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COMPARISON OF S-MAP SOIL INFORMATION WITH THE OLDER FUNDAMENTAL SOIL LAYERS: IMPLICATIONS FOR MODELLING

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Abstract

Managing land resources at broader scales usually requires spatial soil information, along with data on terrain, climate, vegetation, land cover and land use. These data are needed for a range of models. In New Zealand there are two options for obtaining spatial soil information to use in models: the Fundamental Soil Layers (FSL), derived from the New Zealand Land Resource Inventory (NZLRI), and the more modern S-map. The former is complete for New Zealand, whereas the more accurate S-map only covers 35% of New Zealand (as at February 2020). This study compares these two soil data options. First, differences in data definition and data capture are explained. Then, three soil properties – soil order, drainage class and profile-available water (PAW) – are spatially compared. Finally, the two soil datasets are used in four models (droughtiness, highly productive land, OverseerFM and crop suitability) and the differences and their implications are outlined and compared. All these comparisons were carried out in areas where the NZLRI FSL and S-Map coincide. The results showed that differences vary both spatially and in significance. Here are some examples.

- In 39% of the area covered by both FSL and S-map, estimated PAW differs by more than 50 mm. Most of this is in the North Island.
- Soils from the Pumice soil order are more generally in agreement between the two sources of soil data than those from the Gley, Allophanic or Recent soil orders.
- Forty percent of the area in common between the two datasets has different drainage classes assigned.
- The total area of highly productive land in the Canterbury region derived from the two data sources differs by 116,912 ha.
- Modelled estimates of nitrogen (N) loss vary between 20 and 30 kg N/ha/yr.
- Maps of modelled susceptibility to drought in a catchment in Hawke's Bay are different, yet region-wide modelling of land suitability for growing maize in Hawke's Bay is not sensitive to differences in the soil data.

Users of soil information are advised to understand the limitations of the different soil data and ensure they use them appropriately, as determined by their particular purpose.

Background

The New Zealand Land Resource Inventory (NZLRI) (Ministry of Works and Development 1979) is a land resource database comprising an inventory of five physical factors (rock type, soil, slope, present type and severity of erosion, and vegetation) and a Land Use Capability

(LUC) rating. The definition and delineation of the map-unit polygons were based on combining the five factors. The NZLRI was originally compiled at a scale of 1:63,360 (the pre-1979 first edition); there is 1:50,000 coverage for limited areas in the second edition. Consequently, the bulk of the soil information in the NZLRI is a re-interpretation of pre-1979 data and often does not contain the best available linework. In some areas the only source of information was the General Soil Survey maps of New Zealand (1:253,440 scale).

The NZLRI was later enhanced by the addition of 16 soil properties collectively known as the Fundamental Soil Layers (FSL) (Barringer et al. 1998; Wilde et al. 2000). These layers were generated by creating regional legends, which were then correlated using the New Zealand Soil Classification (Hewitt 2010) and referenced to the National Soils Database and other relevant data sources. It is important to understand that the description of each soil property is limited to five (in most cases) predefined intervals or classes, with the representative value of the soil property being taken as the interval midpoint of the nominated class(es). For example, a polygon that is assessed as being in the predefined topsoil carbon class interval of 4–10%, with variation covering the next class interval 10–20%, is simply assigned a midpoint value of 12% carbon (as the midpoint between 4 and 20). A second representative option (the ‘modal’ value) is derived differently, but is also based on the endpoints of the nominated class interval and the variability field. The modal value would be 9% carbon in the example just given. See Newsome et al. (2008) for more detail.

The FSL methodology was largely constrained by the reference datasets and the technology available at the time. Consequently, the FSL is gradually being retired in favour of S-map (Lilburne et al. 2012; Manaaki Whenua - Landcare Research 2020), New Zealand’s newer soil survey database, which is considered to contain better-quality and more reliable data. S-map is a comprehensive database containing soil information on a 1:50,000 (or finer-scale) map-unit (polygon) basis. Each polygon is identified by up to five siblings (a sibling is comparable with the prior classification level of ‘soil type’). Each sibling is identified according to soil classification, drainage, texture, permeability, soil depth, and the array of horizons to 1 m depth or to rock. Each horizon is quantitatively described in terms of the range of its thickness, stoniness, sand and clay content.

The profile depth, root barrier type (if present), root barrier depth, and depth to slowly permeable layer are all specified. These core properties are used to derive other soil properties by means of pedo-transfer functions (ptfs). All soil profiles in the National Soils Data Repository that contain laboratory-measured data have been linked to S-map siblings, allowing the development of ptfs for a wide range of soil properties (Lilburne et al. 2014). These ptfs can be applied over any depth of interest. S-map data and the ptfs are regularly updated as knowledge of New Zealand’s soils improves, so they represent the best available knowledge in the absence of a professionally produced farm-scale soil survey.

Methods

Comparison of two soil properties

The New Zealand Soil Classification soil order from the FSL and the dominant soil sibling in S-map were spatially extracted, and each was then converted to a raster layer with a resolution of 100 m. The FSL layer was masked to the area covered by S-map. The 15 soil orders in these two layers were then cross-tabulated.

Similarly, mean estimated profile-available water (PAW [mm]) of the dominant soil to a depth of 90 cm was extracted from S-map. A depth of 90 cm was used to match the FSL definition of PAW. The modal value of PAW from the FSL was spatially extracted and masked. Both layers were rasterised with a resolution of 100 m, and then a third layer was generated as the difference between S-map and FSL PAW. Drainage class was also extracted from both datasets and the class label compared.

LUC comparison

Currently, a proposed National Policy Statement for the protection of highly productive land (HPL) in New Zealand is being developed (Ministry for the Environment 2019). The proposed default classification of HPL is land with a LUC class of 1, 2 or 3. Just the first two classes were selected in this comparison, representing the most versatile land in the proposed HPL. LUC is an attribute of the LRI layer (as are the FSL attributes). A spatial layer of LUC for Canterbury was extracted from the LRI and masked to areas with S-map data and a LUC class of 1 or 2.

