Preliminary assessment and review of soil parameters in OVERSEER® 6

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Preliminary assessment and review of soil parameters in OVERSEER® 6

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Preliminary assessment and review of soil parameters in OVERSEER® 6.1

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Summary

Project and Client

- AgResearch, on behalf of the OVERSEER® Nutrient Budgets (*Overseer*) Owners, subcontracted Landcare Research in January–August 2014 to review the soil data inputs and processes in *Overseer* as a preliminary step in a longer term programme to improve the *Overseer* model.

Context

- Soil data can be entered into *Overseer* at two levels: a qualitative description of the soil profile characteristics (Level 1) and a quantitative description of the soil moisture characteristics (Level 2).
- Previous work has shown that there may be issues with *Overseer* estimates of leaching and denitrification for some soils.

Objectives

- Compare the available water estimates computed by *Overseer* with those estimated by S-map (New Zealand's primary soil survey database).
- Run *Overseer* on a range of soils to identify any unexpected estimates of nitrate leaching and denitrification that might indicate a potential issue within *Overseer* or the data.
- Recommend improvements in the algorithms within the nutrient and hydrological modules of *Overseer* where *Overseer* can take better advantage of soil physical and chemical properties available in S-map.

Methods

- The S-map database version used is that of May 2014. The *Overseer*® 6.1 DLL (model executable) was provided by AgResearch in June 2014. The key documents used to understand the algorithms used in the hydrological and nitrate modules of *Overseer* are *Nutrient attenuation and hydrology modules for Overseer* (Rutherford et al. 2008) and the *Overseer* manuals (dated November 2013).
- All currently available S-map siblings (representing over 2500 unique soils) were used in an analysis of the *Overseer* Level 1 soil data inputs. The estimated available water to 60 cm depth (AW_{60}) was compared with the S-map estimate. The S-map siblings with very high or low estimates of nitrate leached or denitrified were identified and assessed as to whether these estimates were reasonable.
- The *Overseer* Level 2 soil inputs were tested using 31 soils covering a range of soil types under various profile drainage class, slope and climate scenarios.
- The *Overseer* soil inputs and soil-related algorithms, as documented in the *Overseer* technical manuals, were assessed and compared with soil knowledge and information that is currently available or could be developed within S-map.

Conclusions and recommendations

Level 1 soil inputs

- Using Level 1 soil properties in *Overseer* results in AW_{60} estimates that follow a similar pattern with respect to soil order as the S-map estimates, although with less variability. Relying on soil order alone to define the soil properties used within *Overseer* is not recommended because of low precision.
- There are significant differences between S-map and *Overseer* estimates of available water down to a depth of 60 cm (more than 40% had a difference greater than 20 mm). These may be due to the inherent limitations of the Level 1 properties to fully describe the wide range of soils found in New Zealand.
- We recommend that preference is given to using *Level 2* inputs. If *Level 1* inputs are maintained (for soils where *Level 2* information is not currently available) then there is scope to make limited improvement to this method of characterising soils. To achieve this, the following work is recommended:
    - A revision of the order, subsoil texture group, and non-standard-layer default water content values used within *Overseer*. In particular, *Overseer* appears to overestimate AW_{60} of light soils with a non-standard-layer stony matrix layer
    - Adding additional non-standard layers to allow better characterisation of very stony and organic layers
    - Extend the ability to use the subsoil texture group for other orders, e.g. clayey Pallic soils, rather than being limited to Recent and Brown Soils
    - Organic soils are not well characterised and should be reviewed
    - *Overseer* users need to have a reference for the topsoil texture group options so that they know what the classes mean. We suggest using the texture groups and texture triangle from Taylor & Pohlen (1970).

Level 2 soil inputs

- In general, modelling results from *Overseer* followed expected trends in the relationships between evapotranspiration and available water, runoff and drainage, drainage and available water, denitrification and clay and air capacity, leaching and available water.
- We recommend the adoption of Level 2 soil water characteristics once this has been fully tested in a revised and recalibrated version of *Overseer*.

Modelling

- The *Overseer* soil input ‘depth to impeded layer parameter’ has no effect on Level 1 soil inputs and gives incorrect results for Level 2 soil inputs. This needs to be amended as *Overseer* overestimates AW_{60} values in soils with a pan or that are shallow to bedrock. With respect to the maximum rooting depth parameter, we suggest that the depth to impeded layer parameter is sufficient for hydrological purposes (for soil input levels 1 and 2), at least for pasture simulations.

- We recommend a review of the runoff algorithm in the light of better soil data available in S-map. We also recommend that further work needs to address how *Overseer* may better represent runoff related to slow permeability of subsurface conditions. This should focus on three aspects:
    - Improving estimation of saturated hydraulic conductivity, including using S-map-derived saturated hydraulic conductivity to improve estimates of denitrification and runoff
    - Improving the feedback so that saturation-induced runoff can occur
    - Improving the infiltration model.
- The results from using both Level 1 and Level 2 soil data indicate that estimates of denitrification should be reviewed. The method of estimating denitrification involved a calibration step, and it is probable that the denitrification results are an artefact of the using limited data for the calibration process. The following steps are recommended:
    - The calibration step involving denitrification is removed so that the effect on soils can be isolated
    - Update the runoff model as above so that the model is predicting the 'correct' water-filled pore space
    - Review the relationship between denitrification and clay content, total porosity and K_{s_drain} and denitrification to ensure that *Overseer* is responsive to soils with slow permeability and does not exaggerate the effect of clay content
    - The rationale behind the high variability in the estimates of nitrate leached from well-drained soils with the same AW_{60} should be confirmed, along with denitrification estimates from well-drained very stony soils with low total porosity
    - Adjust *Overseer* to take account of the effect of runoff and slope on evapotranspiration.
- Many of the recommendations above will require *Overseer* to be recalibrated against measured experimental data.

Recommendations to improve Overseer

- A redesign of the user interface for entering soil properties into *Overseer* is essential.
- The release testing programme for *Overseer* should be extended to include 'sensibility testing' of results based on all soils (as covered in S-map) and climates found in New Zealand.
- A formal uncertainty analysis would help clarify the main sources of uncertainty in both data and model assumptions.
- S-map could provide values for some other soil properties used in *Overseer* (e.g. structural vulnerability) and others that are likely to be useful (e.g. risk of preferential flow).
- A practical method for estimating the nutrient budget for a block with multiple soil siblings should be developed.

1 Introduction

OVERSEER® Nutrient Budgets (*Overseer)* is a user-friendly decision support system (DSS) farm model that computes the long-term nutrient budget of many farming enterprises including pastoral, horticultural, arable and vegetable farming (Rutherford et al. 2008; Wheeler & Rutherford 2013). Nutrient budgets are developed at the farm and block scale allowing users to examine the impact of nutrient use within a farm, nutrient use efficiency, and off-farm losses of nutrients and greenhouse gases. *Overseer* provides information that can assist with mitigating the environmental impact of nutrient losses. *Overseer* outputs are increasingly being used in a regulatory environment. Typical users are farm advisors and other rural professionals, landowners (farmers), consultants, and regional council staff.

Overseer estimates of nutrient losses can be particularly sensitive to soil parameters. Consequently, it is important the model uses best available soil information and that the key soil processes are accurately modelled in order to reduce the uncertainties in estimates of nutrient losses.

Soil water holding characteristics are important inputs in the estimation of drainage, and hence nutrient loss by leaching. The best soil information to determine soil water holding characteristics for input in *Overseer* would be a field assessment of a farm by a trained pedologist using laboratory measurements. However, obtaining this type of detailed information is usually a costly exercise and is not generally undertaken. The new S-map[1] soil survey information system (Lilburne et al. 2012) is the next best source of soil information, although it does not yet cover all of New Zealand.

Soils are mapped at a nominal scale of 1:50 000 in S-map, although more detailed mapping can be incorporated into S-map. This level of information can be quite accurate in land areas with limited functional soil variability. S-map comprises basic soil properties and an inference engine for estimating a range of derived soil properties using pedo-transfer functions (ptfs). These ptfs are developed from either statistical or expert analysis of the laboratory data of samples from soil pits that make up the National Soils Database (NSD) (Lilburne et al. 2014). When *Overseer* was developed, S-map did not exist, consequently higher level soil properties (e.g. soil order, series name, type of non-standard layer) were used as proxies for a range of soil data and soil processes within *Overseer*. Mean values for each proxy were derived from the NSD and built into *Overseer*.

AgResearch, on behalf of the *Overseer*® owners, subcontracted Landcare Research in 2014 to provide suggestions for improving the soil parameters and algorithms within *Overseer* in order to capitalise on the more extensive set of soil information that is now available in S-map.[1]

In this report, we review the soil parameters and processes used within *Overseer* to determine how they might be improved using information from S-map. The main objective of this work is an analysis of the soil parameters used in *Overseer* to estimate nutrient and water budgets.

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[1] http://smap.landcareresearch.co.nz

2 Objectives

- Compare the available water estimates computed by *Overseer* with those estimated by S-map (New Zealand's primary soil survey database).
- Run *Overseer* on a range of soils to identify any unexpected estimates of nitrate leaching and denitrification that might indicate a potential issue within *Overseer* or the data.
- Recommend improvements in the algorithms within the nutrient and hydrological modules of *Overseer* where *Overseer* can take better advantage of soil physical and chemical properties available in S-map.

3 Background

As described in Lilburne et al. (2013) and Wheeler (in prep.), there are a number of methods for entering soil properties into *Overseer*, with some overlap between them.

- Soil inputs are broadly categorised into six groupings, namely:
- Soil classification (soil series, soil order and soil group as defined below), which is used to define default values for a range of soil properties.
- Soil profile descriptors. These are used to define soil moisture properties and to define default values for a limited range of soil properties.
- Site-specific properties: these are soil properties that may be measured for a given site, but typically the default values would be used. For example, the bulk density and clay content for topsoil are usually default values based on the soil description selected, but they may be overridden by the user.
- Soil drainage characteristics that define the drainage status of blocks and artificial drainage systems. Inputs such as profile drainage class and hydrophobicity are within scope of this report, but other inputs of drainage status are strongly influenced by farm management and thus they are outside the scope of this report.
- Soil chemical data from soil tests can also be added on the *Soil Tests* tab. Typically, this testing is undertaken as part of fertiliser recommendation programme and hence are site specific and strongly influenced by farm management. Thus, they are outside the scope of this report.
- Soil potential settings. These are typically qualitative assessments of soil status and are outside the scope of this report.

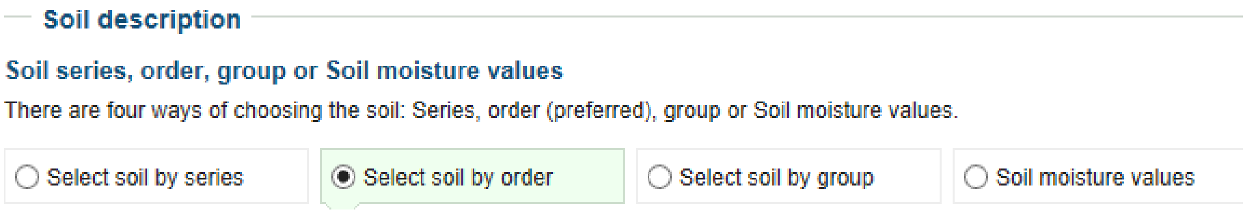
Soil classifications options in *Overseer* (Figure 1) are defined as follows:

- **Soil group** is a very high level classification of soils into seven categories (i.e. Sedimentary, Volcanic, Pumice, Organic, Podzols, Sands, YGE/BGE). With the possible exception of the 'Sands' type, this method is not recommended for use in *Overseer* due to the coarse classification (*Overseer* Management Services Limited 2014) and is not discussed further in this report.
- **Soil series** refers to the original soil names used in the Land Resource Inventory, i.e. the national soil layers developed in the 1980–90s (Newsome et al. 2000). The soil series are a classification of soils grouped according to similarities of soil profiles, temperature, moisture

regime and parent material (Taylor & Pohlen 1970). Series are defined by modal concepts, can encompass a wide range of soil characteristics, and the same soils can be given different series names in different regions. They are, therefore, not suitable for modelling. The default data in *Overseer* for soils series contains some of the user-defined soil properties, but not the soil profile descriptors. Soil series are not recommended for use in *Overseer* (*Overseer* Management Services Limited 2014) and are not discussed further.

- **Soil order** is the first level of the New Zealand Soil Classification (NZSC) as defined by Hewitt (2010). For each of the 13 orders, a set of default soil properties is defined within *Overseer*. These values represent mean properties for each soil order.

Note that soils series are being replaced by well-defined families and siblings from S-map where the quantitative descriptions of soil characteristics were designed to support modelling (Lilburne et al. 2012). S-map soil siblings are defined according to the five levels of the NZSC (Webb & Lilburne 2011).



Soil description

Soil series, order, group or Soil moisture values

There are four ways of choosing the soil: Series, order (preferred), group or Soil moisture values.

○ Select soil by series
● Select soil by order
○ Select soil by group
○ Soil moisture values

Figure 1 Soil description input page in *Overseer* 6.1.

The *Overseer* soil classification is linked to default values for 43 different parameters. Default values for some of these parameters were sourced from the NSD a number of years ago. Many of the remaining parameters are used to drive response curves, or nutrient transformations, and are out of scope, except to note that most of the default values are at a soil order level.

Soil profile descriptors are soil properties used to modify the *Overseer* default values for soil moisture that are associated with each soil order. They apply whenever soil series, order, or group is selected as the soil description option. The soil profile descriptors are entered or selected on the *Soil Profile* tab, i.e. topsoil texture, topsoil stoniness, and lower profile layer characteristics.

Some of the other database-derived default values can be overridden directly by entering site-specific values into the *Soil Properties* tab, i.e. bulk density, structural integrity, carbon, clay (topsoil and subsoil), and into the *Drainage/Runoff* tab, i.e. profile drainage class. Within the model, user-entered site-specific properties have precedence over database-derived values. In practice, database-derived values are likely to be more commonly used, and more consistently used between different users. Therefore, the model allows both options, but with a focus on using database-derived values.

The soil-moisture-focused input option (Figure 1) is an alternative method of describing the moisture characteristics of the soil. This method allows direct entry of soil water properties (water content at wilting point, field capacity, saturation) by three vertical layers (0–30, 30–60 and 60+ cm) as an alternative to entering the soil classification and soil profile properties on the *Soil Description* and *Soil Profile* tabs.

This option was initially added as a possible link to S-map, and hence includes inputs for soil properties from the other soil input pages, such as soil order and profile drainage class. It also allowed entry of 'site-specific properties' derived from S-map that override soil-order-based default values. Note that soil order is still used to access many of the other default soil parameters used within the model.

In the rest of this report, the approach of using the soil classification with further details from on the *Soil Properties* tab and the qualitative options on the *Soil Profile* tab is termed *Level 1* soil data. Using the soil-moisture-focused inputs is termed *Level 2* soil data.

Analysis of the Level 1 soil data is discussed in the next section of the report (Section 4) while Section 5 discusses the use of Level 2 soil data. A more theoretical analysis of the *Overseer* algorithms is given in Section 6 along with some more general comments on the link between S-map and *Overseer* and the user interface for entry of soil data into *Overseer*.

The soil hydrology terms used in this report follow McLaren & Cameron (1996):

- WP (wilting point) = water content at 1500 kPa
- FC (field capacity) = water content at 10 kPa
- TP (total porosity) = water content at 0 kPa
- AW (available water content) = FC − WP
- AC (air capacity) = TP – FC.

Note that macroporosity is defined as the difference between water content at 0 and at 5 kPa, but macroporosity as used in *Overseer* refers to water content at 0 to 10 kPa.

4 Analysis of Level 1 soil inputs

4.1 Introduction

The S-map team derived pedo-transfer functions (ptfs) for the qualitative *Overseer soil profile* categories (Level 1) based on discussions with the *Overseer* team and by experimenting with the effect of different categories. The *Overseer* model converts these soil profile properties to estimates of volumetric water content and available water (AW). *Overseer* uses these estimates in conjunction with other information to estimate drainage and N losses.

It was agreed therefore that the following checks should be made:

- That the S-map team have correctly interpreted and derived the *Overseer* soil profile properties
- That the estimates of AW derived by *Overseer* are reasonable (given the limitations of these soil profile categories).

Both can be readily tested by comparing the S-map estimates of AW to a depth of 60 cm (AW_{60}) directly with the *Overseer* estimates of the same.

Previous work using eight soils from Canterbury has shown that there may be some issues with *Overseer* estimates of leaching and denitrification for some soils (Mojsilovic & Webb 2013). These issues were further explored by running S-map soils (Level 1 input) through *Overseer* to identify those soils with anomalous levels of leaching and/or denitrification.

4.2 Method

4.2.1 Overseer Level 1 soil data

AgResearch provided a test version of *Overseer* v6.1 in the form of a DLL (an executable file) in June 2014. The DLL uses the Delphi development version and provides a means to automatically link extraction of data from S-map to the *Overseer* engine, and to return relevant values electronically to allow data analysis. This allows a large number of soil scenarios to be processed.

The Level 1 soil properties used for testing are listed in Table 1. Currently, the first nine properties are explicitly listed on the S-map factsheets (on page 3) whereas the last five properties can be derived from information elsewhere on the factsheets. These two variations on the Level 1 data are respectively labelled as *Level 1.9* and *Level 1.all* in this report.

S-map data for 2545 soil siblings for each of the properties in Table 1 was downloaded and processed through the *Overseer* DLL. This model uses a set of proprietary ptfs to estimate AW (Characteristics of Soils chapter of the Technical Manual, in prep.). These ptfs are essentially class-based functions whereby all soils of the same order are assigned the same mean AW value. This mean value is further modified when the user provides Level 1 soil properties, including sand, clay, carbon and the non-standard layer.

We note that the 21 topsoil-texture-group options are based on those used in the NSD. There are different definitions of these terms according to which soil texture triangle is adopted. We suggest limiting the options to the texture groups and texture triangle listed in Taylor & Pohlen (1970).

