Kaituna-Pongakawa-Waitahanui & Rangitāiki Catchment Models

APSIM Modelling Report

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1. Introduction

Williamson Water & Land Advisory (WWLA) were commissioned by Bay of Plenty Regional Council (BOPRC) in 2017 to develop hydrological models to simulate the water quantity and quality of the rivers and streams that comprise the Kaituna-Pongakawa-Waitahanui (henceforth Kaituna) and Rangitāiki Water Management Areas (WMAs), using the SOURCE catchment modelling framework. The project goal was to develop functioning integrated catchment models for the Kaituna and Rangitāiki WMAs, that will support policy development under the National Policy Statement for Freshwater Management (NPS-FM).

SOURCE is a hydrological modelling platform developed by the Australian not for profit research organisation eWater Limited. The platform is comprised of an interface integrating various models (as plugins) and internal tools designed to simulate and extract results for all aspects of water resource systems at a range of spatial and temporal scales.

A number of internal (to SOURCE) and external models were integrated using the SOURCE modelling framework. Internal models utilised included the Soil Moisture Water Balance Model (SMWBM) to simulate rainfall runoff processes, and dSedNet to simulate sediment generation. These models are further described in WWLA (2020a).

APSIM was utilised externally from SOURCE to simulate nitrogen leaching from the bottom of the soil profile from various land uses, and then integrated into SOURCE.

This report is a technical documentation of the development and application of APSIM models for land uses commonly found within the Kaituna and Rangitāiki WMAs. APSIM models were developed for the following land uses:

- Dairy
- Sheep and Beef
- Kiwifruit
- Maize
- Forests
- Vegetables
- Lifestyle

1.1 Project History

Eco Logical Australia (ELA) developed the original APSIM models used for generation of TN in the initial phases of this project in 2017. WWLA subsequently refined and updated these APSIM models in the process of calibrating the SOURCE catchment models for in-stream TN concentrations.

Community stakeholder meetings were held in both the Kaituna and Rangitāiki WMAs in late May 2019 to discuss project outcomes and receive further feedback from stakeholders. Revision 3 of this report was issued to BOPRC in June 2019, for review and comment to wider council staff.

This report (Revision 5) presents the development and benchmarking of updated APSIM model based on new information received since June 2019, and incorporates comments and feedback received from BOPRC staff and community stakeholders.

Key updates and changes of note to the APSIM models included:

- Distinction of highland (2.5 cows/ha) and lowland (3.2 cows/ha) dairy stocking rates;
- Inclusion of stock wintering off in the Lowland catchments of Kaituna and Rangitāiki WMAs;
- Updated representation of fertiliser application rates and amounts in the Dairy and Sheep and Beef models;
- Improved parameterisation of Galatea soils physical characteristics; and

- Benchmarking of the Kiwifruit leaching models to the recently released (July 2019) Plant & Food Research study on nitrate balances under Kiwifruit in the Bay of Plenty Region.

Model refinements of TN were based on industry information and stakeholder feedback provided prior to December 2019. Data or information received after that time has not been incorporated due to practical reasons.

1.2 Project Reporting Structure

The modelling and analysis undertaken for this for project is detailed across a suite of three technical reports, which are:

- **WWLA, 2020a.** ***Kaituna-Pongakawa-Waitahanui & Rangitāiki Catchment Models*** – details the development of the water quantity and quality catchment models;
- **WWLA, 2020b*. Kaituna-Pongakawa-Waitahanui & Rangitāiki APSIM Modelling Report*** (this report) – details the development of the APSIM Models.
- **WWLA, 2020c*. Kaituna-Pongakawa-Waitahanui & Rangitāiki Scenarios Modelling Report*** – presents the development and analysis of land use change and mitigation scenarios.

The structure of the report is as follow:

- **Section 2** - overview of the nitrogen cycle and nitrogen leaching;
- **Section 3** - methodology adopted for the APSIM modelling;
- **Section 4** - summary of soil characteristics and soil related parameterisation in APSIM;
- **Section 5** - parameterisation of land use based on land use management practices;
- **Section 6** - APSIM modelling results; and
- **Section 7** - discussion on model uncertainty and limitations.

2. Overview

Soils in New Zealand generally contain between 0.1 and 0.6% nitrogen (N) in the top 15 cm, with the majority (>95%) present in soil organic matter (decomposing plant material, humus and microbial biomass) and not immediately available for plant uptake (Haynes, 1986). Soil inorganic N, consisting of nitrate (NO_3-N), nitrite (NO_2-N) and ammonium (NH_4-N) is directly available for plant uptake and represents a small and transient N pool that accounts for < 2% of the total soil N content (Haynes, 1986). The processes governing the transformation of forms of N in soil are hence vital to understanding the partitioning of N in the soil-plant system and its fate. An overview of the N cycle in soil from agricultural practice is shown in **Figure 1**.

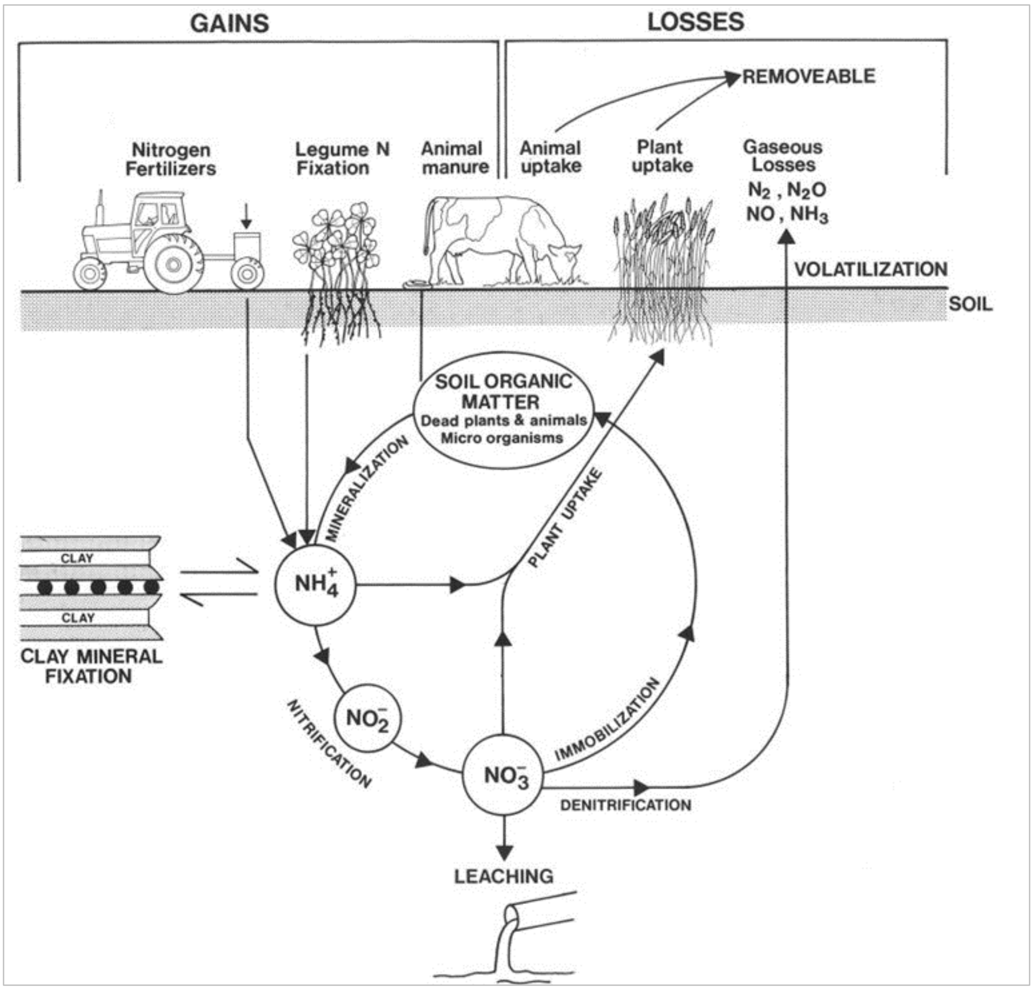

Figure 1. Soil nitrogen cycle (Di and Cameron, 2002).

In clover-based pastoral systems, the three main sources of N are: N fixed by clover plants, N input from fertiliser and N content from supplement feeds a proportion of which is delivered to the soil as animal excreta. Other minor N inputs include the N from effluent application and N wet and dry deposition from atmosphere. 60-90% of consumed N is returned as excreta, of which 70-80% is excreted as urine and 20-30% is egested as dung, resulting in average loading rates up to 1200 kg N/ha/year (Cameron, *et al*., 2013).

Nitrogen return as urine is typified by an irregular array of small patches with elevated N concentration, distributed, on average, across ~25% of the grazed paddock area, and of that 3-5% is overlapping, on an annual basis, and delivered through 8-12 urination events a day of about 2L each, though with considerable seasonal and climatic variability (Haynes and Williams, 1993). Cattle urine contains about 16 g urea/L and about 13 g/L amino acids and peptides (Bristow, *et al*., 1992) resulting in nitrogen concentrations of about 4 g/L, though with a daily variability that ranges from 1-13 g N/L (Hoogendoorn, *et al*., 2010).

Outputs from the nitrogen cycle occur through gas emissions (N_2O-N and N_2-N from denitrification), volatilisation (NH_3-N) and leaching (NO_3-N) loss to groundwater. Biological denitrification occurs naturally when certain bacteria use nitrate as terminal electron acceptor in their respiratory process, in the absence of oxygen. Denitrification consists of a sequence of enzymatic reactions leading to the evolution of nitrogen gas. The process involves the formation of a number of nitrogen intermediates and can be summarized as follows:

$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$

Denitrification occurs in microsites within well-drained soils in forests, grasslands, and agricultural lands, partially to fully saturated soils, aquifers, hyporheic and riparian sediments (Seitzinger *et al.*, 2006). The extent of denitrification in groundwater can have a potentially significant effect upon nitrate attenuation (Smith, *et al*., 2004). The efficiency of denitrification in groundwater ranges from 0% to 100%, and it is spatially heterogeneous which depends on local hydrogeology and mineralogy (Seitzinger *et al.*, 2006). In a regional study in Nebraska (Spalding and Parrott., 1994), denitrification accounted for the annual removal of approximately 1 mM nitrate, or an estimated 46 t of N/yr across a 12-m-deep, 15-km-long transect.

As a soluble and mobile form of N, NO_3-N is prone to leaching in the sub-surface with the drainage. NO_3^- leaching is the most important pathway of N loss from the soil-plant system in humid regions where high soil moisture condition from rainfall or snowmelt and high concentration of NO_3^- exist (Luce *et al*., 2011). The spatially variable land use on the land scape and heterogeneous environmental settings affecting the fate and pathway of NO_3-N pose different degrees of risks in excessive NO_3-N in the sub-surface, groundwater and surface water systems.

The magnitude and temporal variation in NO_3-N leaching is influenced by different land use, practices, and environmental conditions. Surface cropping systems, tillage practices, inorganic and organic N management, soil structure, infiltration of water and the timing of the infiltration event are some of the anthropogenic, physical and hydrological factors interactively leading to the leaching of NO_3-N in the sub-surface (Luce *et al*., 2011). The primary sources of N leachate vary across different land uses. Generally, the excreted animal urine dominates the N loss in the grazing system, with N from fertiliser application being the secondary important source, while, in a cropping system, N from fertilisation and crop residues are the main sources of leached NO_3-N (Menneer *et al*., 2004).

3. APSIM Modelling Approach

3.1 APSIM Framework

The Agricultural Production Systems Simulator (APSIM), is a modelling framework comprising a system model configured from component modules (McCown *et al*., 1996). APSIM is continuously being developed as a tool for the evaluation of alternative management strategies for improving the economics of agricultural production systems and the consequences for the soil resource and the environment.

APSIM is structured around the plant, soil and management modules. These modules include a diverse range of crops, pastures and trees, soil processes including water balance, N and P transformations, soil pH, erosion and a full range of management controls. APSIM resulted from a need for tools that provided more reliable predictions of crop production in relation to climate, genotype, soil and management factors while addressing the long-term resource management issues.

Separate modules handle the various sub-systems, e.g. water balance, dynamics of soil organic matter and nitrogen, solutes, surface residues, erosion, growth of crops or pasture. Alternative modules could be incorporated for sub-systems. This is the case for the water balance where two modules, SoilWater (Probert *et al*., 1998) and SWIM (Verburg *et al*., 1996) are available to simulate the flux in the sub-surface.

APSIM thus consists of three broad groups of modules (Keating *et al*., 2003):

- simulation, or bio-physical modules, defined by the model developer to simulate biological and/or physical farming system processes;
- data modules, for information input; and,
- management modules, which allow the user to specify rules that are required to characterise and control the simulation.

The simulation engine is the critical component that drives the simulation process, facilitates communication between the independent modules and provides the user interface. APSIM has been used in a broad range of applications including:

- support for on-farm decision making;
- farming systems design for production or resource management;
- assessment of the value of seasonal climate forecasting;
- analysis of supply chain issues in agribusiness;
- development of waste management guidelines;
- risk assessment for policy making; and,
- as a guide for research and educational activities.

3.2 Scope of Modelling

APSIM models were developed to simulate soil nitrogen dynamics related to different land use types and agricultural management regimes. The primary expectation for APSIM modelling was to provide more reliable estimates of dominant N leachate (NO_3-N) from different land uses and climate regimes following a processed-based approach. The intended purpose of the simulations were for integration into a regional scale catchment modelling system (WWLA, 2020a), and were not intended to provide detailed individual property scale models of N leaching.

4. APSIM Model Development

This section describes the generic components applicable to all land use models, developed using APSIM.

4.1 Simulation Period and Time Step

A major advantage of APSIM is its' ability to integrate daily climate inputs (rainfall, evaporation, daily minimum and maximum temperature) to produce daily fluxes of water and nutrients, as well as crop production indicators. The APSIM models developed for this project cover the time period 01/07/1976 – 30/06/2018, which is the same period as simulated in the SOURCE catchment models (WWLA, 2020a). All model outputs were reported on a daily time step.

4.2 Climate

APSIM utilises daily climate data obtained from either climate modelling or meteorological stations. Climate inputs required include; daily minimum and maximum temperature, solar radiation, and rainfall. Two constants, the annual amplitude in mean monthly temperature (AMP) and annual average ambient temperature (TAV) were also specified.

