Manaaki Whenua
Landcare Research

New Zealand soils are a nationally strategic asset. Soil information is an essential input to many government policies that underpin our economic and environmental sustainability, and the decisions we make on land use, management, and investment. However, soil information is often taken for granted, and its availability and limitations are not always well understood by decision makers.

Much of New Zealand's current soil information is based on historic surveys, which are of varying quality, and do not meet modern needs.

This briefing note summarises the current state of soil information, and emphasises the need for high quality soil information.

Key Points

- New Zealand's economy and environment depend on the wide range of ecosystem services provided by soils.
- Soil information is widely used by central and local government, research institutes, business and individuals, especially in the consulting and agriculture sectors.
- Most of New Zealand's soil information is based on historical generic soil mapping, which is patchy in location, scale and quality. The older mapping is being superseded by S-map, a new high - quality national geospatial soil database, maintained by Manaaki Whenua - Landcare Research.
- S-map currently covers about 34% of New Zealand, mostly in the larger regions. The expansion of S-map into new areas is piecemeal and depends on the availability of regional council funding.
- S-map is widely used, with 14,000 users of the website alone, downloading 33,000 factsheet last year.
- The direct economic benefit of S-map to current users is estimated to be at least $19.5 million per year. If S-map is extended nationally this would deliver an additional benefit of $11.8 million per year. Over a period of 15 years, the net present value of the benefits is estimated to be between $55.5m and $68.1 million. Better decisions on the use of the country's natural resources and avoided costs will have significant ongoing public benefits.
- National coverage of S-map would require a one off investment of $35 million, and ongoing funding of $1.2 million per year to operate and maintain the information system.
- This will provide a high quality, easily accessible national soil database to meet the strong demand for high quality soil information across a wide range of national issues, including climate change, water quality, food production.
- Once we have achieved national coverage of S-map, it will be an important resource that will be used for many years.

Implementing a nationally funded S-map programme

Background

New Zealand is highly dependent on its natural capital – soils, water, landscapes and biodiversity[1]. These provide a variety of 'free' ecosystem services, which underpin the environment and the country's economy[2].

About half of our land is used for primary production, while about one third lies in the conservation estate. The value of agriculture, fisheries and forestry exports is estimated to be $45.6 billion in 2019[3]. Tourism, which generated $39.1 billion in 2018[4], and other parts of the economy, (e.g. service sectors and manufacturing that supports these activities), also rely indirectly on the country's natural capital.

Beyond their economic benefits, soils provide a wide range of services to society, including carbon storage, a physical foundation for buildings and infrastructure, a medium for plant growth, regulating the loss of contaminants and nutrients to water, and the provision of natural and modified landscapes (Figure 1[5] [6]. Over-exploitation of soil's natural capital can degrade soil resources and the associated societal services.

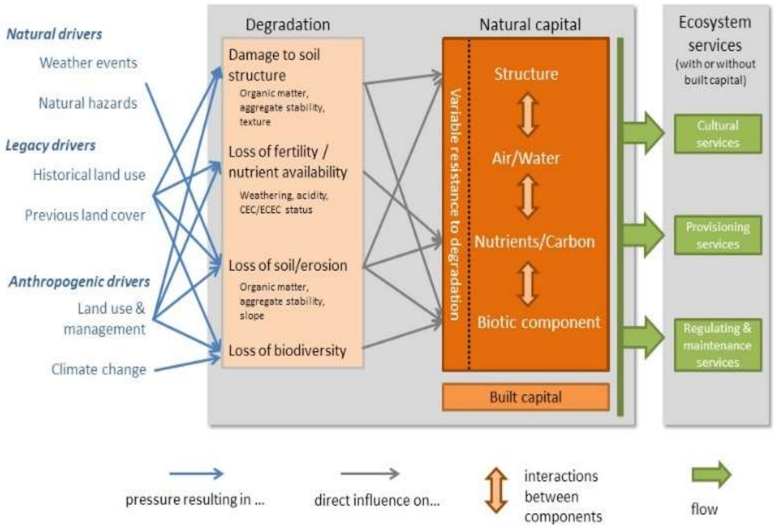

Figure 1 *The relationship between soil natural capital and soil services and land degradation. Source Lilburne et al (2019 in press)*[13]

Despite the significant - but largely unappreciated role - that our soil resource plays in sustaining New Zealand's society, environment and economy, several major reviews[7] have found that soils are coming under increasing pressure from:

- intensifying agricultural production per unit of land area, driven by potential gains in product yield and quality.
- increasing competition for land – urban expansion onto versatile land, conversion of dryland sheep to intensively irrigated dairy farming, urban developments on land prone to liquefaction, and expansion of cropping and forestry onto land highly prone to erosion.
- climate change over the coming decades resulting in increasing erosion rates, and changes to soil biogeochemical cycling, and to hydrological and microbial processes.
- legacy effects – over 150 years of land use change has significantly modified the land and soil as a result of forest clearance, land development and urbanisation.

These reviews highlight the paucity of good quality soil information and emphasise the need for more investment to improve the national soil dataset[8, 9, 10, 11, 12].

With increasing pressure on the country's natural resources, geospatial soil information is increasingly being used along with other biophysical datasets, to evaluate the environmental, social, cultural and economic impacts of land use related decisions [5, 13].

What is soil information used for?

Overview

Soil information is widely used at the national, regional and local levels.

Two primary sources of information – soil maps and site monitoring - describe the state of the country's soil resources. This information, along with other datasets, are used to:

- understand if the country's soil resources are being maintained, and whether the soil is sufficiently healthy to continue supplying services to meet the current and future needs of society.
- determine whether the soil is suitable for different land uses, identify any inherent limitations, e.g. drainage, and the range of ecosystem services provided by the soil.
- identify the reasons for changes to the soil natural capital and emerging issues, e.g. soil compaction.
- evaluate whether actions, e.g. policies, plans, voluntary agreements, are dealing effectively with resource management issues.
- quantify and monitor how land practices may affect the wider environment, e.g. water quality and quantity, climate change.
- assess the value of land and the associated risks to investment, and avoid expensive mistakes[14].

Box 1: What are the different types of soil information?

Soil maps show the distribution of the different types of soils. **Field surveys** collect information about the extent of different soil types, and their characteristics, such as structure, soil texture, density, thickness of soil horizons and depth.

Laboratory analyses of soil samples provide additional information about the physical and chemical properties of the soil, such as pH, soil carbon, porosity, nitrogen and phosphorus availability and contaminant accumulation.

Soil properties can be divided into two broad categories[a]:

- 'inherent' soil properties, which are largely unaffected by management;
- 'dynamic' soil properties which may change with management or environmental conditions.

Inherent properties are used to determine the suitability or capability of the land for different uses. Dynamic properties are used to assess soil health and the effects of land uses on soils, e.g. accumulation of heavy metals or nutrients, and soil compaction.

New methods, such as electromagnetic induction, radiometric, remote and proximal sensing, LiDAR surveys, and data science methods are now being used to inform modern soil mapping methods[15, 16, 17].

Implementing statutes, national policies and regulations

Soil information is an indispensable part of developing and implementing land related national policy and regulations and environmental monitoring.

- The Environmental Reporting Act 2015 and the Environmental Reporting Regulations 2016 require the Ministry for the Environment and Statistics NZ to report on the state of the environment including state of the land and soil, changes to the state of the country's natural resources, and pressures from land uses and climate and natural processes[18].
- The Resource Management Act (1991) sets the regulatory and policy framework for the sustainable management of the country's natural and physical resources including safeguarding the life-supporting capacity of soil[19]. Soil information is often used to implement policies and to inform decisions under the Act.
- The National Policy Statement (NPS) for Freshwater Management 2017 relies on soil spatial data to understand and manage the impacts of land uses on water quality and quantity.
- The National Environmental Standards for Plantation Forestry 2017 use a national classification of erosion susceptibility to regulate the environmental effects of plantation forestry[20].
- The National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health establishes national standards for soil contaminants and planning controls for contaminated or potentially contaminated land[21].

