OVERSEER® Technical Manual

Technical Manual for the description of the OVERSEER® Nutrient Budgets engine

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Block nutrient budgets

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Preface

OVERSEER® Nutrient Budgets

OVERSEER® Nutrient Budgets (OVERSEER) is a strategic management tool that supports optimal nutrient use on farm for increased profitability and managing nutrients within environmental limits.

OVERSEER provides users with information to examine the impact of nutrient use, their flows within a farm and off-farm losses of nutrients and greenhouse gases. An OVERSEER nutrient budget takes into account inputs and outputs and the key internal recycling of nutrients around the farm.

See the OVERSEER website for more detailed information: http://www.overseer.org.nz

This technical manual

OVERSEER is made up of a user interface and an engine. These two components work together to enable users to generate nutrient budget reports. The Technical Manual provides details of the calculation methods used in the OVERSEER engine.

The OVERSEER engine is based on extensive published scientific research. Technical information about the model's development and use can be found in a growing number of conference proceedings and peer-reviewed papers. Given the ongoing upgrades many of the earlier papers no longer reflect the current version.

The Technical Manual chapters provide detailed descriptions of the methods used in the OVERSEER engine's main sub-models. The Technical Manual sets out the underlying principles and sources of data used to build the model engine. It is a description of the model as implemented, and hence references may not now be the most appropriate, cover the range of data of information currently available, or may not necessarily be the most up to date. If the source of some information and/or assumptions is not known or could not be found, this is acknowledged.

This chapter reflects the OVERSEER model as at the date the model was provided to OVERSEER Limited by AgResearch Limited. It doesn't include any changes to the model that have subsequently been made by OVERSEER Limited.

If readers have feedback or further technical information that they consider could contribute to the future development of the model, please provide feedback via the website http://www.overseer.org.nz.

Scientific contribution to model development:

OVERSEER is a farm systems model covering a wide range of science disciplines. Since the model's inception, many researchers from many disciplines and organisations have contributed to its development.

Researchers contributing significantly to the development of specific nutrient sub-models described in this chapter include:

Nitrogen	M A Shepherd, S F Ledgard, C A M de Klein, R Cichota, D R Selbie, V A Snow and D M Wheeler
Phosphorus	R McDowell, A K Metherell and R M Monaghan
Potassium	A K Metherell and P L Carey
Sulphur	B S Thorrold and D M Wheeler
Ca, Mg, Na	P L Carey and A K Metherell
Acidity	C A M de Klein, R M Monaghan and A G Sinclair

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Block nutrient budgets

1. Introduction

1.1. Nutrient budget

A nutrient budget is a tabulation of annual inputs and outputs of nutrients for blocks and the farm, assuming that management is constant. Internal transfers (changes in long-term storage pools due to changes in soil organic matter, weathering, adsorption, etc.) are considered as outputs.

The nutrient budget is derived from a matrix of about fifty terms by eight nutrients, which represent sources (inputs), removals (outputs) from the block or farm being considered for eight nutrients. The terms or processes are split into three categories:

• Inputs	addition of nutrients to a block or farm, such as, fertiliser, effluent, or supplements.
• Outputs	removal of nutrients from a block or farm, such as, in products, or by leaching, runoff and volatilisation.
• Internal transfers	typically nutrients moving from a slowly available pool to a plant available pool, but remaining in the block, for example, immobilisation, adsorption, or weathering of parent material, or where pool sizes change.

This chapter focuses only on the block nutrient budget. The primary difference between block types are the processes considered, and the way parameters for the processes are derived.

This chapter has been split into six sections. Definitions and the source of information for each term of the nutrient budget are listed in section 2. This includes references to variables where the calculations are described in other chapters of the technical manual.

Many of the methods described in the remainder of this chapter are based on trials undertaken on pastoral systems where the urine patch was avoided. Hence, they apply to the background (inter-urine patch) parts of a block. The same processes have been assumed to apply to other block types unless there was specific information to indicate otherwise. The methodologies used to estimate losses of N and other nutrients from the urine patch is described in the Urine Patch technical manual.

Section 3 describes the general characteristics of the model for each nutrient. The methodologies are split into three sections. Those where the methodology is similar for all nutrients are covered in section 4. These include fertiliser inputs, effluent additions, irrigation inputs, supplement inputs, product removal, transfer out and supplements removed which are calculated as a rate applied to the block times a nutrient concentration, or as a loading of a nutrient. Methodologies for processes that are nutrient specific, for example, leaching, atmospheric losses and immobilisation, are covered section 5. Specific block methods are covered in section 6.

1.2. Workings of the technical manual

The aim of the technical manual is to provide a level of detail so that users of OVERSEER can clearly see the underlying principles and sources of data used to build the components of the model. This technical chapter is part of a series of technical manuals currently under development to explain the inner working of the OVERSEER engine.

When describing equations in this manual, units are shown using ( ) and cross-references to other equations and sections within this chapter or to other chapters of the technical manual are shown using [ ]. Equations with multiple '=' options are cascading alternatives in the order they are considered. The condition is shown on the right-hand side. The variable and parameter names used, are generally shortened names of the property. This naming convention is similar to the convention used in the OVERSEER engine model.

1.3. Abbreviations, chemical symbols, and subscripts

Abbreviations

TP	total phosphorus
DRP	dissolved reactive phosphorus
FDE	farm dairy effluent
ASC	anion storage capacity

Chemical symbols:

N, P, K, S, Ca, Mg, Na, and Cl refer to the nutrients nitrogen, phosphorus, potassium, sulphur, calcium, magnesium, sodium and chlorine respectively.

Subscripts

mon	month
nut	the nutrients nitrogen (N), phosphorus (P), potassium (K), sulphur (S), calcium (Ca), magnesium (Mg) and sodium (Na), and either chloride (Cl) or the calculated value for acidity.
block	a given block as defined in the Introduction chapter.

2. Nutrient budget terms

The following tables describing inputs (Table 1), outputs (Table 2) and internal transfers (Table 3) list the terms of the block nutrient budget, expressed as a variable name, the description, the source that term is associated with, and the block types the term is calculated for. For terms that are derived from methodologies in published chapters, the variable name and chapter are listed.

2.1. Inputs

Table 1. Description and source of input terms in the nutrient budget, and the block type the terms are applied to (P = pastoral, CC = cut and carry, FC = fodder crop).

Term	Description and input source	Block type
NBFert	Conventional fertiliser. *Input*: Fert_{nut} [Characteristics of Fertiliser].	P, CC, FC, Crop, Fruit
NBLime	Lime. *Input*: $\text{LimeAdd}_{\text{nut}}$ [Characteristics of Fertiliser].	P, CC, FC, Crop, Fruit
NBOtherFert	Organic material, including composts. *Input*: $\text{OtherFert}_{\text{nut}}$ [Characteristics of Fertiliser].	P, CC, FC, Crop, Fruit
NBFerteff	Imported dairy and piggery effluents. $\text{OtherFertApp}_{\text{nut}}$ [Characteristics of Fertiliser]	P, CC, FC, Crop, Fruit
NBDCD	N added as DCD: *Input*: DCDN [Characteristics of Fertilisers].	P
NBRain	Rainfall deposition. *Input*: Section 4.1.	P, CC, FC, Crop, Fruit, Tree, House
NBNfix	Biological N fixation. *Input*: Section 4.2.	P, CC, FC, Crop, Fruit
NBIrr	Irrigation water. *Input*: Section 4.3.	P, CC, FC, Crop, Fruit
NBSuppImport	Brought in supplements fed on the block or left-over supplements from dairy goats on animal shelters that are fed on blocks. *Input*: $\text{suppImportednutblock}_{\text{block, nut}}$ [Supplements]. $\text{supFarmleftnutblock}_{\text{block, nut}}$ [Supplements].	P, FC, Crop, Fruit,
NBSuppStored	Stored supplements fed on the block. *Input*: $\text{suppStorednutblock}_{\text{block, nut}}$ [Supplements].	P, FC, Crop, Fruit,
NBSuppBlock	Farm grown supplements or crops fed on the block. *Input*: $\text{suppFarmGrownnutblock}_{\text{block, nut}}$ [Supplements]. Crops fed [unpublished].	P, FC, Crop, Fruit,

Term	Description and input source	Block type
NBDrench	Animal health supplements. *Input*: DrenchBlock$_{block, nut}$ [Interblock Distribution].	P, FC, Crop, Fruit,
NBEffLiq	On-farm liquid effluent. *Input*: LiqEff [Effluent Management].	P, CC, FC, Crop, Fruit,
NBEffSolid	On-farm solid effluent. *Input*: SolidEff [Effluent Management].	P, CC, FC, Crop, Fruit,
NBSepticIn	Net transferred to a house to balance losses through septic tanks (Farm scale). *Input*: Section 6.3.3.1.	House
NBSpray	Foliar sprays (fruit crops only). *Input*: Section 6.1.2.	Fruit
NBImportEff	Imported liquid effluent. *Input*: No longer used.	P, CC, FC, Crop, Fruit
NBImportSolid	Imported liquid effluent. *Input*: No longer used.	P, CC, FC, Crop, Fruit
NBVolatother	Volatilisation from imported liquid effluent. *Input*: No longer used.	P, CC, FC, Crop, Fruit

2.2. Outputs

Table 2. Description and source for output terms in the nutrient budget, and the block type the terms are applied to (P = pastoral, CC = cut and carry, FC = fodder crop)

Term	Description and input source	Block type
NBprod	Nutrients removed in animal product (milk solids, wool, velvet, antler), animal live weight, supplements removed, crop product (for example, wheat grain) or fruit sold. *Input*: AnimalProduct$_{block, nut}$ [Interblock Distribution]. HortProduct$_{nut}$ Section 6.1.3. Crop products [unpublished].	P, CC, FC, Crop, Fruit

Term	Description and input source	Block type
NBsuppremove	Nutrients removed as supplements. *Input:* SupRemovedFromBlock$_{\text{block}}$ [Supplements].	P, CC, FC, Crop, Fruit
NBFromBlock	Nutrients consumed on a block and transferred from a block in the gut of animals and deposited in raceways, farm dairies, yards, and pads. *Input*: TransFromBlock$_{\text{antype, nut, mon}}$ [Animal Intakes].	P, CC, FC, Crop, Fruit
NBPastToWP	Nutrients consumed as pasture and transferred to an animal shelter/wintering pad (supplements, crops) in the gut of animals. *Input*: nutpasttowinpad$_{\text{antype, nut, mon}}$ [Animal Intakes].	P, FC, Crop, Fruit
NBFromBlocktoFP	Nutrients consumed as pasture and transferred to a feed pad (supplements, crops) in the gut of animals. *Input*: [Note: Not included in Animal Intakes].	P, FC, Crop, Fruit
NBWPtoPas	Nutrients consumed on an animal shelter/wintering pad (supplements, crops) and transferred to the block when pasture is grazed in the gut of animals and deposited as excreta in the block (negative). *Input*: nutwinpadtopasture$_{\text{antype, nut, mon}}$ [Animal Intakes].	P, FC, Crop, Fruit
NBToBlock	Nutrients consumed on a pad and transferred to a block in the gut of animals (negative). *Input*: TransToBlock$_{\text{antype, nut, mon}}$ [Animal Intakes].	P, CC, FC, Crop, Fruit
NBfertvolat	N volatilised, excluding losses from urine patches. *Input*: FertNVolat [Characteristics of Fertiliser].	P, CC, FC, Crop, Fruit
NBleach	Leached below the root zone, excluding losses from urine patches. *Input*: Section 5.1 for N, 5.2.1.1.4 for P, 5.3.3 for K, 5.4.1for S, 5.5.2 for Ca, Mg and Na, and 5.6.5 for acidity.	P, CC, FC, Crop, Fruit
NBDenit	N lost due to denitrification, excluding losses from urine patches. *Input*: TotDenit [Crop Based Nitrogen Sub-model].	P, CC, FC, Crop, Fruit
NBrunoff	Removed in runoff (overland flow). *Input*: Section 4.4.	P, CC, FC, Crop, Fruit
NBDrains	Lost direct to waterways via the drainage system, or directly deposited in waterways by animals. *Input*: section 4.5.	P, CC, FC, Crop, Fruit

Term	Description and input source	Block type
NBleachUrine	N leached below the root zone from urine patches. *Input*: NurineLeach [Urine Patch Model].	P, CC, FC, Crop, Fruit
NBvolatUrine	N volatilised from urine patches. *Input*: NurineVolat [Urine Patch Model].	P, CC, FC, Crop, Fruit
NBDenitUrine	N lost due to denitrification from urine patches. *Input*: NurineDenit [Urine Patch Model].	P, CC, FC, Crop, Fruit
NBoutwash	Border dyke irrigation outwash. *Input*: Section 4.3.2.	P, CC, FC, Crop, Fruit
NBSepticOut	Septic tank system output. *Input*: Section 6.3.3.2.	House
NBPruning	Prunings removed. *Input*: Section 6.1.5.	Fruit
NBResiduals	Nutrients removed as crop residuals. *Input*: Unpublished.	FC, Crop, Fruit
NBFCoff	Fodder crops exported from a fodder crop or crop block and fed on another block or feed pad. *Input*: Unpublished.	FC, Crop

2.3. Internal transfers and change in pool sizes

Internal transfers are the movement of nutrients from the plant available pool to a long-term storage pool, or in the opposite direction.

Within the model, internal transfers are treated as outputs. Thus, NBframe is positive as it represents the accumulation of nutrients in the frame of fruit crops (a long-term storage pool) and so is treated as an output from the system. In contrast, NBSlowrelease is negative as it represents nutrients that are released by weathering (from a long-term storage pool) to become plant available, so is treated as an input into the system.

Table 3. Description and source for terms in the nutrient budget associated with internal transfer or change in pool sizes, and the block type the terms are applied to (P = pastoral, CC = cut and carry, FC = fodder crop)

Term	Description and input source	Block type
Inputs (negative)		
NBSlowrelease	Nutrients released by weathering (P, Ca, Mg, Na) or from interclay storage (K). *Input*: Sections 5.2.1, 5.3.1, and 5.5.1.	P, CC, FC, Crop, Fruit
NBMinCult	Nutrients released by mineralisation of organic matter. *Input*: CropMineralise [Crop Based Nitrogen Sub-model]. Fruit crops [section 6.1.7].	FC, Crop, Fruit

Term	Description and input source	Block type
Outputs (positive)		
NBImmob	Immobilisation of nutrients in organic matter. If negative, this signifies net mineralisation has occurred. *Input*: Section 5.1 for N, 5.2.5 for P, 5.4.1 for S, and section 3.8 for balancing procedure.	
NBFrame	Nutrients accumulating in the frame of fruit crops. *Input*: Section 6.1.4.	Fruit
NBAdsorp	Nutrients adsorbed onto clay minerals (P). *Input*: Sections 5.2.4 and 5.3.2.	P, CC, FC, Crop, Fruit
Changes (positive or negative)		
NBChangePlant	Difference in amount of nutrient in the standing crop (shoots and roots) between the beginning and end of the reporting year. A negative value is a net decrease. *Input*: unpublished.	
NBChangeStover	Difference in amount of nutrient in the residue (stover and roots) between the beginning and end of the reporting year. A negative value is a net decrease. *Input*: unpublished.	
NBLimeDiss	Nutrients in undissolved lime (year lime added) or from undissolved lime dissolving in year 2 onwards (negative). *Input*: $\text{LimeDiss}_{\text{nut}}$ [Characteristics of Fertiliser].	P, CC, FC, Crop, Fruit
NBInorg	Nutrients accumulating in the plant available pool. A negative value is a net decrease. Estimated as part of balancing. *Input*: Section 5.3.4, 5.4.4, 5.5.3, and 5.6.6.	

2.4. Reporting block nutrient budgets

The terms listed in sections 2.1, 2.2, and 2.3 are aggregated when reporting nutrient budgets. However, the individual components can be viewed by expanding nutrient budget items.

Table 4. Nutrient budget item, its description and nutrient budget terms that are summed to get the nutrient budget item value.

Nutrient budget item	Description
Nutrients added	
Fertiliser, lime, other	Nutrients added as fertiliser, lime, piggery or imported dairy effluents, organic materials (for example, compost), and foliar spray for fruit crops. This item also includes the N added as DCD. *Terms*: NBFert, NBLime, NBOtherFert, NBFerteff, NBDCD
Rainfall/clover N fixation	Nutrients in rainfall, and from biological N fixation. *Terms*: NBrain. NBNfix
Irrigation	Nutrients added in irrigation water. *Terms*: NBIrr
Supplements added	Block: Nutrients imported onto the block: in supplements brought in, in stored supplements, and supplements made on-farm and fed on paddocks, in fodder crops or crops grown on farm and fed on paddocks, and in animal health supplements. *Terms*: NBSuppImport, NBSupplStored, NBSuppIBlock, NBDrench Farm: Nutrients in supplements brought on to the farm or in stored supplements, in animal health supplements or net imports of nutrients into a house block (to balance those removed as sewage loading).
Effluent added	Nutrients in solid and liquid effluent applications arising from the farm dairy and wintering pads/animal shelters. *Terms*: NBEffLiq, NBEffSolid, NBImportEff, NBImportSolid
Sewage loading	Net input into a house block. *Terms*: NBSeptic
Sprays	Nutrients in sprays applied (Fruit crop blocks). *Terms*: NBSpray
Nutrients removed	
As products	Nutrients in products sold such as milk, wool, velvet, live weight, or crops. *Terms*: NBprod
Exported effluent	Nutrients in effluent exported from the farm (farm nutrient budget only). *Terms*: NBEffExport
As supplements and crop residues	Farm: Supplements sold from the farm, exported crop residues, crop defoliation products, and fruit tree prunings.

	Block: Supplements, fodder crops and crops removed from the block and fed to animals elsewhere on the farm. *Terms*: NBsuppremove, NBFCoff
Net transfer by animals	Nutrients transferred in the gut of animals from the block to farm dairy, lanes, and races, to a block after consuming feed on a feed pad, from a block to a wintering pad when pasture is consumed, and from a wintering pad/animal shelter and deposited on a block as excreta using nutrients consumed on the wintering pad. Transfers into the block are negative. *Terms*: NBToBlock, NBFromBlock, NBWPtoPas, NBPastToWP
As prunings	Prunings removed from fruit crop blocks. *Terms*: NBPruning
To atmosphere	Nutrients (nitrogen) losses via volatilisation from urine, fertiliser, or other sources (background), and denitrification from urine or other sources (background). Denitrification also includes nitrous oxide emissions. *Terms*: NBvolatUrine, NBDenitUrine, NBfertvolat, NBvolatother, NBDenit
To water	Nutrients transported from the farm in water, including leaching from urine patches or other sources (background), runoff, direct discharge to stream as drainage and direct deposition by animals, direct pond discharges from a 2-pond treatment system, border-dyke outflow and septic tank losses. *Terms*: NBleachUrine, NBleach, NBrunoff, NBDrains. NBPondToStream, NBoutwash, NBSepticOut
Changes in pools	
Standing plant material	Difference in nutrient amount between the beginning and end of the year in the standing crop. The nutrient level is the total nutrients in the product removed, residues and roots multiplied by the proportion of total growth that has occurred. A negative value indicates that the nutrient in the standing crop was higher at the beginning than end of the year. *Terms*: NBChangePlant
Root and stover residues	Difference in nutrient amount between the beginning and end of the year in stover and roots added as residues. A negative value indicates that the nutrient in the residues was higher at the beginning than end of the year. *Terms*: NBChangeStover
Crop framework	Gain of nutrients in the framework above and below ground of perennial fruit crops as the result of annual tree growth. *Terms*: NBFrame
Organic pool	Mineralisation from cultivation (crops and fodder crops), net immobilisation and mineralisation into soil organic matter, and accumulation in effluent storage ponds if they are emptied less frequently than once a year. *Terms*: NBImmob, NBAccumPond

Inorganic mineral	Nutrients adsorbed on clay minerals or released by weathering or slow-release mechanisms. This also includes the undissolved portion of lime in the year of application, or the portion that dissolves in the year after application, which is negative. *Terms*: - NBSlowrelease, NBAdsorp, NBLimeDiss
Inorganic plant available	Change in the plant available pool for the block. This pool is the pool related to soil test levels. Note that this is for the whole block (camp and non-camp areas) and hence should not be used to estimate maintenance or change in soil tests. A negative value indicates a net loss from the plant available pool. *Terms*: NBInorg

Note that the following nutrient transfers are also identified at the farm level:

NBChangeStore	Difference in nutrient amount between the beginning and end of the year in stored supplements.
NBAccumPond	Estimated accumulation of nutrients in farm dairy effluent management ponds [Effluent Management chapter]..
NBPondToStream	Estimated discharge of nutrients from farm dairy effluent management ponds to stream [Effluent Management chapter].
NBEffExport	Nutrients in effluent exported from the farm dairy or wintering pad/animal shelter effluent management system (Effluent Management chapter), or from septic tank system on house pond (section 6.3.3.2).

3. Nutrient model characteristics

This section describes the key sources and assumptions applied to the calculations for each nutrient. The following section describes the calculations for each source of input or output of nutrient.

3.1. Nitrogen

A N model for cropping fodder crop and fruit crop blocks has been developed and validated against field trials (Cichota *et al*., 2010). A modified form of the crop module was developed and validated against cut and carry trials for a cut and carry block (Wheeler *et al*., 2010b). In pastoral blocks, the inter-urine patches could be considered a cut and carry system, with animals removing the forage rather than machinery. Therefore, the background pasture N module is a version of the cut and carry module. This model is described in the Crop Based Nitrogen Sub-model chapter.

A specific urine patch N model was developed based on Cichota *et al*. (2012). This model for N, and urine patch leaching of K and S are described in the Urine patch chapter.

3.2. Phosphorus

The derivation of the slow release, immobilisation, plant P, and relative yield models are described by Metherell (1994), while the P leaching/runoff model is based on McDowell *et al*. (2005). The key assumptions of Metherell (1994) model are that:

- soluble P fertiliser immediately enters the labile pool.
- labile soil P and soluble fertiliser P are equally available for plant uptake.
- the size of the labile soil P pool can be estimated from the Olsen P test.
- reactive phosphate rock P must dissolve before entering the labile soil P pool.
- soil P losses are proportional to the labile soil P status.

The original immobilisation model of Metherell (1994) included P lost as leaching or runoff, as well as immobilisation and adsorption. With the development of the McDowell *et a*l. (2005) model, leaching/runoff was deducted from the immobilisation model of Metherell (1994).

The losses associated with effluent application, the effect of timing of effluent application on losses, the effect of mole tile drains and high rainfall on P losses, and factors affecting loss (see 5.2.1.6) were developed in consultation with R McDowell and R Monaghan (pers. comm.). The relationship to estimate DRP was updated based on additional information. Olsen P is adjusted to a weight basis using Rajendram *et al*. (2003) as all calibrations were done on a weight basis, whereas Olsen P is measured in the commercial labs on a volume basis. It is conceded that bulk density and volume weight are only moderately correlated.

The change in soil test values (Olsen P) is based on the amount of nutrient required to raise Olsen P by 1 unit, as reported by Roberts and Edmeades (1993).

