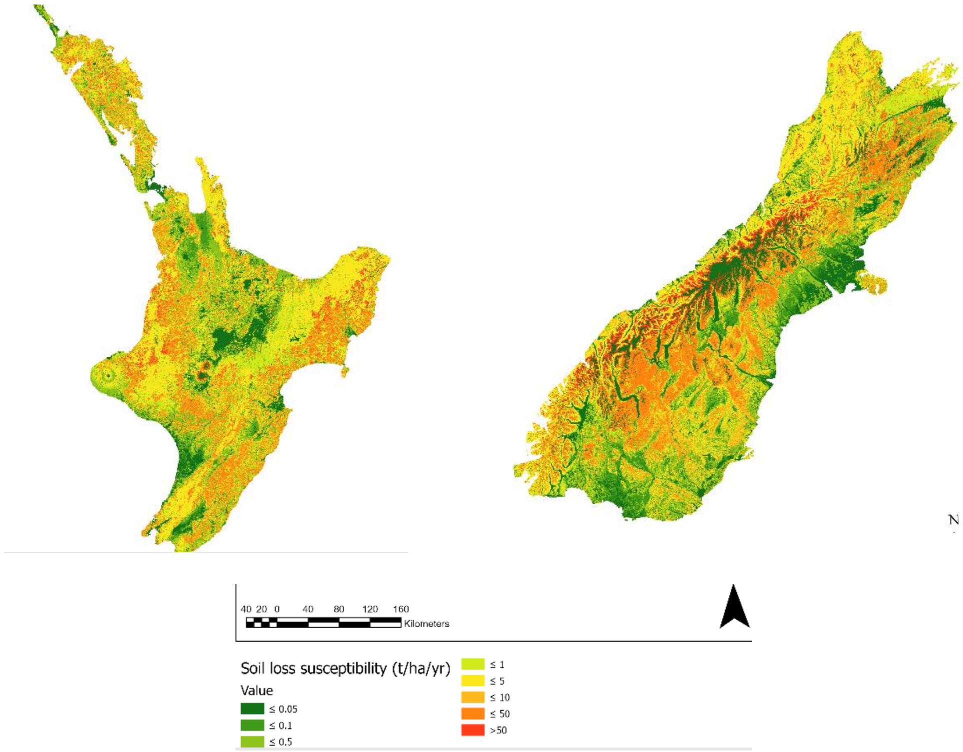
16 Manaaki Whenua – Landcare Research. *FSL North Island v1.0 (all attributes)*. Retrieved 28 August 2022.

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.

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[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 expressed a desire that the estimated risk of N loss for sites with observed data be compared to estimates of loss from Overseer. The Technical Working Group responded to the Regional Council Reference Group questions.

The RIT outputs a risk of N losses via runoff and leaching whose magnitude reflects biophysical and management conditions. Although the risk value may look like a yield of N loss it cannot not be used for nutrient accounting purposes.

There are several other tools that estimate N losses or risk of N loss. Overseer calculates nitrate-N losses by difference of inputs and outputs. The recommendation by MPI's Chief Science Advisor, is to "limit [the] use case for OverseerFM in regulation to subsurface drainage losses of nitrate" (MPI, 2023).

Only a selection (n=29) of empirical measurements of nitrate-N losses of grazed, flat intensively farmed land were used for validating Overseer, whereas a much wider array of measurements was considered (n=155) and deemed suitable (n=96) for validation of the RIT. Therefore, a comparison of each model against the 'true' loss is not possible

From a ‘first principles’ approach the commonalities between the RIT and other tools, centre on the capture of N inputs and soil information. There are few similarities beyond this. The RIT uses a national layer for predicting the likelihood of water transport, which reflects updates in an Open-Source model. Sources of N inputs come from a combination of the user’s input of management and nationally accepted databases like the NZ Agricultural Greenhouse Gas inventory which have defined processes for being updated.

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 *E. coli*, are identified as desired for the RIT. Improved runoff transport, as well as bypass flows (such as

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[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.

incorporating risks associated with artificial drainage), will enable assessment of risks of such contaminants that are typically transported as particulate forms.

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 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 RIT is specifically designed to quantitively account for biophysical (eg, inherent) and management risks, nationally. This allows for risk scores to be comparable between regions and farms over time when using the per hectare scores. Changes would occur if new science indicated risk was materially affected but can be traced and compared to previous versions – allowing risks to be recorded and monitored consistently over time.

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 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 meaningfully establish an accounting capability, it can aid farm scale improvements and a comparison and refinement of the risks at catchment scale.

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Appendix H: Review process

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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. Further, the peer review meeting minutes referred to as appendices in the report have also not been included here.

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:

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For:

Ministry for the Environment

NZ Government

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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

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Disclaimer

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 one 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

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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-to-the-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.

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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.