- The proposed National Policy Statement (NPS) for Highly Productive Land[22] to manage the loss of high-class land[a] from urban sprawl and lifestyle blocks will require detailed, accurate soil maps, delineating the areas of high-class land to implement the national policies.

National Inventory of Greenhouse Gas emissions

New Zealand must report annually on the country's progress towards achieving its international greenhouse gas[b] emission targets[23], and soil data are an essential input into calculating our national greenhouse gas emissions.

Soil is a major reservoir for organic carbon. Changes to land use practices can potentially increase or decrease soil carbon stocks[24]. Soil carbon levels are also highly variable, depending on factors, such as, soil type, climate, topography and present and past land uses. The national soil carbon stock is calculated by sampling representative sites across the country, and using soil and digital elevation maps, to predict the distribution of soil carbon across the country[25].

Nitrous oxide is emitted primarily from agricultural soils[26]. The rate of nitrous oxide emissions is highly variable, and mainly depends on the extent and time that different soils are saturated[27].

Setting water quality and quantity limits

Under the NPS for Freshwater Management, regional councils are required to set objectives for freshwater bodies in their regions and water quality and quantity limits on the use of these resources[28]. Because this process involves working with local communities and assessing the effects of social, economic and environmental factors, models are often used to explore future outcomes, and to describe the consequences of alternative policy options on communities and the environment[29].

Soil information is used in many of these models (Table 1), together with other spatial datasets (e.g., climate, land uses) in order to:

- describe contaminant losses from current land uses[30];
- evaluate different ways of allocating nutrient loads[31];
- identify the most cost-effective combination of measures to reduce catchment sediment losses, (e.g., Kaipara Harbour[32]);
- assess the likely effects of land use change on water quality and quantity and the consequences of different policy options to reduce contaminant losses to water[33].

Farmers also use nutrient budgeting models (e.g. Overseer FM), which require soil information to optimise production and manage nutrient losses within catchment water quality limits.

Table 1. Current land-use and catchment models using soil data [34]

Model Type	Number of models requiring soil data
Farm scale (e.g. OVERSEER FM)	4
Surface & groundwater transport (e.g. CLUES)	22
Soil erosion (e.g. HEM)	1
Land use scenarios (e.g. LURNZ)	7

Monitoring the state of New Zealand's soils

Soil erosion

Soil erosion is a serious problem for the country. Erosion rates are naturally high, because of the climate, steep terrain, geology and soil types, but modelling indicates that a significant amount of soil is also being lost from pasture[35]. The economic cost of soil erosion and landslides was estimated at $250-$300 million a year in 2015.

The loss of highly versatile and productive soils

High class soils are essential for sustainable food production. They are mostly located in four regions – Canterbury, Manawatū-Wanganui, Taranaki, and Waikato. The combination of good climate and few physical limitations allows a wide range of arable and horticultural crops to be grown, both of which are expanding high value export industries[36].

But high-class soils are in short supply and are under threat. They make up just over 14% of New Zealand's land area. Of these, the best soils only cover about 5% of the country[37]. During the 1970s and 1980s[38], and again recently[39], concern has been expressed that these prime food-producing soils are being irreversibly lost to new urban areas and lifestyle developments. Between 1990 and

[a] High class soils are defined as Land Use Capability (LUC) classes 1 to 3.
[b] The greenhouse gases included in the inventory are: carbon dioxide, nitrous oxide, methane and hydrofluorocarbons.

2008, 29% of new urban development encroached onto high class soils. By 2013, lifestyle blocks in rural residential areas occupied about 10% of these soils[40]. If these trends continue, within 50-100 years the country's best soils may be lost to food production[41].

Declining soil health

Regular state-of-environment monitoring shows that New Zealand's soils are coming under increasing pressure from land uses[9].

Monitoring of sites in 11 regions found five of the seven indicators met their target range, but many sites under intensive land uses had high phosphorus levels (33%) and/or were becoming more compacted (44%).

Monitoring also found that cadmium levels were increasing in productive land which has led to a joint government and industry strategy to manage the risk of cadmium entering the food chain[42].

Monitoring drought conditions

Climate change is expected to increase the frequency and intensity of droughts. Droughts can have severe social, economic and environmental effects on regions. Soil moisture and climate indicators are used in the New Zealand Drought Index to monitor the extent and severity of drought conditions across New Zealand[43], and predictions have been shown to be sensitive to the quality of soil information[44].

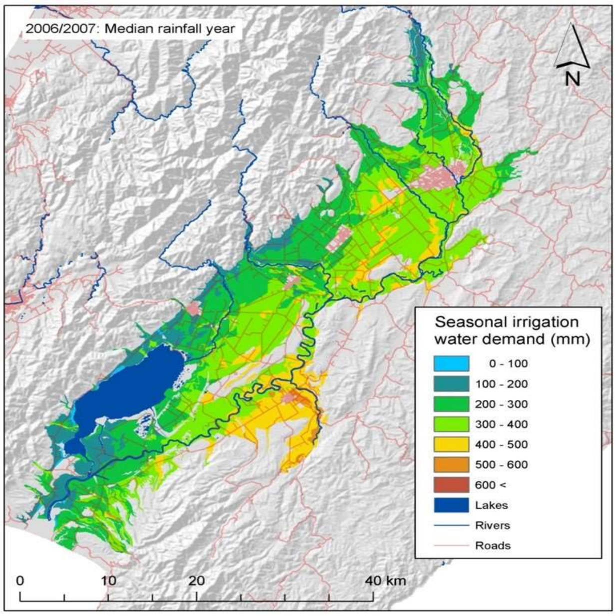

Figure 2. *Seasonal water irrigation demand in the Wairarapa (median year). Source: Lilburne et al (2014)[54].*

Reporting on the state of New Zealand's soil natural capital

Inventories of natural capital require reliable consistent ways of measuring how much stock is present and its condition. Soil natural capital is routinely measured and mapped in soil surveys.

New Zealand's National Environment–Economic Accounts[c], will report on the capital stock of the country's natural resources. The accounts have begun to include the country's soil natural capital, with estimates of soil quality and long-term soil erosion[45]. New indicators – soil health, and productive land – will eventually form part of the natural capital component of the future well-being indicators[46].

Evaluating soil suitability for different land uses

Soil information is a key part of good decision making. It is widely used for land use planning and environmental management:

- *Planning civil engineering works.*

Planning for new infrastructure developments uses soil and geological information to assess likely foundation conditions, and to identify sites for detailed geotechnical surveys[47].

- *Assessing erosion risk.*

The susceptibility of land to erosion depends on the topography, soil properties, geology, and influence of other factors, such as climate and vegetation cover. Soil maps depict the relationship between soil patterns, parent material, and the landscape, and this information can be used to predict the erosion potential of different landforms[48].

- *Locating urban areas and settlements.*

Detailed soil surveys have been used to identify suitable land for new townships (e.g. Rolleston[49]), or proposed new settlements (e.g. Pukaki Tourist village[50]), and to guide the expansion of existing urban areas (e.g. Christchurch[51]).

