S-MAP @ THE FARM-SCALE? TOWARDS A NATIONAL PROTOCOL FOR SOIL MAPPING FOR FARM NUTRIENT BUDGETS

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Abstract

Data that characterise land resources are fundamental to improving both agricultural productivity and environmental quality. Increasing agricultural productivity while also minimising impacts of intensive land use on fresh water is a national priority. Central and regional government policies, as well as industry initiatives, demand quality soil information. Soil survey information has long been a key component of resource management studies at regional and national scale, but new policies and upcoming resource consent requirements indicate that in coming years there will be widespread implementation of farm nutrient budgets and farm environmental management plans (FEMP), greatly increasing the need for accurate farm-scale soil information. While these budgets and plans are targeted at individual farms, collectively they contribute to catchment and regional objectives so it makes sense to ensure that accurate farm-scale soil information is provided in a consistent and auditable manner across a catchment.

Information on soils at the farm scale can be sourced from site observations, chemical and physical laboratory measurements of soil samples, electro-magnetic surveys, and detailed soil survey in addition to coarse-scale land-use capability (LUC) maps. We propose a national protocol for providing farm-scale soil information. We argue that establishing a national protocol has great advantages by providing clarity and certainty to those investing in farm-scale soil information, ensuring equitable and consistent outcomes from farm nutrient budgets and FEMP, as well as making it possible to scale up farm data for catchment-level modelling.

We suggest that the S-map data and informatics system, together with the National Soils Database (NSD), is ideally structured to support farm-scale mapping that follows a national protocol, and we highlight some key development initiatives to achieve this vision. We have characterised the various methods for obtaining soil information into four quality levels, along with a description of the minimum standard for each method. Policymakers can then determine the most appropriate level that is acceptable given the context in which the soil information will be used. Freely-available S-map data may be suitable as the base level for most situations, whereas intensive land use in highly sensitive catchments may require a higher level of information, such as site-specific measurements of key soil attributes.

Introduction

New Zealand has a rapidly growing demand for data that characterise land resources, driven by an increasing agricultural intensity that has raised concerns about the effect of intensive land use on water quality. Minimising the impacts of intensive land use on fresh water has become a national priority. As a consequence, central government, regional government, and industry policies are demanding quality soil information to underpin the widespread implementation of farm nutrient budgets, farm environmental management plans (FEMP), and audited self-management schemes (LaWF 2012; Mulcock and Brown 2013). Both industry and regulatory agencies recognise that the success of these initiatives will rely on a coordinated, consistent and auditable approach that includes the need for accurate farm-scale soil information (Edmeades *et al*. 2011; Mulcock and Brown 2013). While development of these budgets and plans is at individual farm level, collectively they need to contribute to achievement of catchment and regional objectives. Within this context it clearly makes sense to ensure that accurate farm-scale soil information is provided in a consistent and auditable manner across a catchment. The purpose of this paper is to discuss the challenges and opportunities for developing a national protocol and standard methods for the collection and use of farm-scale soil information.

Challenges of farm-scale soil survey

Regional councils are increasingly requiring farmers to provide sound soil information for normal farming activities such as water abstraction, nutrient management, and discharges to land. There is, however, uncertainty about what soil information is required to meet the needs of both councils and the farming industry – in terms of the appropriate scale and types of soil attribute information required, as well as the information accuracy and uncertainty appropriate to the resolution (scale) of farm management. Clearly the type of soil information for semi-extensive farmed hill country would be quite different to that required for intensively farmed lowlands (Manderson and Palmer 2006; Mulcock and Brown 2013).