Daily interval climate data were sourced from NIWA's Virtual Climate Station Network[1] (VCSN). 38 virtual stations were selected from within and surrounding the Kaituna and Rangitāiki WMAs. These stations were mapped across SOURCE sub-catchments, and assigned using a kriging spatial interpolation method to the centroid of each sub-catchment. Therefore, ensuring consistent climate data were used between the SOURCE hydrological models and APSIM modelling.

4.3 Soil Water Component

APSIM has two built-in modules for soil water and flux simulation; the SoilWater and SWIM modules. SoilWater is a cascading water balance model based on the CERES family of models (Jones and Kiniry, 1986). SWIM provides a 1-dimensional simulation of water fluxes through a numerical solution to the Richards' equation (Richards, 1931). The SoilWater module was adopted for this project due to it its similarity to the Soil Moisture Water Balance Model (SMWBM) utilised for the SOURCE catchment models of this project (WWLA, 2020) and due to increased solution stability (non-convergence issues have previously been encountered when using SWIM).

Default values were initially specified during parameterisation of the SoilWater module. Adjustments were made following the protocol documented in the development of soil parameter values for use in APSIM (Dalgliesh *et al*., 2015), and through optimising values to attain comparable drainage rates and temporal patterns to those simulated by the SMWBM (**Section 4.11**). Calibrated values for the SoilWater module are provided in **Appendix A**.

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[1] Virtual Climate station Network (VCSN), NIWA, https://www.niwa.co.nz/climate/our-services/virtual-climate-stations

4.4 Soil Classification

APSIM flow and solute simulations were parameterised based on local soil physical and hydraulic characteristics (e.g. soil depth, bulk density, field capacity, etc.). In order to integrate APSIM with the catchment scale SOURCE models, representative soil types were determined based on the spatial distribution of soils in the Kaituna and Rangitāiki WMAs.

Soils in the Kaituna and Rangitāiki WMAs are generally regionally uniform, and predominantly consist of a mixture of loam and sandy loam soil derived from pumaceous rhyolitic tephra. These soils are of moderate to high permeability and hence have high infiltration and sub-soil drainage characteristics.

The relatively deeper sandy pumice soils are predominately distributed in the high plateau area, and the shallower loamy soil predominately deposited near the low-lying stream valleys. Sandy pumice soil prevails across the Kaituna, while in the Rangitāiki, near the Rangitāiki River, recent fluvial loamy soil is prevalent. The spatial distribution and characteristics are broadly summarised in **Table 1**. As the soil characteristics are to be incorporated into a regional scale modelling framework, only the dominant soil types were specified.

The soils in the region are typically classified as well-drained with rapid permeability.

Table 1. Summary of soil types and characteristics.

WMA	Soil type*	Spatial distribution	Characteristics*
Rangitāiki	Taupof	High plateau area	Deep (>1 m), immature orthic pumice soil **sandy loam over loam**, well drained, rapid permeability.
	Rangitaikif	Downstream valley area	Moderately deep (0.3-0.5 m), alluvium recent fluvial **sandy loam**, well drained, rapid permeability.
	Turangif	Downstream valley area	Deep (>1 m), typical orthic pumice **sandy loam**, well drained, rapid permeability.
Kaituna	Oropif	Across the whole WMA, dominantly distributed in the high plateau area	Deep (>1 m), buried allophanic orthic pumice **sandy loam over loam**, well drained, rapid permeability.
	Turangif	Eastern part of the WMA	Deep (>1 m), orthic pumice **loam over sandy loam**, well drained, rapid permeability.
	Otanewainukuf	Across the whole WMA, majorly distributed near the low-lying stream valleys	Moderately deep (0.6-1 m), orthic allophanic **loam,** well drained, moderate to rapid permeability.
	Paengaroaf	Majorly distributed in the middle Kaituna WMA	Deep (>1 m), buried allophanic orthic pumice **sandy loam**, well drained, rapid permeability.
	Ngakuraf	Distributed in middle Kaituna WMA to the west	Deep (>1 m), typical orthic allophanic **loam**, well drained, rapid permeability.

* Soil information derived from S-map Online, Manaaki Whenua, Landcare Research.

S-map suggests that soil depths across the region vary between approximately 400 mm – 1400 mm. Given that the hydraulic characteristics are relatively uniform, the key variation in soil characteristics is soil depth. Therefore, the soils were categorised into 5 representative types based on soil depth for parameterisation in APSIM, as listed in **Table 2**.

The area weighted average soil depth was calculated for each sub-catchment, and each sub-catchment was represented by one APSIM soil depth model (and multiple land use models – as detailed in **Section 5**).

Table 2. Soil depth classification.

Soil depth APSIM model (mm)	Soil Type	No. of Kaituna catchments	No. of Rangitāiki catchments
0 - 500	Rangitāiki/Urewa Soil: A well-drained sandy loam soil	9	16
500 - 700	Kaingaroa Soil: A well-drained sandy loam soil	6	15
700 -1000	Paengaroa Soil: A well-drained sandy loam soil	19	18
1000 - 1200	Oropi Soil: A well-drained sandy loam over loam soil	38	21
1200 - 1400	Taupo/ Matahina Soil: A well-drained sandy loam soil	47	47

Peat and gley soils of the lowland Kaituna catchments were not explicitly simulated within APSIM. These were typically represented by the Paengaroa Soil (sandy loam soil) model. As a result, these may overestimate N losses on the peat soil, as lower losses from poorly drained soil where there are no field tile drains would be expected from peat soils. However, where there are field tiles and drains, N losses are expected to be higher, hence overall it may balance out.

4.5 Soil Characteristics

4.5.1 Soil Physical and Hydraulic Properties

The main soil physical properties required for SoilWater include:

- bulk density (BD);
- soil moisture (Air dry);
- lower limit of soil moisture at 15 bar (LL15);
- drained upper limit (DUL), saturation (SAT); and
- saturated hydraulic conductivity (KS).

These properties were required for each individual soil layer specified in APSIM. However, vertical profiles of soil physical properties are generally hard to obtain without laboratory data. Therefore, the S-map soils database (Landcare Research, 2016) provided soil information summarising the average properties of each modelled soil type.

In general, the Kaituna and Rangitāiki WMAs are dominated by well drained pumice soil with rapid permeability. No slowly permeable horizon or rock layers are recorded within 1 m based on S-map. Approximate dry bulk density for topsoil and subsoil is 0.85 g/cm^3. The Galatea catchments were assigned specific bulk densities based on information detailed by Plant and Food Research (Green & Mason, 2017). Bulk densities were specified for all other locations based on the average bulk density as listed in SMAP.

A summary of values adapted to represent soil physical condition are shown in **Table 3**. The values specified for each soil layer are detailed in **Appendix A**. Specific values were adjusted for each land use to calibrate the model to expected leaching rates. Within each model there are multiple layers that represent different soil depths, hence, where the physical characteristics vary across layers a range is given.

Table 3. Summary of soil physical characteristics for well-drained pumice soils.

WMA	Model (soil depth – mm)	Bulk Density	Air Dry	Lower limit at 15 bar	Drained upper limit	Saturation	SWCON	Saturated hydraulic conductivity
		g/cm^3	mm/mm	mm/mm	mm/mm	mm/mm	-	mm/day
Kaituna	0-500	0.85	0.09-0.15	0.13-0.16	0.13-0.28	0.62-0.65	0.01-0.1	4-75
	500-700	0.85	0.09-0.16	0.13-0.16	0.13-0.31	0.62-0.65	0.02-0.11	9.5-250
	700-1000	0.85	0.09-0.16	0.13-0.16	0.13-0.31	0.52-0.60	0.02-0.12	9.75-400
	1000-1200	0.85	0.09-0.16	0.13-0.16	0.13-0.30	0.52-0.60	0.05-0.12	6.3-300
	1200-1400	0.85	0.09-0.16	0.13-0.16	0.13-0.30	0.52-0.60	0.02-0.1	7.4-320
Rangitāiki	0-500	0.85	0.09-0.15	0.13-0.16	0.13-0.28	0.62-0.65	0.01-0.12	4-140
	500-700	0.85	0.09-0.16	0.13-0.16	0.13-0.31	0.62-0.65	0.02-0.1	3-115
	700-1000	0.85	0.09-0.16	0.13-0.16	0.13-0.31	0.52-0.60	0.02-0.12	4-210
	1000-1200	0.85	0.09-0.16	0.13-0.16	0.13-0.30	0.52-0.60	0.05-0.12	11-250
	1200-1400	0.85	0.09-0.16	0.13-0.16	0.13-0.30	0.52-0.60	0.02-0.1	4-220
Galatea	0-150	0.91	0.09-0.15	0.13-0.16	0.13-0.28	0.62-0.65	0.01-0.12	4-140
	150-300	1.16	0.09-0.16	0.13-0.16	0.13-0.31	0.62-0.65	0.02-0.1	3-115
	300-600	0.93	0.09-0.16	0.13-0.16	0.13-0.31	0.52-0.60	0.02-0.12	4-210
	600-900	0.76	0.09-0.16	0.13-0.16	0.13-0.30	0.52-0.60-	0.05-0.12	11-250
	900+	0.94	0.09-0.16	0.13-0.16	0.13-0.30	0.52-0.60	0.02-0.1	4-220

Lower limit at 15 bar: Lower limit of soil water content. It is approximately the driest water content achievable by plant extraction

SWCON: Coefficient to define the proportion of difference between soil moisture and drained upper limit that cascades down to the next layer

Drained upper limit: Upper limit of soil water content. It is the content of water retained after gravitational flow, sometimes referred to as "Field Capacity"

Additional crop parameters were required for each soil depth layer to use soils with separate crop components (e.g. AgPasture). These include factors for daily crop water extraction (crop KL/day) and extraction lower limits (crop LL), used to calculate crop Plant Available Water Capacity (PAWC). Crop values were adapted from values provided within the example APSIM simulations and documentation (Dalgleish *et al*., 2015).

4.5.2 Soil Organic Matter

The Soil Organic Matter component is important for controlling mineralisation or immobilisation of nitrogen. The parameters in the soil organic matter module are used for model initialisation. As the simulation progresses, the carbon distribution reaches a quasi-steady state reflecting the land use.

Input parameters include soil-wide constants for the C:N ratio (root and soil), root weight and erosion enrichment coefficients. The transportation of nitrogen is dependent on the C:N ratio (APSIM initiative, 2016). The parameters used to define the C:N ratio in the root and soil zone are summarised in **Table 4**.

Table 4. Parameters used to define the C:N ratio in the root and soil zone.

Parameter	Pasture and Cropping	Forest	Description
Root C:N ratio	40:1	90:1	40:1 for all soils (Dalgliesh *et al*., 2016). Information on C:N in roots is limited, and for fine roots, C:N ratio was reported to range between 23:1 to 226:1 with a mean of 53:1, in addition, (Table 12 - Snowdon *et al*., 2005) indicates a fine root C:N ratio of 80:1 and 89:1 for Eucalyptus and Pinus radiata, respectively.
Root Weight (kg/ha)	1,000	1,000	1,000 for all soils for initialisation (Dalgliesh *et al*., 2016)
Soil C:N ratio	14:1	22:1	For an optimum soil quality, pastures, and cropping and horticulture have C:N ratio of 8-12:1 and 8-20:1, respectively, for forestry, a ratio less than 12:1 is optimal (Graham *et al*., 2008). General rating for all soils and land uses, a C:N ratio of 7-30:1 was considered optimal (Graham *et al*., 2008). Eucalypt forests generally have high (21-33:1) C:N ratio in surface soils and Pine plantations have higher ratios than Eucalypt plantations (Snowdon *et al*., 2005).
Erosion enrichment coefficient A	7.4	7.4	Default values from Dalgliesh *et al*.(2016)
Erosion enrichment coefficient B	0.2	0.2	Default values from Dalgliesh *et al*.(2016)

The organic carbon distribution in the vertical soil profile is rarely available. Therefore, constants for the fraction of biomass and inert C have been adapted from example soil/crop simulations using the recommendations of Dalgleish *et al.,* (2016) and descriptions of organic carbon dynamics in Taupo pumice soils by Jackman (1960). Reference values for inert C (Finert) as a fraction are summarised in **Table 5**. Finert is used for initialisation of the SoilCarbon module, and therefore if appropriately initialised, model results are not sensitive to this parameter.

Table 5. Reference values for inert fraction (Finert) of soil carbon.

AgPasture soil example		Vertosol-Inert (Dalgleish *et al.,* 2016)	
Depth (cm)	**Value**	**Depth (cm)**	**Value**
0-10	0.3	0-15	0.4
10-30	0.5	15-30	0.6
30-60	0.6	30-60	0.8
60-100	0.8	60-180	0.95

The range of initial fractions of carbon in each soil organic matter pool is summarised in **Table 6** and **Table 7** for Kaituna and Rangitāiki WMAs, respectively.

Table 6. Summary of initial fractions of carbon for Kaituna.

Land use	Soil Depth	Range of OC Across all Layers	Average OC	Fbiom	Finert
	(cm)	(%)	(%)	0-1	0-1
Dairy	0-500	2.7-11.1	6.2	0.01-0.03	0.21-0.35
	500-700	1.9-12.5	6.5	0-0.03	0.35-0.59

Land use	Soil Depth	Range of OC Across all Layers	Average OC	Fbiom	Finert
	(cm)	(%)	(%)	0-1	0-1
	700-1000	2.2-14.4	7.2	0-0.03	0.6-1.0
	1000-1200	2.5-16.9	7.5	0-0.03	0.27-0.45
	1200-1400	1.1-16.9	7.7	0-0.03	0.28-0.47
Sheep and beef	0-500	2.2-8.9	5.0	0.01-0.03	0.46-0.77
	500-700	1.6-10.7	5.6	0-0.03	0.54-0.90
	700-1000	1.7-11.6	5.8	0-0.03	0.56-0.94
	1000-1200	2.1-14.2	6.3	0-0.03	0.57-0.95
	1200-1400	1.0-15.1	6.9	0-0.03	0.45-0.75
Maize	0-500	1.6-6.7	3.7	0.01-0.03	0.6-1.0
	500-700	1.9-12.5	6.5	0-0.03	0.51-0.85
	700-1000	2.2-14.4	7.2	0-0.03	0.72-1.0
	1000-1200	2.5-16.9	7.5	0-0.03	0.40-0.67
	1200-1400	1.1-16.9	7.7	0-0.03	0.39-0.65
Kiwifruit	0-500	1.8-7.3	4.1	0.01-0.03	0.54-0.86
	500-700	1.3-8.5	4.4	0-0.03	0.63-1.0
	700-1000	2.0-13.4	6.7	0-0.03	0.72-1.0
	1000-1200	2.4-16.0	7.1	0-0.03	0.66-1.0
	1200-1400	1.8-16.0	7.4	0-0.03	0.60-1.0
Lifestyle	0-500	2.8-11.1	6.2	0.01-0.03	0.43-0.72
	500-700	1.9-12.5	6.5	0-0.03	0.51-0.85
	700-1000	2.3-15.1	7.6	0-0.03	0.66-1.0
	1000-1200	2.6-17.2	7.6	0-0.03	0.58-0.96
	1200-1400	1.1-16.8	7.6	0-0.03	0.51-0.85
Forest	0-500	3.3-13.3	7.5	0.01-0.03	0.66-1.0
	500-700	2.2-14.7	7.7	0-0.03	0.74-1.0
	700-1000	2.5-16.5	8.2	0-0.03	0.78-1.0
	1000-1200	2.8-18.9	8.3	0-0.03	0.75-1.0
	1200-1400	1.3-19.0	8.6	0-0.03	0.76-1.0
Vegetable	1000-1200	2.5-16.9	7.5	0-0.03	0.60-1.0

OC: Organic carbon content: to be used to initialise the carbon content of the soil layers.