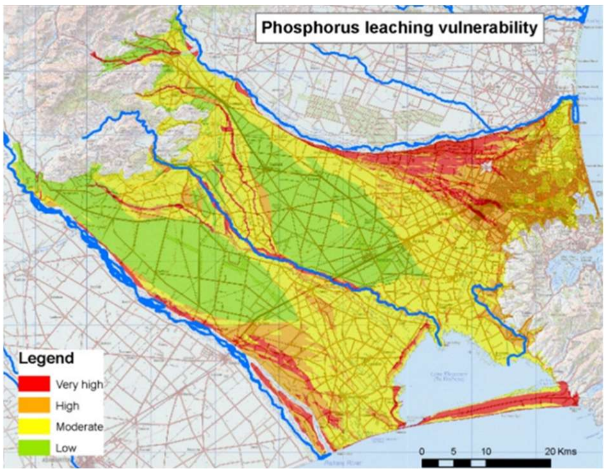

Figure 3*. Phosphorus leaching vulnerability, central Canterbury Plains. Source Lilburne et al. (2014)[54]*

Soil information is also used to delineate areas where ground conditions may limit urban development, such as liquefaction risk in the Hamilton Basin and Christchurch City[52] or earthquake microzoning (e.g. Wellington[53]).

[c] Based on the UN System of Environmental-Economic Accounting (SEEA)

- *Irrigation planning.*

Information on soil properties, combined with climate data and the volume of water authorised by water permits, can be used to predict irrigation water demand[54] (Figure 2). Soil information is also key to good irrigation system design and efficient irrigation management[55].

- *Mapping the vulnerability of land to contaminant losses*

  The capacity of soils to regulate or reduce nitrate, phosphorus and microbial losses from various land uses can be predicted by soil properties, and is a dominant factor in water quality trends across regions[56]. Interpretive maps can be created from S-map showing the relative vulnerability of soils to contaminant losses and which areas are best suited for particular land uses[57] (Figure 3).

  Soil information is also essential for the location, design and operation of domestic, farm, industry and municipal wastewater systems.

Land evaluation for primary production

With the increasing availability of high quality, soil, climate, land cover and terrain geo-spatial datasets, potential areas for primary production can be mapped rapidly at reasonably high levels of detail.

Some examples of these studies include:

- S-map was used to rapidly update the old Land Use Capability maps of the Canterbury Plains[58].
- Regional economic development initiatives, such as the Topoclimate South[59] and growOTAGO®[60] projects, combined S-map with other datasets, such as rainfall, growing degree days, and wind speed, to identify suitable areas for new crops, and to improve the management of existing land uses.
- Mapping potential areas in New Zealand for afforestation and quantifying potential productivity of existing plantations[61].

Farm management

Farmers are increasingly reliant on high quality spatial data to manage their businesses[62]. Nutrient budgets and farm environment plans are now required in many regions[63]. The type and intensity of farming, soil type and climatic conditions all have a major influence on nutrient losses from rural land[64]. Soil information is needed to minimise nutrient losses, and to manage fertiliser applications, irrigation systems, and the discharge of animal effluent and vegetative wastes onto land[65].

In the North Island soft rock hill country, detailed resource maps (e.g. soil, geology, slope), underpin the Sustainable Land Use Initiative, farm plans and associated measures to reduce erosion rates and improve water quality[66]. Soil and land information also underpins industry good management practice initiatives, such those made by Dairy NZ[67] and Beef and Lamb NZ[68].

Land valuation

Rural valuers, banks and real estate agents often use soil information for farm valuations, to market a rural property and to make informed decisions about land purchases and investment risk[69].

What are New Zealand's national soil datasets?

Knowledge of New Zealand's soils is the result of many decades of work by different government agencies and organisations. Manaaki Whenua - Landcare Research is responsible for maintaining New Zealand's national datasets of soil information:

National Soils Database Repository (NSDR)

The NSDR is New Zealand's fundamental national soil dataset. Physical soil samples are stored in the National Soils Archive. It contains detailed descriptions dating from the 1960's of over 2,500 soil profiles, as well as laboratory analyses of physical and chemical properties of the soil layers[70].

These data are used to underpin soil maps, support land management models and New Zealand's carbon inventory, and develop an understanding of how soil properties vary across landscapes and respond to land management.

New Zealand Land Resource Inventory (NZLRI) and the Fundamental Soils Layer

The NZLRI maps of the physical land resource (geology, soil, erosion, slope and vegetation) were compiled between 1973 and 1979, and cover the country at a scale of 1:63,360 (1 inch to the mile). Some North Island maps have subsequently been revised and updated[71].

The NZLRI information was used to derive Land Use Capability maps, which rate the potential capacity of the land to sustain primary production, based on the physical resources, climate, effects of past land use and erosion potential. The soil information used in the NZLRI was compiled or interpreted from historical, often generic soil surveys[72].

The Fundamental Soils Layer was created from the NZLRI and was the first national spatial soils database. It provides a generalised set of national soil maps and limited information on soil properties[73 74]. While nominally produced at a scale of 1:50,000, based on the NZLRI, the majority of underpinning surveys were general reconnaissance surveys at scales greater than 1:100 000. In many parts of the country, the Fundamental Soils Layer is the only source of soil information.

S-map – a national geospatial soil data set

The older soil surveys and the Fundamental Soils Layer are being superseded by S-map, a new geospatial soil information system, created and operated by Manaaki Whenua. S-map stores digital soil maps at a minimum scale of 1:50,000 and detailed data on core soil properties down to 1 metre or to bedrock[75] (Figure 4).

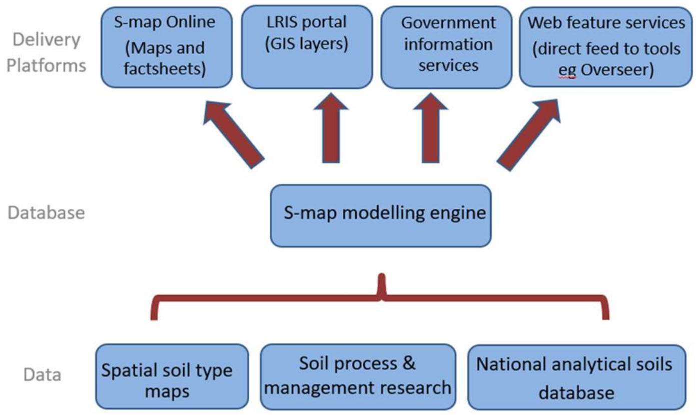

***Figure 4**. Structure of the S-map information system. Source: Manaaki Whenua*

S-map is underpinned by the NSDR and uses algorithms (pedo-transfer functions) to predict soil properties that have not yet been analysed and to derive maps showing a wide range of soil properties[76].

Unlike the Fundamental Soils Layer, S-map can produce higher resolution maps of consistent quality with more detailed quantitative information on soil properties. The system is flexible and designed to accommodate new data at any scale, as soil knowledge, users' needs and tools change.

As of August 2019, S-map covered 34% of New Zealand, mostly in the lowland parts of the country (Figure 5). Over half of the country's most productive land (horticulture, dairying, arable) is covered by S-map, but it covers less than 25% of the area for other land types (forestry, extensive pasture, conservation estate).

***Figure 5**: S-map coverage as at July 2019. Source: Manaaki Whenua*

S-map coverage also varies between regions. Less than 5% of Northland, Taranaki, Manawatū, Nelson and the West Coast regions are mapped. Canterbury, Waikato, Hawkes Bay, Otago, Wellington and Southland, have the highest S-map coverage (over 60%) of highly productive land.

What are the issues with current soil information?

Over the past 20 years, there have been significant advances in soil knowledge and data management technology. Scientific techniques and understanding have changed, new analytical techniques have developed, and the old paper maps and reports have been superseded by geospatial datasets. Increasingly, users of soil information, require up-to-date, detailed quantitative information on the distribution and fundamental properties of soils, delivered by a flexible system that can serve the many, varied users and their changing needs.

