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Landcare Research
Manaaki Whenua

Soil Horizons

International Year of Soil

- LOOKING BACK
- HERE AND NOW
- INTO THE FUTURE

COVER IMAGE: The watercolour by Frank Wright entitled "Karaka Creek, Thames" (1889) depicts a pre-colonial New Zealand landscape. This painting was gifted to Queen Elizabeth, the Queen Mother, on her visit to Auckland in 1958, and now resides in "The Royal Collection of Her Majesty Queen Elizabeth II."

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Contents

Exploring the South Island soil resources	3
Past innovations creating today's productive pastures	4
Breaking in the Pumice Lands	5
Soil Science – NZ Forestry Sector	6
Future land evaluation for farm systems	7
Aerial and remote sensing – bank and cliff erosion	8
The Odyssey of our National Soil Carbon Model	10
Soil mapping in a digital age	11
Global standards for sharing soil information	13
Digital soil morphometrics	14
Next generation soil observation databases	16

Key contacts

EDITORS: Emily Weeks

Carolyn Hedley

Craig Ross

Any enquiries to Carolyn Hedley
hedleyc@landcareresearch.co.nz

THANKS TO: Anne Austin

LAYOUT: Nicolette Faville

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Editorial

During this International Year of Soils it has been exciting to see innovative contributions by New Zealand soil scientists advancing soil research.

This issue of Soil Horizons shows how our traditional approaches to soil science, collecting data, research – and even the way we view soil – have changed. Rapid advances in technology are opening many new soil research opportunities, and these advances are combining with the soil scientist's traditional skills. Soil science is not being left behind or superseded by technology but is using it in current thinking.

Parallel with this development are increasing demands on the finite soil resource and competition for the land of our "talented" soils. The fundamental change from working with an abundant soils resource to struggling to meet multiple demands allows soil scientists to inform on efficient use of the soil resource and promote its value for its environmental as well as productive functions.

Innovations shaping our field include data capture technologies (such as scanning techniques for assessing soil morphological characteristics or video use to assess erosion in hard-to-access areas) and the application of large datasets to digital soil mapping. The common theme, however, is that technology cannot and will not replace the expertise of the soil scientist.

Wise use of soil information requires access to our soil data through electronic maps and improved national soils data, applied at all scales, from the farm, through catchments, to a national and international level. Such data and contributing research underpin the tools needed to integrate soil management across all land uses, to value soils for their full range of functions in the landscape, and to appreciate their contribution to our country's future prosperity.

REECE HILL

2015 President of The New Zealand Society of Soil Science
<http://nzsss.science.org.nz/>

Autobiography and Reflection - Reece Hill

Dr Reece Hill is a soil scientist at Waikato Regional Council and current President of the New Zealand Society of Soil Science. A graduate of Lincoln University, Dr Hill has worked as a soil scientist in New Zealand and Australia for 20 years. His interests include soil mapping, soil-landscape modelling, and the interpretation of land resource information for catchment modelling and policy development. "What got me into soils? Marveling at the story a soil profile can tell".

For more information about the International Year of Soils
visit: <http://www.fao.org/soils-2015/en/>

Exploring and utilising the South Island soil resources

1769: It didn't start well because of an understandable mistake. On James Cook's first voyage around the South Island in 1769, naturalist Joseph Banks observed the tall timbered forests and noted "The size of the plants ... especially the timber trees ... sufficiently evinced the richness of the soil" (Fig. 1). Banks applied a European rule-of-thumb that related big trees to fertile soil. But this was later proved wrong and Bank's rule was termed the "biometric fallacy". The lesson is that we must take care if we extend our models to a new environment. Fortunately subsequent soil research and survey has been much more successful. We select just a few examples.

1968: A major milestone characterising the soil resources for the South Island was the 1968 publication of the General Survey of the Soils of the South Island. The survey used a method that had been developed to meet the demands of rapid war time mapping, generalised at a scale of 4 miles to 1 inch. The information content was sketchy but sufficient to capture the soil and environmental gradients that influenced the establishment and growth of pasture. It proved vital in the research and development of fertility management and the growth of the pastoral industry.

1968: The "Soils of New Zealand" was published in 1968 by the Department of Scientific and Industrial Research, assisted by Soil Bureau. This comprehensive three-volume bulletin provided soil maps for New Zealand at a scale of 1:1 000 000 accompanied by detailed soil chemical, physical, biological, and mineralogical information for a set of reference soils. This was the major soil information resource for New Zealand soils for a number of years following its publication.

1960s – 1970s: Professor Tom Walker of Lincoln University and his colleagues related soil phosphorous, potassium, sulphur, and other key fertility elements to soil sequences of rainfall, soil maturity, and parent materials. The new understanding enabled inferences about soil nutrients across soil types and landscapes, which assisted soil nutrient understanding and soil fertility testing.

1980s – present: Soil information is needed to inform large-scale irrigation developments, and associated research led to improved understanding of soil water storage and dynamics from the physical morphology of soil profiles. The ability to predict soil water drainage characteristics was eventually used in inferences about the vulnerability of soils to leaching nutrients and contaminants. This has become highly relevant to soil management and policy formulation as land use intensity has increased in the 21st century.

There are many soil stories to celebrate but we must not forget the bigger picture. In the 20th century an understanding

of our soils was gradually revealed in response to the demands of land-use opportunities and problems, and the development of land-based industries. It was the co-evolution of soil research and these factors that drove progress in knowledge and land management, and this continues to the present day.

ALAN HEWITT - LANDCARE RESEARCH

E: hewitta@landcareresearch.co.nz



Autobiography and Reflection - Allan Hewitt

Red soil in a road cutting stirred my curiosity as a child and led me to study geology, chemistry, and soils. Over 41 years I have enjoyed mapping and studying New Zealand soils, discovering their wide diversity. Through all of this I have learned many things.

I have been fascinated by the talents of New Zealand soils. These are many and varied and include routing, storing, and filtering our water, providing the nutrients, air, and water to vegetation and crops, and maintaining land stability and flooding control.

Most of the soils have factors that limit their potential, such as acidity, drought, shallowness, erodibility, low nutrients, and steep slopes. The fact that we are able to produce what we do as a nation is a testament to our managers on the land. The area of our most talented soils, those best able to sustain intensive production, is only~5–6% of the nation. It is imperative that we maintain this non-renewable resource in production, not just for our present needs but also for our future.

For far too long good information about our soils has been lacking. The motivation of S-map is to correct this by providing web-based information for all New Zealand. It is important we match our soil talents to the needs of our land uses, so we use our soil resource effectively.

Innovations of the past: Creating the productive pastures of the present

In this the “International Year of the Soil” we reflect on past, present, and future contributions from soil science researchers that have underpinned our understanding of the behaviour of the soilscape in the natural environment in which we live.

Poor soil drainage was a major impediment to agricultural development by early settlers in New Zealand. Research into methods to solve this problem was one driver for the development of soil science as a research discipline in New Zealand in the 1930–1940s. In the Manawatu region, early settlers at the end of the 19th century were provided with small 40 acre (16 ha) blocks of land – and much of it was little more than useless swamp land (Fig. 1). They dug outlets to drain the land, and several of these channels are still maintained today as part of modern drainage systems.

Early in the 20th century farmers discovered the advantage of mole and pipe drainage (Fig. 2) originally developed in England in the 1840s. Over the following decades, assisted by soil physics and hydrological research, large areas of marshland and poorly drained land were converted to productive pastoral land in the Manawatu area (Fig. 3).

