

BEYOND TODAY – SOIL SCIENCE INTO THE FUTURE

The New Zealand economy is centred on the quality of its natural environment, with primary sector production highly dependent on the resilience and health of our many soils. However, a suite of rapid technological disruptions and societal shifts have potentially far-reaching implications for the future of the primary sector. These include new ‘alternative milk and meat’ from lab-based synthetic proteins and plant-based proteins; changing consumer and market drivers (e.g. growing veganism, vegetarianism, and demand for organic foods); the opportunities for data-driven precision technologies based on the ‘Internet of Things’; and increasing environmental constraints (e.g. freshwater limits, nutrient caps, and a prospect of new climate change policies).

Any major changes to primary production paradigms in New Zealand are also expected to have major implications for our soils: the types of pressures on them; the management options needed to conserve and enhance their natural capital; monitoring and reporting needs; and how to capitalise on the opportunities latent in our soils. For example, large-scale shifts to plant protein production (away from dairying, for example) would likely bring different stressors on our soils, such as soil contamination risks from trace elements (e.g. copper applied as part of organic farming systems), and greater frequency of cultivation resulting in risks of structural degradation, organic matter loss, and spikes in nutrient losses at certain times. Soil health monitoring and soil management approaches need to evolve to reflect these different contaminants, and what they mean for ecological and human health. We can also expect to see ongoing focus on new methods to mitigate both current and emergent risks to soil health, such as soil remediation methods, smart ways to increase soil carbon, and advances in precision irrigation.

Science clearly has a key role to play in ensuring these disruptions and shifts are managed in ways that bring benefit to New Zealand. As an example, new science that explores how to capture the benefits of soil biota and micro-biota to enhance productivity and increase ecosystem resilience to drought, disease and contaminants is just one of many exciting potential routes to support future primary sector systems. In this issue of Soil Horizons we explore several aspects of such new, smart soil science. We bring together key strands of irrigation technology, soil carbon, and soil biota; explore the complexities of soil health and soil mapping; and discuss new ways to reduce risk from sediment and erosion, and increase soil health. The articles that follow highlight both recent advances and potential pathways towards increased soil resilience; research that will serve New Zealand well, particularly with the imminent rise of future farm systems.

In this issue, we provide an update on the MBIE-funded *Maximising the Value of Irrigation* programme, which is developing and testing soil and crop sensor technologies to map spatial variability and monitor factors that influence effective irrigation (e.g. soil water status). We also provide an overview of a new project led by Federated Farmers that will better identify the medium- to long-term effect of irrigation on soil water holding properties.

Several articles focus on soil carbon: we showcase some surprising results from an MPI-funded Sustainable Land Management and Climate Change (SLMACC) project on the long-term impact of irrigation on soil properties that may help identify where, and how, irrigation can be used to maintain or increase soil organic matter. We also provide an overview of a SLMACC programme to develop a method to monitor soil carbon stocks and stock changes in managed grasslands, which occupy more than half of New Zealand’s land area, and discuss research on the carbon balance of dryland and irrigated lucerne crops on stony soils, which aims to show that increasing soil carbon can increase soil microbiological communities and reduce leaching.

Other articles demonstrate how new technologies can contribute to resolving key science questions, including new digital approaches in the S-map programme to mapping New Zealand’s highly complex, variable soils, and highlight the opportunities to derive greater value through interoperability from the significant soils data held by Manaaki Whenua – Landcare Research in the National Soils Data Repository.

As the various programmes highlighted in this issue progress, we are excited by the opportunities to explore potential synergies, integrate research findings, and leverage the new knowledge and data to answer some of New Zealand’s biggest questions about our soils. Such holistic approaches are critical as we head into a potentially disruptive future.

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MANAAKI WHENUA – LANDCARE RESEARCH SOIL PROGRAMME LINKAGES GIVE STRENGTH IN NUMBERS

During the last year at Manaaki Whenua – Landcare Research we have greatly expanded our suite of soils research programmes, due to successful funding bids for new multi-year projects from MBIE and MPI. As shown in Figure 1 (below), these new programmes will help us answer some of the big questions in soil research and will have impacts for generations to come. This new research will provide understanding of how key soil properties, such as soil carbon and water-holding capacity, change under different management practices across a wide range of New Zealand’s soil environments. The strong linkages of these programmes with farming industry groups will ensure application of the knowledge generated to help farmers in their ongoing efforts to reduce the impacts of management practices on the environment.

Despite these new projects being stand-alone programmes, we have worked hard to ensure they are well connected to use resources efficiently and maximise benefits. Using measurements taken from common sampling sites for multiple research projects increases efficiency, allows us to build on previous knowledge, and look in greater depth at the variables at play.

For example, Paul Mudge’s SLMACC project will sample 50 sites on adjacent irrigated and unirrigated grassland soils to clarify the impact factors such as soil type and irrigation duration have on soil organic matter. Some of the sampling sites are shared with Sam Carrick’s new sustainable farming fund project, which looks at how irrigation affects the water-holding capacity of soils. This information will also link through to the S-map Next Generation programme where there is a major effort to better characterise the soil water attributes of New Zealand’s soils – key soil information that is used for both irrigation and nutrient management purposes. Research in the Maximising the Value of Irrigation programme further enhances the understanding of soil water dynamics in arable soils, and how sensing technologies can improve irrigation practices. Other sampling sites are in common with Bryan Stevenson’s project that looks at integrating knowledge on long-term soil health and resilience with kaupapa Māori concepts to develop a nationally consistent soil health framework and best practice guidelines to increase productivity within environmental limits. A multi-disciplinary MBIE Endeavour programme led by David Whitehead is investigating ways to manipulate carbon and nitrogen cycling to reduce nitrogen losses. This programme is part of a number of multi-agency collaborative research programmes based at Ashley Dene Research and Development Station. Ashley Dene was set up by Lincoln University as a working-farm platform that enables researchers to develop and test next generation management practices for dairy farming on the stony soils that are widespread in the eastern plains of New Zealand. The following articles contain more detailed information on each of the new research programmes.

The vast amount of data that is being collected in these, and other Manaaki Whenua projects, is also a driving factor behind progress in the National Soils Data Repository (NSDR). The National Soils Database (NSD) contained records for soil observations of around 1,500 soil profiles dating from 1959. However, funding cuts meant that data collected after 1994 were not added into the NSD, leading to a substantial backlog of historic data that have limited long-term usability and impact until they are all integrated within a centrally curated database. Manaaki Whenua has invested significant funding over the last 2 years to rebuild the NSD, now called the NSDR. The repository has been designed to meet modern international database standards, has a capacity for multiple types of soil data, and is now ready to receive new data. It is Landcare Research’s intention that all new soil data collected will be uploaded into the NSDR, and an app is currently being developed that will allow pedologists to upload soil information (including measurements, photos, and GPS coordinates) directly from the field. We are also hopeful that central government will contribute to the maintenance of the NSDR, when a review of investment from the Nationally Significant Collections and Databases fund is carried out over the next year. This will guarantee the soils data collected by New Zealand scientists over many decades will continue to be freely available for research, increasing understanding of soils and the impact they have on the wider environment, ensuring that our land remains healthy and productive into the future.