Fbiom: The ratio to specify biom carbon (more labile, soil microbial biomass and microbial products) that is subjected to decomposition.

Finert: Proportion of initial organic carbon assumed to be inert. (Dalgliesh *et al*.,2016).

Table 7. Summary of initial fractions of carbon for Rangitāiki.

Land use	Soil Depth	Range in OC in each Layers	Average OC	Fbiom	Finert
	(cm)	(%)	(%)	0-1	0-1
Dairy	0-500	2.8-11.1	6.2	0.01-0.03	0.06-0.10
	500-700	1.9-12.5	6.5	0-0.03	0.04-0.06
	700-1000	2.2-14.4	7.2	0-0.03	0.54-0.90
	1000-1200	2.5-16.9	7.5	0-0.03	0.44-0.73
	1200-1400	1.1-16.9	7.7	0-0.03	0.36-0.60
Sheep and beef	0-500	2.2-8.9	6.2	0.01-0.03	0.46-0.77
	500-700	1.6-10.7	6.5	0-0.03	0.54-0.90
	700-1000	1.7-11.6	7.2	0-0.03	0.56-0.94
	1000-1200	2.1-14.2	7.5	0-0.03	0.57-0.95
	1200-1400	1.0-15.1	7.7	0-0.03	0.45-0.75
Maize	0-500	1.6-6.7	3.7	0.01-0.03	0.6-1.0
	500-700	1.9-12.5	6.5	0-0.03	0.3-0.5
	700-1000	2.2-14.4	7.2	0-0.03	0.6-1.0
	1000-1200	2.5-16.9	7.5	0-0.03	0.51-0.85
	1200-1400	1.1-16.9	7.7	0-0.03	0.39-0.65
Kiwifruit	0-500	1.8-7.3	4.1	0.01-0.03	0.54-0.86
	500-700	1.3-8.5	4.4	0-0.03	0.63-1.0
	700-1000	2.0-13.3	6.7	0-0.03	0.72-1.0
	1000-1200	2.4-16.0	7.1	0-0.03	0.66-1.0
	1200-1400	1.8-16.0	7.4	0-0.03	0.6-1.0
Lifestyle	0-500	3.7-15.1	8.5	0.01-0.3	0.06-0.10
	500-700	2.3-15.1	7.9	0-0.03	0.42-0.70
	700-1000	2.3-15.1	7.6	0-0.03	0.54-0.90
	1000-1200	2.6-17.2	7.6	0-0.03	0.48-0.80
	1200-1400	1.1-16.8	7.6	0-0.03	0.36-0.60
Forest	0-500	3.3-13.3	7.5	0.01-0.03	0.63-1.0
	500-700	2.2-14.7	7.7	0-0.03	0.74-1.0
	700-1000	2.5-16.5	8.2	0-0.03	0.78-1.0
	1000-1200	2.8-18.9	8.3	0-0.03	0.77-1.0
	1200-1400	1.3-18.9	8.6	0-0.03	0.76-1.0
Vegetable	500-700	1.9-12.5	6.5	0-0.03	0.04-0.06
	700-1000	2.2-14.4	7.2	0-0.03	0.54-0.90
	1000-1200	2.5-16.9	7.5	0-0.03	0.6-1.0
	1200-1400	1.1-16.9	7.7	0-0.03	0.36-0.60

Drewry *et al*. (2015) summarised the organic carbon content across land use types from four New Zealand regions based on 322 soil samples, shown in **Figure 2**. Market garden (i.e. vegetables) had a median OC content of less than 5% and is lower than median OC content from drystock, horticulture, and forestry land use. Amongst these four land use types, forestry showed a greater variation in OC. The thickness weighted composite OC from each land use model presented in **Table 6** and **Table 7** are consistent with the ranges shown from the **Figure 2.**

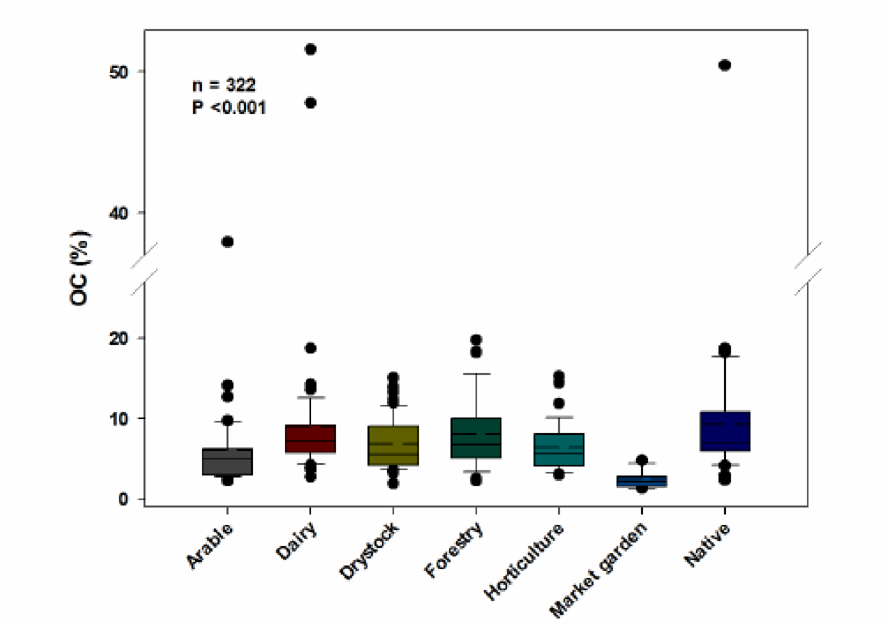

Figure 2. Organic carbon grouped by land use for Auckland, Waikato, Hawke's Bay and Wellington regions (Figure 2 from Drewry *et al.*, 2015).

4.5.3 Soil Initial Conditions

Initial Water provides a means to set the starting water content (between DUL (100%) and LL15 (0%)) and selected initial soil properties (e.g. pH). All simulations used a starting water content of 25% and pH of 5.9 as per the Lismore (NZ) Silt Loam soil example (APSIM, 2019) which was used as it is the predominant soil type within the catchment, and provides a reasonable starting condition for the APSIM models.

The soil nitrogen (SoilN) model component operates in conjunction with the SoilWater component to model fluxes of both nitrogen and carbon in the soil, including the mineralisation from organic pools, redox transformations, and loss through denitrification and leaching. Input parameters consisted of initial values of nitrate (NO_3-N) and ammonium (NH_4-N) used to initialise the simulation.

During initial model setup it was found that the effect of initial N on the model simulation diminished quickly as the simulation progressed. Therefore, the model was considered not sensitive to initial N values.

Surface Organic Matter is used to represent the surface residues production and attenuation process. In the context of land use modelling this is relevant for modelling surface mulching of woody material after felling of plantations, as well as ongoing pasture and crop residues. The mass and C:N ratio of surface material influences immobilisation of soil nitrogen, while the mass and type of residue influence soil water evaporation and, consequently drainage. Default values from the surface organic matter module were adopted.

4.6 Crop and Cover

A number of crop components are provided within APSIM, including the AgPasture component that was used for conversion and grazing simulations within this project. The AgPasture component contains dry matter parameters and calculations for a ryegrass-white clover pasture. The component default comprised an initial pasture with 2,000 kg/ha above ground dry matter weight and 600 kg/ha root dry matter weight split between 75% ryegrass and 25% white clover.

Table 8. Parameterisation of the AgPasture component.

Land use/Year	**Pasture Composition (%)**		**Initial Above Ground Dry Matter Weight (kg DM/ha)**		**Initial Root Dry Matter Weight (kg DM/ha)**		**Initial Rooting Depth (mm)**	
	Ryegrass	*White Clover*	*Ryegrass*	*White Clover*	*Ryegrass*	*White Clover*	*Ryegrass*	*White Clover*
3-5 years since pasture establishment	75	25	1,500	500	450	150	250	250

4.7 Management

A number of management components are available within APSIM to represent farming practices (e.g. irrigation, fertilisation, stock management, grazing and harvest, etc). These are assumed to be homogenous at a paddock scale and readily scalable to a farm scale. Further details are provided within the Land Use Modelling section (**Section 5**).

4.8 Fertilisation

Regular fertiliser application was simulated in land use models where fertilisation practices occur. Fertiliser was also added to simulate the additional nitrogen inputs for a farming system (e.g. supplement feed). Fertiliser type was generally set to urea_n. Descriptions of the additional nitrogen inputs applied for each land use are provided in **Section 5**.

4.9 Grazing

Basic pasture management modules are available in APSIM that operate within the AgPasture plant module. These include fixed date and interval grazing, and grazing rotations based on target and residual herbage mass. Rotational grazing between herbage target and residual was used in modelling, with fixed interval grazing used in selected contexts; this reflects best practice grazing management. Inputs within the user-interface control the target and residual pasture mass (kg/ha), the amount of pasture consumed per day, the fraction of ingested nitrogen returned to the soil as dung and urine, and the depth of urine return.

Calculated daily consumption can be used as a proxy for paddock stocking rate; a one-day paddock stay was assumed for most situations, based on common practice. Albeit grazing duration on each paddock varied temporally depending on stocking levels and animal type in the farming practice. Herbage dry matter (DM) to start and end grazing were adapted from industry guidelines (e.g. Dairy NZ, 2008).

At the level of the single paddock, the nitrogen return factor reflects the metabolism of the stock on the paddock. Nitrogen use efficiency for grazing animals, particularly dairy cattle, is well documented (e.g. Castillo *et al.,* 2000, Powell and Rotz., 2015). Based on available literature, a default value for milking cattle of 0.72 (72% of nitrogen excreted) was adopted, which was modified based on spatial and temporal patterns of harvesting methods or grazing rotations, or nutrient content of cattle feed. A value of 0.85 was adopted for sheep and beef grazing. Default values were retained for the fraction of waste deposited as urine (0.6) and the urine was assumed to deposit close to the surface (10 mm).

The nitrogen return factor was also used as a lumped parameter to reflect variation in management across the dairy farm blocks (grazing rotation, silage, fodder crops) and the associated variation in nitrogen inputs. It was also used as a means to model high nitrogen loading within urine patches. The approach to farm scale modelling is detailed in **Section 4.10.1**.

4.10 Consideration for Modelling Grazing System

This section is adapted from Eco Logical (2017) Draft "APSIM Modelling of Farm System Nutrient Dynamics," that developed the approach for modelling grazing systems during the initial APSIM models developed for BOPRC.

4.10.1 Farm Scale Management Using APSIM

Management inputs and nutrient outputs associated with the AgPasture modules nominally apply to a single paddock rather than the multiple paddocks typically used on a dairy farm to facilitate stock rotation and pasture regrowth. Paddocks are managed collectively to ensure sufficient feed for stock on a given grazing event as well as throughout the year. As a result, individual paddocks may be subjected to different management regimes such as intense grazing, resting, collection of surplus pasture for silage, or forage crop rotations. Supplementary feed may also be imported onto the paddock in response to a seasonal feed deficit. Variation in management regime can significantly alter the amount of nutrients added or removed from the paddock soil and thus affects leaching. Differing management of paddocks also occurs in the modelling due to uneven application of effluent (from the milking shed) and mulch (from pine slash).

Within the APSIM modelling framework, the basic AgPasture management modules do not include a setup for multiple paddocks within a farm. Therefore, parameters reflecting differing N inputs across paddocks have been averaged into a single paddock model. This has been applied to:

1. Harvestable herbage and residual pasture to account for seasonal demand and supply of pasture;
2. Daily consumption for the grazing herd to facilitate varying paddock stay times and thus influence the timing of grazing recurrence; and,
3. Nitrogen removed and return fractions to account for variability in the proportion of pasture harvested for silage (all nitrogen removed) or grazed (a proportion of nitrogen is returned through excrement)

Further detail on these approaches are provided for individual land use descriptions (**Section 5**). The approach was optimised for a standard dryland dairy farm and adapted for other land uses.

A three-season modelling approach was conceptualised to enable temporal variability in stocking, feed supply, and paddock management to be modelled in AgPasture management modules. Selected parameters within the block script provided means of integrating nitrogen inputs from non-pasture blocks and for averaging the impact of grazed and cut pasture.

4.10.2 Consideration of Urine Patches

On dairy farms, urine excreted from cattle is the primary source of leached nitrogen, hence appropriate treatment of urine patches in the models was a primary objective for the modelling of dairy farms. Several New Zealand studies have suggested that urine patches are deposited on approximately 3-5% of a paddock within a given grazing event (Chicota *et al*., 2010). Over multiple grazing days throughout a year approximately 15-25% of the paddock can be affected by urine patches. The greatest leaching typically occurs from patches deposited during late summer and autumn. Leaching from overlapped urine patches is typically 40% greater than single urine patches (Romera *et al*., 2012).

The approach to account for the effects of urine patch nitrogen loads involved the use of ‘background’ (i.e. no urine deposited) and ‘urine patch’ paddocks which were then spatially weighted and combined. The method to represent concentrated urine return is summarised in **Table 9**.

Table 9. Computation of N return factor to represent urine patch.