In a 2013 exercise for Environment Canterbury (unpublished), the common traits underpinning the LUC classification of the potentially irrigable land in the region were identified. The limiting criteria underpinning the LUC classes were analysed, and new 'rules' relating S-map attributes to LUC Class were established. These new rules were used to assign LUC class values to the soil siblings contained in the S-map database for the Canterbury region. The land with S-map-derived LUC classes 1 or 2 was extracted into a spatial layer, and this layer was then compared with the LUC layer.

Droughtiness comparison

A water-balance model was developed based on WatYield (Fahey et al. 2010), the FAO-56 (guidelines for computing crop water requirements) report, and the SWAT model (developed by The Unites States Department of Agriculture). The key outputs of the water-balance model are two drought indicators: soil moisture deficit (SMD) and evapotranspiration deficit (ETD). These describe the soil moisture drought and crop water demand in a period of interest. In this study we have used maize as our target crop and chose ETD as an indicator of droughtiness. ETD is the total amount of water that is not available for a crop to have an unstressed transpiration process.

The water-balance model calculates daily soil water balance by taking the inflow from precipitation into the system and removing water by canopy interception, drainage and evapotranspiration. The daily soil water content (SWC) is obtained from the water balance equation:

$$SWC_i = SWC_{i-1} + PCP_i - I_i - Q_i - E_i$$

where SWC_i = soil water content in the root zone at the end of day i (mm)
SWC_{i-1} = soil water content in the root zone at the end of the previous day $i-1$ (mm)
PCP_i = precipitation on day i (mm)
I_i = interception on day i (mm)
Q_i = drainage on day i (mm)
E_i = evapotranspiration on day i (mm).

Initial SWC is set to the PAW of the soil.

Four variables as well as three parameters are required to run the model. These are listed below.

Variables

- precipitation (PCP): water inflow into the system
- reference crop evapotranspiration (ET_0): an evapotranspiration rate from a reference surface that is a hypothetical grass reference crop with specific characteristics; it is the evaporative demand of the atmosphere independently of crop type, crop development and management practices
- profile-available water (PAW): the capability of soil to retain water available to plants
- profile-readily-available water (PRAW): the fraction of PAW that plants can extract from the root zone without suffering water stress.

Parameters

- crop coefficient (Kc): an integration of the effect of characteristics that distinguish field crops from grass
- interception fraction (ICF): an estimation of the total proportion of precipitation lost through interception
- interception storage capability (ISC): the maximum amount of water that can be intercepted by the canopy.

The data sources for the variables and the parameter values used are listed in Table 1.

Table 1. Variables and parameters required by the water-balance model

Variable/ parameter	**Type**	**Value**	**Format**	**Source**
PCP	Climate	Daily PCP	GeoTiff 5 × 5 km	NIWA VCSN[b]
ET_0		Daily PET[a]		
PAW	Soil	S-map & FSL	ESRI shapefile	MW[c]
$PRAW$				
K_c	Crop	1.2	Text	FAO, MW
ICF		0.1		MW
ISC		0.5		

[a] Potential Evapotranspiration

[b] Virtual Climate Network from NIWA

[c] Manaaki Whenua – Landcare Research.

The Karamu catchment (Figure 1) in Hawke’s Bay was chosen as the study area for this comparison of ETD (aligning with parallel work in a climate change project for the Deep South National Science Challenge).

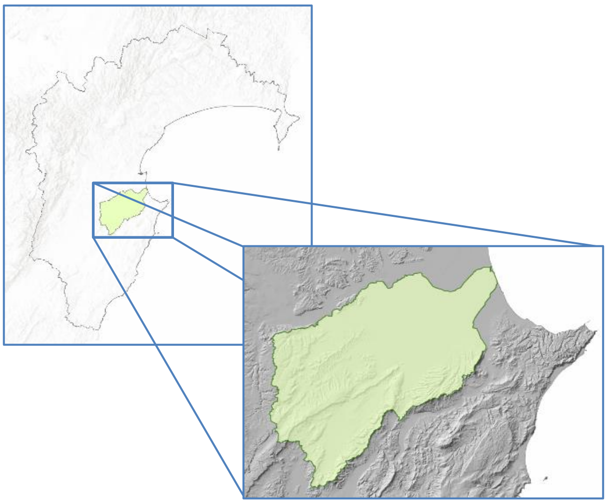


Figure 1. Karamu catchment in the Hawke’s Bay region.

For this comparison of soil data from S-map and FSL we used PAW and PRAW from each dataset (based on the dominant soil in S-map) to run the model separately while keeping the climate and crop inputs the same:

- spatial resolution: 100 m × 100 m
- temporal resolution: daily
- time window: 20 years (1984–2003)

Comparison of OverseerFM estimates of N loss

A mixed beef and dairy grazing farm in North Canterbury was set up in OverseerFM using the following data inputs from FSL or S-map (soil descriptions were limited to information from the two datasets; no local knowledge was applied):

1. soil order from the FSL (dominant soil within the management block)

2. soil order plus soil profile descriptions derived from the FSL “MOD” fields of drainage class (DRAIN), topsoil stones (GRAV), potential rooting depth (PRD) and depth to slowly permeable layer (DSLOW) (dominant soil within the management block)

3. S-map (dominant sibling in the management block)

4. S-map (main three siblings within the management block)

5. S-map (dominant sibling in a soil polygon).

The total farm losses of N to water were recorded for each of the above scenarios.

Crop suitability assessment comparison

The final comparison is the effect of the two data sources on a simple model of suitability of land for growing maize. This model characterises and quantifies the growth-related environmental factors (climatic and land characteristics), then defines the degree of fitness for the production of maize. A four-class system (Kidd et al. 2015) for suitability was defined as follows:

- well suited: no limitations to productivity
- suited: minor limitations to productivity

- marginally suited: moderate limitations to productivity
- unsuited: severe limitations to productivity.

Each maize-relevant environmental factor was classified into the four categories based on maize-specific suitability rules obtained from New Zealand experts (Table 2). The overall suitability was calculated by using the most-limiting-factor approach (Klingebiel & Montgomery 1961; Webb & Wilson 1994; Carrick 2002).