3.3. Potassium

The relationships for estimating plant K concentrations and relative yield were based on analysis of trial data from the database of K fertiliser trials. Equations were extracted from the original Overseer/outlook model software and associated spreadsheets.

3.4. Sulphur

The sulphur model has not been published and hence is described in more detail in this section.

Within the sulphur sub-block model, the equation for estimating inputs from rainfall (NBatmosin) is from Ledgard and Upsdell (1991), leaching (NBleach) is based on a report by Wheeler (2003), and immobilisation is based on rearranging a model described by Thorrold *et al* (see Wheeler, 2020). Thorrold validated the immobilisation component of the model as part of a model to predict change in soil sulphur levels.

Database analysis indicated that the change in sulphate S test one year after application was small, although the effect on yield was larger (Wheeler and Thorrold, 1997). Given that the model is a quasi-equilibrium model, this effect is ignored unless fertiliser S applied last year differs. Hence, the change in the inorganic pool (NBchangeinorganic) is normally zero.

The accumulation of S seen in some subsoils, particularly those with high ASC in the subsoil, is ignored. For maintenance calculations, it is assumed that this fraction is largely unavailable for plant uptake, and hence below the root zone, which is the lower boundary for the nutrient budget. However, in these soils the loss of S to the environment may be less than that indicated in the nutrient budget.

The soil sulphate test is only used to estimate the initial organic S test value when the user does not have an organic S soil test value. The estimate of organic S assumes that sulphate and organic S are at an equilibrium level at the time of sampling.

Any positive balance remaining after the above calculations is added to NBleach under a ‘use it or lose it principle’. If the balance is negative, immobilisation is reduced (outputs are > inputs, and hence immobilisation is reduced). In this case, NBleach is the minimum leaching value noted above.

Total S test (in units of mg/kg soil) has been added to the model, as there was an improved relationship between total S and relative yield (Rajendram, 2008). The relationship for other factors for which PESo test is used has not been developed. Therefore, total S is converted to PESo based on a regression using over 150 soils in which PESo and total S were measured (Rajendram, Waller, pers. comm.).

3.5. Calcium, magnesium, and sodium

The calcium model is based on Carey and Metherell (2002), using the equations in CaMgNa overseer.xls as supplied by Peter Carey. The model for each nutrient has the same general form. In developing their model, Carey and Metherell (2002) assumed that:

- QT soil test measures are proportional to the available (solution plus exchangeable) pool.
- soluble fertiliser inputs of Ca, Mg and Na immediately enter the available pool.
- soluble fertilisers containing Ca and Mg and the soil available Ca-Mg pool are equally accessible for plant uptake.
- there are Mitscherlich relationships between soil available Ca, Mg and Na, and the relative yield and herbage concentration of each nutrient.

- animal Ca, Mg and Na losses are proportional to the stocking rate.

Weathering model was based solely on Profile model application and no calibration with field data was possible.

All the cation models need some feedback mechanisms added so that under high balance, weathering decreases, or under high negative balance, leaching decreases. These regions of the model were not covered by the data but do occur in the field.

3.6. Acidity

The acidity model is based on deKlein *et al*. (1997). The acidity model differs from the other nutrients in that it calculates acidity (H+) based on the difference between the amount and form of N entering a system, and the amount and form of N leaving the system (through leaching and gaseous losses). The unit the model was developed in was keq/ha/year. However, as the molar unit of H^+ is 1, then kg H^+/ha/year is approximately equivalent.

The characteristics of the acidity model that differ from the other nutrients include:

- the forms of N inputs (urea, ammonium, or nitrate) affect the rate of acidification (deKlein *et al*., 1997).
- for a given nutrient budget input or output category, the change in acidity shown is due to processes associated with that category rather than the movement of acidity per se. For example, for leaching and atmospheric losses, the change in acidity is due to the effect of adding ammonium and removing nitrate leaving behind acidity, rather than H or OH ions moving per se.
- in the nutrient budget, negative numbers indicate alkalisation (a gain in OH ions or a potential increase in soil pH).
- the correlation between the common measure of acidity (soil pH) and the unit in the nutrient budget is low due to soil buffering capacity being difficult to estimate.
- the effect of plant growth on soil acidity is estimated from the excess cation (EC) concentration of the herbage, as plants will exude/excrete H^+ when cation uptake exceeds anion uptake. Where possible, the effect of nutrient transfers as product (for example, supplements) on acidity is also estimated using excess cations.

The acidity model is only applied to pastoral blocks.

3.7. Inter-nutrient relationships

Currently, nutrient models can be largely run separately for each individual nutrient as little interaction occurs between nutrients. The exception is that N sub-model calculations must be completed before calculating Ca leaching and acidity as N leaching affects Ca leaching, and changing acidity depends on N losses to the atmosphere, as leaching, or is immobilised.

Due to the existence of farm and block scales, and the requirement of block scale information for farm scale calculations, and vice versa, the order of calculation of terms within the sub-block nutrient budget is important.

Leaching due to mole-tile drains is included in the P model, is partially covered for the N model as part of the drainage calculation contributing to leaching and ignored for the other nutrients. Increased leaching under border dyke irrigation on stony soils is covered for all nutrients, although the size of the effect for most nutrients is approximate.

There are generally no cross-nutrient interactions except that Ca leaching is dependent on N leaching, soil K status but not K inputs affect Mg and Na leaching losses, and acidity changes are affected by N transformations and fertiliser type.

In practice, accumulation of OM would likely result in immobilisation of N, P and S. These are currently modelled separately, and better coordination between the models would be beneficial.

There is also little data available on the effect of high inputs of one nutrient on leaching losses of other nutrients; for example, Early (1998) reported losses of Mg and Na under urine patches. There is no information on the cations lost if high rates of S or Cl are added, which has occurred in some farm scenarios, or the counter ion if high K rates is applied, which occurs on some effluent blocks.

3.8. Balancing the budget

For pastoral and cut and carry blocks, within a nutrient budget, the model assumes that inputs equal outputs (nutrients removed and changes in long-term storage pools). The difference between initially estimated inputs and outputs (the balance) also includes any errors associated with entered data or the estimation of terms in the nutrient budget, and unaccounted nutrients.

To balance the budget, the ‘balance’ is allocated to items within the nutrient budget. The methodology to achieve this varies with each nutrient as described in section 5.1.1 for N, section 5.2.6 for P, section 5.3.4 for K, section 5.4.4 for S, section 5.5.3 for the cations Ca, Mg, and Na, and section 5.6.6 for acidity.

In cropping, fodder crop and fruit crop blocks, there is a change in nutrients in the standing crop between the beginning and end of the year. Hence a balancing method is not required.

4. Item-based models

Many of the item-based models are described in separate chapters, as indicated in Table 1 to Table 3. This section covers items not described elsewhere, or where the outputs from a specific model may be modified.

4.1. Rainfall additions

N inputs in rainfall has a single average value of 2 kg N/ha/year since previous research showed little variation around this value throughout NZ (unpublished research of Saunders, Cooper, Ledgard and others). Atmospheric N sources may have increased since this work was done due to changes in farm practices and increased industrialisation.

Fish (1976) reported P concentrations in rainwater of 0.054 g/ha/mm. These were considered low enough to ignore for a block nutrient budget.

Rainfall inputs for S are based on Ledgard and Upsdell (1991), who used distance from nearest coast but reported different equations for east and west coast. The combined equation was used so that S in rainfall was estimated as:

Equation 1: $NBrain_S = Exp(1.4 - 0.015\ distcoast + 0.00069\ rain - 0.00000012\ rain^2)$

distcoast is the entered distance from coast (km).

rain is the annual rainfall (mm/year) [Climate].

The inputs for K were assumed to be half those for S (source unknown).

Rainfall inputs for Ca, Mg and Na were based on Carey and Metherell (2002), using supplied equations (P Carey, pers. comm., in CaMgNa overseer.xls). The method estimates concentration in rainfall (mg/L) and then multiplies this by rainfall to give total loading. The equations for rainfall concentrations of Ca, Mg and Na differ from those in the published report which is relevant only to Southland whereas the excel spreadsheet includes the entire data set which was used. Thus, for Ca, Mg and Na, rainfall inputs are estimated as:

Equation 2: $NBrain_{nut} = Crain0 * Exp(Crain1 * distcoast) * rain / 100$

Crain0 and Crain1 and nutrient specific constants [Table 5].

distcoast is the entered distance from coast (km).

rain is the annual rainfall (mm/year) [Climate].

100 is a conversion factor (mg/l to kg/ha).

Table 5. Constants for estimating rainfall inputs for cations Ca, Mg and Na.

	Ca	Mg	Na
Crain0	0.438	1.0461	6.6551
Crain1	-0.0165	-0.0197	-0.031

Yates and Hedley (2008) in a study of winter Na rainfall deposition in Taranaki showed that distance from the coast for the prevailing winds was a better predictor of average Na concentrations in rainfall than distance from the closest coast. They estimated average Na concentrations (mg/l) as:

Equation 3: $\text{NaRain} = 6.44 + 20.9 * \exp(-0.132 * \text{distcoast})$

This gave higher concentrations than reported by Carey and Metherell (2002). Yates and Hedley (2008) reported that Overseer modelled Na input was similar to measured winter (May to September) Na deposition, and hence may be underestimating annual Na inputs for Taranaki. Yates and Hedley (2008) also showed that a model for Na deposition from highly exposed sites (to the wind) was similar to the Overseer model, but the Overseer model would over-estimate deposition at low exposure sites. Gray and O'Connor (1988) also noted that local topography could also affect S deposition, possibly due to rain shadow effects.

The definition of 'distance from coast' varies with the reports. Ledgard and Upsdell (1991) used distance to nearest coast but reported differences between East and West coast sites. Yates and Hedley (2008) used direction of prevailing winds. Carey and Metherell (2002) had a strong bias on Southland sites. Salt spray was an important source of rainfall nutrients (Ledgard and Upsdell, 1991; Gray and O'Connor, 1988; Yates and Hedley, 2008). Yates and Hedley (2008) also reported that K, Mg and Ca rainfall inputs were correlated with Na inputs, and that the ratio of Na:Mg inputs in rainfall were similar to the Na:Mg ratio in sea water.

Given the results above, distance from coast has been interpreted as 'Distance from coast in the direction of the prevailing wind. In areas where there is no strong direction, distance to nearest coast probably suffices. However, in areas with strong prevailing winds (for example, Taranaki), or where there are topographic effects on sea salt deposition, then the effect on rainfall deposition can only be adjusted by selecting an appropriate distance to coast.

The form of the equations for atmospheric inputs for S and K, and for Ca, Mg and Na differ, and they come from different data sets. Ledgard and Upsdell (1991) also reported equations for S concentration in rainfall, with different equations for east and west coast. The spreadsheet supplied by Carey (pers. comm., in CaMgNa overseer.xls) for Ca, Mg, and Na also contains data for K, but this data is currently not used for the model. Yates and Hedley (2008) also reported additional sources of information that have not been included in the analysis. A re-analysis using a consistent definition of distance to coast would be expected to yield a function of similar form (that is, estimate of concentration) which could be applied to all rainfall inputs.

Volcanic ash deposition in years when volcanic eruptions occur is also a known source of Ca, K, Mg, S and Se (Cronin *et al*., 1996), with sufficient S being added to supply pasture S requirements. The amount of deposition is related to the thickness of the ash. Ash deposition from volcanic eruptions has been ignored in the model.

4.2. N fixation

The model includes the symbiotic fixation of atmospheric N from pasture, as described in the Characteristics of Pasture chapter, and from N fixing crops, such as beans, peas, lentils, and clover seed crops (Crop Based Nitrogen Sub-model chapter).

On pastoral blocks, the amount of N fixation is adjusted for clover levels, development status, hard grazing, and balancing when setting up a block nitrogen budget. N fixation is adjusted by balancing routines to ensure that the budget balances.

Non-symbiotic inputs are assumed to be small and are included in the calculation of symbiotic N fixation. A minimum value of pasture of 8 kg N/ha/year is set to cover this.

N fixation other than in clover can also occur, for example, gorse, broom, and N fixers in native forest.

4.3. Irrigation and border dyke outwash

The estimated amount or irrigation water supplied is obtained from the water balance model (see Hydrology chapter). Irrigation waters typically contain nutrients which are inputs into the block.

The model assumes that nutrients in border dyke outwash leave the block. Outwash typically has higher nutrient contents than the applied water. Water that is border dyke outwash from another block within the farm, or from another farm, can also be applied to blocks. If recycled border outwash is used as a source of water, then the nutrient in the outwash stays in the farm.

4.3.1. Irrigation supplied

The model assumes that all the nutrients in the supplied irrigation are applied to the block. Irrigation water loss as extra atmospheric loss is assumed to have no nutrients.

The amount of nutrients added to a block in the supplied irrigation water is estimated as:

Equation 4: $\text{NBirr}_{\text{nut}} = \text{IrrSupplied} * \text{Cirr}_{\text{nut}} / 100$

IrrSupplied is the total annual irrigation supplied (mm/year) [Hydrology].

Cirr_{nut} is the concentration of nutrient in irrigation water (mg/L, µg/ml, mg/m^3, ppm).

Irrigation water concentrations can be specified as either program default values (see section 4.3.3), computer default values (standard values the user adds), or user-entered values for each block. Program default values are used if border dyke outwash or recycled border dyke outwash is selected as the source (see section 4.3.4).

In addition, there are losses from the delivery system caused by leaking pipes, connections, and taps, or losses from water races, etc. The amount of nutrients in irrigation losses from the delivery system (DeliveryDrainageLoss) is estimated and added to background leaching. Thus, nutrients loss in delivery drainage (kg nutrients/ha/year) is estimated as:

Equation 5: $\text{DeliveryDrainageNutLoss}_{\text{nut}} = \text{DeliveryDrainageLoss} * \text{Cirr}_{\text{nut}} / 100$

DeliveryDrainageLoss is the total annual supplied irrigation losses from the delivery system, including from leaking pipes, connections, and taps, or water races, etc (mm/year) [Hydrology].

4.3.2. Border dyke outwash

Border dyke outwash is estimated during irrigation input calculations.

Equation 6: $\text{IrrOutWash}_{\text{nut}} = \text{Outwash} * \text{Coutwash}_{\text{nut}} / 100$

Outwash is the total annual irrigation outwash (mm/year) [Hydrology].

$\text{Coutwash}_{\text{nut}}$ concentration of nutrients in outwash water (mg/L, µg/ml, mg/m^3, ppm) [section 4.3.4].

4.3.3. Default supplied water concentrations

Program default concentrations are 2.5, 0.1, 1.6, 2.5, 9.3, 2.2, and 9.5 mg/L for N, P, K, S, Ca, Mg, and Na respectively. The default concentrations for K, Ca, Mg, and Na are based on average concentrations of nutrients found in river waters from monitored sites around New Zealand (GNS 1999). It is uncertain where the default concentrations for N, P and S were derived from. The two sets of known data used when the model was developed were the average concentrations from GNS (1999) which were 378, 448, 7.4 and 8.2 mg/L for N, P, S, and Cl, and average nutrient concentrations in irrigated water estimated from Monaghan *et al*. (2009) which were 0.25, 0.08, 1.1, 9.3, 0.8, and 2.3 mg/L for N, P, K, Ca, Mg, and Na respectively. There was a note that it was assumed that applied irrigation water had little contamination of N and P, hence lower concentrations were used.

GNS (1999) indicated considerable variation in concentrations of cations between river systems (2 to 3 fold differences in concentrations). Better default values could be achieved by using typical data from each river catchment or groundwater source. If it is assumed that irrigation is applied in late spring, summer and early autumn, and that irrigation is not applied when sediment loads are high (for example, the river is in flood), then a mean weighted average for each river over the irrigation season may be a better indication of typical irrigation concentrations (R Reeves, GNS, pers. comm., 2003).

Bore water nutrient concentrations from confined aquifers tends to be more constant, although identification of the aquifer may be important as local bore water may be highly variable (R Reeves, GNS, pers. comm., 2003). However, Hansen (2002) identified a wide range of nitrate concentrations in bore water on the Canterbury plains. This data indicates that default values may not always be adequate.

Fertigation can be handled either as irrigation with high nutrient concentrations or as irrigation (with low or default nutrient levels) plus fertiliser applied.

4.3.4. Outwash concentrations

The program default concentrations of nutrients in outwash water were based on preliminary results measured in border dyke outwash (Monaghan *et al*., 2009), and are 11.0, 2.1, 13.1, 10.0, 26.9, 9.5, and 37.5 mg/L for N, P, K, S, Ca, Mg, and Na respectively. Monaghan *et al*., (2009) noted that ammonium comprised 18% to 75% of total N (ammonium plus nitrate), with an average of about 50%, and this ratio is used in the acidity model. Dissolved reactive P (DRP) was about 80-90% of total P.

The nutrient concentrations are higher than the input water due to contamination from sources such as faeces, fertiliser, soil, and pasture exudates. These are currently fixed.

4.4. Runoff or overland flow

Runoff nutrient losses are defined as nutrients that move in water due to overland flow and are assigned to the nutrient budget variable NBrunoff. Note that for the nutrient P, leaching is included in the runoff loss estimate.

4.4.1. Overland flow P losses

4.4.1.1. *Pastoral blocks*

The overland flow model for overland flow P losses for pastoral blocks is based on McDowell *et al*. (2005) and is described in section 5.2.1. Note that the losses in overland flow (runoff) and as leaching, and through artificial drainage systems are combined in McDowell *et al*. (2005), but losses through artificial drainage systems are separated for this model.

The overland flow P loss for fodder crop, cropping, fruit crop and cut and carry blocks is based on the pastoral block model and is described in sections 4.4.1.2 to 4.4.1.4.

P loss from house and tree blocks are described for the respective block models (unpublished). Mitigation of overland flow P losses by grass filter or riparian blocks is also described separately (unpublished). Wetlands are assumed to have no effect on P losses, or the mitigation of P loss.

4.4.1.2. *Fodder crop, arable and vegetable cropping systems*

There is little experimental data for losses of P from arable cropping systems in New Zealand (Gray *et al*., 2015), although Rutherford *et al*. (1987) ‘estimated’ that particulate associated P losses from cultivated land could be up to 2 kg P/ha/year. Compared with other land uses, arable cropping generally occurs in areas with a perceived low risk of P loss, that is, relatively flat topography with low rainfall.

The estimation of P losses from arable cropping systems uses the pastoral sub-model because there was little available data describing P losses from arable systems. Due to the greater proportion of bare ground, a mean increase in P loss has been applied that is equivalent to double that of pastoral block losses. This doubling is based on a study that compared ungrazed pasture with ungrazed and grazed winter forage crops (McDowell *et al*., 2005).

In addition, incidental effluent P loss runoff is doubled. Incidental fertiliser P loss and the loss from artificial drainage is not altered.

4.4.1.3. *Cut and carry systems*

The proportion of P associated with cut and carry systems can be attributed to that lost from the soil and plant system without the influence of dung and treading by grazing ruminants. Hence the pastoral P loss model is used but soil (background) P losses are halved. This modifier is based on the findings of one study investigating relative P losses from pasture, soil, treading and dung from a single grazing rotation on one soil type (McDowell *et al*., 2007).

In addition, incidental runoff and losses through the drainage system remain the same.

4.4.1.4. *Fruit crop blocks*

Fruit crop blocks are treated the same as cut and carry blocks, that is, the pastoral P loss model is used but soil (background) P losses are halved, and incidental runoff and losses through the drainage system remain the same.

4.4.2. Other nutrients

For nutrients other than P, nutrient loss in runoff is sourced from dung deposited on the block and, nutrients derived from sediment (particulate and dissolved). Thus, nutrient loss in runoff (kg nutrient/ha/year) is estimated as:

Equation 7: $\text{NBRunoff}_{\text{nut}} = (\text{runoffdung} + \text{runoffsed}) * \text{slopeabsorp} + \text{Deereffect} + \text{Effrunoff}$

Runoffdung is the nutrient in dung lost in runoff (kg nutrient/ha/year) [4.4.2.1].

Runoffsed is the nutrient in sediment lost in runoff (kg nutrient/ha/year) [4.4.2.2].

slopeabsorp is a factor accounting for adsorption depending on slope [section 4.4.2.3].

DeerEffect is nutrient in runoff from deer pacing and fallows [section 4.4.2.4].

Effrunoff is nutrient in runoff from effluent applications [4.4.2.5].

4.4.2.1. *Runoff from dung*

Background runoff is based on a survey with little data on N losses in runoff. The impact of cattle on background runoff was assumed to be similar to that of P runoff. Soil runoff of nutrients (kg nutrient/ha/ year) is estimated as:

Equation 8: $\text{runoffdung} = \text{runoff} * (\text{dungconc}_{\text{nut}} + \text{dungconc}_{\text{nut}} * \text{stockratio}) * \text{slopeeffect}$

runoff is the calculated runoff (mm/ year) [Hydrology].

$\text{dungconc}_{\text{nut}}$ is the nutrient concentration in runoff water ((kg nutrient / mm rainfall) [4.4.2.1.1].

stockratio is ta factor to account for stocking rate of the block [section 4.4.2.1.2].

slopeEffect is a slope factor [section 4.4.2.1.2].

Note that on cut and carry and some cropping blocks, there will be no dung deposition, but the contribution is still estimated. However, the contribution from cattle would be zero.

4.4.2.1.1. Dung nutrient concentrations

A brief literature review showed that:

- A regression on the runoff and N loss in runoff data of Lambert *et al*. (1985) gave a slope of 0.0197 kg N/ha/mm runoff.
- In forests, measured N concentration in runoff was 1.98 mg N/l (0.0198 kg N/ha/mm runoff) (reference could not be found).
- In effluent plots, 1.8-0 mg NO_3/l, and 1.5-0.8 mg NH_4/l was measured in runoff (reference could not be found).
- An Australian study measured an average of 0.62 kg N/ha loss in runoff, range of 1-51 mm runoff and 4-376 kg sediment (average 179). This equated to about 0.0248 kg N/ha/mm runoff (reference could not be found).
- Monaghan *et al*. (2000) reported runoff and total N for a Fleming soil, where runoff was low (< 20 mm) compared to Ballantrae (Lambert *et al*., 1985). However, the average N content in runoff was 0.0197 kg N/ha/mm runoff.

Based on this, it was assumed that the N content in dung was 0.001970 kg N/ha/mm runoff. The nutrient content assumed in runoff from dung (dungconc, kg nut/mm runoff) was 0.001970, 0, 0.00947, 0.00338, 0.00476, 0.00275, 0.00079, 0 for N, P, K, S, Ca, Mg, Na, and acidity respectively. The derivation of the values for other nutrients is now unknown.

For nitrogen, the concentration in dung is multiplied by a fertiliser factor,

Equation 9: dungconc = defdungconc * (0.002 * Ninput + 1)

defdungconc is the default N content in dung (kg nut/mm runoff) [see text].
Ninput is the sum of fertiliser and other fertiliser soluble N, with a maximum value of 400 (kg nut/ha) [Characteristics of Fertiliser].