Despite these advances, there are still significant deficiencies in our knowledge of the country's soils:

Lack of an accurate, up to date national soil map

Paper soil maps, often accompanied by a report, were published from the late 1930's to 2001. Many of these older soil surveys were carried out to meet different, often simpler, needs, such as taxonomic classification, and they do not meet the modern demands for quantitative data. This limits the scope for reporting on and managing, the effects of land uses, and for evaluating the ecosystem services delivered by soils, and the accuracy of modelling for policy needs[77].

The Fundamental Soils Layer was created to provide a generalised national digital soil map. It was compiled from historical paper maps, and relies on older, coarser mapping, and qualitative description of soil types and their properties[78]. The reliability of the soil mapping outside of the S-map areas is very low (Figure 6)[79].

Because national S-map coverage is incomplete, the older Fundamental Soils Layer or the Land Use Capability maps are often used as the source of soil information. For example, assessments of the impact of urban sprawl and lifestyle developments on versatile soils have relied on the older NZLRI Land Use Capability maps[80].

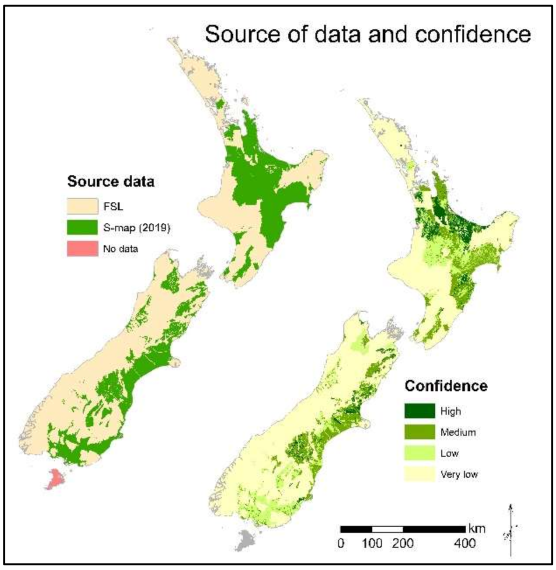

Figure 6. *Map (updated)showing the reliability of current soil mapping* [79]

The difference between the detail and quality of historic and modern soil mapping is highlighted when the older soil and S-map information are applied to different uses and compared. Here are some examples:

- The Overseer FM nutrient predictions of nitrate leaching are substantially improved using S-map data compared to Fundamental Soils Layer data, which do not capture the variation in key soil properties compared to S-map data[81].
- The lack of detailed soil maps will hinder the implementation of the proposed NPS for Highly Productive Land. The definition of highly productive land is crucial as it will determine the extent of highly productive land in each region. For example, estimates of the amount of high-class land in Canterbury vary by up to 600,000 ha, depending on the source of soil information (Table 2).

  The proposed NPS uses Land Use Capability maps to define the spatial high-class land despite the acknowledged problems with the dataset, which will require a significant investment in higher resolution soil data to correct[82].
- The Erosion Susceptibility Classification, which underpins the National Environmental Standards for Plantation Forestry 2017, was also hampered by a lack of good soil data, and required several revisions before it was sufficiently accurate for regulatory use[83].

Table 2. Variation in estimates of high-class land in the Canterbury Region

Data source	Area (ha)	
	LUC 1& 2 classes	LUC 1, 2 & 3 classes
Land Use Capability (LUC) maps	293,497	838,437
Fundamental Soil layer	513,270	1,437,166
S-map data	200,722	737,672

(Source Manaaki Whenua)

Better data is needed on soil properties and their spatial distribution

Much of the soil data collected between the 1930s and 1980s are now inadequate for many uses. Many of New Zealand's soil types were not sampled, and many of the older data do not meet the current data requirements or needs of current users, policies and tools. There is a risk that the variation in accuracy, detail and coverage of soil information may not be understood, noticed or considered when the information is used[84].

Despite the extensive demand and widespread use of soil information, there are still large gaps in the quality, consistency and coverage of national soil datasets[85]. For most of New Zealand, the Fundamental Soils Layer remains the only source of soil data on soil properties. In areas remapped by S-map over 5,000 unique soils have been identified, which has led to a fundamental change in the understanding of one of the country's core natural resources[86].

Currently, New Zealand's soil datasets cannot provide a comprehensive consistent picture of the state of country's soil resources. Much of the soil information does not meet minimum requirements for national indicators[87]. Similarly, the recent national environment report – *Our Land 2018* – commented on the lack of soil data and the knowledge of key soil processes[88].

High degree of uncertainty with modelling results

Biophysical models are used extensively to support policy development, to explore possible outcomes if environmental or economic conditions change, and to report on, and monitor trends in, the state of the environment.

Despite the sophistication of many models and the quality of many data[d] the accuracy of model outputs suffers if one or more of the datasets is not of comparable quality. Soil data are a key input for many models, but often the soil information is based on a simple estimate of soil properties, (e.g. NZ Drought Index[43]), or uses the existing patchy soil data with 'work arounds' or requires additional sampling to calibrate the model (e.g. the national spatial model of soil carbon[89]).

Even with calibrated models, there are still large uncertainties. Estimates of nitrous oxide emissions from agricultural soils are calculated to have an uncertainty of ± 55% for 2017, primarily because of the effect of weather, climate and soil types on the emissions from grazing livestock excreta[90]. Estimates of nutrient discharges using the Overseer FM model have an estimated uncertainty of at least 25-30%, and they are highly sensitive to the quality of soil data[91].

The historical investment in soil information needs to be captured

A lot of unpublished soil data and soil maps are stored in files, papers, theses, and reports, representing a considerable national publicly funded investment in soil research, but they remain largely inaccessible to the public, organisations and models, such as Overseer FM [92].

Manaaki Whenua, regional councils and primary industry organisations, have funded the capture of high value legacy soil water data, doubling the number of sites in the NSDR that underpin both S-map and Overseer FM, which is highly sensitive to these data. To collect the same data today would cost an estimated $3.8 million. An additional 157 sites could be added to the NSDR. Similarly, good quality detailed legacy soil surveys in lowland areas of Manawatū and Taranaki could be added to S-map[78].

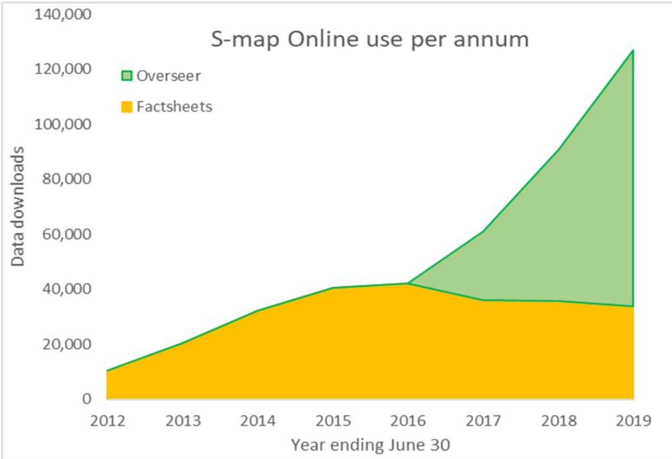

Figure 7: *Summary of data usage from S-map Online up to June 2019. Source: Manaaki Whenua.*

Who uses S-map information?

S-map is a public resource that is delivered to users by a variety of methods (Figure 7). The S-map Online website[e] is the main access point for most people seeking soil information.Users can download basic soil information free of charge for their location, such as fact sheets,[93] or obtain the S-map data directly via tools or models, such as the Overseer model, Dairy NZ's Farm Dairy Effluent Storage Calculator or through the Environment Canterbury Farm Portal.

