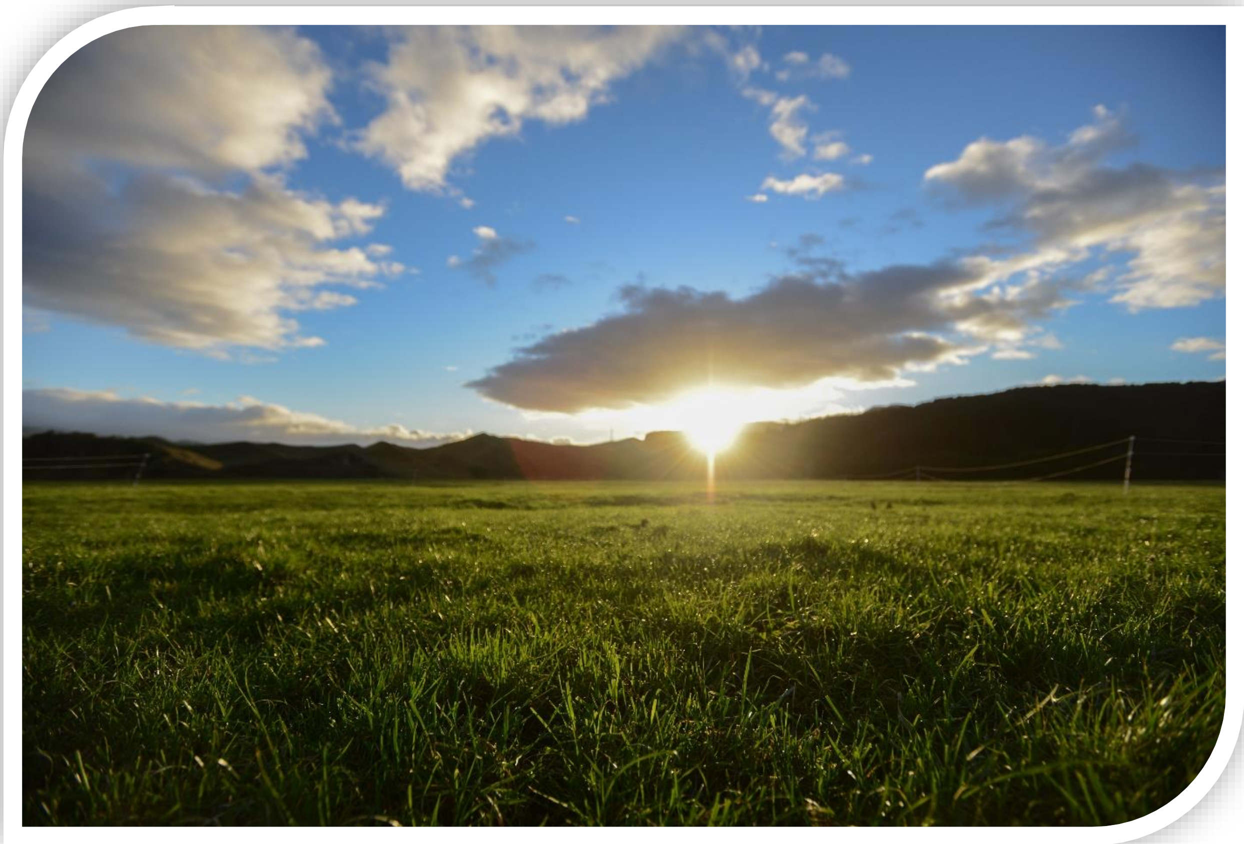

Assessment of Overseer model performance with experimental data from grazed pastures

Jean Paul Tavernet

August 2023

Report prepared for:

MPI
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Report prepared by:

Jean Paul Tavernet
Lead modeller
Overseer Ltd
31 May 2023

Report approved by:

Jill Gower
CEO
Overseer Ltd
31 May 2023

Report reviewed by:

Alexander Hunt-Painter
Science Program Manager
Overseer Ltd
28 August 2023

Diana Selbie
Science Team Leader – Environmental South
AgResearch
25 May 2023

Richard Muirhead
Senior Scientist
AgResearch
25 May 2023

Other key dates:

Revised in line with TAG comments.
MPI, Jean Paul Tavernet, and Alexander Hunt-Painter
August 2023

Presented to TAG
MPI, Jean Paul Tavernet
19 June 2023

Contents

Executive summary

Background

The Overseer model is an agricultural management tool that allows for the estimation of nutrient flows in a productive agricultural system and identifies potential risks to the environment through nutrient loss, including runoff and leaching, and greenhouse gas emissions. The Overseer model is a computer software model based on scientific principles derived from dedicated research on New Zealand farming systems and conditions, employing assumptions where knowledge gaps exist. The model was calibrated based on field measurements that capture the wide range of attributes of the farming system in NZ. In this context, evaluations are essential to verify the robustness of the Overseer model and give confidence in its estimates.

The aim of this study was to perform a specific type of evaluation, a comparison of Overseer model paddock-scale N leaching estimates with experimental data from paddock-scale grazed pastures, and to show the challenges and limits of such an exercise.

Approach

This report is primarily based on research by Selbie et al. (2020) which reviews the published literature on N leaching from grazed pastures (dairy and sheep and beef farms) and on Smith et al. (2020) describing the method to configure these experimental measurements in OverseerSci. The adopted approach selects the experimental data according to the conditions of use of the model. These are discussed in this document and further described in the appendices.

Findings

With the proposed approach, the comparison of Overseer model N leaching estimates with experimental data from NZ paddock-scale grazing systems shows a linear correlation and produces a 'very good' performance rating using the metrics of Moriasi et al. (2007). Similarly, comparison of the Overseer model N leaching estimates with experimental data produces a 'satisfactory' to 'good' performance rating for a limited cropping system. This study also shows the importance of the selection of experimental data, the difficulty of representing these measurements in the model and the limits of such comparisons on a short number of experimental sites.

The complementary use of other methods such as scenario analysis or comparison with process-based models seems reasonable due to methodological limits of comparisons with experimental data. The use of different types of evaluation will constitute a body of evidence that further demonstrates the performance of the Overseer model.

1 Purpose

Mathematical modelling tools have been developed to represent the effects of agricultural practices on the environment due to the complexity of soil-water-plant interactions. For trust in model outputs, it is crucial to assess the reliability of a model in its validity domain. In this context, comparisons against experimental data are essential to evaluate a model but are not the only approach. Expert judgement, scenarios, or sensibility testing are valid and complementary approaches when evaluating a complex model.

A comparison of Overseer model estimates with experimental block-scale data is the focus of this report. Although the Overseer model gives estimates of farm-scale N leaching as the sum of individual interacting blocks, it makes sense to focus on the block level where there is a greater possibility of finding measurements available for comparison. The Overseer model covers several types of blocks, but this report will focus mainly on grazed pastoral blocks, given their scale and importance in the New Zealand farming system and that most of the experimental data available is for this type of block. Some limited cropping systems are also examined.

Most experimental sites were not designed for model comparisons. Generally, they were set up to test hypotheses about the effects of management practices or sustainable environmental measures. Consequently, not all available measurements are suitable for reliability assessments. Therefore, this report's second objective is to identify the challenges and limitations when constructing a set of adequate and unbiased experimental measurements.

2. Introduction

> *"Models will always be constrained by computational limitations, assumptions, and knowledge gaps. They can best be viewed as tools to help inform decisions rather than as machines to generate truth or make decisions. Scientific advances will never make it possible to build a perfect model that accounts for every aspect of reality or to prove that a given model is correct in all aspects for a particular regulatory application. These characteristics…suggest that model evaluation be viewed as an integral and on-going part of the life cycle of a model, from problem formulation and model conceptualization to the development and application of a computational tool."*

U.S. National Research Council,
Committee on Models in the Regulatory Decision Process (NRC, 2007)

OverseerFM® (OverseerFM) and OverseerSci utilise the same farm-scale model (Overseer model) that incorporates the key elements relevant to examining nutrient flows and GHG emissions in most farming systems in New Zealand. It is challenging to measure these losses or emissions directly at the farm level; therefore, models are used. To estimate farm-scale nutrient losses or GHG emissions, the Overseer model incorporates complex interactions between farm managements, soils, plants, animals, and climate. However, like any mathematical model, the Overseer model is a set of equations that simplify complex processes. Accordingly, all models have assumptions and inherent limitations, areas of application, and conditions of use. Beyond these limits, model results should be taken with caution as they are potentially inaccurate. Appendix A recalls the main hypotheses and limitations of OverseerFM and the Overseer model, and Appendix B gives the consequences in terms of use.

A critical part of developing, maintaining, or improving a model Is to compare its outputs against experimental data as a part of the routine evaluation, calibration, and validation processes. The Overseer model's N leaching estimation is evaluated by comparing its estimates to experimental data at various levels, despite the challenges of this exercise. The comparison can be undertaken for each sub-model used in the calculations leading to the estimation of N leaching. These comparisons can only be made at the block scale as there is no way to directly measure farm-scale N leaching. This means that the various calculations grouping the N transfers in space (between blocks, laneways, etc) and in time are not evaluated.