4.4.2.1.2. Stock ratio

It was considered that nutrients in runoff would increase as stocking rate increased Note that there was an additional impact of cattle stocking rate including slope effect (section 4.4.2.1.3). It was assumed that runoff nutrients would increase as stocking rate (RSU/ha) increased, with the maximum effect at 15 RSU/ha. For convenience, the block stocking rate was estimated from block DM consumption multiplied by a typical pasture ME content of 10.5 MJ ME/kg DM divided by 6000 MJ ME to give RSU. The stock factor was estimated (with a maximum value of 1) as:

Equation 10: Stockratio = (consume$_{\text{block}}$ * 10.5 / 6000) /15

consume is the block DM consumption (kg DM/ha/year) [Interblock Distribution].

4.4.2.1.3. Slope effect

Italians (reference could not be found) measured < 15 kg N/ha in runoff from flat (0.5% slopes) but 30 kg N/ha on 10% slope.

Lambert *et al*. (1985) indicated that on hill country, runoff losses of N were 1.4 times higher, and losses of P 2.1 times higher under cattle than under sheep. Furthermore, there were no differences between rotational or set stocking for sheep, and between high and low fertility soils. This suggests that losses under cattle are dependent on slope and are probably due to higher sediment losses when cattle graze steeper slopes. An arbitrary slope effect for cattle is assigned with a value of 1, 1.1, 1.25, and 1.4 for flat, rolling, easy hill, and steep hill topographies respectively.

Equation 11: slopeeffect = (1 – CattleSU) + TopoEffect * CattleSU

TopoEffect is the slope effect for cattle [see text].

It is assumed that the impact of cattle on a block is proportional to the intake of cattle, which is estimated as:

Equation 12: CattleSU = blockSU$_{\text{dairy}}$/100 + blockSU$_{\text{dairyrep}}$/100 + blockSU$_{\text{beef}}$/100

blockSU is the proportion of pasture intake by given animal type [Animal model].

On crop blocks, the parameter slope effect is used to reflect the higher potential for runoff losses from these blocks and is assigned a value of 1.5.

4.4.2.2. *Runoff from sediment*

The runoff from sediment is estimated as:

Equation 13: runoffsed = runoff * runoffconc

runoff is the calculated runoff (mm/year) [Hydrology].

$\mathrm{runoffconc_{nut}}$ is the nutrient concentration in runoff water (kg nutrient/mm rainfall) [section 4.4.2.2.1].

4.4.2.2.1. Sediment Nutrient concentrations in runoff

The average content of N in soils was 0.229%, with a range from 0.067 to 0.832. N content averaged 0.204 on brown soils. The values of N loss per mm runoff (kg N/ha/mm runoff) in the literature are similar to the N content (%) of soils divided by 10. As most of the nutrients in runoff are probably loss of soil sediment, then as a first approximation, the concentration of nutrients in soils was based on average concentration in soil divided by 10. It was assumed that runoff concentrations were twice as high for cattle as for sheep. Hence, the nutrient concentration in runoff water for sheep is estimated as:

Equation 14: $\mathrm{runoffconc_{nut}}$ = RunoffNutConc /10 /2

RunoffNutConc (%) is the average nutrient contents of soils [Characteristics of Soil].

4.4.2.3. *Slope re-adsorption*

Runoff is probably re-adsorbed as it moves overland. Re-absorption was considered more likely on hill country. To account for this, runoff was reduced by a slope re-adsorption factor, which was estimated as 0.7 for flat, 0.6 for rolling, 0.4 for easy hill and 0.25 for steep hill topography categories.

4.4.2.4. *Deer effect*

If deer are present on the block, then a similar procedure as used for P is applied [section 5.2.1.2.2 and 5.2.1.2.3]. Thus:

Equation 15: Deereffect = (runoffsed * 0.98) + (runoffsed * 4 * 0.02) + wallow

runoffsed is the sediment runoff (kg nutrient/ha/year) [4.4.2.1].

and where a wallow present it is assumed to be 5 kg nutrient/ha for all nutrients.

4.4.2.5. *Run off from effluent applications*

For N, it is assumed that N inputs from organic material would have a lesser effect on N in runoff than fertiliser N inputs, although the size of that effect is not known.

Liquid effluent was included as an Other N source, as well as incidental effluent loss. Therefore, a factor of 0.5 was used.

The model assumes that loss of other nutrients from incidental application of effluent is similar to the effluent P mechanism. Thus, runoff from effluent (kg nutrient/ha/year) is estimated as:

Equation 16: $EffRunoff_{nut}$ = LossEffluent + LossImport + LossSolid

For a liquid effluent source, the amount of nutrient lost as runoff is estimated as:

Equation 17: $LossEffluent_{nut} = LiqEffluent_{nut} * ratio$

LiqEffluent is the amount nutrient in liquid nutrient applied to the block (kg nutrient/ha/year). [Effluent management].

and were:

Equation 18: ratio = (effloss + efflossWP + efflossvillage) / $LiqEffluent_{P}$

effloss, efflossWP, and efflossvillage is the estimated P loss from each liquid effluent source (kg P/ha/year) [section 5.2.1].

LiqEffluent is the amount of P applied as liquid effluent (kg P/ha/year). [Effluent management].

A similar approach is used for the imported and solid effluent sources.

4.5. Direct loss to water

Direct loss to water includes nutrients lost direct to waterways via the drainage system or directly deposited in waterways by animals. Thus:

Equation 19: $NBdrain_{nut} = Drain_{nut} + DirectToStream_{nut} + EffToDrain + PondtoStream_{nut}$

Drain are nutrients lost direct to waterways via the drainage system (kg nutrient/ha/year) [section 4.5.1].

DirectToStream are nutrients deposited in waterways by animals (kg nutrient/ha/year) [section 4.5.2].

EffToDrain are nutrients in effluent loss via the mole toile drainage system (kg nutrient/ha/year) [section 4.5.3].

PondDischarge are nutrients discharged directly into a waterway from a 2-pond effluent system (kg nutrient/ha/year) [Effluent Management].

4.5.1. Artificial drainage losses

For nutrients other than P, the initial calculation of leached nutrients is partitioned to drains based on an estimate of drainage efficiency. The amount of leached nutrients is reduced accordingly. Thus:

Equation 20: $\text{Drain}_{\text{nut}} = \text{NBleachout}_{\text{nut}} * \text{propDrain}$

Equation 21: $\text{NBleach}_{\text{nut}} = \text{NBleachout}_{\text{nut}} * (1 - \text{propDrain})$

NBleachout is the initial estimate of NBLeach (kg nutrient/ha/year).

propDrain is the proportion of water entering the drainage system [Hydrology].

The direct loss to water of P from artificial drainage for pastoral blocks is described in section 5.2.2. The same method is used for other block types.

4.5.2. Animal deposition in streams

Bagshaw (2002) estimated that for beef animals about 0.04 (4%) of excreta was deposited in streams. The measurements were made on steep slopes and probably overestimated typical transfer rates to streams.

Best management practices recommend that streams should be fenced, although on easy hill and steep topography many small ephemeral streams cannot be easily fenced. Therefore, the transfer was split into base loss, representing loss into small ephemeral streams, and a loss if the blocks are not fenced. A base conservative estimate of total loss was used given 0.017 and 0.026 for beef animals on easy hill and steep hill topography respectively.

It was also assumed that most of this came from dung. Direct transfer of urine to streams was set at one third that of dung. Thus, for dairy, dairy replacement and beef animal enterprises, the amount of nutrients directly deposited in stream (kg nutrient/ha/year) is estimated as:

Equation 22: $\text{BlockToStream}_{\text{nut}} = \sum_{\text{ansys, mon}} \text{streamdung}_{\text{nut}} + \text{streamurine}_{\text{nut}}$

where

Equation 23: $\text{streamurine} = \text{blockUrine}_{\text{block, nut, mon, antype}} * \text{TranToStream} / 3$

blockUrine is the provisional amount of nutrient deposited in urine on a block by each animal enterprise each month (kg nutrient/ha/month) [Distribution of farm data to block scale].

TranToStream is the transfer rate to stream [Equation 25].

Dung that could be deposited on a block is recorded at the block level, not an animal enterprise level. Therefore: for dairy, dairy replacement and beef animal enterprises:

Equation 24: $\text{streamdung} = \text{blockDung}_{\text{block, nut, mon}} * \text{BlockSU}_{\text{block, antype}} / 100 * \text{TranToStream}$

blockDung is the provisional amount of dung depsoited on a block (kg nutrient/ha/month) [Distribution of farm data to block scale].

BlockSU is the relative yearly intake of each animal enterprise on a block (%) [Animals].

TranToStream is the transfer rate to strream [Equation 25].

Dung and urine deposited in streams is subtracted from dung and urine deposited on a block. The transfer rate is estimated as:

Equation 25: TranToStream = base + access

where the base rate is estimated as:

Equation 26: base = $\text{streamtransferbase}_{\text{topography}}$* $\text{blockSU}_{\text{block, antype}}$ / 100

Streamtransferbase is the transfer rate for ephemeral streams [Table 6].

blockSU is the relative yearly intake of each animal enterprise on a block (%) [Animals].

If the option ‘Access to stream’ is unchecked, then:

Equation 27: access = $\text{streamtransfer}_{\text{topography}}$ * $\text{blockSU}_{\text{block, antype}}$ / 100

streamtransfer is the transfer rate for deposition that can be controlled by fencing [Table 6].

blockSU is the relative yearly intake of each animal enterprise on a block (%) [Animals].

This is the benefit of fencing waterways to prevent direct deposition in streams.

Table 6. The base (from ephemeral streams) and access (deposition that can be reduced by stream fencing) transfer rates to stream for dairy, dairy replacement, and beef animal enterprises.

Topography	Base	Access
Flat	0	0.01
Rolling	0	0.011
Easy hill	0.005	0.012
Steep hill	0.01	0.016

4.5.3. Effluent loss

The model assumes that loss of other nutrients from incidental application of effluent is similar to the effluent P mechanism. Thus, runoff from effluent (kg nutrient/ha/year) is estimated as:

Equation 28: $\text{EffToDrain}_{\text{nut}}$ = LossEffluent + LossImport + LossSolid

For liquid effluent source, the amount of nutrient lost as runoff is estimated as:

Equation 29: $\text{LossEffluent}_{\text{nut}}$ = $\text{EffluentLiq}_{\text{nut}}$ * ratio

EffluentLiq is the amount nutrient in liquid nutrient applied to the block (kg nutrient/ha/year). [Effluent management].

and where:

Equation 30: ratio = (moleeffloss + moleefflossWP + moleefflossvillage) / EffluentLiq_P

Moleeffloss, moleefflossWP and moleefflossvillage is the estimate P loss from drainage system each liquid effluent source (kg P/ha/year) [section 5.2.1].

EffluentLiq is the amount nutrient in liquid nutrient applied to the block (kg P/ha/year) [Effluent management].

A similar approach is used for each source.

4.6. Border dyke outwash

The model assumes the 16% of border dyke irrigation added ends up as outwash and this represents a net loss of nutrients from the block. The nutrient concentrations are greater than in the water supply due to contamination from sources such as faeces, fertiliser, soil, and the pasture.

If irrigation is applied using border-dyke, then the nutrient loss from border dyke outwash is estimated during irrigation input calculations.

Equation 31: $\text{NBoutwash}_{nut} = \text{irr} * 0.16 * \text{Coutwash}_{nut} / 100$

Irr is the amount of irrigation applied (mm/year) [Hydrology].

0.16 is the proportion of added irrigation that ends up as outwash.

Coutwash_{nut} is the concentration of nutrients in outwash water (%) [section 4.3.4].

5. Nutrient based models

5.1. Nitrogen

The total amounts of N fixed, volatilised, denitrified, leached, immobilised, and mineralised from organic matter decomposition is estimated as the sum of the monthly outputs for the reporting year (months 13 to 24) (Crop Based Nitrogen Sub-model chapter). These are used in the nutrient budgets. For crop blocks, the change in soil mineral N pool is also used in the nutrient budget.

The amount of N volatilised, denitrified, leached, and immobilised from urine deposited on pastoral and crop blocks is described in the Urine patch sub-model chapter.

5.1.1. Immobilisation

For pastoral blocks, if the immobilisation potential is selected to be none, then immobilisation is set to zero. Otherwise, if immobilisation is less than a minimum value, immobilisation is set to the minimum value based on the estimated change in soil carbon at a C:N ratio of 10. The minimum value is estimated as:

Equation 32: $minImmob = ChangeC / 10$

changeC is the change in soil carbon (kg C/ha/year)
[Characteristics of Soils].

On cut and carry, and cropping blocks, immobilisation is estimated as part of the crop N model (Crop N sub model chapter).

5.1.2. Balancing

For pastoral and cut and carry blocks, the model assumes that there is no net change in soil inorganic N levels (or than it is negligible). Therefore, the expectation is that under normal conditions, the change in soil inorganic N should be zero. Hence any balancing requires adjusting of some other inputs or outputs. This is done by adjusting either immobilisation or N fixation, as neither is a key output. The increasing focus on N fixation and the balancing term which includes an error or closing term, indicates that it may be better to separate the balance terms from immobilisation and N fixation and report them separately.

The procedure is based on the immobilisation potential, although it is no recommended that this be used. If the immobilisation potential is high, then urine N leaching and denitrification are reduced by 20% and the balance recalculated.

If the immobilisation potential is none, then if the balance is less than zero, the balance is subtracted from N fixation (as balance is negative this in effects adds it to N fixation). Otherwise, if the balance is greater than 0, then:

- Leaching and denitrification are increased by 20% and 10% respectively, and a new balance calculated
- if balance is greater than N fixation less 10, then N fixation is set to 10 and the balance recalculated.
- The balance is then allocated pro rata to leaching and denitrification

Otherwise, if the immobilisation potential is standard or high, and the balance is greater than 0, then:

- if (balance is greater than N fixation, then N fixation is halved; else
- N fixation is reduced by half of the balance

Else if the balance if less than zero then change is estimated as:

Equation 33: $change = (-balance * 0.5)$

such that change has a maximum value of 40. Change is added to N fixation. The balance is recalculated, and the resultant balance added to immobilisation.

For cropping blocks, soil N levels can change between years, and hence N is not balanced. This means that the estimate of net immobilisation is important

5.2. Phosphorus

5.2.1. Overland P loss for pastoral blocks

P loss due to runoff (overland flow) is estimated as:

Equation 34: $NBrunoff_P = SoilPloss + FertPloss + EffPloss$

SoilPloss is background P loss (kg P/ha/year) [section 5.2.1.2].

FertPloss is incidental fertiliser P loss (kg P/ha/year) [section 5.2.1.2].

EffPloss is incidental effluent P loss (kg P/ha/year) [section 5.2.1.2].

5.2.1.1. *Background*

P loss via runoff to surface water for pastoral blocks is based on McDowell *et al*. (2005). The model separates sources of P losses into two types: i) background (soil) losses and ii) incidental (fertiliser and effluent) losses (Figure 1). P losses associated with border dyke irrigation (section 4.3.2), discharge from artificial drainage systems (section 4.4.2.1), or pond discharge are not included here because their point of discharge from the farm differs. Leaching losses are incorporated in the calculation of runoff propensity (section 5.2.1.6.2) and leaching and runoff losses are reported as runoff losses.

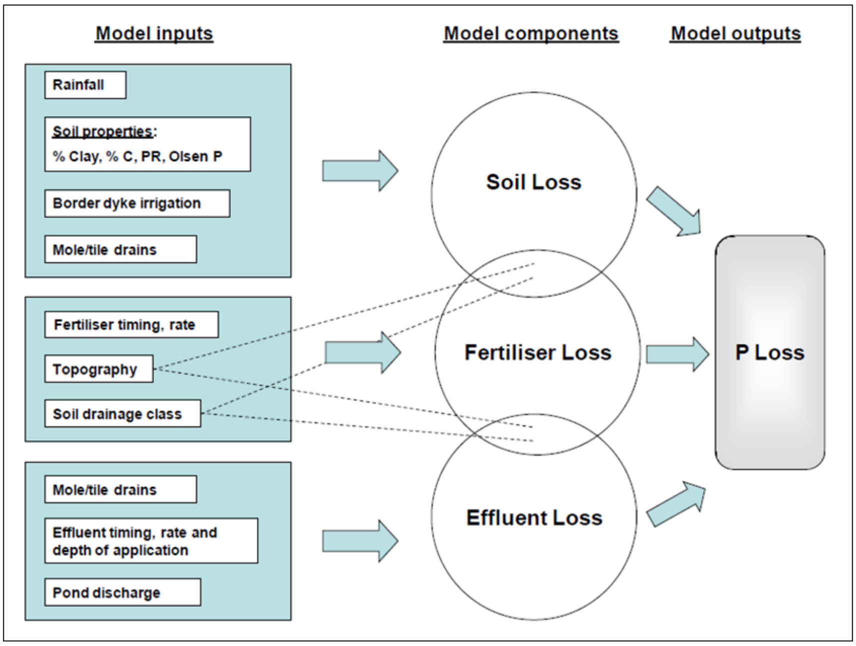

Figure 1. Conceptual diagram of model structure (from McDowell *et al*., 2005)

In simple terms, P losses from all agricultural systems can be quantified as the interaction of P sources with transport pathways, modified by management.

5.2.1.1.1. Definitions

Runoff was defined by McDowell *et al*. (2005) as being either surface flow, interflow, or subsurface flow (inclusive of leaching that is not partitioned to deep drainage to groundwater) that enters up to second order streams (a stream that has two first order tributaries).

In the definition, the location of the streams are not defined – they may be within or outside the block. The important aspect is that the P lost from a given block as overland flow ends up in a stream somewhere. In areas where there is a long flow path or strong disconnect between the source and the stream, then overland flow losses may be over-estimated.

Critical source areas (CSA) are areas where most of the P loss occurs. Typically, 80% of P loss occurs from 20% of a block (McDowell and Srinivasan, 2009). Critical source areas within a block are not specified in the model. Given that the model has been calibrated against catchment scales, some of the critical sources have been accounted for. Mitigation options that specifically target CSA, with the exception of deer fence line pacing and wallows, are not included in the model.

5.2.1.1.2. Sources of P

Soils supply plants with P but often are also the main source of P loss to surface water bodies. Soil P loss is separated arbitrarily into either dissolved P (also called filtered P or soluble P) or particulate P.

In grazed pasture systems, plants act as a source of P because grazing animals tear forage and expose P present in cell vacuoles. McDowell *et al*. (2007) estimated that this source could account for on average 20% of the P lost from a paddock grazed by dairy cattle. Another plant source is the breakdown of plant residues (unutilised forage) left on the soil surface. However, the potential of this source of P loss will depend on the P concentration of the plant material, how frequently the forage is grazed, and how long plant residues remain in the paddock.

In grazed pasture systems, the quantity of dung (and therefore P) returned to the soil varies with animal type and diet. The potential for P loss from dung is greatest immediately after deposition, but losses decline exponentially with time as it crusts over. This prevents interaction with surface runoff as the dung decomposes or invertebrates incorporate it into the soil. When climate, soil and overland flow conditions were held constant, McDowell (2006) showed potential rates of P loss from dung deposition were highest for cattle, followed by sheep and deer.

Dung and plant P are assumed to be captured by including Olsen P in the relationships.

5.2.1.1.3. Incidental P loss

Incidental P losses occur in situations where a flow event coincides with a concentrated source of available P, such as a fertiliser and/or farm dairy effluent

(FDE) application, leading to short-term P losses. Incidental P losses are calculated separately to background losses, but rely on the same transport factors, along with additional management factors such as the concentration, rate and timing of fertiliser/effluent application, the type of P fertiliser applied, and the speed of effluent application.

5.2.1.1.4. Leaching

Subsurface flows of P (leaching) have been shown to be important in circumstances where soils have a high P status, a low P sorption capacity or when soils are saturated with P, and hydrological conditions are conducive to drainage from soils (McDowell *et al*., 2015). Several studies have measured P leaching losses from New Zealand soils. For example, Toor *et al*. (2004) measured leachate from Lismore silt loam (Olsen P 53 µg/mL), after an application of 45 kg P/ha (as superphosphate). The average concentration of P in leachate was 0.09 mg TP/L, mostly in unreactive forms, equivalent to an average annual loss of 0.75 kg TP/ha. McDowell and Monaghan (2015) measured filtered reactive phosphorus (FRP) leaching losses of 75, 1 and 7.8 kg P ha/year in Organic, Podzol and intergrade soils respectively.

On sandy soils or soils with low profile available water content (PAW), the model is adjusted to take account of the higher risk of P loss due to leaching. However, the leaching component is currently not separated from runoff when reporting P loss.

5.2.1.1.5. Best management practices

Daily management can affect P loss, particularly when fertiliser and effluent are applied to soil (sections 3.2 and 3.3). The effect of poor management is difficult to quantify, as the degree of poor management is typically based on subjective assessments that need to be integrated over time. As a consequence, they are also difficult to model. Hence daily management practices are normally covered by assuming that best management practices are followed. If best management practices are not followed, then P loss is expected to be higher.

Best management practices are covered in the Introduction chapter.

5.2.1.1.6. Treading by grazing animals

The prolonged grazing of animals on wet soils can lead to soil erosion and compaction. Soil erosion can exacerbate the loss of P in particulate form. Soil compaction can affect soil water flow pathways (for example, by decreasing soil infiltration) resulting in infiltration-excess overland flow, or more commonly, reduced soil water holding capacity, increasing the soils susceptibility to saturation-excess overland flow (McDowell *et al*., 2003a). Heavy animals such as cattle generally cause the most treading damage, but smaller animals can also cause severe local effects (for example, compaction by deer along fence lines, McDowell *et al*. (2008)). Apart from deer (sections 5.2.1.2.2 and 5.2.1.2.3), the severity of treading damage is not implicitly captured.

5.2.1.2. *Background (soil) P loss*

Background or soil P losses arise from P that has had an opportunity to react with the soil and is lost in flow events that may occur throughout the year. It is estimated as the sum of TP losses from the soil, as influenced by different transport and management factors. Losses induced by deer behaviour are also included.

In general, soil P losses from pastures is estimated as the sum of losses as dissolved and particulate P from an overland flow event. It is based on factors affecting transport of P from the landscape to streams including rainfall, overland flow potential and topography. Soil P losses (kg P/ha/year) are estimated as:

Equation 35: SoilPloss = BasePloss + deerpace + deerwallow

BasePloss is the base soil P loss (kg P/ha/year) [section 5.2.1.2.1].

Deerpace is the P loss due to fence-line pacing of deer (kg P/ha/year) [section 5.2.1.2.2]

deerwallow is the P loss due to wallowing of deer (kg P/ha/year) [section 5.2.1.2.3].

5.2.1.2.1. Base soil P loss

In general, soil P losses from pastures is estimated as the sum of losses as dissolved and particulate P from an overland flow event. It is based on factors affecting transport of P from the landscape to streams including rainfall, overland flow potential and topography. Thus, soil P loss in overland flow to second order streams (kg P/ha/year) is estimated as:

Equation 36: BasePloss = (DissolvedP + ParticulateP) / 2 * Runoffpropen * SlopePlossfactor

DissolvedP is the dissolved P concentration (kg P/ha/year) [Equation 37].

ParticulateP is the particulate P concentration (kg P/ha/year) [Equation 39].

Runoffpropen is the factor for the propensity of runoff to occur [section 5.2.1.6.2].