With the support of a grant from the Department of Scientific and Industrial Research in 1938, soil scientists at the Massey

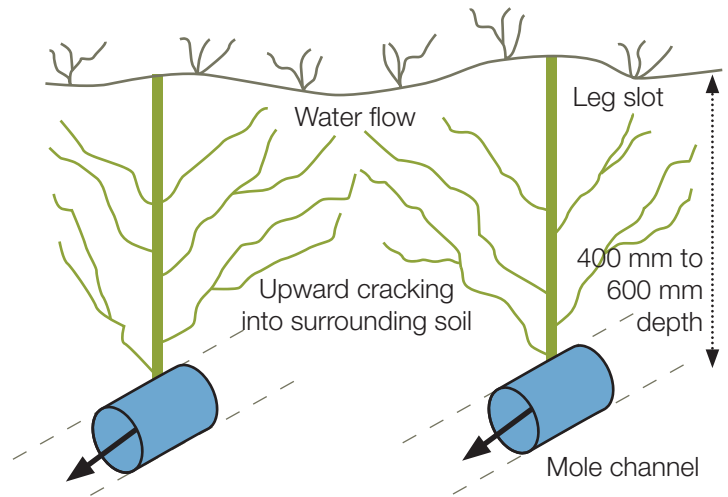


FIGURE 2 Pioneering land drainage research supported the conversion of thousands of hectares of swamplands to productive pastoral land with the installation of mole and tile drains

Agricultural College pioneered New Zealand research into land drainage, conducting experiments on the hydrology of mole drainage systems. This work led to the publication of a landmark book in 1940 “Mole Drainage in New Zealand” by Hudson and Hopewell. The Massey Agricultural College Drainage Extension Service was established in 1946.

FIGURE 1 Ploughing swamplands for the first time c1890s (Photo: Palmerston North City Library Archive)





FIGURE 3 Drained productive pastures support the economy of the Manawatu region today

Encouraged by farmers, local authorities, and Government Departments, they researched ways to overcome the limitations of wet, poorly drained soils for cultivation and agricultural production, to enable the local economy to develop.

As one travels through the farming districts of New Zealand, and of the North Island in particular, one cannot help being struck by the fact that there are thousands of acres on this country crying out to be drained.... There is no doubt that as time goes on, more and more if it will be drained, and it has been the object of Mr Hudson and his assistant Mr Hopewell to get to the bottom of some of the more unsatisfactory aspects of drainage so that the work of development may be carried out with the minimum of mistakes and waste of money.

G.S.Peren, 1940, Massey Agricultural College,
Palmerston North

Soils research played a pivotal role in the successful conversion of thousands of hectares of poorly drained soils in the Manawatu region into productive free draining pastures. The Drainage Extension Service were active right into the beginning of the 21st Century, at which stage other commercial companies took over the installation and maintenance of the mole and tile drain networks laid by them in the preceding decades.

The development of this soil and water research discipline laid the foundation for our ability to tackle current issues such as the quality of drainage water, irrigation and effluent management. Now, in some regions of New Zealand, research is underway to understand which specific parts of drained landscape, might need to be reverted to wetlands to slow-down losses of nitrogen and phosphorus, in drainage waters, into surrounding waterways and groundwater.

CAROLYN HEDLEY - LANDCARE RESEARCH

E: hedleyc@landcareresearch.co.nz

Breaking in the Pumice Lands

One of the most mystifying agricultural problems in the first part of the 20th century was the wasting illness termed 'bush sickness' that affected sheep and cattle introduced onto recently converted tussock plains and shrublands on pumice parent materials in the centre of the North Island. Scientists originally diagnosed the problem as a form of iron deficiency, and it took more than 20 years for the exact cause to be identified.

This research pioneered the way for many future research projects investigating the relationship of animal metabolism to soil characteristics.

Before they were solved, these animal health problems had led to the conversion of the recently established pastoral farming on pumice soils (Fig. 1) to exotic forestry. *Pinus radiata* trees were planted into a large area, now known as the Kaingaroa Forest. This forest became the largest exotic forest in the world, with world-beating growth rates. The exotic forestry development was very successful, forming the basis of New Zealand's future exotic timber industry.

Meanwhile, soil scientists were determined to discover the reasons for the 'bush sickness' problems. Soil surveys in the mid-1930s by Les Grange and Norman Taylor studied volcanic ash deposits and showed that bush sickness only occurred where tephras had been deposited during the Taupō and Kaharoa eruptions (about 200 AD and 1314 AD). Chemical analyses revealed that the sickness was caused by a deficiency in the trace element cobalt and that other trace elements, selenium and copper, were also deficient.

By the late 1930s the widespread use of cobaltised superphosphate had successfully controlled bush sickness and opened the way for successful pastoral development of these problem areas.



FIGURE 1 Pumice soil profiles

Soil Science in the New Zealand Forestry Sector

The predominant production system followed by the New Zealand forestry sector is a low input, short rotation model. This results in significant disturbance to forest soils on a much more frequent basis than occurs in other countries, e.g. rotation lengths of 30 years compared with 60 years. This increased pressure placed on soil resources has the potential to degrade the ability of the soil to support forest establishment and growth, resulting in reduced yield over multiple rotations.

In response, Crown Research Institute for forestry, Scion, has conducted extensive research into the factors that affect the ability of soil to support productive forests. This research has extended over time from simple assessments of soil nutrient pools to assessments of the stability of soil processes that determine the flux and availability of those nutrients, the activity of the soil microbial communities that influence forest health and growth, and the importance of the physical structure of soil to the sustainability of forestry operations.

Although this research has identified a range of opportunities to develop improved forest management systems, to date it has resulted in only limited changes to silvicultural practices. A key reason for this is unfamiliarity with soil itself as an indicator of site productivity. Analysis of foliar tissue has long been considered the simplest method to determine if a forest stand is deficient in key nutrients. To further explore issues in the use of soil-based data in forest management, we surveyed opinions on the role of soil research across the forestry sector.

The survey collected information from 130 respondents, including farm foresters, small-block owners, corporate foresters, and independent forestry consultants across most regions of New Zealand. Survey information indicated that the vast majority of respondents regarded soils as relevant

FIGURE 1 Workshop attendees observing the preparation of a soil surface for sample collection in a mature stand of radiata pine



FIGURE 2 Equipment required to deal with the various issues encountered when collecting soil bulk density soil samples in plantation forests

to forest productivity and were interested in making use of soil data. However, it was equally apparent that most respondents considered themselves unable to conduct soil sampling effectively, or to take soil data and translate it into practical actions that could be incorporated into their forest management strategies.

To address this lack of confidence, Scion has instigated a series of forest soil sampling workshops to provide the sector with greater understanding of methods for soil sampling (Fig. 1). Issues discussed included the use of mapping systems and sufficient replication to ensure soil samples are representative of the area in question, the timing of sampling efforts within the life of the forest stand, and the level of resolution in sampling across the landscape – balanced against the cost-effectiveness of investment in soil collection and analysis. The workshops comprised a field component, allowing the attendees to become familiar with the various tools and techniques used to obtain the different kinds of soil samples, which is a critical element in understanding the time required to conduct such sampling (Fig. 2).

Through the “Growing confidence in forestry’s future” (GCFF) research programme, Scion works closely with the sector to address the successful use of soil data to inform forest management. This spans a diverse range of projects, including issues of precision nutrient management, enhancing the activity of beneficial soil microbes, and maintaining license to operate through assessment of the environmental sustainability of management.

SIMEON SMAILL – SCION

E: simeon.smairl@scionresearch.com

Looking to the future of land evaluation and farm systems analysis

Future shape of land evaluation

Land evaluation is formally defined as ‘the assessment of land performance when used for a specified purpose’ and has a long history of describing and quantifying the differences between units of land. The procedure uses limiting factors arising from climate, hydrology, landforms, soils and vegetation as the basis for evaluation of sustainable yields, with critical values determining the boundaries of suitability. In New Zealand, land use capability classification is the basis for assessing suitability for sustained production.