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IMPACT OF IRRIGATION ON SOIL CARBON AND NITROGEN

The topic of irrigation is regularly in the news, with the focus generally on economic benefits and impacts on water quantity and quality. However, there is surprisingly little information about the long-term impact of irrigation on many soil properties, including soil organic matter (SOM). Carbon and nitrogen are major components of SOM, which is important for stable soil structure, soil water holding capacity, soil nutrient retention, and can be a sink for atmospheric CO₂.



Figure 1. Soil cores from a Recent (A) and Pallic (B) Soil in the Wairarapa.



Figure 1. MWLR soil programme linkages

To our surprise, results from a recent SLMACC research project revealed significantly less carbon and nitrogen in soils under irrigated pastures than under adjacent unirrigated pastures at 34 sites across New Zealand. These results were consistent with results from the long-term (~50 year) irrigation trial at the Winchmore Research Station, although other studies have found either no difference or increases in

carbon under irrigated compared with unirrigated pastures.

Together with Louis Schipper (University of Waikato) and students, we have initiated a broader SLMACC-funded investigation of irrigation effects on soil organic matter to determine the importance of region, soil type and irrigation duration. The ultimate aim is to identify where and how irrigation can be used to maintain or increase soil organic matter and the multiple associated benefits.

We are sampling an additional 50 paired irrigated and unirrigated pasture sites spread across Hawke's Bay, Wairarapa, Canterbury, and Otago. These four regions account for 80% of all irrigated land in New Zealand and also contain more than 80% of the potential future irrigable area. Good progress is being made, with sites in Hawke's Bay and Wairarapa sampled in June 2017 and sampling in the other regions starting in August 2017.

A dedicated BSc(Tech) student, Alesha Roulston, helped greatly with the project by identifying more than 4,000 pivot irrigators from which sampling sites were randomly selected. A directly aligned study sampling irrigated and unirrigated Pumice Soils in the Reporoa area is the focus of Jamie Millar's MSc research.

A number of sampling sites in Canterbury will be common with [Sam Carrick's Sustainable Farm Fund project](#) investigating the effect of irrigation on soil physical properties; and this work builds on existing research on this topic being undertaken in the MBIE Programme "Maximising the Value of Irrigation". The MBIE programme "Soil Ecosystem Health and Resilience," led by [Bryan Stevenson](#), will likely utilise samples from a subset of sites for detailed chemical analyses. Through SSIF funding we have also made, or plan to make, measurements of (1) carbon and nitrogen cycling, (2) sensitivity of respiration to temperature and moisture (Olivia Petrie MSc), (3) microbial community composition/function, and (4) different fractions (pools) of carbon and nitrogen on samples from the same sites. Alignment of projects at the same locations will allow a much more comprehensive understanding of the impact of irrigation on soil properties than if projects were all completed in isolation. The broad-scale sampling in different regions and soils also complements [our more detailed work at research platforms](#) such as continuous measurements of carbon inputs/outputs and microbial processes at the Ashley Dene Farm near Lincoln.

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THE CARBON BALANCE OF DRYLAND AND IRRIGATED LUCERNE GROWING ON STONY SOILS

Casual scanning of stories in the newspaper almost every day reveals concerns about the environmental consequences of the widespread expansion of intensive irrigated pastoral agriculture (particularly dairy farming). A major focus has been on Canterbury, which produces 64% of New Zealand's primary sector exports, mainly from shallow, stony soils prone to leaching. On-farm solutions are required to reduce negative environmental consequences while maintaining productivity and profitability.

The basis of our new research programme is that increasing soil carbon inputs will favour microbiological communities that retain nitrogen for plant growth and reduce losses. We are testing this on small experimental plots, for a range of management options from grazed grassland to cut-and-carry crops. For scaling-up to paddock scale, we are using dryland and irrigated lucerne, at Lincoln University's Ashley Dene Research & Development Station. In these two paddocks, we have installed large lysimeters to directly measure nutrient and carbon leaching losses.

To test our idea that nitrogen losses are linked to carbon inputs, we have estimated the annual carbon balance of the two lucerne paddocks, for two seasons starting with the conversion period. The two major terms contributing to the carbon balance are the net exchange of carbon dioxide (CO₂) with the atmosphere and the removal of harvested biomass. The net CO₂ exchange is the difference of CO₂ uptake by photosynthesis and CO₂ emission from respiration. This difference is obtained by measuring rapid variations in CO₂ concentration and vertical wind speed at 2 m above ground (Fig. 1). The exported carbon in biomass is measured by weighing and analysing harvested samples. Minor contributions to the carbon budget are the amounts of carbon applied with effluent and fertilisers, and carbon leached.



Figure 1. Measurement site in irrigated lucerne field, with weather station on left and CO₂-exchange instrumentation on the right. The lucerne around the site has just been harvested, and the vegetation left standing is about to be cut by our team to determine the biomass-carbon accumulated since the previous harvest. (Photo: John Hunt)

Cumulative carbon balances are shown in Fig. 2, for the first and second year in the left- and right-hand panels, respectively. In the first year, both paddocks were converted from oats to lucerne by cultivation, and irrigation began in December. The carbon balance for the oat crop was neutral. Following that, respiration from the bare soil during the conversion period caused a carbon loss of 1.75 t C/ha. Once growing, the irrigated lucerne recovered 74% of this loss (while being harvested twice). By contrast, the dryland lucerne did not establish well and thus did not recover any of the conversion loss.

In the second year, both lucerne crops grew well throughout spring and summer. The irrigated and dryland lucerne were harvested five and four times, respectively. For the first three harvests, the carbon balance for both paddocks was positive but the fourth and fifth harvest periods turned this around into net losses. During the second year, carbon removed with harvested biomass for animal feed amounted to 3.14 and 5.78 t C/ha for the dryland and irrigated sites, respectively.

Our data show by how much irrigation increased net CO₂ uptake and biomass production, compared with the dryland site. However, the irrigated lucerne also recorded greater net carbon losses than the dryland lucerne, which suggests the carbon from the additional net CO₂ uptake was almost entirely allocated to above-ground biomass, which was then harvested as feed stock.

These results will be linked with other strands of our research programme to understand the below-ground carbon and nitrogen budgets. In order to analyse differences in microbiological activity, we extracted soil cores down to 1.7 m depth from both sites in early winter. We are yet to analyse the effects of irrigation on nitrogen leaching, because drainage at 1.5 m depth only started to occur in late autumn, following heavy rainfall. Our research combines measurements of carbon, water and nitrogen inputs and losses for stony soils where there are few data available. Our findings will inform policymakers and farmers of the environmental impacts of lucerne production on stony soils.

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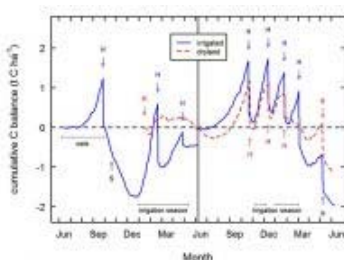


Figure 2. Cumulative carbon balance for irrigated and dryland lucerne over two years (left panel: 2015/16; right panel: 2016/17). The S label indicates sowing of lucerne (3 weeks after the harvest of the preceding oats crop).