SlopePlossfactor is a factor for topography [section 5.2.1.6.2].

Dissolved P is generally defined as inorganic and organic P that passes through a 0.45 µm filter; the fraction greater than 0.45 µm is particulate P. The amount of dissolved P loss depends on how much P is in soil (for example, Olsen P) and the ability of a soil to retain P (for example, anion storage capacity) (McDowell and Condron 2004).

Dissolved P concentration on an event basis (kg P/ha/year) is estimated as:

Equation 37: DissolvedP = (DRP / 0.03) * surplusrain

surplusrain (mm) is the normalised surplus precipitation [section 5.2.1.6.1].

DRP is dissolved reactive P on an event basis (mg/L) [Equation 38].

Dissolved reactive P (DRP) on an event basis (mg/L) is estimated from Olsen P and anion storage capacity (ASC) as:

Equation 38: DRP = 0.022 * (OlsenP / ASC) + 0.022

OlsenP is the Olsen P on a mass basis (µg/g soil) [Characteristics of Soils].

ASC is the anion storage capacity [Characteristics of Soils].

The original constant of 0.024 in McDowell and Condron (2004) has been changed to 0.022 with the inclusion of an additional 8 soils to the model (McDowell, AgResearch, pers. comm. 2007).

Olsen P as measured in commercial New Zealand laboratories is provided on a volumetric basis (µg/ml). This is converted from a volumetric to a mass-based value (µg/g soil) as described in the Characteristics of Soils chapter.

Particulate P is generally defined as inorganic and organic P that doesn't pass through a 0.45 µm filter. Losses of particulate P reflect detachment of soil by erosion processes and can be significant when there is soil disturbance such as cultivation. Particulate P concentrations is estimated as:

Equation 39: particulateP = (OlsenP * StructIng) / 2

OlsenP is the Olsen P on a mass basis (µg/g soil) [Characteristics of Soils].

StructIng is the structural integrity index [Characteristics of Soils].

5.2.1.2.2. Deer fence line pacing

The occurrence of fence-line pacing and wallowing of deer have both been shown to exacerbate P loss. Deer pace along fence lines when they are stressed, reducing pasture cover and compacting soil, both of which increase the potential for surface runoff and the loss of sediment and associated particulate P.

McDowell and Paton (2004), McDowell (2006) and McDowell and Stevens (2006) quantified P loss from deer grazed paddocks and fence-lines. Because there is large variation of Olsen P within deer-grazed paddocks due to faecal returns along fence-lines (for example, 53 mg/kg at the fence-line compared to 30 mg/kg in the rest of paddock), P losses were calculated via sediment losses. Without any noticeable pacing, sediment loss from fence-lines was 50% greater than losses from the rest of the paddock and double if fence-line pacing was observed (McDowell and Paton 2004). In addition, they also found that P loss was enhanced by the selective erosion of P-rich fine sediment over low-P coarse sediment. The enrichment ratio, that is, the concentration of P in sediment within runoff compared to the same weight of whole soil) is equal to 2 - 0.16 * ln(sediment discharge) (Sharpley 1980). Normalised for a runoff event of 100 mm and an enrichment ratio of 1.76, P loss is approximately four times that of the rest of the paddock. Typically, fence-line pacing covers about 2% of the paddock. Therefore, P loss due to wallows was estimated as:

Equation 40: $\text{deerpace} = \text{BasePloss} \times 0.98 + \text{SoilPloss} \times 4 \times 0.02$

BasePloss is the estimated background soil P loss [section 5.2.1.2.1].

The user can select the option to exclude this loss if mitigation options for fence-line pacing have been implemented.

5.2.1.2.3. Deer wallows

The action of deer can also be a source of P loss through their propensity to create wallows. McDowell and Stevens (2006) and McDowell *et al.*, (2007) indicated that losses from wallows from deer ranged from 0.5 - 3.5 kg P ha/year averaged over a block, and that wallows only occurred on rolling, easy hill, and steep country (not on flats). As result, a P loss value of 1 kg P ha/year was added for deer farming systems on land categorised as ‘non-flat’ topography (McDowell *et al.*, 2008). This is added to the soil P loss component of blocks with deer grazing on them, although the user has the option to indicate that wallows have been hydrologically isolated from streams, a possible mitigation option.

5.2.1.3. *Incidental P loss (Fertiliser)*

5.2.1.3.1. Background

Fertiliser is applied to soils to replenish plant available P. However, after application it takes time for fertiliser to dissolve into the soil solution and be sorbed onto soil surfaces. The potential for P loss from fertiliser is therefore greatest immediately after application and declines exponentially with time as P from fertiliser is sorbed from soil solution onto the soil. Overall, the potential for P loss will depend on the rate of P fertiliser application, and on the form and solubility of P fertiliser (McDowell *et al*., 2003b).

In this context, soluble fertiliser P is defined as the difference between total fertiliser P (conventional) and rock phosphate P. This implies that for P fertilisers that are not rock phosphates but are less soluble than superphosphate, as these are included as soluble P then the potentially lower losses due to lower solubility will not be reflected in estimated P losses. Hence losses associated with fertilisers with a lower proportion of P that is citric soluble such as DAP, serpentine based superphosphates, or slow or controlled release fertilisers are not included. Losses from organic fertilisers are assumed to be zero.

The primary factors determining P loss from recent applications of fertiliser are the P concentration, rate of application, the type of fertiliser applied, and hydrologic and topographic factors. Application rates (kg P/ha/year) are multiplied by hydrologic and topographic factors to give incidental fertiliser P.

Thus, total incidental fertiliser P loss (kg P/ha/year) is estimated as:

Equation 41: $\text{FertPLoss} = \sum_{mon}(\text{RPRloss}_{mon} + \text{SolublePLoss}_{mon})$

SolublePLoss is incidental fertiliser P loss from soluble fertiliser (kg P/ha/year) [section 5.2.1.3.2].

RPRloss is incidental fertiliser P loss from rock phosphate fertiliser (kg P/ha/year) [section 5.2.1.3.3].

5.2.1.3.2. Soluble fertiliser

Incidental losses from soluble P fertilisers (fertiliser P applied less P applied as rock phosphate) for blocks not receiving border dyke irrigation depend on whether the fertiliser is applied in a high-risk month (section 5.2.1.5). Incidental P loss (kg P/ha/month) from soluble P fertiliser applied in each month is estimated as:

Equation 42: $\text{SolublePLoss}_{mon} = \text{FertSoluble}_{mon} * \text{lossrate} * \text{factor}$

FertSoluble is the amount soluble P applied in a given month (kg P/ha/month) [Characteristics of Fertilisers].

lossrate is 0.3 if soluble fertiliser P is applied in a high risk month, or 0.1 otherwise.

factor is as shown in Equation 43.

The parameter factor is estimated as:

Equation 43: $\text{factor} = \text{Runoffpropen} * \text{SlopePlossfactor} * \text{DissolvedP} / 5$

Runoffpropen is the factor for the propensity of runoff to occur [section 5.2.1.6.2].

SlopePlossfactor is a factor for topography [section 5.2.1.6.2].

DissolvedP is the estimated soil P loss [Equation 37].

If blocks are receiving border dyke or flood irrigation and soluble P is applied in the same month as irrigation, then:

Equation 44: $\text{SolublePLoss} = \text{FertSoluble}_{mon} / 12 * \text{Runoffpropen} * \text{surplusrain}$

FertSoluble is the amount soluble P applied in a given month (kg P/ha/month) [Characteristics of Fertilisers].

Runoffpropen is the factor for the propensity of runoff to occur [section 5.2.1.6.2].

surplusrain (mm) is the normalised surplus precipitation [section 5.2.1.6.1].

else if border dyke or flood irrigation is not applied in the month soluble P is applied, then if soluble P is applied in a high-risk month Equation 42 is applied using a loss rate of 0.3, otherwise for a low risk month P loss is estimated as:

Equation 45: $\text{SolublePLoss} = \text{FertSoluble}_{mon} / 50 * \text{Runoffpropen} * \text{surplusrain}$

FertSoluble is the amount soluble P applied in a given month (kg P/ha/month) [Characteristics of Fertilisers].

Runoffpropen is the factor for the propensity of runoff to occur [section 5.2.1.6.2].

surplusrain (mm) is the normalised surplus precipitation [section 5.2.1.6.1].

A maximum of 80% of soluble fertiliser P applied in each month can be lost.

5.2.1.3.3. Rock phosphate fertiliser

Incidental P losses from RPR (reactive phosphate rock) fertilisers is estimated as:

Equation 46: $\text{RPRloss} = \text{RPR}_{\text{mon}} * 0.01 * \text{factor}$

RPR is the amount of rock phosphate applied in a given month (kg P/ha/month) [Characteristics of Fertilisers].

factor is as estimated in Equation 43.

A maximum of 80% of RPR fertiliser P applied in each month can be lost.

5.2.1.4. *Incidental P loss (Effluent)*

5.2.1.4.1. Background

The effluent management system determines the separation of effluent into liquid and solid components (Effluent management chapter). Solid effluent is that portion of effluent that settles in ponds, are separated solids as defined using the separation options, or are solid effluents removed from pads.

The risk of P loss via land application can be high on those soils with a propensity for preferential flow, where rapid drainage via artificial drainage or coarse structure occurs, where surface runoff via an infiltration or drainage impediment occurs or where FDE is applied to sloping land. This is incorporated into the model by weighting the application depth and three groundspeed settings of a typical effluent spray irrigator (section 5.2.1.6.7), and including a factor to account for high-risk months when effluent is being spread (section 5.2.1.5). Strategic management of deferred irrigation is captured by accounting for the method used to manage effluent (section 5.2.1.6.8) and the months when effluent is applied (section 5.2.1.6.5) both of which must be supplied by the user. The model does not cover the effect of day-to-day management because best or good management practices are assumed to have been followed. Given that on some soils, a small leakage or over-application can result in P losses similar to those estimated by the model, active management (section 5.2.1.6.6) is expected to be better than best management practices (section 5.2.1.1.5).

Note that discharges from a 2-pond direct to stream are generally a greater source of P loss to waterways compared to land applications, but this is not always the case if the propensity for runoff is high.

Total incidental effluent P loss (kg P/ha/year) is estimated as:

Equation 47: $\text{EffPloss} = \sum_{\text{mon, source}}(\text{EffLiquidPloss} + \text{EffsolidPloss} + \text{EffVillageloss})$

EffLiquidPloss is the P loss from liquid effluents applied on the block (kg P/ha/year) [section 5.2.1.4.1].

EffsolidPloss is the P loss from solid effluents applied on the block (kg P/ha/year) [section 5.2.1.4.3].

EffVillageloss is the P loss from the outdoor pig villages (kg P/ha/year) [not published].

5.2.1.4.2. Liquid effluent

Incidental P loss (kg P/ha/month) from liquid effluent from farm dairy or wintering pads (EffluentPmon or EffluentWPPmon respectively, see Effluent management chapter) applied in each month is estimated as:

Equation 48: $\text{EffLiquidPloss}_{\text{mon}} = \text{LiquidEffP}_{\text{mon}} * \text{timing} * \text{factor}$

LiquidEffP is liquid effluent P from the farm dairy or wintering pad applied on a given block in a given month (kg P/ha/year) [Effluent management].

timing is a factor that accounts for the risk associated with the month of application [section 5.2.1.6.5].

where factor is the cumulative factor of transport mechanisms not dependent on the time (month) of application, and is estimated as:

Equation 49: $\text{factor} = \text{Runoffpropen} * \text{SlopePlossfactor} * \text{ActMan} * \text{depth} * \text{operation}$

Runoffpropen is a factor accounting for the propensity of runoff to occur [section 5.2.1.6.2].

SlopePlossfactor is a factor accounting for topography [section 5.2.1.6.4].

ActMan is a factor accounting for active management [section 5.2.1.6.5].

depth is a factor accounting for depth of application [section 5.2.1.6.7].

operation is a factor based on the selected liqud effluent management option [section 5.2.1.6.8].

5.2.1.4.3. Solid effluent

Incidental P loss from solid effluent from all sources applied in each month is estimated as:

Equation 50: $\text{EffsolidPloss}_{\text{mon}} = \text{EffluentSolidPmon}_{\text{mon}} * 0.01 * \text{factor} * \text{timing}$

EffluentSolidPmon is the total solid effluent P applied on a given block in a given month (kg P/ha/year) [Effluent management].

timing is the factor that accounts for the risk associated with the month of application [section 5.2.1.6.5].

where factor is the cumulative factor of transport mechanisms not dependent on the time (month) of application, and is estimated as:

Equation 51: factor = Runoffpropen * SlopePlossfactor

Runoffpropen is the factor accounting for the propensity of runoff to occur [section 5.2.1.6.2].

SlopePlossfactor is the factor accounting for topography [section 5.2.1.6.4].

The loss rate (0.01) for solid effluent is assumed to be similar to RPR.

5.2.1.5. *High risk months*

The timing of fertiliser or effluent P application to soil can influence P loss, mainly because of the effect soil moisture can have on the propensity for the generation of runoff. To account for this, months of the year have been classified into one of two groups for each region depending on the probability that an overland flow event will occur. A month is deemed as high risk for runoff when the potential for saturation excess is greater than 60% of available water balance of 120 mm at Meteorological stations around the country (McDowell *et al.*, 2005) (Table 7).

One exception is infiltration-excess overland flow, prevalent on hydrophobic soils and therefore likely to occur in some areas during summer (Doerr *et al.*, 2003). A month is deemed as high risk where this occurs (Table 7).

Table 7. Regional risk months for runoff (1 = yes, 0 = no) (derived from New Zealand Meteorological Service 1989)

Region	Met. Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Northland	Kaikohe	0	0	1	1	1	1	1	1	1	1	0	0
Auckland	Auckland Airport	0	0	0	0	0	1	1	1	1	0	0	0
Waikato/Coromandel	Ruakura	0	0	0	0	1	1	1	1	1	1	0	0
Bay of Plenty	Whakarewarewa	0	0	0	1	1	1	1	1	1	1	0	0
Central Plateau	Taupo	0	0	0	0	0	1	1	1	1	1	0	0
King Country	Rukuhia	0	0	0	0	1	1	1	1	1	1	0	0
Taranaki	Stratford	0	0	0	1	1	1	1	1	1	1	1	1
Manawatu/Wanganui	Grasslands	0	0	0	0	0	1	1	1	1	0	0	0
Wellington	Kelburn	0	0	0	0	1	1	1	1	1	0	0	0
East Coast North Island	Gisborne Airport	0	0	0	0	1	1	1	1	1	0	0	0
East Coast North Island[1]	Gisborne Airport	0	1	1	0	1	1	1	1	1	0	0	0
West Coast South Island	Hokitika Airport	1	1	1	1	1	1	1	1	1	1	1	1
Nelson	Nelson Airport	0	0	0	0	1	1	1	1	1	1	0	0
Marlborough	Lake Grassmere	0	0	0	0	0	0	0	0	0	0	0	0
Canterbury	Lincoln	0	0	0	0	0	0	1	1	0	0	0	0
Otago	Dunedin Airport	0	0	0	0	0	0	0	1	0	0	0	0
Southland	Gore	0	0	0	0	1	1	1	1	1	0	0	0
High Country[2]	Hermitage, Mt Cook	1	1	1	1	1	1	1	1	1	1	1	1
High Country[3]	Omarama	0	0	0	0	0	0	0	0	0	0	0	0

[1] If rainfall is less than 1000mm and topography is not flat, then high risk is allocated to February and March in this region due to the presence of hydrophobic soils and likely infiltration-excess overland flow during a storm event (A. Gillingham, AgResearch, pers. comm.).

[2] High country (> 300m), high rainfall (> 700mm).

[3] High country (> 300m), low rainfall (< 700mm).

5.2.1.6. *Factors*

5.2.1.6.1. Surplus rain

Rainfall is an important factor affecting P loss to streams, particularly when precipitation (rainfall plus irrigation) exceeds the soil infiltration rate and overland flow results. Generally, for flow to occur, a surplus of precipitation must exist (termed surplus rainfall).

Surplus rainfall is normalised using annual rainfall (mm/year, Climate chapter) and estimated annual irrigation (mm/year, Hydrology chapter) and mean national potential evapotranspiration which is 681 mm/year (New Zealand Soil Bureau 1968). The mean value of potential evapotranspiration is used as the overall range (540 to 740 mm) varies little across the country relative to rainfall inputs. Thus, normalised surplus precipitation (surplusrain) is estimated as:

Equation 52: $\text{surplusrain} = (\text{precipitation} - 681) / 300$

precipitation is the sum of annual rainfall and annual irrigation (mm/year) [Hydrology].

if precipitation is less than or equal to 1500. If precipitation is greater than 1500 surplus precipitation is estimated as:

Equation 53: $\text{surplusrain} = 4.6 - 4.6 * \text{Exp}(-0.000603 * \text{precipitation})$

Surplus rainfall has a minimum value of 0.1. Equation 53 was included to attenuate P loss at high rainfall locations and is based on expert opinion (Monaghan and McDowell, AgResearch, pers. comm.).

In irrigation systems where water is applied to minimise drainage and runoff losses, such as deficit irrigation using low-rate application, this approach may overestimate surplus rainfall, and hence P losses.

5.2.1.6.2. Runoff propensity

Runoff propensity is an estimate of the potential for overland flow to occur. The term hydrological class has been used by McDowell *et al*. (2005). A high value indicates that the soil is susceptible to overland flow. Conversely, a low value indicates that the soil is unlikely to produce overland flow. Two methods are used to estimate runoff propensity. The first is based on the current profile drainage class (Table 9) and the second is the product of the hydrologic drainage class and mean slaking/dispersion index (Equation 54). The greatest estimate of the two methods is used.

The calculation of runoff propensity using the first method depends on soil order and profile drainage class. Propensity class is determined using soil order (Table 8) and then combined with profile drainage class to obtain the first estimate of runoff propensity (Table 9) (McDowell, AgResearch, pers. comm.).

Table 8. Propensity class for each soil order.

Soil order	Propensity class
Oxidic, Allophanic, Brown, Melanic	1
Granular, Gley,	2
Recent, Pallic Pumice	3
Ultic, Semi-arid, Organic	4
Podzol	5

Table 9. Runoff propensity for each profile drainage class and propensity class (Table 8).

	Propensity class				
Profile drainage class	**1**	**2**	**3**	**4**	**5**
Well	0.04	0.08	0.12	0.16	0.20
Moderately well	0.08	0.16	0.24	0.32	0.40
Imperfectly	0.12	0.24	0.36	0.48	0.60
Poorly	0.16	0.32	0.48	0.64	0.80
Very poorly	0.20	0.40	0.60	0.80	1.00

The calculation of runoff propensity using the second method uses the product of two factors. The first factor, the hydrological drainage class, is based on the USDA curve number method for determining the soil's hydrologic drainage class and uses soil texture as a basis for drainage, and hence is an indicator of the likely potential for saturation-excess overland flow. The second factor, the dispersion index, takes account of the potential that soil damage will influence soil hydrology. By taking the product of both factors, an estimate of Runoff propensity is determined. Thus, using the second method, runoff propensity based is estimated as:

Equation 54: Runoffpropensity = hydrodrainclass * dispindex

hydrodrainclass is the hydrological drainage class.

dispindex is the mean slaking/dispersion index [Characteristics of Soils].

The hydrological drainage class accounts for leaching losses. If the soil group is a sand or the topsoil texture is a sand, and ASC is less than 20 then hydrological drainage class is estimated using the method in section 5.2.1.6.3. Otherwise, hydrological drainage class is estimated from soil properties (Characteristics of Soils chapter) and then adjusted for the profile drainage status if the current profile drainage class is greater than the default profile drainage class (that is, the current status is poorer draining than the default status), giving:

Equation 55: hydrodrainclass = hydrodrainclass + (0.1 * diff) * (1 – hydrodrainclass)

hydrodrainclass on the right hand side is the hydrological class based on soil properties [section 5.2.1.6.3].

diff is the difference between the current profile drainage class index and the [Characteristics of Soils].

5.2.1.6.3. Hydrological drainage class to account for leaching losses

To account for leaching losses, if the soil group is a sand or topsoil texture is a sand, and ASC is less than 20, then the hydrological drainage class is estimated as:

- If soil group is a peat then hydrodrainclass is set to 0.4
- If soil group is a podzol then hydrodrainclass is set to 0.6
- If soil group is a sand, or soil order is recent, then
  - If current profile drainage class is greater than 2 (imperfect or poorly drained) then
    - If artificial drainage occurs, then Equation 56 is used; else
    - hydrodrainclass is set to 0.5
  - Otherwise hydrodrainclass is set to 1 (other sandy soils with a low ASC)

The hydrological drainage class if artificial drainage occurs is estimated as:

Equation 56: hydrodrainclass = 0.5 + 0.5 * (1 – propDrain / 100)
propdrain is the proportion of drainage that goes to drains [Hydrology].

5.2.1.6.4. Slope factor

Slope is also one of the main drivers of P loss from soils. Topography, a compulsory user input, is a measure of the terrain of a block. Each topography can have a range of slope classes, for example, steep hill topography has areas of very steep and flat slopes. The effect of topography is captured by a subjective weighting implemented by SlopePlossfactor which has values of 0.15 for flat, 0.5 for rolling, 0.75 for easy hill and 1.0 steep hill topographies (McDowell *et al*., 2005).

If a slope is entered (available in some dll options), then the SlopePlossfactor is based on a regression through the estimated mid-slope for each topography category to give:

Equation 57: SlopePlossfactor = 0.0372 * slope
slope is slope in degrees.

with a maximum value of 1.5.

5.2.1.6.5. Timing

If the application of P (fertiliser or effluent) is during a high-risk month (section 5.2.1.5) then timing is set to 7, otherwise it is set to 1.

5.2.1.6.6. Active management

The active management option implies that during effluent application, there is regular checking of application equipment and the paddock surface to ensure there is no effluent ponding, and that soil moisture is monitored to ensure that the application rate is less than the soil’s capacity to hold water. In addition, this option also implies the use of deferred effluent application technology, and that there are no losses from the effluent storage system. Given that on some soils, a small leakage or over-application can result in P losses similar to those estimated by the model, active management is expected to be better than best management practices.

The factor for active management was based on expert opinion and is set to 0.4 if ‘Actively managed’ is selected, otherwise it is one. This mean that the effect of selecting active management is to reduce pertinent losses to 40% of what they would otherwise be

5.2.1.6.7. Factor for depth per application

The factor for the depth per application (Table 10) is a measure of the potential for loss depending on the selected depth per application. As depth per application increases, the risk of incidental P loss from effluent increases. The depth per application is a compulsory input if effluent is applied on a block.

Table 10. Factor for depth per application.

Selection options	Factor
Low application method	0.2
Irrigator - fast (< 12 mm)	0.4
Irrigator - medium (12-24 mm)	0.7
Irrigator - slow (> 24 mm)	1

5.2.1.6.8. Factor for liquid effluent management option

For farm scale inputs describing liquid effluent management, the options ‘Stir and spray regularly’ and ‘Spray infrequently’ both imply some storage is occurring, and hence deferred irrigation within the month is occurring. This is recognised by the factor for liquid effluent management (Table 11), which is referred to as operation in Equation 43 in section 5.2.1.4.2. Note that deferred irrigation, where effluent is stored and applied in another month specified by the user, is captured via the timing factor (section 5.2.1.6.5).