Two new trends emerging from land evaluation frameworks globally are the recognition of the wider functions provided by landscapes and the need for greater stakeholder participation in exploring the balance between economic, environmental, social, and cultural outcomes. With increasing demands on the finite land resource, land evaluation must go beyond assessment of land suitability for primary production alone and consider the performance of all services provided by a combination of land type, climate, land use, and management practices, as well as impacts on receiving environments.

A rapidly emerging multi-disciplinary approach to assess the multi-functionality of natural resources is the ecosystems approach based on the concepts of natural capital and ecosystem services. Natural capital is defined as the ‘stocks

of natural assets that yield a flow of ecosystem goods or services into the future’. This concept comes from trying to frame the contribution of natural resources to the economy alongside built capital (factories, buildings), human capital (labour, skills), and social capital (education, culture). Ecosystem services are defined as ‘the benefits people obtain from ecosystems’ – not only food, but also flood mitigation, nutrients filtration, greenhouse gas regulation or pest regulation.

Adding an ecosystems approach to land evaluation enables the supply of ecosystem services to be directly linked to the performance of a combination of land type, land use and management intensity to deliver specific outcomes.

Emerging farm systems analytical capability

Farms are often an assemblage of multiple landscapes with a mixture of topographies and soil types, both of which influence pasture and crop production, as well as other ecosystem services. Importantly, these land units show different responses to inputs and practices. Today’s intensive agricultural systems are the product of successfully combining built capital with diverse natural resources (e.g. land, water) to produce food and fibre for profit. Future analysis of the farm system will need to be extended to include the implication of decision-making not just on food and fibre production,

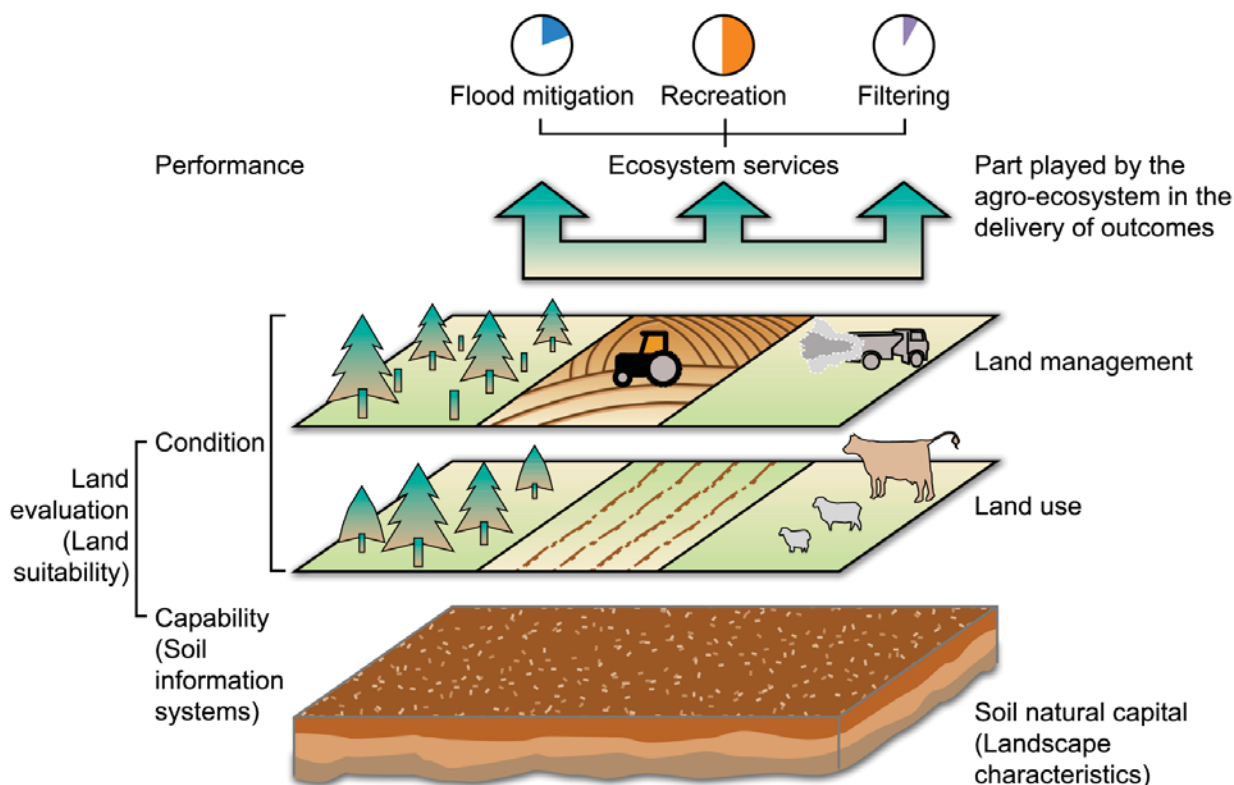


FIGURE 1 Combining land capability with resource condition under a land use to quantify ecosystem services provision for multi-function land evaluation

but also on the services our farm systems provide. This ecosystems approach creates the ability to define 'ecological boundaries' within which resources should be managed, addressing the purpose of the Resource Management Act 1991 (Section 5).

In our research programme, we are developing a new farm systems model "INFORM" (Integrated Farm Optimisation and Resource Allocation Model) that integrates biological data from each land management unit (similar natural resources and management practices) (LMU) within the farm. It uses LMU information to identify the mix of production enterprises

and management regimes that maximise profit (EBIDTA) for the business.

This method helps isolate and examine the value of investments targeted at specific parts of the farm on the whole farm business, and could potentially offer analysis that will make best use of resources within defined boundaries, for targeted performance of ecosystem services delivery.

**ALEC MACKAY, ESTELLE DOMINATI, JOHN RENDEL -
AGRESEARCH**

E: alec.mackay@agresearch.co.nz

Using aerial survey and remote sensing to assess bank and cliff erosion in Hawke's Bay

Landcare Research scientists have been collecting video footage of bank erosion in Hawke's Bay to help them study the stability of the landscape.

The new information will be used to improve SedNetNZ, a process-based sediment budgeting model being developed by Landcare Research (see Soil Horizons issue 21, September 2012), because the model will benefit from more detailed bank erosion data.

Bank erosion data are normally collected using ground reconnaissance, but this is time-consuming and often limited by accessibility problems (e.g. see Fig. 1).

Therefore we used a helicopter to fly hand-held, high-resolution video cameras along selected river channels, covering approximately 100 kilometres of river channel in about two hours' flying time. An example of the imagery obtained from this method is shown in Figure 1.

The video footage was then interpreted on-screen, in conjunction with an ortho-rectified image of the areas flown, to identify the total length of river banks and cliffs affected by different erosion types. This information was then digitised in GIS software using a river centreline subdivided by erosion category (Fig. 2), and statistics generated on the length of bank and cliff affected by erosion as a proportion of the total length of river channel.

Erosion categories identified and mapped were cliff erosion (erosion of bedrock cliffs), alluvial bank erosion, undercut slab failures, surface erosion, gullies, slumps, and shallow landslides, along with categories for those channel margins that were not eroding or were obscured.

The aerial survey approach was very successful for the following reasons:

- Continuity of coverage: High-resolution video gives a near-continuous, high-quality, interpretable, qualitative record of erosion types along channel margins. Videos can be freeze-framed to yield a good-quality still photograph of any scene along the flight path. By comparison, obtaining a comparable record from the ground is not feasible.
- Ability to interpret and map from video imagery: Using a recent vertical aerial photographic survey as a base, we were able to use the video imagery objectively to map the full extent (length) of erosion along entire channels. From this we could quickly derive the total proportion of channel length affected by different erosion types, and assess their relative significance. Many of the erosion features were not clearly visible on vertical aerial imagery, further underpinning the usefulness of the video survey.
- Cost: The aerial survey, while presenting a relatively large up-front cost, yielded data that would have been more costly to acquire using traditional ground-based methods, and impossible to collect from inaccessible parts of the river bank.