Separate reports summarise the sub-model evaluation at the block scale against experimental data for drainage (Shepherd, 2019), cropping systems (Brown et al., 2020), inter-urine patch areas (Shepherd & Selbie, 2019), dry matter and N intake (Shepherd et al., 2020), urine patch (Shepherd & Selbie, 2020) and pastoral block N model (Shepherd et al., 2020). In general, the evaluation demonstrates that the sub-model output is reasonably consistent with the available experimental data, except for the pastoral block model.

The purpose of this report is to evaluate the performance of the Overseer N model against experimental data from grazed pastures at the paddock scale. First, the focus will be on the challenges encountered with and the associated limitations of comparing Overseer model estimates against experimental data. An evaluation is then presented, the details of which are described in the appendix. Finally, the possible long-term evaluation prospects are discussed.

3 Evaluation with experimental data

The Overseer model is an empirical, deterministic, and steady-state model. The model describes whole-farm systems in a "steady state", allowing the use of long-term average empirical relations between processes in quasi-equilibrium (farm production proportional to inputs) and for which good management practices are in place (Appendix A). These hypotheses must be considered when assessing the performance of the Overseer model and selecting experimental data. Moreover, the limitations and challenges with translating these experimental data into a suitable form in the model must be considered for a meaningful comparison.

3.1 Challenges And Limitations

Selecting the right data and translating them into a suitable form for modelling are the main challenges when comparing model outputs with experimental data. However, the experiment sites available for model evaluation were not set up for the purpose of model evaluations; consequently, the published studies contain knowledge gaps and often require additional explanations from the original researchers to substantiate the experiments (Selbie et al., 2020) and to model them using the Overseer model. Moreover, experiments are usually run over a short period of time (1-3 years) compared to the long-term hypothesis of the Overseer model.

3.1.1 Purpose of experiments

All available data are from research carried out at an experimental scale, not at farm block scale. Typically, they were designed to evaluate hypotheses about the effects of management practices on productivity, profitability, and environmental sustainability. The disparity of the experiments' purposes is reflected in heterogeneous nature of the measurement methodologies used and data that's been collected.

3.1.2 Short experiment duration

An ideal comparison of the Overseer model's estimates would require long-term averages across different research sites to know whether the experimental site is at least in a steady state, which is the Overseer model's central assumption. Ledgard et al. (1996) already emphasised the need for long-term measurements of N leaching due to variations in annual rainfall, drainage, and changes in soil N immobilisation (a process removing N that could be potentially leached). Unfortunately, this type of long-term data is scarce. For example, Selbie et al. (2020) found one experiment in the whole dataset with a duration of 10 years, while the average duration of experiments in this dataset is only 2.9 years, making it challenging to identify suitable data for comparison with Overseer model results.

Another challenge in this context is the significant variability of the climate over a few years, which may result in extreme values over short periods. An appropriate comparison with a long-term average model like Overseer requires an average over several years. Conversely, a short experiment may show the greatest leaching losses because of N inputs prior to the start of the experiment that are not modelled by the Overseer model, or for an exceptional and atypically wet year outside of Overseer's terms of use. A process for quantifying the biases introduced by these types of measurements and a mechanism for deciding whether or not to take these measurements into account should be put in place; however, it will always include some level of a subjective element where there is insufficient data.

3.1.3 Small number of experimental site locations

The total number of experimental sites where data has been collected is relatively low; also, the experiments were undertaken in a limited number of regions. In addition, the number of measurements per site varies significantly. Therefore, one site or a region may dominate and bias an assessment. As a result, the available data for model evaluation does not represent the full range of soil types, climates, and farm systems across NZ.

3.1.4 Uncertainty in measurements

Uncertainty is to be expected in all data collection processes. The measurement of N leaching from the soil is complicated because it depends, among other things, on the following:

- The spatial distribution of the urine patches,
- Depending on the measurement method, the measured or estimated drainage, or the proportion of running water on the paddock intercepted by a drainage system.

Consequently, N-leaching experimental results need to be interpreted considering the limitations of the chosen experimental method. Measurements are usually made during the drainage season. Thus, measured values are not absolute and have notable uncertainties, as described in Selbie et al. (2020).

3.1.5 Uncertainty in the Overseer file setup ('Modelled')

The Overseer model is a farm system model. Therefore, to evaluate the results generated by the Overseer model against experimental data, each experimental site and each experimental treatment must be set up as an individual farm system in OverseerFM (or OverseerSci). Consideration must be given to the relevance and timing of entries describing climate, experiment management, livestock, and nitrogen inputs to have a realistic description of the experiment. But sometimes even the key parameters for estimating N leaching, such as the number of animals for example, were not available in the published articles or reports (Smith et al., 2020). It is therefore essential to gather a set of information about the experiment to ensure that the configuration of the Overseer file produces the best representation of the measured data. Although the compilation of these files is conducted in a rigorous manner, certain information may be erroneous or missing in the publications, leading to uncertainties in the modelled results.

3.1.6 Measured and modelled N leaching distributions

Figure 1a) shows the distribution of all the measurements; Figure 1b) the distribution of selected measurements.

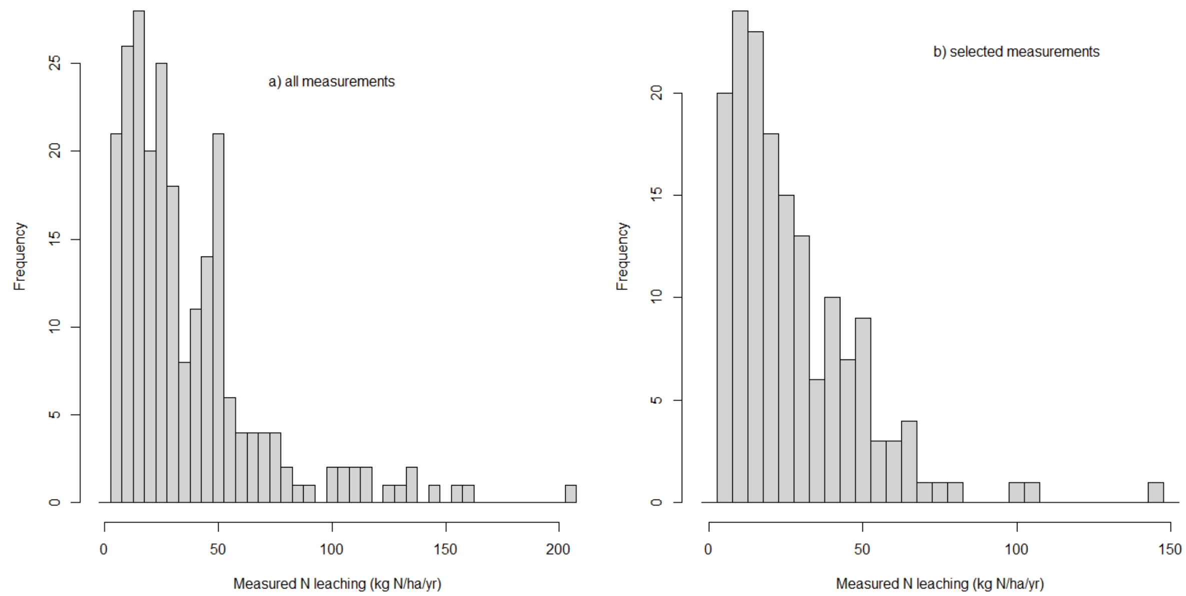

Figure 1*: Measured N leaching distribution for (a) all the single measurements referenced in Selbie and al. (2020) and (b) for all selected measurements described in Appendix C.*

We used the Shapiro-Wilk test (Shapiro & Wilk, 1965) to assess the normality of our data set. This test compares scores from a sample to normally distributed scores with the same mean and standard deviation. If the test gives a p-value greater than 0.05, the data is not significantly different from a normal distribution and, therefore, can be considered normally distributed.

With p-values less than 2.2e-16 and equal to 4.7e-12 for the distributions (a) and (b) respectively, these distributions cannot be considered normally distributed.

The measurements used in comparisons are the averages on experiments, soils and treatments or averages on experiments and treatments. The distributions of the averages are presented in Figure 2.

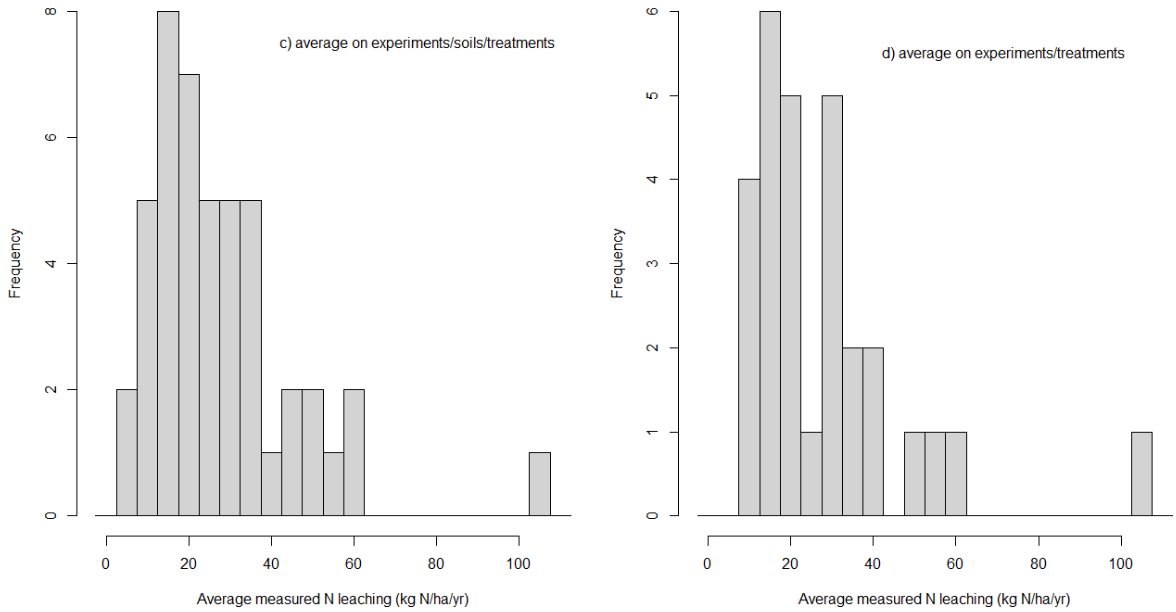

***Figure 2**: Average Measured N leaching when the calculation used (c) experiments, soil types and treatments and (d) experiments and treatments to group the measurements.*

The S hapiro-Wilk test gives p-values of 3.0e-5 and 3.3e-5 for the distributions (c) and (d), respectively; these distributions cannot be considered normal.