Table 11. Liquid effluent management method factor.

Liquid effluent management	Factor
Spray regularly	1
Stir and spray regularly	0.7
Spray infrequently	0.7
Otherwise	1

5.2.1.7. *Reporting P losses*

5.2.1.7.1. Output values

The outputs from the P loss model are shown in Table 12.

Table 12. Outputs from the pastoral P loss model.

Output	Definition	Section
SoilPloss	Soil (background) P loss	5.2.1.2
FertPloss	Incidental P loss from fertiliser	5.2.1.3
EffPloss	Incidental P loss from farm dairy liquid effluent	5.2.1.4
EffPlossWP	Incidental P loss from wintering pad liquid effluent	5.2.1.4
EffPlossSolid	Incidental P loss from solid effluents	5.2.1.4
MoleSoilPloss	Soil (background) P loss through the artificial drainage system	5.2.2.1
MoleEffPloss	Incidental P loss from farm dairy liquid effluent through the artificial drainage system	5.2.2.2
MoleEffPlossWP	Incidental P loss from wintering pad liquid effluent through the artificial drainage system	5.2.2.2
MoleEffPlossSolid	Incidental P loss from solid effluents through the artificial drainage system	5.2.2.2

5.2.1.7.2. P risk categories

In the Block P report, total P lost (kg P/ha/year) and P lost (kg P/ha/year) is reported for each block, along with the risk indices. The risk indices are based on the conditions shown in Table 13. Note that losses from drains are included in soil and effluent risk categories.

Table 13. Range of calculated P loss (kg P/ha/year) for each risk category.

Risk category	Soil [1]	Fertiliser	Effluent [1]
n/a	0	0	< 0.001
Low	> 0 and < 0.7	> 0 and < 0.1	≥ 0.001 and < 0.1
Medium	≥ 0.7 and < 1.4	≥ 0.1 and < 0.25	≥ 0.1 and < 0.25
High	≥ 1.4 and < 3.0	≥ 0.25 and < 0.5	≥ 0.25 and < 0.5
Extreme	≥ 3	≥ 0.5	≥ 0.5

[1] Losses from artificial drainage are included.

5.2.1.7.3. Flags

Flags are used to advise users when fertiliser P loss is high, extreme or outside the range of data available in New Zealand. There was a debate about setting the upper limit for incidental P fertiliser loss. One option was to set a maximum P loss to 25% of P fertiliser applied, because this is about the maximum loss reported in the literature (at that time). An alternative was using a maximum loss of 80% of P fertiliser applied because it was considered that situations could occur where P losses were greater than 25% of P applied; indeed, McDowell and Monaghan (2015) reported a loss of > 80% for a low ASC Organic soil. As a compromise, comments are included in the block comments section as shown in Table 14.

Table 14. Flags and conditions.

Condition	Message
FertPloss > 0.1 * totalPloss [1]	Fertiliser P loss is greater than 10% of total P loss - this is outside the range of data available for New Zealand and P loss data should be used with caution
fertPloss > 1.5	Fertiliser P loss is greater than 1.5 kg P ha/year - this is outside the range of data available for New Zealand and P loss data should be used with caution
Fertiliser P loss risk factor is high or extreme	Fertiliser P loss is high or extreme - consider changing form or timing of fertiliser applications

[1] totalPLoss is the sum of soilPloss (section 5.2.1.2), fertPloss (section 5.2.1.3), effPloss (section 5.2.1.4), molePloss (section 5.2.2.1), and moleEffPloss (section 5.2.2.2).

If the first two conditions in Table 14 occur, the following text is shown on the P report interface:

* Data for a block is outside the range of New Zealand data - use with caution

5.2.2. Artificial drainage (mole/tile)

Additional losses from artificial drainage systems, including mole/tile drains, are estimated for background and effluent losses. It is assumed that drains have no effect on incidental fertiliser P losses. P loss from artificial drainage systems is assumed to be lost direct to streams.

Equation 58: $\text{Drain}_P = \text{molePloss} + \text{moleEffPloss}$

molePloss is background P loss through artificial drains (kg P/ha/year) [section 5.2.2.1].

MoleEffPloss is incidental effluent P loss through artificial drains (kg P/ha/year) [section 5.2.2.2].

5.2.2.1. *Soil P loss*

Mole/tile drains provide a direct pathway for water enriched from topsoil P to be lost directly to streams. If artificial drainage (mole/tile or other system) is selected by the user, an additional 0.25 kg P ha/year is lost based on P loss from mole/tile drains reported by Monaghan *et al*. (2003). It is estimated as:

Equation 59: $\text{molePloss} = 0.3125 * \text{propdrain}$

propdrain is the proportion of drainage that goes to drains [Hydrology].

The constant 0.3125 kg P ha/year is estimated as 0.25 kg P ha/year divided by the maximum effectiveness of drains (0.8).

5.2.2.2. *Effluent*

If artificial drains are present, then the amount of this loss that ends up in drains and hence goes direct to stream is estimated as:

Equation 60: $\text{moleEffPloss} = \text{EffP} * \text{factor} * \text{timing} * \text{mole}$

EffP is liquid effluent P from the farm dairy or wintering pad applied and total solid effluent P applied on a given block in a given month (kg P/ha/year) [Effluent management].

factor is the cumulative factor of transport mechanisms not dependent on the time (month) of application, and is estimated using Equation 49 for liquid effluents, and Equation 51 for solid effluents.

timing is a factor that accounts for the risk associated with the month of application [section 5.2.1.6.5].

mole accounts for the efficiency of the drainage system [Equation 61].

The effect of the efficiency of the drainage system is estimated as:

Equation 61: $\text{mole} = (1.25 * \text{propdrain}) - 0.1$

propdrain is the proportion of drainage that goes to drains [Hydrology].

The constant 1.25 is based on the maximum effectiveness of a drainage system being 80%, and propdrain is a measure of the effectiveness of the drainage system, with a maximum of 0.8.

5.2.3. Slow release

Metherell (1994) noted that slow release of P was added as a means of stabilising the model, and is estimated as:

Equation 62: $\text{NBSlowrelease}_{P} = \text{Pslow}_{soil}$

Pslow is the soil dependent P reelease parameter [Characteristics of Soils].

5.2.4. Adsorption

The amount of P sorption was estimated from a plot of the anion exchange capacity (AEC or PR) and soil P loss for trials reported by Metherell (1994). A line was fitted that appeared to be an adequately representation of P adsorption (

Figure 2). Thus, P adsorbed (kg P/ha/year) is estimated as:

Equation 63: $\text{NBAdsorp}_{P} = \text{LabileP} * 0.05 * 0.75 * \text{AEC} / 100$

LabileP is labile P pool (kg P/ha) [Characteristics of Soils].

AEC is anion exchange capacity [Characteristics of Soils].

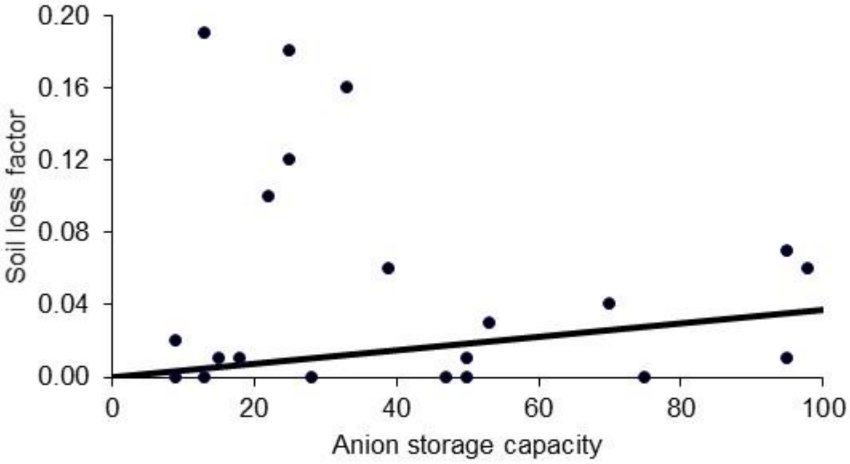

Figure 2. Relationship between anion storage capacity and soil loss factor from data in Metherell (1994).

This model was also applied to fruit crop blocks.

5.2.5. Immobilisation

The original immobilisation model of Metherell (1994) included P lost as leaching or runoff, as well as immobilisation and adsorption. With the development of the McDowell *et al*. (2005) model, leaching and runoff was deducted from total soil P loss model of Metherell (1994). Thus:

Equation 64: $NBImmob_P = LabileP * Ploss_{soil} – NBAbsorp_P - NBLeach_P$
LabileP is labile P pool (kg P/ha) [Characteristics of Soils].
Ploss is the soil dependent P loss parameter [Characteristics of Soils].
NBAbsorp is the amount of P sorption (kg P/ha/year) [5.2.4].
NBLeach is the amount of P sorption (kg P/ha/year) [5.2.1.1.4].

A cut and carry block is assumed to be similar to a pastoral block and hence is estimated as:

Equation 65: $NBImmob_P = LabileP * 0.04$
LabileP is labile P pool (kg P/ha) [Characteristics of Soils].

5.2.6. Balancing

The balance is calculated and assigned to the change in soil plant available pool (NBInorg).

5.3. Potassium

5.3.1. Slow-release

Slow-release potassium is estimated using the method of Metherell (pers. comm.) as:

Equation 66: $NBSlowrelease_K = slow1 * Exp(-slow2 * ksoil) + slow3$
ksoil is the soil K level (kg/ha/year) [section 5.3.3.1].

slow1, slow2 and slow3 are determined as in section 5.3.1.2.

5.3.1.1. *Soil K level*

The soil K level that can reduce slow-release K is estimated as:

Equation 67: $\mathrm{ksoil} = \mathrm{QTK} * 27 + \mathrm{NBfert}_K + \mathrm{NBIrr}_K - \mathrm{NBirroutwash}_K$

QTK is the entered soil QT K level.

NBFert is the amount of K added as fertiliser (kg K/ha/year) [Characteristics of Fertiliser].

NBIrr is the amount of K added in irrigation water (kg K/ha/year) [4.3.1].

NBIrr is the amount of K added in reapplied irrigation outwash water (kg K/ha/year) [.

5.3.1.2. *Slow-release parameters*

The parameters slow1, slow2, and slow3 are based on how the K reserve status for a block is entered. The options offered to the user are the TBK soil reserve soil test, a K reserve category, or the kc test (nitric acid extractable K). The latter is included in National Soils database and hence is the default soil K release status for soil order and S-map siblings.

If soil test reserve K status is greater than zero, or soil type is selected then:

Equation 68: $\mathrm{resK} = \mathrm{TBK} - 0.07 * \mathrm{QTK}$

TBK is the entered TBK soil L reserve test.

QTK is the entered soil QT K level.

and slow1, slow2 and slow3 are determined as in section 5.3.1.4. If K reserve category has been selected (advanced soil option) then slow1, slow2, and slow3 are taken from Table 15 (section 5.3.1.3).

Given the wide range of slow-release status and leaching potentials within a soil group or order, any discrepancies in the estimation of the accumulation of K in the soil inorganic pool are usually due to incorrect estimations of these terms.

5.3.1.3. *Estimating parameters from K reserve category*

The original concept of slow-release K was based on K reserve categories. The user either selects a K reserve category or enters a TBK reserve soil test value. Each category has a set of parameters (see Table 15) which is used to calculate slow-release K.

Table 15. Parameters for estimating slow-release K based on K reserve category

K reserve category	slow1	slow2	slow3
High	300	0.005923	10
Medium	150	0.005281	10
Low	90	0.004808	10
Very low	40	0.004057	10
Extremely low	10	0.002774	0

5.3.1.4. *Estimating parameters from reserve K*

Estimating K reserve category from the TBK soil reserve K test meant that a small change in the soil reserve K test could result in a large change in slow-release K. To even this out, a relationship between soil reserve K test and the parameters slow1 and slow2 were developed from the midpoint range of the soil reserve K test for each K reserve category (see Characteristics of Soils) and the associated slow1 and slow2 values (see Table 15) so that there was a continuous relationship, as shown for slow1 in Figure 3.

The first parameter, slow1, is estimated as:

Equation 69: $$\text{slow1} = \begin{cases} 333.33\ \text{resK} + 6.6667 & \text{if resK} < 0.1 \\ 100\ \text{resK} + 30 & \text{if resK} <= 0.6 \\ 2.9088\ \text{resK}^{2} + 45.338\ \text{resK} + 61.75 & \text{otherwise} \end{cases}$$

If resK is greater than zero then the second parameter, slow2, is estimated as:

Equation 70: $\text{slow2} = 0.00050203 * \text{Ln(resK)} + 0.0051146$

The parameter slow3 has the value of 10 if the soil group or soil order is a podzol.

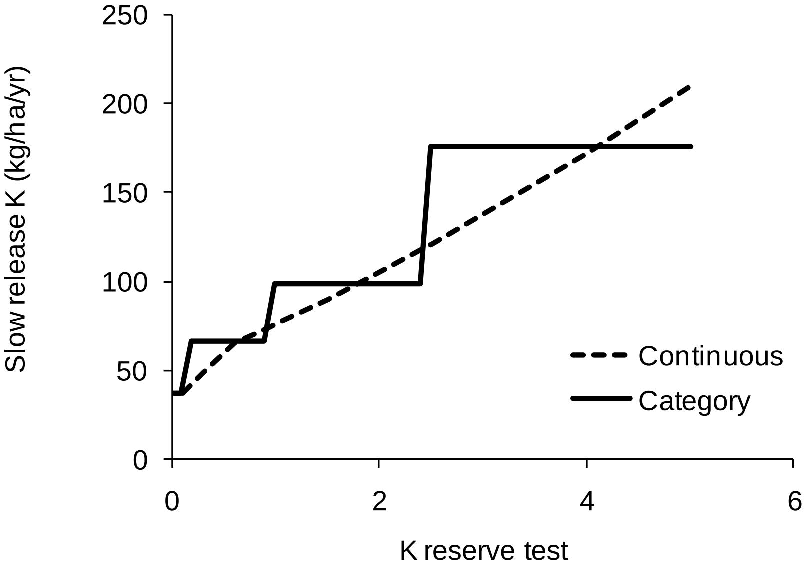

Figure 3. Relationship between estimated K reserve test value and slow-release K parameter slow1 using the category or continuous method.

5.3.2. Adsorption

Any adsorption of K in soils (for example, into 2-layer clays) is ignored.

5.3.3. Leaching

K leaching (NBleach) is modelled based on background soil K levels (K soil nutrient level). Losses from urine patches are modelled separately.

Equation 71: $NBleach_K = ksoil * lossfactor * Fstony$

ksoil is the soil K level (kg/ha/year) [section 5.3.3.1].
lossfactor is the soil loss factor [section 5.3.3.3].
Fstony is a factor for stony soils [section 5.3.3.2].

5.3.3.1. *Soil K level*

The soil K level that is estimated to be susceptible to leaching is estimated as:

Equation 72: $ksoil = QTK * 27 + NBFert_K$

QTK is the entered soil QT K level.
NB variables are defined in section 2.2 (kg/ha/year).

There is no apparent reason why the soil K level for leaching (this section) and slow-release (section 5.3.1.1) differ.

5.3.3.2. *Non-standard soil effect*

The factor Fstony is assigned the value of PMleachfactorborder (Table 17, section 5.5.2.4).

5.3.3.3. *Soil K loss factor*

The potassium (K) loss factor was initially modelled using data extracted from the K database. The loss factor was subsequently modified based on Parfitt (1991, 1992) who reported that the preference for adsorption decreases as exchange K increases, and hence K is more prone to leaching. It was assumed that adsorption could be estimated from soil K level. Thus, soil K loss factor is estimated as:

Equation 73: Kloss = (0.0075 + 0.00005 * soilKrate) * Kleachingpot
soilKrate is the soil K level (kg K/ha/year) [Equation 72].
Kleachingpot is the K leaching potential [Characteristics of Soils]

5.3.4. Balancing

The balance is estimated usual the standard procedure as the difference between sum of inputs less outputs.

Metherell (pers. comm.) indicated that it is likely that slow-release K reduces if there is surplus K (balance K > 0) in the soil. As an initial model, it was assumed that the size of the reduction in reserve K increased exponentially with a positive balance up to a maximum of 0.75 of slow-release K (Figure 4). Note that in most cases the balance is positive unless slow-release K status is low or extremely low or the K reserve soil test is low. Thus, if balance is greater than zero (net K inputs) then:

Equation 74: $\text{NBslowrelease}_{K} = \text{NBslowrelease}_{K}$ * reduction_factor

The reduction factor is estimated as:

Equation 75: reduction_factor = NBslowrelease_{K} * (0.75 - 0.75 * Exp(-0.03 * balance))

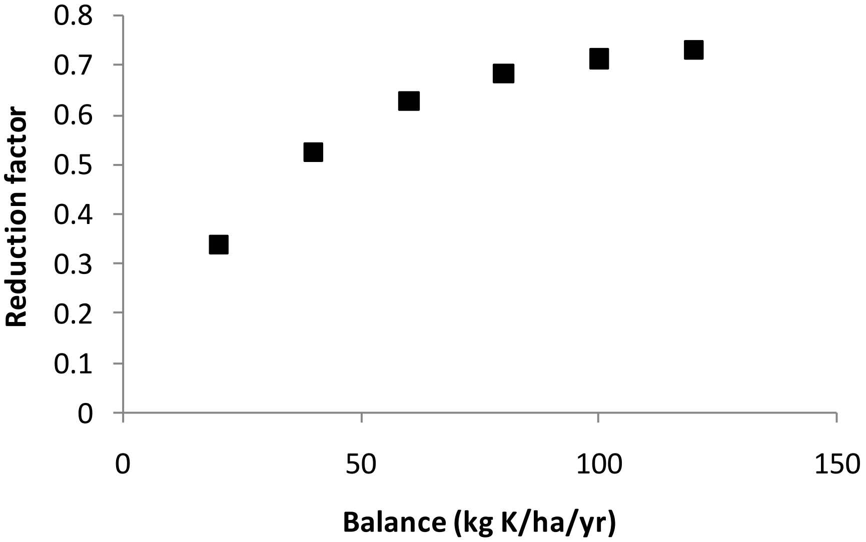

Figure 4. Relationship between the balance and reduction factor for decreasing slow-release K when the balance is greater than zero.

The balance is recalculated, and the balance is assigned to the change in soil plant available pool (NBInorg).

Given the wide range of slow-release status and leaching potentials within a soil group or order, then any discrepancies in the estimation of the accumulation of K in the soil plant available (inorganic) pool are usually due to incorrect estimations of these terms.

5.4. Sulphur

The derivation of the S model is based on the models of Cornforth and Sinclair (1984) and Thorrold and Woodward (1995). Further discussion on S modelling has been reported by Nguyen and Goh (1993) and Edmeades *et al*. (2005). Pasture response and pasture sulphur concentrations are detailed in the Characteristics of Pastures chapter.

5.4.1. Minimum leaching

To account for all S inputs and outputs in the nutrient budget, leaching losses may increase if inputs exceed outputs under a 'use it or lose it' principle (Thorrold, pers. comm.). This means that it is not possible to estimate a maintenance rate, because as more fertiliser is applied, more is leached without any change in the plant available pool. To improve the estimation of maintenance S losses, a minimum leaching rate was estimated (Wheeler, 2003).

The minimum S leaching rate is based on the maintenance model of Cornforth and Sinclair (1984). The Cornforth and Sinclair (1984) model was designed to estimate maintenance fertiliser requirements which excluded camp areas. It was assumed that some S losses from the urine patch largely occurred on campsites, and hence an additional term Urineleach was added as an estimate of additional S loss through urine spots. Cornforth and Sinclair (1984) also reported animal loss over the range of the S leaching index (SLI, Characteristics of Soils chapter). The loss at an SLI of 0 (no leaching) was interpreted as transfer losses, which are calculated separately in this model. The difference between losses at SLI = 0 and SLI = 6 were interpreted as leaching losses associated with animals. The minimum leaching rate was estimated as:

Equation 76: $\text{leaching}_S = \text{Baseleach} + \text{Send} + \text{NBrain}_S * \text{Frain} + \text{Fanimal}$

Baseleach is the minimum S leaching (kg S/ha/year) [Equation 77].

Send is the sulphate leached at the end of the season (kg S/ha/year) [Equation 78].

NBrain is the amount of S added in rainfall (kg S/ha/year) [section 4.1].

Frain is the fraction of rainfall S that is leached (kg S/ha/year) [Equation 79].

Fanimal is a factor accounting for stocking density [Equation 80].

The minimum S leaching on pastoral blocks is the estimated S leaching loss through urine patches on a whole block area basis. On high leaching soils (SLI = 6) this was assumed to be 8 kg S/ha/year for dairy and 4 kg S/ha/year for sheep/beef. On cut and carry, fodder crop, cropping and fruit crop blocks a minimum leaching rate of 2 kg S/ha/year was assumed. Hence Baseleach (kg S/ha/year) is estimated as:

Equation 77: $\text{Baseleach} = \text{kbase} * \text{SLI} / 6$

kbase is 8 kg S/ha/year for dairy blocks, and 4 kg S/ha/year non-dairy blocks, and 2 kg/ha/year for cut and carry, fodder crops and cropping blocks.

SLI is the sulphur leaching index [Charactetristics of soils].

This value could be made more site-specific and related to estimated urine and dung S deposition. The term Send, the S leached at the end of the season, was based on Cornforth and Sinclair (1984, Table 11), and is estimated as:

Equation 78: $\text{Send} = -0.1111\ \text{SLI}^3 + 1.119\ \text{SLI}^2 - 1.7222\ \text{SLI} + 0.1905$

with a maximum value for SLI of 6. The proportion of rainfall S that is leached was based on Table 12 in Cornforth and Sinclair (1984), and is estimated as:

Equation 79: Frain $= 0.038 * \text{SLI} + 0.2565$ $\quad \text{SLI} > 7.6$
$= -0.0038 * \text{SLI}^3 + 0.0517 * \text{SLI}^2 - 0.1042 * \text{SLI} + 0.0189$ $\quad$ otherwise

The term Fanimal was based on Cornforth and Sinclair (1984, Table 10). The difference in total S loss (kg S/SU) was dependent on the stock, farm type, and SLI when SLI was greater than 2. Thus, if SLI is greater than 2, Fanimal is estimated as:

Equation 80: $\text{Fanimal} = \text{Fstocktype} / 4 * \text{SR}$

SR is the stocking rate (SU/ha).
4 is the range of SLI.
Fstocktype is a stock type factor (kg S/SU) [Equation 81 or Equation 82].

For the leaching model, stocking rate is estimated as block DM pasture production divided by 750 kg DM/SU, where 750 kg is a standard amount of DM grown to feed a standard stock unit. Cornforth and Sinclair (1984, Table 10) based the amount of S loss due to animals (Fstocktype, kg S/SU) on the increase in stock loss through animals, and this increased as SLI increased from zero to 6. For dairy, it was estimated as:

Equation 81: Fstocktype	= 0.5	easy hill or steep topography
	= 0.7	otherwise.