Despite being linked to government and industry policies and regulation, there is no consistency in how farm-scale soil information is provided. Soil information is available from a range of sources, produced using a variety of methods, and varies in the degree of fitness for purpose. Farm soil maps may be provided at any nominal scale, with no quality indication as regards the accuracy or uncertainty of the mapping. The level of detail needed to resolve the soil pattern in areas with significant risk of leaching or runoff depends upon the nature of soil variability. In a highly variable floodplain we would expect significant improvement in the accuracy of leaching and runoff predictions with soil maps at finer scales, with 1: 10,000 map scale often suggested as an appropriate standard (Manderson and Palmer 2006). In a low variability landscape, such as loess-covered downlands or glacial outwash surfaces of the Canterbury Plains, a coarser-scale soil map may provide an appropriate level of accuracy. Likewise, the scale of soil mapping appropriate for semi-extensive hill country is likely to be different to that required for intensively farmed lowlands (Manderson and Palmer 2006). Given the potential high cost of preparing farm soil maps, guidelines are needed on the cost–benefit of producing different-resolution soil map information for combinations of different soil landscapes and land use intensity. Precision agriculture has demonstrated that, in some landscapes, there is good economic return on investment to be derived from high quality farm soil maps (Hedley *et al*. 2009). However, there is a risk that these gains in farmers' confidence to invest in detailed soil information may be eroded if quality standards are not maintained or expensive soil survey is done in landscapes that do not warrant it.

Soil maps are often confused with single-attribute mapping; e.g. the use of detailed electromagnetic induction survey to predict soil water holding capacity. Extrapolation of single-attribute maps beyond their original purpose may be inappropriate; e.g. the use of a soil water holding capacity map for farm dairy effluent system design, which is strongly affected by a number of other soil attributes such as soil drainage, infiltration rate, subsoil permeability and bypass flow vulnerability. Likewise soil survey can be confused with other farm-scale assessment, such as land-use capability (LUC) mapping or farm plan assessment. Soil information is a crucial underpinning component of these assessments, rather than a direct derivative.

Central to the consistency in farm-scale soil information provision is the professional capacity of agencies and individuals completing the soil survey. Accreditation to identify an acceptable level of expertise would greatly aid confidence both to those investing, as well as those auditing the quality of the soil information provided. Such accreditation is already present in other countries (CPSS, 2014; SSSA, 2014). Another challenge for farm soil mapping is consistency in description and attribute-measurement methods. For example there are at least four different field description handbooks in use (Taylor and Pohlen 1979; Milne *et al*. 1995; Manderson *et al*. 2007; Schoenberger *et al*. 2012), resulting in different categories of key soil attributes such as texture and soil structure. There are also various approaches to measurement or estimation of soil attributes such as water holding capacity or infiltration rate, ranging from 'rules of thumb' estimates, to field estimation from morphology attributes, to modelled pedo-transfer functions, to standard laboratory methods and proximal sensors. As farm nutrient budgets and FEMP will be used to underpin catchment-scale water quality goals, there is a need for consistency in mapping, description and soil attribute measurement so that farm soil maps can be scaled up to represent larger areas (e.g. catchments). The S-map information system provides an ideal basis for scaling up soil maps. This is because soil descriptions in S-map are based on clearly defined classes in the New Zealand *Soil description handbook* (Milne *et al*. 1995) and the *New Zealand soil classification* (Hewitt 2010; Webb and Lilburne 2011). This consistency in data provision allows a workable and functional system for information gathering and modelling that produces consistent, reliable outputs, which in turn provides the consistency in soil-input data for end-user tools and models. This does not necessarily mean one size fits all, but a consistent set of standard methods that integrate with end-user tools and models will ensure reliable, equitable and auditable outcomes to inform catchment-scale decision making.