3.1.7 Outlier management

The quality assurance of the data is described in Table 4 of Appendix C of the report; the reasons to reject measurements are:

- Measurements made at 300mm depth instead of 600mm depth
- Land use in transition, in contradiction with the steady-state hypothesis of Overseer
- Single measurements, because only average observations were included, which requires several years of data
- Extremely wet year resulting in significant variability in measurements, overshadowing differences between treatments.

Although the experimental data were selected with care, a statistical study shows the existence of an outlier (light blue points in Figure 4, page 15) on the 'Scott farm P21' experiment for the paddock with a "matangi" soil type.

Figure 3 shows the boxplot of the measurements of all paddocks with the same treatment on the 'Scott farm P21' experiment.

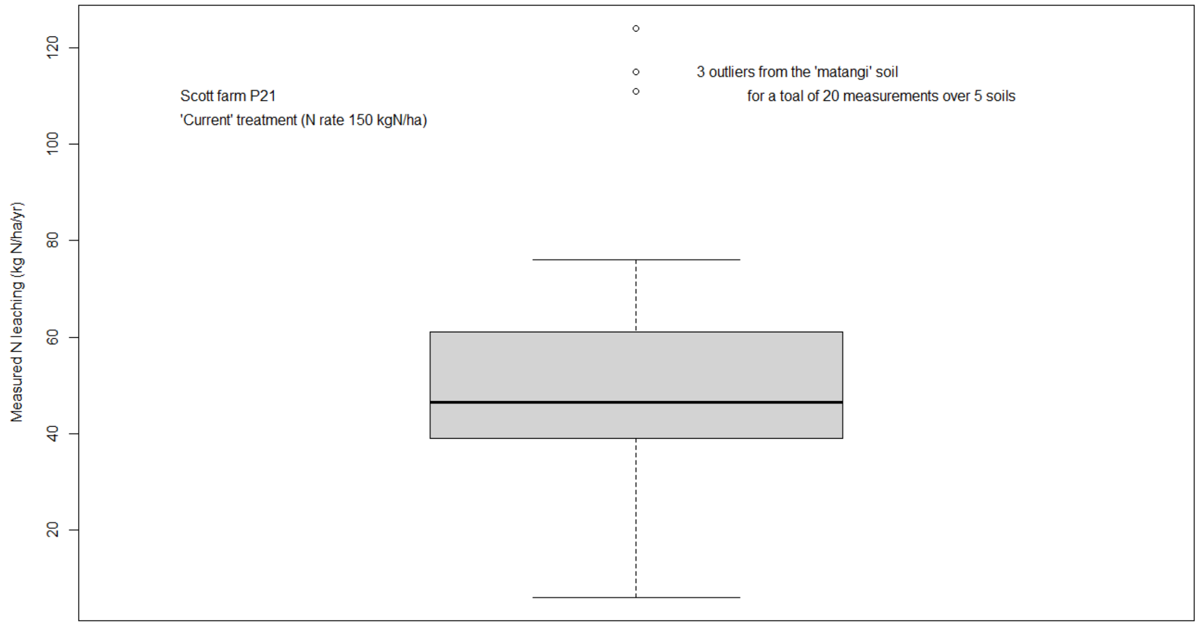

Figure 3*: Boxplot of measurements of all paddocks with treatment called 'current' (N rate of 150 kg N/ha) of the 'Scott farm P21' experiment.*

Three measurements over the four in total from the paddock with the soil type ‘matangi’ are considered outliers (unfilled circles in Figure 3). This paddock was historically used for spraying effluents and hence the high losses relative to the other soil types in this experiment may be a legacy effect from this historical management (Muirhead, 2023). This paddock is removed in the graphs where experimental and modelled annual nitrogen leaching losses are compared using Overseer 6.5.2 (Figure 6 and Figure 7, see page 17).

3.2 Comparison with measured data from paddock-scale experiments

Assessing the performance of the Overseer model against experimental data from grazed pastures is not a random choice. To begin with, the area of agricultural land used for cattle grazing far exceeds any other agricultural land use in New Zealand, accounting for around three-quarters (72.5%) of all agricultural land (EHINZ, 2021). Furthermore, most evaluations over time have focused on this type of block, a major source of N loss through leaching, and therefore the data used is relatively well documented.

The list of grazed pasture experiments within NZ is documented by Watkins & Shepherd (2014). This list, called paddock-scale experiments (or farmlets in some publications), is based on research undertaken up to 2015. It provides a summary of experiments which could be used for comparing with outputs from models such as the Overseer model. The paddock-scale experiments include N-leaching measurements at the paddock level or plot level within a paddock sufficiently large enough to allow grazing of animals and sufficient experimental detail to be modelled. This list is expanded in Selbie et al. (2020) to include both new experiments and a break-down of individual measurement years. Even though this list of experimental data is well documented and used for various analyses, its use has limitations and associated risks.

3.2.1 Limitations and risks

About half of the experiments are from Waikato, the other half from a combination of Manawatū, Southland, Central Plateau, Bay of Plenty, Otago, and Canterbury. Dairy farming accounts for more than three-quarters of the data set. This distribution reflects the principal dairy regions and proximity to major research stations.

The weaknesses and possible biases of this dataset (Selbie et al., 2020) are the following:

- Four of the five experiments with the largest datasets (in terms of total number of measurements) were based in Waikato, which will significantly influence the assessment of modelled versus measured values.
- The lack of experiments in Canterbury is noteworthy. This is a significant gap, particularly for the shallow soils and irrigation common to Canterbury's dairy industry.
- Rainfall is a crucial parameter for N leaching, and here, over 50% of the dataset falls into the 900 – 1200 mm range of mean annual rainfall, representing a large bias towards the middle range of annual rainfall.
- Additionally, the extremes are underrepresented, with only 12% of the dataset coming from experiments with greater than 1500 mm of rainfall, highlighting a gap in data from high rainfall sites. At the other extreme, sites with low precipitation (<900 mm) account for less than 25% of the dataset.
- 80% of the experiments were conducted on free-draining soils. Therefore, approximately 20% of the dataset represent heavy soil types (e.g., clay-based). Moreover, all of data from the heavy soils use artificial drainage systems in the form of moles/tiles or drainpipes, the results of which are difficult to interpret.
- Though robust research methods are used, some experimental results are unusual or unexpected, as noted in Watkins and Shepherd (2014). These results can be filtered to avoid bias in comparisons, but filtering depends on a subjective assessment of the quality of the experimental data and the purpose of the analysis.

In this report, the model evaluation is based on the paddock-scale experiments referenced in Watkins and Shepherd (2014), excluding experiments considered not to be in steady state or in a land use transition. These experiments were excluded because farms considered not to be in steady state or in a land use transition is in contradiction with the Overseer model hypotheses. The list of experiments used is documented in Appendix C, which also describes the specific reasons for exclusion. The exclusion process is unavoidably subjective.

3.2.2 OverseerFM files

The steps to prepare experimental data and set up the Overseer files to best represent the sites and treatments are described in Smith et al. (2020). This significant work is directly used here. Overseer files were created to represent each measurement. Therefore, an individual Overseer file represents a single experimental site with a single treatment for a single year. Finally, the results from individual years were combined to give an average per treatment and per site.

3.2.3 Comparison with experimental data from grazed pastures

Figure 4 shows the straightforward comparison of the modelled N-leaching averages per treatment, site, and soil with experimental data from selected grazed pastures. With two to three measurements per soil type, treatment, and site, the average becomes sensitive to outliers. It should be noted that the presence of an aberrant value in Figure 4 requires further study to investigate its origin. There is a reasonable scatter around a 1:1 line with a highly significant positive observed correlation. In total, 48 averages, one per site, treatment, and soil are represented and detailed in Appendix C.

This study uses three performance indicators detailed in Moriasi et al. (2007). These methods are (i) Nash-Sutcliffe efficiency (NSE), (ii) percentage bias (PBIAS), and (iii) ratio of root mean square error to standard deviation of measured data (RSR). According to the suggested criteria, the lower the RSR and the higher NSE are, the better the model performs.

Table **1** summarises recommended statistics to rate a model's performance.