We intend to develop this method in future work, with the possibility of deriving three-dimensional measurements of erosion features through stereo image analysis and/or the incorporation of LiDAR data to help us better understand sediment fluxes from these sources

NOTE: LiDAR: Light Detection and Ranging is a remote sensing method used to examine the surface of the Earth.

HARLEY BETTS AND MIKE MARDEN - LANDCARE RESEARCH
E: bettsh@landcareresearch.co.nz



FIGURE 1 Video image of “Cliff erosion” from the upper Tutaekuri catchment

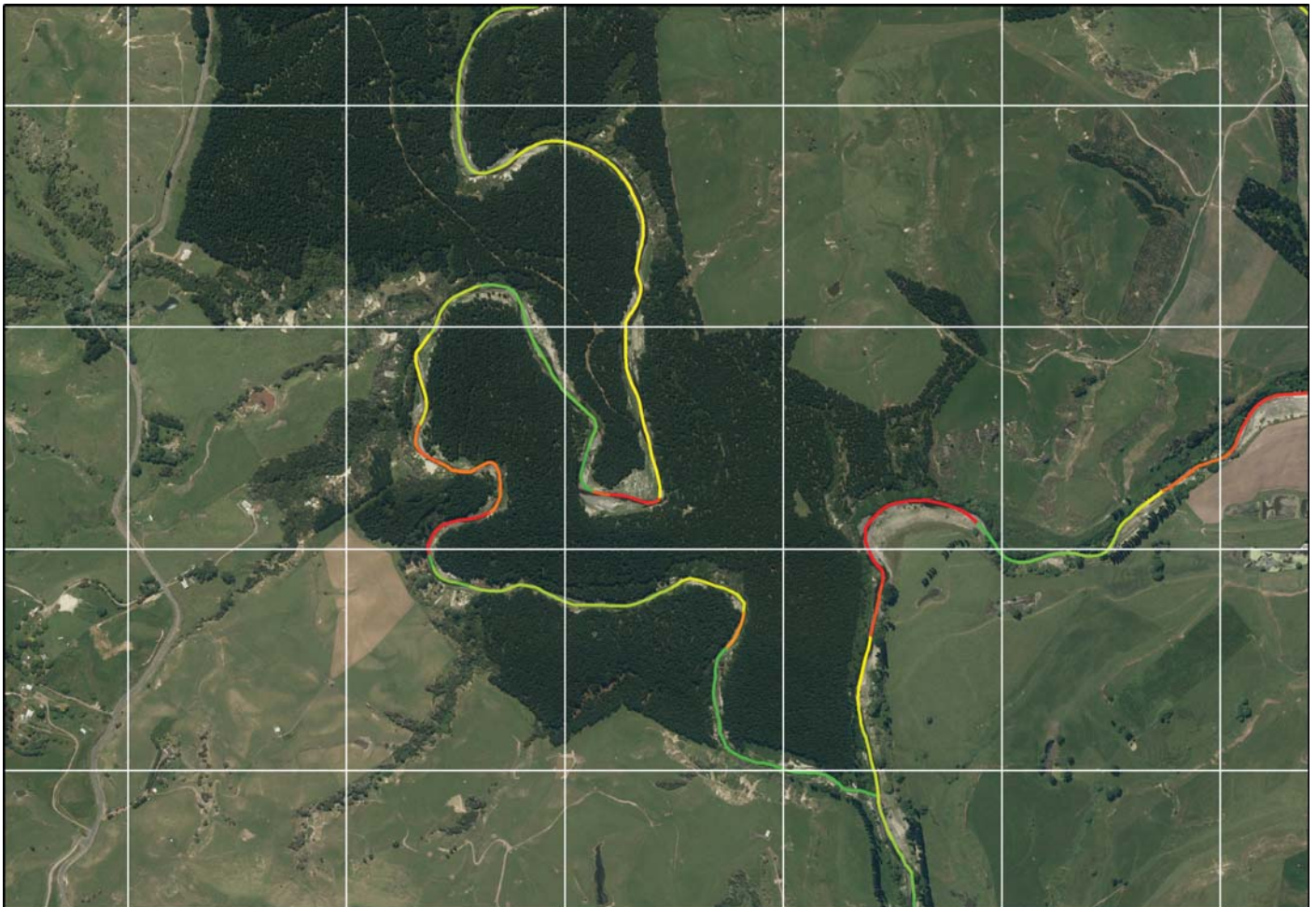


FIGURE 2 Erosion mapping for part of the Mangaone catchment, with randomly coloured segments corresponding to mapped erosion classes. A change from one segment to another indicates an erosion class change on at least one bank. Grid interval is 500 m



The odyssey of a national soil carbon model

The Ministry for the Environment (MfE) established the Land Use and Carbon Analysis System (LUCAS) for reporting on New Zealand's land use, land-use change, and forestry (LULUCF) sector in the national greenhouse gas inventory, submitted each year to the United Nations Framework Convention on Climate Change (UNFCCC). As part of LUCAS, the **Soil Carbon Monitoring System** (the 'Soil CMS') was developed to extrapolate national soil carbon stocks and estimate and report the effect of land-use change on the soil carbon pool to meet the UNFCCC reporting guidelines. Under those guidelines, countries can rely on simple, prescribed methods using global default values (called a Tier 1 approach), use country-specific data with Tier 1 methods (a Tier 2 approach), or implement more specific and sophisticated methods, such as process-based models (a Tier 3 approach). The tier structure is hierarchical, with higher tiers implying increased accuracy of the method and/or emissions factors and other parameters used in the estimation of the emissions and removal. Following the IPCC good practice guidance, countries are expected to use appropriate available data and methods at the highest tier possible depending on national circumstances, especially for reporting on important ("key") categories of greenhouse gas emissions and removals. In addition, the principle of continuous improvement encourages each Party to refine and improve its approach through time.

1990s: The Soil CMS Model emerges

From the outset, New Zealand sought to report on soil carbon using a Tier 2 approach, setting it on an odyssey of meeting both scientific research and international policy challenges. After the UN Conference on Environment and Development, the "Earth Summit" held in Rio de Janeiro in 1992, Landcare Research Scientist Kevin Tate recognized the need to pull together New Zealand's soil data for the future reporting requirements, and MfE initiated the development of the Soil CMS in 1996. The main focus of this first version was the then major land use change in New Zealand of afforestation of former pastures. The underlying principle was to calculate

the difference between assumed equilibrium soil C stocks where land-use change occurs, applying the IPCC default of linear change to a new equilibrium over a 20-year period (the approximate duration of exotic forests being harvested). With that aim in mind, the soil CMS model was developed based on biophysical principles using existing national soil data sets to estimate SOC taking into account site variables such as climate, topography, soil type, and land use. The soil CMS model was further developed with additional data, and a move from a linear regression model to a general least squares fitting procedure and a correction for spatial autocorrelation.

2010: International review

The soil CMS met resistance from an "external review team" (ERT) of New Zealand's 2010 submission (for the 2008 reporting year), its first annual submission for Commitment Period 1 (2008–2012) of the Kyoto Protocol. The ERT commended New Zealand for undertaking the Tier 2 approach but questioned its statistical validity, especially detecting the effect of particular land-use transitions on soil carbon stock changes. The ERT encouraged New Zealand to re-examine the methodological approach, as well as collect more data for land-use categories under-represented in the calibration data set.