Table 1 Level 1 soil properties entered into *Overseer*. Heavy line indicates subdivision of *Level 1.9* from *Level 1.all*

Overseer soil property	Depth	Unit	Overseer description and usage
Soil order			NZSC soil order
Profile drainage class			5 drainage classes
Topsoil texture			21 texture classes
Topsoil stoniness			True/false
Subsoil texture group			Light/Medium/Heavy options for Recent and Brown soil orders only
Non-standard layer			None/Sandy/Stony/Stony matrix
Depth to non-standard layer		cm	Depth to the non-standard layer if present
Max. rooting depth		cm	Maximum rooting depth
Depth to impeded layer		cm	Depth to impeded layer
Topsoil bulk density	0–10 cm	Kg/m^3	
Clay	0–10 cm	%	Percentage clay in the top 10 cm
Sand	0–10 cm	%	Percentage sand in topsoil
Clay subsoil	10+ cm	%	Percentage clay in the subsoil – depth not defined
AEC		%	Anion exchange capacity (phosphate retention)

4.2.2 S-map AW data

New S-map ptfs estimating water content values at various points on the water retention curve have recently been developed (McNeill et al. in prep.). These are based on a statistical analysis of measured laboratory data held in the NSD. The ptfs use a two-stage approach:

- Firstly, the θ_{1500} was fitted using logistic regression with soil order, soil functional horizon description ([2]Topsoil, [3]Texture, [4]Ped size, [5]Tephra, [6]Rock class fines, [7]Soil order, [8]Drainage and [9]Strength) and texture as explanatory variables.
- Secondly, the difference between the θ_{100} and θ_{1500} was modelled with a generalised linear model (GLM), using a log-link and a Gamma distribution for the response. This process was

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[2] **Topsoil:** logical factor indicating the presence of a topsoil

[3] **Texture**: sand, silt, clay

[4] **Ped size:** ordered categorical variable with values: '*nullpedsize*', '*earthy*', '*fine*', '*coarse*'

[5] **Tephra**: unordered categorical variables with values of '*nulltephra*', '*acidic*', '*basic*'

[6] **Rock class fines**: consisted of 6 rock types from which the fine-textured soil material was derived

[7] **Soil order**: the number of soil orders for this study was 16

[8] **Drainage class**: are compressed into 3 groups: '*poorly drained*', '*imperfectly drained*', '*well drained*'

[9] **Strength**: values that range from: '*nullstrength*'; '*loose*'; '*weakslightlyfirm*'; '*compact*'; '*firm*'; '*dense*' to '*pan*'.

then repeated for successive differences between $\theta(h)$ curves, i.e. between θ_{40} and θ_{100}, and so on. Thus for a given soil description, the θ_{1500} estimate comes from applying the logistic regression, while prediction for other tension values comes from the value at θ_{1500} plus a difference from the GLM prediction. In this way, points on the $\theta(h)$ curve are forced to observe both the observed data distribution and the monotonic order with respect to tension. The relationship between observed and simulated θ at different h shown in Figure 2 is very encouraging (McNeill et al. 2012).

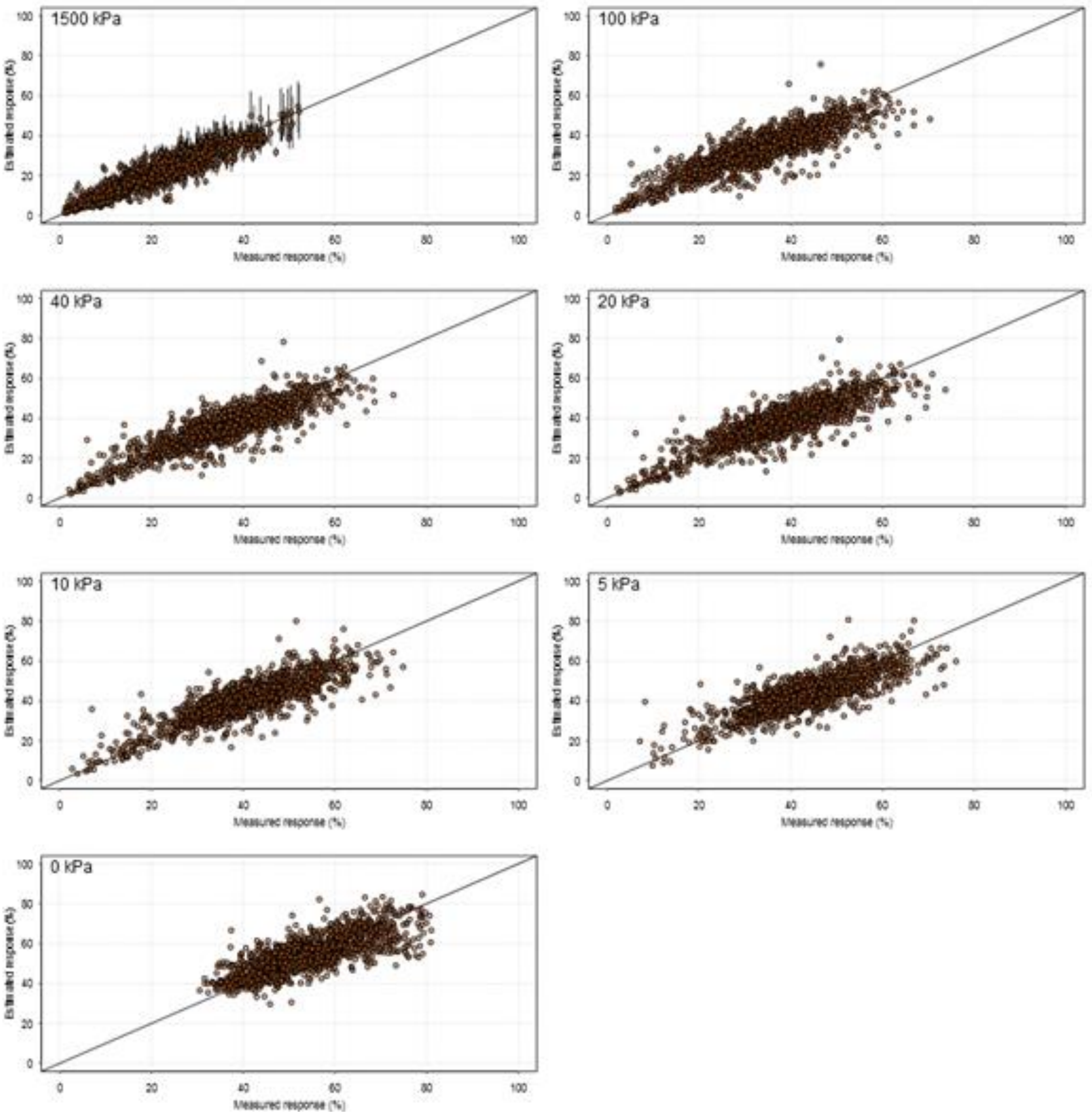


Figure 2 Observed and predicted θ at different suctions by using logistic regression with soil order and generalised linear model by using soil functional horizon description and texture as explanatory variables (McNeill et al. 2012).

The upper-right plot (‘New TAW model’) on Figure 3 shows the predicted versus estimated percent available water content values of the horizon data in the NSD. These results can be compared with the earlier class-based model ('Simple TAW model') of available water, which is analogous to the *Overseer* Level 1 model of available water, on the left-hand side.

The lower-right plot shows the standard error of the estimate. The estimate of the standard error of the Simple TAW model is shown on the left-hand side. The errors are much higher than those in the new model.

The S-map calculation of AW_{60} is based on the estimated percent water content from the new model. The total water content (mm) for each horizon (with stones accounted for) is summed to a depth of 60 cm, or to a physical root barrier if this is above 60 cm.

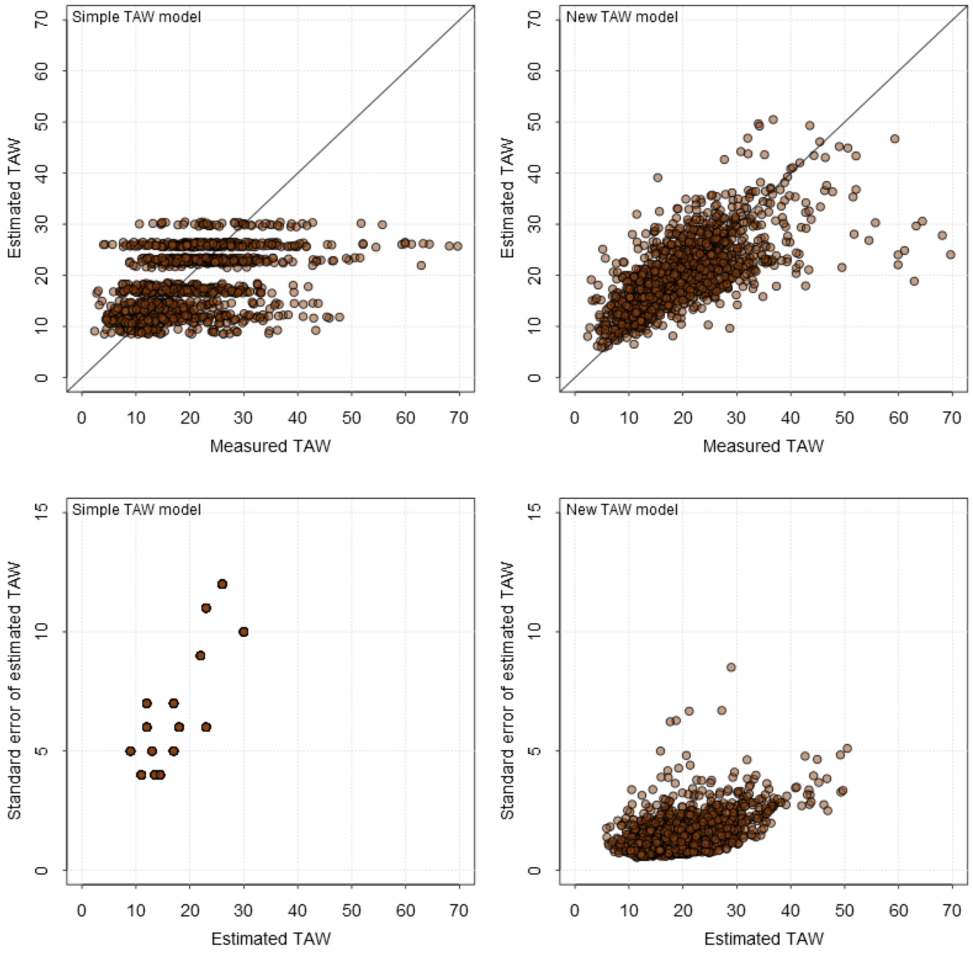


Figure 3 Results of the statistical analysis of available water content data (%) by horizon from the NSD

4.2.3 Overseer model

All test simulations are based on a simple farm system of dairy cows grazing permanent pasture on flat land in Canterbury with a rainfall of 1000 mm per annum with no artificial drainage, irrigation, fertiliser, or supplements. The *Overseer* farm file was supplied by AgResearch. Note that the farming system has no effect on soil water properties generated by *Overseer*, but does affect other outputs such as N-leaching.

Two sets of simulations were run:

1. All the siblings currently in the S-map database, to look for anomalous outputs (extreme values)
2. A smaller set of seven Canterbury soils (Table 2) as defined in Appendix 3 of Lilburne et al. (2010), to compare outputs against expected trends in a 'sensibility test' (do the results seem sensible on the basis of first principles or results from simulation models?).

Table 2 Set of seven Canterbury soils for testing trends in *Overseer* outputs

Soil code	Description	S-map sibling
XL	Extremely light	Rang_18b.1
VL	Very light	Eyre_23a.2
L	Light	Balm_26a.1
M	Medium	Temp_2a.1
D	Deep	Barr_3a.3
PdL	Poorly drained light	Wate_2a.1
Pd	Poorly drained deep	Flax_9a.1

4.3 Results

4.3.1 Comparison of the available water estimates

Figure 4 shows the high variability of AW to 60 cm within each soil order as estimated by S-map ptfs. The variation is due to differences in horizon thickness, texture and stone content and the presence or otherwise of a rooting barrier. Given wide variability and the importance of AW in calculating the nutrient budget, we believe that the use of a default value based on soil order alone is not satisfactory, and will result in inaccurate estimates of soil drainage and nutrient losses.

Figure 5 shows boxplots of the AW_{60} as calculated according to four approaches:

- by *Overseer* using just soil order
- by *Overseer* using the first nine 'Level 1' soil properties listed in Table 1
- by *Overseer* using all the 'Level 1' properties listed in Table 1
- by S-map as described above.

As expected, the mean values of AW_{60} between the four methods were similar. However, the range in predicted values was much greater for S-map-derived AW_{60} than *Overseer*-derived estimates of

AW_{60} using either the Level 1.9 soil parameters (lower profile texture, and non-standard layer) or the Level 1.all properties.

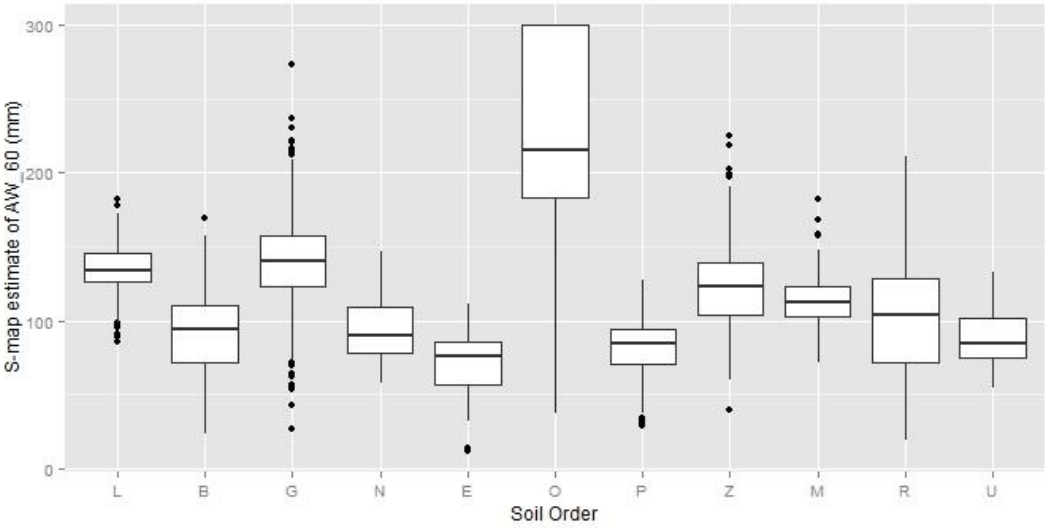


Figure 4 Variability of AW to 60 cm depth within each soil order (as estimated by S-map ptfs). The central line in the box indicates the median, the outer edges of the box indicates the interquartile range (50%), the whiskers extend to the most extreme point that is less than 1.5 times the interquartile range, and points indicate outliers beyond this range.

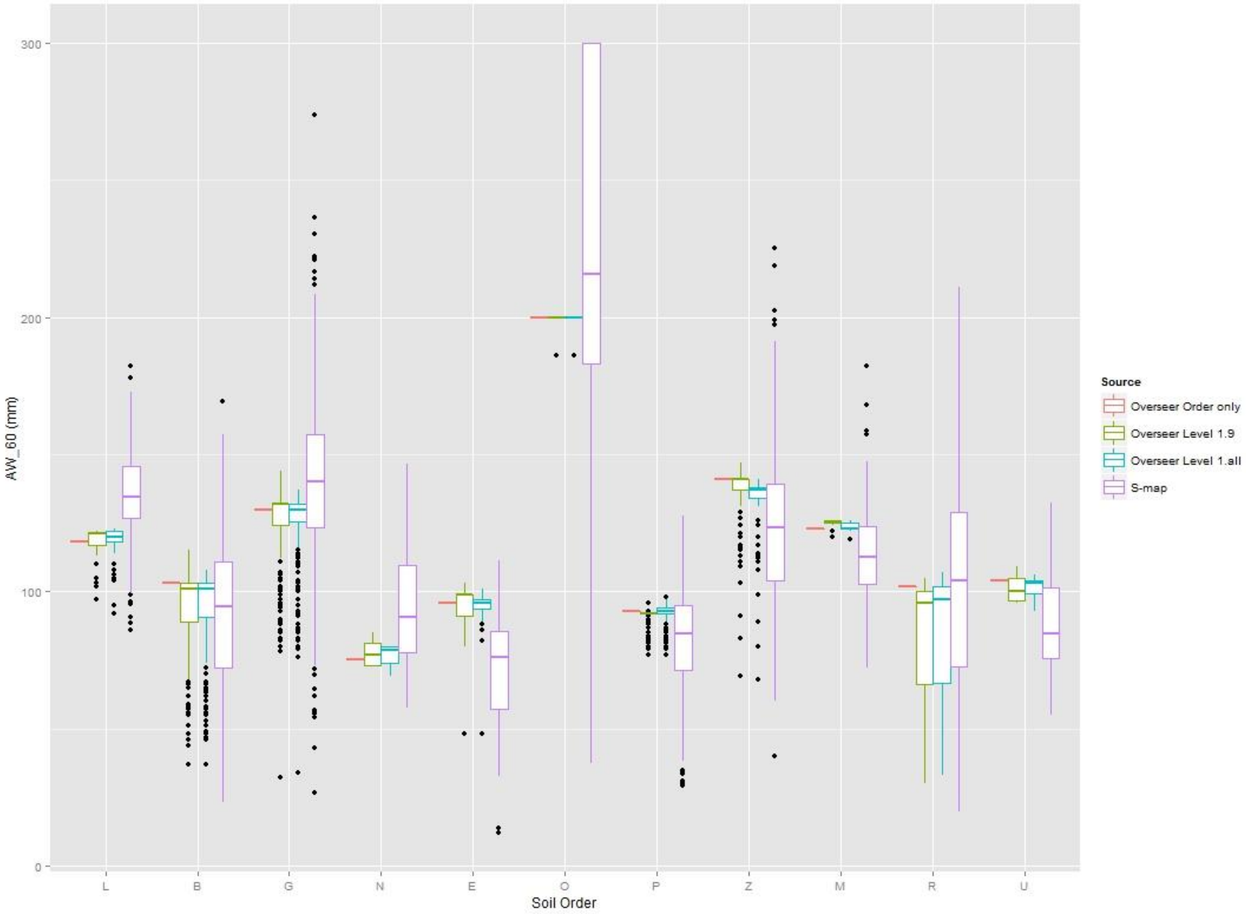


Figure 5 Variability of estimates of AW_{60} within each soil order as determined by four different methods

An x–y plot of *Overseer* (Level 1.all) and S-map estimates of AW_{60} shows a poor match between the two estimates (Figure 6). The $y = x$ line highlights that there are significant differences. More than 40% have a difference greater than 20 mm.