Process	Description	Variables	N return
Pastures utilisation	Percentage of pasture utilised by stock	f_2 (85% for dairy, 70% for sheep and beef)	$(M_1+M_2-M_3)\times f_1\times f_2$
N inputs	Pasture production within the paddock	M_1	$(M_1+M_2-M_3)\times f_1$
	Additional supplement feed	M_2	
N outputs	Pasture harvested as silage transported out of paddock	M_3	
N return factor	Fraction of N returned as excreta	f_1 (72% for dairy, 85% for sheep and beef)	
Urine return	Fraction of N returned as urine in excreta	f_3 (60%)	$(M_1+M_2-M_3)\times f_1\times f_2\times f_3$
Concentrated urine return	Area ratio between pasture utilisation and urine patch within a paddock	25*	$(M_1+M_2-M_3)\times f_1\times f_2\times f_3\times 25$
N return factor – adjusted	Lumped parameter for modelling purpose	F	$\frac{(M_1+M_2-M_3)*f_1*f_2*f_3*25}{M_1}$

*Urine Patch coverage in a single grazing event - urine patches affect 3-5% paddock on a given grazing day (Chicota, *et al*., 2010); urine was assumed to be retuned to 4% of the paddock. As pasture is consumed evenly over 100% of the paddock (as modelled) and returned to 4% of the paddock, the amount of N returned through urine is 25 times higher than what is consumed from that part of the paddock.

Pasture production is a simulation variable from APSIM. To represent the elevated N return from a urine patch, N inputs (additional feed), N outputs (silage production) and other factors shown in **Table 9** above were lumped into one factor (F) to be parameterised in the model. Additional conditions for urine patch N return are summarised in **Table 10**.

Table 10. Conditions in N return from urine patch.

Process	Condition	N return factor
Urine patch return	Proportion of N returned through urine set as 1	F
Background N return	Proportion of N returned through urine set as 0	$\frac{(M_1+M_2-M_3)*f_1}{M_1}\times 0.4$
Urine Patch Overlap	Area ratio of multiple urine patches and pasture utilisation land	0.01*

*Romera, *et al*. (2012) estimated approximately 23% of urine affected area was affected by multiple urinations. Assuming 5% paddock is affected by single grazing event, then (0.23 x 5%) approximately 1% of the paddock area is affected by multiple urine depositions.

As there are no management modules in APSIM to represent N returns from supplemental feed on the paddocks during winter (May-Aug), this was indirectly modelled using the fertiliser module. The amount applied accounted for the amount fed, excreted, and the proportion of urine and dung as a result of the supplementary feed. A separate manure application (to the surface organic matter pool) was also applied to account for faecal returns from the supplement. These are further defined in **Section 5.1** and **Section 5.2**.

4.10.3 Impact of Urine Patch Deposition

The greatest contribution to annual nitrogen leaching is from a high soil nitrogen content which has built up from urine patches deposited during summer and early-autumn (Vibart *et al,* 2015). A preliminary dairy model was tested where urine was deposited in selected months and the remaining months were modelled using background settings (i.e. N returns through manure, fertilizer, and surface litter only). Selected months were lumped to account for the uncertain timing of grazing events during late-autumn and winter given the longer pasture growth intervals. The annual leaching rate resulting from each urine deposition month and grouped months are shown in **Figure 3**.

Deposition in February and winter was selected to represent multiple urinations (median leaching of overlapping set) and January was selected to represent leaching of single urine patches. These periods, along with the background model were applied as spatially weighted sub-models.

Differences between background and urine patch pasture growth – The increased nitrogen return to urine patch models results in higher pasture growth and more frequent triggers to graze (and thus return N). To control for this, the grazing interval for urine patch models were fixed based on typical recurrences seen in the background model (approximately 30 days for summer and 24 days for spring; while winter was allowed to run based on the available pasture trigger). It is acknowledged that there will still be some variation between the number and timing of graze/return events between the background and urine patch models; however, this has been deemed to be within the bounds of the modelling precision.

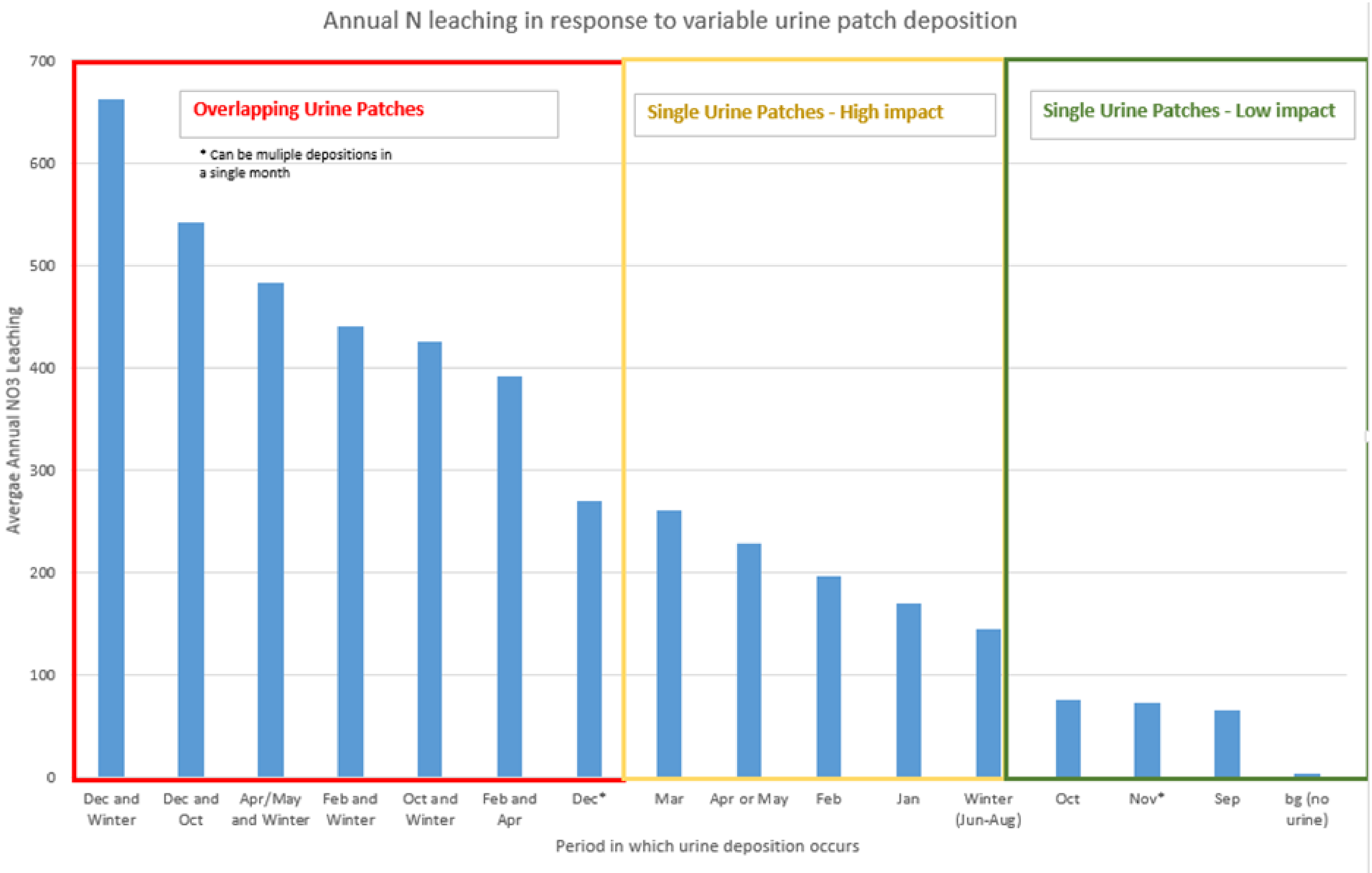

Figure 3. Annual leaching rates determined under different urine patch considerations (Eco Logical, 2017).

In addition to the heterogeneity of urine patch deposition, the seasonal shift of farming practice on a typical dairy and sheep and beef land use will also influence the overall N discharge. Support farming (i.e. heifer grazing or the wintering off of cows) will have less N discharge compared to an established dairy farming, but higher N discharge than a dry stock farming (i.e. sheep and beef). The dairy support or sheep and beef support were not explicitly simulated. Instead a proportion of simulated N discharge from dairy background sub-models were used to represent support farming practice for dairy and sheep and beef land uses.

The sub-models used to represent a composite dairy and sheep and beef models are summarised in **Table 11** and **Table 12**.

Table 11. Summary of sub-paddocks in the dairy model.

Model	Dairy support	Background	Single or Low-Leach Urine patch	Multiple or High Leaching Urine Patch
Composition	20%	60%	16%	4%
Operation	Represented by dairy background	• No urine deposition; • Manure deposited on each grazing event; • Fertiliser applied; and • Used to ensure yearly harvest supports modelled herd.	• Represented by urine patches deposited in January based on selection of 'upper middle' yearly leaching rate from test models of urine deposited in single alternating months; • Grazing during January results in urinary and faecal n returned to soil; • Grazing during other months only results in faecal n returned to soil; • Timing of graze events and mass of pasture consumed on paddock based on typical intervals and harvest of background sub-paddock (i.e. fixed days between graze and fixed harvest amount); and • Fertiliser applied as per background paddock.	• Represented by urine patches deposited during February and in winter (i.e. June-August), based on the middle yearly leaching rate from selected trials of urine deposition on two months of the year; • Grazing during February, June or July results in urinary and faecal n returned to the soil; • Grazing during other months only results in faecal n returned to the soil; • Timing of gaze events and mass of pasture consumed on paddock based on typical intervals and harvest of background sub-paddock (i.e. fixed days between graze and fixed harvest amount); and • Fertiliser applied as per background paddock.

Table 12. Summary of sub-paddocks in the sheep and beef model.

Model	Sheep and beef support	Background	Single or Low-Leach Urine patch
Composition	20%	68%	12%
Operation	Represented by dairy background	• No urine deposition • Manure deposited on each grazing event • Fertiliser applied • Used to ensure yearly harvest supports modelled herd.	• Represented by urine patches deposited in January based on the peak of cattle stocking within the summer/autumn period (shown to be the time period associated with the greatest risk of leaching). • Grazing during January results in urinary and faecal n returned to soil • Grazing during other months only results in faecal n returned to soil • Timing of gaze events and mass of pasture consumed on paddock based on typical intervals and harvest of background sub-paddock (i.e. fixed days between graze and fixed harvest amount). • Fertiliser applied as per background paddock

4.11 Benchmarking APSIM Drainage with SMWBM

Soil drainage from the bottom layer specified in the SoilWater Module was compared to sub-soil drainage, also referred to as “percolation” to groundwater, from representative calibrated catchments in the Soil Moisture Water Balance Model with Vadose Zone (SMWBM_Vz) from the SOURCE catchment model (WWLA, 2020a). APSIM SoilWater parameters were modified within physically realistic bounds until general agreement between simulated outputs from the two models were achieved. The selected representative catchments have different soil depths and climate regimes, with predominantly dairy land use. The selected catchments are summarised in **Table 13.**

Table 13. Selected SMWBM from SOURCE sub-catchments for comparison.

Soil depth APSIM model (mm)	SOURCE Catchment No.	SMWBM Soil depth (mm)	Dominant Geology	WMA
0 - 500	Rangitāiki 6	480	Ignimbrite	Mid and Upper Rangitaiki
500 - 700	Rangitāiki 5	662	Ignimbrite	Mid and Upper Rangitaiki
700 -1000	Kaituna 100	762	Peat	Pongakawa-Waihi Lowland
1000 - 1200	Kaituna 5	1165	Ignimbrite	Mid and Upper Kaituna
1200 - 1400	Kaituna 118	1348	Ignimbrite	Waitahanui

Comparisons of subsoil drainage from APSIM and the SMWBM are shown in **Figure 4** to **Figure 8.** Good agreement in both magnitude and timing of percolation was achieved between the two models across the six representative sub-catchments.

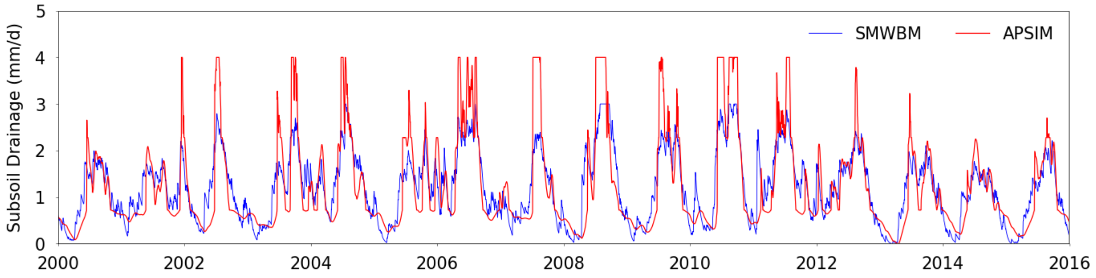

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Figure 4. Comparison of subsoil drainage from APSIM dairy model and SMWBM for Rangitāiki Sub-Catchment 6.

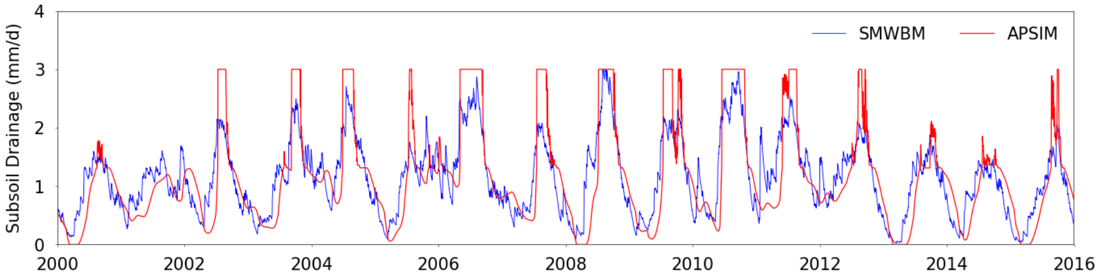


Figure 5. Comparison of subsoil drainage from APSIM dairy model and SMWBM for Rangitāiki Sub-Catchment 5.