The H labels indicate times of harvests, highlighting the steep reductions in carbon balance associated with removal of biomass.

THE EFFECT OF MEDIUM- TO LONG-TERM IRRIGATION ON SOIL WATER HOLDING PROPERTIES



Farmers are becoming increasingly interested in how soils change under irrigation, as a result of their on-farm observations and experiences. Former South Canterbury Federated Farmers President, Ivon Hurst, is chairman of a MPI Sustainable Farming Fund research project that will examine those understandings over the next 3 years through scientific measurements and peer-reviewed data. “Anecdotal evidence is not enough,” Ivon says. “It has to be scientifically validated and that’s the way forward for all future land management practices.”

The project is led by Federated Farmers and backed by contributions in cash and kind from Environment Canterbury, Beef + Lamb, Irrigation NZ, Dairy NZ, Manaaki Whenua – Landcare Research, and seven Canterbury irrigation companies. Manaaki Whenua’s Sam Carrick will lead the project research, and a range of extension activities will be led by Katherine McCusker, of The AgriBusiness Group, supported by Lionel Hume from Federated Farmers. A recent Lincoln University Masters graduate, Veronica Penny, has been contracted at Manaaki Whenua to work on the project.

This project involves working with farmers, rural professionals, scientists, and regulators to:

- access previous research knowledge and findings on the response of soil physical properties to irrigation
- fill an important knowledge gap, through field measurements, to quantify whether, under medium- to long-term irrigation, soil water holding capacity increases compared with the same soil and farm system under dryland conditions
- upskill them on the knowledge and understanding of how soils respond to irrigation, and which practices will potentially have the greatest positive impact on the ability to efficiently manage water and nutrients.

The first task, already underway, is to gather what written material and data are already available, by searching previously published research in a range of sources from scientific journals to reports from past research stations such as Winchmore, Templeton, and Timaru. “There’s a huge amount of good stuff that has never seen the light of day since it was written”, says Katherine, and she is really keen to “dust off the shelf and get the knowledge into the hands of our innovative farmers and irrigation industry specialists”.

The second stage of the project, also underway, will involve field sampling across 48 farms in Canterbury to quantify whether, under medium- to long-term irrigation, soil water holding capacity increases compared with the same soil, in the same farm system, but under dryland conditions. Through the use of Manaaki Whenua’s GIS mapping skills, the project has identified a range of potential pasture paddocks across Canterbury that may contain both irrigated and dryland areas (Fig. 1). Thanks to Federated Farmers’ membership database, The Agribusiness Group and their network of contacts, and the local knowledge of the participating irrigation companies, the project team is currently refining this list against suitability criteria, with the field work due to start in August 2017. The project will also look at the effect of soil type and length of time under irrigation, to determine their roles in how soil water holding properties may change under irrigation.

A strength of the project is the collaboration involved, shown by the large number of co-funding industry groups and the active cooperation with other funded science projects. The field sampling research works directly with both the MBIE funded *S-map NextGen* and MPI funded *Impact of Irrigation on Soil Carbon Stocks* projects – both of which are described in this issue of Soil Horizons. For the extension side of this project, we are working closely with the IrrigationNZ project “*SMART Tools and Tips for Irrigators*”, also funded by the MPI Sustainable Farming Fund, as well as with the extension programmes of our other co-funding partners.

The third major component of this project is to have a regular presence in industry magazines, farmer field days, etc. over the next three years, highlighting not just our research findings, but the knowledge generated in other science projects that may not have the degree of connectivity to a range of end-users that Federated Farmers has linked together in this Sustainable Farming Fund project.

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Figure 1. This project will study paddocks with both irrigated and dryland areas, to research how soil water properties may change under medium- to long-term irrigation.

MONITORING CHANGES IN SOIL ORGANIC CARBON STOCKS IN NEW ZEALAND'S MANAGED GRASSLANDS



Manaaki Whenua – Landcare Research has obtained Sustainable Land Management & Climate Change funding from the Ministry for Primary Industries to develop a method to monitor soil organic carbon stocks and stock changes in New Zealand's managed grasslands, which occupy more than half the country's total land area.

Countries worldwide place great emphasis on maintaining, or preferably increasing, soil organic carbon stocks for sustainable development and to address the impacts of climate change, and so we are developing a method to monitor any changes in soil organic carbon stocks at the national scale. An increase in soil organic carbon is a direct removal of carbon dioxide from the atmosphere and, therefore, one way to alleviate climate change impacts. If farm management practices exist that can reduce the loss or increase the rate of organic carbon sequestration into soils, governments will encourage these practices by providing financial incentives in carbon trading schemes. However, for this to happen, management methods must be auditable. Delegates from 111 countries, including New Zealand, recently met at an FAO meeting in Europe to review the role of soil organic carbon in the context of climate change and sustainable development. Top on their recommendations was the need to ensure countries are able to measure, map, monitor, and report on soil organic carbon stocks and stock changes to support management decisions.

Soil organic carbon stocks are inherently spatially and temporally variable, so sampling at field sites is problematic. Therefore, we are designing a fit-for-purpose soil organic carbon monitoring protocol, suitable for use in New Zealand's managed grasslands. In this SLMACC project, the protocol will be implemented in hill country, where there is potential to increase the value of production, and where information is lacking on any potential impacts of increased intensification on soil organic carbon stocks. Hill country occupies 38% (9.9 million hectares) of all managed grasslands, and is broadly defined as the more rugged parts of our landscape, with slopes $>15^\circ$ and located below an altitude of 1,000 m. The method is being designed to be implemented over upcoming decades, and to be appropriate for national reporting, i.e. accurate, consistent, transparent, and compliant with international IPCC (International Panel on Climate Change) standards. The important contribution of an appropriate sampling design (i.e. how to select field sampling positions) cannot be overemphasised in this exercise, as this determines the quality of the end result. The sampling design is determined using prior knowledge of the spatial distribution of soil organic carbon stocks (i.e. existing measurements) and other factors that influence its accumulation (see Table 1), which are available to this project as digital map layers.

Table 1. Datasets that relate to the distribution of soil organic carbon stocks

Variable	Data-layer examples
Soil factors	Soil depth, clay content, drainage class
Climate	Rainfall, temperature
Biota (including human activity)	Land use
Relief	Elevation, slope, aspect
Parent material	Geology, inferred from soil order

A dataset of soil organic carbon stocks collected previously from 3,010 sites has been assembled for the target area and this, together with the digital map layers, provides the resources needed to select sampling positions objectively. A statistical approach is being used to do this, and once the positions are selected, new soil samples will be collected in a field campaign, due to begin this year. The new soil organic carbon data will be spatially modelled to derive a mean estimate of soil organic carbon stock within defined confidence intervals (e.g. $\pm 10\%$) for New Zealand's hill country in 2017. These confidence intervals can be narrowed by collecting more samples, and future campaigns will repeat this method to assess for any changes.