S-map data are also supplied directly to a number of regional councils, central government agencies and primary sector companies for use in their own 'in-house' information systems.

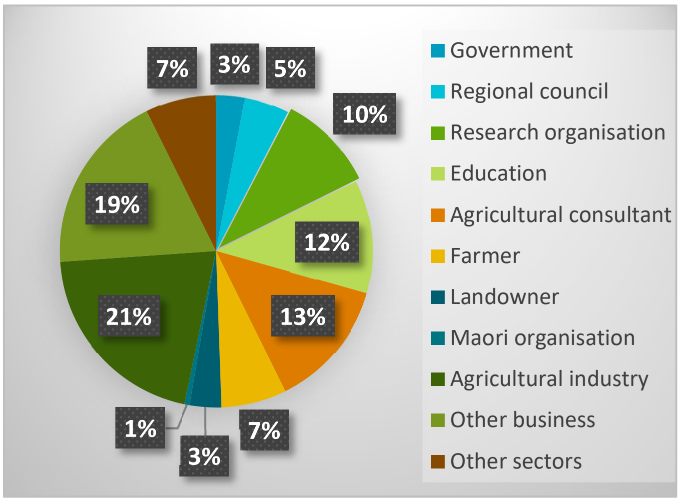

Figure 8: *S-map online users as at 2017. Source: Manaaki Whenua.*

The number of individuals and organisations using S-map Online is increasing annually (Figure 7). Since 2012, there have been 300,000 visits to the S-map website. Although S-map covers only 34% of New Zealand, currently there are over 14,000 registered users, who last year downloaded over 33,000 soil factsheets, which provide targeted soil information of relevance to end users[94]. A further 93,000 data requests came from Overseer model users. S-map users span the private sector (64%), research organisations and academia (22%), and central and local government (8%) (Figure 8)[f].

[d] For example: the national digital elevation model has a resolution of 15 metres and LIDAR data has a resolution of 0.15 metres.

[e] https://smap.landcareresearch.co.nz/

[f] The percentage of agricultural organisations and regional council users is likely to be underestimated as many of these organisations hold copies of S-map.

S-map is a national investment

Good science information is a long-term national investment, and does not depreciate in value. Indeed, over time it is refined, improved and continually put to use.

A recent survey[95] of S-map Online users estimated the direct value of S-map to be about $19.5 million annually, mostly in the regions with good S-map coverage, e.g. Canterbury and Waikato. In areas with poor S-map coverage, the value of S-map related work is proportionately lower. If S-map is extended across the remainder of New Zealand, this would create an additional benefit to users, primarily in the professional and agricultural sectors of about $11.8 million per year. Over a 15 year period, the direct economic benefit to users would have an estimated net present value of between $55.5 and $68.1 million.

The value of S-map varies across different sectors, with professional, science and technical services directly benefiting by $7.7million, followed by agriculture – dairying ($4.3 million), sheep, beef, cattle and grain farming ($2.5 million) and horticulture and fruit growing ($1.7 million). Other sectors, such as forestry, real estate, and public administration, directly benefited by about $3.3 million.

In addition to the direct user benefits, there will be public good benefits from the widespread use of good quality soil information in land use decisions and policy development. Whilst difficult to quantify in monetary terms, there will be a substantive benefit to New Zealander's wellbeing, such as improving freshwater quality, safer drinking water, and national food security.

Historically, much of the government funded research carried out by the Department of Scientific and Industrial Research (DSIR), National Water and Soil Conservation Organisation (NWASCO) and other agencies up to the mid-1980s, was seen as a 'public good', and the results of the work were available to anyone without paying royalties or being constrained by intellectual property rights. With the economic changes in the 1980s and 1990s, a contestable science funding model was introduced, commercial Crown research agencies were established and the scope of basic research funding was limited to a narrower range of objectives[96]. Central government funding of soil mapping largely ceased, replaced by *ad hoc* funding from regional councils and community trusts.

Despite the shift to a market funded science model, much of the current national and regional natural resource policy work (e.g. proposed NPS for Highly Productive Land) still relies heavily on the legacy of soil and land-use inventory mapping carried out by the DSIR and NWASCO.

How much would it cost to complete S-map coverage of New Zealand?

The two main areas requiring investment in S-map are:

- one-off funding to complete coverage of the country and to capture the historical soil site data.
- ongoing funding to operate the database and delivery system.

The total cost to complete S-map coverage of New Zealand is estimated at $35 million, spread over 7 years (Table 3). The variation in costs reflects the land types, mapping techniques and the quality of soil information required. For example, the Department of Conservation estate covers about 30% of New Zealand, primarily comprising Class 7 & 8 land.

Table 3: Projected costs to complete S-map coverage

Land Type	% NZ	% NZ not in S-map	Cost $/ha	Completion cost ($ million)
Multiple use	25	9	6	14.5
Pasture/forest	30	19	3	15
Classes 7 & 8	45	39	0.5	5.5
Total	**100%**	**67%**	**-**	**$35 million**

Ongoing funding to maintain and operate the S-map database and delivery system to all S-map users is estimated at $1.2 million per year (Table 4). This would deliver:

- a complete up-to-date stocktake of a core natural asset that underpins New Zealand's economy and society.
- a geospatial information system that meets the strong demand for quality soil information across significant national issues.
- a flexible, easy-to-access soil information system for a wide range of users.

- improved quality of decision making and confidence in the large investments New Zealand needs to make about the use of land, and the services soils provide to society, such as healthy waterbodies, sustaining the production of food and fibre, and managing greenhouse gas emissions.

Table 4 Estimated S-map operating costs

S-map systems	Maintenance	Development	Estimated costs ($M)
Database	Regular maintenance & updates to the software system	Further improvements to update new models and data for end-user tools	**$0.7**
Delivery	Operating S-map online, LRIS[g] Portal and Soils Portal websites and help desk. Servicing end user tools & models, e.g. OVERSEER FM, hydrological & climate models	Improving S-map Online website, fact sheets content usability, user support new direct data feeds to third parties	**$0.5**

Where to from here?

Despite the fundamental role that soil plays in meeting core human needs, and in supporting New Zealand's economy and environment, there have been decades of under-investment in soil research in New Zealand[97].

The lack of a comprehensive, high quality national soil dataset is hampering the implementation of national and regional policies, and contributing to the lack of definitive reporting on the state of the environment.

For a relatively modest public investment, the country would obtain a high-quality geospatial soil dataset that would generate significant direct benefits to S-map users, and indirectly broader public benefits from better decisions about the use of the country's natural resources.

Unlike other interpretative land use classifications, a stocktake of the country's soils is a long-term investment in the basic knowledge of the country's natural resources. Like the historical soil mapping, the data and knowledge gathered for S-map will be used for many years.

The S-map geo-spatial system can be readily updated with the latest surveys and research, avoiding the problem with printed material which becomes dated as new data are acquired.

The geospatial dataset will improve the quality of environmental reporting, encourage the development of new 'downstream' applications, and support the development of other land use products or classifications, such as land use suitability mapping.

Acknowledgments
Prepared by Raymond Ford, Environmental Policy Consultant. I would like to thank Dr Sam Carrick and Dr Linda Lilburne, Manaaki Whenua for suggesting and supervising this project. Many thanks to Dr Gerald Rhys, Ministry of Primary Industry and Ray Prebble for giving up their time and reviewing the paper. Their suggestions and edits improved the final product.