Table 2. Suitability rules for maize

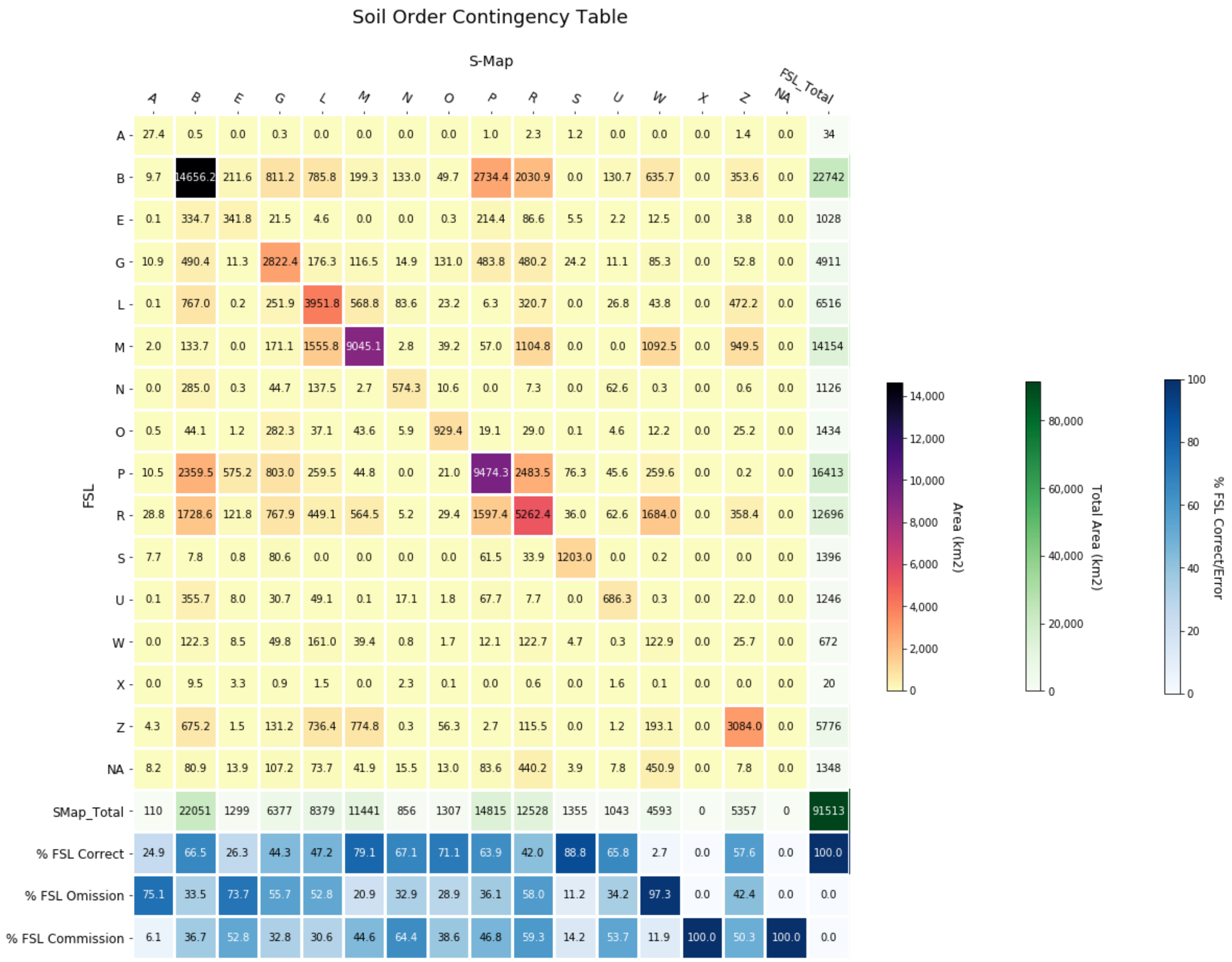
Factors	**Well suited**	**Suitable**	**Marginally suitable**	**Unsuitable**
Soil rooting depth (m) (PRD)	>60 cm	40–60 cm	30–40 cm	<30 cm
Soil drainage class (DRAIN)	Well drained, Moderately well drained	Imperfectly drained	Poorly drained	Very poorly drained
Slope (percentage)	<10	10–25		>25
Frost in spring (any day 15 Sep to 15 Oct with min. temperature ≤1°C)	< 1 year in 5	1/5−2/5	2/5−3/5	>3/5
Frost in Autumn (any day 15 Mar to 15 Apr with min. temperature ≤1°C)	< 1 year in 5	1/5−2/5	2/5−3/5	>3/5
Growing degree days above 8°C (15 Oct. – 15 Apr.)	>1,400	1,300−1,400	1,100−1,300	<1,100

The climate-related data (30 years from 1972 to 2001) were resampled to 500 × 500 m resolution and masked to the Hawke's Bay region. PRD and DRAIN for the region were extracted from the FSL and S-map databases and rasterised to 500 × 500 m resolution. The suitability rules were run twice for each pixel, with FSL and S-map soil data, respectively.

Results

Soil order

Some soil orders (e.g. Pumice and Semiarid soils) have fairly good agreement (~80% of FSL are correctly identified), but others (e.g. Gley, Allophanic and Recent) are much worse (~45% correct) when comparing the area of New Zealand covered by both S-map and FSL. About 34% of the area identified in the FSL as having the most common soil (Brown) is not Brown according to S-map. The cross tabulation of the 15 soil orders is shown in Figure 2.