According to Moriasi et al. (2007), the Overseer N model performance is satisfactory, satisfactory, and very good as indicated by RSR, NSE and PBIAS, which are equal to 0.65, 0.57 and 12.1%, respectively.

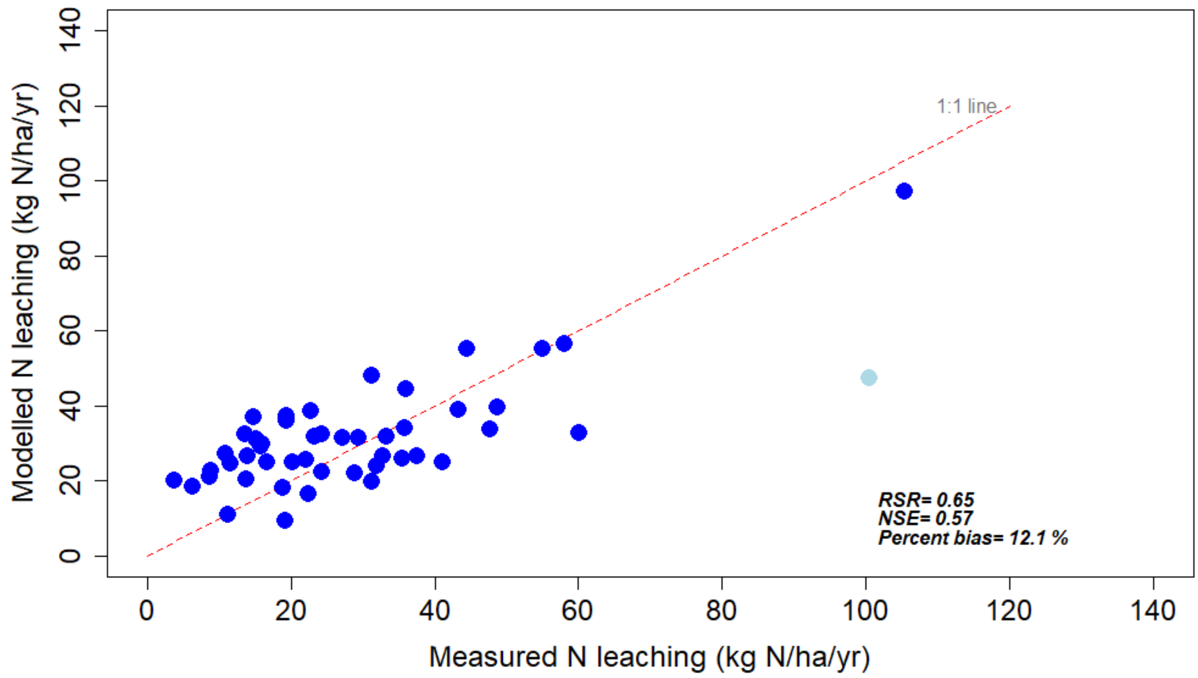

***Figure 4**: Comparison between experimental and modelled annual nitrogen leaching loss (kg N/ha/year) based on measured data from New Zealand paddock-scale grazing system studies and modelled using the Overseer model. Data are the mean of measurements over years per treatment, site, and soil with at least 2 measurements. The points are indicated by brackets '[]' in Appendix C. The outlier is highlighted in light blue.*

***Table 1**: General performance ratings for recommended statistics for a monthly time step model, extracted from Moriasi et al. (2007).*

Performance rating	RSR	NSE	(N, P) PBIAS (%)
Very good	$0.00 \leq RSR \leq 0.50$	$0.75 < NSE \leq 1.00$	$PBIAS < \pm 25$
Good	$0.50 < RSR \leq 0.60$	$0.65 < NSE \leq 0.75$	$\pm 25 \leq PBIAS < \pm 40$
Satisfactory	$0.60 < RSR \leq 0.70$	$0.50 < NSE \leq 0.65$	$\pm 40 \leq PBIAS < \pm 70$
Unsatisfactory	$RSR > 0.70$	$NSE \leq 0.50$	$PBIAS \geq \pm 70$

The limitations of this comparison should be noted because:

- Most of the points come from only one region (Waikato), because the measurements were made on different types of soils (Appendix C).
- Well-drained soils are overrepresented.
- Averages are calculated over a small number of measurements, which cannot represent a long-term average, and whose values become more sensitive to measurement uncertainties.

To reduce the impact of the Waikato region, Figure 5 compares the modelled N-leaching averages per treatment and site (measurements of different soil types are included in the calculation of averages) with experimental data from selected grazed pastures.

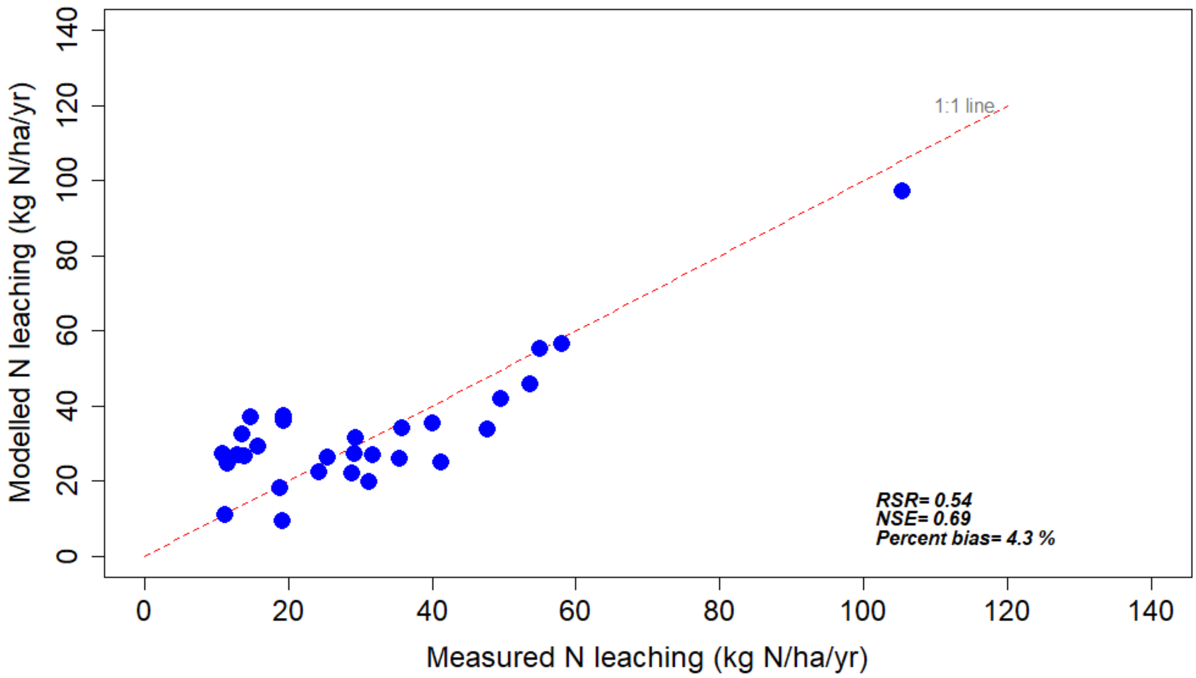

***Figure 5**: Comparison between experimental and modelled annual nitrogen leaching loss (kg N/ha/year) based on measured data from New Zealand paddock-scale grazing system studies and modelled using the Overseer model. Data are the mean over years per treatment and per site with at least 2 measurements. The points are indicated by parentheses '()' in Appendix C*

There is a reasonable scatter around a 1:1 line with a highly significant positive observed correlation. The RSR, NSE, and PBIAS values indicate that the Overseer model performs good, good, and very good respectively in estimating N leaching from grazed pasture.

It should be noted in Figure 1 that the average values, as represented by a single point, are not equivalent since they are calculated from a significantly different number of measurements, with 20 measurements for a treatment on one site and only two for another.

3.2.4 Updating graphs with Overseer 6.5.2

During the redevelopment program the model underwent significant changes. The information in Figure 4 and Figure 5 above shows measured and modelled N leaching data using a now out-dated version of the Overseer model (6.3.1). To show how the current version of the model performs, this section presents the same information from Figure 4 and Figure 5 above when using the latest version of the Overseer model (6.5.2, released on 25 June 2023).

The main upgrades from 6.3.1 to 6.5.2 are:

- Deep-rooted plant
- New crop model
- S-map soil updates
- Troubleshooting: nitrogen concentration in pasture, animal live weight gain, ME parameters update, and others.

In the following graph, only the modelled N leaching values are updated.

Figure 6 compares the modelled N-leaching averages per treatment, site, and soil with experimental data from selected grazed pastures. There is a reasonable scatter around a 1:1 line. Overseer's performance improves slightly compared to the 6.3.1 version, given the indicator values detailed in Moriasi et al. (2007). In total, 46 averages, one per site, treatment, and soil, are represented and detailed in Appendix C. The two averages from the 'matangi' soil-type paddock have been removed.