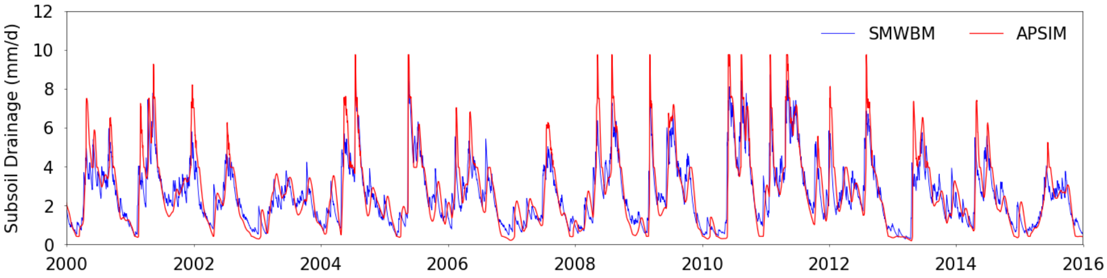


Figure 6. **Comparison of subsoil drainage from APSIM dairy model and SMWBM for Kaituna Sub-Catchment 100.**

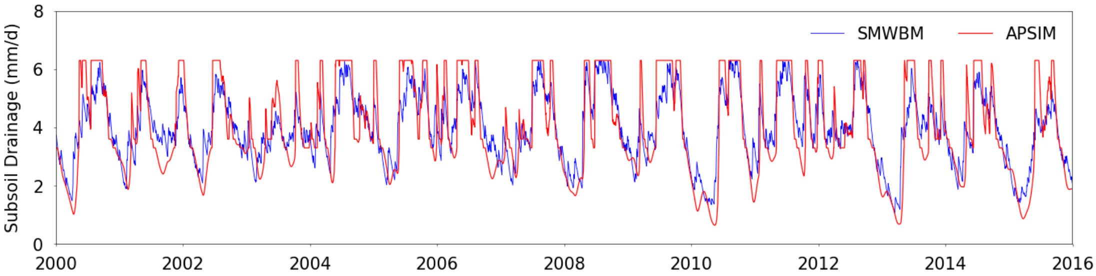


Figure 7. **Comparison of subsoil drainage from APSIM dairy model and SMWBM for Kaituna Sub-Catchment 5.**

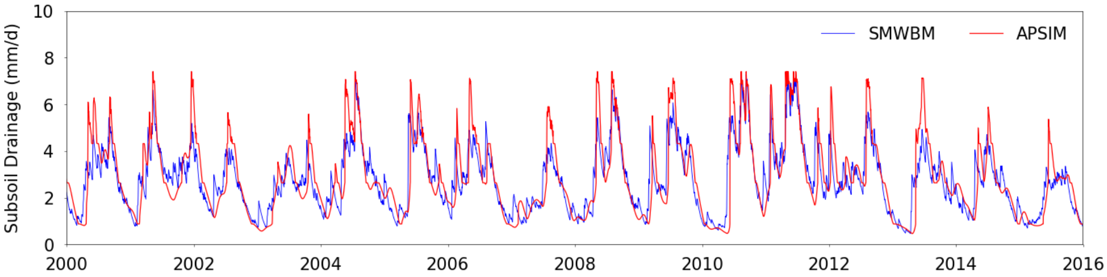


Figure 8. **Comparison of subsoil drainage from APSIM dairy model and SMWBM for Kaituna Sub-Catchment 118.**

The water mass balance was also compared, and shown to have good agreement between the two models (**Table 14**).

Table 14. Water mass balance comparison from selected APSIM and SMWBM model.

Soil depth APSIM model	Water budget component	APSIM drainage		SMWBM percolation	
		(mm/day)	(%MAP*)	(mm/day)	(%MAP*)
0-500	rain	3.85	100.0	3.85	100.0
	runoff	0.96	24.9	0.97	25.0
	Interception + evapotranspiration	1.60	41.5	1.61	41.8
	drain	1.29	33.4	1.28	33.3
500-700	rain	3.70	100.0	3.70	100.0
	runoff	0.92	25.0	0.93	25.0
	Interception + evapotranspiration	1.57	43.0	1.58	43.0
	drain	1.20	32.0	1.20	32.0
700-1000	rain	3.91	100.0	3.91	100.0
	runoff	0.08	2.0	0.11	3.0
	Interception + evapotranspiration	1.35	34.0	1.35	34.0
	drain	2.46	63.0	2.45	63.0
1000-1200	rain	6.43	100.0	6.43	100.0
	runoff	0.79	12.3	0.79	12.2
	Interception + evapotranspiration	1.61	25.1	1.64	25.5
	drain	4.00	62.2	4.00	62.2
1200-1400	rain	4.57	100.0	4.57	100.0
	runoff	0.23	5.1	0.28	6.1
	Interception + evapotranspiration	1.65	36.2	1.64	35.8
	drain	2.66	58.1	2.63	57.6

*Mean annual precipitation

Table 15. Values used in the SoilWater module.

SoilWater Parameter	Description	Value	Reference
Summer Cona	Second stage evaporation-coefficient of cumulative second stage evaporation against the square root of time for the summer period	3.5	(Dalgliesh *et al*., 2016 - Table 7) Cona and U.
Summer U	First stage evaporation amount of cumulative evaporation before soil supply falls below atmospheric demand for the summer period	6	
Summer Date	Summer date	1-oct	
Winter Cona	Second stage evaporation-coefficient of cumulative second stage evaporation against the square root of time for the winter period	2	
Winter U	First stage evaporation amount of cumulative evaporation before soil supply falls below atmospheric demand for the winter period	1	
Winter Date	Winter date	1-apr	
Diffusivity Constant	Coefficients for computing proportional flow of water content gradient between layers when soil water content is below field capacity	250 25	(Dalgliesh *et al*., 2016 - Table 8) Diffusivity constant and slope by texture class. For loam and sand, 88 and 250 are recommended for diffusivity, 35 and 22 are recommend for slope.
Diffusivity Slope			

SoilWater Parameter	Description	Value	Reference
Soil Albedo	Soil albedo	0.16	(Dalgliesh *et al*., 2016 – Table 9) Soil albedo recommendations for loamy sand.
Bare soil runoff curve number:	Curve number for average antecedent rainfall conditions for bare soil, defining the partition between infiltration and runoff	77.5	Adjusted based on the comparison between drainage and percolation
Max. reduction in curve number due to cover:	Surface residue inhibits the transport of the water across the soil surface during runoff event*. The reduction in curve number due to the cover on the land use.	10	
Cover for max curve number reduction:	The maximum cover for the reduction in curve number. A threshold surface cover above which there is no effect on the curve number	0.8	

5. Land use Modelling

This section presents the model parameterisation specific to each of the representative land uses modelled for the Kaituna and Rangitāiki WMAs.

5.1 Dairy

The representative dairy model was developed based on stock and pasture management information provided by Landcorp Farming Limited (LFL), for the Upper Waikato Catchment in the Wairakei - Lake Taupo area. This information was compiled into OVERSEER modelling by Agribusiness Group (2018) and then was used to inform parameterisation of the representative dairy model in APSIM.

A paddock and feed assessment was undertaken to confirm whether pasture growth simulated by APSIM was appropriate to support farm operations, and the additional nitrogen inputs associated with supplementary feed into the paddock during winter, and exports as silage production during spring. This analysis was used to determine the seasonal variation in nitrogen return to the soil. Full details and calculations of the paddock and feed assessment are provided in **Appendix B**.

The initial Dairy models were developed based on a stocking rate of 2.5 cows/ha. Dairy models representing a stocking rate of 3.2 cows/ha were developed by applying a multiplier (1.28) to the initial dairy model outputs.

Wintering off of stock in the lower Kaituna and Rangitāiki catchments was accounted for by substituting the Dairy for a composite dataset of 50% Sheep and Beef and 50% Sheep and Beef background from June 1st to July 31st. Full descriptions of these models are provided in **Table 12**.

A summary of the key dairy model parameters, their values and references are provided in **Table 16**.

Table 16. Dairy model parameterisation.

Component/Variable	Value	Justification	References
Manager Folder **Fertilise on Fixed Dates (for pasture blocks)**			
FertiliseOnFixedDates – Application Dates	15-Apr, 15-Jun, 15-Aug, 15-Dec		BOPRC
FertiliseOnFixedDates – Application Depth	10 mm		
FertiliseOnFixedDates – Amount Applied (type)	150 kg N/ha/yr (urea_n)		BOPRC
Fertilise on Fixed Dates (in lieu of effluent addition)			
FertiliseOnFixedDates – Application Dates	1-Jan 1-Feb 1-Mar 1-Apr 1-Sep 1-Oct 1-Nov 1-Dec	Regular stir and spray during spring and summer only.	Agribusiness OVERSEER model – pasture block reports
FertiliseOnFixedDates – Application Depth	3 mm	Surface application via spray.	
FertiliseOnFixedDates – Amount Applied	19 kg N/ha/yr (urea_n)	Agribusiness (2018) modelling assumed application of 64 kg N/ha over 57 ha of the farm. Based on this, we assumed the same quantity of effluent applied uniformly across paddocks, therefore: 64 kg/ha x 57 ha/190 ha of effluent application = 19 kg N/ha/yr	
Fertilise on Fixed Dates (in lieu of urination from consumed supplement in winter)			
FertiliseOnFixedDates – Application Dates	15-Jun	Applied once during winter.	
FertiliseOnFixedDates – Application Depth	90 mm	Average of urine1 and urine2 application depths in AgPasture module (account for centre vs edge of patch, splash and direct stream).	
FertiliseOnFixedDates – Amount Applied	68 (urea_n)	17 kg N/ha urinary-N (from Paddock and Feed Assessment) x (1/4% paddock coverage during single grazing) = 68 kg N/ha/yr Multiply by 25 to account for deposition on 4% of paddock area = 137 kg N /ha.	

Component/Variable	Value	Justification	References
Manure on Fixed Dates (in lieu of faecal-N from supplement consumption)			
ManureOnFixedDates – Application Dates	May 15, June 15, July 15, August 15	Entered as day of year in block script.	
Manure amount	60 kg/ha	Total manure set so that N returned from manure = 11 kg N/ha divided by 4 applications = approx. 3 kg N/ha per application. i.e. Manure kg/ha = 3/(ratio of N to C): = 3/(1/20) = 60 kg manure/ha	
Manure CNR	20	default	
Rotational Grazing Between Two Limits *Time intervals added through following alterations to management module script:* - *Change 'Todays Date' parameter to a 'Day of Year' range* - *Replicate script block using if/elseif/else based on different time periods* - *Alter upper amount, lower amount, and dm_frac directly in script block*			
Herbage to Start Grazing [upper_amount]	2,700 kg/ha (Sep – Apr) 2,200 kg/ha (May - Aug)	Approximately 2.5 leaf stage ryegrass height (Dairy NZ 2011). Slightly under mass representing 3-leaf stage of ryegrass development during winter (recommended benchmark) - Dairy Australia (2016).	DairyNZ (2011, 2016, 2019)
Herbage to End Grazing [lower_amount]	1,500 kg/ha (July – Apr) 1,200 kg/ha (May– June)	Dairy NZ recommended residual (Dairy NZ 2008, 2011). Reduced residual ok in winter due to reduced carbohydrate usage (Dairy NZ 2011).	
Daily amount or remove once (-1) [amount]	-1 (Sep – Apr) 600 (May – Aug)	Assume average stocking rate for summer graze (12-24 hour stay) – paddocks assumed to be sized to enable feed demand to be met. See Paddock and Feed Assessment for pasture demand calculations.	
Fraction Returned as Excreta [dm_frac]	0.72 (default dairy return factor). This is multiplied by the following factors Summer = 0.75 Spring (Sep – Dec) = 0.57 Winter (May – Aug) – 0.72	Default + 7% additional feed required as supplement (i.e. 7% more excretion than is grazed from pasture). Feed assumed to be lower protein such as maize. Assume 60% of pasture crude protein. Therefore, N return in summer: = 0.72 x (1+(0.07*0.6) =0.75	Powell and Rotz (2015) Castillo *et al*. (2000) FAO (1996)

Component/Variable	Value	Justification	References
	Urine return month = multiply the above factors by 12.75	Default x # of paddocks required for spring regrowth interval. Remainder of paddocks to silage with no excrement return = 0.72 x 24/30 paddocks (based on average pasture regrowth for spring in trial APSIM runs) = 0.57 Default N return used as additional supplement is accounted for using an additional fertiliser and manure application. Includes the following calculations: Any factors considered above Multiply by 0.6 (60% of excreted N as urine). Multiply by 85% pasture utilisation (uneaten pasture will not contribute to excreted N). Apply an additional 50% reduction for winter urine to account for lower paddock utilisation. Multiply by 25 (urine deposited on 4% of paddock area so urine patches have 25 x the N excreted than was consumed from the corresponding area).	
Fraction of Returned N in Urine [urine_n_frac]	Default = 0.6 Background paddocks = 0 Urine return month(s) = 1	AgPasture default/FAO (1996). Manure assumed to be uniformly deposited. N returned through manure considered negligible in comparison to urine patch.	FAO (1996)
Urine Deposit Depth	200 mm		

5.2 Sheep and Beef

The Sheep and Beef model was designed to replicate the OVERSEER model (Agribusiness Group, 2015) of the Ministry of Primary Industries Waikato – Bay of Plenty Sheep and Beef Farm Monitoring Model. The approach described for the Dairy model was adapted to account for different herd management and stocking within a sheep and beef farm. The main changes included:

- Sheep and Beef farm stocked at approximately 36% of dairy farm based on revised stock units and monthly pasture consumption within AgriBusiness (2015) OVERSEER modelling; and
- Therefore, the same pasture target and residuals as for Dairy, however, pasture consumed over three days.

The assumptions in the urine patch simulation were as follows:

- Urine patches from beef cattle assumed to be major source of leached N.
- Urine patches from sheep more evenly spread and less volume than those from cattle. Bell *et al.* (2012) suggest that the return of urine within sheep grazing systems can be considered uniform for stocking rates up to 1,200 sheep/ha. The modelled stocking rate (paddock maximum) was well below this density. Nitrate leaching at 60 cm below sheep urine patches was less than 3% of that under cattle urine patches (Williams and Haynes 1994). Therefore, it was assumed that sheep urine is largely taken up by pasture.
- Modelling of urine patches assumed deposition during January – corresponds with the peak of cattle stocking and period of higher leaching impact. Due to minimal cattle on farm during winter, winter urine deposition was not modelled.
- Assumed reduced urine patch coverage over the year due to the lower cattle stocking rate.

Values used within APSIM management modules are detailed in **Table 17** below.

Table 17. APSIM Sheep and Beef model parameterisation.