Soil Order Contingency Table

FSL \ S-Map	A	B	E	G	L	M	N	O	P	R	S	U	W	X	Z	NA	FSL_Total
A	27.4	0.5	0.0	0.3	0.0	0.0	0.0	0.0	1.0	2.3	1.2	0.0	0.0	0.0	1.4	0.0	34
B	9.7	14656.2	211.6	811.2	785.8	199.3	133.0	49.7	2734.4	2030.9	0.0	130.7	635.7	0.0	353.6	0.0	22742
E	0.1	334.7	341.8	21.5	4.6	0.0	0.0	0.3	214.4	86.6	5.5	2.2	12.5	0.0	3.8	0.0	1028
G	10.9	490.4	11.3	2822.4	176.3	116.5	14.9	131.0	483.8	480.2	24.2	11.1	85.3	0.0	52.8	0.0	4911
L	0.1	767.0	0.2	251.9	3951.8	568.8	83.6	23.2	6.3	320.7	0.0	26.8	43.8	0.0	472.2	0.0	6516
M	2.0	133.7	0.0	171.1	1555.8	9045.1	2.8	39.2	57.0	1104.8	0.0	0.0	1092.5	0.0	949.5	0.0	14154
N	0.0	285.0	0.3	44.7	137.5	2.7	574.3	10.6	0.0	7.3	0.0	62.6	0.3	0.0	0.6	0.0	1126
O	0.5	44.1	1.2	282.3	37.1	43.6	5.9	929.4	19.1	29.0	0.1	4.6	12.2	0.0	25.2	0.0	1434
P	10.5	2359.5	575.2	803.0	259.5	44.8	0.0	21.0	9474.3	2483.5	76.3	45.6	259.6	0.0	0.2	0.0	16413
R	28.8	1728.6	121.8	767.9	449.1	564.5	5.2	29.4	1597.4	5262.4	36.0	62.6	1684.0	0.0	358.4	0.0	12696
S	7.7	7.8	0.8	80.6	0.0	0.0	0.0	0.0	61.5	33.9	1203.0	0.0	0.2	0.0	0.0	0.0	1396
U	0.1	355.7	8.0	30.7	49.1	0.1	17.1	1.8	67.7	7.7	0.0	686.3	0.3	0.0	22.0	0.0	1246
W	0.0	122.3	8.5	49.8	161.0	39.4	0.8	1.7	12.1	122.7	4.7	0.3	122.9	0.0	25.7	0.0	672
X	0.0	9.5	3.3	0.9	1.5	0.0	2.3	0.1	0.0	0.6	0.0	1.6	0.1	0.0	0.0	0.0	20
Z	4.3	675.2	1.5	131.2	736.4	774.8	0.3	56.3	2.7	115.5	0.0	1.2	193.1	0.0	3084.0	0.0	5776
NA	8.2	80.9	13.9	107.2	73.7	41.9	15.5	13.0	83.6	440.2	3.9	7.8	450.9	0.0	7.8	0.0	1348
SMap_Total	110	22051	1299	6377	8379	11441	856	1307	14815	12528	1355	1043	4593	0	5357	0	91513
% FSL Correct	24.9	66.5	26.3	44.3	47.2	79.1	67.1	71.1	63.9	42.0	88.8	65.8	2.7	0.0	57.6	0.0	100.0
% FSL Omission	75.1	33.5	73.7	55.7	52.8	20.9	32.9	28.9	36.1	58.0	11.2	34.2	97.3	0.0	42.4	0.0	0.0
% FSL Commission	6.1	36.7	52.8	32.8	30.6	44.6	64.4	38.6	46.8	59.3	14.2	53.7	11.9	100.0	50.3	100.0	0.0

Figure 2. Contingency table showing area (km^2) of FSL soil order vs S-map soil order.

Soil drainage class and profile-available water

Sixty percent of the area covered by both S-map and FSL matches with respect to drainage class; 40% does not match. The left-hand side of shows these results spatially. This is slightly worse than the 35% mismatch identified in 2015 in a similar exercise of the land covered by S-map at that time by Manderson et al. (2015).

The right-hand side of shows the difference in estimated PAW derived from the two data sources for the area covered by S-map. A histogram of the differences is shown in Figure 4. Thirty-nine percent of the area covered by S-map and FSL differs by more than 50 mm, 25% by more than 75 mm, and 16% by more than 100 mm.