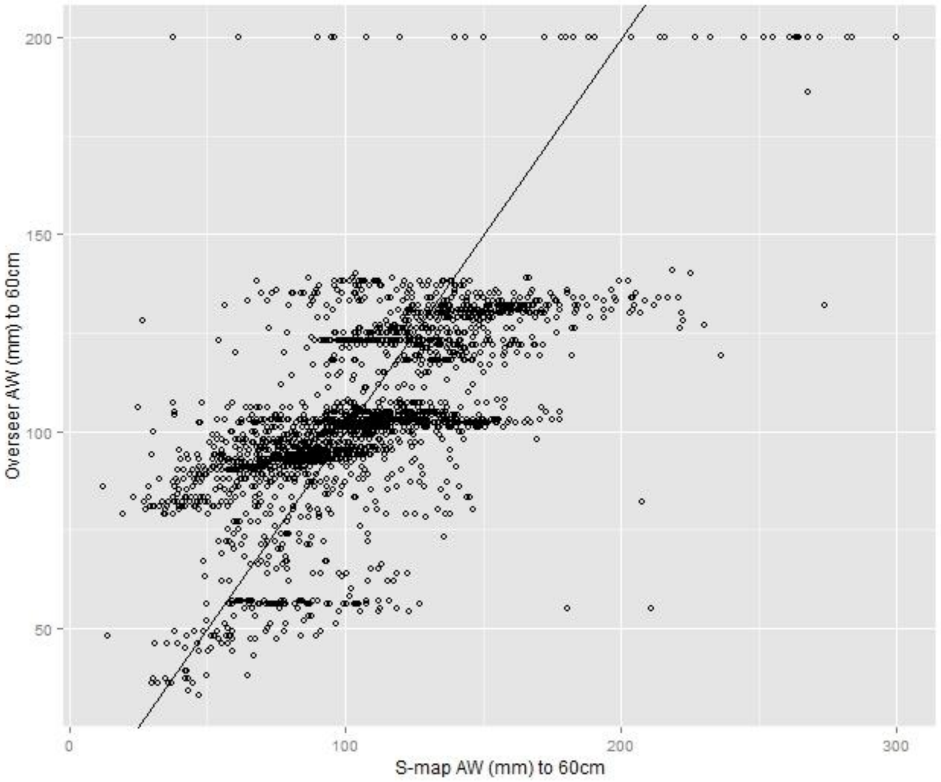


Figure 6 Comparison of *Overseer* and S-map estimates of AW_{60}.

Further analysis of these differences by graphing them by a range of factors did not yield any simple explanations. For example, Figure 7 shows the differences by soil order and non-standard layer. *Overseer* underestimated AW_{60} for soils with a sandy non-standard layer but overestimated it for soils with a stony matrix. However, bigger differences were found in soils with no non-standard layer. Allophanic, Gley, Granular and Recent soils are generally underestimated; Melanic, Pallic, Podzols and Ultic soils are generally overestimated. Organic soils have the biggest errors, followed by Gley and Recent soils.

From a more specific analysis of a few of the soils with big differences in Figure 6, we note that:

- Soils with average to moderately high levels of stones (20–50% stone content) were not well handled by *Overseer*. For example a Shaldash_8 sibling has an S-map AW_{60} of 33 mm due to 45% and 60% stones in the top two functional horizons yet *Overseer* estimated 81 mm AW_{60}. This discrepancy is not surprising given *Overseer's* limited ability to describe stone content using the Level 1 parameters.
- The 'root barrier' and 'depth to impeded layer' parameters have no effect on estimates of AW_{60}. This means that *Overseer* estimates of AW_{60} for soils with pans or soils that are shallow to rock are too high. This affects about 15% of current S-map siblings. We note that the impeded layer depth parameter *does* have an effect in the currently released version of *Overseer* (as opposed to our test DLL), but this effect still appears to be incorrectly calculated in *Overseer*.

- *Overseer* estimated the AW_{60} of Pallic soils with clayey subsoils. This could potentially be improved by allowing Pallic soils to specify a heavy soil TextureGroup (subsoil). Currently, only the Recent and Brown soils can use this parameter.
- The stony matrix non-standard layer did not reduce the AW sufficiently, so *Overseer* estimates were too high.
- Organic soils are not well described.

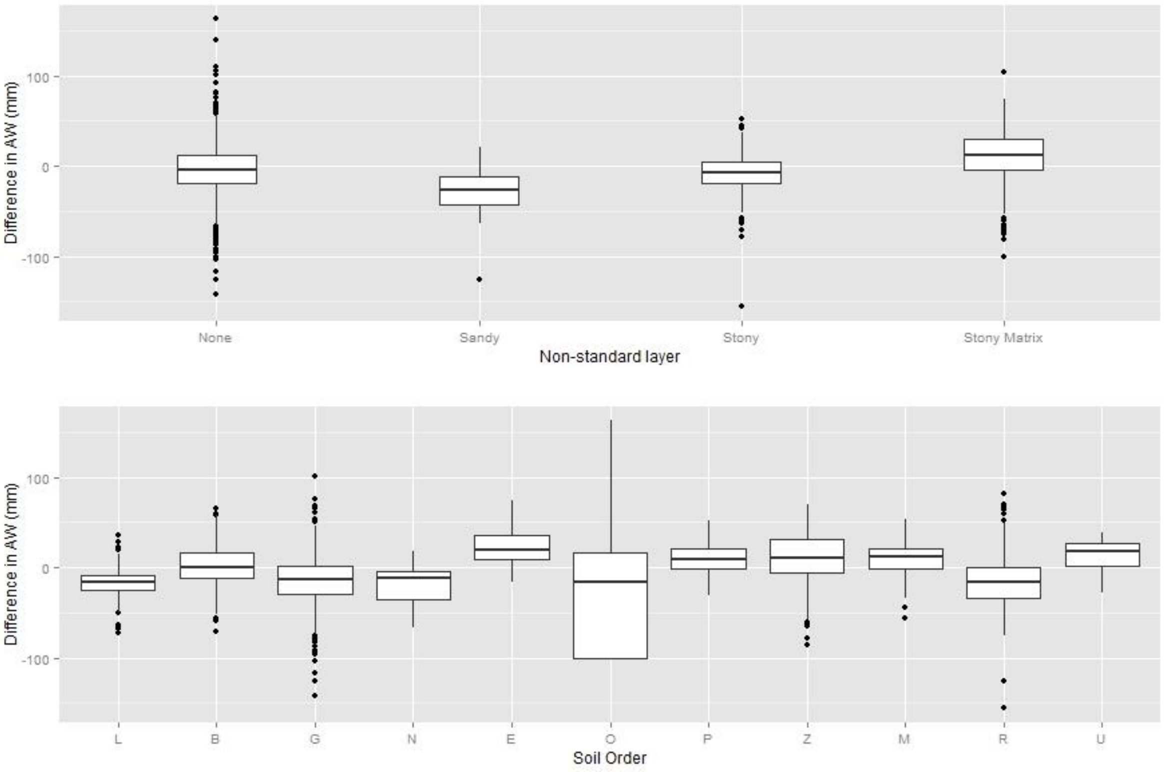


Figure 7 Differences between *Overseer* and S-map estimates of AW_{60} by non-standard layer (upper graph) and soil order (lower graph). Positive values are overestimates by *Overseer*.

Figure 8 compares the two estimates of AW_{60} for the set of seven Canterbury soils (Table 2). This shows a similar trend in AW_{60} from XL to L soils. While general conclusions cannot be drawn from such a small dataset, we note that L and PdL soils are predicted to have similar AW_{60} to the M and D soils, whereas we would expect them to have less AW_{60}.

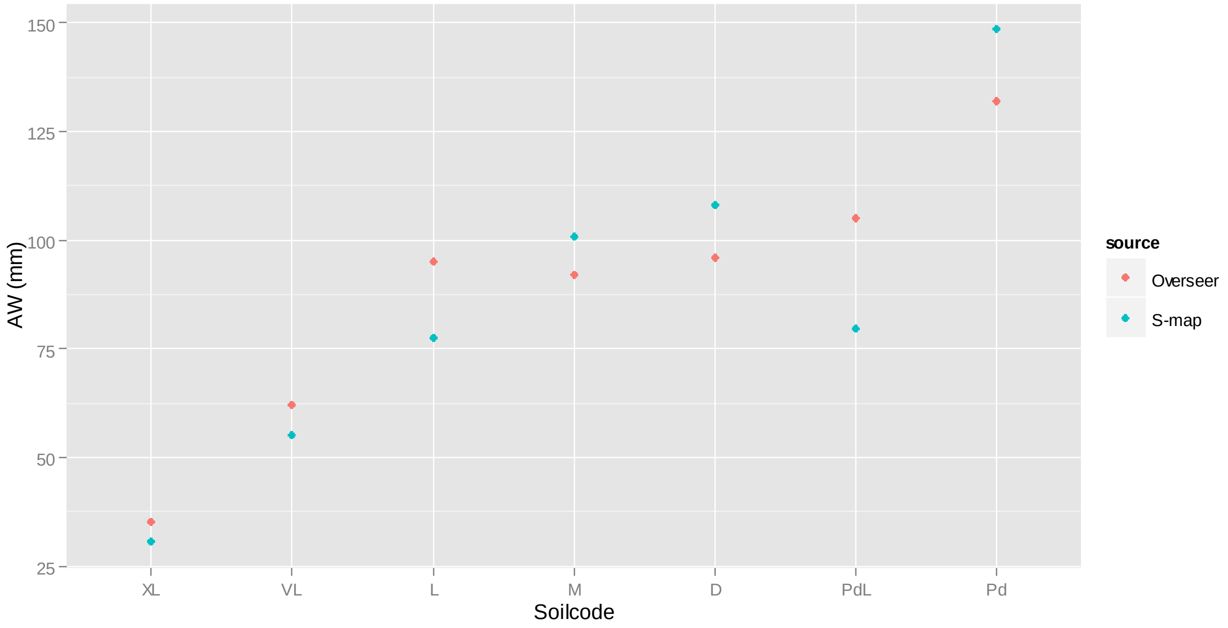


Figure 8 Comparison of available water to 60 cm depth as estimated by S-map and *Overseer* (Level 1) for a set of seven soils covering the range of soils in Canterbury.

4.3.2 Analysis of nutrient losses and denitrification

Estimated nutrient losses from soils within S-map according to soil order are shown in Figure 9 and by AW_{60} and drainage class in Figure 10. Highest losses are from the Brown and Recent soils. As expected, N leached is inversely proportional to AW_{60} (Figure 10) due to the higher water holding capacity resulting in lower drainage and hence lower N leaching. There is less N leached on the more poorly drained soils (probably due to higher denitrification). It is unclear as to why there is a wide range in nitrate-leached estimates from well-drained soils with similar AW_{60}. In particular, the high estimates from these soils should be verified.

Analysis of estimated denitrification from the full S-map dataset indicates some values that seem unreasonably high. These values appear to be due to a combination of low air capacity and high topsoil/subsoil clay (Figure 11and Figure 12).

Figure 12 shows a strong effect of clay on denitrification: where default clay values are used (i.e. under Level 1.9) the estimates of denitrification do not exceed 80 kg/ha, whereas when topsoil and subsoil clay is specified as part of Level 1.all, the maximum value of denitrification is almost 130 kg/ha. Figure 13 shows the interaction between topsoil and subsoil clay content in influencing denitrification. Potential issues with denitrification are explored further in later sections of this report.

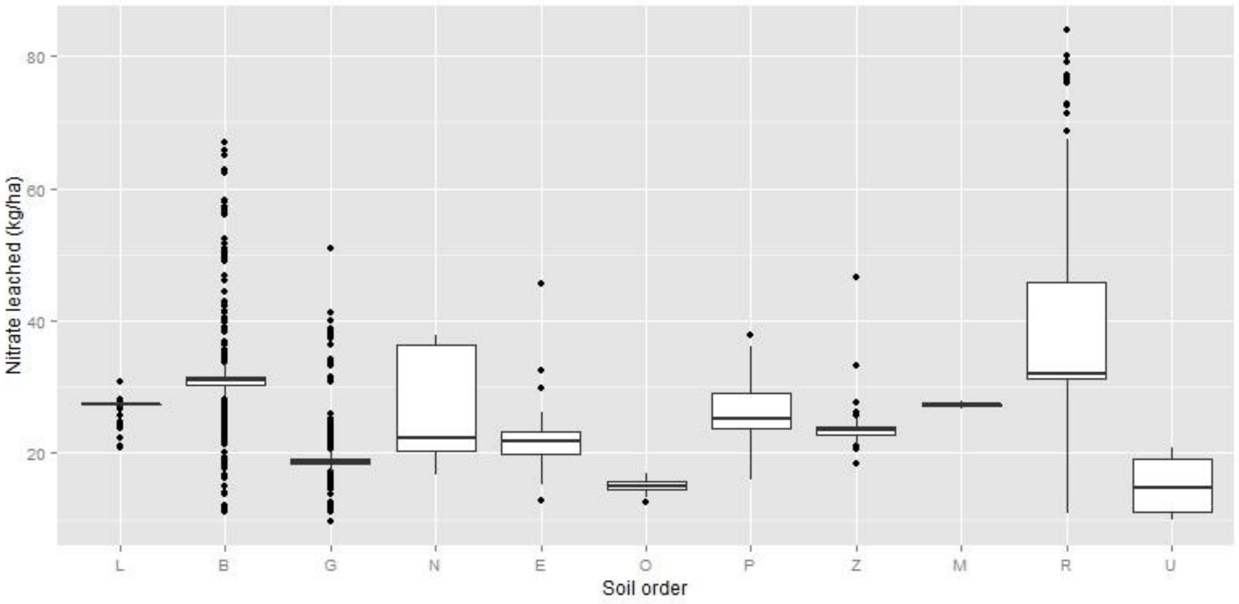


Figure 9 Boxplot of nitrate leached by soil order.

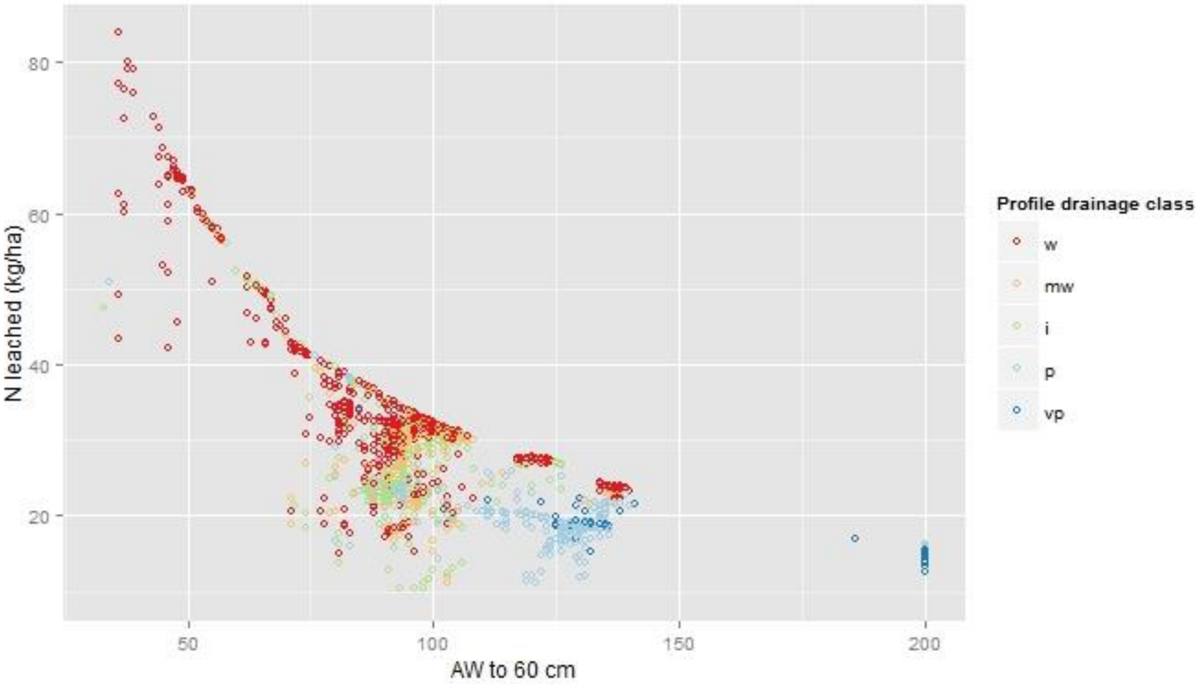


Figure 10 Nitrate leached by soil drainage class as estimated from Level 1.all soil parameters.