In summary, a fit-for-purpose method is being designed to monitor soil carbon stocks at approximate 5-year intervals over upcoming decades. This monitoring will support New Zealand's commitment to the Paris Agreement to reduce greenhouse gas emissions by 30% below 2005 levels by 2030. If soil carbon sequestration is occurring, this can then be audited and used as an offset to greenhouse gas emissions in national accounting systems.

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Figure 1. Example of steepland pastoral hill country in the Wairarapa region. Soils have developed on erodible Tertiary siltstones and loessial parent materials. The original podocarp–hardwood native vegetation was cleared between 1860 and 1890 and replaced with grasslands for sheep and cattle grazing, which has increased the susceptibility of the soils to erosion.

SOIL HEALTH AND RESILIENCE: ONEONE ORA, TANGATA ORA – EXPANDING WHAT SOIL HEALTH MEANS

The MBIE-funded project *Soil health and resilience: oneone ora, tangata ora* aims to support the development of a longer-term and more comprehensive view of soil health and resilience; and to develop an integrated soil health framework that can be used by a wide range of end-users. It is important that this framework is flexible, to enable it to adapt to both technological and societal changes impacting on the primary sector.



The ongoing capacity of soil ecosystems to maintain the services they provide is fundamental to our economic, cultural, social and environmental well-being. We estimate that in economic terms, around 17% of NZ's GDP depends directly on our soils, but the importance of soil to our social, cultural, and long-term environmental well-being is less well understood. Current measures of soil health focus on short-term “dynamic” soil characteristics (such as pH and soil nutrients) that may be inadequate to assess long-term changes to soil health and resilience. Also, present measures in Aotearoa-New Zealand do not recognise cultural perspectives, such as mātauranga Māori, which are very important considerations when defining and assessing soil health in our multicultural and pluralistic society

The three major interacting objectives of the project are to:

1. test long-term land-use sequences on different soils to gauge the effects of land-use intensification on soil properties in order to better define soil resilience;
2. develop concepts of soil health from a Māori perspective;
3. integrate cultural value systems and mātauranga Māori with new scientific knowledge and other forms of technical knowledge to articulate and express long-term effects of land use on soil ecosystems.

The overall goal is to develop a universal soil health framework that can be used by a wide range of end-users, from primary industry, landowners, iwi/hapū, to central and local government. This new innovative framework, based on blending science excellence and Māori knowledge and perspectives, will be designed to complement existing soil monitoring programmes.

Work to date has focussed on identifying monitoring sites, trialling analyses and aligning existing programmes (see diagram at end of section) through collaborative efforts to better achieve our goals. We have also begun our exploration of the concept “soil health and resilience” from a ‘kaupapa Māori’ – mātauranga Māori/Māori values based – perspective using Māori knowledge frameworks, concepts, and terms to define soil ecosystem health characteristics, pressure-state and impact indicators, and describe soil resilience characteristics from a Māori lens. To accomplish this we are working with a large range of Māori organisations, including a number of iwi/hapū representatives and organisations, Tumu Paeroa, Hua Parakore standards and certification, Te Waka Kai Ora, Māori industry groups, other CRIs, University researchers, selected Māori Trusts and Incorporations, Māori landowners, and private consultants.

In June 2017 we conducted a survey, seeking input from a wide range of soil professionals, land owners and other end-users. By seeking diverse perspectives, the survey was intended to provide:

- a baseline understanding of the different ways people understand soil health and value soil as a resource
- information on which aspects of soil health are currently being monitored, and where gaps are perceived, and
- a network of interested parties who would like to keep in touch with progress in the project.

The survey resulted in 235 responses from every region of New Zealand, with 15% of respondents identifying as Māori. Of all respondents, 91% said soil was important or very important to them in their profession (just under 40% of respondents identified as farmers), and 85% of respondents strongly agreed that soil health was essential for both the economic and environmental well-being of New Zealand. 70% of respondents agreed or somewhat agreed that “Soil health is important to me from a cultural perspective”. A wide range of descriptions defined soil health (see word cloud), and considerable information was provided on which aspects of soil health are monitored and where gaps are perceived. Integration of Māori-world views on soil health with a traditional science approach (developed both from New Zealand and international collaborators) will facilitate productive and sustainable use of our soils.

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NEXTGEN S-MAP: STRENGTHENING THE SCIENCE THAT UNDERPINS NEW ZEALAND'S SOIL INFORMATION SYSTEM



Environment Southland staff (Lisa Pearson and Rob Williamson) completing a suite of soil physics measurements as part of the collaboration with the S-map NextGen programme

Soils are one of New Zealand's most valuable and strategic resources, but they are highly complex and variable. Better soil mapping is required to enable more informed decisions to be made on a range of topics, including land use decision-making, how to optimise use of marginal land, efficient irrigation, and what nutrient leaching mitigation options are relevant to this soil. The *S-map Online* website already provides access to NZ soil information, being widely used by farmers/growers, advisors, industry bodies, and councils. However, only 30% of NZ has been mapped thus far, with the majority of this focussed on the more intensively used lowland areas. 61 % of the lowlands have been mapped, but hilly to mountain lands occupy > 75% of NZ, and so far only 13% of this land has S-map coverage.

Thus, there is an urgent demand from industry for cost-effective extension of mapping coverage, as well as more accurate, fit-for-purpose, multi-scale soil information on soil hydrological properties and their dynamic response to land management. Meeting this need requires research to answer questions in three areas:

1. How can new technologies be employed to map NZ's highly complex and variable soils cost-effectively and accurately?
2. How does water move through soils and what is the dynamic response of soils to land management?
3. Can the provision of soil information to decision-makers be made more culturally responsive, scale appropriate, and interactive?

This new NextGen S-map research programme (yellow boxes) has been designed to integrate with the existing S-map and National Soils Data Repository (NSDR) infrastructure (grey boxes) as shown in Fig 1. The existing infrastructure includes managing detailed observations and laboratory measurements of soil profiles in the NSDR, the S-map database for managing the spatial soil survey data, an inference engine that estimates a suite of derived soil properties, and the website S-map Online.

Research Aim 1.1: Led by Pierre Roudier, the spatial backbone of the next-generation soil information system will build on the concept of a 'soilscape' in which areas with similar patterns in soil forming processes are identified and delineated. These soilscape areas are where soil variability has similar drivers and can thus be described by a single predictive model (e.g. a digital soil mapping (DSM) model). Machine-learning techniques will be applied to create a hierarchical set of soilscapes and thus a spatially consistent NZ-wide framework of nested DSM models that quantify multi-scale soil spatial variability within and between soilscapes. This framework will facilitate faster and more fit-for-purpose soil mapping of currently unmapped and poorly mapped areas of NZ.

In year 1 we have identified and collated the key covariate layers for digital soil mapping and developed a new framework for optimal soil sampling in the field. In the coming year we will focus on developing and testing soilscapes along with applying our new sampling design framework, in support of new co-funded mapping in Waikato, Hawkes Bay and Canterbury.