Relationship between S-map and farm-scale soil survey

S-map is not just a map but, rather, is an integrated and dynamic soil information system. The S-map information system (Figure 1) comprises databases of spatial and attribute variation, a modelling and interpretation inference system, and a number of platforms to deliver soil information to end-users (Lilburne *et al*. 2012, 2014; Landcare Research 2014). The S-map system has been designed to accommodate soil data at any scale, and be adaptable to both changing soil science knowledge and end-user needs. Up to now, soil data generation has been funded by regional councils, with priority to meet regional and catchment-level policy needs, and to digitise the historical soil surveys. As a result the resolution of the spatial soil data (soil maps) is mostly 1:50,000 scale, although there are finer-resolution data in some areas. Soil attribute data within S-map include soil classification, drainage, texture, stoniness, density and parent material. S-map also contains soil attributes (e.g. water available to plants, phosphate retention) derived from correlation with analytical data stored in the National Soils Database (NSD) (McNeill *et al*. 2012; Lilburne *et al*. 2014). One of the features of S-map (due to its national coverage, consistent soil attribute definition and link with the NSD) is its ability to predict soil data in areas where these analytical data have not been collected. We recognise that there are parts of the country where we have limited underpinning data in the NSD (a case in point is the small number of Pumice soils with physical data) and in these areas estimated soil characteristics have high uncertainty. Conversely, there is also a great deal of soil attribute data/information that has been measured by various public agencies, and is sitting in files and papers, that needs to be added to the NSD. Landcare Research currently has a program that is focused on adding new data to the NSD and providing an enhanced database platform to access all the data. Even with the inclusion of all this historic data, it is likely that some NZ soils will be under represented and will require funding to make new measurements.

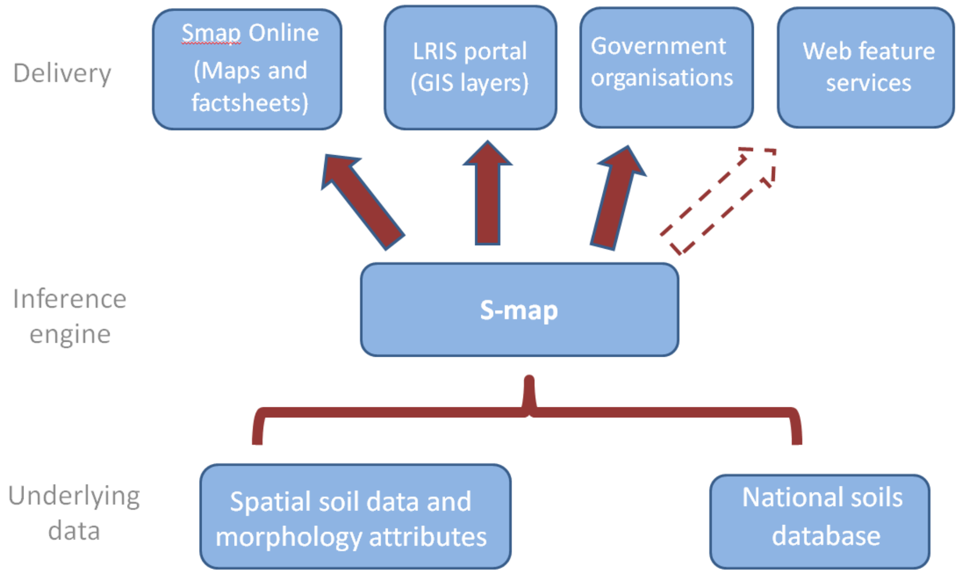

Figure 1 Structure of the S-map soil information system.

There are a number of key S-map development initiatives at each level of the information system that can support farm-scale mapping. The flexibility of the factsheet generator allows the information provided on the soil factsheets to be customised to meet end-user needs. Recently we have developed an additional factsheet page targeted at providing soil information to support the OVERSEER® Nutrient Budget Model. Likewise, we were able to add the soil classification categories that are used in the Dairy Effluent Storage Calculator. A real advantage is that the factsheets can adapt as the end-user tool requirements change, so OVERSEER targeted soil information on the S-map factsheets can be readily updated to stay relevant to future versions of the model. Critical to the success of farm nutrient budgets, FEMP, and audited self-management will be consistent assessment of environmental risk and spatial targeting of good management practices to suit the specific nature of a farm's land features and soil types (Mulcock and Brown 2013). The S-map information system has developed a set of models to identify the environmental risk for each soil type that are already available on the S-map factsheets (Webb *et al*. 2010; Lilburne *et al*. 2014).