For other stock, the increase in stock loss through animals is also dependant on grazing intensity. It was assumed that an intensive system corresponded to a stocking rate of 15 SU/ha and less intensive, 5 SU/ha. Thus, for non-dairy blocks:

Equation 82: Fstocktype	$= 0.4 + 0.2 * \text{SR}$	steep topography
	$= 0.65 + 0.01 * \text{SR}$	easy hill topography or border dyke irrigation.
	= 0.8	otherwise.

Cornforth and Sinclair (1984) use a modified animal loss factor based on pasture development index. It was assumed that this term was a measure of immobilisation, which in estimated separately (section 5.4.2.2).

5.4.2. Immobilisation

5.4.2.1. *Derivation*

Dynamic (daily time step) models have shown that organic S is important when considering S transformations in soils (Thorrold and Woodward, 1995; Martindale, 1999). The change in the phosphate extractable organic sulphur S test (PESo) over time can be derived from Thorrold and Woodward (1995) as:

Equation 83: $PESo_{n+1} = PESo_n - \mu * PESo_n + g * RY_n$

PESo is the phosphate extractable sulphur (µg S/g soil).

n is a given year.

µ is a organic S specific mineralisation rate (/year).

g is the maximum rate of return of S to the organic S pool (µg S/g soil/year).

RY is the relative pasture yield due to combined P and S deficiency.

If it is assumed that:

- the fraction of material that is recalcitrant in plant material (roots and shoots) and in dung is the same,
- 60% of total herbage S (roots and shoots) was consumed,
- all the recalcitrant S eaten (60% of total herbage) ends up in the dung,
- and that a proportion (1-X) of dung is returned to the productive area.

then the maximum rate of return, g, can be estimated as:

Equation 84: $g = Y_{max} * Cs * [(1-X) * 0.6 + 0.4] * (1/0.75) * 0.012$

Y_{max} is the maximum plant yield including root production (kg DM/ha/year).

Cs is the recalcitrant S concentration in herbage and roots (kg S/kg DM).

X is the proportion of dung transferred to non-productive areas.

0.6 is the proportion of total plant production (including roots) utilised by animals.

0.4 is the proportion of total plant production which returns in litter.

(1 / 0.75) is a factor for conversion of kg S/ha to µg S/g soil (0-75mm).

0.012 is a factor to convert total organic S to PESo [Watkinson and Perrott, 1990].

The value of X was assumed to be the same used by the P model of Metherell *et al.* (1995) and varies with slope class. The S in animal product is assumed to be derived from the non-recalcitrant portion of plant S.

Barrow and Lambourne (1962) reported that the S content of merino wether faeces was 0.00114 kg S/ kg DM consumed, and this was assumed to be recalcitrant S that contributes to S immobilisation. This value was used for recalcitrant S, and it was assumed that it was the same for all sites, and pastoral types.

Thorrold and Woodward (1995) estimated maximum plant yield (including roots) from initial stocking rate (SR_o), initial relative yield (RY_o), constants for herbage intake per stock unit (550 kg DM/SU), and utilisation of plant growth (0.6). Root growth is included to allow for input of organic S through root turnover. The animal utilisation rate of plant yield is set at a constant value (0.6) based on Winchmore studies (Metherell, pers. comm.). This constant value implies either a constant root:shoot ratio and constant shoot utilisation, or a declining root:shoot ratio (with increasing production) balanced by decline in utilisation of shoot growth. In practice, it is likely that with increasing production the root:shoot ratio will decrease (Metherell, pers. comm.) and utilisation may not change. However, measurements at the Winchmore site showed that with increasing stocking rate the proportion of dung returned to the productive area was greater (Nguyen and Goh, 1992) and that the overall effect of increasing fertility and stocking rate was that there was a relatively constant relationship between stocking rate and organic S return.

The remaining 40% of total herbage DM is returned as litter and root turnover, all to the productive area. The input of S into the organic S pool (kg S/ha) is converted to μg S/g soil (1/0.75) assuming a soil bulk density of 1 t/m^3 and then to PESo units by multiplying by 0.012 (Watkinson and Perrott (1990), data for Taupo soil only). The potential return of S to the organic S pool (g) is reduced by the level of P and S deficiency, which will obviously reduce herbage yield and organic S cycling.

Experimental evidence shows that the addition of dung led to elevation of the PESo test level, but fertiliser S applications and consequent microbial activity, or urine addition had no effect (Watkinson and Kear, 1996). No information was found that looked directly at the effect of root and plant top litter on organic S accumulation; however, it seems fair to assume that plant litter can also play a role in raising organic S levels. It is then assumed that the rate of input of S into the organic S pool is a function of the amount of recalcitrant organic S in plant dry matter that is returned to the soil, either as dung or as decaying litter and roots. It is assumed that both dung and litter have the same concentration of the slowly available organic S. Mineralisation studies have shown that organic S is initially more rapidly mineralised from litter than dung (Blair *et al.*, 1994) but that after a year there is little difference in the mineralisation rates. As the model used an annual time step, it is assumed that both dung and litter dry matter returned have the same impact on organic S levels. It has also been assumed that S fertility has no effect on the concentration of recalcitrant S in dry matter. Data from Winchmore (Nguyen and Goh, 1992) indicates that this is a reasonable assumption if we accept that C bonded S in soil is related to the slowly available organic S.

Organic S is reduced by mineralisation, and it is assumed that PESo and total organic S remain in a constant ratio. The value of the specific mineralisation parameter (μ) was chosen to give results consistent with available data which indicate that a 1–2 unit deviation in PESo units is all that is achieved under markedly different S fertiliser (and pasture yield) regimes over a ten year period.

5.4.2.2. *Net immobilisation*

The amount of net immobilisation of S (kg S/ha/year) in pastoral blocks is initially estimated (Equation 85) and then adjusted if it is lower than a minimum value. The initial immobilisation rate is estimated as:

Equation 85: NBImmob = Immobilisation - Mineralisation

Immobilisation is the estimated amount of S immobilised (kg S/ha/year) [Equation 86].

Mineralisation is the estimated amount of S mineralised (kg S/ha/year) [Equation 87].

Using terms in the nutrient budget, rearranging Equation 83 and Equation 84, and including recalcitrant S in applied effluent, immobilisation can be estimated as:

Equation 86: $$\text{Immobilisation} = \text{DMpasture} * (1 - \text{utilisation}) * \text{Cs} + \text{DMpasture} * \text{rs} * \text{Cs} + \text{dung} * \text{Cs} + \text{effluentS} / 0.003 * 0.5 * \text{Cs}$$

DMpasture is the pasture dry matter yield (kg DM/ha/year).

utilisation is the annual utilisation rate.

Cs is the recalcitrant S concentration (kg S/kg DM).

rs is the proportion of top dry matter yield to dry matter root yield.

dung is the amount dry matter excreted and deposited on the block (kg DM dung/ha/year).

effluentS is the amount of S added as effluent (kg S/ha/year).

The first and second terms in Equation 86 give the immobilisation rates from top and root senescence. The later assumed that the proportion of top dry matter yield to root yield (rs) was a reasonable estimated of root turnover and senescence, and a value of 0.3 for rs was assumed. Barrow and Lambourne (1962) indicated that the average dung S concentrations was 0.114 g per 100 g DM eaten, hence Cs had a value of 0.00114 kg S/kg DM. Effluent S is converted to DM by assuming that there is 0.3% S in effluent DM, and that half of the S in effluent is from urine which is inorganic.

Rearranging Equation 83 and Equation 84, the mineralisation rate (kg S/ha/year) can be estimated as:

Equation 87: $$\text{Mineralisation} = \text{PESo} * \mu * 0.75 / 0.012$$

There is insufficient data to get site-specific rates for organic S mineralisation (μ), or for conversion of total organic S to PESo (factor 0.75). The former is likely to vary with region due to different temperature and soil moisture regimes. The latter may not be required if the total S test is used.

Curtin *et al*. (2007) reported that carbon-bonded S increased in parallel with total N. Hence on sites where N immobilisation was high, it was assumed that S immobilisation would also be high. In cut and carry blocks, S immobilisation was estimated by assuming that the minimum amount of S immobilisation is equal to the amount of N immobilisation times the N:S ratio in organic matter, that is:

Equation 88: $$\text{NBImmob}_\text{S} \geq \text{NBImmob}_\text{N} * \text{OMns}$$

For fruit crop blocks, the same method that is used for P is used (section 5.2.5). In cropping blocks, immobilisation is assumed to be zero.

5.4.3. Change in inorganic sulphur

A meta-analysis of field trials indicated that the change in sulphate S test one year after application was small, although the effect on yield is larger (Wheeler and Thorrold, 1997). Hence, the change in yield is based on a conceptual soil sulphur pool (Thorrold, pers. comm.), estimated as:

Equation 89: $SS_{n+1} = SS_n * (1- \lambda) + Z + Fs_n * (1-\lambda) + [k_e * (Fe_n + E_n)] * (1-\lambda)$

λ is the rate of decline in the effectiveness of fertiliser S (/year).

Z is the amount of S added in rainfall and irrigation water S (kg S/ha/year) [section 4.1].

Fs is the amount of inorganic S fertiliser added (kg S/ha/year).

Fe is the amount of elemental S fertiliser added (kg S/ha/year).

En is the amount of unoxidised elemental S from previous years fertiliser applications (kg S/ha/year).

ke is the release rate of elemental S [Ghani *et al*., 1995].

If no elemental S fertiliser is applied, the change in soil sulphur pool can be simplified to:

Equation 90: $\text{change} = (1 - \lambda) * (F_S – \text{Slast})$

where Slast is the fertiliser applied last year. The nutrient budget model is a quasi-equilibrium model, and hence Slast should equal current fertiliser inputs. The quasi-equilibrium model also implies that for inputs of elemental S, the input and release rates are in equilibrium. Thus, the change in the soil sulphur pool is zero.

5.4.4. Balancing

The balance is calculated (section 3.8) and if greater than zero then balance is added to leaching ($NBleach_S$) otherwise the balance is added to immobilisation ($NBImmob_S$). Note that the minimum leaching (section 5.4.1) and immobilisation (section 5.4.2.2) have already been determined before the balance is estimated.

5.4.5. Sub-soil sulphur

The accumulation of S has been reported in some subsoils (Metson and Blakemore, 1978), particularly in those with high ASC in the subsoil. The accumulation of S in the subsoil has been ignored, and in soils with high accumulation rates the loss of S to the environment may be less than that indicated in the nutrient budget. For maintenance calculations, it is assumed that this fraction is largely unavailable for plant uptake, and hence can be ignored.

5.5. Calcium, magnesium, and sodium

Modelling of calcium, magnesium, and sodium (Ca, Mg and Na) are based on the model of Carey and Metherell (2002).

5.5.1. Slow-release

The release of Ca, Mg and Na by mineral weathering is more important in low intensive systems where the slow-release of Ca, Mg and Na may be sufficient to meet pasture requirements. Cations released by weathering are included in the ‘Slow-release’ category of the nutrient budget (NBslowrelease).

Cation weathering is based on a mean soil mineral composition for each soil group and the weathering model, PROFILE (Carey and Metherell 2002), using the equations in Carey (2002). This required an estimate of mean temperature and average annual soil moisture range (MC). Default mean soil temperatures used in the original model were based on 30 years normals for each region (New Zealand Meteorological Service, 1989).

The weathering model is dependent on soil mineralogy, for example, a 2% increase in hornblende led to a 30% increase in weathering rates. The weathering rates could be re-calculated if data on soil mineralogy was included.

Slow release (weathering) of Ca, Mg and Na is estimated as:

Equation 91: $$\text{NBSlowrelease}_{\text{nut}} = \text{Dep}_{\text{soil}} * \text{W}_{\text{nut, soil}} / \text{origBC}_{\text{soil}} * \text{Exp}(0.0165 * \text{coastin}) * \text{MC}_{\text{soil}} * \text{origBC}_{\text{soil}} * \text{SMC}^{0.78} * \text{temp} * \text{origBC}_{\text{soil}} * \text{Exp}(0.084 * \text{AnnualTemp}) * \text{k}_{\text{nut}}$$

coastin is distcoast, the entered distance from coast (km) with a maximum value of 100.

SMC is the average annual soil moisture range factor [Equation 92].

Dep, MC, origBC and temp are soil based parameters related to weathering [Characteristics of Soils].

W is a weathering constant for each cation dependent on soil characteritics [Characteristics of Soils].

AnnualTemp is the mean annual air temperature (°C) [Climate].

k is the atomic weight, being 20, 12, and 23 for Ca, Mg, and Na respectively

Bug: k for Ca is currently coded as 12 rather than 20. Temperature should probably be soil temperature rather than air temperature.

In Carey (2002), average annual soil moisture factor SMC had an integer value that varied from 1 to 6 depending on the mean annual soil moisture contents at 0-15 cm and 15-30 cm (Table 16).

Table 16. Mean annual soil moisture values (% v/v) for 0-15 cm and 15-30 cm to determine moisture condition factor.

MC	0-15 cm	15-30 cm
1	5	10
2	10	15
3	15	20
4	20	25
5	25	30
6	30	35

This parameter was outside the criteria for inclusion in the model but could possibly be added with the updated drainage model. At the time of implementing this model, a method based on rainfall was developed, with a maximum value of MC (6) occurring at 1000 mm rainfall, and a minimum value of 1. Thus, the moisture condition factor is estimated as:

Equation 92: $MC = 0.01 * rain - 4$

Rain is the annual rainfall (mm/year) [Climate]

The effect of using this relationship or any soil group differences on model output has not been investigated.

5.5.2. Leaching

Leaching models for the cations Ca, Mg and Na were based on empirical relationships, as there was limited data to develop models that are more complex (Carey and Metherell, 2002; Carey 2002). The leaching model is based on a limited range of trials on allophanic, brown, and pallic soils only.

Enhanced losses under mole/tile drains are currently ignored.

5.5.2.1. *Calcium*

The amount of Ca leached is dependent on the amount of N leached, but there was no evidence that Mg or Na leaching increased as N leaching increased. For calcium, when including the effect of stony or shallow soils, it is assumed that N driven part of Ca leaching always occurs as N leaching already accounts for losses on stony or shallow soils. Thus, the leaching rate (kg Ca/ha/year)

Equation 93: $NBleach_{Ca} = baseCaleach * Fstony$

Fstony is a factor to account for stony soils [section 5.5.2.4].

such that calcium leaching is greater than or equal to the amount of N leached times 0.786. The base leaching rate (kg Ca/ha/year) is estimated as:

Equation 94:
$$\begin{aligned} baseCaleach = & -(33.7 + adjCa_{soil}) \\ & + QT\_Ca * 7.68 \\ & + (Nleach_N * 0.786 / Fstony) \\ & + Kratio * 112.8 \end{aligned}$$

QT_Ca is the user entered soil quick test values.

$Nleach_N$ is the background block N leached (kg N/ha/year) [section 3.1].

adjCa is a soil parameter associated with leaching [Characteristics of Soils].

Fstony is a factor to adjust for stony soils [section 5.5.2.4].

Kratio is the ratio of the quicktest value to the sum of the Ca, Mg, and K values [section 5.5.2.1.1].

For Ca, increased leaching due to a non-standard soil layer (sandy, stony, or stony matrix) is associated with increased N leaching that would occur on these soils, whereas it is assumed that entire Ca loss would be affected by non-standard soil layers. Therefore, the leaching associated with the N leaching component is adjusted by Fstony first.

5.5.2.1.1. Other cations

The effect of potassium on leaching is estimated as the ratio of quick test soil tests as:

Equation 95: $\text{Kratio} = \text{QT\_K} / (\text{QT\_Ca} + \text{QT\_Mg} + \text{QT\_K})$

QT_Ca, QT_Mg, and QT_K are user entered soil quick test values.

5.5.2.2. ***Magnesium***

Leaching of Mg (kg Mg/ha/year) is estimated as:

Equation 96:
$$\begin{aligned}\text{NBleach}_{Mg} = 41.3 &- \text{sadjMg}_{soil}\\ &- \text{MgR} * 39.8\\ &+ \text{Drainage} * 0.02\\ &+ \text{MgLime}\\ &+ \text{FstonyMgleach}\end{aligned}$$

adjMg is a soil parameter associated with leaching [Characteristics of Soils].

MgsqR is the ratio of the Mg quicktest value to the sum of the Ca, Mg and K values [section 5.5.2.2.2].

Drainage is the annual drainage at 600mm depth (mm/year) [Hydrology].

MgLime is the magnesium lime factor [section 5.5.2.2.3].

FstonyMgleach is a factor to account for stony soils [section 5.5.2.2.1].

such that the estimation excluding FstonyMgleach has a minimum value of 1.

5.5.2.2.1. Non-standard soil layer

The effect of a non-standard soil layer on Mg leaching is estimated as:

Equation 97: $\text{FstonyMgleach} = \text{Drainage} * 0.02 * (\text{Fstony} - 1)$

Drainage is the annual drainage at 600mm depth (mm/year) [Hydrology].

Fstony is a factor to adjust for stony soils [section 5.5.2.4].

5.5.2.2.2. Other cations

The term MgsqR is estimated as:

Equation 98: $\text{MgsqR} = \text{QT\_Mg} / (\text{QT\_Mg} + \text{QT\_K})$

QT_Ca, QT_Mg, and QT_K are user entered soil quick test values.

In the model, increasing QT Mg produces declining leaching losses, which appear counter-intuitive. The reason this is occurring is because the multiple regression approach from the limited data available picked up that the lowest leaching losses occur if retention of Mg is high. In the model, high Mg retention is identified by high QT Mg values relative to low QT QT Ca and QT K values. Consequently, if QT Mg is low relative to QT Ca and QT K values, it is assumed Mg retention is low and leaching is high. This particularly affects volcanic and pumice soils where QT Mg values and leaching tend to be low due to good retention, resulting in the model over-estimation Mg leaching. Additional data sets that are more balanced are required.

5.5.2.2.3. Lime effect

Carey and Metherell (2002) reported that Mg leaching can increase with lime applications, and that the effect of lime can be observed several years after the lime application. This was attributed to the extra Ca added displacing Mg from the exchange site, resulting in additional leaching of Mg. This is estimated as:

Equation 99: $\text{MgLime} = \sum \text{MgLlime}$

MgLlime is the additional amount of Mg leached for a given application (kg Mg/ha) [Equation 100 or Equation 101].

Carey and Metherell (2002) estimated that the additional amount of Mg leached for a given application is dependent on the type of lime, time since lime was applied, and the rate of lime applied. If the total lime applied is dolomitic, defined as lime with Mg content of greater than 10%, then if the number of years since lime was applied is less than or equal to 1.5 times the lime rate, then the additional amount Mg leached is estimated as:

Equation 100: $\text{MgLlime} = 1.2 * \text{LimeRate}$

LimeRate is the rate of lime (T/ha/year) applied on a block [Characteristics of Fertiliser].

If the lime is a non-dolomitic lime, then if the number of years since lime was applied is less than or equal to the lime rate, then the then the additional amount Mg leached is estimated as:

Equation 101: $\text{MgLlime} = 0.8 * \text{LimeRate}$

If lime is applied more than 7.5 years previous, it is assumed that there is no additional Mg leaching.

5.5.2.3. ***Sodium***

Leaching of Na (kg Na/ha/year) is estimated as:

Equation 102: $$\begin{aligned}\text{NBleach}_{\text{Na}} = {} & 0.3 - \text{sadjNa}_{\text{soil}} \\ & + \text{Drainage} * 0.06 \\ & + \text{Kratio} * 118.6 \\ & + \text{FstonyNaleach}\end{aligned}$$

adjNa is a soil parameter associated with leaching [Characteristics of Soils].

Drainage is the annual drainage at 600mm depth (mm/year) [Hydrology].

Kratio is the ratio of the quicktest K value to the sum of the Ca, Mg, and K values [section 5.5.2.1.1].

FstonyNaleach is a factor for Na to account for stony soils [section 5.5.2.3.1].

such that the estimate excluding FstonyNaleach has a minimum value of 1.

5.5.2.3.1. Non-standard soil layer

The effect of a non-standard soil layer on Na leaching is estimated as:

Equation 103: FstonyNaleach = Drainage * 0.06 * (1 - Fstony)
Drainage is the annual drainage at 600mm depth (mm/year) [Hydrology].
Fstony is a factor to adjust for stony soils [section 5.5.2.4].

5.5.2.4. *Stony factor*

A non-standard soil layer is where a sandy, stony, or stony matric occurs at depth. The enhanced leaching loss of N with irrigation on stony soils (Di and Cameron 2002) was also likely to occur for other nutrients. To account for additional leaching from stony shallow soils, a factor is used. If the depth to a non-standard soil layer is less than 60cm then:

Equation 104: Fstony = 1 + ((0.6 - NonStddepthm) * PMleachfactor)
NonStddepthm is the entered depth to the non-standard layer (cm).
PMleachfactor is the factor in the absence of border dyke irrigation [Table 17].

otherwise the result is 1. The values in Table 17 were based on likely change in leaching if the whole profile was the deselected parent material. The losses were expected to be larger under border-dyke of flood irrigation, and hence stony factor is then adjusted if border dyke irrigation is applied as:

Equation 105: Fstony = Fstony * PMleachfactorborder
PMleachfactorborder is a factor to account for additional leaching under border dyke irrigation [Table 17].

Table 17. Coefficients for adjusting leaching on non-standard soils.

Parent material	PMleachfactor	PMleachfactorborder
Sandy	1.26	1.13
Stony	1.40	1.25
Stony matrix	0.7	1.05

The effect on non-standard soil layers is only modelled when selecting a soil series, order or group, or when information describing an S-map sibling includes a description of a non-standard soil layer. If the S-map sibling has soil water content data, then Fstony is 1.

5.5.3. Balancing

The balance is calculated and assigned to the change in soil plant available pool (NBInorg).

5.5.4. Feedback mechanisms

The approach used means that for Ca, Mg and Na, there is no feedback between high inputs, the amount of leaching or the gains in soil pools. On soils receiving large inputs, such as effluent, the model may over-estimate the change in inorganic pool, and underestimate leaching. Ghani *et al.*, (2005) noted that a high proportion of added cations (K, Mg, and Na) could be leached.

Conversely, using an empirical approach to estimate leaching coefficients may lead to overestimation of Ca, Mg and Na leaching, resulting in large negative balances. For example, a Pumice soil, 150 km from coast (with little rainfall input), and a soil Na test of only 2 was modelled as losing 48 kg Na/year, resulting is a large negative change in inorganic Na. This suggests that there needs to be a feedback loop when estimating Na leaching to adjust negative balances as there is little evidence of the need for maintenance Na applications. To implement this may require additional field trial data to be collected (Peter Carey, pers. comm.).

For the calcium, magnesium and sodium leaching models, the rate of inputs has no effect on leaching losses, and leaching is largely driven by soil nutrient levels. Thus, in years when capital applications are applied, leaching is only affected by the increase in soil test result that may follow capital applications.

5.6. Acidity

Acidity can change when nitrogen leaves the system in a different form or quantity than when it entered the system. For example, adding N in the ammonium form and having it leach in the nitrate from results in a change in acidity. Change in acidity is generally not due to H^+ or OH^- ions moving per se. Hence the two important ions containing N that affect acidity are nitrate and ammonium. de Klein *et al.*, (1997) reported the net amount of H^+ produced (kmol H+ per kg N lost) from various forms of N inputs and losses from a pasture, and assuming that kmol H^+ is equivalent to kg H^+.