Research Aim 1.2: Led by Linda Lilburne. The existing technical infrastructure will be extended to readily respond to new information as it becomes available by building in workflows (documenting processes and information uncertainty). The new soilscape framework and associated layers of environmental data (covariates layers) will be built into the extended infrastructure. It will also manage and integrate the various predictive DSM models for soil mapping and for individual soil properties, ensuring they are spatially consistent with each other, and also across soilscape boundaries. Most national soil survey programmes adopt a single technical approach for the whole country. By combining multiple approaches we will be able to select the most appropriate data and soil-landscape model for each different soilscape. Work is starting in this area, with an initial focus on segmentation processes where the raster (i.e. grid) products from DSM are converted into S-map polygons that describe soil variability at an appropriate scale.

Research Aim 1.3: Led by Sam Carrick. There is a substantial work programme to improve the soil water information supplied by S-map. Soil properties that characterise the storage and movement of water in soil are expensive to measure. Thus we have to target resources to measure in a few representative locations and use models to predict attributes for the wider group of soils mapped in S-map. Pedotransfer functions (PTFs) predict soil properties, such as soil water-holding capacity and hydraulic conductivity, from more readily measured soil data such as soil texture. We will complete soil

water measurements across a range of typical soils, substantially expanding the number of sites that S-map can use for developing soil hydraulic PTFs for New Zealand soils, thus improving our predictions of these critical soil properties. Some additional experiments will also be conducted by Plant and Food Research soil scientists to determine the relative impact of management practices (e.g. tillage or artificial drainage) on soil water properties, for developing PTFs that can respond to knowledge of soil management. The knowledge gained from this experimental work, together with recent modelling advances, will be used to develop a set of new integrated PTFs predicting soil hydraulic properties for a wide range of soil types in S-map.

In year one of the project we focussed on completing stocktake reviews of both soil water measurement methods, and the international progress on PTF development. We also completed a pilot study of full soil water characterisation of four Southland soils, in a funding partnership with Environment Southland. In the coming year the soil measurement campaign will initially focus on soils in the Canterbury region. A PhD student, Balin Robertson, will study the water-holding capacity of stony soils. Research will also begin on measuring the effect of land-management practices on soil water properties.

Research Aim 1.4: Led by Andrew Manderson, this research aim will focus on developing tools to help scale soil data downwards to farm scale and upwards to catchment scale, as well as novel and more interactive ways of visualising soil information and the effect of land management on soil properties. Garth Harmsworth has started an active co-development approach between Māori and the S-map science team that aims to produce tailored soil information from S-map that will support Māori economic growth objectives. We will work with Māori organisations in three main regional growth areas to increase the relevance and utilisation of S-map to identify how best to support Māori aspirations for their land in a manner that promotes taiao and kaitiakitanga. Further work over the coming year will also involve collaboration with NIWA to link S-map with their TopNet catchment hydrological model.

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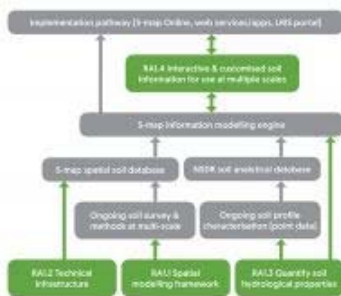


Figure 1. The structure of the NextGen S-map research programme (green boxes) showing its integration with existing S-map and National Soils Data Repository (NSDR) infrastructure (grey boxes)

INCREASING WATER QUALITY IN RIVERS BY SOIL CONSERVATION ACTIONS ON LAND

Since European settlement in New Zealand, large-scale catchment disturbance (e.g. forest clearance, establishment of agricultural land uses, and stream channel modification) has led to increased soil erosion and sediment loads in rivers, lakes, and estuaries. By international standards, sediment loads in some New Zealand rivers are very high. This increase in suspended fine sediment in river water reduces both visual clarity and feeding opportunities for birds and fish, causes changes in the migratory habits of some fish species, and also affects invertebrates in the river ecosystem.

Suspended sediment can also damage the gills of fish, limiting their growth and making them more susceptible to disease. Furthermore, it lessens the depth to which light can penetrate (euphotic depth), thus reducing the area where aquatic plants can photosynthesise. Mitigating the numerous impacts this fine sediment has in rivers requires a catchment-wide approach to reducing soil erosion.

Targeting areas for soil conservation to reduce the sediment load in rivers is possible through existing models such as SedNetNZ. However, the relationships between sediment load and attributes such as visual clarity and euphotic depth are poorly understood. Developing methods that allow these relationships to be quantified are necessary to assist catchment management groups to set targets for optical water quality.

We have recently published a scientific paper demonstrating methods that clarify these relationships. They require at least twenty concurrent samples of sediment concentration, as well as visual clarity and euphotic depth at a river site where discharge is continuously measured. A mathematical relationship can then be established that quantifies the increase in visual clarity and euphotic depth relative to the decrease in sediment concentration (see Fig. 1).

Our studies were carried out on the Wairua River in Northland, where the Northland Regional Council aims to improve water quality in the river and the downstream Kaipara Harbour by undertaking soil conservation action in the area. We were able to show that a sediment load reduction of 50% from widespread soil conservation on nearby pastoral land would lead to an increase in the median visual clarity from 0.75m to 1.25m – making the river suitable for swimming much more often. The same reduction in sediment load would increase the euphotic depth from 1.5m to 2.0m, benefiting a wide range of organisms from stream invertebrates to birds and fish. In the Wairua River we showed that the sediment load could be reduced by 70% if all pastoral farming land was reconverted to forestry. This is unlikely, however, due to the large economic benefits of pastoral farming and the imperatives of food supply. Targeting soil conservation efforts at highly erodible land is a more likely scenario, involving afforestation on highly erosion-prone land, space-planted poplars on erosion-prone land, and stock-exclusion fencing of rivers and streams. This option is less costly than widespread soil conservation, yet still has the potential to create a reduction in sediment load of approximately 40% and dramatically improve water quality.

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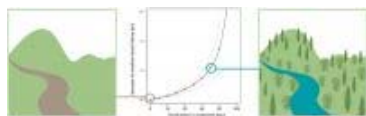


Figure 1. In the Wairua River, Northland, a 70% reduction in sediment load due to tree planting would lead to an increase of the median visual clarity of river water by over 1 m.

USING SEDNETNZ IN POLICY AND PRACTICE

SedNetNZ is an erosion model that predicts the generation and transport of sediment through river networks, based on a relatively simple physical representation of hillslope and channel processes at small sub-catchment scale (average c. 40 ha).¹ The model provides estimates of long-term average annual sediment load (t yr^{-1}) and yield ($\text{t km}^{-2}\text{yr}^{-1}$). It improves on available erosion models in New Zealand by providing estimates of sediment load generated by different erosion processes (landslides, gullies, earthflows, surface, and bank erosion) and sediment deposition on floodplains.

This allows improved targeting of erosion mitigation to the key contributing processes, and analysis of the linkages between upstream sediment generation and downstream sediment loading. It is also highly suited for scenario analysis of changes in land management and implementation of erosion mitigation practices. Several regional councils have recently commissioned SedNetNZ analyses of large catchments to support land and water policy development.