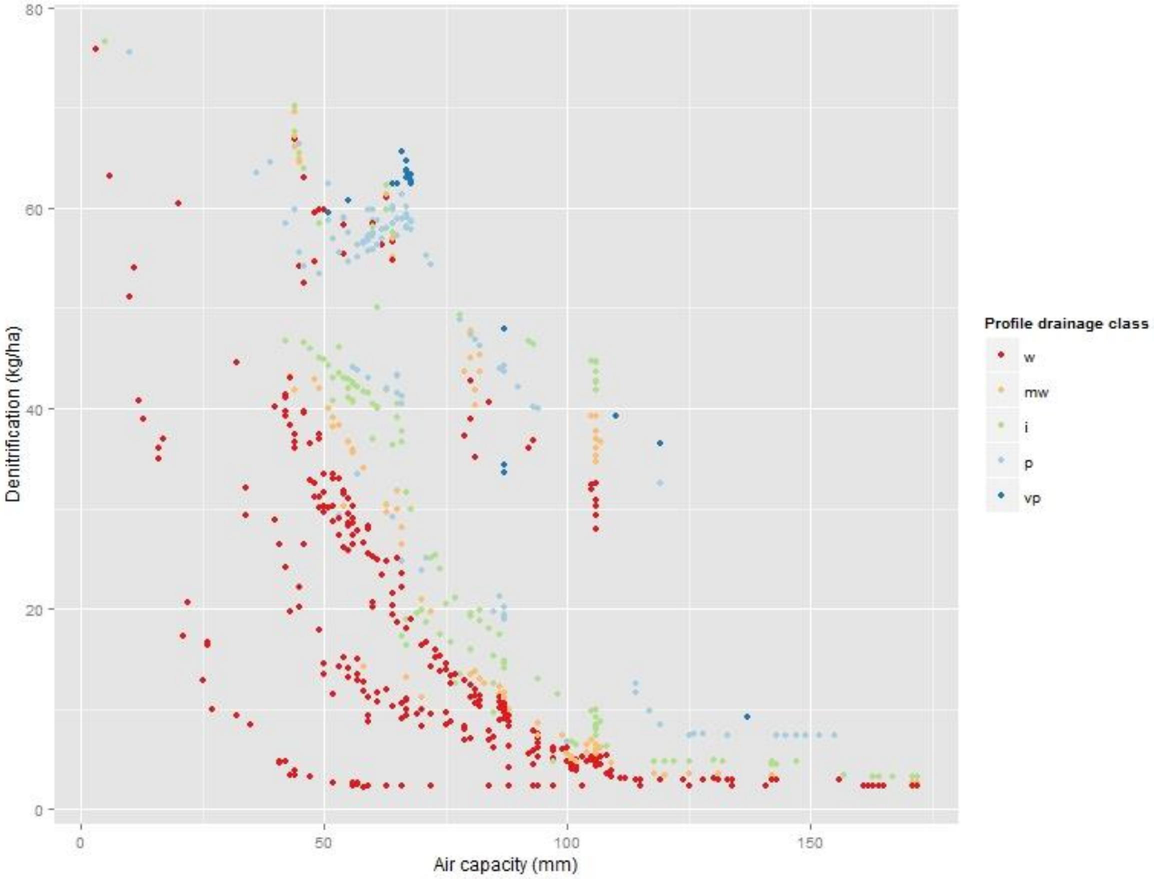


Figure 11 *Overseer* estimates of denitrification by air capacity and profile drainage class from the Level 1.9 soil inputs.

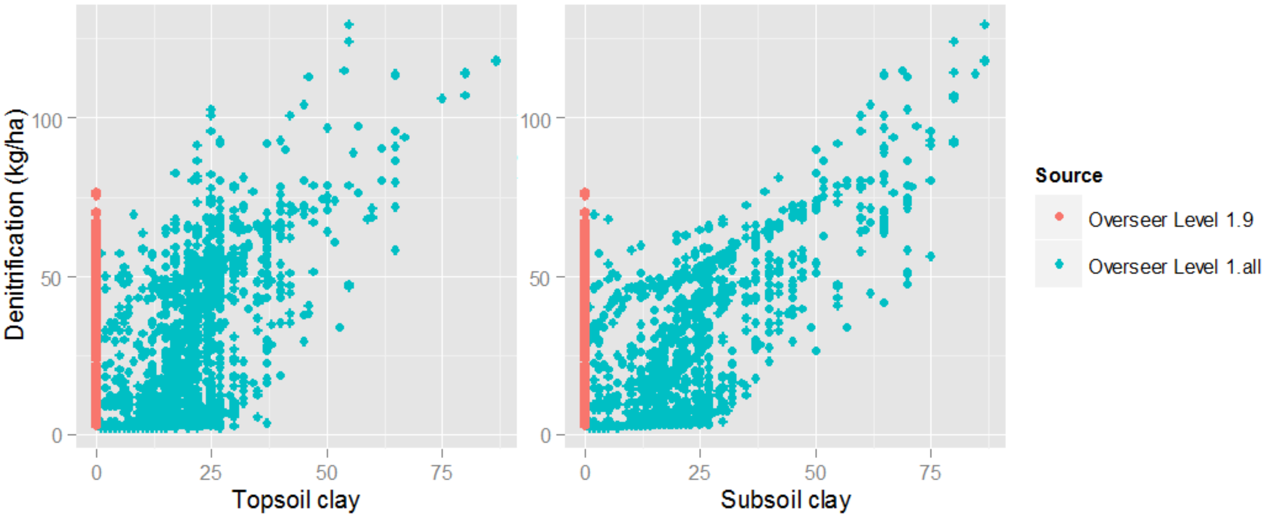


Figure 12 Comparison of denitrification estimates when topsoil clay is specified (blue-green symbols) and when default values are used (red symbols).

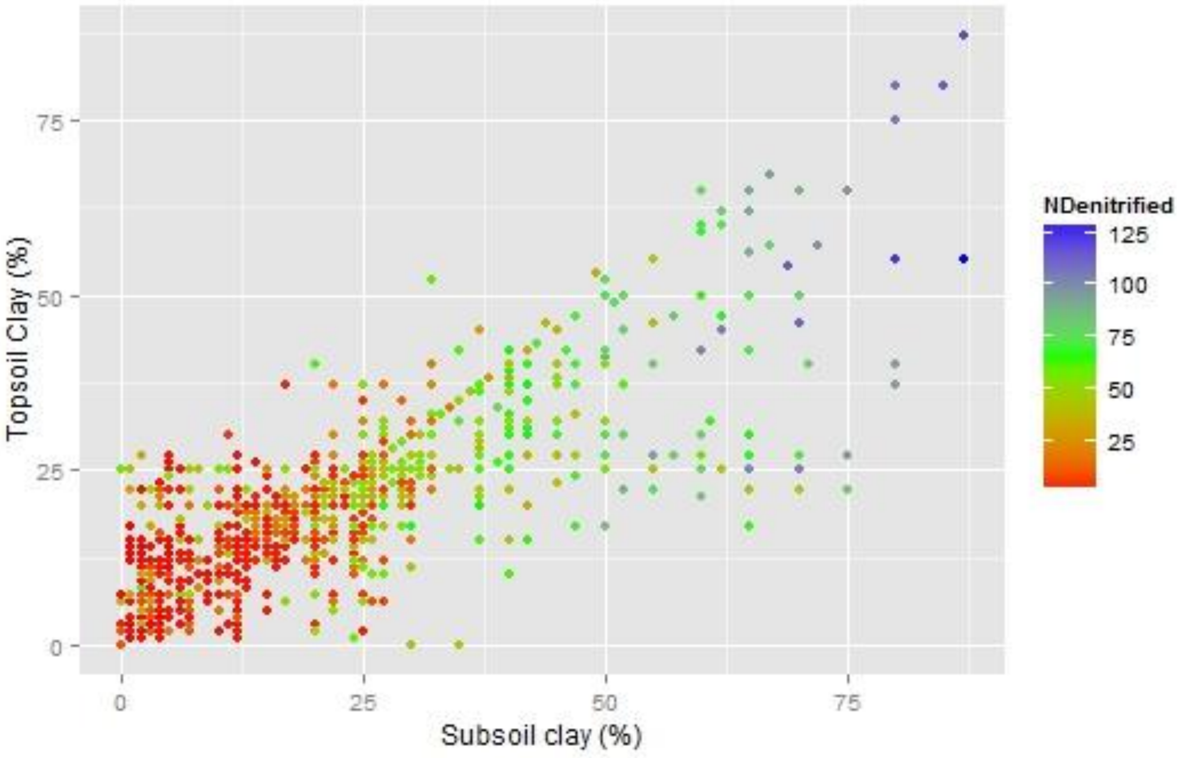


Figure 13 Estimated denitrification by topsoil and subsoil clay content

Figure 14 shows the key *Overseer* outputs from the seven Canterbury soils. The pattern generally follows expected trends as currently understood from measurements and predictions from more mechanistic models. Exceptions to this are:

- L and PdL soils have lower profile available water (AW_{60}) and should therefore have greater drainage and leaching than M and D soils
- XL soils have the fastest drainage rate and should not have lowest values of denitrification. Denitrification values on the M and D soils need checking – they may be too high
- Lower values for of volatilisation for XL are unexpected but probably unimportant, because differences are small (1–1.5 kg N/ha)
- Some runoff is expected on the poorly drained soils due to greater likelihood of ponding.

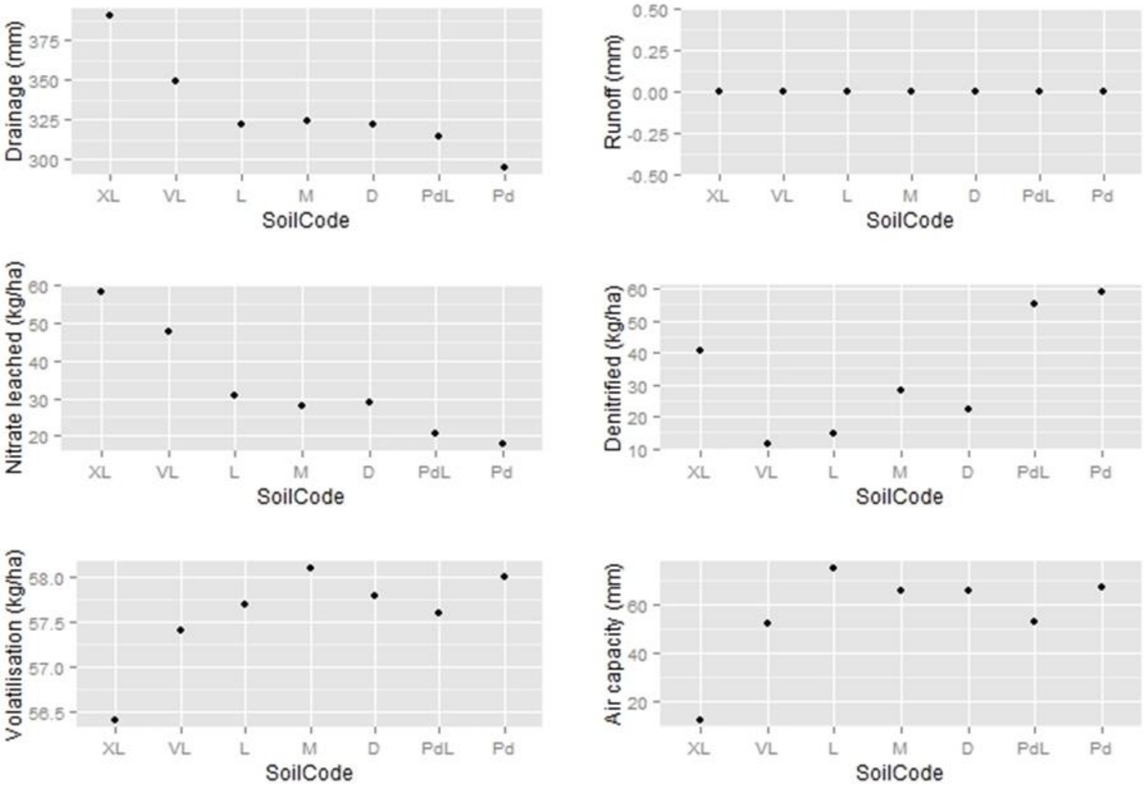


Figure 14 Key *Overseer* outputs for the seven Canterbury soils based on their Level 1.9 soil properties.

Figure 15 compares the Level 1 results with the equivalent Level 2 results. Generally, the Level 2 estimates are an improvement on the Level 1 results, with more separation of the L, M, D and PdL soils. The difference in denitrification and air capacity estimates for the XL soil indicates that the Level 1 issue of very high denitrification for well-drained stony soils with good aeration (noted above) may be due to default total porosity values for the *stony* non-standard layer that are too low. Denitrification from the M and D soils under Level 2 appears to be too high – but this needs testing with experimental data.

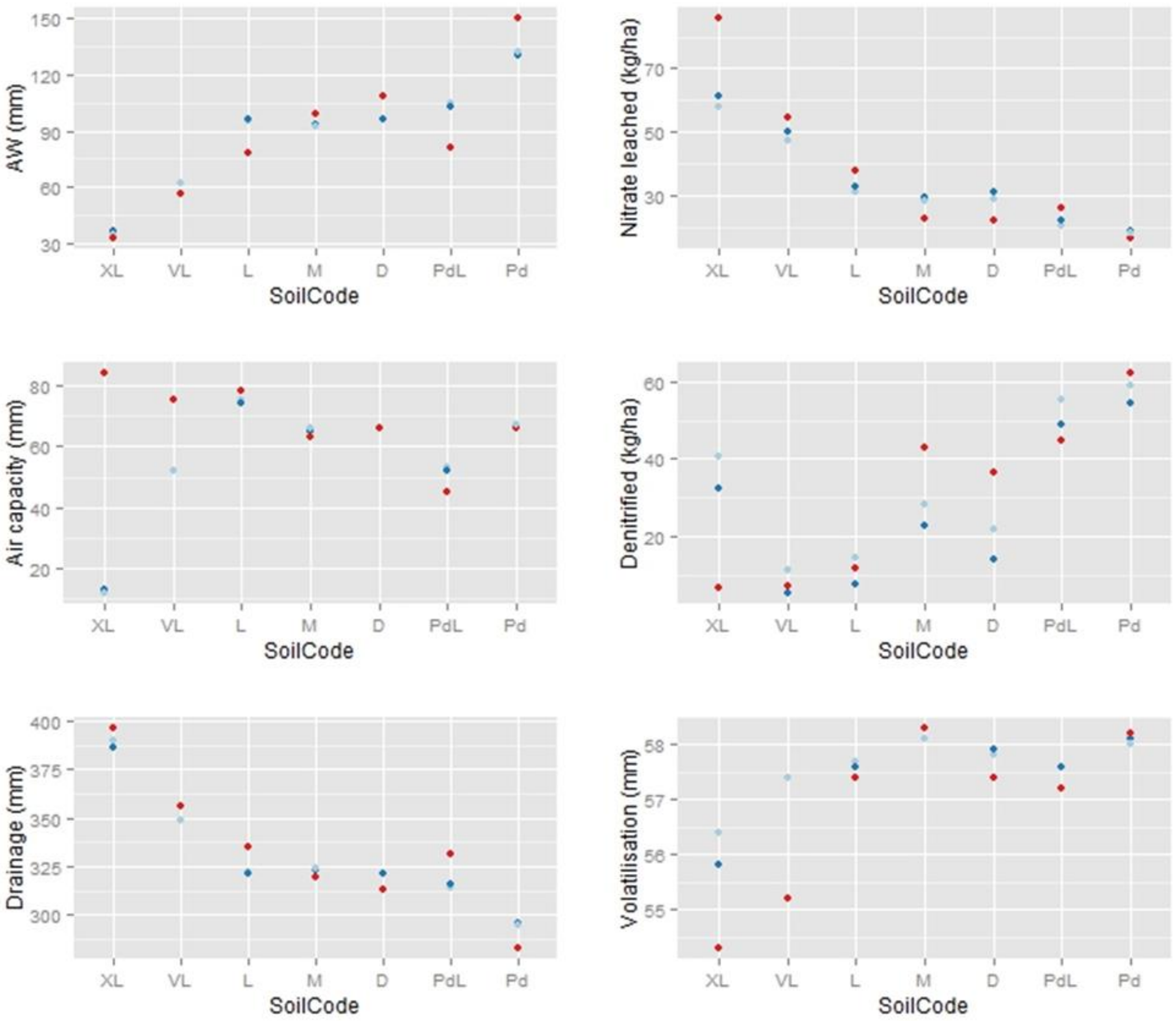


Figure 15 Comparison of *Overseer* results from entering Level 1.9 (top 9 parameters in Table 1 – light blue), Level 1.all (all the parameters in Table 1 – dark blue) and Level 2 (red) soil data. Where there is only one blue symbol, the two Level 1 options have the same result.

4.4 Summary and recommendations relating to Level 1 soil inputs

Soil order alone should not be used to define the soil properties within *Overseer* as it does not capture the significant variability of key soil properties within each soil order. Using the Level 1 soil properties in *Overseer* results in AW_{60} estimates that follow a similar pattern with respect to soil order as the S-map estimates, but with less variability.

We have identified several areas for further development and/or further investigation:

- There are significant differences in *Overseer* and S-map estimates of AW_{60} (which have been noted by end users). No simple cause or source of error for these differences was found. The differences may be due to the inherent limitations of the Level 1 properties to describe the wide range of soils found in New Zealand. For example, soils with moderate stoniness are not well described by the Level 1 properties. Given that there is a need to maintain the Level 1 description of soils where the Level 2 information is not yet available, some attention should be given to improving the Level 1 characterisation:

  - We recommend a revision of the order, subsoil texture group, and non-standard-layer default water content values used within *Overseer*. In particular, *Overseer* appears to overestimate AW_{60} of light soils with a non-standard-layer stony matrix layer.
  - Additional non-standard layers may be needed allowing a better characterisation of very stony and organic layers.
  - The ability to use the subsoil texture group could be extended to other orders, for example, clayey Pallic soils, rather than being limited to Recent and Brown soils.
  - Rooting depth and depth to impeded layer are not working correctly within the model, so the *Overseer* overestimates AW_{60} for soils containing a pan and soils that are shallow to bedrock. This issue is probably already partly resolved.