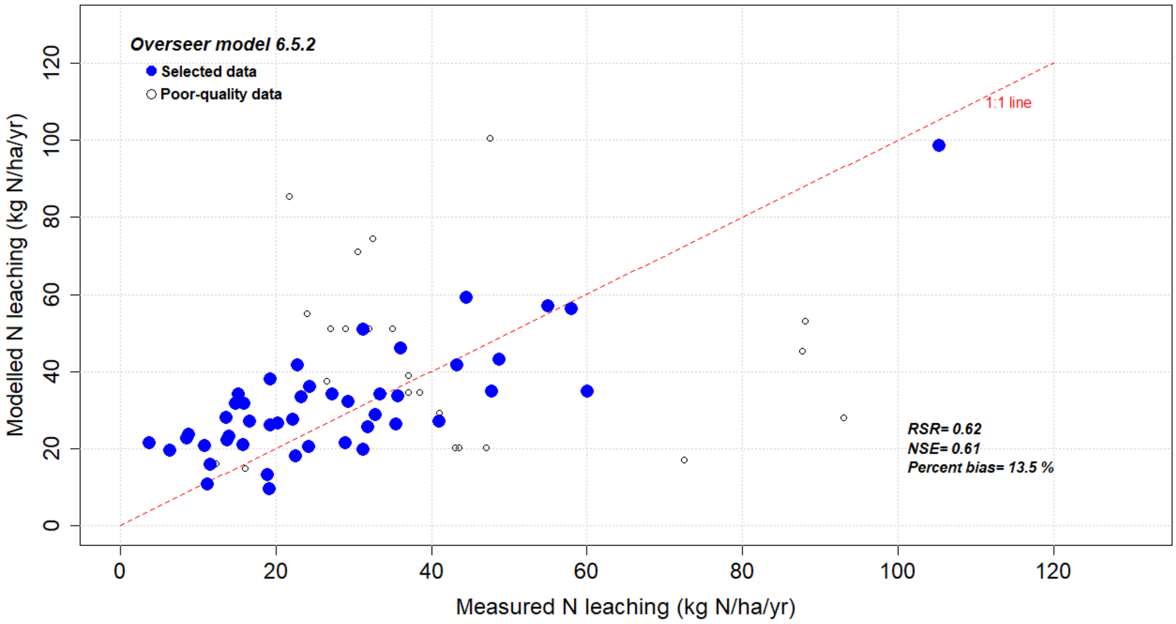

***Figure 6**: Comparison between experimental and modelled annual nitrogen leaching loss (kg N/ha/year) based on measured data from New Zealand paddock-scale grazing system studies and modelled using the Overseer model. Data are the mean of measurements over the years per treatment, site, and soil, with at least 2 measurements. The points are indicated by brackets '[]' in Appendix C. Unfilled circles represent the poor-quality data described in Appendix C.*

Figure 7 compares the modelled N-leaching averages per treatment and site (measurements of different soil types are included in the calculation of averages) with experimental data from selected grazed pastures.

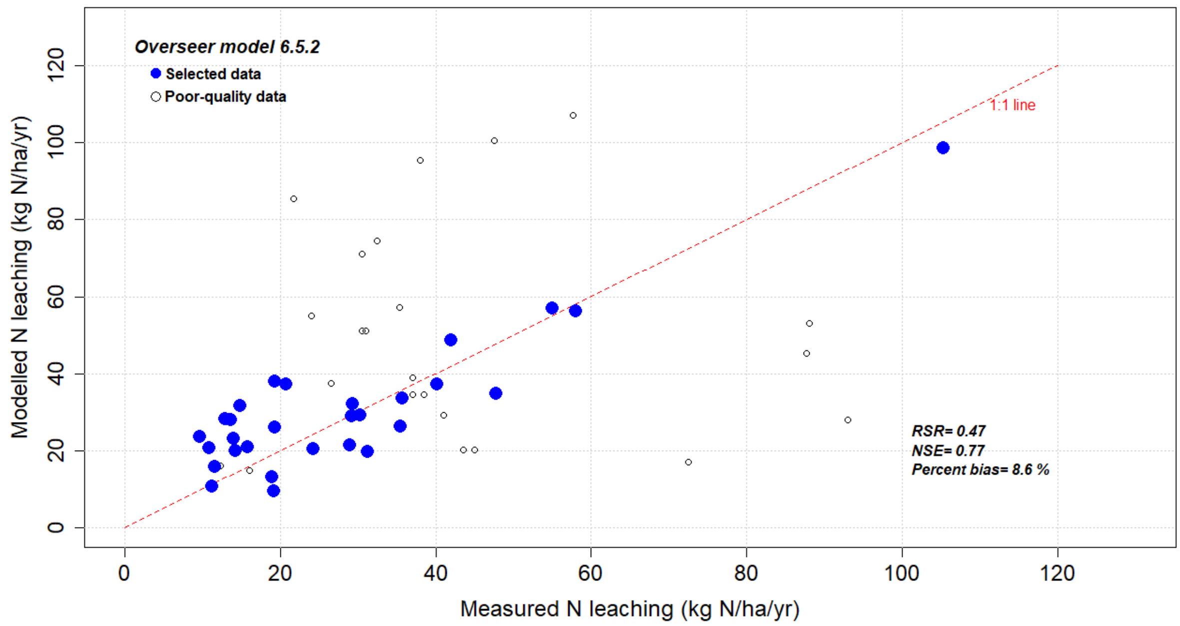

Figure 7:*Comparison between experimental and modelled annual nitrogen leaching loss (kg N/ha/year) based on data from New Zealand paddock-scale grazing system studies. Data are the mean over years per treatment and per site with at least 2 measurements. The points are indicated by parentheses '()' in Appendix C. Unfilled circles represent the poor-quality data described in Appendix C.*

There is a clear improvement in the performance of the Overseer model in version 6.5.2 compared to the 6.3.1 version. The values of the three indicators (RSR, NSE and PBIAS) indicate that the Overseer model performance is 'very good', 'very good' and 'very good', respectively, in estimating N leaching from grazed pastures.

3.2.5 Comparison with cropping systems

The experimental data was obtained from a 2-year (2005–07) controlled crop rotation field trial located at the New Zealand Institute for Plant and Food Research Limited, Lincoln site. This carefully controlled and intensively monitored experiment was designed to quantify N losses through leaching from a range of fertiliser and irrigation practices (Khaembah et al., 2015). It has been extensively analysed to account for N leaching and used in previous assessment and model development exercises, so there is a high level of confidence in the observed values and management records. Measured annual leaching ranged from 10 to 230 kg N/ha.

The trial evaluated two crop rotations over two years:

- Sequence 1: potatoes → winter fallow → spring peas → potatoes
  Each main plot was split into two different irrigation rates:

- W1 (optimum), where irrigation was applied weekly or fortnightly to return the soil to field capacity.

  The sub-plots were further split into three fertiliser treatments:
  - N0 = no fertiliser applied.
  - N1 = optimum fertiliser N rate (determined by fertiliser calculators).
  - N2 = excess (twice the amount applied to N1).
- W2 (excess) where irrigation was 1.75 greater than W1.

  The sub-plots were further split into three fertiliser treatments (N0, N1 and N2)

- Sequence 2: potatoes → autumn wheat → potatoes
  Each main plot was split into two different irrigation rates (W1 and W2) and the sub-plots were further split into three fertiliser treatments (N0, N1 and N2)

Therefore, a total of 12 treatments are available, i.e., 24 measurements over the two years of experience, therefore 12 average measurements over the duration of the experience. This data is shown in Figure 8.

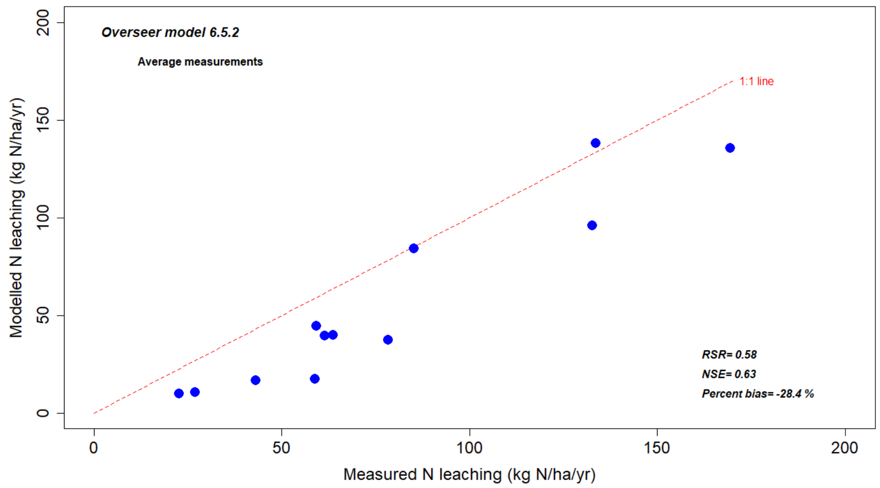

Figure 8*: Average Overseer-estimated annual N leaching in relation to average observed annual leaching values over the duration of the experience. The values of the three indicators (RSR, NSE and PBIAS) indicated.*

This assessment showed reasonable agreement between the observed and the Overseer- estimated N leaching. With the average measurement, the Overseer performance is rated 'good', 'satisfactory' and 'good' according to Moriasi et al. (2007).

3.2.6 Conclusions

These results show that the current Overseer model (6.5.2) produces 'very good' results in estimating nitrogen leaching from grazed pastures and 'satisfactory' to 'good' results for crops, building confidence in the Overseer model. This study also shows the importance of the selection of experimental data, the difficulty of representing these measurements in a model, and the limits of such comparisons on a short number of experimental sites.