2015: A refined Soil CMS Model

The LUCAS programme sought to meet ERT expectations by collecting additional data and recalibrating the model. Although the first attempts to add new data sets (for cropland soils) were helpful in terms of expanding the data set, the model improvements were deemed insufficient to meet the ERT critique. So, New Zealand reverted to using a Tier 1 approach for estimating and reporting soil carbon emissions and removals for the 2010 and 2011 reporting years (submitted in 2012 and 2013, respectively). Further model development and recalibration involved adding a wetland soils data set to the calibration data and a thorough investigation into approaches used to model SOC and determine the significance of land-use transitions, resulting in an improved version of the soil CMS that could be used for a Tier 2 approach. Thus, in 2014, New Zealand returned to using a Tier 2 approach for soils for the 2012 reporting year. The ERT commended New Zealand for this improvement in its 2014 review, but also noted the ongoing need to verify SOC stocks for land-use categories currently lacking data.

Since the 2014 return to the Tier 2 approach, a further refinement has been made to the soil CMS model. After a data collection campaign in 2014 (Fig. 1), soil data from the post-1989 forests were added to the model, and the updated land-use coefficients were used in the 2015 submission (for the 2013 reporting year).



FIGURE1 Soil carbon accumulates in topsoils



Although New Zealand has found its way back to reporting soil carbon at a Tier 2 level, further improvements could be made to modelling national soil carbon for greenhouse gas inventories, even after these 20 years of research and development (thus making it a longer quest than the fabled 20-year sojourn of Odysseus!). Despite these keen efforts made to develop the soil CMS model, it is still incomplete. As noted by the ERT, certain land uses are not well characterised due to inadequate, or a total lack of, data. Subcategories of grassland are ill-defined, which obscure any significant effect on SOC of land-use change among them. Moreover, the model's relatively large residual standard error indicates uncaptured effects on SOC. Evolving understanding, of course, also makes it necessary to reconsider underlying assumptions, such as equilibrium states. All this effort has not been for nought: the soil CMS model is currently the best estimate of national carbon stocks for New Zealand with existing datasets, which can be used to assess the

effect of land-use change. For the purposes of greenhouse gas inventories, it is a sophisticated approach to Tier 2, which allows an unbiased estimate of national carbon stocks using country-specific data. Rather, the unfinished nature of this particular story has more to do with the complexity of the subject matter, improved (or shifting) understanding of the system from research findings, and funding limitations on data gathering and model development, all set against the backdrop of global environmental change and socio-economic practices altering conditions on the ground. Odyssey indeed.

NANCY GOLUBIEWSKI - Nancy Golubiewski was the LUCAS Soils Workstream Lead at MfE from 2012 to 2014, and contracted to Landcare Research in 2015.

STEPHEN MCNEILL - LANDCARE RESEARCH
E: mcneills@landcareresearch.co.nz

Back to the future: Soil mapping in a digital age

Soil maps and the information they provide are fundamental not only to resource managers, but also to decision makers in local and central government. Soils provide essential ecosystem services, including the production of food, fibre, and fuel, the provision of habitat, nutrient cycling, contaminant transformation, and water cycling. Generally in New Zealand, soil survey and mapping has been undertaken at map scales between 1:15 000 and 1:250 000, with S-map online requiring a minimum map scale of 1:50 000. More recently, land managers and regulators have shown interest in the development of maps at finer resolutions. With the advent of LiDAR we are now able to develop maps that represent the Earth's surface at 5-m, 2-m, or even 1-m cell-size resolution (pixels). Add to this Landcare Research's ability to predict soil chemical and physical properties from existing databases through S-map online, and we now have a powerful method to deliver high quality soil information not available before.

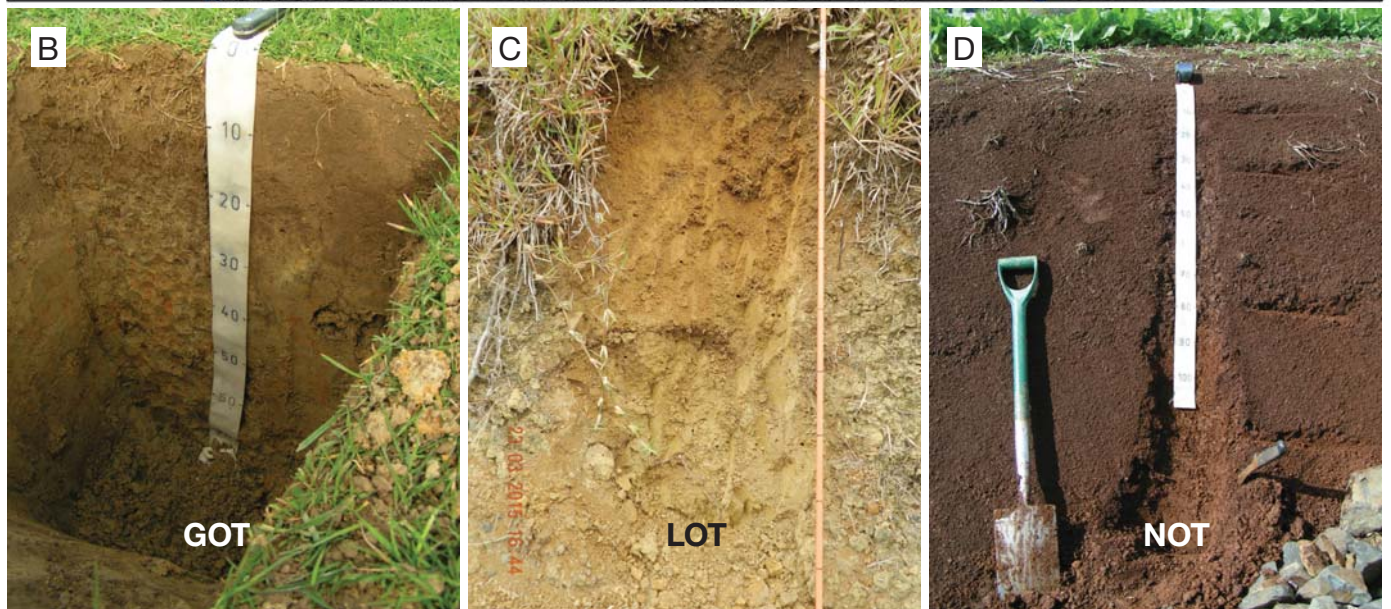
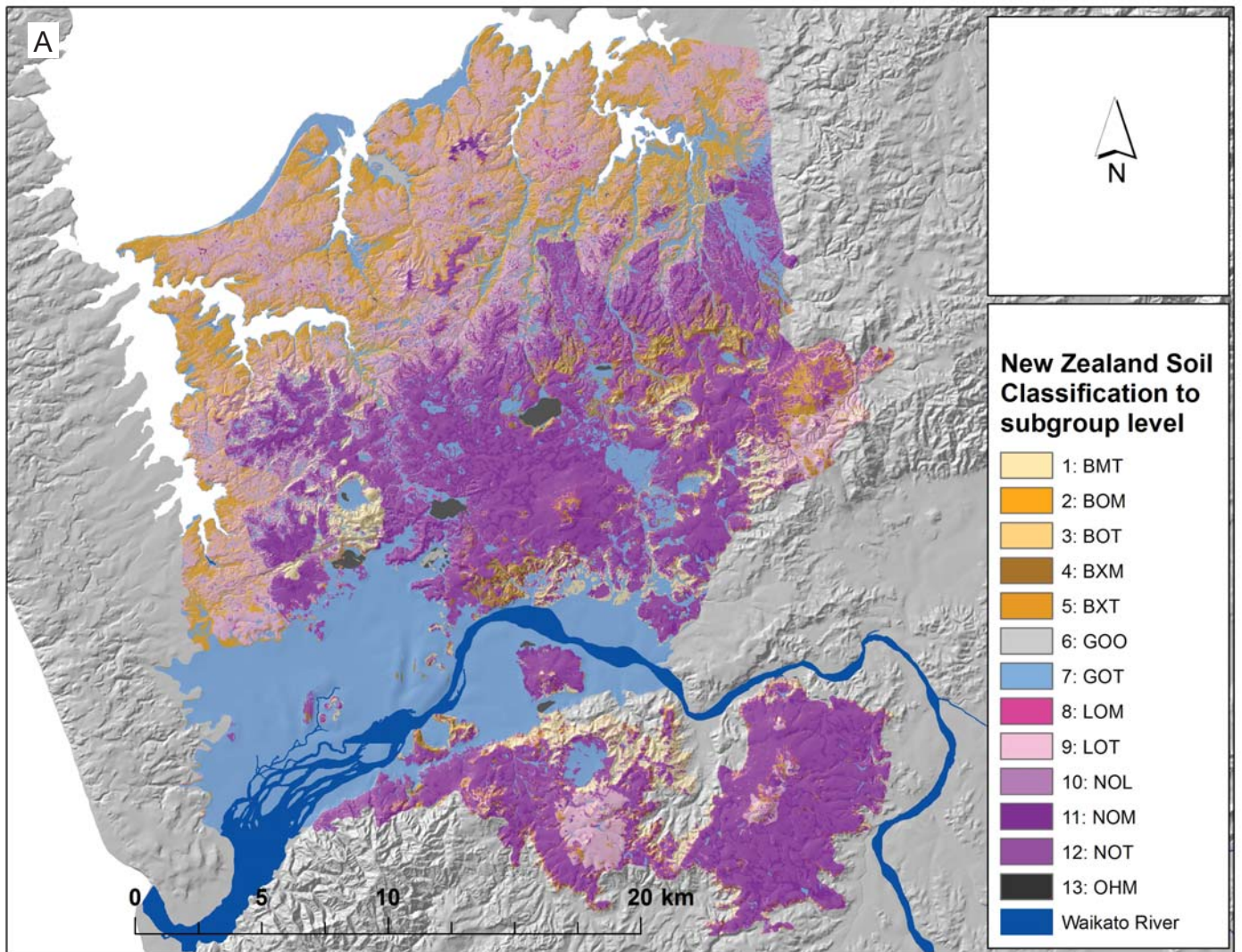
A field soil survey has traditionally been used to develop soil maps, and continues to be an essential part of mapping today. A soil survey involves collecting soil information across the landscape from soil pits, soil augering, road side cuttings, erosion scars, and describing their soil characteristics and properties. Soils are mapped across the landscape, based on the soil surveyors' knowledge and conceptual ideas of where and how a soil occurs, using resources like aerial photographs. Digital Soil Mapping (DSM) and modelling follows a similar approach, except it builds quantitative statistical relationships between the soils observed and