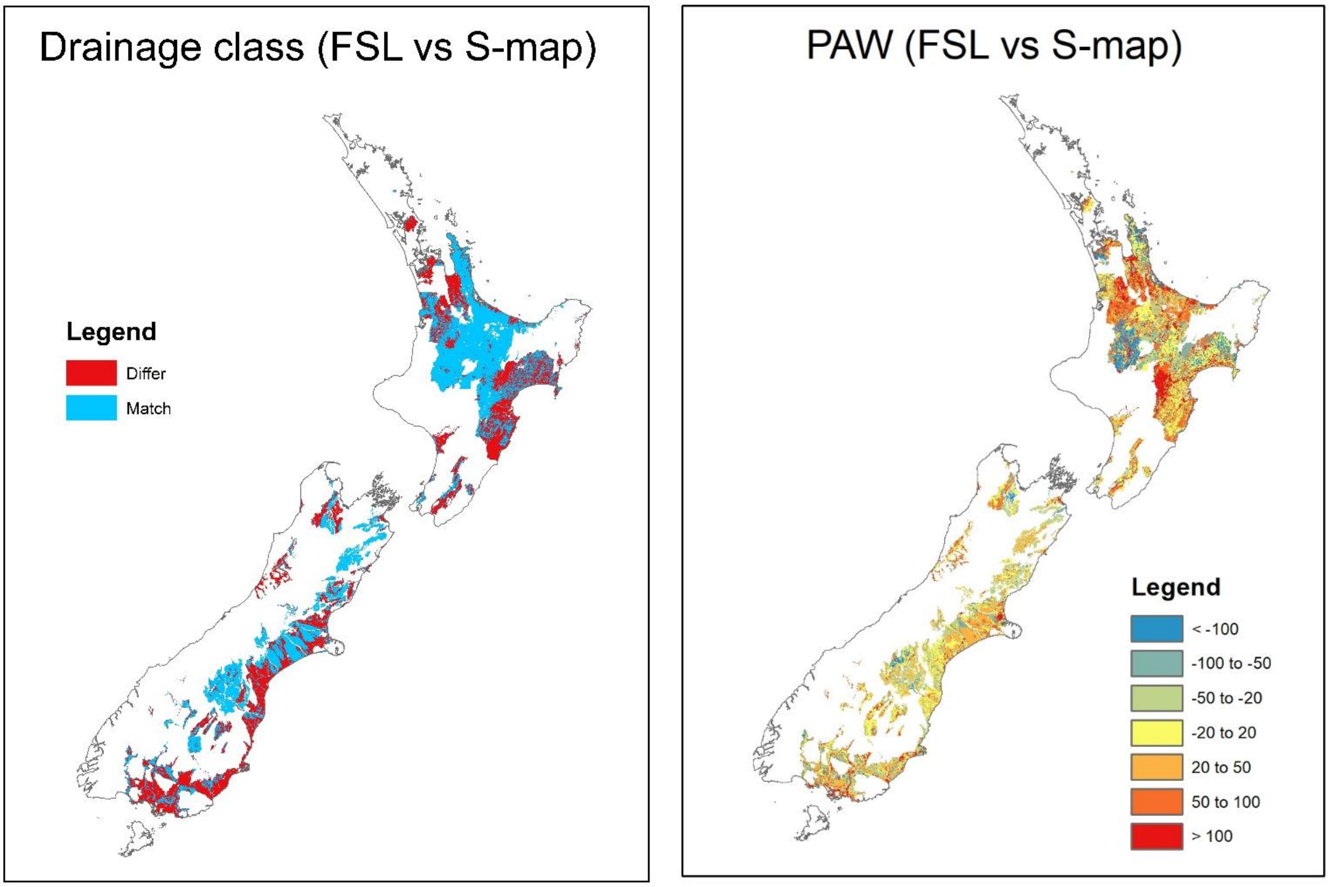


Figure 3. Comparison of the five drainage classes (left) and the difference in PAW (right) between FSL and S-map.

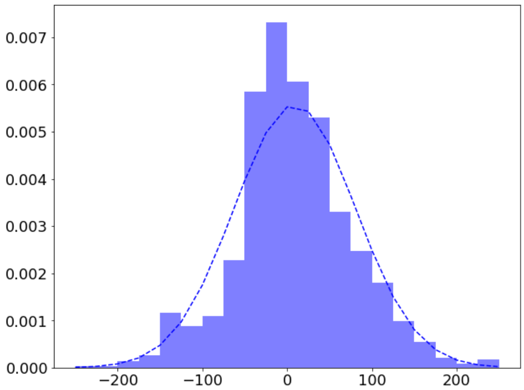


Figure 4. Histogram of the difference in PAW (mm) between S-map and FSL.

Droughtiness

Figure 5 shows maps of the 20-year average ETD in the Karamu catchment in Hawke's Bay according to soil data from S-map and FSL. Figure 6 shows histograms of ETD from the two sources of soil information.

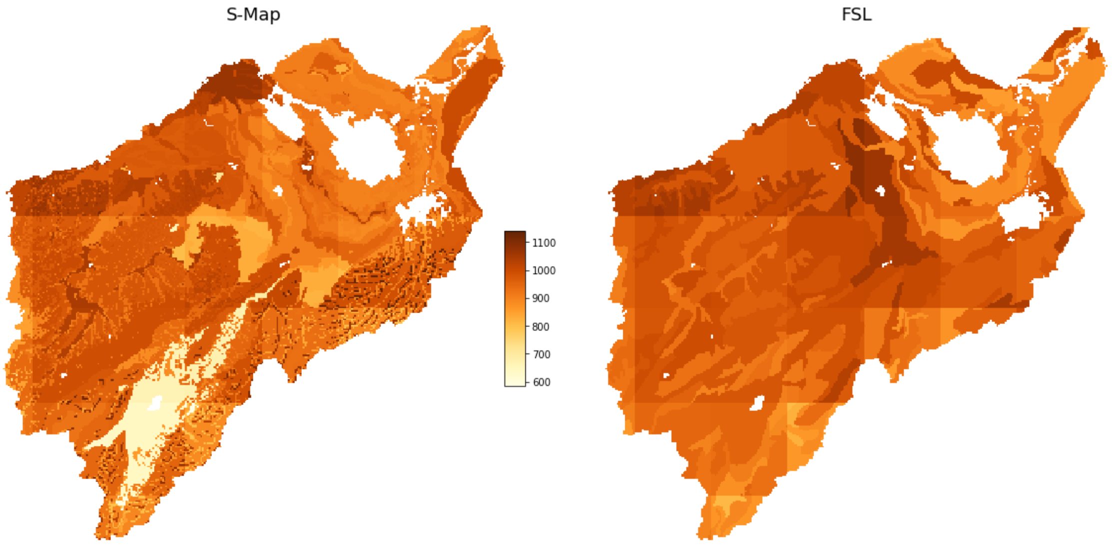


Figure 5. Maps of the 20-year average annual evapotranspiration deficit (mm) using S-map and FSL soil data.