[g] LRIS stands for the Land Resource Information Systems Portal https://lris.scinfo.org.nz/

Endnotes

[1] PCE 2004 Growing for good: intensive farming, sustainability and New Zealand's environment Parliamentary Commissioner for the Environment October 2004.

[2] Dymond, J ed. 2013. Ecosystems services in New Zealand – conditions and trends. Lincoln, Manaaki Whenua Press.

[3] MPI 2019. Situation and outlook for primary industries, Wellington, Ministry for Primary Industries. https://www.mpi.govt.nz/news-and-resources/open-data-and-forecasting/situation-and-outlook-for-primary-industries-data/ Downloaded 1 April 2019.

[4] https://www.stats.govt.nz/information-releases/tourism-satellite-account-2018 Downloaded 1 April 2019.

[5] Dominati, EJ 2013 Natural capital and ecosystem services of soils. *In* Dymond JR ed. Ecosystems services in New Zealand – conditions and trends. Lincoln, Manaaki Whenua Press.

[6] Aislabie, J. Deslippe, J. 2013 Soil microbes and their contribution to soil services. . *In* Dymond JR ed. Ecosystems services in New Zealand – conditions and trends. Lincoln, Manaaki Whenua Press.

[7] Collins A, Mackay A, Basher L, Schipper L, Carrick S, Manderson A, Cavanagh J, Clothier B, Weeks E, Newton P. 2014. Phase 1: Looking Back. Future requirements for soil management in New Zealand. Palmerston North, National Land Resource Centre. PCE 2004 Growing for good: intensive farming, sustainability and New Zealand's environment Wellington, Parliamentary Commissioner for the Environment October 2004. MfE & Stats NZ (2018). New Zealand's Environmental Reporting Series: Our Land 2018. Wellington, Ministry for the Environment & Stats NZ.

[8] Manderson, A. Palmer, A. 2006 Soil Information for agricultural decision making: a New Zealand perspective. Soil Use and Management 22:393-400.

[9] MfE & Stats NZ (2018). Our land 2018

[10] Motu Research 2018 Land use modelling in New Zealand: current practice and future needs. Motu Working Paper 18-16 November 2018, Wellington.

[11] PCE 2018 Keynote address to the New Zealand Society of Soil Science Conference, Napier. 6 December 2018 https://www.pce.parliament.nz/our-work/news-insights/address-at-the-new-zealand-society-of-soil-science-conference Downloaded 15 April 2019

[12]http://archive.stats.govt.nz/browse_for_stats/environment/environmental-economic-accounts/environment-domain-plan.aspx. Downloaded 16 April 2019

[13] Lilburne, L; Eger, A, Mudge, P., Ausseil, A., Stevenson, B., Herzig, A.,Beare, M. 2019 The Land Resource Circle: supporting land-use decision making with an ecosystem service based framework of soil functions (paper in press)

[14] Klingebiel, A 1966 Costs and returns of soil surveys. Soil Conservation 32: 3-6

[15] Hedley, C. B., Roudier, P, Peterson P, 2016. Gamma soil surveys – investigating soil patterns for nutrient and water management. *In* Currie, L, D, Singh, R. eds. Integrated nutrient and water management for sustainable farming. Occasional Report No. 29. Fertilizer and Lime Research Centre, Massey University, Palmerston North.

[16] Hedley, C. Basher, L., Lawrence, H. 2008 An electromagnetic induction survey of soils in the Motupiko Catchment to interpret existing soil maps and assess differences relating to sustainable land use change Envirolink Medium Advice Report grant Report LC0708/069 prepared for Tasman District Council.

[17] Manaaki Whenua – Landcare Research 2018 Remote sensing utilised https://www.landcareresearch.co.nz/publications/innovation-stories/remote-sensing-utilised Down loaded 31 May 2019.

[18]http://www.legislation.govt.nz/regulation/public/2016/0127/latest/DLM6855401.html
http://www.legislation.govt.nz/act/public/2015/0087/latest/DLM5941105.html#DLM5941101
Downloaded 20 July 2019

[19] S. 5 (2)(a) Resource Management Act 1991

[20]http://legislation.govt.nz/regulation/public/2017/0174/latest/DLM7373517.html?src=qs Downloaded 20 April 2019

[21]http://www.legislation.govt.nz/regulation/public/2011/0361/latest/DLM4052228.html Downloaded 28 July 2019

[22] MPI & MfE 2019 Valuing Highly Productive Land: a discussion document on a proposed national policy statement for highly productive land. Ministry for Primary Industries & Ministry for the Environment https://www.mpi.govt.nz/news-and-resources/consultations/proposed-national-policy-statement-for-highly-productive-land/ Downloaded 20 August 2019.

[23] https://www.mfe.govt.nz/publications/climate-change/new-zealands-greenhouse-gas-inventory-1990-2017-snapshot Downloaded 1 May 2019.

[24] PCE 2019 Farms, forests and fossil fuels: the next great landscape transformation? Report by the Parliamentary Commissioner for the Environment. March 2019.

[25] LCR 2016 Reducing New Zealand's Agricultural Greenhouse Gases: mapping soil organic carbon stocks. A fact sheet prepared by New Zealand Agricultural Greenhouse Gas Research Centre, Pastoral Greenhouse Gas Research Consortium and Landcare Research.

[26] PCE 2019 Farms, forests and fossil fuels

[27] Van der Weerden, T. J., Kelliher, F.M. et al. (2012). "Influence of pore size distribution and soil water content on nitrous oxide emissions." Soil Research 50(2): 125-135.
Van der Weerden, T.J.; Laurenson, S. Vogeler,I, Beukes, P.C., Thomas, S.M, Rees, R.M , Topp, C.F.E, Lanigan, G, de Klein, C.A.M. 2017 Mitigating nitrous oxide and manure-derived methane emissions by removing cows in response to wet soil conditions, Agricultural Systems, Volume 156: 126-138, https://doi.org/10.1016/j.agsy.2017.06.010.

[28] MfE 2017 National Policy Statement for Freshwater Management 2014. Updated August 2017 https://www.mfe.govt.nz/publications/fresh-water/national-policy-statement-freshwater-management-2014-amended-2017 Downloaded 20 August 2019.

[29] Anastasiadis, S., Kerr, S., Arbuckle, C. Elliot, S., Hadfield, J., Keenan, B., McDowell, R., Webb, T., Williams, R. 2013 Understanding the Practice of Water Quality Modelling. Wellington, Motu Economic and Public Policy Research.

[30] Lilburne L, Webb T, Snow V, Brown H. 2015. Soil and climates in Canterbury: clusters for the Matrix for Good Management project. Client report for Environment Canterbury (unpublished).

[31] For example: Daigneault, A., Samarasinghe, O., Lilburne, L 2013. Modelling economic impacts of nutrient allocation policies in Canterbury: Hinds Catchment. Report prepared by Landcare Research for the Ministry for the Environment. Daigneault, A. Elliot, S. 2017 Land-use contaminant loads and mitigation costs: a technical paper prepared for Motu Economic and Public Policy Research, Wellington.

[32] Daigneault, A., Dymond, J., Basher, L. 2017 Kaipara Harbour sediment mitigation study: catchment economic modelling. Report prepared by Landcare Research for Streamlined Environment Ltd.

[33] For example: Lilburne, L., Mojsilovic, O., North, H., Robson, M. 2017 Land use modelling for the Waimakariri land and water solutions programme. Memo from Mannaki Whenua Landcare Research to Matt Dodson Environment Canterbury, dated 20 February 2017. Shaw, H., Palmer, K., 2015 Waitaki Limit Setting Process: Technical Overview. Environment Canterbury Report no. R15/99; Moran, E., Pearson, L., Couldrey, M., Eyre, K. 2017. The Southland Economic Project: Agriculture and Forestry. Environment Southland report no 2017-02

[34]https://teamwork.niwa.co.nz/display/IFM/Compilation+of+models+and+their+attributes Downloaded 10 May 2019 See also: Motu Research 2018 Land Use modelling in New Zealand: current practice and future needs. Motu Working Paper 18-16.