- Organic soils are not well characterised and should be reviewed.
- The rationale behind the high variability in the estimates of nitrate leached from well-drained soils with the same AW_{60} should be confirmed.
- The following observations indicate that estimates of denitrification should be reviewed:
  - Estimates appear to be overly sensitive to topsoil clay and insensitive to other relevant parameters. The use of clay content as the main driver of the denitrification function should be reviewed
  - The very high estimates of denitrification from an extremely stony soil with good drainage indicate an issue with the way denitrification is calculated
  - The *Overseer* estimates of denitrification of the medium and deep soils seem too high.

  It is noted that the method of estimating denitrification involves a relationship with clay to improve calibration, but the calibration process used a limited range of soil data. It is probable that the denitrification results are an artefact of the calibration process.

- The model does not predict any runoff from poorly drained soils on flat slopes. This is discussed further in Section 6.3.
- *Overseer* users need to have a reference for the topsoil texture group options so that they know what the classes mean. We suggest using the texture groups and texture triangle from Taylor & Pohlen (1970).
- Adoption of any of these recommendations will require a recalibration of the *Overseer* model.

Finally, the Level 1 data currently provided by S-map factsheets could be extended to cover the last five properties on Table 1, or changed to reflect the Level 2 properties. Note that the changeover to Level 2 will result in quite different outputs from *Overseer* for some soils.

5 Analysis of Level 2 soil inputs

This section presents an analysis of the Level 2 soil inputs, i.e. the quantitative soil moisture inputs. The relevant soil data was derived from the NSD and S-map and processed through the test *Overseer* DLL provided by AgResearch.

A set of 558 contrasting scenarios was used to test the sensitivity of *Overseer* outputs to soil attributes and to assess the results according to expert knowledge.

5.1 S-map data used in *Overseer*

The Level 2 soil parameters specify the soil-water properties directly rather than using the Level 1 descriptions of texture and non-standard lower layer to predict values for the soil-water properties.

Table 3 lists the Level 2 soil properties, and shows those properties that were varied as part of the scenarios described in the following section.

Table 3 Level 2 soil properties entered into *Overseer*

Symbol	Depth [m]	Varied	Unit	Name	Overseer description and usage
WP_1	0–0.3	Y	%	Wilting point	Moisture content at wilting point (1500 kPa)
WP_2	0.3–0.6	Y			
WP_3	0.6–0.9	N			
FC_1	0–0.3	Y	%	Field capacity	Moisture content at field capacity (10 kPa)
FC_2	0.3–0.6	Y			
FC_3	0.6–0.9	N			
TP_1	0–0.3	Y	%	Total porosity	Moisture content at saturation (0 kPa)
TP_2	0.3–0.6	Y			
TP_3	0.6–0.9	N			
D_{imped}		N	cm	Depth to impeded layer	Depth to impeded layer
$CLAY_1$	0–0.1	Y	%	Clay content	Percentage of clay
$CLAY_2$	0.1–0.3	N			
$SAND_1$	0–0.1	N	%	Sand	Percentage of sand in topsoil
$DRAIN_{clas}$	0–0.1	Y	1–5	Drainage class	Drainage in natural state
AEC	-	N	%	AEC	Anion exchange capacity (phosphate retention)
Order	-	N	-	Soil Order	NZSC soil order

5.2 Scenarios tested in *Overseer*

This section describes the contrasting 558 scenarios tested.

The standard settings used in all scenarios are listed in

Table 4. These were taken from a simple dairy-farm-system file supplied by AgResearch.

Table 4 Fixed options for all scenarios tested in *Overseer*

Description	Values
Land use	Pastoral, grass only, area 134 ha
Cows	700 milking cows (5 cows/ha)
Hydrophobic	Never
Occurrence of pugging	Rare
Drainage method	None
Fertiliser	None
Supplements	None
Effluent application	None
Wintering off	No

The two climates tested are defined in Table 5.

Table 5 Climate and irrigation scenarios, where PR is annual precipitation, ET is annual evapotranspiration and TEMP is average annual temperature

Symbol	Climate	Location	PR (mm/year)	Irrigation (mm/year]	ET (mm/year)	Temp. (°C)
$CLIM_{dry}$	Dry	South Island, *Canterbury*	600, Low seasonal	380, Centre pivot/lateral (October to March)	900, Moderate seasonal	10°C
$CLIM_{wet}$	Wet	North Island, *Waikato*	1500, Moderate seasonal	0	800, Moderate seasonal	14°C

The three drainage classes are shown in Table 6 and the three slopes tested are summarised in Table 7.

Table 6 Profile drainage class scenarios with the associated saturated hydraulic conductivity K_s as specified in Wheeler & Rutherford (2013)

Symbol	Class number	Current profile drainage class	K_s (mm/day)
$Drain_1$	1	Well	508
$Drain_3$	3	Imperfect	170
$Drain_4$	4	Poor	103

Table 7 Slope scenarios

Symbol	Description	Degree
$Slope_0$	Flat	0°–7°
$Slope_{10}$	Rolling hill	8°–15°
$Slope_{20}$	Easy hill	16°–25°

Four contrasting soil profiles (all Brown Soils) were selected from the NSD (N = normal):

- Cy/N = Tahora – a deep moderately clayey soil
- Lm/N = Edendale – a deep loamy soil
- Sa/N = Mahinapua – a deep sandy soil
- Lm2/N = Lismore – a shallow loamy soil.

To create a further three profiles, the Lismore profile was amended by progressively increasing stone content to create Lismore stony (Lm2sty/N), Lismore very stony (Lm2vsty/N) and Lismore extremely stony (Lm2Xsty/N). Further modification in the soil parameters (except for Lm2Xsty/N) was achieved by increasing or decreasing clay content by 20% (Cy−/Cy+) or total porosity by decreasing or increasing TP by half the difference between TP and FC (TP−/TP+).

The resulting soil properties are reported in Table 8.

Table 8 Soil scenarios. WP is *wilting point*; FC is *field capacity*; TP is *total porosity*, ST is *stoniness*; Subscript 1 stands for layer one and 2 is for layer two as mentioned in the nomenclature of Table 3. The soil textures are *clayey* (Cy); *Loamy* (Lm); *Sandy* (Sa); *Stony loamy* (Lm2Sty); *very stony loamy* (Lm2vsty); *extremely stony loamy* (Lm2Xsty). *Cy−* means that there is 20% less clay; *Cy+* means that there is 20% more clay; TP− indicates reduced TP where TP− = TP − (TP − FC)/2; TP+ indicates increased TP where TP+ = TP + (TP − FC)/2; N means normal)

Symbol	NSD	Texture	Variation	WP_1 (%)	WP_2 (%)	FC_1 (%)	FC_2 (%)	TP_1 (%)	TP_2 (%)	SAND (%)	CLAY (%)	ST_1 (%)	ST_2 (%)
Cy/N	**SB09555**	**Cy**	**N**	25	30	44	38	60	48	4	36	0	0
Lm/N	**SB10134**	**Lm**	**N**	25	29	43	43	56	50	2	28	0	0
Sa/N	**SB10013**	**Sa**	**N**	7	1	25	7	50	45	79	7	0	0
Lm2/N	**SB10111**	**Lm2**	**N**	14	13	34	24	52	52	13	23	0	0
Lm2Sty/N	**SB10111**	**Lm2Sty**	**N**	14	8	33	15	51	29	13	23	0	44
Lm2vsty/N	**SB10111**	**Lm2vsty**	**N**	8	6	19	11	29	23	13	23	44	55
Lm2Xsty/N	**SB10111S**	**Lm2Xsty**	**N**	6	4	16	8	24	17	13	23	53	67
Cy/Cy-	**SB09555**	**Cy**	**Cy-**	25	30	44	38	60	48	4	29	0	0
Lm/Cy-	**SB10134**	**Lm**	**Cy-**	25	29	43	43	56	50	2	22	0	0
Sa/Cy-	**SB10013**	**Sa**	**Cy-**	7	1	25	7	50	45	79	6	0	0
Lm2/Cy-	**SB10111**	**Lm2**	**Cy-**	14	13	34	24	52	52	13	18	0	0
Lm2Sty/Cy-	**SB10111**	**Lm2Sty**	**Cy-**	14	8	33	15	51	29	13	18	0	44
Lm2vsty/Cy-	**SB10111**	**Lm2vsty**	**Cy-**	8	6	19	11	29	23	13	18	44	55
Cy/Cy+	**SB09555**	**Cy**	**Cy+**	25	30	44	38	60	48	4	44	0	0
Lm/Cy+	**SB10134**	**Lm**	**Cy+**	25	29	43	43	56	50	2	33	0	0
Sa/Cy+	**SB10013**	**Sa**	**Cy+**	7	1	25	7	50	45	79	9	0	0
Lm2/Cy+	**SB10111**	**Lm2**	**Cy+**	14	13	34	24	52	52	13	28	0	0
Lm2Sty/Cy+	**SB10111**	**Lm2Sty**	**Cy+**	14	8	33	15	51	29	13	28	0	44
Lm2vsty/Cy+	**SB10111**	**Lm2vsty**	**Cy+**	8	6	19	11	29	23	13	28	44	55
Cy/TP-	**SB09555**	**Cy**	**TP-**	25	30	44	38	52	43	4	36	0	0
Lm/TP-	**SB10134**	**Lm**	**TP-**	25	29	43	43	50	47	2	28	0	0
Sa/TP-	**SB10013**	**Sa**	**TP-**	7	1	25	7	38	26	79	7	0	0
Lm2/TP-	**SB10111**	**Lm2**	**TP-**	14	13	34	24	43	38	13	23	0	0
Lm2Sty/TP-	**SB10111**	**Lm2Sty**	**TP-**	14	8	33	15	42	22	13	23	0	44
Lm2vsty/TP-	**SB10111**	**Lm2vsty**	**TP-**	8	6	19	11	24	17	13	23	44	55
Cy/TP+	**SB09555**	**Cy**	**TP+**	25	30	44	38	68	54	4	36	0	0
Lm/TP+	**SB10134**	**Lm**	**TP+**	25	29	43	43	63	54	2	28	0	0
Sa/TP+	**SB10013**	**Sa**	**TP+**	7	1	25	7	63	64	79	7	0	0
Lm2/TP+	**SB10111**	**Lm2**	**TP+**	14	13	34	24	61	66	13	23	0	0
Lm2Sty/TP+	**SB10111**	**Lm2Sty**	**TP+**	14	8	33	15	60	36	13	23	0	44
Lm2vsty/TP+	**SB10111**	**Lm2vsty**	**TP+**	8	6	19	11	34	29	13	23	44	55

5.3 Analysis of the hydrological model

Figure 16 illustrates the *Overseer* model's description of soil hydrology. The model, depicted by the red 'bucket' in the figure, has one layer that is subdivided into three layers for the sole purpose of 'distributing' the water uptake by the vegetation.

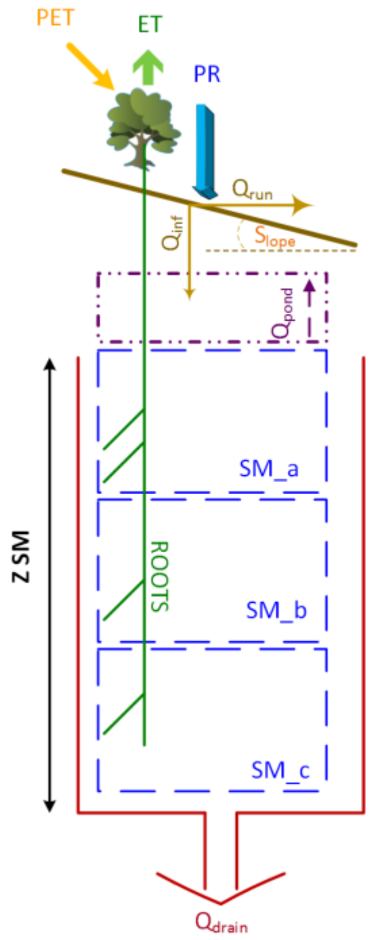


Figure 16 Schematic description of *Overseer*. Where Q_{drain}, Q_{pond}, Q_{run}, Q_{inf}, PR, ET, PET are respectively the flows of *drainage*, *ponding*, *runoff*, *infiltration*, *precipitation*, *evapotranspiration* and *potential evapotranspiration*.

5.3.1 Expected hydrological results as a result of scenario modelling

From a hydrological perspective, it is expected that as the *slope* of the terrain becomes steeper more *precipitation* goes to *runoff* (Q_{run}) and less water infiltrates into the soil. This means that there is less water available in the soil for uptake by vegetation and therefore there should be a reduction in *evapotranspiration* (ET) and *drainage* (Q_{drain}). Similarly, when the topsoil *clay* content increases, *runoff* increases with associated reduction in *evapotranspiration* and *drainage*. On the other hand, an increase in the minimum profile *saturated hydraulic conductivity* (K_{s_drain}) should result in an increase in *drainage* and therefore a decrease in *evapotranspiration* and *runoff*. This is due to the increase in drainage reducing the water stored in the soil and the available water for plant uptake.

As *available water content* (AWC) increases then more water can be stored in the soil, causing an increase in *evapotranspiration* and a decrease in drainage, but decreasing the probability that the soil becomes saturated and therefore decreases the probability of *runoff*. Table 9 summarises the trends that are expected to occur as result of modelling the same land use across different environmental parameters.

Table 9 Expected results of the behaviour (increase or decrease) of *evapotranspiration* (ET), *drainage* (Q_{drain}) and *runoff* (Q_{run}) when *slope* (Slope), bottom *hydraulic conductivity* ($K_{\mathrm{s\_drain}}$), *topsoil clay* ($CLAY_1$), *available water content* (AWC) where AWC = FC − WP. The water fluxes ET, Q_{drain}, Q_{run} are depicted in Figure 16

An increase:	Causes		
↗↗	ET	Q_{drain}	Q_{run}
Slope	↘	↘	↗↗
$CLAY_1$	↘	↘	↗↗
$K_{\mathrm{s\_drain}}$	↘	↗↗	↘
AWC	↗↗	↘	↘

The following equation describes the relationship between *evapotranspiration*, *drainage* and *runoff*:

$$\mathrm{PR} + \mathrm{IRRIGATION} = \mathrm{ET} + Q_{\mathrm{run}} + Q_{\mathrm{drain}} + \Delta S \qquad (1)$$

where PR is precipitation, ET is evapotranspiration, Q_{run} is runoff, Q_{drain} is deep drainage, and S is the amount of water stored in the soil profile.

5.3.2 Assessment of the hydrological results

The hydrological outputs did not respond to the following *Overseer* soil parameters:

MaxRootDepth (*maximum rooting depth*): Had no effect on hydrology outputs. In the model, rooting depth only affects the amount of N leached.

ImpededLayerDepth (*depth to impeded layer*): had no effect in Level 1, and in Level 2 resulted in incorrect values for total FC and WP, and therefore AW_{60} (see Table 10). This is a known bug.

Note we are not convinced of the need for both parameters for the hydrology model.

Table 10 AW_{60} estimates when MaxRootDepth and ImpededLayerDepth parameters are changed

AW mm (0–30 cm)	AW mm (30–60 cm)	MaxRootDepth (cm)	ImpededLayerDepth (cm)	Overseer AW_{60}	Correct AW_{60}
42	15	-	-	57	57
		30	30	47	42
		-	30	47	42
		30	-	57	57

The results show that the long-term storage of the water in the soil (ΔS) equals 0. This seems to be a reasonable assumption for long-term simulations as performed by *Overseer*.

Expected results for runoff

Figure 17 shows that an increase in slope causes an increase in *runoff* (overland flow) and a decrease in *drainage* and an increase in topsoil clay causes a decrease in *infiltration* and an increase in *runoff*.

Unexpected results for runoff

We would have expected that a decrease in permeability (increasing Drain1) would have caused an increase in *runoff* and a decrease in ET. *Overseer* appears to limit the prediction of runoff to the topsoil clay content and ignores the effect of drainage class. This is partly due to a known bug whereby soil profile moisture contents can increase above saturation but there is no feedback on runoff (http://www.*Overseer*.co.nz/*OVERSEER*Model/Bugs.aspx).