described, and maps representing the Earth's surface. These maps may include attributes like slope, elevation, curvature, distance to streams, exposure to wind, areas of erosion, and landscape position on the Earth's surface. Climate maps of rainfall, temperature, solar radiation, and soil moisture are also frequently used, as are maps of parent materials, and vegetation cover. The idea is that maps are chosen to represent the main soil forming factors: climate, organisms (including humans), relief, parent material, and time. As a generalised example, waterlogged, poorly oxygenated soils with pale subsoil colours are likely to occur in parts of the landscape where water accumulates (e.g. valley bottoms and in swales and hollows) (Fig. 1B), compared with well-drained soils that are more likely to occur on parts of the landscape shedding water (e.g. hill tops and ridges) (Fig. 1C&D).

In our mapping we used about 1300 observations across the Franklin region between Manukau Harbour and the Waikato River to predict subgroup soil classes at a 5-m cell size resolution (See Fig.1A). The main advantages of DSM over other mapping techniques are that the techniques are transparent, repeatable, and able to be up-dated (when more information becomes available), and that probability maps are provided along with model and validation statistics.

DAVID PALMER, SCOTT FRASER AND SHARN HAINSWORTH - LANDCARE RESEARCH
E: palmerd@landcareresearch.co.nz





LEGEND

BMT – Typic Mafic Brown Soils
 BOM – Mottled Orthic Brown Soils
 BOT –Typic Orthic Brown Soils
 BXM – Mottled Oxidic Brown Soils

BXT – Typic Oxidic Brown Soils
 GOO – Peaty Orthic Gley Soils
 GOT – Typic Orthic Gley Soils
 LOM – Mottled Orthic Allophanic Soils
 LOT – Typic Orthic Allophanic Soils

NOL – Allophanic Orthic Granular Soils
 NOM – Mottled Orthic Granular Soils
 NOT – Typic Orthic Granular Soils
 OMH – Mellow Humic Organic Soils

FIGURE 1 Digital soil map of the Franklin region with representative soil profiles

An international soils data interoperability experiment: First steps to a global standard for sharing soils information

The need for detailed understanding of soil distribution, function, and state has never been more important to support science and policy development, and improve productivity in a sustainable manner. Well organised and accessible soil data, made accessible in a consistent and consumable way, underpin this understanding. The importance of soil information is particularly under the spotlight this year after the United Nations General Assembly declared 2015 the International Year of Soils.

Modern digital mapping and modelling techniques are valuable for understanding soils. However, they depend on dispersed, inconsistent, and difficult to access digital data. Modern, harmonized, and interoperable information systems are required to integrate these data into a consistent set of soil data. Initiatives have started work on this by defining soil data information models. A few examples are the Australian and New Zealand ANZSoilML project, the European INSPIRE, e-SOTER and ISO SoilML, and the International GlobalSoilMap.net consortium. The UN FAO Global Soil Partnership recognises the value of these initiatives, but we still need to reconcile multiple systems that often attempt to do the same thing.

In May 2015, the International Union of Soil Sciences (IUSS) Working Group on Soil Information Standards (WG-SIS) proposed an initiative to consolidate these information models, and reconcile them into a single language for the exchange of soil data. The first step in standardization is running an Open Geospatial Consortium (<http://www.opengeospatial.org/>) Interoperability Experiment. (The OGC is an international consortium of public, commercial, and academic institutions that cooperates in the development of globally accepted standards for the exchange of data.)

Landcare Research, in partnership with the Commonwealth Scientific and Industrial Research Organisation (CSIRO, Australia) and ISRIC World Soil Information Institute (Netherlands), are the lead agencies in the 6-month interoperability experiment, with Landcare Research staff taking the roles of manager and technical lead. Other international participating agencies include Agriculture and Agri-Food Canada, the US Department of Agriculture National Resources Conservation Services, the US Geological Survey, and the Research Centre for Agrobiolgy and Pedology (Italy).

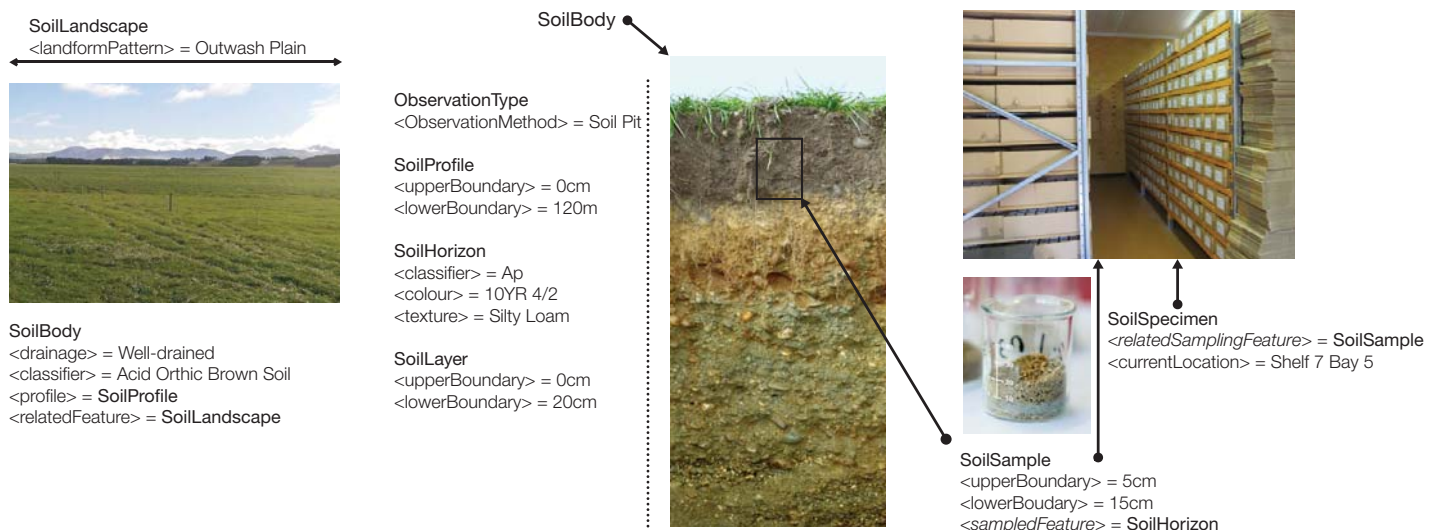
The experiment held its initial meeting in June 2015 at the OGC Technical Committee Meeting in Boulder, Colorado. It will end in December 2015 in Sydney with presentation of a technical engineering report to an international audience of technologists, scientists, businesses, and government agencies who participate in the OGC. There will also be a demonstration of soil information systems sharing data using the draft standard. If the results of the IE are approved by the OGC, an OGC soils standards working group will be established to progress the draft to an international standard.