The S-map information system has also been designed to provide soil information at any scale. Whereas historical funding sees the current data focused on regional council needs, these data could easily be upgraded to finer-resolution mapping. For example, if a sensitive catchment was remapped at 1:10,000 scale it could be loaded into the S-map system to gain the full benefits of the information system, to access the factsheet generator and other models of the inference engine, and use the delivery platforms to feed the detailed soil information to end-user tools and models. Likewise the soil factsheet generator could be of great benefit to farm-scale mapping, where often the cost prohibits the full analytical measurement of soil attributes for each soil type that has been mapped. If soil types on a farm map are identified using the *New Zealand soil classification* and standard description methods (e.g. Milne *et al*. 1995), then the S-map system could be used to generate consistent and auditable factsheets for each soil type, with targeted soil information for input into end-user tools and models such as OVERSEER. The regional-scale S-map data, with their underlying soil-landscape models, can also be of great help to farm-scale soil mappers to inform them of the likely variability, pattern and range of soil types present (Fraser *et al*. 2014). This, together with environmental covariate data such as digital terrain models, landform elements and geological maps, can be used when mapping to spatially target observation points (Hedley *et al*. 2010; Roudier and Hedley 2013).

Developing a national protocol for farm-scale soil mapping

The purpose of a national protocol and set of methodology standards is to provide clarity as to the appropriate methods and options for farm-scale mapping, as well as transparency in the accuracy, reliability and acceptability of the data. Collection of farm-scale soil information is not cheap, but a coordinated suite of methods and support tools should aim to minimise costs, while ensuring the maximum benefit and usability of the information for both the farm and the catchment. In the Mataura River catchment, such a coordinated approach to soil mapping has been shown to have the potential for a 1:6 cost benefit within the first year, when using the catchment soil map to spatially target mitigation management practices to soils with the highest vulnerability to nitrogen leaching (Carrick *et al*. 2010). Similar relationships have been found in other studies looking at the cost benefit of soil survey (Garland and Baker 1998; MacKay *et al*. 1998).

We suggest that a national protocol for farm soil information needs to be tailored to different landscape environments, and to follow a simple and consistent structure (McKenzie 1991; Manderson and Palmer 2006). This recognises that soil information and mapping scale for semi-extensive hill country would be quite different to those required for intensively farmed lowlands. Manderson and Palmer (2006) proposed three landscape environments: Non-domesticated land; Agricultural and Forestry land on slopes <15°; and Agricultural and Forestry land on slopes >15°. The LUC classification is also a logical starting point for defining landscape environments. For example, LUC classes 1–4 would capture the most versatile soil landscapes with potential for multiple land uses.

We propose a 'strawman' protocol for farmland (<15°) with multiple land use potential, where we have characterised the various methods for obtaining soil information into four quality levels (Table 1). Policymakers, industry bodies, and catchment community groups can then determine the most appropriate quality level that is acceptable given the context in which the soil information will be used. Freely available S-map data may be suitable as the base level for most situations. In areas of high soil variability, a detailed 1: 10,000 soil map may be linked to the S-map factsheets to provide better information, whereas areas with intensive land use in highly sensitive catchments may require a higher level of information, such as detailed soil survey and site-specific measurements of key soil attributes.

For each quality-level examples of the baseline minimum standard of soil information is provided, but others could be added as the protocol is developed. This protocol would need to be underpinned by referenced standard methods. For example standard methods exist for both the minimum observation density for different scale mapping (Manderson and Palmer 2006) and soil description and classification in New Zealand (Milne *et al*. 1995; Hewitt 2010; Webb and Lilburne 2011), as well as laboratory methods for soil chemical and physical analysis (Blakemore *et al.* 1987; Dane *et al*. 2002; McKenzie *et al*. 2002; Carter and Gregorich 2008). Standard methods for monitoring temporal change of soil attributes also exist, such as the visual soil assessment guides (VSA) (Shepherd 2000), measurement of soil infiltration (McKenzie *et al*. 2002), and the ongoing development of soil quality monitoring indicators (MacKay *et al*. 2013). To be successful this set of referenced standard methods needs to be a live document, allowing it to grow in response to new research and technologies, as well as potentially to remove methods from the approved list as better methods become available.