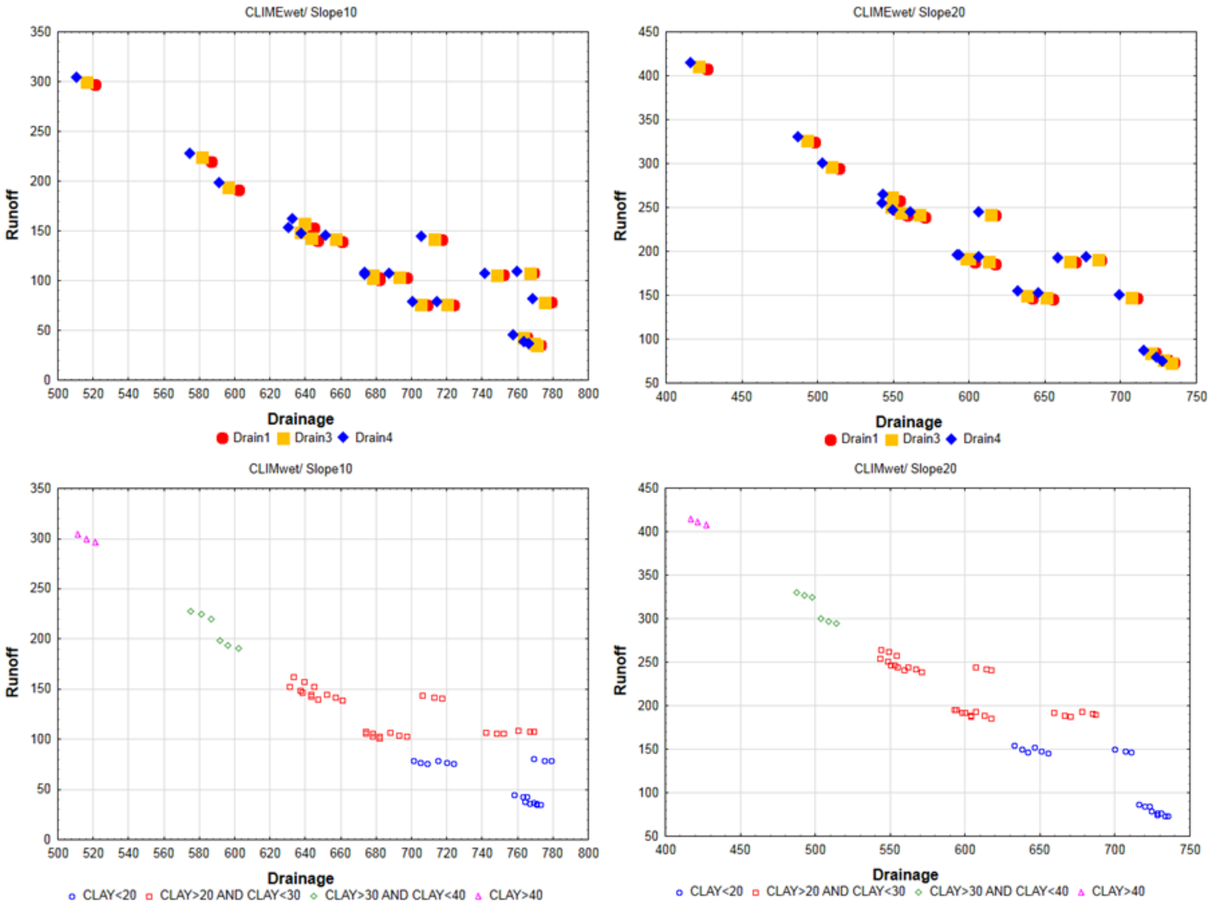


Figure 17 Correlation between drainage in mm/year (Q_{drain}) and runoff in mm/year (Q_{run}) subdivided into slope (0–7 and 8–15 degrees) drainage class (well-drained, imperfectly drained and poorly drained) (upper graphs) and topsoil clay percent (lower graphs). Drainage class is described in Table 6.

.

Expected results for drainage

The negative correlation between AWC and *drainage* for soils with AWC less than 43%, as shown in Figure 18, is expected. The more water a soil can store (greater AWC), the less likely that water will be lost to drainage. *Overseer* predicts well that higher drainage occurs for the wetter climate (note the large difference in the *y*-axis scales).

Unexpected results for drainage

Under the dry-climate scenario there appears to be an anomaly in the relative drainage between the four soils with highest AWC. For example, we would not expect the Lm and LmSty soils to have greater drainage than the Cy and Sa soils since they have a lower AWC.

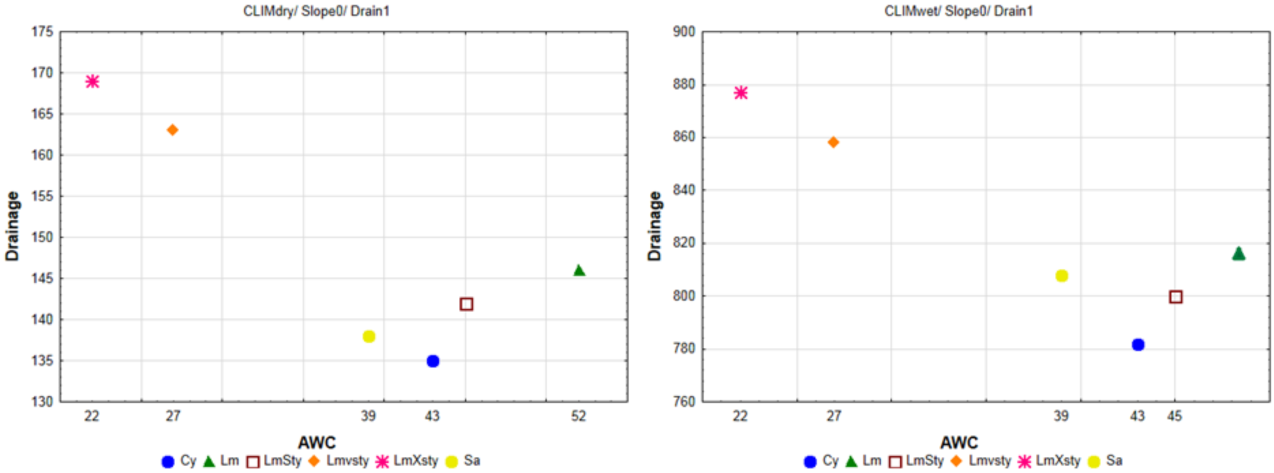


Figure 18 Correlation between AWC (%) with drainage (mm/year) for the six base soils (Table 8) symbolised by texture class. There is a negative correlation between drainage and AWC

Expected results for evapotranspiration

The shape of the AWC − ET curve (Figure 19) looks correct. An increase in the water storage capacity of the soil, characterised by AWC, causes an increase in ET. If soil has a high AWC (allowing plenty of available water), the grass could transpire to its maximum rate during most of the year and thus ET becomes close to the potential evapotranspiration (PET). This explains why the AWC − ET relationship levels off above 12% AWC.

The ET of CLIM_{dry} (837 mm) is much greater than CLIM_{wet} (691 mm). This is mainly explained by the 100 mm greater PET for CLIM_{dry}. Also CLIM_{dry} is irrigated during months of high PET and low rainfall.

Unexpected results for evapotranspiration

Figure 19 shows that ET did not respond to slope. We would expect that steeper slopes should reduce the amount of water infiltrated into the soil by increasing *runoff* and thus decrease ET (Table 9). The possible underestimation of runoff has been noted earlier.

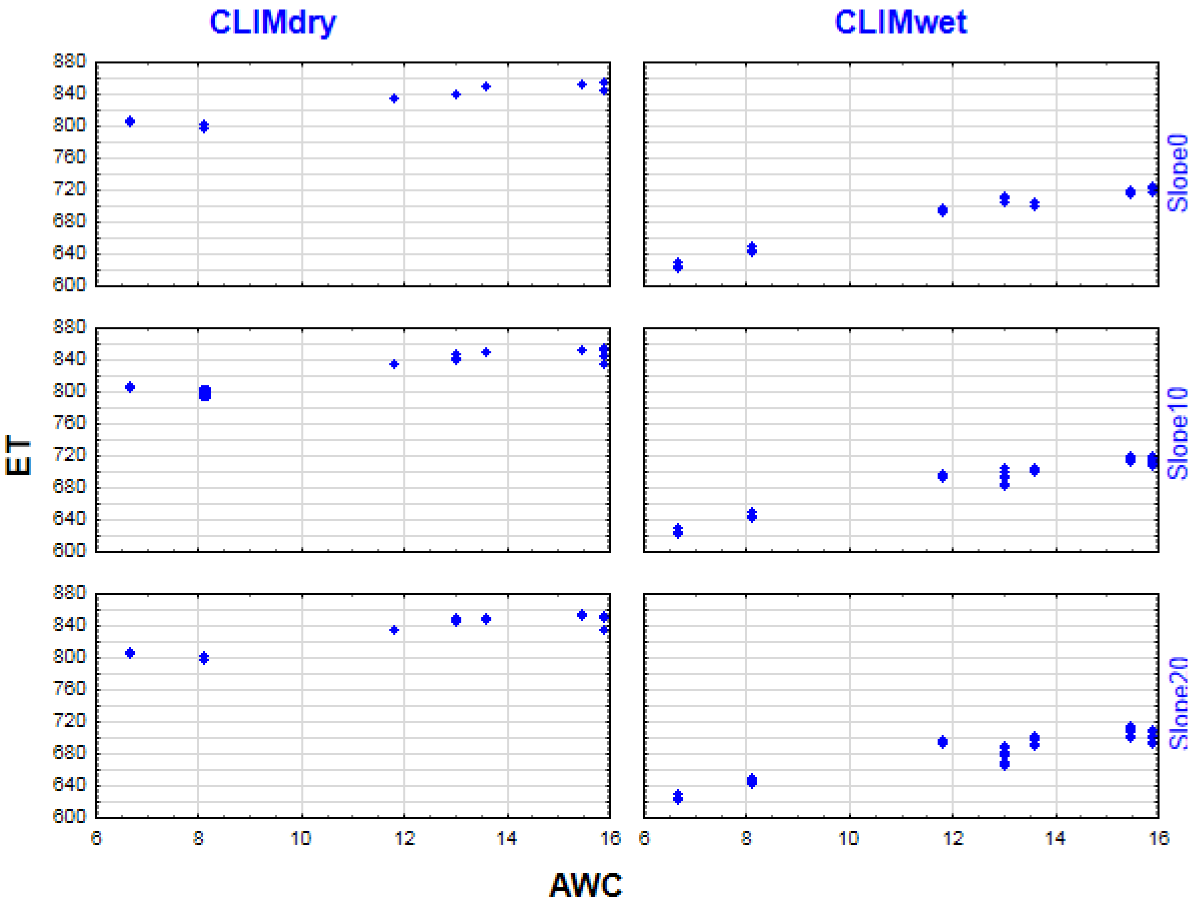


Figure 19 Correlation between AWC (%) for 0–60 cm depth [FC − WP] and ET (mm/year) for three slope classes (0–7, 8–15, 16–25 degrees) used in *Overseer* and for $CLIM_{dry}$ and $CLIM_{wet}$.

5.4 Analysis of the nutrient model

For this part of the investigation we have set SLOPE to $Slope_0$ (to eliminate interactions with runoff) and we ran the scenarios for both $CLIM_{dry}$ and $CLIM_{wet}$.

5.4.1 Expected trends for nutrient outputs

From a hydrological and biochemical perspective, *denitrification* (N_{denit}) is carried out by anaerobic bacteria, which reduce nitrogen to a gaseous form. Bacteria activity thrives in warmer climates. For N_{denit} to take place, the soil should contain no more than 10% oxygen and therefore denitrification begins when threshold water-filled-porosity values are exceeded (Wheeler 2012; Wheeler et al. 2014).

Denitrification (N_{denit}) is expected to increase with:

- INCREASING TEMPERATURE: bacteria more active in warmer climates
- INCREASING RAINFALL: greater potential for inflow of water to fill pore spaces
- INCREASING CLAY CONTENT: clay has a greater proportion of smaller pores and therefore is more susceptible to lower oxygen diffusion rates
- DECREASING AIR CAPACITY: greater probability of having low aeration when FC is exceeded
- DECREASING AWC: in soils with similar permeability, soils with lower AWC will have greater frequency of water being at or above FC
- DECREASING KS_DRAIN: increases the probability of waterlogging
- DECREASING NITRATE LEACHED: more nitrogen remains in the soil to be subject to denitrification.

Nitrate leaching (N_{loss}) is expected to increase with:

- INCREASING RAINFALL: increased percolation through the soil
- DECREASING CLAY CONTENT: when clay content decreases runoff, there is greater infiltration with greater potential for water to drain
- DECREASING AWC: increased percolation through the soil because less water is stored in the profile
- DECREASING DENITRIFICATION: more nitrogen remains in the soil to be subject to leaching.

These expected trends of denitrification and nitrate leaching are summarised in Table 11.

Table 11 Expected results of the behaviour (increase or decrease) of *denitrification* (N_{denit}) and *nitrate leaching* (N_{loss}) when the following variables increase: *temperature (TEMP), precipitation* (PR), *topsoil clay* (*CLAY*), *air capacity* (AC) [TP−FC], *available water content* (AWC) [FC−WP], bottom *hydraulic conductivity* ($K_{\text{s\_drain}}$)

An increase:	Causes	
↗↗	N_{denit}	N_{loss}
TEMP	↗	-
PR	↗	↗↗
CLAY	↗	↘
AC	↘↘	-
AWC	↘	↘↘
$K_{\text{s\_drain}}$	↘↘	-
N_{denit}	-	↘
N_{loss}	↘	-

5.4.2 Assessment of the nutrient results

Expected results for denitrification

The results shown in Figure 20 show that the driving factors for N_{denit} in *Overseer* are (1) climate, (2) clay, and (3) AC (air capacity = TP − FC %). Denitrification in *Overseer* appears to be more sensitive to CLAY content than to AC. As expected, N_{denit} is higher for $\mathrm{CLIM}_{\mathrm{wet}}$ than under $\mathrm{CLIM}_{\mathrm{dry}}$. This is because the average temperature of $\mathrm{CLIM}_{\mathrm{wet}}$ in the North Island is 14°C compared with 10°C in the South Island.

Figure 20 shows that N_{denit} increases markedly at two thresholds of approximately AC < 12% and CLAY > 20%. There is a general increase in N_{denit} with increasing CLAY and with decreasing AC.

Unexpected results for denitrification

The lower graphs of Figure 20 record the effect of AC and $\mathrm{K}_{\mathrm{s\_drain}}$ (drainage class) on $\mathrm{N}_{\mathrm{denit}}$. We expected $\mathrm{N}_{\mathrm{denit}}$ to be very sensitive to the drainage class but the results show only a weak relationship. The drainage class is a surrogate used to estimate $\mathrm{K}_{\mathrm{s\_drain}}$ for the soil (see K_{s} association with drainage in (

Table 6). With lower K_{s_drain} water will accumulate above FC in the soil when the addition of water at the surface exceeds the drainage rate determined by K_{s_drain}. Under these conditions, water-filled-pore-space will decrease below threshold values (the main driver of denitrification, see fig. 2 in Wheeler (2012)) and thus promote denitrification. This suggests that the effect of K_{s_drain} in Overseer is too weak, and should be reviewed.

The relatively high denitrification values for the well-drained LmSty and Lmvsty soils (Figure 20) are higher than we would expect, particularly under wet climate. These soils have reduced TP (Table 8) and thus have low AC. However, these soils have high permeability, good aeration in the fine fraction, and therefore low vulnerability to denitrification (Mojsilovic & Webb 2013). We recommend that this result for very stony soils be further verified under other farm scenarios to confirm that high levels of denitrification for stony soils can be justified (especially given the moderate levels of denitrification using Level 1 soil parameters for some extremely stony soils with very low AC and low clay content – see Figure 14).

Comparing model results for the Cy/N and two Lm/N soils also highlights disturbingly high estimates of denitrification for the Lm/N soil with very low AC in the subsoil. We would expect denitrification to be similar for the two Lm soils and less than the Cy soil. Some examples of these results are given in Table 12.

Table 12 Denitrification estimates for three soils under different climate/slope/drainage class scenarios

	Denitrification (kg/ha)	
Soil	ClimWet/Slope0/Drain1	ClimDry/Slope20/Drain3
Cy/N	69	42
Lm/N	108	82
Lm2/N	4	2

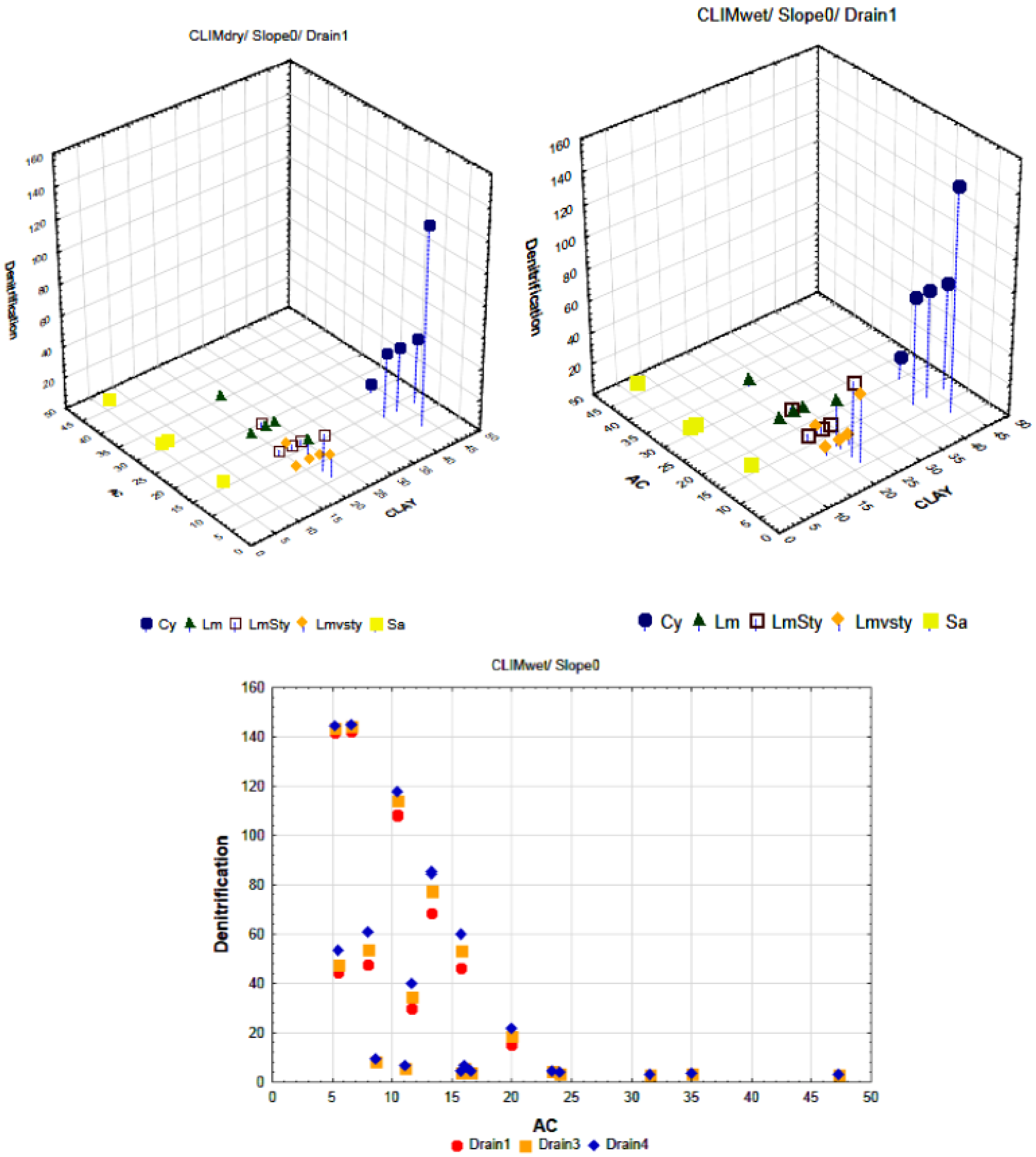


Figure 20 Correlation between CLAY (%), AC (%) and denitrification (kg/ha) subdivided by *texture* (upper graphs) and *drainage class* (for the bottom graph).