The development of a soils data standard would be timely, offering benefits for a number of New Zealand initiatives under development that depend on good quality soil information. These include the national science challenge 'Our Land and Water', and farm and land use planning, as well as central government and regional sector efforts in environmental reporting.

DAVID MEDYCKYJ-SCOTT AND ALISTAIR RITCHIE

E: medyckyj-scott@landcareresearch.co.nz

FIGURE 1 Example soil concepts



Digital soil morphometrics: Bringing quantitative pedology to the soil profile

Pedologists study, examine, and classify soils in their natural environment, by investigating a vertical section of the soil, called a “soil profile”, visually and manually interpreting soil properties. Soil colour, stoniness, number of roots, and soil horizon depths can be assessed visually; and soil texture and structural stability can be assessed by feeling and touching soil particles and aggregates. This process involves digging holes, and is physically demanding, time consuming, and subjective.

Now a wide range of exciting new technologies are emerging that can assist the pedologist to examine and classify soils in their natural environment. ‘Digital soil morphometrics’ is this new discipline and it provides a framework to apply new methods and technologies to assist traditional pedological method. It quantitatively and objectively collects data, numerically analyses the data, and derives valuable information on soil profile properties.

We developed a low-cost and comparatively quick soil profile extraction and surface preparation method in order to trial some of these new digital soil morphometric methods (Fig. 1). We extracted a ‘soil monolith’; a well-established method for extracting whole soil profiles for transport and subsequent preparation, examination, and measurement under controlled conditions. Next step was to collect digital images from the soil monoliths using a standard digital camera, calibrated using a set of reference colour chips, under controlled lighting conditions. These images give information on 3 colours – red, green, blue (RGB) – at an intensely high spatial resolution (1 pixel represents a 1×1-mm square on the soil profile) (Fig. 2). The images were enhanced by combining them with data collected using a handheld Vis-NIR spectrometer. The Vis-

NIR spectrometer records approximately 2150 wavebands in the visible and near-infrared parts of the light spectrum, at nanometre resolution, complementing the RGB bands obtained by the digital camera, and allowing the researcher to relate the data quantitatively to soil properties, including morphometric features, such as soil structure, horizonation, and drainage features.

These soil profile imaging techniques with numerical analysis of the data therefore enabled a precise, objective investigation of soil characteristics including (i) horizon boundaries, and (ii) discrete areas of soil differences, for example, the grey veins observed in the Ohakea profile (Fig 3B).

Potential applications of digital soil morphometric methods include improving the estimation of soil organic carbon stocks, and understanding the flow pathways controlling the drainage and nutrient-leaching potential of individual soils.

PIERRE ROUDIER, ANDREW MANDERSON, CAROLYN HEDLEY
E: roudierp@landcareresearch.co.nz

Autobiography and Reflection - Pierre Roudier

You could argue that I became interested in soils through the lens of a satellite. Even though I studied agronomy at university, I’ve always had a soft spot for maths and physics. As a result, I picked a specialisation that would allow me to nurture that interest, and specialised in applying a wide range of information technologies to study the environment. It was only after my PhD that I had the opportunity to apply my craft to soils, and by then the field of digital soil mapping, which aims to produce soil information from quantitative analysis of a suite of environmental data, was developing.

I find soil science to be very humbling. It’s always a wonder to realise how little we understand about soils. Despite being one of our primary resources, along with fresh water and clean air, gaps in both knowledge and information will keep the field busy for years to come. Of particular interest for me, is that we lack the spatial datasets that could reconnect soils with other fields of science.

A long time ago, in 1941, a pedologist called Hans Jenny published *The Factors of Soil Formation*, a seminal book in which he proposes a quantitative approach to pedology, and puts soil formation into an equation. Of course, back then, Jenny’s vision was purely theoretical as he was limited by lack of data, as well as lack of computing power. But an exciting challenge ahead of us is to bring that vision to life for New Zealand soils, and take advantage of the staggering amount of environmental data that is available to improve our soil information system.



FIGURE 1 The soil monolith extraction device in place



FIGURE 2 The RGB images collected using a standard digital camera on 3 soil monoliths extracted around Palmerston North.

These colour photos were recorded using a standard digital single-lens reflex camera. The colours were calibrated using a set of reference colour chips (these are used by photographers to get a correct white balance). The 3 channels of the photos (red, green, blue) record the soil colour at a very high spatial resolution (1 pixel represents a 1×1-mm square on the soil profile).