For denitrification and leaching, the source of N that denitrified or leached is not known. Therefore, it is assumed that the contribution of the different forms can be pro-rated across total N inputs. The estimation of the sources of N is shown in 5.6.1, and change in acidity associated with N fixation, immobilisation, atmospheric loss, and leaching are shown in subsequent sections.

5.6.1. Sources of N

To estimate the pro-rata effect of different forms of N, total N inputs (kg N/ha/year) is estimated as:

Equation 106: $$\text{Ntotinputs} = \text{NBFert}_N + \text{NBLime}_N + \text{NBOtherFert}_N + \text{NBFerteff}_N + \text{NBDCD}_N + \text{NBRain}_N + \text{NBIrr}_N + \text{NBSuppImport}_N + \text{NBSuppStored}_N + \text{NBSuppBlock}_N + \text{NBDrench}_N + \text{NBEffLiq}_N + \text{NBEffSolid}_N + \text{NBImportEff}_N + \text{NBImportSolid}_N + \text{NBImportEff} + \text{NBImportSolid} + \text{NetTransfer} + \text{NBToBlockN} + \text{NBFromBlockN} + \text{NBWPtoPasN} + \text{NBPastToWPN} + \text{NBSlowreleaseN}$$

NB variables are defined in section 2.1 and 2.2 (kg N/ha/year).

NetTransfer is net amount of N that is transferred out of the block (kg N/ha/year) [Equation 107].

If N immobilisation in the background model is less than zero, then it is subtracted from total N inputs. The net amount of N that is transferred out of the block is estimated as:

Equation 107: $$\text{NetTransfer} = \text{NBToBlock}_{\text{N}} + \text{NBFromBlock}_{\text{N}} + \text{NBWPtoPas}_{\text{N}} + \text{NBPastToWP}_{\text{N}}$$

NB variables are defined in section 2.2 (kg N/ha/year).

The inputs that may affect acidification are separated into ammonium or nitrate forms. The proportion of ammonium and nitrate in each source is shown in section 5.6.1.1. The remaining N in inputs were assumed to have no effect on acidification. Thus, the ammonium N source (kg N/ha/year) is estimated as:

Equation 108: $$\begin{aligned}\text{AmmonInput} = {} & 0.178 * \text{NetTransfer} \\ & + 0.178 * \text{NBEffLiq}_{\text{N}} \\ & + 0.178 * \text{NBImportEff}_{\text{N}} \\ & + 0.05 * \text{NBEffSolid}_{\text{N}} \\ & + 0.05\ \text{NBImportSolid}_{\text{N}} \\ & + \sum \text{OtherInorgN}_{\text{mon}} \\ & + 0.5 * \text{NBIrr}_{\text{N}}\end{aligned}$$

NB variables are defined in section 2.1 (kg N/ha/year).

NetTransfer is net amount of N that is transferred out of the block (kg N/ha/year) [Equation 107].

OtherInorgN is inorganic N in other fertiliser types (kg N/ha/year) [Characteristics of Fertilisers].

Constants are the proportion of NH_4 in each source [section 5.6.1.1].

The nitrate N source (kg N/ha/year) is estimated as:

Equation 109: $$\begin{aligned}\text{NO3Input} = {} & 0.007 * \text{NetTransfer} \\ & + 0.007 * \text{NBEffLiq}_{\text{N}} \\ & + 0.007 * \text{NBImportEff}_{\text{N}} \\ & + 0.006 * \text{NBEffSolid}_{\text{N}} \\ & + 0.006 * \text{NBImportSolid}_{\text{N}} \\ & + \sum\sum \text{FertNtype}_{\text{NO3, mon}} \\ & + 0.5 * \text{NBIrrN} \\ & + \text{NBRain}_{\text{N}}\end{aligned}$$

NB variables are defined in section 2.1 (kg N/ha/year).

FertNtype is the N in fertiliser in nitrate form (kg N/ha/year) [Characteristics of Fertilisers].

Constants are the proportion of NO_3 in each source (kg N/ha/year) [section 5.6.1.1].

Ammonium based fertilisers are estimated separately as:

Equation 110: $$\text{AmmonFert} = \sum\sum \text{FertNtype}_{\text{otherNH4, mon}} + \sum\sum \text{FertNtype}_{\text{DAP, mon}}$$

FertNtype is the N in fertiliser in DAP or other NH_4 forms (kg N/ha/year) [Characteristics of Fertilisers].

5.6.1.1. *Product N types and NH_4, NO_3 contents*

NH_4 and NO_3 contents are used in estimation of acidification rates. Note that the organic to inorganic N (NH_4 and NO_3) ratios are used in estimation effluent pathways.

Farm dairy effluent nitrogen is assumed to consist of 17.8% as NH_4, 0.7% as NO_3, and the rest in an organic form (Longhurst *et al.*, 2000). Solid effluents are assumed to have low amounts of both ammonium and nitrate forms.

Irrigated water is assumed to be 50/50 NH_4 and NO_3 forms.

Rainfall N is assumed to be in the nitrate form. As the amount is small, the form of N in rainfall is not important although it should be checked with other field measurements for consistency.

5.6.2. N fixation

It is assumed that some of the N leached is derived from N fixation. Hence:

Equation 111: $\text{NBNfix}_{H+} = 0.07 * \text{NBLeach}_N * \text{NBNFix}_N / \text{Ntotinputs}$

NB variables are defined in section 2.1 and 2.2 block (kg N/ha/year).

Ntotinputs (kg N/ha/year) is described in section 5.6.1.

5.6.3. Immobilisation

The accumulation of acidity associated with immobilisation is calculated as the acidity induced by a change in organic levels plus the net amount of H^+ produced for removal or storage of assimilated N (de Klein *et al.*, 1997). Thus:

Equation 112: $\text{NBImmob}_{H+} = \text{changeOM} + \text{Nimm}$

The acidity induced by a change in organic levels was estimated as the product of change in OM, electrical charge of the soil OM, and difference in soil pH from point of zero charge (pH 3.0). Thus:

Equation 113: $\text{changeOM} = \text{changeC} * 0.00035 * (\text{pH} - 3)$

pH is the top soil pH [Characteristics of Soils].

changeC is the change in soil carbon (kg C/ha/year) [Characteristics of Soils].

If immobilisation is greater than zero, then out[nitrogen] > 0) then

Equation 114: $\text{Nimm} = -0.07 * \text{NImmob}_N * \text{AmmonInput} / \text{Ntot}$
$+ 0.07 * \text{NImmob}_N * \text{NO3Input} / \text{Ntotinputs}$

NImmob_N is the background block N immobilised (kg N/ha/year) [section 5.1].

AmmonInput, NO3Input and Ntotinputs are described in section 5.6.1.

5.6.4. Atmospheric loss

It is assumed that there is no volatilisation from the NO_3 form of N. Volatilisation of ammoniacal forms can occur, especially from sources such as effluent and fertiliser. It has been assumed that acidification due to losses from these sources are negligible, and therefore can be ignored.

The accumulation of acidity when N is denitrified is dependent on nitrate and ammonium levels in the sources of N added to the soil. The accumulation rate is estimated as:

Equation 115: $\mathrm{NBDenit}_{H+} = -0.07 * \mathrm{NDenit}_N * \mathrm{AmmonInput} / \mathrm{Ntotinputs}$
$+ -0.07 * \mathrm{NDenit}_N * \mathrm{AmmonFert} / \mathrm{Ntotinputs}$
$+ 0.07 * \mathrm{NDenit}_N * \mathrm{NO3Input} / \mathrm{Ntotinputs}$

NDenit_N is the background block N denitrified (kg N/ha/year) [section 5.1].

AmmonInput, AmmonFert, NO3Input and Ntotinputs are described in section 5.6.1.

5.6.5. Leaching

The accumulation in acidity when N is leached is dependent nitrate and ammonium levels in the sources of N added to the soil. The accumulation rate is estimated as:

Equation 116: $\mathrm{NBLeach}_{H+} = -0.07 * \mathrm{NLeach}_N * \mathrm{AmmonInput} / \mathrm{Ntotinputs}$
$+ -0.14 * \mathrm{NLeach}_N * \mathrm{AmmonFert} / \mathrm{Ntotinputs}$
$+ -0.07 * \mathrm{TotNurineleach}$

Nleach_N is the background block N leached (kg N/ha/year) [section 5.1].

TotNurineleach is the N leached from urine patchs (kg N/ha/year) [Urine Patch model].

AmmonInput, AmmonFert and Ntotinputs are described in section 5.6.1.

5.6.6. Balancing

The balance is calculated and assigned to the change in soil plant available pool (NBInorg).

6. Specific block models

In general, different block types use the same models as for the pastoral blocks, but parameterisation may change. This approach was adopted as in most cases, limited or no data was found. This section outlines where differences for a particular block type have been implemented. Note than losses from farm structures such as pads, the farm dairy or lanes are described in the effluent management chapter.

6.1. Fruit crop blocks

6.1.1. Description of block

A fruit crop block is considered as two components, the fruit crop area itself, and the area under the canopy (understory). The understorey can be in pasture, a herbicide strip or no pasture (bare ground). If the understory is in pasture or a herbicide strip, then animals can graze the block.

As the crop matures, the area of the crop block covered by the canopy is assumed to increase linearly from planting until a maximum is reached at years to full cover as shown in Table 18. Thereafter, the crop increases in size until maturity, defined as the number of years since planting until yield is near maximum (Table 18). For the deciduous crops, there is a seasonal pattern (see Crop Based Nitrogen Sub-model chapter).

Table 18. Years for canopy to reach maximum coverage, and years to maturity (defined as when fruit production is near maximum).

	Years to full cover	Years to maturity
Kiwifruit	3	5
Apples	5	10
Grapes	5	6
Avocados	14	30
Peaches	5	10

This approach allowed the pasture component to be included by allocating pasture intake across multiple blocks (Distribution of farm data to block scale chapter) and for the different characteristics of the pasture and fruit crop N sub-models to be captured. An example is illustrated with fertiliser inputs:

> *For fruit crop blocks, the user can select whether fertiliser is applied as bands, or broadcast over the crop area. When broadcast, it is assumed that the fertiliser application rate on the inter-row area is lower than closer to the crop. Hence, if fertiliser is applied by broadcast and an inter-row area exists, then the fertiliser application rate for the crop is increased by 30%, and for the inter-row area decreased by 30%. If N fertiliser is applied as bands, then fertiliser inputs of the inter-row area are set to zero. The estimation of fertiliser volatilisation uses sward presence as an indicator of cover.*

Characteristics of fruit crop blocks that differ from other blocks include:

- Trees increase in size up to maturity, defined as the time when near maximum yields occur.
- As trees increase in size, so does the amount of prunings or leaf loss.
- Nutrients are removed from the block as product. Pruning nutrients are also removed if this option is selected.
- As the frame size increases with age, nutrients accumulating in the frame are treated as an internal transfer (long-term storage).
- Leaf loss occurs but it is assumed all leaves remain on the block, hence there is no net loss of nutrients due to windblown leaves.
- Foliar sprays may be applied.
- At planting there is potential for a large disturbance of soil leading to increases mineralisation of N in year 1.

- A fruit crop block can be grazed by animals if understory option selected is herbicide or full pasture.
- For nutrients other than N, the methods for estimating terms in the nutrient budget are assumed to be same as for pastoral blocks unless otherwise stated. For N, the pasture and fruit crop component use the crop N sub-model but with different input parameters (Crop Based Nitrogen Sub-model chapter)

6.1.2. Sprays

Foliar sprays can be applied to crops such as apples. The range of sprays considered in the model are shown in Table 19, along with spray type and the rate of application of N per spray. Thus:

Equation 117: $NBSpray_N = \sum (N_i * rateN_i)$

Equation 118: $NBSpray_{Ca} = \sum (N_i * rateN_i * NCaRatio_i)$

N is the entered number of sprays applied.

rateN is the rate of N applied in an individual spray (kg N/ha) [Table 19].

NCaRatio is the N: Ca ratio for the given spray [Table 19].

Table 19. For each spray type, the rate of N applied in each application and the N:Ca ratio of the spray.

Spray type	Rate of N per application (kg N/ha)	N:Ca ratio
Calcium nitrate	1.19	1.22
Calcium ammonium nitrate	2	0.3
Urea	3	0

6.1.3. Product nutrient removal

The yield of product (in kg DM/ha) removed from the block is based on the yield of wet product removed as this is usually known. If not, typical default values are provided. The proportion of product rejected after leaving the orchard is also important when the supplied yield is the “packed yield”. For example, kiwifruit yield can be measured as the ‘packed’ yield. The reject rate is the difference between the picked and measured yield, divided by the measured yield. In other cases, yield is measured at the product leaving the orchard, and hence reject rate is zero. Note that some fruit may be picked but discarded on the orchard. This is ignored as no nutrients leave the block. Thus:

Equation 119: $productYld = ProductYield * WgtPerUnit * DMcontent * (100 / (100 - Reject)) / area$

ProductYield is the entered yield using the units shown in Table 20.

WgtPerUnit is the weight per unit (kg) [Table 20].

DMcontent is the DM content of the wet fruit [Table 20].

Reject is the entered reject rate (%)

Area is the block area (ha).

Table 20. The unit of product yield, weight per unit (kg), typical product yield, and the DM content of fruit crops.

	Unit	Weight (kg) per unit	Typical product yield (units/ha)	DM content
Kiwifruit	trays sold	3.6	8000	0.169
Apples	tonnes picked	1000	90	0.161
Grapes	tonnes picked	1000	10	0.187
Avocados	tonnes picked	1000	36	0.257
Peaches	tonnes picked	1000	20	0.123

The amount of nutrient in product is estimated as:

Equation 120: $\text{HortProduct}_{\text{nut}} = \text{productYld} * \text{ProdConc}_{\text{nut}} / 100$
productYld is the product yield [Equation 119].
Prodconc is the concentration of nutrients in the product (%) [Table 21].

Table 21. Product nutrient contents for fruit crops (% DW).

	N	P	K	S	Ca	Mg	Na
Kiwifruit	0.934	0.236	1.959	0.129	0.153	0.177	0.029
Apples	0.189	0.044	0.716	0.004	0.044	0.031	0.03
Grapes	0.539	0.053	1.021	0.14	0.075	0.027	0.011
Avocados	1.231	0.159	2.328	0.955	0.043	0.152	0.039
Peaches	0.908	0.097	1.596	0.14	0.041	0.057	0.03

The source of the nutrient concentrations of Kiwifruit were provided courtesy of the Rick Hall Nutrition Guide website (https://www.verywellfit.com/nutrition-415708). The nutrient contents of other crops are probably from USDA Nutrient database for Standard Reference, release 12 (March 1998). Apples are raw with skin on, and grapes are raw American type (slip skin). No S data was available from the USDA. The source of the S data in unknown. Variations in nutrient contents of fruit between locations, and cultivars or varieties within a species were noted but ignored. In particular, the potential variation between green and yellow kiwifruit varieties was not considered.

6.1.4. Gain in frame

As the crop size matures, there is an accumulation of nutrient in the crop frame that is 'stored' on the block and is a contributor to nutrient uptake. It is assumed that frame size increases linearly until the fruit crop is mature (yield is near maximum). Thus, if the entered number of years since planting is less than the years required to reach maturity (Table 22), then:

Equation 121: $\text{gain\_frame} = \text{MatFrame} * (\text{CropAge} / \text{TimeMat})$
MatFrame is the frame size at maturity (kg DM/ha) [Table 22]
CropAge is the entered number of years since planting.
TimeMat is the number years before the tree crop is mature [Table 22].

After maturity, it is assumed that the frame still increases in size but at a reduced rate (10% of initial rate. Thus:

Equation 122: gain_frame = MatFrame * (1 / TimeMat) * 0.1
MatFrame is the frame size at maturity (kg DM/ha) [Table 22]
TimeMat is the number years before the tree crop is mature [Table 22].

Nutrients that are accumulated in the frame are estimated as:

Equation 123: $\text{NBframe}_{\text{nut}}$ = gain_frame * $\text{FrameConc}_{\text{nut}}$ / 100
gain_frame is the weight gain of the frame during the year (kg DM/ha/year) [Equation 121 or Equation 122].
FrameConc is the concentration of nutrients in the product (%) [Table 22].

Table 22. The frame size at maturity (kg DM /ha), years to maturity (defined as when fruit production is near maximum) and frame nutrient contents (% of DM).

	Frame size	**Years to maturity**	**N**	**P**	**K**	**S**	**Ca**	**Mg**	**Na**
Kiwifruit	15000	5	0.87	0.12	0.72	0.14	0.67	0.13	0.02
Apples	30000	10	0.75	0.10	0.43	0.12	0.29	0.11	0.02
Grapes	10000	6	0.31	0.20	0.65	0.14	0.39	0.19	0.10
Avocados	106000	30	0.77	0.09	0.41	0.15	0.36	0.17	0.02
Peaches	10000	10	1.4	0.13	0.51	0.13	0.48	0.26	0.02

The weight of the canopy frame and years to maturity were based on data extracted from the Spasmo model as part of the Nitrogen management for environmental accountability program (MPI, 2008; Whiteman and Brown, 2009). The source of the nutrient concentrations could not be found.

6.1.5. Prunings removed

The options to manage prunings are ‘Mulched’ or ‘Removed’. Removed prunings are an output of nutrients from the block, whereas mulched prunings contribute to immobilisation. If removal of prunings is selected, it is assumed that complete removal didn’t occur, with 20% remaining on the block. Thus, nutrients removed in prunings are estimated as:

Equation 124: $\text{NBPruning}_{\text{nut}}$ = MatPrunings * fAge * PruningFate * $\text{PrunConc}_{\text{nut}}$ / 100
MatPrunings is the amount of prunings at maturity (kg DM/ha) [Table 23].
fAge is a factor to account for the entered age of the crop [6.1.5.1]
PruningFate is 0.8 if prunings are removed, and 0 if mulched.
PrunConc is the concentration of nutrients in the product (%) [Table 23].

Thus, the amount of nutrients that remain on the block and become incorporated in the organic matter cycle is:

Equation 125: $\text{LeftPrune}_{\text{nut}}$ = MatPrunings * fAge * (1 – PruningFate) * $\text{PrunConc}_{\text{nut}}$ / 100

Table 23. The amount of prunings removed at maturity (kg DM/ha/year), and the nutrient content (% of DM) of prunings

	Prunings	N	P	K	S	Ca	Mg	Na
Kiwifruit	8274	0.87	0.12	0.72	0.14	0.67	0.13	0.02
Apples	4860	0.75	0.10	0.43	0.12	0.29	0.11	0.02
Grapes	6450	0.31	0.20	0.65	0.14	0.39	0.19	0.10
Avocados	10282	0.77	0.09	0.41	0.15	0.36	0.17	0.02
Peaches	6825	1.4	0.13	0.51	0.13	0.48	0.26	0.02

The weight of prunings was based on data extracted from the Spasmo model as part of the Nitrogen management for environmental accountability program (MPI, 2008; Whiteman and Brown, 2009). It was assumed that nutrient content in prunings was the same as in the frame.

6.1.5.1. *Age factor*

If the entered number of years since planting is equal to or greater than the age that the crop reaches maturity, then the age factor (fAge) is 1. Otherwise:

Equation 126: fAge = CropAge / TimeMat

CropAge is the entered number of years since planting.

TimeMat is the number years before the tree crop is mature [Table 22].

6.1.6. Leaf drop

It is assumed that leaves remain on the block, where the nutrients in leaf drop becomes either immobilised or are returned to the plant as uptake through the crop N-submodel. The nutrient in the dropped leaves is estimated as:

Equation 127: $LeafDrop_{nut}$ = MatLeafDrop * fAge * $LeafConc_{nut}$ / 100

MatLeafDrop is the amount nutrient in dropped leaves at maturity (kg DM/ha) [Table 24].

fAge is a factor to account for the entered age of the crop [section 6.1.5.1]

LeafConc is the concentration of nutrients in dropped leaves (%) [Table 24].

Table 24. The amount of leaves dropped at maturity (kg DM/ha/year), and the nutrient content (% of DM) in dropped leaves.

	Leaf drop	N	P	K	S	Ca	Mg	Na
Kiwifruit	4726	2.48	0.2	2.12	0.34	3.24	0.35	0.02
Apples	6140	2.14	0.17	1.28	0.28	1.41	0.30	0.02
Grapes	3883	0.89	0.32	1.94	0.32	1.87	0.50	0.10
Avocados	2173	2.19	0.14	1.22	0.35	1.73	0.45	0.02
Peaches	3175	4.00	0.20	1.50	0.30	2.35	0.70	0.02

The weight of the leaves dropped were based on data extracted from the Spasmo model as part of the Nitrogen management for environmental accountability program (MPI, 2008; Whiteman and Brown, 2009). The source of the nutrient concentrations could not be found.

6.1.7. Mineralisation

In some orchards, there is significant disturbance and cultivation of the soil prior to replanting. This disturbance probably results in increased mineralisation of organic matter, and the release of N, P and S.

Therefore, if the entered fruit block age is entered, and the option block cultivated at establishment is selected, then 210, 21, and 21 is added to NBMinCult for N, P and S respectively. The value for N was based on expected N mineralisation released based on an earlier annual model, and P and S assuming that N:P and N:S ratio in organic matter mineralised was 1:10.

6.1.8. Immobilisation

Immobilisation includes an estimate of immobilisation from residuals (prunings, leafloss) that may occur. For N, P and S

Equation 128: $NBImmob_{nut} = ImmPrune_{nut} + ImmLeaf_{nut} + ImmBkd_{nut}$

For N, P and S, it was assumed that immobilisation rates from prunings would be high due to their woody nature. Thus, if prunings are mulched then:

Equation 129: $ImmPrune_{nut} = 0.66 * LeftPrune_{nut}$

LeftPrune is the amount of nutrients in mulched prunings (kg nutrient/ha/year) [section 6.1.5].

For leaf loss, it was assumed that immobilisation rates would be lower, and for N would be zero. Hence for P and S it was estimated as:

Equation 130: $ImmLeaf_{nut} = 0.20 * leaf\_drop$

leaf_drop is the nutrients in leaf drop prunings (kg nutrient/ha/year) [section 6.1.6].

Background immobilisation is based on immobilisation methods used for individual nutrients. This is for N:

Equation 131: $ImmBkd_N = NBfert_N * 0.3 + fFertImm + NBFix_N * 0.25$

fFertImm is an adjustment assuming limited immobilisation occurs on non-pasture areas [Table 25].

NB variables are defined in section 2.2 (kg/ha/year).

For P

Equation 132: $ImmBkd_P = labileP * Ploss * fCover$

labileP is labile P pool (kg P/ha) [Characteristics of Soils].

Ploss is the soil dependent P loss parameter [Characteristics of Soils].

fCover is the expected block area to be covered by pasture [Table 25].

For S, immobilisation is estimated using same procedure as for pasture.

Table 25. Maximum expectant block area to be covered by pasture (fCover), and immobilisation adjustment assuming limited immobilisation occurs on non-pasture areas (fFertImm).