4 Perspectives in evaluation at long term

Comparison with experimental data is one of the methods generally used to evaluate the performance of a model. However, we have shown above some limits of this approach, for example, due to the limited access of appropriate data, number of experimental sites, etc. Consequently, complementary qualitative or quantitative methods must be implemented over the long term to assess how the Overseer model corresponds to reality.

4.1 Scenario Analysis or Sensibility Analysis

Scenario (or sensibility) analysis is part of Overseer Limited's ongoing scientific work stream and will inform users and stakeholders about the confidence in N leaching estimates in different conditions. Scenario analysis is a process of examining and evaluating certain events or scenarios that could occur. The different estimates of a scenario or the direction of the changes are assessed using experimental data, the results from other models, or with the expectations of experts in the relevant field(s).

The first step will be to generate cases to be used in scenario analysis in collaboration with scientists. These discrete scenarios will likely include variations in management practices (e.g., stocking rate, fertiliser, or irrigation) and farm characteristics (e.g., soils, climate, and typography). In order to select, set-up, and assess the results from these scenarios, the Overseer science team will need to collaborate closely with the relevant experts from different fields to set up a framework of comparisons with experimental data, other models, or expert expectations.

This project is in a scoping state, with the desire to have the first tranche of scenarios evaluated within the next 12 months.

4.2 Process-based model comparisons

Another workflow that can be opened to build confidence in the Overseer model's N-leaching estimates and the comparison of N-leaching estimates is to use long-term averages of outputs of process-based models like APSIM. The Agricultural Production Systems sIMulator (APSIM) is internationally recognised as a highly advanced platform for agricultural systems modelling (Keating et al., 2003). It contains a suite of modules that enable the simulation of systems for a diverse range of plant, animal, soil, climatic, and management interactions.

This type of comparison was undertaken on a small scale when implementing the N uptake mechanism below 600 mm by deep-rooted crops (Brown, 2022). The Overseer model N leaching outputs were compared to APSIM outputs averaged over 20 years. The results were consistent but showed that a calibration step is necessary for certain input variables due to the greater modularity of APSIM. This work was completed for one specific cropping system but could be undertaken on a larger scale for diverse types of farming systems in the long-term.

5 Conclusions

The evaluation of a model is essential to check its robustness. The comparison of model estimates with experimental data is commonly used to evaluate the model's performance. However, this comparison of the Overseer model, which estimates long-term leaching losses on an annualised basis, presents challenges, limitations, and risks. Among these, the number and short duration of experiments, unusual experimental results, inherent measurement uncertainties, and the difficulty in representing a measurement in an Overseer file have been detailed in this report.

This report is focused on the evaluation or model performance assessment of the Overseer model against NZ paddock-scale grazing systems studies. The approach adopted selects the experimental data according to the conditions of use of the model, which are also discussed in this document. This selection is unavoidably subjective, and a different approach to collating results or experimental sites could lead to differences in assessment.

With the proposed approach described in this study, the comparison of the Overseer model N leaching estimates with experimental data produces a 'very good' (RSR=0.47 and NSE=0.77) performance rating for NZ paddock-scale grazing systems. This result is consistent with the analysis described by Welten et al. (2021), who used another approach to select experimental data. It is also consistent with the historical assessment of 2012 (Anon, 2012) despite significant changes since that date, such as the use of S-map (Lilburne et al., 2012) and monthly climate data. Although this model evaluation has limitations, this study demonstrates the effectiveness of the Overseer model for the grazed pastoral system, representing around three-quarters of NZ agricultural land.

In addition to this, comparison of the Overseer model N leaching estimates with experimental data produces a 'satisfactory' to 'good' (RSR=0.58 and NSE=0.63) performance rating for a limited cropping system. It is desirable to further compare Overseer model estimates with experimental data for the other types of agriculture modelled by the Overseer model. Welten et al. (2021) describe a reasonable agreement with cropping systems.

The complementary use of other methods such as scenario analysis and comparison with process-based models seems reasonable due to methodological limits of comparisons with experimental data. This will constitute a body of evidence further demonstrating the performance and limits of the Overseer model.

6 References

Anon (2012) Changes to the pastoral N model. OVERSEERFM Technical note 5, August 2012.

Brown, H., (2022). Uptake of nitrogen below 600 mm by deep rooted crops: Analysis of the extent of the phenomenon and a proposed mechanism to account for this in Overseer. Plant&Food research, PFR SPTS No. 22790.

Brown, H., Khaembah, E.N. 2020. Evaluation of the overseer nitrogen model for cropping systems. Plant&Food research, PFR SPTS No. 20143.

EHINZ, Environmental Health Intelligence NZ. September 2021. https://www.ehinz.ac.nz/assets/Factsheets/Released_2021/Agricultural-Land-Use_FA.pdf

Freeman, M, Robson, M, Lilburne L, McCallum-Clark, M, Cooke, A, & McNae, D. 2016. Using OVERSEER in regulation – technical resources and guidance for the appropriate and consistent use of OVERSEER by regional councils, August 2016. Report prepared by Freeman Environmental Ltd for the OVERSEER Guidance Project Board.

Keating, B. A., Carberry, P. S., Hammer, G. L., Probert, M. E., Robertson, M. J., Holzworth, D., … & Smith, C. J. (2003). An overview of APSIM, a model designed for farming systems simulation. European journal of agronomy, 18(3-4), 267-288.

Khaembah E.N., Brown H.E., Sharp J.M., Zyskowski R. 2015. Soil nitrogen and soil water dynamics in crop rotations: Estimation with the multiple crop single purpose model. In: Currie L.D., Burkitt L.L. eds. Moving farm systems to improved nutrient attenuation Occasional Report No 28. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. Pp. 10.

Ledgard, S. F., Clark, D. A., Sprosen, M. S., Brier, G. J. & Nemaia, E. K. K. 1996. Nitrogen losses from grazed dairy pasture, as affected by nitrogen fertiliser application. Proceedings of the New Zealand Grasslands Association, 57, 21-25.

Lilburne, L., Carrick, S., Webb, T., and Moir J. (2012) Computer-based evaluation of methods to sample nitrate leached from grazed pasture. Soil Use and Management, 28 (1) (2012), pp. 19-26

Moriasi, D.N., Arnold, J.G., Liew, M., Bingner, R.L., Harmel, R.D., & Veith, T.L. (2007). Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations. Transactions of the ASABE, 50, 885-900.

Muirhead R., AgResearch. Pers. Comm. June 2023

NRC (National Research Council) (2007) Models in Environmental Regulatory Decision Making. Committee on Models in the Regulatory Decision Process, Board on Environmental Studies and Toxicology, Division on Earth, and Life Studies. Washington, D.C.: National Academies Press.

Selbie, D., Smith, C., Mercer, G., and Shepherd, M. (2020). Evaluation of the OVERSEER® pastoral block N model (v.6.3.1): 1. Selection of farmlet experiments. Report for Overseer Limited. Client report number: re450/2020/051

Shapiro, S. S.; Wilk, M. B. (1965). An analysis of variance test for normality (complete samples). Biometrika. 52 (3–4): 591–611. doi:10.1093/biomet/52.3-4.591. JSTOR 2333709. MR 0205384. p. 593

Shepherd, M. (2019). Evaluation and validation of the OVERSEER® drainage model (v.6.3.1). Report for Strategic Science Investment Fund. AgResearch Report no. RE450/2019/052.

Shepherd, M., Selbie, D. (2019). Evaluation and validation of the OVERSEER® pastoral background N leaching sub-model (v.6.3.1). Report for Strategic Science Investment Fund. AgResearch Report no. RE450/2019/040.

Shepherd, M., Smith, L.C., Selbie, D. (2020). Comparison of Overseer-estimated dry matter and nitrogen intake with measured data. Report for AgResearch Ltd. AgResearch Report no. RE450/2020/029.

Shepherd, M., Selbie, D. (2020). An evaluation of the OVERSEER® urine patch N leaching sub-model. Report prepared for Strategic Science Investment Fund. AgResearch Report no. RE450/2020/022.

Shepherd, M., Selbie, D., Smith, L.C., Mercer, G. (2020). Evaluation of the OVERSEER® pastoral block N model (v.6.3.1) 3. Results. Report for Overseer Limited. AgResearch report no. RE450/2020/053.

Shepherd, M., Wheeler, D., Freeman, M., and Selbie, D. (2015). Rationale for Overseer® Nutrient Budgets evaluation and recalibration. AgResearch report no. RE500/2015/034.

Smith, C., Selbie, D., Mercer, G., and Shepherd, M. (2020). Evaluation of the OVERSEER® pastoral block N model (v.6.3.1): 2. Setting up files & systems. AgResearch report no. RE450/2020/053.

Tavernet, J.P., 2022. Sensitivity and uncertainty analyses for N-loss estimates by the Overseer model. In: Adaptive Strategies for Future Farming. (Eds. C.L. Christensen, D.J. Horne, and R. Singh). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 34. Farmed Landscapes Research Centre, Massey University, Palmerston North, New Zealand. 8 pages.

Watkins, N. L., and Selbie, D. (2015). Technical Description of OVERSEER for Regional Councils. AgResearch report no. RE500/2015/084.

Watkins, N. L., and Shepherd, M. A. (2014). A compendium of New Zealand pasture farmlet experiments measuring nitrogen leaching. Nutrient management for the farm, catchment, and community. L. D. Currie and C. L. Christensen. Palmerston North, New Zealand, Fertilizer and Lime Research Centre, Massey University. 27.