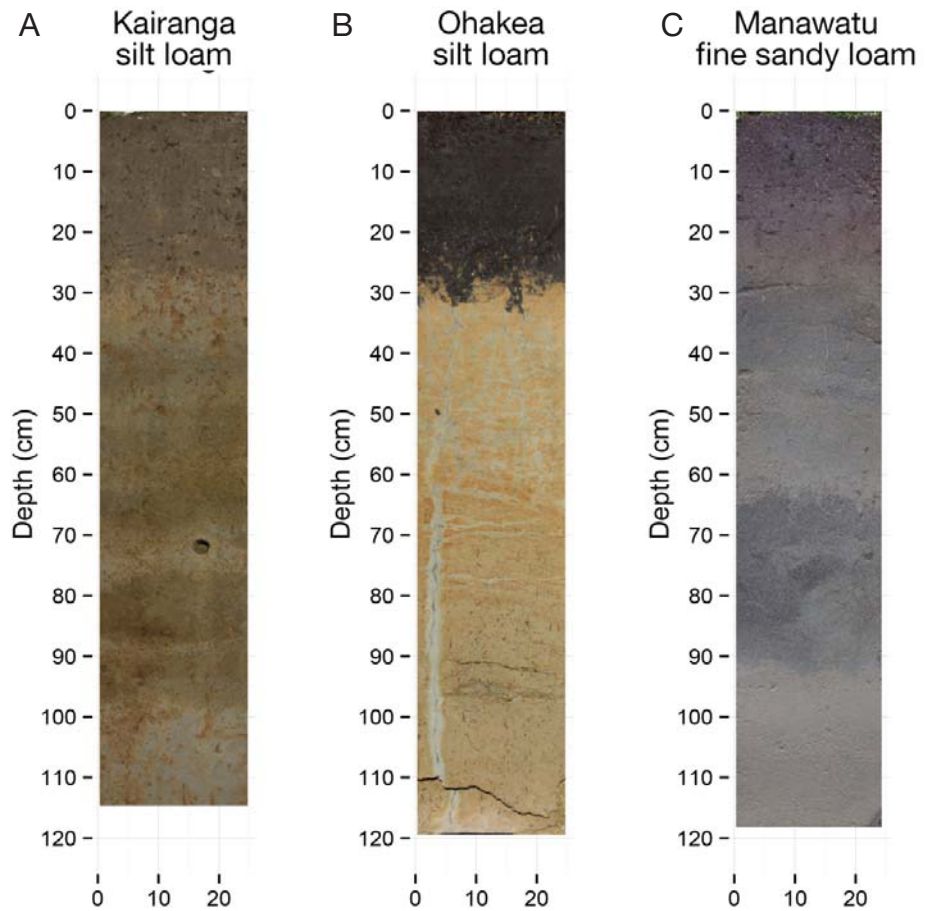
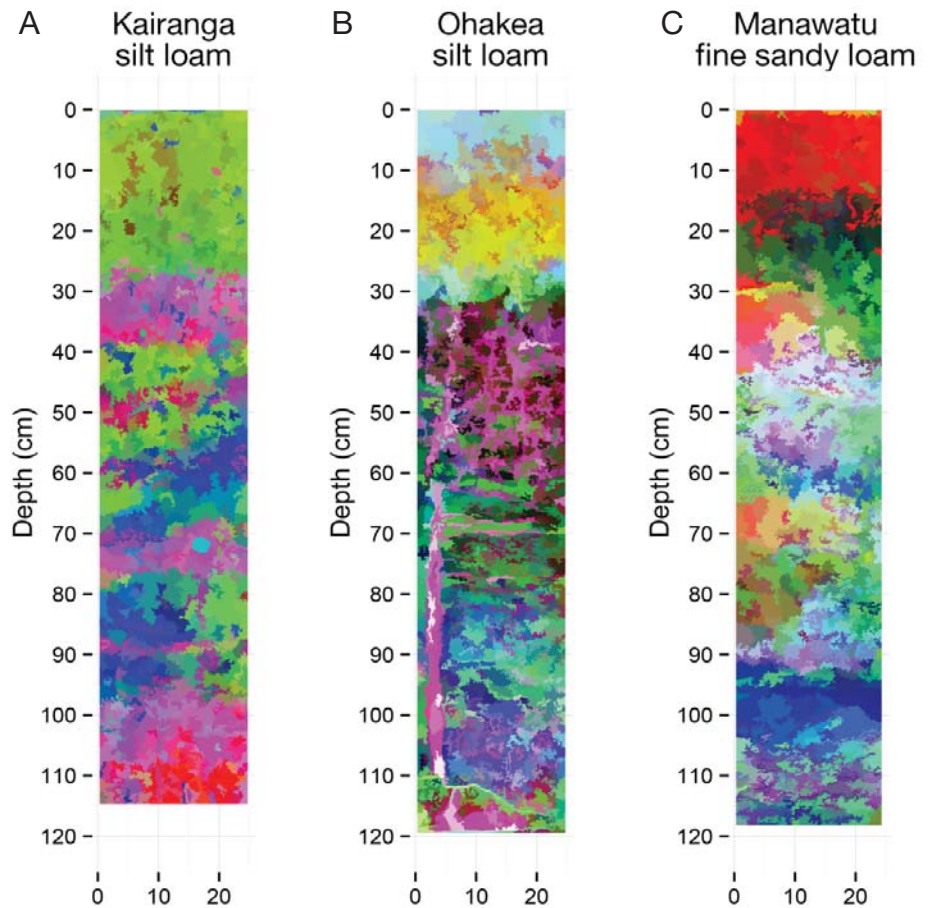


FIGURE 3 Enhanced visualisations of the same 3 soil monoliths using digital soil morphometrics techniques, combining digital camera photography with visible near-infrared spectroscopy.

These enhanced soil monolith visualisations combine the spatial resolution of the digital camera (each pixel being a 1×1 mm square) with the spectral richness of the Vis-NIR spectra recorded on the soil profiles. The images show a condensed view of the variations captured using Vis-NIR spectroscopy on approximately 2150 wavebands in the visible and near-infrared parts of the light spectrum. They allow quantitative analysis of the soil profile, including the prediction of soil properties (carbon, clay) and soil morphometric features (such as soil structure, horizon boundaries and drainage features).



Next generation databases for soil observation data

For the last two years staff at Landcare Research have been working to improve the National Soils Database (NSD). The NSD is a database containing descriptions of about 1500 New Zealand soil profiles, together with their chemical, physical, and mineralogical characteristics.

The NSD is a critical part of our soil data legacy in New Zealand. The first database was created in the 1980s and contained records back to the 1950s. The data have been migrated to three different databases in the intervening period and maintaining and improving the NSD has been a challenge due to continual changes in information technology (software and computer systems) and lack of priority funding for soil science.

In June 2012 a review of the NSD identified a significant number of issues and a plan of action was formulated to redevelop and improve the NSD to make it fit for purpose for today's soil data needs. It was agreed that we needed to create a next generation, world-class soils observation data system.

The resulting National Soils Data Repository (NSDR) is a versatile soil observation database that now hosts the original National Soils Database. Whereas the original National Soils Database was very specific in purpose (for storage and presentation of pedological data sampled by horizon with a minimum suite of analytical results), the NSDR database has been specifically designed with the capability of housing a variety of soil datasets that differ in content, format, and utility (such as accommodating soils sampled by depth intervals or sites resampled over time).

The NSDR is designed and implemented so that each dataset can include full provenance information, such as detailed descriptions of the methods used to collect and analyse the data, while audit trails can track changes to the data over time. Access to a dataset can be managed, ensuring that sensitive or confidential information can be securely stored and published. A key component of the NSDR is a registry of a full set of definitions for soil properties that includes their categorical value, related analysis methods, and units of measurement.

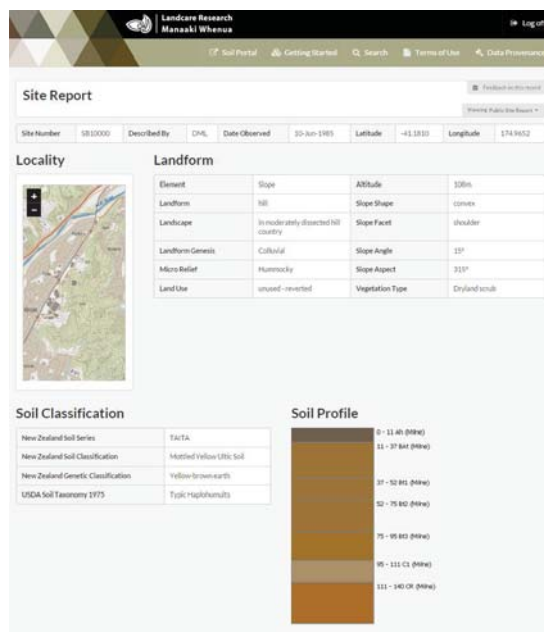


FIGURE 1 The NSDR Viewer provides access to soil data

The goal of this next generation database is to be able to process data cost effectively to generate new soils information from a diverse set of data sources. This will allow integration of a range of resources such as soil quality data, National Soils Database data, and S-map observations. Fully utilised, the NSDR will result in a more cohesive system for soil resource information accessed through a web portal and advanced web data services that conform to national and international data standards and sharing protocols.

The NSDR Viewer (Beta) (Fig. 1) is the first element of the NSDR to be released. Using the viewer, users can get access to data from the original National Soils Database (<https://viewer-nsdr.landcareresearch.co.nz/search>). As we improve the system, more soils data will be made available to end users.

DAVID MEDYCKYJ-SCOTT, ALISTAIR RITCHIE, JIM PAYNE AND BRYAN STEVENSON

E: medyckyj-scott@landcareresearch.co.nz

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