SedNetNZ was used in Hawke's Bay to estimate current sediment load for each major sub-catchment (see Fig. 1 for an example). The outputs from SedNetNZ were intersected with farm boundaries from AgriBase to estimate farm sediment loads and the potential for reducing sediment loads from hillslope erosion processes through the adoption of soil conservation farm plans, assuming a 70% reduction in sediment where farm plans were fully implemented. In the Tukituki catchment, it was estimated the current sediment load is 761,000 t yr^{-1} but this could be reduced by 27% to 556,000 t yr^{-1} by implementing farm plans on the 100 farms with the greatest area of highly erodible land. The model was also used to calculate the potential reduction in bank erosion that could be achieved by fencing to exclude stock from riparian areas, assuming a reduction in stream bank erosion of 80% as a result of stock exclusion. In the Tukituki catchment the current sediment load from bank erosion was estimated to be 162,000 t yr^{-1} but this could be reduced to 34,000 t yr^{-1} if all streams were fenced.

Hawke's Bay Regional Council is using the SedNetNZ results to help identify priority areas of erosion/sediment production and relate this information back to stakeholder/farmer groups involved in land and water plan change processes, and to help implementation of the National Policy Statement for Freshwater Management. It has allowed Council to supply stakeholders with estimates of the scale of the sediment issue, estimates of costs associated with reducing sediment, and possible ways this may be achieved. The modelling is also helping direct policy discussions on setting sediment reduction targets and whether they can be achieved through non-regulatory methods.

In Northland, SedNetNZ has been used in a project to develop a model for assessing costs and benefits of sediment mitigation scenarios for the Kaipara Harbour Catchment. SedNetNZ provides the annual sediment loads from each erosion process so that reductions in sediment loads can be calculated for different mitigations that have variable costs. Approximately 52% of sediment in the catchment is estimated to come from hillslope sources (landslide, gully, earthflow, and surficial erosion), while the remaining 48% is from bank erosion. SedNetNZ shows that implementing catchment-wide soil conservation works for hillslope and bank erosion could reduce sediment loads to Kaipara Harbour by c. 40%. Sediment loads were translated to freshwater sediment attributes (visual clarity, euphotic depth, and suspended sediment concentration) through a sediment concentration-discharge rating curve and used to predict how changing sediment load after implementation of erosion mitigation would change these sediment attributes (Fig. 2). Sediment loads resulting from the various mitigations were also translated into annual average sedimentation rates at nine depositional zones within the Kaipara Harbour. SedNetNZ was also used in the development of a farm management tool to be used by land management advisors to formulate farm-scale sediment mitigation plans that target critical source areas of sediment under different land uses.

The results from the project will assist Northland Regional Council and Auckland Council with making decisions about current and new regulatory and non-regulatory initiatives to manage sources of sediment in the Kaipara Harbour Catchment. It will also help the community better understand erosion and its effects on fresh and coastal water quality.

The Hawke's Bay work was funded by Hawke's Bay Regional Council. The Kaipara work was funded by the Ministry for the Environment, Northland Regional Council, and Auckland Council and was carried out in association with Streamlined Environmental, NIWA, University of Otago, and University of Maine.

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¹ For a complete description of SedNetNZ see

Dymond JR, Herzig A, Basher L, Betts HD, Marden M, Phillips CJ, Ausseil A-G, Palmer DJ, Clark M, Roygard J 2016. Development of a New Zealand SedNet model for assessment of catchment-wide soil-conservation works. *Geomorphology* 257: 85–93

DEVELOPING SOIL GUIDELINE VALUES TO PROTECT TERRESTRIAL BIOTA (ECO-SGVs)

Soil guideline values developed to protect terrestrial biota (soil microbes, invertebrates, plants, wildlife and livestock) (Eco-SGVs) provide a useful means for assessing potential environmental impact of contaminants. The absence of national Eco-SGVs has resulted in inconsistency and a lack of focus to ensure protection of terrestrial biota from contaminant impacts through territorial and regional/unitary council functions. An Envirolink Tools Project was initiated to address this gap. Specifically, the project established agreed methods for developing Eco-SGVs, and developed values for the most commonly encountered contaminants, and outlined their intended application.

An advisory group of representatives from the Regional Waste and Contaminated Land Forum, Land Monitoring Forum, Land Managers Group, the Ministry for the Environment, and the Ministry for Primary Industries oversaw the project. The advisory group confirmed the range of receptors to be considered in the development of Eco-SGVs (Fig. 1), and the contaminants for which Eco-SGVs were derived.

Eleven priority contaminants that have different physico-chemical properties, and thus behaviour in the environment, were selected: arsenic, boron, cadmium, chromium, copper, fluorine, lead, zinc, DDT, total petroleum hydrocarbons, and polycyclic aromatic hydrocarbons. These included the most common contaminants identified at contaminated sites, as well as contaminants for which toxicity to livestock (fluorine) or bioaccumulation in wildlife (DDT) need also to be considered.

Eco-SGVs are developed by collation and analysis of toxicity data for individual contaminants. The values for Eco-SGVs are influenced by decisions made about the toxicity data used and the level of environmental protection intended to be afforded by the Eco-SGVs. These decisions are often more a matter of policy and consensus rather than science, and should take into account the intended application of the Eco-SGVs. As such a series of workshops with regional council staff, organic waste sector representatives and contaminated land practitioners were held to provide input to the development of the methodology.

The 'added-risk' approach was used to derive Eco-SGVs for trace elements. This considers that the availability of the background concentrations of a contaminant is zero or sufficiently close that it makes no practical difference, and that it is the added anthropogenic amounts that are of primary consideration for toxicity considerations. Eco-SGVs are thus developed by adding the contaminant limit developed by analysis of toxicity data (referred to as the added contaminant limit, ACL) to the background concentration. Thus regional variations in background concentrations are taken into account.

Determination of background concentrations as described in Cavanagh et al. (2015) is based on the premise that background soil concentrations are predominantly influenced by the underlying geology. The background concentrations are naturally occurring levels, which differ from ambient concentrations that arise from diffuse or non-point sources by general anthropogenic activity but not attributed to industrial or commercial land use. These can also be used to develop Eco-SGVs. Currently there are insufficient data to robustly determine ambient concentrations of contaminants of concern across New Zealand. The predicted background concentrations are available at <https://iris.scinfo.org.nz/layer/48470-pbc-predicted-background-soil-concentrations-new-zealand/>.

The ACLs were developed through review of toxicity data, using species sensitivity distributions (SSDs) where sufficient data were available. This enables the selection of different levels of protection. A summary of the level of protection provided for different land-use classes is shown in Table 1. Where possible, contaminant aging was taken into account, and also contaminant limits developed for sensitive, typical, and tolerant soils, based on basic soil properties (pH, carbon content, cation-exchange capacity).