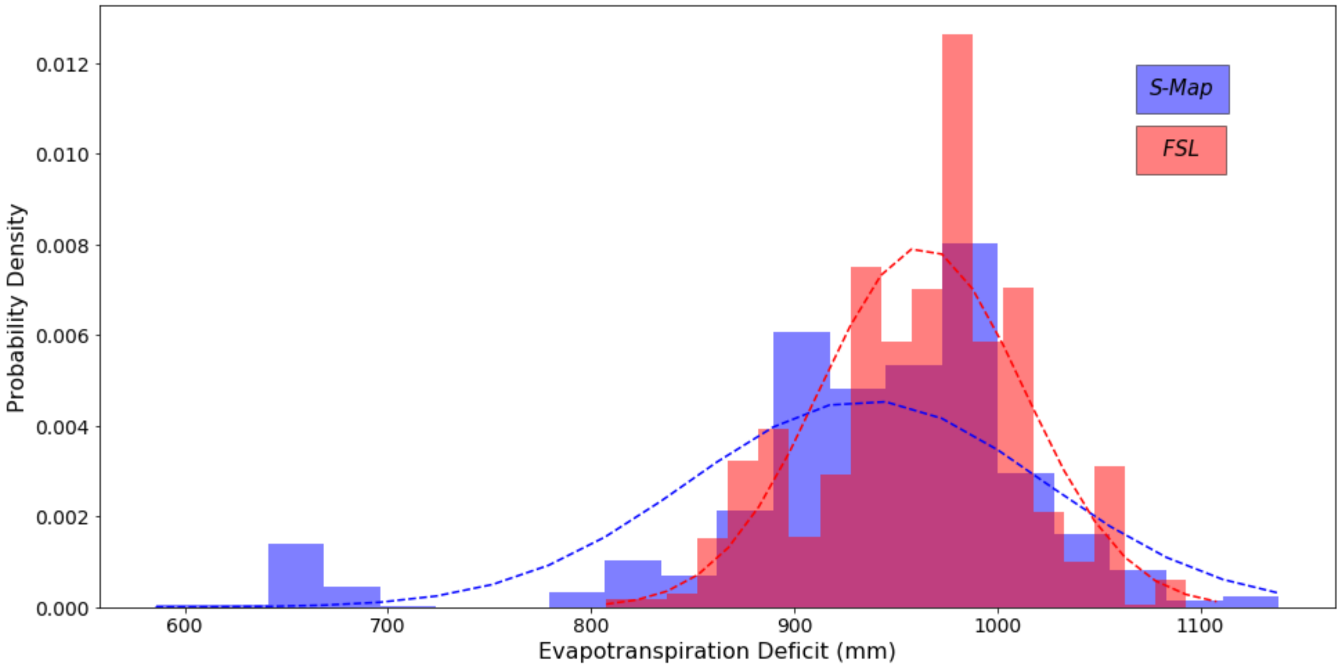


Figure 6. Histograms showing the distribution of the 20-year average annual evapotranspiration deficit calculated from S-map and FSL.

Highly productive land (LUC class 1–2)

Figure 7 shows the similarities and differences in LUC class 1–2 land derived from S-map and from the LRI for Canterbury. The difference in total area of HPL (LUC 1 or 2) in Canterbury varies from 169,107 ha (S-map) to 286,019 ha (LRI). Table 3 indicates that half of the land identified by S-map is not identified by the LRI (yellow areas in Figure 7), and 70% of the land identified by LRI as being LUC 1 or 2 is not identified by S-map (pink in Figure 7).

Table 3. Number of hectares with the same or different classification of LUC 1 or 2 from FSL and S-map. Note: land with no LUC class in one source is excluded (e.g. urban land)

	LRI LUC 1–2	LRI LUC 3–8	Total
S-map LUC 1–2	84,796	84,310	169,107
S-map LUC 3–8	201,222		
Total	**286,019**		

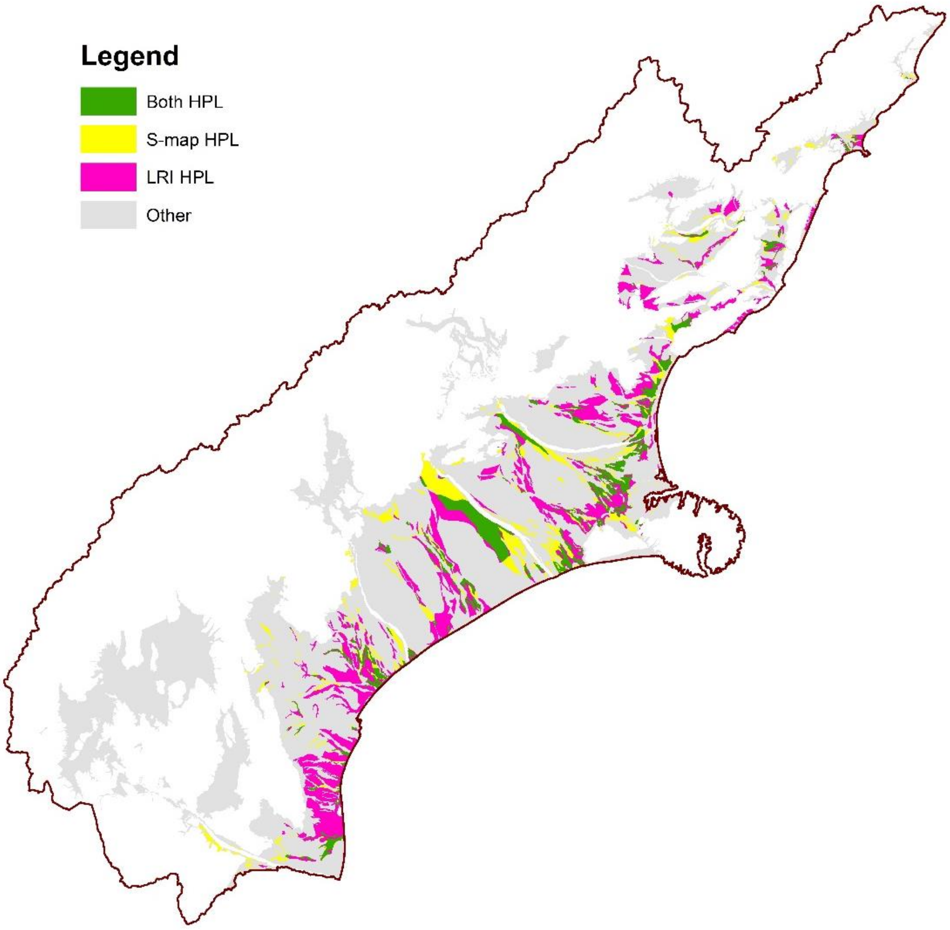


Figure 7. Comparison of where HPL in Canterbury, as defined by LUC 1 or 2, is identified by one of the soil information sources, by both, or by neither. Note: land with no LUC class (e.g. urban) is excluded.

OverseerFM estimates of N loss

Table 4 shows the total farm loss of N to water. The three S-map variants had similar N loss estimates. The highest estimate was when FSL soil order was supplemented with other FSL properties. While the overall farm N loss was similar between methods, the differences on individual blocks were much greater, especially on cropping blocks, e.g. a threefold difference.

Table 4. Estimates of N losses from the farm

Data entry scenario	OverseerFM N loss (kg/ha/yr)
FSL soil order (dominant soil in mgmt block)	25

FSL soil order + PRD, GRAV, DRAIN, DSLOW (dominant soil in mgmt block)	29
S-map dominant sibling in mgmt block	25
S-map 3 most common siblings in mgmt block	26
S-map dominant sibling × soil polygon	25

Crop suitability assessment

Figure 8 shows the suitability ranking for growing maize in the Hawke's Bay region when using either S-map or FSL data. Table 5 shows the match between each of the four suitability rankings. Simplifying the four categories into two: suitable (well suited to marginal) vs unsuitable resulted in agreement between FSL and S-map for 96.1 % of the region. Only 2.4% was assessed as suitable by S-map but not by FSL, and 1.5% was assessed as suitable by FSL but not by S-map.