Table 1 'Strawman' proposed national standard for farm-scale soil mapping in farmland (<15°) with multiple land use potential, in relation to key land management issues. For each quality-level examples of baseline soil information are provided, but others could be added as the protocol is developed.

Farm soil map quality-level	Irrigation management		Nutrient, soil and sediment management			Farm dairy effluent	
	Design	Monitoring	N and P leaching	P, sediment, and bacteria runoff	Compaction / pugging	Design	Monitoring
Poor	Fundamental Soil Layer (LRIS 2014) Coarse-scale published historical soil data (e.g. Kear *et al*. 1967) 'Rules of thumb' soil attribute data	Visual/tactile inspection of soil moisture Surface ponding Subsurface drains are flowing indicating excess irrigation	Farm-scale LUC-based nutrient budgets Overseer inputs from Fundamental Soil Layer	LUC maps 1:50,000 Use of the River Environment Classification or topomaps to identify poorly drained and artificially drained areas, sloping areas, and location of waterways and water bodies	Farmer awareness of areas of land that pug, compact or pond after heavy rain	Fundamental Soil Layer Coarse-scale published historical soil data 'Rules of thumb' soil attribute data	Visual/tactile inspection of soil moisture Surface ponding Subsurface drains are flowing indicating excess irrigation
Basic	S-map-derived soil map and factsheets (medium or high soil map quality confidence)[1] Field check of key soil types by consultant	Handheld soil moisture meter Desktop soil water balance scheduling	S-map-derived soil map and factsheets (medium or high soil map quality confidence) OVERSEER soil type inputs from S-map On-farm monitoring topsoil fertility status	10- to 25-m DEM-based landform, waterway and 'connectivity to waterway' maps On-farm identification of critical source areas Farm-scale LUC map	S-map-derived soil map and factsheets (medium or better soil map quality confidence) Farm-scale LUC map On-farm visual soil assessment (VSA guideline)	S-map-derived soil map and factsheets (medium or better soil map quality confidence) Field check of key soil types by consultant 10- to 25-m DEM-based landform, waterway and 'connectivity to waterway' maps	Handheld soil moisture meter Desktop soil water balance scheduling

[1] As defined in S-map Online (Landcare Research 2014).

Table 1 continued.