Expected results for nitrate leached

Figure 21 shows that AWC is a major driving factor for N_{loss} (leaching). As expected, leaching is high at the low end of AWC and vice versa. The lower leaching for Cy soils is attributed to greater denitrification.

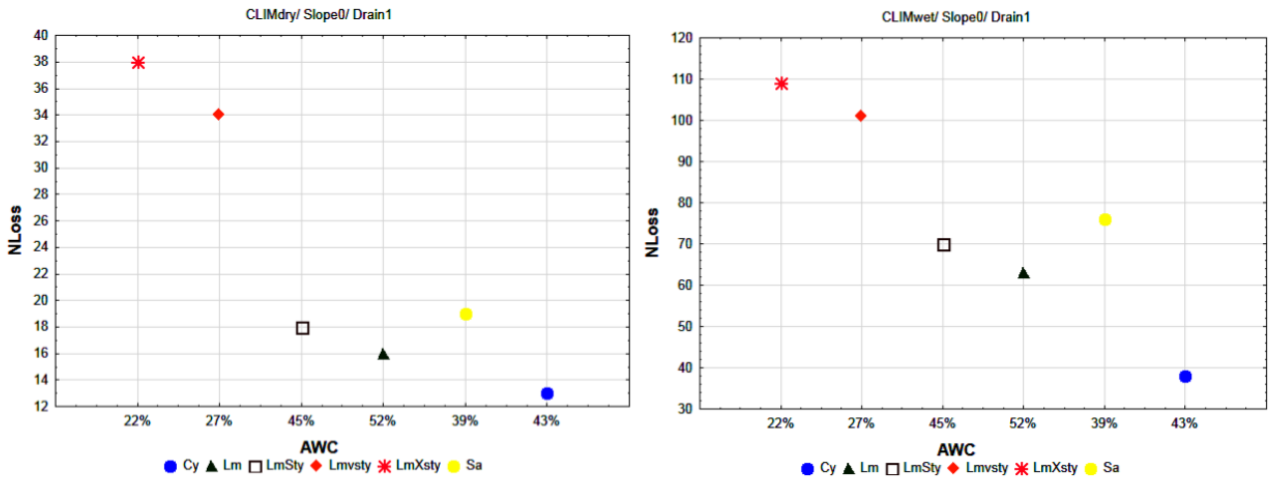


Figure 21 Correlation between AWC with N_{loss} (kg/ha) for the six base soils (Table 8), symbolised by texture class

Expected results of relationship between leaching and denitrification

A negative correlation between N_{loss} and N_{denit} was expected for soils with the same leaching potential (similar AWC) since as denitrification increases, there is less nitrate available to be leached. The Cy and Lm soils in Figure 22 have similar AWC and as expected the Cy soil, with high denitrification, has lower leaching loss compared with Lm. However, the differences are smaller than expected, e.g. in the dry-climate simulation, the increase of 39 kg/ha in denitrification relates to a nitrate loss difference of just 3 kg/ha.

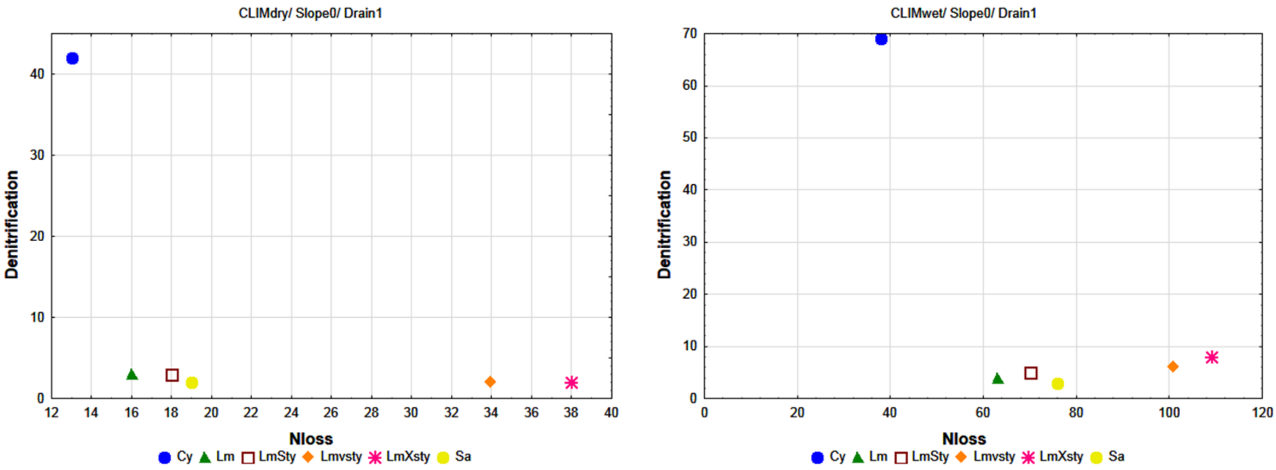


Figure 22 Correlation between denitrification and leaching (N_{loss}).

5.5 Summary and recommendations from the Level 2 soil analysis

5.5.1 Use of the soil water characteristics information (Level 2)

Landcare Research has recently developed new S-map ptfs for estimating water content (θ) at key points on the soil moisture release characteristic curve ($\theta(h)$) (section 4.2.2). Additional ptfs have been developed to calculate values for TP (θ_0), FC (θ_{10}) and WP (θ_{1500}) over three depth ranges (0–30 cm, 30–60 cm and 60+ cm). These values were tested in the Level 2 analyses. As discussed in Section 4, describing the soils with the more quantitative Level 2 will better describe the variability found in New Zealand's soils than the more qualitative Level 1 approach, and the reported *Overseer* AW_{60} estimates will be the same as the AW_{60} reported on the S-map factsheets.

However, before the Level 2 approach can be recommended to users, the following issues need to be resolved:

- Use of the maximum rooting depth and depth to impeded layer parameters in *Overseer* should be corrected.
- Estimates of denitrification especially from the extremely stony soils using Level 2 data from S-map should be investigated.
- A cropping scenario should also be tested. Our modelling has focused on a pasture scenario; we have not looked at the soil parameters to a depth of 1.5 m as modelled in a cropping farm.
- The significance of using just two layers of 0–30 cm and 30–60 cm to describe a soil profile to 60 cm depth should be tested.

5.5.2 Other findings

The following results require further investigation and testing:

- DRAINAGE CLASS (K_{s_drain}): has practically no impact on runoff, percolation, evapotranspiration, denitrification and nitrate leaching. This may be due to the lack of any feedback between saturated soils and runoff.
- TOPSOIL CLAY CONTENT: impact seems to be over-exaggerated compared with other factors. For example (a) CLAY is a more important factor than drainage class in the computation of drainage and runoff; (b) CLAY is more important in the computation of denitrification than the permeability of the profile.
- LOW POROSITY IN VERY STONY WELL-DRAINED SOILS: causes higher denitrification than expected.
- SLOPE: was found to be insensitive to evapotranspiration.
- DEPTH TO IMPEDED LAYER & MAXIMUM ROOTING DEPTH: soil parameters give incorrect results. The option to enter the 'maximum rooting depth' parameter should be reviewed – we suggest that the 'depth to impeded layer' parameter is sufficient at least for pasture simulations.

In the next section we will propose methods to improve the partitioning between ponding, runoff and infiltration. This would also improve the estimates of drainage.

6 Further analysis of soil-related issues in *Overseer*

In this section we take a more theoretical approach to examining some of the issues identified in our analysis of both the Level 1 and Level 2 soil data. We also make some more general comments related to using soil information from S-map.

6.1 Improved methods of estimating saturated hydraulic conductivity

In *Overseer* the *saturated hydraulic conductivity*, K_s, is computed solely from the clay content using the following equation (Wheeler & Rutherford 2013):

$$K_s = 14611 \times CLAY^{-3.48} \, . \tag{2}$$

The estimation of K_s is based on the average clay content for topsoil horizons within each natural soil drainage class for soils in the NSD. This is a reasonable method of grading K_s when limited soil data are available. However, data held at Landcare Research indicate that the K_s values may be on the high side, as reported in Table 13. Changing these values is likely to have an impact on daily drainage rates, which affect the wetland and riparian strip models, and on runoff induced by soils becoming saturated.

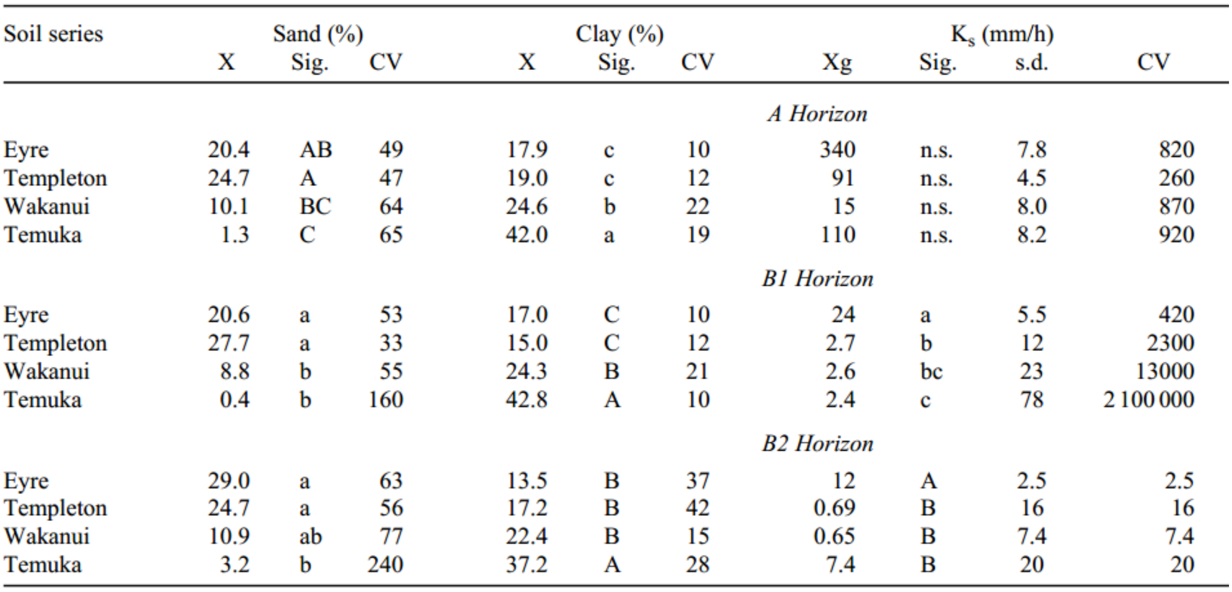
Table 13 Saturated hydraulic conductivity K_s for current profile drainage class currently used in *Overseer* (Wheeler & Rutherford 2013) compared with the ones suggested by us (based on our datasets)

Class number	Current profile drainage class	Overseer K_s (mm/day)	Proposed K_s (mm/day)
1	Well	508	240
2	Moderately well	261	168
3	Imperfect	170	96
4	Poor	103	24
5	Very poor	38	0.72

The current *Overseer* estimate may be in error as topsoil clay content is not necessarily a good prediction of subsoil factors that are limiting the drainage rate, and soil texture (clay content) is not always a good predictor of hydraulic conductivity. This can be seen in the results from a study of soil physical properties for four soil series in Canterbury (Table 14). The data show that clay soils often have high K_s in the upper horizons. Soils with high clay content generally form well-developed structural aggregates that transmit water along structure faces. The same dataset also indicates that dense silt loam horizons in Pallic soils often have values for K_s less than 0.22 mm/day.

Therefore we believe that there is an opportunity to provide more accurate K_s values wherever S-map data is available. There are two methods that could be used to derive K_s from S-map data (0 and 6.1.2).

Table 14 Relationship between soil texture and saturated hydraulic conductivity for four soil series in Canterbury (from Webb et al. 2000). Results are averages for 27 cores from 9 soil profiles. (X, mean; CV, % coefficient of variability; Xg, geometric mean; s.d., standard deviation multiplication/division factor for geometric mean)



Soil series	Sand (%)			Clay (%)			K_s (mm/h)			
	X	Sig.	CV	X	Sig.	CV	Xg	Sig.	s.d.	CV
							A Horizon			
Eyre	20.4	AB	49	17.9	c	10	340	n.s.	7.8	820
Templeton	24.7	A	47	19.0	c	12	91	n.s.	4.5	260
Wakanui	10.1	BC	64	24.6	b	22	15	n.s.	8.0	870
Temuka	1.3	C	65	42.0	a	19	110	n.s.	8.2	920
							B1 Horizon			
Eyre	20.6	a	53	17.0	C	10	24	a	5.5	420
Templeton	27.7	a	33	15.0	C	12	2.7	b	12	2300
Wakanui	8.8	b	55	24.3	B	21	2.6	bc	23	13000
Temuka	0.4	b	160	42.8	A	10	2.4	c	78	2 100 000
							B2 Horizon			
Eyre	29.0	a	63	13.5	B	37	12	A	2.5	2.5
Templeton	24.7	a	56	17.2	B	42	0.69	B	16	16
Wakanui	10.9	ab	77	22.4	B	15	0.65	B	7.4	7.4
Temuka	3.2	b	240	37.2	A	28	7.4	B	20	20

6.1.1 Estimating saturated hydraulic conductivity from morphologic descriptors

Morphologic descriptors available in S-map such as *ped size*, *ped type*, *packing class*, *tightness* and *clay content* can be used to predict K_s. Griffiths et al. (1999) developed functional horizons based on these morphologic descriptors to predict K_s. For instance, they found a combination of *low packing* and *fine peds* with *rough surfaces* indicated a large K_s, while one of *high packing*, *coarse peds* with *smooth faces* was associated with a low K_s (Griffiths et al. 1999; Webb 2003). The results of the prediction of K_s and K_{s_40} (h = 40 kPa) based on functional horizons based on *ped size*, *packing* and clay are shown in Figure 23.

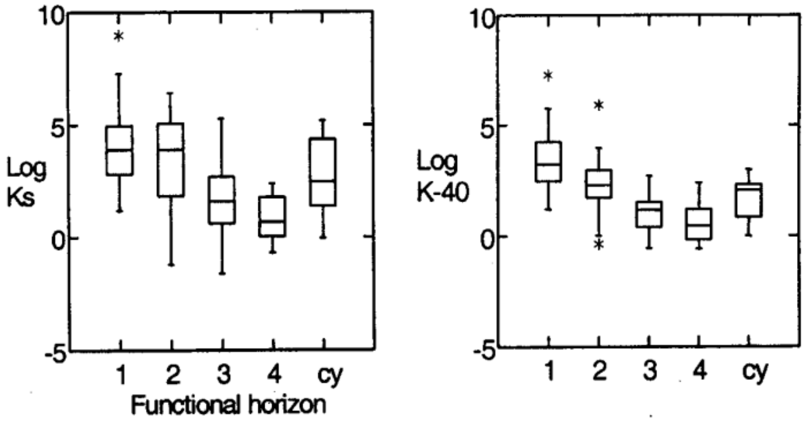


Figure 23 Statistical box-plots for K_s and K_{s_40}. The three lines of the boxes show medians and upper and lower quartiles. Whiskers show values within 1.5 times the quartile spread; values outside this range are shown by an asterisk (Webb 2003).

6.1.2 Predicting saturated hydraulic conductivity from the soil-water characteristic curve

Pollacco et al. (2012) compute K_s from the parameters describing the soil water/tension curve. The results show that the uncertainties of the K_s model are comparable with the uncertainties in measurements of K_s ($R^2 = 0.71$ of the log-transformed K_s). The results of the K_s model are shown in Figure 24; equations are not shown because of the need to show lengthy derivation, which can be found in the original article.

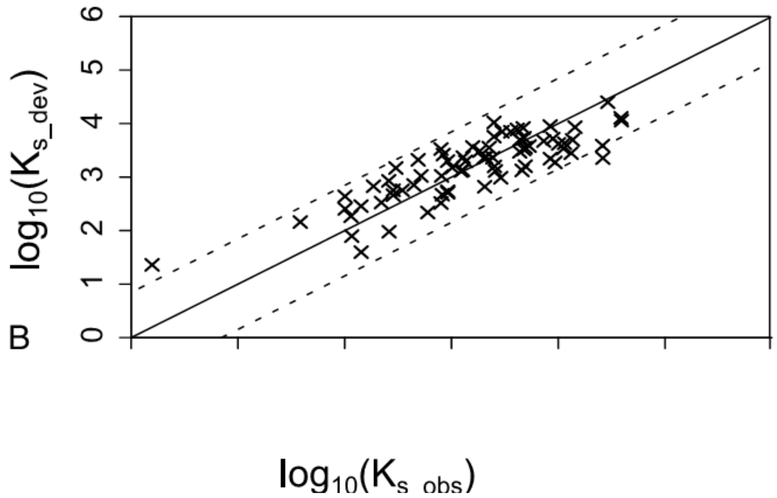


Figure 24 Uncertainty bands related to the 95% confidence interval for the proposed K_{s_dev} model with observed K_s

6.2 Other soil properties that could be derived from S-map

We have not considered the effect of preferential flow on hydrology and nutrient loss. Under most situations, preferential flow is expected to have only small effects on drainage and nitrate leaching.

However, preferential flow can have significant effects on leaching of phosphorus and microbial contaminants. Preferential flow is challenging to quantify; however, land can be classified into relative vulnerability classes on the basis of soil characteristics (Lilburne et al. 2014). At this stage we suggest a need for a review of research to date, with a view to adding this soil property to *Overseer*.