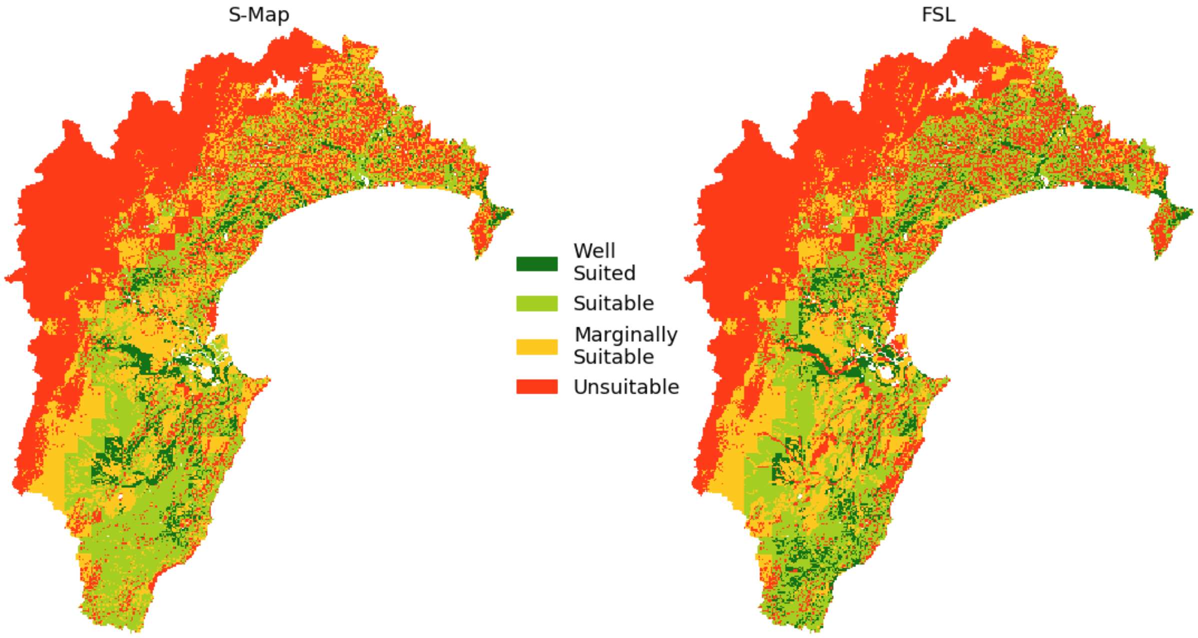


Figure 8. Suitability for growing maize in Hawke's Bay

Table 5. Area (km^2) of maize suitability categories by FSL and S-map

		S-map			
		Well suited	Suitable	Marginally suitable	Unsuitable
FSL	Well suited	498	285	208	24
	Suitable	96	2,544	1,190	46
	Marginally suitable	189	548	1,793	139
	Unsuitable	60	118	152	6,047

Discussion

FSL soil information is often used because it has national coverage and is readily available. The 16 FSL soil properties are either defined soil taxonomic categories (e.g. soil drainage class), or predefined intervals of a numeric soil property (e.g. 0–2, 2–4, 4–10, 10–20, 20–60% carbon). An expert assessment approach was used to assign the class or predefined interval to each LRI soil map unit based on the recorded soil name. Two nominal values were assigned to each polygon in addition to the class or interval identifier (usually 1–5). One is the mid-point of the one or more intervals indicated by the uncertainty code. The other 'modal' value is derived from the assigned interval endpoints and the uncertainty code. End-users and modellers use one or other of these nominal values.

Soil properties in S-map are either values or ranges observed by the original field-based soil surveyor, or estimates from a model or a ptf based on the observed values (Lilburne et al. 2012). The observed and modelled quantitative information is not constrained to predefined intervals like the FSL.

While it is the responsibility of those who generate data to provide meta-data describing its provenance and limitations (Devillers et al. 2007), end users are responsible for considering the adequacy of the data for their specific purpose (Refsgaard et al. 2007). Ideally, they will determine a threshold of accuracy, risk or reliability that is tolerable for their intended purpose. Data or model output that does not meet this threshold is then not fit for the purpose.

PAW is used for a range of applications, from irrigation management to catchment modelling of surface and ground water (Richardson et al. 2019). The latter use is more likely to be able to tolerate some error because, for performance reasons, these models are often run with a spatially coarse resolution in which errors can spatially cancel out. For example, Odgers et al. (2019) discuss the effect of resolution on estimates of droughtiness. Irrigation managers, however, need to minimise over- or under-irrigation and are therefore likely to have a more limited tolerance of error. Given the degree of difference between FSL and S-map in the results above, the FSL PAW data are unlikely to be fit for irrigation-related purposes.

Differences between the LRI and S-map in the identification and distribution of LUC classes 1 and 2 in Canterbury are significant. This largely reflects improved assessment through increased observation density and knowledge of soil function with the more modern S-map. Improvements pertinent to this HPL difference include:

- more accurate differentiation and determination of soil characteristics such as soil texture, drainage, permeability, depth to slow layers, rooting depth, and topsoil stoniness
- reduction in the concept of perceived wind erosion risk with the introduction of improved management techniques, such as direct drilling and widespread irrigation
- broadening of the concept of 'arable suitability' to include not only cereal cropping but a wide range of annual crops such as field-grown vegetable, root and seed crops
- a re-evaluation of the impact of fragipans on soil quality, resilience and stability, especially on downland terrain
- a downgrading of the value of wet, poorly drained soils due to their more limited versatility.

If HPL land were to be protected in the future, based on the LRI, this could cause problems for the affected land owners as well as the council in terms of non-compliance issues due to the unreliable data.

The difference in droughtiness estimates is likely to be significant for many purposes. An analysis of, for example, the impact of climate change might be compromised if the FSL data were used. This would need to be assessed by the modellers. The FSL version of regional maize suitability shows a very similar pattern to that derived from S-map. This is because this simple national scale model is driven more by climate and slope than by soil properties. In addition, some differences in soil property values have no effect on the suitability classification. For example, different soil depths of 65 cm and 100 cm will not change the suitability classification. Thus, this simple model of suitability might be useful for a regional-scale screening-level assessment, but is less likely to be useful at a farm scale due to the coarseness of the model and available climate data.