Welten B., Mercer G., Smith C., Sprosen M., and Ledgard S. (AgResearch); with contribution from: Khaembah E., Fraser T., and Thomas S. (Plant and Food Research) 2021. Refining estimates of nitrogen leaching for the New Zealand agricultural greenhouse gas inventory. Report for Ministry for Primary Industries, client report number: RE450/2020/077.

Appendix A

KEY OVERSEER MODEL ASSUMPTIONS AND LIMITATIONS

The Overseer model incorporates important hypotheses and limitations that are outlined below (derived from Watkins & Selbie, 2015):

Model scope

- The Overseer model boundary relevant to this report is the farm boundary and the root zone (below 600 mm).

Key Assumptions

- The Overseer model assumes steady-state conditions (i.e., inputs and site characteristics are in equilibrium with farm production).
- The Overseer model estimates annual average outputs assuming that the farm management and inputs are constant.
- The Overseer model assumes that the production did occur for the given inputs.
- The Overseer model assumes that certain practices or levels of practice ("good management practices") are occurring, e.g., fertiliser is spread evenly, dairy shed effluent ponds are sealed.
- The Overseer model assumes long-term average rainfall, PET, and temperature and a specific daily rainfall pattern based on location.

Limitations

- The Overseer model assumes near equilibrium farm systems; the losses that occur as the system changes are not captured.
- OverseerFM and the Overseer model are not a day-to-day decision management tools.
- The Overseer model does not model extreme episodic events (landslips, severe flood…)
- The Overseer model is not spatially explicit beyond the level of defined blocks.
- Not all management practices or activities that have an impact on nutrient losses are captured in the Overseer model.
- OverseerFM and the Overseer model do not represent all farm systems in New Zealand.
- Components of the Overseer model have not been calibrated against measured data from every combination of farm systems and environment.
- Scientific knowledge has been used to add components and to extrapolate to circumstances where calibration data has not been collected. The estimated loss uncertainties are likely to increase according to circumstances.

Appendix B

KEY OVERSEERFM AND OVERSEER MODEL TERMS OF USE

A complete description of the OverseerFM terms of use is reported by Freeman et al. (2016). The technical principles are summarised below.

Technical principle	Explanation
1 The use of OverseerFM and the Overseer model must recognise that the Overseer model only models some sources of nutrients	The Overseer model currently models seven nutrients, including N and P. For these nutrients, The Overseer model models losses from agricultural systems; it does not model nutrient losses from all activities that may occur in a catchment (e.g., losses from many point sources, landslips, some riverbed/bank erosion, and non-agricultural land are not captured). Importantly for P, the Overseer model does not explicitly model Critical Source Areas (CSA), potentially leading to underestimation of the actual P losses.
2 The use of OverseerFM and the Overseer model must recognise that the Overseer model does not model all farm management or mitigation practices and that there are some assumed management practices within the Overseer model	There are some farm management practices that are used on farms, and are understood to impact some nutrient losses, but that are not captured in OverseerFM, e.g., contour ploughing or management of break feeding. There are also some "good management practices" that are assumed within OverseerFM. If practices occurring on farms are not modelled by OverseerFM, or the assumed levels of practice are not happening, the modelled losses may over- or underestimated relative to the actual losses from a farm.
3 The use of OverseerFM and the Overseer model must recognise that the Overseer model only estimates nutrient loss from the farm boundary and root zone	OverseerFM estimates nutrient loss from a farm (through leaching, runoff, direct to streams) as losses from the farm boundary or root zone (below 60 cm).

4 The use of OverseerFM and the Overseer model must recognise that the Overseer model is a steady-state model and does not model the effects of transition e.g., transition from dryland to irrigated or farm system change such as forestry to pastoral farming	When a system is in transition, e.g., conversion from dryland to irrigation or conversion of pasture to cropping, there are likely to be soil processes occurring that significantly impact on the actual nutrient losses during the transition period. However, OverseerFM assumes near-equilibrium farm systems, so the losses occurring as the system changes are not captured. Therefore, OverseerFM may underestimate or overestimate losses during a transition period.
5 The use of OverseerFM and the Overseer model must recognise that data inputs to OverseerFM (actual or estimated) need to reflect a long-term, biologically feasible farm system	In general, OverseerFM does not 'sense check' the production data entry into the model. OverseerFM assumes that the system being described by the user is biologically feasible. This means that implausible farm systems can be modelled. Also, a farm practice may be viable for a short time, e.g., mining soil nutrients. However, if this is not feasible in the long term, the estimated losses of these 'short-term' practices may underestimate the actual requirements and effects of that farm system over the longer term. Therefore, OverseerFM data inputs can be from actual farm data or estimated data. Where actual farm data is used, it should be consistent with technical principle 7. Where estimated, data inputs should be supported by either other modelling (e.g., Farmax or crop calculators) or farm system expertise.
6 OverseerFM and the Overseer model require significant expertise to enable farm systems to be modelled accurately, and the user must recognise that the quality of the data inputs impacts the uncertainty associated with the estimated nutrient losses	As with other models, if the input data and modelling methodologies used to construct an OverseerFM nutrient budget are poor, this will impact the quality of the modelled result and in turn the uncertainty associated with the estimated nutrient loss. Where OverseerFM is being used and the quality of the data is poor, this should be recognised as a factor likely to increase uncertainty in the Overseer model results. Using OverseerFM and the Overseer model require significant expertise.

7	The use of OverseerFM and the Overseer model must recognise the long-term climate input assumptions built into the Overseer model and choose data inputs consistent with those assumptions	The Overseer model incorporates several significant assumptions based on a stable long-term farm system, with similarly stable average climate conditions. Any modelling application that does not match these assumptions must be undertaken with care and is likely to increase the uncertainty of the estimates. Therefore, OverseerFM data inputs should be consistent with the climate assumptions.
8	The use of OverseerFM and the Overseer model must recognise the differences in N and P loss processes and how these are modelled in the Overseer model.	There are significant differences in N and P loss processes and the way the Overseer model models these losses. These differences are important for modelling nutrient losses and understanding and implementing mitigations.

Appendix C

NEW ZEALAND EXPERIMENTS MEASURING N LEACHING FROM GRAZED PASTURES

THE complete NZ grazed pastoral block (called paddock-scale experiment) studies measuring N-leaching loss based on research are listed in Selbie et al. (2020). A brief description of these experiments can be found in the appendices of Welten et al. (2021), and different observations/comments are highlighted in Shepherd et al. (2015). Another concise summary of experimental sites undertaken up to 2015 is made in Watkins and Shephard (2014).

The dairy paddock-scale experiments used in this report are listed in Table 2, with information on the location of the site, the publication describing the measurements, the total number of measurements available, and comments on the results obtained.

For an experiment, the total number of measurements is the sum of treatments multiplied by the number of years of measurements. The treatments do not necessarily have the same number of years of measurement for a given experiment.

Table 2*: Summary of dairy paddock-scale experiments used to assess OverseerFM performances against experimental data from grazed pastures.*

Site	Reference	Brief description	Total number of treatments (with at least 2 measurements) [and with different type of soil]	Total number of measure-ments	Comments
Southland					
Edendale	Monaghan et al. (2002; 2005)	Impact of N fertilisation and stocking rate on N leaching.	4 (4) [4]	12	Higher immobilisation potential had been assumed in the OverseerFM version 5 calibration.

Tussock Creek	Monaghan et al. (2009)	Effectiveness of DCD in reducing N leaching from a grazed dairy pasture.	2 (2) [2]	20	
Tussock Creek	Monaghan et al. (2016)	Effectiveness of various grazing strategies on N leaching	4 (3) [3]	11	Variable drainage recovery.
Otago					
Kelso	Monaghan & Smith (2004)	Impact of effluent application on nutrient losses in hydrologically isolated plots.	1 (1) [1]	3	
Telford P21	Shepherd et al. (2017)	P21 paddock-scale experiment. Animals housed off paddock for periods	3 (3) [3]	9	
Manawatu					
Massey DCG	Christensen et al. (2012)	Controlled duration grazing experiment investigating impact on N, P and faecal microbes in drainage and runoff.	2 (2) [2]	6	Small losses because even standard practice removes cows for long periods.
Massey P21	Shepherd et al. (2017)	P21 paddock-scale experiment, investigating impact of feed pads and controlled duration grazing on nutrient losses.	2 (0) [0]	2	

Waikato					
Ruakura N	Ledgard et al. (1999)	Investigating the fate of N with varying stocking rates and N fertiliser application.	3 (3) [3]	9	
Scott Farm RED	Ledgard et al. (2006)	'RED' experiment investigating mitigation practices to reduce N leaching.	3 (3) [8]	30	Different soil-types available. Unusually high N leaching for some treatments. Additional N mineralisation arising from historical N inputs possible.
Scott Farm Prototype	Glassey, 2013 and unpublished	Continuation of the 'RED' experiments – zero N, control, and standoff treatments.	3 (3) [9]	27	Different soil-types available. An extremely wet 2008 resulted in significant variability in the measurements, overshadowing differences between treatments.
Scott Farm P21	Beukes et al. (2017)	P21 paddock-scale study, investigating various stocking rates, N fertiliser rates and use of stand-off pads on nutrient losses.	2 (2) [10]	40	Different soil-types available. Unusually high N leaching for some treatments.
Total			**29 / (26) / [45]**	**169**	

Remark: In Figure 4, measurements from the "Prototype" experiment for the extremely wet year 2008 are excluded because even if the best monthly climate data are entered, the model uses a typical daily pattern which does not cover extremely wet weather. Direct use of the 2008 daily climate can allow assessing the performance of the model under these extreme conditions.