Farm soil map quality-level	Irrigation management		Nutrient, soil and sediment management			Farm dairy effluent	
	Design	Monitoring	N and P leaching	P, sediment, and bacteria runoff	Compaction / pugging	Design	Monitoring
Good	Farm-scale soil map (e.g. 1:10,000 scale in areas with high soil variability) Field analysis of key attributes for main soil types matched to S-map fact sheets	On-farm soil moisture sensors on dominant soil types Real-time soil water balance scheduling for each soil/ management zone On-farm visual soil assessment (VSA guideline)	Farm-scale soil map (e.g. 1:10,000 scale in high soil variability areas) Field analysis of key attributes for main soil types matched to S-map factsheets On-farm monitoring topsoil fertility status	<10-m DEM-based landform, waterway and 'connectivity to waterway' maps On-farm identification and monitoring of critical source areas Farm-scale LUC maps	Farm-scale soil or LUC map Regular on-farm visual soil assessment (VSA guideline)	Farm-scale soil map (e.g. 1:10,000 scale in high soil variability areas) Field analysis of key attributes for main soil types Soil factsheets for each soil from S-map	On-farm soil moisture sensors on dominant soil types Real-time soil water balance scheduling for each soil/ management zone On-farm visual soil assessment (VSA guideline)
Premium	Farm-scale soil map with high confidence (e.g. ± 10% variance in area of each soil type) Statistically replicated field and laboratory measurements of attributes for main soil types, using accredited methods	Replicated on-farm soil moisture sensors for each soil type Real-time soil water balance scheduling for each soil/ management zone On-farm visual soil assessment (VSA guideline) On-farm monitoring of temporally dynamic soil attributes (e.g. infiltration rate, macroporosity)	Farm-scale soil map with high confidence (e.g. ± 10% variance in soil type area) Statistically replicated attribute measurements for main soil types On-farm monitoring topsoil fertility status. On-farm targeted leachate monitoring to validate models (e.g. lysimeters)	<2.5-m DEM-based landform, waterway and 'connectivity to waterway' maps On-farm identification and monitoring of critical source areas On-farm monitoring of temporally dynamic soil attributes (e.g. infiltration rate, macroporosity, topsoil fertility)	Farm-scale soil or LUC map Regular on-farm visual soil assessment (VSA guideline) On-farm monitoring of temporally dynamic soil attributes (e.g. infiltration rate, macroporosity, topsoil fertility)	Farm-scale soil map with high confidence (e.g. ± 10% variance in area of each soil type) Statistically replicated attribute measurements for main soil types	Replicated on-farm soil moisture sensors for each soil type Real-time soil water balance scheduling for each soil/ management zone On-farm monitoring of temporally dynamic soil attributes (e.g. infiltration rate, macroporosity, topsoil fertility, visual soil assessment)

Given the high cost of farm-scale mapping we believe it is unlikely that there will be large single-agency mapping programmes that occur in the near future. Detailed farm-scale mapping at the good to premium quality-levels of Table 1 costs around $35–$100 per hectare depending on the complexity of the soil pattern and the amount of soil attribute measurements undertaken (Manderson and Palmer 2006). It is likely that in most situations farm-scale soil mapping will proceed in an ad hoc manner. Even within a catchment, farms could be mapped according to the different quality-levels suggested in Table 1, and mapped at different time periods by different agencies and individuals. In this context, implementation of the national protocol and standard methods would greatly improve consistency and repeatability between the soil maps. It will also enable much more reliable and consistent auditing of soil information quality, and decisions by regulatory authorities. Implementation of a national protocol and standard methods also enables much greater certainty for those agencies investing in developing farm-mapping support tools and databases, as well as end-user tools and models. For example, the widespread adoption of the OVERSEER® Nutrient Budgeting Model has provided the certainty needed for the S-map programme to develop a coordinated set of soil information products specifically targeted at the OVERSEER model. Also, the S-map information system allows soil information to be easily adapted as the OVERSEER model evolves over the coming years.

Recommendations on next steps

Given the central importance of agriculture to the New Zealand economy it is surprising that soil survey has struggled to obtain a stable funding platform. This has not been the case in other countries, with comprehensive and detailed national soil survey programmes in at least nine European countries, plus nations such the UK and USA (Manderson and Palmer 2006).

We believe that a national protocol and standard methods for providing farm-scale soil information is attainable within the short time frame that is required to support the widespread implementation of farm nutrient budgets and farm environmental management plans (FEMP). The S-map soil information system has been designed to support farm-scale mapping that follows a national protocol, and with some key development initiatives it can be easily adapted to meet farm-scale mapping requirements. The advantages of the small size of New Zealand means there is a relatively small number of agencies and individuals involved in land resource assessment, so development of a national protocol is attainable within a short time frame provided a clear mandate is given by regulatory, industry and community agencies.

As a starting point we recommend creating a working group tasked with developing a national protocol. Ideally funding and development would be as a pan-agency initiative, but could also be initiated as a joint regional council project. To be successful this small group needs to cover technical expertise, accommodate the requirements of policy, industry tools and models, and coordinate with education and training providers.

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