Component/Variable	Value	Justification	References
<u>**Manager Folder**</u>			
Fertilise on Fixed Dates (for pasture blocks)			
FertiliseOnFixedDates – Application Dates	1-May, 1-Aug	From OVERSEER modelling	Agribusiness (2015)
FertiliseOnFixedDates – Application Depth	10 mm		
FertiliseOnFixedDates – Amount Applied (type)	40 (urea_n)	Lower than dairy farm due to reduced pasture consumption, both from lower stocking rate and lower pasture utilisation. Corresponds with value used in Agribusiness OVERSEER modelling	BOPRC
Manure on Fixed Dates (N excreted from consumption of feed supplements during winter)			
FertiliseOnFixedDates – Application Dates	15-May 15-Jun 15-Jul 15-Aug		
Amount manure to apply (kg/ha)	50	From feed calculations	
Manure CNR	20	Module default	
Manure CPR	50	Module default	
Rotational Grazing Between Two Limits *Time intervals added through following alterations to management module script:* *Change 'Todays Date' parameter to a 'Day of Year' range* *Replicate script block using if/elseif/else based on different time periods* *Summer – Jan to Apr = (day >= 1) and (day <= 120)* *Winter – May to Aug = (day >=121) and (day < 214)* *Spring – Sep to Dec = (day >= 215) and (day <= 365)* *Alter upper amount, lower amount, and dm_frac directly in script block*			
Herbage to Start Grazing [upper_amount]	2800 (Sep – Apr) 2400 (May - Aug)	2800 represents approximately 2.5 leaf stage ryegrass height (Dairy NZ 2011) In winter 2400 kg DM/ha approximates the 3-leaf stage of ryegrass development (recommended benchmark) - Dairy Australia (2016)	Dairy Australia (2016) Dairy NZ (2011)

Component/Variable	Value	Justification	References
Herbage to End Grazing [lower_amount]	1,500	Beef/lamb industry recommendations	
Daily amount or remove once (-1) [amount]	-1		
Fraction Returned as Excreta [dm_frac]	0.8 (default dairy) Summer (Jan – Apr) – 0.8 Spring (Sep – Dec) – 0.72 Winter (May – Aug) – 0.8	Default Default – 15% of pasture to silage = 0.8 x 85% = 0.72 default	AgPasture documentation
Urine Deposit Depth	200 mm		

5.3 Kiwifruit

There is currently no kiwifruit module included in the APSIM modelling framework. Therefore, the Grape Vine module was utilised and adapted to simulate leaching from kiwifruit, based on advice provided by the developers of APSIM.

The kiwifruit model was developed with the key objective to simulate N leaching only, and was not intended to simulate the plant biomass growth of kiwifruit in detail given the intended purpose for use in a regional water quality modelling assessment. Drainage and N leaching from the kiwifruit model was verified against those simulated by the Soil Plant Atmosphere System Model (SPASMO) kiwifruit models for the Bay of Plenty region developed by Plant & Food Research (PFR) (Green, 2019). A high-level comparison of results between the two models is provided in **Section 5.3.1**.

The calibrated input parameters related to kiwifruit growth and management are shown in **Table 18**.

Table 18. Input parameters of kiwifruit model.

Modules and parameters		Value	Comment *	Notes
Sow	Sow density (plants/m^2)	0.0421	• 1 vine per 23.75 m^2 (i.e. spacing of 5 m x 4.75 m).	(pers. Comm., Jason Benge)
	Sow depth (mm)	100	• Root systems for most orchards were established decades ago. Feeder roots are near the soil surface (< 1 ft)	50 mm (pers. Comm., Jason Benge) Not a sensitive parameter in the APSIM model.
	Row spacing (m)	4.75	• 4.75 m	
	Bud number (per plant)	710	• 30 winter buds per m^2 and assuming that a vine occupies 23.75 m^2 (5 x 4.75 spacing) then this equates to approx. 710 winter buds per plant.	
Management	Prune date	Feb-15	• Winter pruning – June to August • Summer pruning – October to March	Current APSIM model works with one time prune every year in the management module.
	N fertilization at bud break (September, kg/ha)	80	• 75 kg N/ha (average for all conventional varieties) – soil applied. • Foliar applications of N typically made throughout the season. • Organic orchards apply around 115 kg N/ha in the form of compost.	(Green, 2019)
	N fertilization at flowering (November, kg/ha)	40	• 40 kg N/ha (average for all conventional varieties) – soil. • Foliar applications of N typically made throughout the season. • Organic orchards may apply small amounts of N to the soil in the form or organic inputs like liquid fish fertiliser.	

* Comments provided by Jayson Benge, Zespri (Email correspondence)

It was advised that foliar application of N is not a major source of nitrogen and it is also targeted at leaves instead of soil. Given the current scope of modelling, it was advised by Jayson Benge to dismiss foliar application.

5.3.1 Kiwifruit Model Calibration

High-level calibration of the APSIM kiwifruit model's drainage and N leaching were undertaken through comparisons to model outputs from PFR's SPASMO kiwifruit models (Green, 2019). The SPASMO models were calibrated against measured drainage and nutrient leaching data collected from seven orchards across the Bay of Plenty Region, and included both green and gold kiwifruit varieties, across a range of soil types. The SPASMO models are therefore considered to provide a realistic representation of drainage and nutrient leaching from kiwifruit across the Bay of Plenty region, for the purposes of allowing high-level calibration of the APSIM models.

It should be noted, the SPASMO models were developed to represent individual site-specific conditions, e.g. distinct soil types, while the APSIM models were developed for the purposes of regional scale water quality modelling. Therefore, the objective was to ensure the APSIM models produced a consistent temporal signal, and magnitude of N leaching to that of the SPASMO models, rather than achieving a perfect match between the two.

SPASMO model outputs were provided by PFR, and consisted of weekly average time series results for four soil types, under three different rainfall regimes, over the period 2006 to 2018.

Three APSIM sub-catchment models covering a range of soil depths, and of similar rainfall regimes to the SPASMO models were selected for calibration. Parameters adjusted during the calibration process were then transposed to all kiwifruit models where appropriate.

The parameters adjusted from those presented in **Section 4**, specifically for calibration of the kiwifruit models are presented in **Table 19**.

Table 19. Kiwifruit specific model parameter adjustments.

Sub-catchment	Soil Layer Depth (mm)	SWCON (-)	Runoff Curve Number (-)	Finert (-)	C:N Ratio
Kaituna SC38	0-100	0.5	94	0.8	10
	100-300	0.4		0.9	
	300-600	0.35		1	
	600-900	0.3		1	
	900-1,200	0.2		1	
	1,200-1,400	0.1		1	
Kaituna SC40	0-100	0.6	94	0.85	10
	100-300	0.375		0.95	
	300-600	0.35		1	
	600-900	0.25		1	
	900-1,200	0.25		1	
Rangitāiki SC38	0-100	0.6	95	0.97	10
	100-300	0.55		0.98	
	300-600	0.425		0.99	
	600-900	0.3		1	
	900-1,000	0.1		1	

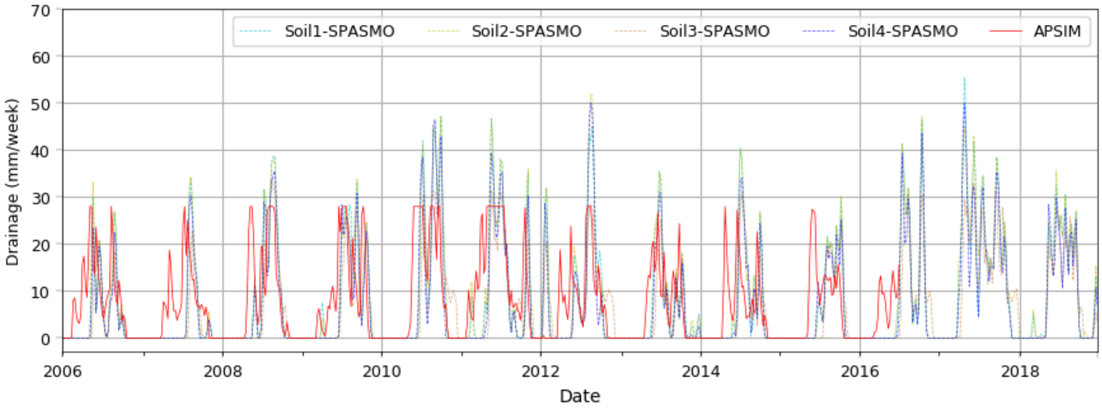
Table 20 presents a comparison of drainage as a percentage of annual rainfall, and annual average N leaching from the four SPASMO soil models and three APSIM soil depth models. Given the differing spatial scales (site

specific vs. regional catchment) of the two modelling systems, the general close agreement in summary statistics presented in **Table 20** and time series comparisons in **Figure 9** and **Figure 10** is considered to demonstrate the appropriateness of the APSIM kiwifruit models for the intended purpose (i.e. regional scale modelling).

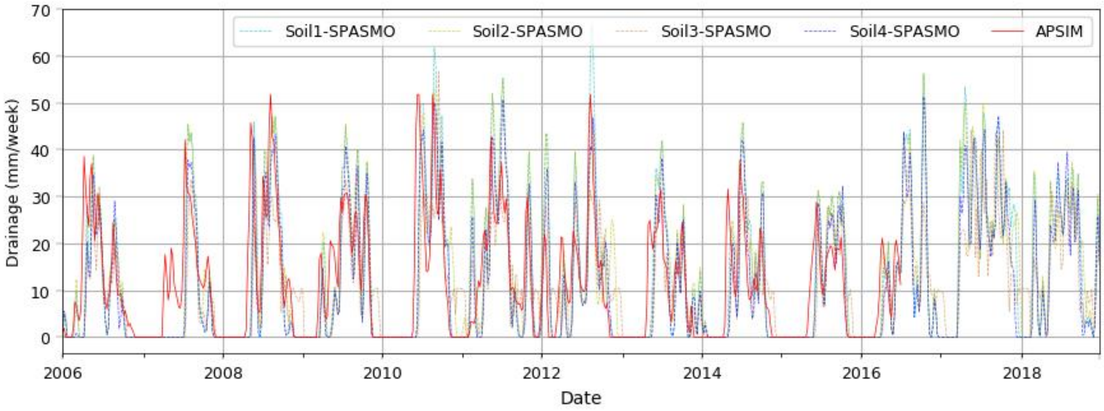
Table 20. Comparison of Drainage and NO_3-N Leaching between APSIM and SPASMO.

	SPASMO (Te Puke Rainfall)				APSIM		
Soil Type	**Ohinepanea Loamy Sand**	**Paengaroa Sandy Loam**	**Te Puke Sandy Loam**	**Opotiki Sandy Loam**	**Kaituna SC38 (1200-1400 mm)**	**Kaituna SC40 (1000-1200 mm)**	**Rangitāiki SC38 (700-1000 mm)**
Drainage (% of Rainfall)	36%	37%	29%	31%	35%	38%	30%
NO_3-N Leaching (kg/ha/yr)	43.6	30.2	45.2	31.4	41.4	47.2	42.7

Rangitāiki Sub-catchment 38 – Te Puke minus 25%



Kaituna Sub-catchment 38 – Te Puke



Kaituna Sub-catchment 40 – Te Puke plus 25%

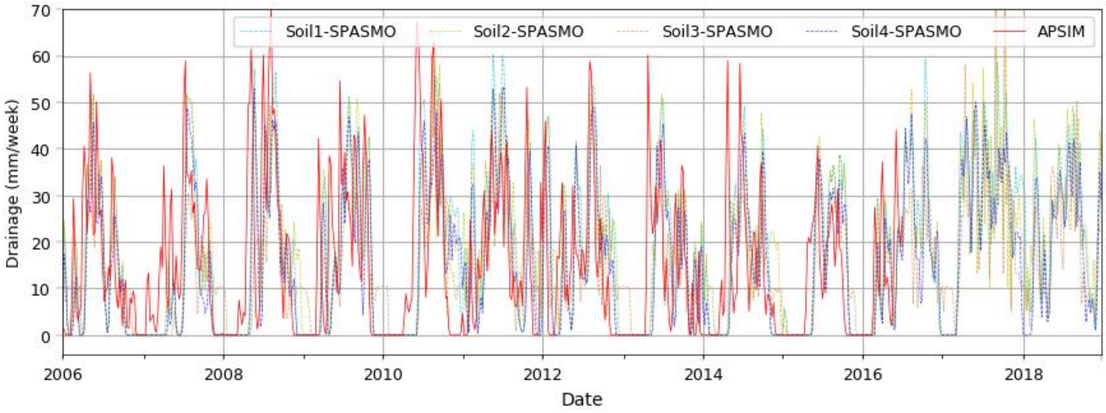
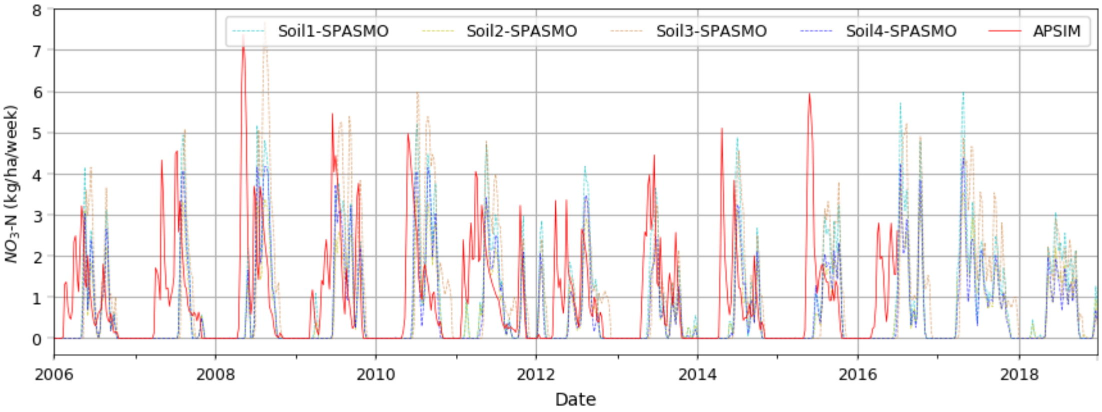
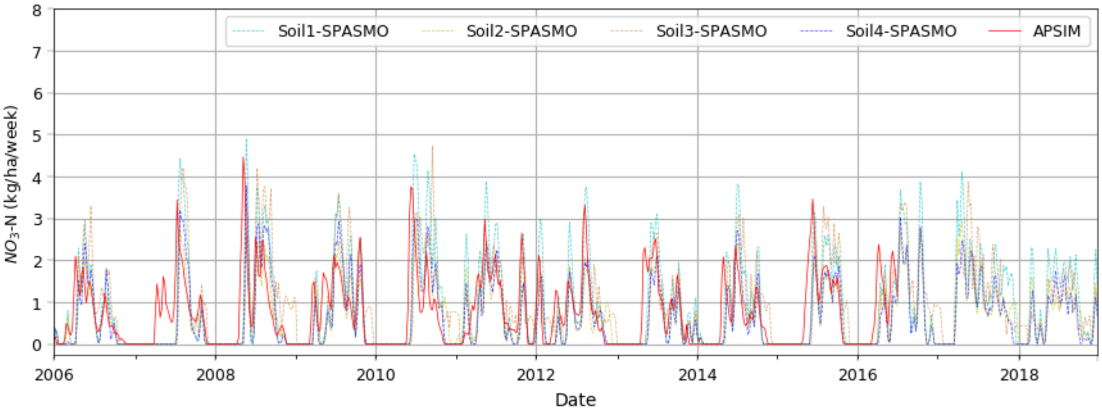


Figure 9. Comparison of modelled drainage from SPASMO and APSIM.