Table 3 summarises beef/sheep/deer paddock-scale experiments used in this report with information on the location of the site, the publication describing the measurements, the number of measurements available, and comments on the results obtained.

***Table 3**: Summary of beef/sheep/deer paddock-scale experiments used to assess OverseerFM performances against experimental data from grazed pastures.*

Site	Reference	Brief description	Total number of treatments (with at least 2 measurements) [and with different type of soil]	Total number of measures	Comments
Manawatu					
Grasslands Ruz-Jerez	Ruz-Jerez et al. (1995)	N leaching under clover-based pasture and N fertilised pasture grazed by sheep	3 (0) [0]	3	
Waikato					
Lake Taupo Hoog	Hoogendoorn et al. (2011)	Compare N leaching from sheep, cattle, and deer	3 (3) [3]	6	
Total			**6 / (3) / [3]**	**9**	

The paddock-scale experiments and the reason why they are not used in the comparison with OverseerFM are detailed in Table 4. Comments come from Watkins and Shepherd (2014) or discussions with original researchers:

***Table 4**: Summary of paddock-scale experiments not used to assess OverseerFM performances against experimental data from grazed pastures.*

Site	Reference	Brief description	Total number of		Comments
			Treatments	Measures	
Canterbury					
LUDF	Unpublished	In-paddock lysimeters monitoring farm N leaching losses	-	-	Experimental data and OverseerFM files from the LURF experiment in Canterbury were not available for this work.
Waikato					
Ruakura SR	Sprosen et al. (2002)	Impact of four stocking rates on N leaching.	9	24	Experimental results show a negative linear relationship between stocking rate and N leaching (i.e., as stocking rate increases, nitrate leaching decreases). These experimental results were excluded from the validation dataset, as the changes to farm management that are associated with increasing stocking rate and that lead to less N in urine during the autumn were not available. Compiling the necessary dataset would take time, but should be undertaken. Welten et al. (2021) also excluded these data, as they concluded, based on Sprosen et al. (2002), that stocking rate with limited imported feed may be

					a poor indicator of N leaching, given that N leaching tended to be higher at lower stocking rates in this experiment. Shepherd et al. (2015) suspected that other factors e.g., severe pugging at higher stocking rates were involved in contributing to the observed trend, despite the fact that there were no differences in pugging between the stocking rate treatments and differences in soil microporosity were small. Roche et al. (2016), having estimated the differences in dietary and per ha nitrogen surplus in the experiment, explained that this effect was related to a reduction in urinary N content and output per cow due to a reduction in N intake per cow. .
Bay of Plenty					
Wharenui	Ledgard et al. (2008)	Options to reduce N & P loss from pasture land into Rotorua Lakes	3	6	Land use in transition (beef&sheep to dairy) Uncertainty over the soil type Steady-state and soil type assumed in OverseerFM

Parekarangi	Sprosen & Ledgard (2014)	SFF-funded project comparing grazed paddocks	2	4	Land use in transition Immobilisation likely limited N leaching Steady-state assumed in OverseerFM
Lake Taupo Barton	Betteridge et al. (2011)	N leaching under undisturbed control pasture and high sugar ryegrass	2	-	Measurements just after sowing and so associated with a release of N from soil associated with the sowing. Not modelled in OverseerFM.
Manawatu					
Ballantrae	Hoogendoorn et al. (2017)	Effect of stocking rate and slope on N leaching with sheep	4	12	Measurements at 300mm. Issues with the use of buried mini-lysimeters. N leaching modelled below 600mm in OverseerFM.

Betteridge K, Crush J, Ledgard S, Barton M, Barton S. (2011). Nitrogen leaching implications of poor pasture persistence. In: Pasture Persistence - Grassland Research and Practice Series. pp. 79-84.

Christensen CL, Hanly JA, Hedley LD and Horne DJ. (2012). Three years of duration controlled grazing: what have we found. Advanced Nutrient Management: Gains from the Past – Goals for the Future. Palmerston North, New Zealand: Fertilizer and Lime Research Centre, Massey University., Fertilizer and Lime Research Centre. 25.

Glassey C, Roach C, Lee JM, and Clark DA. (2013). The impact of farming without nitrogen fertiliser for ten years on pasture yield and composition, milk solids production and profitability; a research farmlet comparison., New Zealand Grassland Association. 75: 71-78.

Hoogendoorn CJ, Betteridge K, Ledgard SF, Costall DA, Park ZA, Theobald PW. (2011). Nitrogen leaching from sheep, cattle and deer grazed pastures in the Lake Taupo catchment in New Zealand. Animal Production Science 51, 416-425.

Hoogendoorn CJ, Lambert MG, Devantier BP, Theobald PW, and Park ZA. (2017). "Nitrogen fertiliser application rates and nitrogen leaching in intensively managed sheep grazed hill country pastures in New Zealand." New Zealand Journal of Agricultural Research 60(2): 154-172.

Ledgard SF, Ghani A, Reading M, Sprosen M, Balvert S, Smeaton D. (2008). Farmers taking control of their future: Research into minimising nitrogen and phosphorus from pasture land into Rotorua Lakes. In: Carbon and nutrient management in agriculture. eds L. D. Currie & L. J. Yates), Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand.

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

Ledgard S, Sprosen M, Judge A, Lindsey S, Jensen S, Clark D, Luo J. (2006). Nitrogen leaching as affected by dairy intensification and mitigation practices in the resource efficient dairying (RED) trial. In: Implementing Sustainable Nutrient Management Strategies in Agriculture (2006) (Eds L. Currie and J. Hanly). Occasional Report No. 19. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand.

Monaghan RM, Paton RJ, Drewry JJ. (2002). Nitrogen and phosphorus losses in mole and tile drainage from a cattle-grazed pasture in eastern Southland. New Zealand Journal of Agricultural Research 45, 197-205.

Monaghan RM, Paton RJ, Smith LC, Drewry JJ, Littlejohn RP. (2005). The impacts of nitrogen fertilisation and increased stocking rate on pasture yield, soil physical condition and nutrient losses in drainage from a cattle-grazed pasture. New Zealand Journal of Agricultural Research 48, 227-240.

Monaghan RM, Smith LC. (2004). Minimising surface water pollution resulting from farm-dairy effluent application to mole-pipe drained soils. II. The contribution of preferential flow of effluent to whole-farm pollutant losses in subsurface drainage from a West Otago dairy farm. New Zealand Journal of Agricultural Research 47, 417-428.

Monaghan RM, Smith LC, Ledgard SF. (2009). The effectiveness of a granular formulation of dicyandiamide (DCD) in limiting nitrate leaching from a grazed dairy pasture. New Zealand Journal of Agricultural Research 52, 145-159.

Monaghan RM, Smith LC, Muirhead RW. (2016). Pathways of contamination transfers to water from and artificially drained soil under intensive grazing by dairy cows. Agricultural, Ecosystems and Environment 220: 76-88.

Roche J., Ledgard S., Sprosen M., Lindsey S., Penno J., Horan B., and Macdonald K. (2016). Increased stocking rate and associated strategic dry-off decision rules reduced the amount of nitrate-N leached under grazing. Journal of Dairy Science, Volume 99, Issue 7, 2016, Pages 5916-5925, ISSN 0022-0302, https://doi.org/10.3168/jds.2016-11024.

Ruz-Jerez BE, White RE, Ball PR. (1995). A comparison of nitrate leaching under clover-based pastures and nitrogen-fertilized grass grazed by sheep. Journal of Agricultural Science 125, 361-369.

Shepherd M., Wheeler D., Freeman M., and Selbie D. (AgResearch) 2015. Rationale for OVERSEER® Nutrient Budgets evaluation and recalibration. Report prepared for Oversser, report number RE500/2015/034.

Shepherd M, Hedley MJ, MacDonald KA, Chapman D, Monaghan RM, Dalley D, Cosgrove GP, Houlbrooke D and Beukes P. (2017). A summary of key messages arising from the pastoral 21 research programme. Science and policy: nutrient management challenges for the next generation. L. D. Currie and D. I. Hedderley. Palmerston North. New Zealand, Fertilizer and Lime Research Centre, Massey University. 30.

Sprosen M, Ledgard SF, Lindsey SB, Macdonald KA. (2002). Effect of stocking rate on leaching of nitrate and associated nutrients. In: Dairy farm soil management. eds L. D. Currie & P. Loganathan, Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand.

Sprosen M, Ledgard S. (2014). Meeting nutrient loss targets on dairy farms in the Lake Rotorua catchment: Interim report on results from the Parekarangi Trust farm. AgResearch report no. RE500/2013/057. 11pp.

Welten B., Mercer G., Smith C., Sprosen M., and Ledgard S. (AgResearch); with contribution from: Khaembah E., Fraser T., and Thomas S. (Plant and Food Research) 2021. Refining estimates of nitrogen leaching for the New Zealand agricultural greenhouse gas inventory. Report for Ministry for Primary Industries, client report number: RE450/2020/077.

For further information:

Contact the Science team at Overseer Ltd via email at
science@overseer.org.nz