Understorey	fCover	fFertImm
No pasture	0	0.3
Herbicide strip	0.5	0.75
Full pasture	0.75	1

6.2. Tree block calculations

Tree blocks represent an area of the farm that is covered with mature forest or scrubland, and where nutrient losses are expected to be negligible. The input options are:

- Area (ha)
- Rainfall (mm)
- Distance to coast (km)
- Bush type, with options being ‘Pines’ or ‘Native’.

Macaskill *et al.* (1977) noted stream nitrogen contents were lower in streams flowing through exotic than native forest in their study. Concentrations of total N in the soil were 50% higher in native than exotic forests. This was attributed to lower nitrifying potential in exotic forests, resulting in higher soil NH_4 levels which is more readily retained in the soil than $N0_3$. Macaskill *et al*. (1977) also noted that the P content of streams flowing through native forest were 80% of those streams flowing through exotic forest.

Davies (2005) noted that leaching loss of N from undisturbed plantation forests are usually low (2 kg N/ha/year) and similar to native forests but harvesting can cause short term release. The reference to the values used has not been located but is probable based on deliberations during the part of the Lake Taupo trading scheme as this value, and then other inputs and losses estimated.

N fixation was estimated as 0.5 kg N/ha/year for the Pines bush type, and 1 kg N/ha/year for the Native bush type.

For P, slow-release ($NBslowrel_P$) was estimated as 0.1 kg P/ha/year for pines, and 0.12 kg N/ha/year for the ‘Native’ bush type. Leaching ($NBleach_P$) was set to slow-release P ($NBslowrel_P$). For the other nutrients, leaching losses are set to atmospheric inputs:

Equation 133: $NBleach_{nut} = NBrain_{nut} + NBNfix_{nut}$

NB variables are defined in section 2.1 (kg N/ha/year).

For N, as rainfall input is 2 kg N/ha/year; this gives a value of N leached of 2.5 kg N/ha/year for the Pines bush type, and 3 kg N/ha/year for the ‘Native’ bush type.

This model is balanced as inputs equal outputs by definition.

6.3. House block

6.3.1. Introduction

On many agricultural properties, there is a house block, which is defined as the area of a farm containing the house and associated land occupied for personal use.

The house block model was originally developed to align with a model Environment Bay of Plenty was using to assess the impact of different land uses on water quality. There was evidence that septic tank effluent may have been an important contributor to stream N loading on pumice soils. For example, Hoare (1984) noted that nitrate concentrations in urban streams were higher than those from rural streams, and this was consistent with the loads discharged to septic tanks in the stream catchment. Ray *et al*. (2000) noted reports of similar or higher levels of N in stream water that was attributed to septic tanks in the Lake Taupo area. A school science fair project also indicated that losses from urban house property could be significant (these results are presented later in section 6.3.4).

Three general types of losses were considered to be important for house blocks, namely from the sewage system, from vegetated areas (lawn and gardens) and ‘miscellaneous’ losses. This section outlines the model used to derive house block nutrient budgets.

The described model captures nutrient losses from a house block. The required inputs are block area, rainfall (mm) and distance from the coast (which can be copied from other blocks), the number of people on the property, the effluent management system (options are septic tank, advanced septic tank, and reticulated) and the percentage area under cultivation. It was noted that much of the information used to develop this model was in internal reports that are not readily found using normal search methods. Thus, it is probable that some of the underlying estimates will change as further data become available.

The N leaching loss per ha from the house block, particularly those with cultivated areas and/or older style septic tank systems, can be similar to losses from dairy farms. Thus, on small blocks (< 10-20 ha) the losses from the house block can be a significant contributor to total property nutrient losses. For large farms, the losses from the house block are normally insignificant and can be ignored. The model is not intended to be used for urban areas.

Greenhouse gas emissions from house blocks are ignored, although N loss through leaching is included in indirect losses.

6.3.2. Inputs for sub model

User inputs for the house block are:

- Annual rainfall (mm/year)
- Distance to coast (km)
- Sewage disposal method. Options are 'Conventional septic tank', 'Reticulation or compost', and 'On-site septic tank package'
- Number of people
- Percent area cultivated

- Block area (ha)

6.3.3. House effluent management

Effluent from houses in rural areas can be managed through septic tank or reticulated systems. Nutrients are added to the system as household waste (NBSepticIn, section 6.3.3.1) and then either exported (NBEffExport through the reticulated system or removed as sump waste), leached from the septic tank drainage system or remains on the property.

6.3.3.1. *Nutrient added*

Nutrients entering septic tanks is reported to have a relatively constant composition (USEPA, 2002; Whelan and Titammis, 1982). The study of Whelan and Titammis (1982) was the only study that reported nutrient concentrations covering the range of nutrients modelled. Annual per person nutrient loadings to septic tanks can be estimated from the concentrations of Whelan and Titammis (1982) and the wastewater flow allowance.

A typical wastewater flow allowance is 180 l/person/day (ARC Technical Publication No. 58). This reduces to 140 litres per person per day for houses with only roof water supply, and to 115 litres per person per day for houses with roof water supply that use water reduction fixtures. It is probable that most rural areas are on a roof tank, or on a farm bore or low-pressure reticulated system where the expected water use is similar to those that use roof tank systems. Hence, a value of 140 litres per person per day was considered the most appropriate value to use.

Septic tank nutrient loading rates based on a wastewater flow allowance of 140 l/person/day, and the concentration data of Whelan and Titammis (1982) are shown in Table 26.

Table 26. Average concentration of effluent entering a septic tank system (Whelan and Titammis, 1982), and effluent load based on wastewater flow allowance of 140 l/person/day.

	N	NH_4-N	Total P	Sol P	Na	K	Ca	Mg
Concentration µg/ml	125.4	109	17.08	16.56	150.4	34.74	39.3	13.7
Load kg/person/year	6.40	5.56	0.87	0.85	7.68	1.77	2.00	0.70

The dominant N form in septic tank effluent is NH_4. However, total N changes quickly from NH_4 to the predominant NO_3 form when septic tank effluent enters the soil via the drains (Whelan and Barrow, 1984a; USESPA, 2002). Most of the P is present as soluble P (Whelan and Titammis, 1982; Whelan and Barrow, 1984a; USESPA, 2002). Given the dates of many of the studies and the general reduction in the phosphate levels of detergents in recent decades, P loss is expected to be lower than that shown here, although the degree of the reduction could not be assessed.

The amount of nutrient entering the house effluent management system (kg nutrient/ha/year) is estimated using the loads shown in Table 26. It was assumed that S load was the same as for P, and acidity was ignored (set to zero). Thus:

Equation 134: $NBSepticIn_{nut}$ = $septictank_{nut}$ * people / area

septictank is the load (kg/person/year) of 6.40, 0.85, 1.77, 0.85, 2.00, 0.70, 7.68 and 0 kg/year for N, P, K, S, Ca, Mg, Na and acidity respectively.

people is the number of people [user input].

area is the area of the house block (ha) [user input].

6.3.3.2. *Nutrient lost*

USEPA (2002) reported that in a fine sand, nutrient concentrations in soil water as a percent of effluent concentrations in added effluent 0.6 m from the source was 50% for total N and Cl, and 5% for P. At 1.2 m, the reduction was 31% and 41% for N and Cl respectively, and 2.5% for P. This indicates that the soil has some ability to reduce N and P concentrations. It was assumed that cations (K, Ca, Mg, Na) are similar to N and Cl. The reduction of Cl, a free moving ion with low soil sorption affinity, indicates that some processes other than those normally associated with the reduction of N may be present, and that the actual reduction in N content may be about 30% as estimated from the different reductions of N and Cl. On sandy soils in Perth, there was no reduction in total inorganic N below the drains of septic tanks (Gerritse *et al*., 1995; Geary 2005). Gunn (2003) indicated that there was a 15% reduction on coarse grained soils, and 25% on fine grained soils.

Therefore, the discharge of N from septic tanks to ground water was estimated using the per person loading data in *Equation 134*, but reducing N loading by 30% to account for loss processes, to give a septic tank emission to ground water of 4.48 kg N/person/year.

Lower emissions can be obtained from new advanced septic tank systems (Scholes, 2007, USEPA 2006). The average reduction of N content in effluent was 60% in advanced septic tank systems, which was about twice that of conventional systems (USEPA 2006). For the Rotorua lakes, a target of 15 mg/l has been set which is equivalent to 1 kg N/person/year. However, measured data indicates a typical loss of 1.5 kg N/person (Scholes, 2007). Advanced septic tank systems were added to the model by assuming the N loss to water was 1 kg N/person/day with an additional 30% reduction applied, 60% in all. For P, the effluent loading was multiplied by 0.70 (the median loss reported by Scholes, 2007), and then scaled based on the anion exchange capacity of the soil. For the other nutrients, loading was also multiplied by 0.7. It will be up to regional council to define systems that meet the advanced system criteria.

It should be noted that the performance of septic tanks is dependent on proper installation and maintenance of the tank and soak fields. For example, Environment Bay of Plenty noted that some systems in the Rotorua area behave more like soak holes, which could have much higher emissions than septic tank systems.

For conventional septic tank systems the nutrients lost from the system through the field (NBSepticOut) and exported off-farm as septic tank waste (EffExport) is estimated as:

Equation 135: $NBSepticOut_{nut}$ = $NBSepticIn_{nut}$ * fnut * fAEC / area

$NBSepticIn_{nut}$ is the nutrient added to the house effluent system (kg nutrient/ha/year) [section 6.3.3.1].

fnut is 0.7 for N, and 1 for other nutrients.

fAEC is estimated for P to account for soil AEC [Equation 140] and is 1 for other nutrients.

Equation 136: $\text{EffExport}_{\text{nut}} = 0$

For 'Reticulation or compost' systems, the loss to the field, NBSepticOut is zero and EffExport is equal to NBSepticIn. The loss from an 'On-site septic tank package' (advanced systems), as N is:

Equation 137: $\text{NBSepticOut}_{\text{nut}} = 1 * \text{people}$

1 is the load per person (kg N/person/year) [see text].

people is the number of people [user input].

The loss for other nutrients is estimated as:

Equation 138: $\text{NBSepticOut}_{\text{nut}} = \text{NBSepticIn}_{\text{nut}} * 0.7$

NBSepticIn is the nutrient added to the house effluent system (kg nutrient/ha/year) [section 6.3.3.1].

0.7 is the median loss to soil [see text].

For all nutrients, exported nutrients is estimated as:

Equation 139: $\text{EffExport}_{\text{nut}} = \text{NBSepticIn}_{\text{nut}} * 0.3$

NBSepticIn is the nutrient added to the house effluent system (kg nutrient/ha/year) [section 6.3.3.1].

EffExport, along with other effluent exports, is added to the term NBEffExport.

P from septic tanks appears to contribute little to stream loads in the Rotorua Lakes area (Hoare, 1984), with Ray *et al*. (2000) noting that phosphorus is strongly bound to soil types found in the Rotorua Lakes area. On sandy soils in Perth, there was a correlation between the ability of the soil to sorb P, and the amount of P absorbed below the septic tank (Whelan *et al*., 1981; Whelan and Barrow, 1984b; Gerritse *et al*., 1995; Geary, 2005). However, the ability of these sandy soils to remove P appeared to be limited to between 1 and 8 years (Geary, 2005, Gerritse *et al*., 1995). Thereafter, P can readily move through to the water table (Geary 2005, Gerritse *et al*., 1995, Whelan *et al*., 1981). USEPA (2002) presented results that indicate P penetration into soils could be 52 cm per year on sands and 10 cm/year on silt loams. It is also probable that P losses will be lower on soils with high phosphate retentions, although it was noted that there was no simple method for predicting phosphorus removal rates at site levels (USEPA 2002).

Thus, the loss of P from the soil under septic tank drainage fields appears to be driven by the ability to absorb P and a drainage factor. The factor for adjusting P loss to take account of the ability of the soil to sorb P (fAEC) was based on the anion exchange capacity (AEC), ignoring any effects from profile drainage. Thus, fAEC and was arbitrarily estimated as:

Equation 140: $\text{fAEC} = 1 - \text{AEC} / 120$

AEC is the annion storage capacity [Characteristics of Soils], weighted across blocks by area where soil type is defined.

6.3.4. N losses from lawns, gardens, and hard surfaces

In a school science fair project, six 100 mm cores were taken from three separate areas (lawn, flower garden, and vegetable garden) from the author's property in Hamilton in May (Wheeler *et al*., 2010a). The vegetable garden is largely a compost-driven system. The flower garden gets a little fertiliser once a year. These columns were leached over 10 days, leachate collected and analysed for NO_3-N and NH_4-N. The proportion of lawn, flower garden, and vegetable garden on the property was also measured. Annual N loss was estimated as the N concentration in the leachate times the surface area of the lysimeter times the average drainage Hamilton. This gave an average annual section N loss of 22 kg N/ha/year.

Table 27. N concentration in leachate, annual and N loss and % coverage of the section for lawns, flower, and vegetable garden (from Wheeler *et al*., 2010a).

Source	N concentration in leachate (ppm)	Annual N loss (kg N/ha/year)	% coverage of section
Lawn	2.7	4	28
Flower	58	87	9
Vegetable	170	258	5

The design of the experiment means that these results must be used with caution, but the high losses from a compost driven vegetable garden does indicate the potential for high N losses from cultivated areas on small blocks.

Although there are several references that suggest that house lawns can be a significant contributor to nutrient loadings, little measured data was found. King and Balogh (2006) reported runoff and drainage losses of 2-4 kg N/ha/year and up to 1 kg P/ha/year from golf courses and included a reference to a loss of 3.8 kg N/ha from lawns in Illinois. In a report prepared for Environment Bay of Plenty by Elliott, it was noted that:

> *"The storm yield for residential catchments in Rotorua was 1.9 kg N/ha/annum and 2.3 kg N/ha/annum for urban areas (Macaskill et al. 2002). Some of this runoff probably comes from road surfaces. A typical stream concentration measured at the outflow is 0.5 g N/m^3, although this is probably influenced by a rural component. With a base flow runoff of 500 mm, the base flow yield would be 2.5 kg/ha/annum. Hence, the total yield from an urban property is 4.8 (2.3 + 2.5) kg N/ha/annum."*

The crop N sub-model (Crop Based Nitrogen Sub-model chapter) for cut and carry blocks indicates that losses from no fertiliser systems were generally in the 5-10 kg N/ha/year range. Modelling the rotations and management practices of the home vegetable garden using the crop N sub-model for crop blocks indicated losses could range from 40-150 kg N/ha/year range.

Based on the above information, N loss for lawns was set at 3 kg N/ha/year and for cultivated areas at 87 kg N/ha/year, adjusted for rainfall. Thus, total N loss (kg N/year) was estimated as:

Equation 141: gdleach= ((4 * arealawn) + (87 * areacult)) * fLeach

fLeach is an annual leaching factor assuming drainage rainfall less 650mm [7.1].

Leaching from the garden and lawns had a minimum value of 2 kg N/ha times the block area (ha).

The area under cultivation is calculated as the block area, which is a user input, multiplied by the percentage of the block under cultivation, which is a user input:

Equation 142: areacult = area * AreaCultivated /100

AreaCultivated is the entered percentage of house block cultivated.

Area under buildings or hard surfaces was based on average house size of 0.0149 ha over the period 1970 to 2010, although this has been increasing with time (Quotable values, 2011). Adding in an area for drives and paths gave 0.02 ha.

The area of lawns was estimated as the block area, less the area under cultivation (Equation 142), less the estimated area under buildings or hard surfaces (drives and paths).

Drainage was assumed to be rainfall less 680, where 680 is a typical evapotranspiration rate.

6.3.5. Miscellaneous losses

Miscellaneous losses were taken as the nutrient losses from hard surfaces such as the drive and rooves via their drainage systems. It was assumed that the difference in storm yield between residential catchments and urban areas noted above was due to runoff from hard surfaces. Hence, a miscellaneous base loss of 0.51 kg N/ha/year was used for a rainfall of 1500 mm (average rainfall in Rotorua area) and weighted for rainfall.

6.3.6. Leaching

Equation 143: $NBLeach_{nut}$ = MiscLoss * rain / 1500 + gdleach / area

1500 is the average rainfll for Rototrua area (mm/year).

gdleach is the N leached from lawns and gardens (kg N/year) [6.3.4].

area is the house block area (ha).

MiscLoss is the miscellaneous base loss from hard surfaces (kg N/ha/year) [6.3.5].

rain is the annual rainfall (mm/year) [Climate].

For P, it was assumed that P losses would be similar to that for tree blocks, and hence was set to 0.1 kg P/ha/year. For nutrients other than N and P, it was assumed that the loss by leaching was equal to input from rainfall.

6.3.7. Other terms

The input from rainfall was estimated using standard procedures (section 4.1). For nutrients other than N and P, the amount leached (NBLeached) was the same as input from rainfall (NBrain) and hence the block nutrient budget was balanced.

For N, it was assumed that the difference between waste nutrients added to the house effluent management system (NBSepticIn, section 6.3.3.1), and those that leached or exported (NBSepticOut, EffExport) (section 6.3.3.2) were denitrified. Thus:

Equation 144: $NBDenit_{nut} = NBSepticIn_{nut} – NBSepticOut_{nut} - EffExport_{nut}$

NBSepticIn are the nutrients added to house effluent system (kg nutrient/ha/year) [Equation 134].

NBSepticOut are the nutrients lost to the septic tank field (kg nutrient/ha/year) [Equation 135, Equation 137 or Equation 138].

EffExport are the nutrients exported from the farm (kg nutrient/ha/year) [Equation 136 or Equation 139].

N fixation from the lawn area was estimated as:

Equation 145: $NBNfix_N = arealawn * 5000 * 0.15 * 0.065 / area$

arealawn is the area of the lawn (hha) [section 6.3.4]

5000 is arbitrary annual yield (kg DM/ha/year)

0.15 is an arbitrary clover content

0.065 is the fixation rate (kg N/kg DM) [Characteristics of Pasture]

area is the house blcok area (ha)

and the block balanced for N as:

Equation 146: $NBmincult_N = NBLeach_N – NBRain_N – NBNfix_N$

NBLeach is the amount of N leached from a house block (kg N/ha/year) [section 6.3.6].

NBNfix is the N fixed on lawns (kg N/ha/year) [Equation 145]

NBRain is nutrients added in rainfall (kg N/ha/year) [section 4.1].

For P, it was assumed that the difference between waste nutrients added to the house effluent management system, and those that are lost from the septic tank field (NBSepticOut) or were exported (EffExport) was adsorbed. Thus:

Equation 147: $NBAdsorp_P = NBSepticIn_P – NBSepticOut_P – EffExport_P$

NBSepticIn is the amount of P added to house effluent management system (kg P/ha/year) [section 6.3.3.1].

NBSepticOut is the amount of P leaving the septic tank field (kg P/ha/year) [section 6.3.3.2].

$EffExport_P$ is the amount of P expored from the house effluent managemetn system (kg P/ha/year) [section 6.3.3.2].

The block was balanced as:

Equation 148: $NBmincult_P = NBLeach_P$

NBLeach is the amount of P leached from a house block (kg P/ha/year) [section 6.3.6].

Block P loss was assigned to P soil loss category.

6.4. Residue area

When a residue area is estimated (section 7.2.2) then an estimate of nutrients added and lost from the non-productive area is made so that when estimating losses on a farm basis, undeclared areas contribute something to the total. The inputs and outputs from residue areas were largely based on the tree block as no data was found on what these would be. As these were calculated as part of the farm scale nutrient budget, total nutrient movement was estimated.

For nutrients other than N and P, total input from rainfall was estimated, and this was assumed to leach.

For N, rainfall input was estimated as:

Equation 149: $NBRain_N = 2 * fLeach * ResidueArea$

fLeach is an annual leaching factor assuming drainage rainfall less 650mm [section 7.1].

ResidueArea is the difference between entered and declared areas (ha) [section 7.2.2].

N fixation was estimated as 0.5 kg N/ha/year. NBleach was estimated as the sum of rainfall input and N fixed.

P loss was estimated as:

Equation 150: $Ploss = 0.12 * surplusrain * ResidueArea$

surplusrain (mm) is the normalised surplus precipitation [section 5.2.1.6.1].

ResidueArea is the difference between entered and declared areas (ha) [section 7.2.2].

and was added to the slow-release (input) and runoff (output) terms in the nutrient budget.

7. Calculations

7.1. Leaching factor

The annual model (version 5) used a leaching factor to estimate N leaching based on annual drainage or rainfall. If drainage is greater than 550 mm, then:

Equation 151: $fLeach = 1.6 - 1.6 * Exp(-0.000805 * (drainage + 680))$

drainage is the annual drainage (mm) [Hydrology].

otherwise

Equation 152: $fLeach = 1.6 - 1.6 * Exp(-0.0018 * drainage)$

and such that fLeach has a minimum value of 0.05.

7.2. Areas

The user enters a compulsory area for each block, while the total farm area is optional. Total area entered in most cases should be the legal farm area. In general, block areas should be the effective area of the block. For pastoral blocks, the effective area should include the area of fodder crop or pasture fallow that rotates through it. For Fodder crop blocks, the block area is zero, but the area of the block is recorded as a rotation area. For crop blocks, the area may include the headland and non-cropped areas as well. Note that block or farm areas can be erroneous by as much as 10-20%, and this may have a significant effect on the farm's nutrient budget estimates.

The declared area is the sum of the block areas. If the total farm area is entered, the sum of the entered block areas must be equal to or less than the total farm area.

7.2.1. Pastoral and fodder crop blocks

For calculation purposes, the area of the fodder block is set to the rotation area. To maintain constant areas, the area of pastoral blocks that have a fodder crop rotating through it are adjusted as:

Equation 153: area = Area - AreaFodderCrops * EnteredArea / AreaPastoralFodder

Area is the entered pastoral block area (ha).

AreaFodderCrops is the sum of the fodder crop rotation areas (ha).

AreaPastoralFodder is the sum of the area of all pastoral blocks that have a fodder crop block rotating through them (ha).

7.2.2. Lane area

The area of lanes is not used in estimating losses (Effluent management chapter) but may affect the estimation of residue area (7.2.3). Lane areas are estimated as 1.5% of the sum of all pastoral blocks grazing dairy animals, and 1.0% of the area of other pastoral blocks except those grazing merino.

7.2.3. Residue area

The non-productive area is estimated as the difference between the entered farm area and the declared farm area, where the declared farm area is the sum of the entered areas for each block.

7.2.4. Camp area

Camp areas are used in the estimation of maintenance fertiliser nutrient requirements. In dairy blocks, the camp area represents those areas of nutrient accumulation that are seen around gateways, troughs, etc. Merino data supplied by Boswell (pers. comm.) indicated that camp areas in steep to high country running merinos was as low as 6.4% of total area. Therefore, it was assumed that the campsite was half that of other sheep breeds. Expert opinion indicated that there was no evidence that the actual amount of nutrient transfer under merino was any different when compared with other breeds, and hence the internal block transfer coefficient remains the same.

Camp area is estimated as 2% of pastoral dairy blocks, 7.5% of pastoral blocks with merino sheep, and 15% for other pastoral blocks.

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