Rangitāiki Sub-catchment 38 – Te Puke minus 25%



Kaituna Sub-catchment 38 – Te Puke



Kaituna Sub-catchment 40 – Te Puke plus 25%

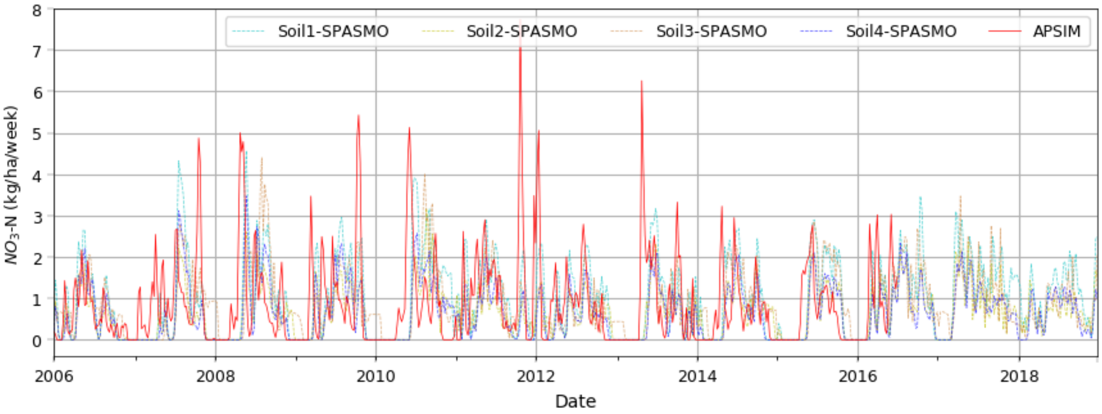


Figure 10. Comparison of NO_3-N leaching modelled from SPASMO and APSIM.

5.4 Maize

The Maize model was developed using the maize plant module in APSIM. The assumptions and management operations are summarised in **Table 21**.

Table 21. Management inputs in Maize model

Management	Parameter	Value	Assumptions*
Rotation	Summer fallow end date	15-Mar	• BOP growers are unable to do two maize crops in a year as the plant harvest window is approx. 135-140 days. A single crop is planted from 25 September. • The fields are usually sown with rye grass after the maize harvest, and it is grazed once over winter and harvested for silage in spring.
	Winter fallow end date	23-Aug	
Sow	Sow date	25-Sep	
	Sow density (plants/m^2)	5	
	Sow depth (mm)	50	
	Row spacing (mm)	800	
Fertilisation	Date	10-Mar, 25-May, 25-Jul,15-Oct, 1-Dec	• 200 kg/ha DAP by mid-October (18% N) • 350 kg/ha urea or sustain N as side dressing in late November or December (46% N) • 150 kg/ha DAP in March (18% N) • 100-125 kg/ha urea or sustain N in late May (46% N) • 100-125 kg/ha urea or sustain N in late July or August (46% N) In total N content is equal to 316 kg/ha
	Application depth (mm)	10	
	Annual fertilisation amount (kg N/ha)	316	
	Fertiliser type	Urea_n	
Grazing	Herbage amount to start grazing (kg/ha)	1,000	
	Herbage amount to stop grazing (kg/ha)	500	
	Nitrogen return as excreta	0.8	
	Fraction of nitrogen returned as urine	0.3	
	Urine deposition depth (mm)	300	
Cut	Herbage amount (kg/ha)	10,000	

*Information provided in memo “Draft recommended amendments to land use practice assumptions for E-source/APSIM modelling in Rangitāiki and Kaituna-Pongakawa-Waitahanui WMAs” collated by Nicki Green, BOPRC – 9/11/2017.

5.5 Forest

The Egrandis (Eucalyptus grandis) module was used as the basis for the forest model. The modules used are summarised in **Table 22**.

The composition of different aged trees in a catchment could not be directly simulated in APSIM. In practice, the fertiliser is individually applied to the seedlings and to 0-4-year old trees, as stated in **Table 23**. The distribution of trees with different ages and its implication on the fertiliser usage was indirectly simulated using a fertiliser module. A description of fertiliser amount applied, and justifications are detailed in **Table 23**.

Table 22. Summary of management operations in the forest model.

Management	Parameter	Value	Assumptions*
Planting	Planting date	15-Jun	Trees are planted in winter and not in summer. The density of stems range between 800 – 1,000 stems/ha. The tree planting date was changed to 15-Jun, and density was modified to 1,000 plants/ha
	Sow density (plants/ha)	1,000	
Fertilisation on a fixed date	None	0.57 kg/ha/year urea-N is applied on 15-Sep	

Table 23. Summary of forest model information and calculation.

Assumptions*	Calculation	Value
• Age of trees in catchment: of 15% (0-4 years), 19% (5-10 years), 36% (11 to 20 years) and 30% (>20 years) • Tree planting density ranges between 800 - 1000 stems/ha • Fertiliser was hand applied to 0- 4 years trees • Trees are planted in Winter not Summer • 88% is standing crop or being replanted • Assuming only pine trees are planted	0 - 4 years old trees	0.15 (15% within a block)
	Number of planting cycle	1 / 0.15 = 6.67
	Fertilisation amount/tree (1,000 trees planted across each planting cycles)	56 g urea per tree**
	Urea-N (kg) applied each planting cycle	56 * 1,000 = 56,000 g Urea 56,000 / 1,000 = 56 kg Urea 56 * 46%^ = 25.76 kg Urea-N
	Total mass of Urea-N (kg)	25.76 * 6.67 = 172
	Urea-N (kg) equivalent to the whole catchment (1 ha)	172 * 0.15 * 0.88 = 22.7
	Urea-N (kg/ha/year)	22.7 / 40 = 0.57

*Information provided from Draft recommended amendments to land use practice assumptions for E-source/APSIM modelling in Rangitāiki and Kaituna-Pongakawa-Waitahanui WMA (collated by Nicki Green).
**Value based on West (1983).
^ Standard composition of N in Urea

5.6 Vegetables

Sweetcorn was modelled as a representative vegetable crop due to its suitability for growth in the more temperate parts of the country, also supported by the fact that maize is also grown in the region. Fababean (broad bean) was modelled as a complementary winter crop due to its consistent yield and response in the model to a seasonal crop rotation. Each crop was planted within a summer and winter planting window and fertilised upon sowing. The management parameters are summarised in **Table 24**.

Table 24. Summary of management inputs for vegetable model.

Management	Parameter	Value
Sow corn	Start sowing window	15-Oct
	End sowing window	1-Jan
	Cultivar	Dealb_xl82
	Sow density (plants/m^2)	100
	Sow depth (mm)	30
	Row spacing (mm)	250
Fertilisation at sowing	Amount of starter fertiliser (kg/ha)	50
	Fertiliser type	Urea_N
Sow beans	Start sowing window	15-May
	End sowing window	10-Jul
	Cultivar	Fjord
	Sow density (plants/m2)	25
	Sow depth (mm)	30
	Row spacing (mm)	250
Fertilisation at sowing	Amount of starter fertiliser (kg/ha)	50
	Fertiliser type	Urea_N

5.7 Lifestyle

A lifestyle land use model was established assuming the existence of native vegetation and less intensive grazing. The egrandis model was selected to represent native vegetation, and a regular grazing module was used to represent the less intensive grazing on the paddock. The management inputs are summarised in **Table 25**.

Table 25. management inputs for lifestyle land use.

Management	Parameter	Value
Grazing	Pasture type	AgPasture
	Herbage to start grazing (kg/ha)	2,500
	Herbage to stop grazing (kg/ha)	1,200
	Nitrogen returned as excreta	0.4
	Fraction of returned nitrogen in urine	0.2
	Urine deposition depth (mm)	300

6. APSIM Modelling Results

Mean annual NO_3-N leaching was calculated from the daily time series results of each land use model. Descriptive statistics are summarised in **Table 26**, and presented visually as a boxplot in **Figure 11** and **Figure 12** for the Kaituna and Rangitāiki WMAs respectively. On these plots, the boxes indicate the 25th percentile, median and 75th percentiles, and the whiskers represent the minimum and maximum leaching rates.

In the pasture grazing systems, a mean annual NO_3-N leaching of 68 kg/ha was simulated for dairy, and 24 kg/ha for sheep and beef. Cropping and arable farming (Mazie and Vegetable land use) had a simulated leaching rate of 54-65 kg/ha.

Table 26. Descriptive statistics of mean annual NO_3-N leaching.

WMA	Land use	Mean Annual NO_3-N leaching (kg/ha/year)						
		Mean	Standard Deviation	Minimum	25th percentile	50th percentile	75th percentile	Maximum
Kaituna	Dairy	67.6	11.0	52.3	60.2	65.4	71.2	99.7
	Sheep and Beef	23.6	5.1	13.7	18.9	22.6	28.0	35.5
	Kiwifruit	43.5	2.4	38.3	41.7	43.4	45.1	49.8
	Lifestyle	10.1	4.0	3.7	6.8	10.0	13.7	17.8
	Maize	53.4	13.4	28.1	49.7	57.7	62.5	68.0
	Forest	4.1	0.6	3.3	3.5	3.9	4.6	5.2
	Vegetable*	44.0						
Rangitāiki	Dairy	54.9	8.1	38.6	48.6	54.3	60.6	76.2
	Sheep and Beef	20.5	4.9	12.9	16.5	19.0	24.4	33.2
	Kiwifruit	41.2	2.6	33.7	39.7	41.7	43.1	48.7
	Lifestyle	12.1	5.9	1.6	9.0	10.3	14.9	23.5
	Maize	57.0	6.6	48.2	50.7	58.4	60.9	72.9
	Forest	4.4	0.9	3.3	3.5	4.2	5.3	6.3
	Vegetable	64.8	2.6	63.2	63.2	63.7	65.2	68.6

*There was only one vegetable land use model for Kaituna, and therefore full descriptive statistics could not be calculated.

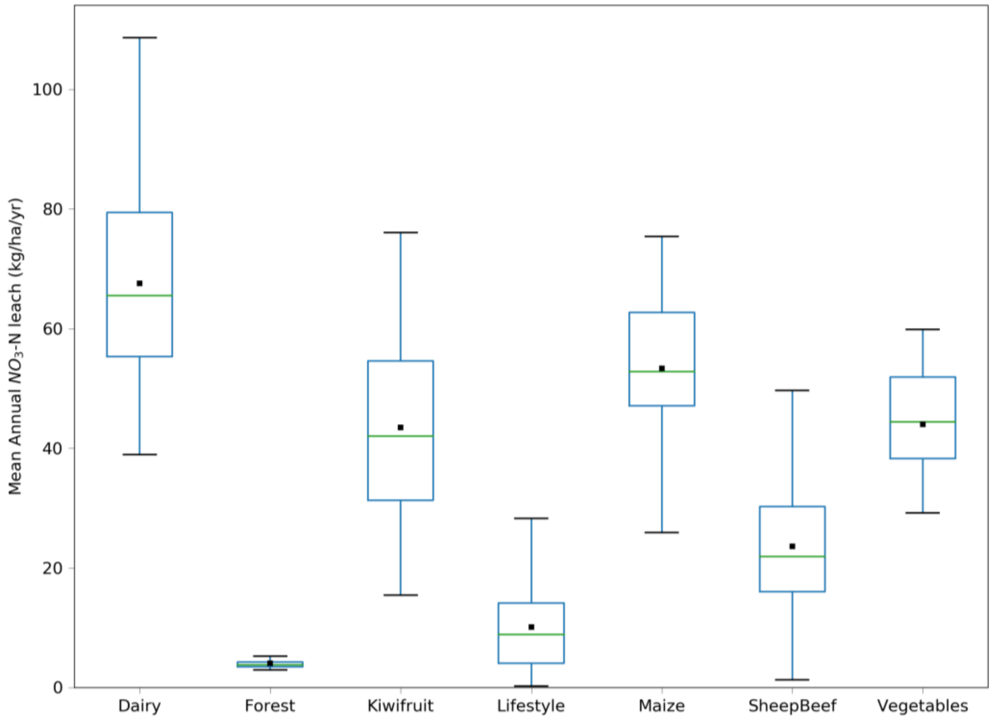


Figure 11. Boxplot of mean annual NO_3-N leaching for land use in Kaituna.

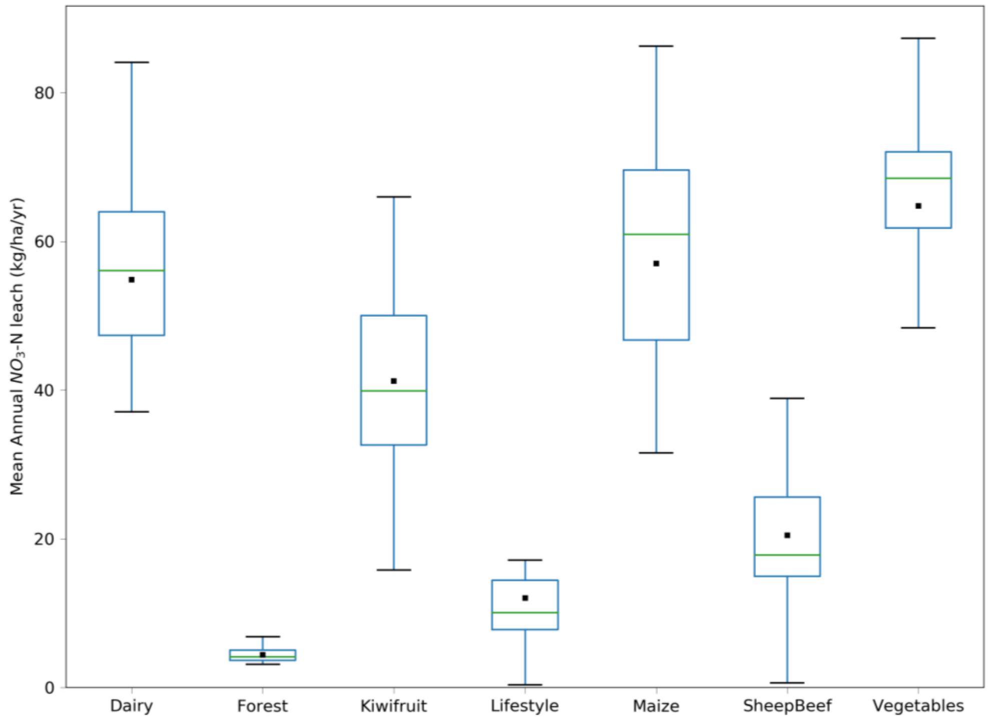


Figure 12. Boxplot of mean annual NO_3-N leaching for land use in Rangitāiki.