OverseerFM estimates of N loss were only compared on one farm so they cannot be generalised. However other work shows the importance of soil properties in OVERSEER (Pollacco et al. 2014). As a result we do not consider FSL data to be suitable for use in farm nutrient budget estimates of N loss. S-map information is expected to be more accurate but is still scale-limited and not as reliable as professionally collected site information (Carrick et al. 2014; Grealish 2017).

Conclusion

Spatial soil and land information vary in quality, definition, methodology, resolution, age, extent and other factors that can affect the usefulness of the data for any particular purpose. Users are advised to understand and consider the limitations of the FSL and S-map soil data and to assess whether the data are fit for their purpose. We expect that the FSL data, in particular, will not be fit for many purposes but could be acceptable for some.

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References

Barringer J, Wilde H, Willoughby J, Burgham S, Hewitt A, Gibb R, Newsome P, Rijkse W 1998. Restructuring the New Zealand Land Resource Inventory to meet the Changing Needs for Spatial Information in Environmental Research and Management. 10th Colloquium of the Spatial Information Research Centre, University of Otago, New Zealand, 16-19 November 1998. Pp. 25-33. https://www.researchgate.net/publication/228892268.

Carrick S, Hainsworth S, Lilburne L, Fraser S 2014. Smap@ the farm scale? Towards a national protocol for soil mapping for nutrient budgets. In: Currie LD, Christensen CL ed. Nutrient management for the farm, catchment and community, Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. Pp. 11. http://flrc.massey.ac.nz/publications.html.

Carrick ST 2002. Methodology for soil versatility evaluation in the Southland region, Landcare Research Contract Report: LC0203/013. 45 p.

Devillers R, Bédard Y, Jeansoulin R, Moulin B 2007. Towards spatial data quality information analysis tools for experts assessing the fitness for use of spatial data. International Journal of Geographical Information Science 21(3): 261-282, 10.1080/13658810600911879.

Fahey B, Ekanayake J, Jackson R, Fenemor A, Davie T, Rowe L 2010. Using the WATYIELD water balance model to predict catchment water yields and low flows. Journal of Hydrology (NZ) 49(1): 35-58.

Grealish G 2017. New Zealand soil mapping protocols and guidelines, Landcare Research Contract Report LC3050. http://www.envirolink.govt.nz/assets/Envirolink/Tools/R12-4-New-Zealand-soil-mapping-protocols-and-guidelines.pdf.

Hewitt AE 2010. New Zealand Soil Classification. 3rd ed. Lincoln, Canterbury, New Zealand, Manaaki Whenua Press. 136 p.

Kidd D, Webb M, Malone B, Minasny B, McBratney A 2015. Digital soil assessment of agricultural suitability, versatility and capital in Tasmania, Australia. Geoderma Regional 6: 7-21, http://dx.doi.org/10.1016/j.geodrs.2015.08.005.

Klingebiel AA, Montgomery PH 1961. Land-capability classification. USDA Soil Conservation Service Agric. Handbook 210.

Lilburne L, Webb T, Palmer D, McNeill S, Hewitt A, Fraser S 2014. Pedo-transfer functions from S-map for mapping water holding capacity, soil-water demand, nutrient leaching vulnerability and soil services. In: Currie LD, Chistensen CL ed. Nutrient management for the farm, catchment and community, Massey University, Palmerston North, New Zealand. http://flrc.massey.ac.nz/workshops/14/Manuscripts/Paper_Lilburne_2014.pdf.

Lilburne LR, Hewitt A, Webb T 2012. Soil and informatics science combine to develop S-map: a new generation soil information system for New Zealand. Geoderma 170: 232-238, 10.1016/j.geoderma.2011.11.012.

Manaaki Whenua - Landcare Research 2020. S-map - New Zealand's national digital soil map. http://dx.doi.org/10.7931/L1WC7.

Manderson AA, Lilburne LR, Hewitt AE, Pollacco J, Carrick S 2015. Recommendations and interim soils data to support the development of a national freshwater reporting model, Landcare Research Report No LC2380.

Ministry for the Environment 2019. Protecting our valuable land – our proposal, your views. Retrieved 18/1/2020 2020, from https://www.mfe.govt.nz/consultation/proposed-nps-highly-productive-land

Ministry of Works and Development 1979. Our Land Resources: a bulletin to accompany NZ Land Resource Inventory worksheets.

Newsome PFJ, Wilde RH, Willoughby EJ 2008. Land resource information system spatial data layers. Data dictionary. 74 p. https://lris.scinfo.org.nz/document/162-lris-data-dictionary-v3/.

Odgers N, Lilburne L, Guo J, Vickers S, Webb T, Carrick S, Barringer J 2019. Methods for upscaling and downscaling S-map information: Provision of spatial soil information in various formats and scales. In: Currie LD, Christensen CL ed. Nutrient loss mitigations for compliance in agriculture, Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. Pp. 15. http://flrc.massey.ac.nz/workshops/19/Manuscripts/Paper_Odgers_2019.pdf.

Pollacco JAP, Lilburne LR, Webb TH, Wheeler DM 2014. Preliminary assessment and review of soil parameters in OVERSEER® 6, Landcare Research Contract Report LC2002. https://www.overseer.org.nz/files/download/214da86c9e6fc9b.

Refsgaard JC, van der Sluijs JP, Hojberg AL, Vanrolleghem PA 2007. Uncertainty in the environmental modelling process - A framework and guidance. Environmental Modelling & Software 22(11): 1543-1556.

Richardson J, Lilburne L, Carrick S, Ford R 2019. Assessing the value of soil information: results of a survey of S-map users, Landcare Research Contract Report LC3644. https://smap.landcareresearch.co.nz/assets/Uploads/LC3644-S-map-users-survey.pdf.

Webb TH, Wilson A 1994. Classification of land according to versatility for orchard crop production, Landcare Science series, No.8

Wilde RH, Willoughby EJ, Hewitt AE 2000. Data manual for the national soils database spatial extension. 32 p.