There are other soil properties within *Overseer* that S-map could provide using either existing ptfs or through the development of new ones. These include the structural integrity, soil carbon, hydrological class, dispersion index, nitric acid reserve *K* test, and runoff/infiltration parameters.

6.3 Improving estimation of ponding, runoff and infiltration

The correct partitioning between runoff (Q_{run}) and infiltration (Q_{inf}) is important for an accurate estimation of nitrate and phosphorus loss. Q_{run} occurs if daily rainfall (daily rainfall is 'distributed' to hourly rainfall given by an isosceles triangle) exceeds a runoff threshold (fig. 3 in Wheeler & Rutherford 2013). In *Overseer,* the value of the runoff threshold depends on the following factors: (1) slope; (2) previous moisture condition; (3) K_{s_drain}; (4) hydrophobicity; (5) mole/ tile drains.

Overseer uses topsoil clay content as the prime soil factor to estimate runoff (section 4.4.2; eqn 54 in Wheeler & Rutherford 2013). This assumes that runoff is only dependent on soil surface infiltration conditions. This assumption is correct when the surface infiltration rate is slower than permeability of underlying soil horizons. However, when subsurface hydraulic conductivity is lower than the infiltration rate, the soil becomes saturated to the surface as water perches on these slow-permeability layers. These saturated soil conditions then induce runoff.

In many situations, runoff rate will be more dependent on subsurface permeability than topsoil infiltration rate. For example, Pearce and McKerchar (1979) reviewed the source of runoff from 17 small catchments in New Zealand. They conclude that *'in all catchments studied, storm runoff during small events can be explained by saturation overland flow on small proportions of the catchment.* Pearce and McKerchar also conclude that '*The bulk of storm runoff in larger events is generated by rapid subsurface flow from between 40 and 90 percent of the catchment area*.' The catchments studied were mainly catchments with '*steep slopes, thin soils with high saturated hydraulic conductivity, and incised stream channels which are typical of New Zealand hill and mountain land*.' There are, however, significant areas of silty soils with dense subsoils with very low hydraulic conductivity. On these areas, the bulk of runoff is generated from saturated flow (Orchiston et al. 2013). Because these soils have low clay content, they would not generate significant runoff in *Overseer*. It is important to use a hydraulic conductivity that reflects this case.

In addition to the above, it is known that runoff can occur on flat land. This may be the result of differences in microtopography, coupled with issues with infiltration and slow permeability of subsurface conditions.

We recommend a review of the runoff algorithm. Options to improve the runoff modelling include computing infiltration/runoff computed through a simplified, more physically-based model, based on the Green and Ampt (1911) infiltration model. The inclusion of Green–Ampt methodology as a module within *Overseer* would have the following benefits: (1) compute ponding time and time distribution of runoff, which is important to improve the predictions of denitrification; (2) partition between infiltration, runoff and drainage; (3) account for previous soil moisture; (4) include the effect of hydrophobicity (Hilpert & Glantz 2013); (5) take account of slope in a physical manner

(Chen & Young 2006); (6) the parameters can be obtained from S-map. Another option is to consider the curve number approach, or the approach of McDowell et al. (2005) used for the P runoff model. All of the above approaches are more difficult in hill country, as indicated by the block-scale hydrology model for wetlands outlined in Wheeler & Rutherford (2013).

We recommend a review of the runoff algorithm in the light of better soil data available in S-map. We also recommend that further work needs to address how *Overseer* may better represent runoff related to slow permeability of subsurface conditions. This should focus on three aspects:

- Improving estimation of saturated hydraulic conductivity
- Improving the feedback so that saturation-induced runoff can occur
- Improving the infiltration model.

Consideration could also be given to taking account of pugging effects on runoff. There has been significant research in Otago and Southland on the effect of winter stocking on runoff (Monaghan et al. 2007; Orchiston et al. 2013). It is probable that pugging damage could result in:

- Decreased infiltration due to sealing of the surface, resulting in increased runoff
- Decreased runoff due to ponding in the hoofprint
- Increased bulk density and reduced macroposity due to compaction.

Research has focused on individual paddocks, but there is little information on the impact on a block scale, as is required by *Overseer*.

6.4 Sensibility, sensitivity, and uncertainty analysis

This project has highlighted the value of linking *Overseer* with S-map information. *Overseer* can be tested against a much wider range of soils and climates than the small calibration dataset. Unlikely results can be examined in detail and thus assist with the early identification of model issues during model development. These issues can be prioritised by means of a formal sensitivity analysis. It is recommended that similar tests as outlined in this report are rerun using a broad spectrum of soil properties, to identify any potential issues with changes to soil properties. In addition, a formal uncertainty analysis would help clarify the main sources of uncertainty in both data and model assumptions.

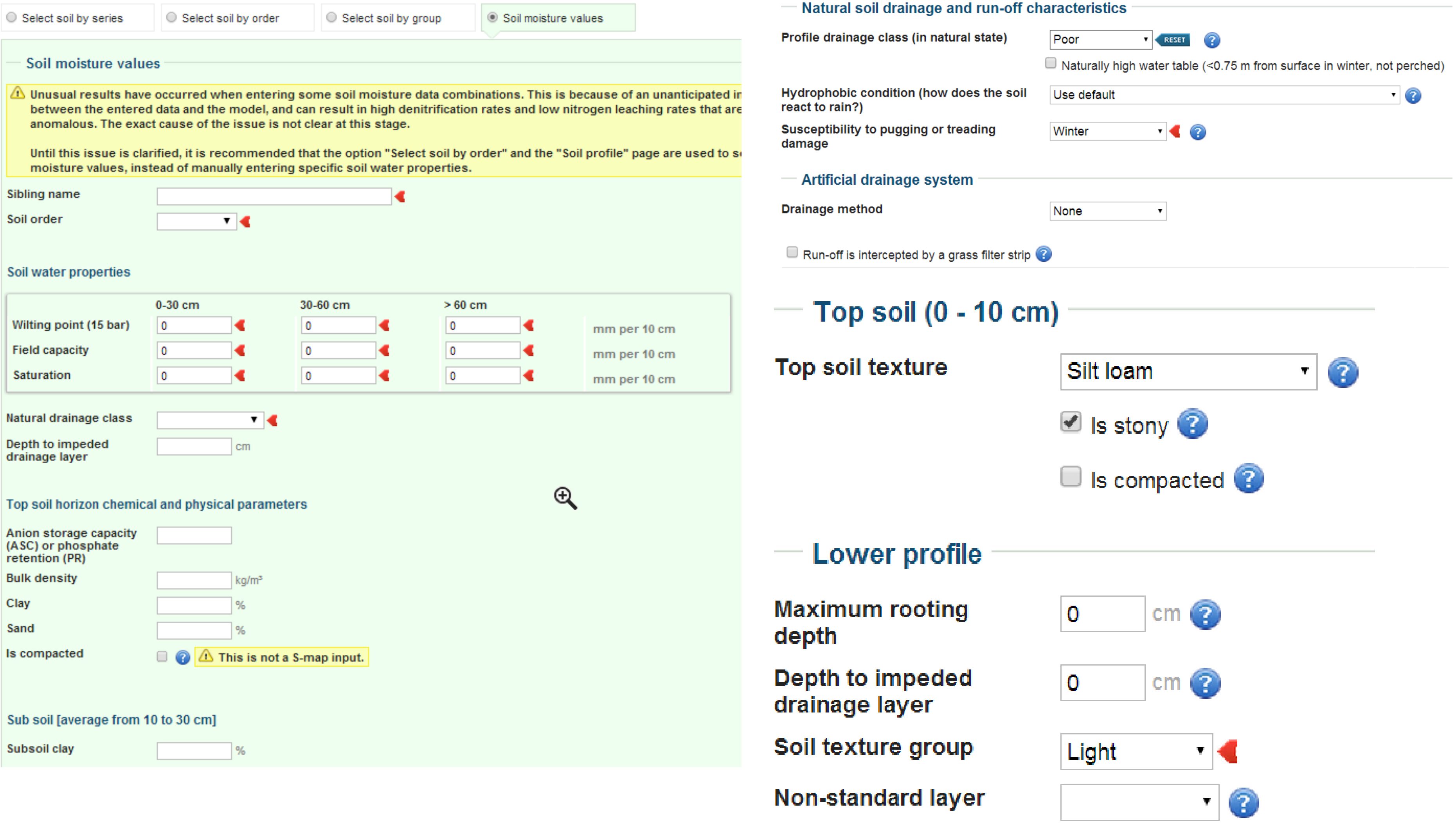
6.5 Improving the Graphical User Interface of *Overseer*

Data entry of soil information into *Overseer* is based on a principle of allowing users to enter as much site-specific soil information as is available. Where information is unavailable, default values and internal ptfs are used to estimate the required soil information.

As noted in Section 2, information can be entered at multiple levels. This reflects historical data options, the need to maintain backwards compatibility, and the two sources of data, namely database derived or user input. The three screen snapshots shown in Figure 25 represent two options, namely soil moisture (left) and soil classification plus descriptors (lower right).

The evolution of these input forms over time has led to some duplication. For example, one can enter the soil moisture parameters (three layers) in the new *Soil Moisture Values* tab on the *Soil description* page, as well as for a single layer on the *Soil properties* page (under the *Specify soil water properties* drop-down form). This and other examples of duplication lead to a lack of clarity for the user. For example what happens when a user enters both lower profile non-standard layer and water content data? What happens if a different soil order is entered in the *Soil Moisture Values* tab than on the *Select by Soil by Order* tab. Or if different profile drainage classes are entered on the *Soil description* page (under the *Soil Moisture Values* tab) and the *Drainage/runoff* page. Clay content is an important input – but it is not clear to the user what default value is being used, so they cannot evaluate whether the default value is reasonable.

It would be desirable as part of an update of the soils model and input pages that the interface is upgraded to make it clear to the user as to which set of soil property values override others associated with the soil classification or the S-map-derived data. S-map can provide information for soil properties that are currently entered on four input screens. The user interface for entering in soil information should be revised to remove the duplication and to reduce the number of places where soil information can be entered. In addition, an output report for the block that summarises the specific soil property values (user specified and derived within *Overseer*) used within *Overseer* would make them much more transparent.


○ Select soil by series ○ Select soil by order ○ Select soil by group ● Soil moisture values

Soil moisture values

⚠ Unusual results have occurred when entering some soil moisture data combinations. This is because of an unanticipated in between the entered data and the model, and can result in high denitrification rates and low nitrogen leaching rates that are anomalous. The exact cause of the issue is not clear at this stage.

Until this issue is clarified, it is recommended that the option "Select soil by order" and the "Soil profile" page are used to s moisture values, instead of manually entering specific soil water properties.

Sibling name:

Soil order:

Soil water properties

	0-30 cm	30-60 cm	> 60 cm	
Wilting point (15 bar)	0	0	0	mm per 10 cm
Field capacity	0	0	0	mm per 10 cm
Saturation	0	0	0	mm per 10 cm

Natural drainage class:

Depth to impeded drainage layer: cm

Top soil horizon chemical and physical parameters

Anion storage capacity (ASC) or phosphate retention (PR):

Bulk density: kg/m³

Clay: %

Sand: %

Is compacted ☐ ⚠ This is not a S-map input.

Sub soil [average from 10 to 30 cm]

Subsoil clay: %

Natural soil drainage and run-off characteristics

Profile drainage class (in natural state): Poor

☐ Naturally high water table (<0.75 m from surface in winter, not perched)

Hydrophobic condition (how does the soil react to rain?): Use default

Susceptibility to pugging or treading damage: Winter

Artificial drainage system

Drainage method: None

☐ Run-off is intercepted by a grass filter strip

Top soil (0 - 10 cm)

Top soil texture: Silt loam

☑ Is stony

☐ Is compacted

Lower profile

Maximum rooting depth: 0 cm

Depth to impeded drainage layer: 0 cm

Soil texture group: Light

Non-standard layer:

Figure 25 Three of the soil related input forms in *Overseer* showing that there are overlapping inputs, e.g. soil texture.

6.6 Future soil data entry options

A new web service is currently being developed that can automatically populate some of the soil parameters directly from S-map. This will require some development on the part of the *Overseer* team if they wish to access this web service.

Some thought should be given to the workflows for end users in managing information supplied by the S-map web service in conjunction with some site-specific soil information, perhaps from a farm-scale soil survey. The advantage of using the S-map web service will be in minimising errors in data entry of soil information – and in having access to the most up to date information provided by S-map.

S-map is dependent on ptfs that are part of an active development programme, and hence are likely to evolve over time. Thus it would also be useful for end users to be able to verify from year to year that the S-map soil properties they used previously in *Overseer* are unchanged.

This web service will also facilitate data entry of multiple soils in a block. Currently, it is common practice to enter the soil properties of the dominant soil in a block (*Overseer* Management Services Limited 2014). Many blocks, however, contain multiple soils. The mapping units within S-map may also contain multiple soils. In some areas, e.g. on the alluvial plains, these soils can have markedly different nutrient losses. We recommend that an approach to manage multiple soils be developed and tested. This is expected to involve calculating a weighted average of nutrient budget outputs based on the proportion of the significantly different soils within each block.

Note that the web service will return spatial data, which could be of use in the development of a spatial *Overseer* in the future.

6.7 Summary of key points from this section

- Consider using an S-map-derived saturated hydraulic conductivity to improve estimates of denitrification and runoff.
- Consider using the Green–Ampt equation to improve estimates of infiltration, ponding, runoff, water balance and denitrification.
- S-map could provide values for some other soil properties used in *Overseer* (e.g. structural vulnerability) and others that are likely to be useful (e.g. risk of preferential flow).
- A redesign of the user interface for entering soil properties into *Overseer* is essential.
- The release testing programme for *Overseer* should be extended to include sensibility testing of results based on all soils (as covered in S-map) and climates found in New Zealand.
- A formal uncertainty analysis would help clarify the main sources of uncertainty in both data and model assumptions.
- A practical method for estimating the nutrient budget for a block with multiple soils should be developed, and the workflow for managing updates to soil information should be analysed.

7 Recommendations

We recommend that preference is given to using Level 2 inputs. Where these inputs are unavailable, Level 1 inputs are still required but we recommend that improvements are made to this method of characterising soils. To achieve this, the following work is recommended:

- A review of the Level 1 soil profile descriptors including a revision of order, subsoil texture group, and non-standard-layer default water content values used within *Overseer*. In particular, *Overseer* appears to overestimate AW_{60} of light soils with a non-standard-layer stony matrix layer.
- Adding additional non-standard layers to allow better characterisation of very stony and organic layers.
- Extend the ability to use the subsoil texture group for other orders, e.g. clayey Pallic soils, rather than being limited to Recent and Brown soils.
- Organic soils are not well characterised and should be reviewed.
- *Overseer* users need to have a reference for the topsoil texture group options so that they know what the classes mean. We suggest using the texture groups and texture triangle from Taylor & Pohlen (1970).
- The rationale behind the high variability in the estimates of nitrate leached from well-drained soils with the same AW_{60} should be confirmed.

From a modelling perspective, we recommend that the following soil data and processes within *Overseer* should be the priority for revision/development:

- Modelling issues using rooting depth and depth to impeded layer are resolved.
- Modifying the runoff algorithm to better represent runoff related to slow permeability of subsurface conditions. This should focus on three aspects:
  - Improving estimation of saturated hydraulic conductivity, including using S-map-derived saturated hydraulic conductivity to improve estimates of denitrification and runoff
  - Improving the feedback so that saturation-induced runoff can occur
  - Improving the infiltration model.
- That *Overseer* be adjusted to take account of the effect of runoff and slope on evapotranspiration.
- That the denitrification algorithm be reviewed. The method of estimating denitrification involved a calibration step, and it is probable that the denitrification results are an artefact of using limited data for the calibration process. In particular, it is recommended that:
  - The calibration step involving denitrification is removed so that the effect on soils can be isolated.
  - The runoff model is updated as above so that the model is predicting the ‘correct’ water-filled pore space.
  - The relationship between denitrification and clay content, total porosity and K_{s_drain} and denitrification is reviewed to ensure that *Overseer* is responsive to soils with slow permeability and does not exaggerate the effect of clay content.

  - Denitrification from well-drained very stony soils with low total porosity is evaluated.
- Adoption of any of the above recommendations will require a recalibration of the *Overseer* model. The soil properties used in the calibration datasets should be derived from specific site measurements or observations rather than the default values built into *Overseer*.
- The formal testing programme for *Overseer* releases should be extended to include a sensibility test using the full range of soils information from S-map under a range of climates and farm types. *Overseer* will be used across New Zealand under a wide range of farm, climate and soil scenarios that are far outside the measured calibration dataset, thus the potential for spurious results is high. By testing *Overseer* on all the climates and soils (as partly illustrated in this report), any issues can be checked by the development team before release – and it can be determined if there are some climate–soil combinations where use of *Overseer* is not recommended.
- A formal uncertainty analysis is undertaken to clarify the main sources of uncertainty in both data and the model assumptions, and to identify the significance of each source. Only a formal analysis can determine the significance of any data, computational or conceptual issues and bugs identified in this and other reports.

Other recommendations include:

- A redesign of the data entry forms (GUI) for soil data to reduce duplication, provide more clarity and transparency in what values have precedence over others, and to better match the soil information the user is likely to have.
- Targeted experimental information is obtained to improve the representation of key processes and to inform the calibration process. In particular, measurements of denitrification and catchment-scale information to quantify runoff are needed.
- We note that S-map could provide values for some other soil properties used in *Overseer* (e.g. structural vulnerability) and others that are likely to be useful (e.g. risk of preferential flow).
- A practical method for estimating the nutrient budget for a block with multiple soil siblings should be developed.
- It is recommended that an electronic link between S-map and *Overseer* is established especially once the Level 2 data is used in *Overseer*, to help avoid mistakes by end users.

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