It should be noted, the APSIM models were developed to simulate representative N losses from given land uses, and not intended to represent specific or individual properties. The mean annual leaching rates simulated are consistent with the review of N losses from different land uses in New Zealand, undertaken Menneer *et al*., (2014) and presented in **Table 27**.

Table 27. Summary of researched N losses from different land uses in New Zealand covering a range of fertiliser N inputs (Retabulated from Table 1 from Menneer *et al* (2014)).

Land use	N leaching loss (kg N/ha/year)		References
	Range	Mean	
Market gardening	80-292	177	Williams *et al*. (2003); Francis *et al*. (1992; 2003).
Dairy pasture	15-115	65	Ledgard *et al*. (1999, 2000 and unpublished research); Roach *et al*. (2001); Steele *et al*. (1984); Monaghan *et al*. 2000); Silva *et al*. (1999).
Mixed cropping or arable farming	35-110	61	Francis *et al*. (1994; 1995); Adams and Pattinson (1985); Ludecke and Tham (1971).
Orcharding	50[a]	50[a]	Ledgard *et al*. (1992).
Sheep	6-66	21	Brock *et al*. (1990); Ruz-Jerez *et al*. (1995); Heng *et al*. (1991); Magesan *et al*. (1994, 1996); Burden (1980).
Forestry	3-28	3[b]	Parfitt *et al*. (1997, 2002, 2003); Magesan *et al*. (1998).

a Single study with Kiwifruit

b Best estimates for undistributed exotic forestry

As detailed in this report, APSIM produces a daily times-series of N mass per hectare (kg/ha/day) for each combination of soil depth, climate and land use (575 combinations in Kaituna and 341 in Rangitāiki). To integrate the simulated N leaching into SOURCE, an area-weighted aggregation process was used to combine the predicted TN loads for each land use in each sub-catchment, i.e. accounting for all land uses across the soil types and climate regime in each sub-catchment.

Full details on the integration of APSIM model outputs with the SOURCE catchment models is provided in **Section 7.2.5** of WWLA (2020a) *Kaituna & Rangitāiki Catchment Models,* including details on the process and technique applied to simulate transformation through the Vadose Zone and mixing with groundwater.

7. Uncertainties and Limitations

Nitrate-nitrogen (NO_3-N) generated as a non-point source leachate is difficult to measure or accurately quantify. The intrinsic spatial variation in the NO_3-N leached from a given land use makes it unfeasible for the direct comparison between observation and simulation at spot locations, and this type of comparison is less meaningful to the understanding of leaching at a catchment scale.

APSIM simulates agricultural practices and the chemical, physical, biological and hydrologic processes based on a unit paddock scale. However, APSIM simulation results are incorporated into a much larger regional scale catchment model. A number of assumptions are implied in the APSIM model parameterisation and validation processes:

- **Scale of the modelling:** Simulated land use practices were in general guided by conventional agricultural practice (e.g. sow, rotation, grazing, harvesting) and relevant information involved (e.g. fertilisation usage and application date, planting density) at a national/regional scale. The soil parameterisation was in general guided by the regional soil conditions and catchment characteristics. The simulated results are therefore representative in the context of regional scale assessment. There were no long-term monitored farms or orchards within the Kaituna or Rangitāiki WMAs to undertake detailed site-specific calibration/verification.
- **APSIM revised drainage:** The drainage dynamics in the selected APSIM models was revised based on simulated percolation from the SMWBM, calibrated to observed flows at a SOURCE sub-catchment scale (where available). This was to ensure the two model components could be parameterised to simulate a consistent drainage. It is impractical to validate and re-parametrise the APSIM models based on each individual catchment, therefore the validated soil model was applied broadly to all the catchments on the basis of similarity in regional soil condition. The SMWBM was calibrated against flow gauge observations at the catchment level, and the consistency between APSIM drainage and SMWBM percolation is considered to reduce uncertainty in the simulated NO_3-N leaching.

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Appendix A. Soil characteristics parameters

Table A1. Values in soil physical characteristics parameterisation.

APSIM Model	**Soil Layer Depth**	**Bulk Density**	**Air Dry**	**Lower limit at 15 bar**	**Drained upper limit**	**SAT**	**SWCON**	**KS**	**Bulk Density***	**Air Dry**	**Lower limit at 15 bar**	**Drained upper limit**	**SAT**	**SWCON**	**KS**
	Mm	**g/cc**	**mm/mm**	**mm/mm**	**mm/mm**	**mm/mm**	**-**	**mm/day**	**g/cc**	**mm/mm**	**mm/mm**	**mm/mm**	**mm/mm**	**-**	**mm/day**
		Kaituna							**Rangitāiki**						
0-500	0-100	0.85	0.09	0.13	0.13	0.62	0.1	75	0.85	0.09	0.13	0.13	0.62	0.12	140
	100-200	0.85	0.09	0.13	0.13	0.63	0.1	30	0.85	0.09	0.13	0.13	0.63	0.1	30
	200-300	0.85	0.11	0.13	0.27	0.65	0.06	5	0.85	0.11	0.13	0.27	0.65	0.06	5
	300-500	0.85	0.15	0.16	0.28	0.64	0.01	4	0.85	0.15	0.16	0.28	0.64	0.01	4
500-700	00-100	0.85	0.09	0.13	0.13	0.62	0.11	250	0.85	0.09	0.13	0.13	0.62	0.1	115
	100-300	0.85	0.09	0.13	0.13	0.63	0.08	120	0.85	0.09	0.13	0.13	0.63	0.08	80
	300-400	0.85	0.11	0.13	0.29	0.65	0.06	50	0.85	0.11	0.13	0.29	0.65	0.06	40
	400-500	0.85	0.15	0.16	0.30	0.64	0.04	15	0.85	0.15	0.16	0.30	0.64	0.04	15
	500-700	0.85	0.16	0.16	0.31	0.64	0.02	9.5	0.85	0.16	0.16	0.31	0.64	0.02	3
700-1,000	0-100	0.85	0.09	0.13	0.13	0.60	0.12	400	0.85	0.09	0.13	0.13	0.60	0.12	210
	100-300	0.85	0.09	0.13	0.13	0.60	0.11	220	0.85	0.09	0.13	0.13	0.60	0.11	150
	300-600	0.85	0.11	0.13	0.29	0.59	0.085	125	0.85	0.11	0.13	0.29	0.59	0.085	90
	600-900	0.85	0.15	0.16	0.30	0.52	0.06	30	0.85	0.15	0.16	0.30	0.52	0.06	30
	900-1,000	0.85	0.16	0.16	0.31	0.52	0.02	9.75	0.85	0.16	0.16	0.31	0.52	0.02	4
1,000-1,200	0-100	0.85	0.09	0.13	0.13	0.60	0.12	300	0.85	0.09	0.13	0.13	0.60	0.12	250
	100-300	0.85	0.09	0.13	0.13	0.60	0.075	150	0.85	0.09	0.13	0.13	0.60	0.075	150
	300-600	0.85	0.11	0.13	0.25	0.59	0.07	15	0.85	0.11	0.13	0.25	0.59	0.07	30
	600-900	0.85	0.15	0.16	0.28	0.52	0.05	10	0.85	0.15	0.16	0.28	0.52	0.05	20

APSIM Model	Soil Layer Depth	Bulk Density	Air Dry	Lower limit at 15 bar	Drained upper limit	SAT	SWCON	KS	Bulk Density*	Air Dry	Lower limit at 15 bar	Drained upper limit	SAT	SWCON	KS
	Mm	g/cc	mm/mm	mm/mm	mm/mm	mm/mm	-	mm/day	g/cc	mm/mm	mm/mm	mm/mm	mm/mm	-	mm/day
		Kaituna							Rangitāiki						
	900-1,200	0.85	0.16	0.16	0.30	0.52	0.05	6.3	0.85	0.16	0.16	0.30	0.52	0.05	11
1,200-1,400	0-100	0.85	0.09	0.13	0.13	0.60	0.1	320	0.85	0.09	0.13	0.13	0.60	0.1	220
	100-300	0.85	0.09	0.13	0.13	0.60	0.08	150	0.85	0.09	0.13	0.13	0.60	0.08	150
	300-600	0.85	0.11	0.13	0.25	0.59	0.07	15	0.85	0.11	0.13	0.25	0.59	0.07	15
	600-900	0.85	0.15	0.16	0.28	0.52	0.06	10	0.85	0.15	0.16	0.28	0.52	0.06	10
	900-1,200	0.85	0.16	0.16	0.30	0.52	0.04	10	0.85	0.16	0.16	0.30	0.52	0.04	10
	1,200-14,00	0.85	0.16	0.16	0.30	0.52	0.02	7.4	0.85	0.16	0.16	0.30	0.52	0.02	4

Air Dry: Soil water content at the air dry condition. Laboratory-based measurement of the soil water characteristics. Estimates are required when measured data is not available.

Lower limit: 15 Bar: lower limit of soil water content, indicating the driest water content achievable by plant extraction. Estimates are required when measured data is not available.

Drained upper limit: Field capacity. The cascading saturated layer flow is driven by the difference of DUL and simulated soil moisture content.

SAT: Rarely available. It is generally calculated from the total porosity of the soil determined from measured bulk density and assumed rock density of 2.65*.

SWCON: Significant effect on the overall quantum of saturation flow (when the soil moisture content is greater than DUL but smaller than SAT). An increase in value proportionally increases the amount of drainage that occurs when the soils are wet.

KS: Significant effect on the overall quantum of the above saturation flow (when the soil moisture content is above the SAT). An increase in value proportionally increases the amount of flow cascading downward.

***** The bulk density values applied for the Galatea models are provided in **Table 3.** All other parameters for the Galatea models were as per above.

Appendix B. Dairy - Paddock and Feed Assessment

An example representative farm paddock and feed assessment was undertaken by Eco Logical (2017), and is presented below.

The paddock and feed assessment were conducted to determine:

- If the APSIM modelled pasture growth can support the farm operation;
- the nitrogen return factors to account for seasonal pasture surplus and deficit and corresponding silage production or supplementary feed; and
- average rotation lengths to set grazing intervals in urine patch paddocks.

The conditions for the modelled representative farm reflect a middle/upper elevation sub-catchment farm with a stocking rate of 2.5 cows/ha, and is summarised in **Table B1**.

Table B1. Example farm conditions for a paddock feed assessment for upper and middle sub catchments.

Farm condition	Value	Units
Farm size	184	ha
Herd size	456	count
Weight	450	kg/cow
Feed requirement	15 (Summer) 14 (Spring)	kg DM/cow/day
Pasture utilisation	85	%
Available pasture	1,200	kg DM/ha

Feed assessments for individual seasons are summarised in **Table B2**.

Table B2. Summary of feed assessments for Summer, Spring and Winter.

Variables	Summer	Spring	Winter
Sources of feed	Feed is provided from a combination of pasture production and supplementary feed imported	Less feed required. Feed is provided from pasture production. Extra paddocks are used for silage production to be stored as feed for winter season	Feed is provided from pasture production, forage crop growth in the winter, and the silage storage from the spring.
Number of rotations	4.2 (based on test APSIM runs, model farm pasture growth rates and long term pasture growth rates (Dairy NZ)	5	
Number of days	120 (Jan to April)	120	58 days by pasture, 16 days by winter fodder crop, 51 days by silage produced in spring*
Number of paddocks	120 / 4.2 = 29 (29 days per rotation) Assuming cows stay one day on each paddock, for each rotation, 29	24 (6 extra paddocks for silage production consumed in winter)	**Pasture supply:** Herd size at 50% of maximum production, so 50% intake assumed. Also assume that per cow intake is reduced by 50% (not milked). However, excess pasture is offered (i.e.

Variables	Summer	Spring	Winter
	paddocks needed. 1 extra paddock used to grow high energy forage crop for winter consumption)		equivalent to 50% of herd at full summer consumption) to allow for decreased utilisation/reduce paddock damage grazing event on a single paddock maintains the herd for 2 days with 42.5% utilisation (i.e. half of default 85% utilisation rate). Therefore 58 days in winter supported by pasture. **Fodder crop supply:** 6.13 × 10 tons/ha × 0.85 = 52,105 kg DM 52,105 / 456 / (14 / 2) = 16 days **Silage supply:** Silage production 6 × 5 × 7,356 = 220,680 kg DM 220,680 / 8,047 = 55 days Dry matter return from silage feed: 220,680 × 0.85 = 187,578 kg DM N consumed from silage feed: 187,578 × 0.0256(Kjehldahl conversion) = 4,801 kg N returned from silage feed: 4,801 × 0.72 = 3,457 kg 3,457 / 184 = 19 kg/ha N returned as urine: 19 × 0.6= 11 kg/ha N returned as dung: 19 × 0.4 = 8 kg /ha
Area of individual paddock (ha)	184 / 30 = 6.13		
Feed required on a grazing day (kg DM)	15 × 456 = 6,840	14 × 456 = 6,384	
Feed required to be produced (kg DM)	6,840 / 0.85 = 8,047	6,384 / 0.85 = 7,510	
Available feed in the paddock (kg DM)	6.13 × 1,200 = 7,356	7,356	
Additional feed required (kg DM)	8,047 - 7,356 = 691	0	
N content in the additional feed (kg)	691 × 0.6 = 415	-	
N return from the pasture utilisation (kg)	7,356 × 0.72 = 5,296	-	
N return from the additional feed (kg)	415 × 0.72 = 298	-	
Total N return (kg)	5,296 + 298 = 5,595	-	
N return factor-adjusted	5,595 / 7356 = 0.76	0.72 × 24 / 30 = 0.58 (0.72 was the N return factor based on 30 paddocks, only 24 paddocks will be grazed in spring)	