Table 1. Summary of land use categories, receptors covered, and level of protection of plants, soil processes, and invertebrates for Eco-SGVs

Land use	Receptors covered	Level of protection (%) ¹	
		Plants	Soil processes/ invertebrates
Commercial /Industrial	Soil microbes, plants, invertebrates	60 (65)	60 (65)
Residential and recreational areas	Soil microbes, plants, invertebrates, wildlife	80 (85)	80 (85)
Agriculture, including pasture, horticulture and cropping	Soil microbes, plants, invertebrates, wildlife and livestock	95 (99)	80 ² (85)
Non-food production land	Soil microbes, plants, invertebrates, wildlife	95 (99)	95 (99)
Ecologically sensitive areas	Soil microbes, plants, invertebrates, wildlife	99	99

¹ This is based on using EC30/LOEC toxicity data. The value in brackets is the level of protection that should be provided for biomagnifying contaminants. Due to mathematical constraints, if the level of protection is 95%, the increased level of protection is 99%.²

The proposed application of Eco-SGVs was developed through workshops with regional councils and serves two purposes; assisting with contaminated land management and protecting soil quality (Table 2).

Table 2. Proposed application of Eco-SGVs for each land-use category and purpose

Land-use category	Contaminated land management	Protection of Soil quality
Commercial /Industrial	Inform remediation standards ¹ –specifically the quality of any soil imported onto site Trigger further site investigation, including off-site effects, in the event of significant exceedance ²	na
Residential and recreational areas	As above Identification of contaminated land	Consent limits for application of wastes (e.g. biosolids, cleanfill, managed fill) to land
Agriculture	As above ³	As above
Non-food production land	As above ³	As above
Ecologically sensitive areas	As above ³	As above

¹ noting that Eco-SGVs for copper and zinc, in particular, should not automatically be applied as remediation standards – the effect of excavation and disposal of soil should be considered relative to the effect of actively managing the land to reduce concentrations over time.

² >2 times the Eco-SGV over an area of 25 m²

³ Typically for small areas of contamination such as sheep dips, spray sheds.

na – not applicable

The Eco-SGVs developed through the Tools Project are currently being adopted in an ad hoc manner by different councils. To facilitate consistent use of the background concentrations and Eco-SGVs determined in this project nationally, three key next steps are recommended:

- International peer review of the derivation methodology for the Eco-SGVs, taking into account the intended applications.
- Wider consultation with regional councils, industry groups (e.g. contaminated land practitioners, waste industry, organic waste sector), and other stakeholders on the currently proposed application for background soil concentrations and Eco-SGVs. The latter would ensure complementarity and consistency with other sector developed guidelines, including *Technical Guidelines for Disposal to Land* (WasteMinz 2016), and with guidelines for the beneficial use of organic waste (under development at the time of completion of the Tools Project).
- The development of national policy or standards for the protection of soil quality and for contaminated land management that is inclusive of protection of terrestrial biota.

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For further reading see:

Cavanagh JE 2016. User Guide: Background soil concentrations and soil guideline values for the protection of ecological receptors (Eco-SGVs) – Consultation draft. Landcare Research Report for Envirolink Tools Grant C09X1402.

Cavanagh JE, Munir K 2016. Development of soil guideline values for the protection of ecological receptors (Eco-SGVs): Technical document. Landcare Research Report for Envirolink Tools Grant C09X1402.

Cavanagh JE, McNeil S, Arienti C, Rattenbury 2015. Background soil concentrations of selected trace elements and organic contaminants in New Zealand. Landcare Research Report 2440 for Envirolink Tools Grant C09X1402.

All available at: <http://www.envirolink.govt.nz/envirolink-tools/land-and-soil-tools/>

MAXIMISING THE VALUE OF IRRIGATION



Figure 1. Receptors considered in the development of ecological soil guideline values.

Major technological advances in irrigation systems over the last two decades have significantly improved their ability to accurately apply water at appropriate intensities to agricultural land. The machines obviously need to be well maintained and managed to achieve their potential water use efficiency, and effectively convert water to productive growth while minimising water and nutrient losses through drainage and run-off. Examples of productivity gains, when effective irrigation eliminates crop water stress, include potato yield increases by 12 t/ha; pasture production increases from 8 to 10 t DM/y to 14-16 t DM/y; and avoided yield reductions of 12–20 kg/ha/mm from water stress in maize and barley crops.



Figure 1. Programme scientists and an industry advisory group discussing irrigation trials in the Plant & Food rain-out shelter facility, at Lincoln, where controlled trials are being conducted to investigate the ability of crop sensors to assist spatial crop water use predictions.

Methods to best manage irrigation systems are a focus of our MBIE Programme “Maximising the Value of Irrigation” because water quality is declining in many water bodies and inappropriate irrigation poses a risk of over-applying water and increasing drainage of nutrients to these freshwater systems, which can contribute to declining water quality. Our research is developing and testing soil and crop sensor technologies that map spatial variability and monitor factors that influence effective irrigation, including soil water status and crop water use. The data can be relayed to remote devices in near real-time to inform irrigation scheduling and potentially be uploaded to new software controlled systems.

Initially, detailed surveys establish which areas under one system require different irrigation due to one or more factors. These factors include soil, crop, and topographic differences (e.g. slopes and hollows). There are also operational factors to be considered, including avoiding overlaps, raceways, and other no-go areas (e.g. streams and ditches).

Sensor technologies are being tested at experimental plots and participating commercial farms to monitor changes in soil moisture, drainage, crop growth and crop water stress (see Figs 1, 2 and 3) at approximate 30-minute intervals. Scenario modelling of the collected data using The Agricultural Production Systems sIMulator (APSIM) allows us to simulate different irrigation management methods. A recent output from our research is a new APSIM module that models water movement through soil profiles, and, for the first time, takes into account preferential flow pathways (Fig. 4). Despite a general awareness of the important role that preferential flow plays both in reducing plant uptake of irrigation water and increasing the likelihood of leaching and drainage, existing models have lacked the ability to incorporate this effect. In response, our programme developed and parameterised a conceptual multi-pore model, and coded it into APSIM, which will help the model better simulate field conditions. Full soil parameterisation of APSIM is accomplished by relating site-specific soils to an S-map soil description and then extracting full APSIM soil definitions from S-map using a web processing service (WPS).

Some initial results for one focus farm using precision irrigation of variable soils shows that there is 10–15% water saving when irrigation scheduling is customised to the soil pattern, with similar reductions in drainage losses. This would save 16,260 cubic metres of extracted water per year and avoid 15,351 cubic metres of water lost through drainage each year on this farm. It would also reduce any nutrient leaching that might accompany the drainage losses. Further modelling is underway to establish the potential benefit of precision irrigation at our other research sites.

The Ministry for Business, Innovation and Employment fund the research programme ‘Maximising the Value of Irrigation’. It is jointly led by Landcare Research and Plant & Food Research. The Foundation for Arable Research, Lincoln AgriTech, and Massey University are also research providers to the Programme.

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Figure 2. Wireless sensor networks installed onto irrigated farms are monitoring soil moisture and rainfall and sending this to end user apps and web browsers in near real-time.