[35] Mfe & Stats NZ (2018). New Zealand's Environmental Reporting Series: Our Land 2018. Ministry for the Environment & Stats NZ, Wellington.

[36] https://plantandfood.co.nz/page/news/media-release/story/new-zealand-horticulture-reaches-new-height/ Downloaded 20 July2019.

[37] Mfe & Stats NZ (2018) Our Land 2018.

[38] Molloy, L., Forde, B. 1980 Land Alone Endures: land use and the role of research. Department of Scientific and Industrial Research discussion paper.

[39] Curran-Cournane, F., Golubiewski, N., Buckthought, L 2018 The odds appear stacked against versatile land: can we change them? NZ Journal of Agricultural Research (3) 315-326

[40] Andrew, R. Dymond, J. 2013 Expansion of lifestyle blocks and urban areas onto high class land: an update for planning and policy. Journal of the Royal Society of New Zealand 43 (3) 128-140.

[41] Rutledge, D.,Price, R., Ross, C. , Hewitt, A. Webb, T., Briggs, C. 2010 Thought for food: impacts of urbanisation trends on soil resource availability in New Zealand. Proceedings of the New Zealand Grassland Association 72: 241-246.

[42] MAF 2011 Cadmium and New Zealand agriculture and horticulture: a strategy for long-term risk management MAF Technical paper 2011/02

[43] NIWA 2018? New Zealand Drought Index and Drought Monitor Framework https://www.niwa.co.nz/climate/information-and-resources/drought-monitor Downloaded 8 May 2019

[44] Odgers N, Lilburne L, Guo J, Vickers S, Webb T, Carrick S, Barringer J. 2019. Methods for upscaling and downscaling S-map information: provision of spatial soil information in various formats and scales. *In* Currie, L, D, Christensen, CL eds. Nutrient loss mitigations for compliance in agriculture. Occasional Report No. 32. Fertilizer and Lime Research Centre, Massey University, Palmerston North.
Porteous A.S., Basher R.E., Salinger M.J. (1994) Calibration and performance of the single-layer soil water balance model for pasture sites. New Zealand Journal of Agricultural Research, 37: 107-118.

[45]http://archive.stats.govt.nz/browse_for_stats/environment/environmental-reporting-series/environmental-indicators/Home.aspx Downloaded 15 April 2019.

[46] Stats NZ 2019 Indicators Aotearoa New Zealand – Nga Tutohu Aotearoa https://www.stats.govt.nz/indicators-and-snapshots/indicators-aotearoa-new-zealand-nga-tutohu-aotearoa/ Downloaded 31 May 2019.

[47] Dellow, G., Beetham, R. 2008 Geotechnical methods for assessing foundation conditions for flood control structures GNS Science consultancy report 2008/59.

[48] https://soils.landcareresearch.co.nz/index.php/soils-at-manaaki-whenua/our-projects/bp-soil-and-erosion-mapping/ Downloaded 10 May 2019.

[49] Rennie, W, Bennett, C. 1981 Soils of the Rolleston new town site, Canterbury, New Zealand. NZ Soil Survey Report 61.

[50] Webb, T. 1980 Soils and soil use interpretations of the proposed Pukaki Tourist Village, South Canterbury, New Zealand. Part of New Zealand Soil Bureau Report 44.

[51] Webb, T, Smith, S, Trangmar, B. 1991 Land Resource Evaluation of Christchurch City. DSIR Land Resources Contract Report prepared for Canterbury Regional Council and Christchurch City Council.

[52] McKay, A, Lowe, D, Moon, V 2017 Evaluating soil and landscape models to predict liquefaction susceptibility in the Hinuera Formation, Hamilton Basin. Paper presented to the 20th NZGS Symposium http://www.nzgs.org/library/nzgs20_mckay/?hilite=%27s-map%27 Downloaded 8 May 2019
ECan 2001 ?? The Q files: the Solid Facts on Christchurch Liquefaction A3 factsheet.

[53] Milne, J.D., Northey, R. 1975 Soils of the Wellington Urban area *in* 'Microzoning for earthquake effects in Wellington, N.Z. Grant-Taylor, T. *et al*. N.Z.DSIR Bulletin 213.

[54] Lilburne L, Webb T, Palmer D, McNeill S, Hewitt A, Fraser S (2014) Pedo-transfer functions from S-map for mapping water holding capacity, soil-water demand, nutrient leaching vulnerability and soil services. *In* Currie, L.D, Christensen C. L. eds Nutrient management for the farm, catchment and community (Occasional Report 27. Fertilizer & Lime Research Centre, Massey University, Palmerston North. http://flrc.massey.ac.nz/publications.html.

[55]https://www.irrigationnz.co.nz/KnowledgeResources/COP/Design https://www.irrigationnz.co.nz/PracticalResources/GMP/Scheduling . Downloaded 20 July 2019.

[56] https://ourlandandwater.nz/future-landscapes/physiographic-environments-of-nz/ Downloaded 20 July 2019

[57] Webb, T, Hewitt, A, Lilburne, L, Close, M, McLeod, M. 2010 Mapping of vulnerability of nitrate and phosphorus leaching, microbial bypass flow, and soil runoff potential for two areas of Canterbury. Environment Canterbury Technical Report R10/125.

[58] Lynn, I, Lilburne, L. 2013 Deriving Land Use Capability Classes from the S-map database. Unpublished memo from Landcare Research to Raymond Ford, Environment Canterbury, dated 26 April 2013.

[59] Purdie, J, Hutchinson, G, Allen, D. 1999 Topoclimate south: integrated climate and soil mapping in Southland. Weather and Climate 19: 15-22.

[60] http://growotago.orc.govt.nz/ Downloaded 31 May 2019

[61] Watt, M., Palmer, D., Hock,B. 2011 Spatial description of potential areas suitable for afforestation within New Zealand and quantification of their productivity under *Pinus radiata*. NZ Journal of Forestry Science 41: 115-129.

[62] Chan, D, and Kempson, A, 2018. Delivering tailored farm environment plans at scale. In *In* Currie, L,D, Christensen, CL eds.: Farm environmental planning – Science, policy and practice. Occasional Report No. 31. Fertilizer and Lime Research Centre, Massey University, Palmerston North. http://flrc.massey.ac.nz/publications.html.

McDowell, R. Lucci, G. Peroux, G. Yoswara, H. Cox, N. Brown, M., Wheeler, D., Watkins, N., Smith, C., Monaghan, R., Muirhead, R., Stafford, A. Risk, J., Old, A. 2015 Mitigator™ : a tool to estimate and mitigate the loss of contaminants from land to water. Currie, L.D, Burkit, L, eds. Occasional Report No. 28. Fertilizer and Lime Research Centre, Massey University, Palmerston North. http://flrc.massey.ac.nz/publications.html

[63] For example: Hawkes Bay Regional Resource Management Plan – Plan Change 6 Tukituki River Catchment; Proposed Southland Water and Land Plan Part A (appeals version 1 June 2018); Proposed Waikato Regional Plan Change 1- Waikato and Waipa River Catchments

[64] MGM 2015 Overview Report: Canterbury Matrix of Good Management project. https://www.ecan.govt.nz Downloaded 20 August 2019.