Figure 3. Lincoln Agritech crop canopy sensors on the Plant & Food rain-out shelter, Lincoln.

An active optical sensor, thermal imaging camera and near infra-red camera with RTK-GPS receiver, are being use to assess crop water stress for irrigation requirement. [Photo: Armin Werner, Lincoln AgriTech]

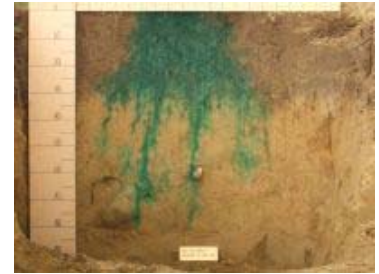


Figure 4. Preferential flow pathways that rapidly transport water down the profile often occur in soils. The flow pathways shown in this photo are identified using a dye stain technique, where dye is poured onto the soil surface and its flow patterns can be seen by subsequent destructive sampling [Photo: Sam Carrick; Soil Horizons Issue 16, 2007, p. 8]

REPRESENTATIVENESS OF REGIONAL COUNCIL STATE OF THE ENVIRONMENT (SOE) SOIL QUALITY DATA SET

The representativeness of a data sample can be thought of as how accurately the data reflect all possible relevant data. For instance, if soil samples are intended to characterise all possible soil orders of New Zealand, then a representative sample should contain enough samples within each soil order in proportion to the area each soil order occupies. Further, the procedure for determining whether a data sample covers the whole range of some variable requires that the whole range of that variable is known. For instance, if representativeness is required for soil order over New Zealand, then the coverage of all soil orders over the country is also needed.

A preliminary assessment of the coverage and representativeness of current soil quality monitoring sites was made on the basis of region, land use, and soil order – the latter two being key factors in the selection of soil quality sampling sites. To do this, regional council data previously provided to Manaaki Whenua – Landcare Research were cross-checked with sampling inventories provided by a recent stocktake of regional council data to generate a spreadsheet that captured all sites used for current soil quality monitoring. Since more recently (i.e. 2015, 2016) established sites did not have locational information, these are excluded from the assessment. The data included sites that had been resampled over time. Locational information was used to identify resampled sites, and only the most recently sampled sites were retained. This resulted in 1,187 sites in the “representativeness” data set, located as shown in Fig. 3, which compares to a total of approximately 1,143 current sites based on the current stocktake. The greater number of sites in Fig. 1 is due to the retention of resampled sites that differed in location by more than 10 m. As soil quality monitoring is currently not undertaken in Gisborne, Manawatū-Whanganui, Otago, or West Coast regions, these regions were automatically excluded.

In addition to the basic site data (land use, location) provided with the data sets, information for each site was extracted on land use (land cover), soil order, and region name from external data sets (LCDB, S-Map and fundamental soil layer (FSL)). Representativeness was determined by a comparison of the expected percentage of the soil quality samples (calculated from the area of a region/soil order/landcover, as a percentage of the total land area), with the actual percentage of soil quality samples calculated from the number of samples from that region/soil order/landcover as a percentage of the total number of samples).

For valid statistical analysis, perfect representativeness across all soil order and/or land-use combinations is not necessarily required. A minimum number of sites are needed to provide sufficient statistical power to determine differences, for example, a relatively rare element (assuming that element is considered important enough to be sampled) may need to be over-represented in the data set. On the other hand, elements that make up a large area can be somewhat under-represented, as there will be enough samples to provide sufficient statistical power. Nonetheless, one implicit requirement for representativeness is that a data sample should be taken from the widest spatial coverage available, rather than close proximity sampling in one region.

To enable assessment of the area for a given land use, landcover classes from the Landcover Database (LCDB) (2012) classes were used. These were aggregated to enable the interpretation of representativeness to be more straightforward. However, there is some difference in classification arising from ‘on the ground’ assessment at the time of sampling and that determined from the LCDB class (Table 1). The greatest ‘misclassification’ arises for dry-stock land use (as determined from ‘on the ground assessment’), with 82 sites being classified as cropping by LCDB. This highlights the challenge faced in aligning different sources of information on land use.

Table 1. Cross-tabulation of on-site classification with that determined from LCDB (number of sites)

On-site Land Use	LCDB					
	Cropping	Forestry	Hort.	Native	Other	Pasture
Arable Cropping	216	0	3	0	0	40
Indigenous/background	2	6	0	73	1	20
Dairy	2	1	2	2	2	238
Dry-stock	82	5	4	3	1	245
Forestry	1	70	0	0	0	16
Horticulture Crop	36	0	4	1	1	14
Other	0	0	1	1	1	1
Pasture	1	0	0	0	0	14
Perennial Crop	3	0	58	1	1	8
Urban	0	0	0	1	0	0

On a regional basis, some regions are under-represented (Southland, Northland, Taranaki) while most regions with active soil quality monitoring programmes are over-represented (e.g. Waikato, Wellington, Auckland, Canterbury), and others could arguably be seen as representative with respect to the region (Hawke's Bay, Tasman).

Based on LCDB land cover class, the pattern of the actual sample coverage follows the expected coverage, although there is strong evidence of over-sampling in 'Cropping' and 'Horticulture', whereas under-sampling is evident in 'Native' (Table 2). This reflects the interest in more intensive land uses and potentially a lack of native vegetation areas to sample. Incorporation of indigenous site data from other data sets (e.g. the LUCAS dataset for carbon accounting) into the National Soils Data Repository (NSDR) could be used to fill some of the gaps where data are lacking.

Table 2. Assessment of representativeness of current soil quality sites with respect to land use, as determined from LCDB (2012): comparison of the expected % of samples for that land use based on area and the actual % of samples

Land cover class	Area km ²	Expected %	Actual %
Pasture	132,924	55	50.3
Cropping	3,698	1.5	29.2
Forestry	20,406	8.4	6.9
Native	81,374	33.6	6.8
Horticulture	1,036	0.4	6.2
Other	2,399	1	0.7

Based on soil order, over-sampling is evident for all soil orders except Brown soils. For some soil orders (Pallic, Recent), the differences are less marked than for region and land use, perhaps reflecting the complex spread of soil order across regions and land use.

This preliminary analysis highlights that the specific context for determining representativeness is required for its effective determination. With respect to land-use and soil order, extension of this analysis would include its determination based on the combined land use and soil order at a national and regional level, and assessment of the proximity of sampling sites to each other.

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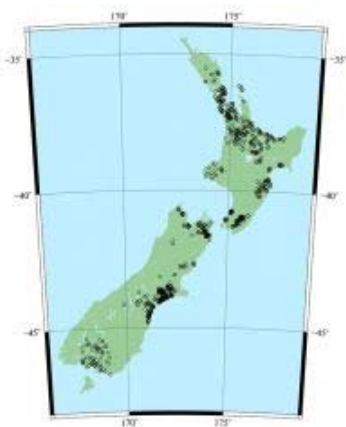


Figure 1. Location map of the samples used to determine representativeness. Soil quality monitoring is currently not undertaken in Gisborne, Manawatu-Whanganui, Otago, or West Coast Regions.