[65] Ritchie, A., Carrick, S. Lilburne, L 2012. Web enabling soil data for the Farm Dairy Effluent Storage Calculator Envirolink Advice Report grant Report 1067- MLDC72 prepared by Landcare Research for Marlborough District Council. Wang, H. 2008 Land application of vegetable processing wastes: technical information for establishment and environmental monitoring of land application systems. Envirolink Advice Report grant Report 330-GSDC44 prepared by SCION for Gisborne District Council.

[66] Todd, M.D., 2018. Learnings from ten years of hill country farm plan mapping. *In* Currie, L, D, Christensen, CL eds.: Farm environmental planning – Science, policy and practice. Occasional Report No. 31. Fertilizer and Lime Research Centre, Massey University, Palmerston North. http://flrc.massey.ac.nz/publications.html.

[67] Dairy NZ 2016 Good management practices: a guide to good environmental management on dairy farms.

[68] https://beeflambnz.com/compliance/environment/holding-soil Downloaded 20 July 2019.

[69] Unpublished results of an online survey by Landcare Research of S-map users undertaken 2017.

[70] Hewitt, A Barringer, J., Claydon, J., Campbell, S., Carrick, S., Fraser, S, Gray, C., Lynn, I, Medyckj-Scott, D, Ritchie, A, Webb, T. 2012 National Soil Database Utility: a review and process for development. Envirolink Medium Advice Report grant Report 1072- MLDC73 prepared for Marlborough District Council. June 2012.

[71] https://lris.scinfo.org.nz/layer/48076-nzlri-land-use-capability/ Downloaded 16 April 2019

[72] Lilburne, L, Webb, T, Palmer, D. 2013 Applicability of S-map and Fundamental Soils Layer data for the uptake and use in Overseer. Report prepared by Landcare Research for AgResearch Ltd.

[73] Hewitt, A. 2013 Survey of New Zealand soil orders. *In* Dymond JR ed. Ecosystems services in New Zealand – conditions and trends. Lincoln, Manaaki Whenua Press.

[74] https://lris.scinfo.org.nz/ Downloaded 16 April 2019

[75] Lilburne L, Hewitt A, Webb T. 2012 Soil and informatics science combine to develop S-map: a new generation soil information system for New Zealand. Geoderma 170, 232238.

[76] Lilburne L, Webb T, Palmer D, McNeill S, Hewitt A, Fraser S (2014) Pedo-transfer functions from S-map for mapping water holding capacity, soil-water demand, nutrient leaching vulnerability and soil services. *In* Currie, L,D, Christensen, CL eds. Nutrient management for the farm, catchment and community Occasional Report 27. Fertilizer & Lime Research Centre, Massey University, Palmerston North. http://flrc.massey.ac.nz/publications.html.

[77] For example: Timar, L, White, D, Hedy, J 2018 Land-use modelling in New Zealand: current practice and future needs. Motu Economic and Public Policy Research. Motu Working Paper 18-6. PCE 2018 Commentary by the Parliamentary Commissioner for the Environment on "Our Land 2018". Downloaded https://www.pce.parliament.nz/publications/

[78] Webb, T. Wilson, A. 1995 A manual of land characteristics for evaluation of rural land. Landcare Research Science series no. 10.

[79] Manderson, A., Lilburne, L. Hewitt, A, Pollacco, J. Carrick, S. 2015. Recommendations and interim soils data to support the development of a national freshwater reporting model. Report prepared by Manaaki Whenua-Landcare Research for the Ministry for the Environment.

[80] For example: Rutledge, D, Price, R., Ross, C. , Hewitt, A. Webb, T., Briggs, C. 2010 Thought for food: impacts of urbanisation trends on soil resource availability in New Zealand. Proceedings of the New Zealand Grassland Association 72: 241-246. Andrew, R. Dymond, J. 2013 Expansion of lifestyle blocks and urban areas onto high class land: an update for planning and policy. Journal of the Royal Society of New Zealand 43 (3) 128-140.

[81] Pollacco, J, Lilburne, L, Webb, T, Wheeler, D. 2014. Preliminary assessment and review of soil parameters in Overseer ver 6.1. Report prepared by Landcare Research Ltd for Overseer Limited.

[82] MPI MfE 2019 Valuing Highly Productive Land: a discussion document on a proposed national policy statement for highly productive land. Wellington, Ministry for Primary Industries & Ministry for the Environment https://www.mpi.govt.nz/news-and-resources/consultations/proposed-national-policy-statement-for-highly-productive-land/ Downloaded 20 August 2019

[83] MPI 2017 Plantation Forestry Erosion Susceptibility Classification: risk assessment for the National Environmental Standards for Plantation Forestry. Ministry for Primary Industries Technical Paper No 2017/47 July 2017.

[84] Molloy, L., Forde, B. 1980 Land alone endures: land use and the role of research. Department of Scientific and Industrial Research discussion paper.

[85] Ministry for the Environment & Stats NZ (2018). New Zealand's Environmental Reporting Series: Our land 2018.

[86] Manderson, A., Lilburne, L. Hewitt, A, Pollacco, J. Carrick, S. 2015. Recommendations and interim soils data to support the development of a national freshwater reporting model. Report prepared by Manaaki Whenua Landcare Research for the Ministry for the Environment. See also Carrick S, Palmer D, Webb T, Scott J, Lilburne L 2013. Stony soils are a major challenge for nutrient management under irrigation development. *In* Currie, L,D, Christensen, CL eds. Accurate and efficient use of nutrients on farms. Occasional Report No. 26. Fertilizer and Lime Research Centre, Massey University. Palmerston North.

[87] http://archive.stats.govt.nz/browse_for_stats/environment/environmental-reporting-series/environmental-indicators/Home/Land.aspx Downloaded 30 May 2019

[88] MfE & Stats NZ (2018). Our land 2018.See Table 4.

[89] McNeil, S 2015 A new spatial model for New Zealand soil carbon. Soil Horizons Newsletter 22. https://www.landcareresearch.co.nz/publications/newsletters/soil/issue-22/soil-carbon Downloaded 29 May 2019

[90] MfE 2019 New Zealand's Greenhouse Gas Inventory 1990- 2017 Ministry for the Environment Report no ME 1411. April 2019.

[91] PCE 2018 Overseer and regulatory oversight: models, uncertainty and cleaning up our waterways. Wellington, Parliamentary Commissioner for the Environment. December 2018. See also Pollacco et. Al [82].

[92] Hewitt, A Barringer, J., Claydon, J., Campbell, S., Carrick, S., Fraser, S., Gray, C., Lynn, I., Medyckj-Scott, D., Ritchie, A., Webb, T., 2012 National Soil Database Utility: a review and process for development. Envirolink Medium Advice Report grant Report 1072- MLDC73 prepared for Marlborough District Council. June 2012.

[93] https://smap.landcareresearch.co.nz/ Downloaded 16 April 2019

[94] Carrick, S. Hainsworth, S., Lilburne L, Fraser S (2014) S-map@the farmscale? Towards a national protocol for soil mapping for farm nutrient budgets. *In* Currie, L,D, Christensen, CL eds. Nutrient management for the farm, catchment and community). Occasional Report 27. Fertilizer & Lime Research Centre, Massey University, Palmerston North. http://flrc.massey.ac.nz/publications.html.

[95] Market Economics 2019 S-Map - indicative benefits. Report prepared by Market Economics Consulting for Landcare Research.

[96] Galbreath, R. 1998 DSIR: Making Science work for New Zealand: themes from the History of the Department of Scientific and Industrial Research 1926 -1992 Victoria University Press.

[97] Dr. S Carrick, pers comm. See also Molloy, L., Forde, B. 1980 Land alone endures: land use and the role of research. Department of Scientific and Industrial Research discussion paper.