Future Requirements for Soil Management in New Zealand

Contents

The following reports have been produced as part of a three-phase project to understand the future requirements for soil management in New Zealand. The project aims to inform future policy and good practice principles to protect and realise the full potential of New Zealand's soil resource.

Phase 1 sets the direction by identifying the pressures and impacts on New Zealand's soil resource and related environments (such as freshwater) identifying:

- The importance of soil to the environment and economy, as well as its non-renewable and finite nature as a natural resource
- The continuing expectation of economic growth from the primary sector, but the emergent shift towards high value products and recognition of the critical role of Maori a new paradigm for natural resource management
- That globally recognition is building around the need for appropriate soil governance and nationally around the need for choices to be made so natural resources such as soil are not degraded
- Socio-economic factors are the 'driving force' that underpins the long-proud tradition we have in land development and highly productive land-based industries. However these same factors also give rise to the pressures of today and tomorrow, as well as influence the scale and severity of impacts on the soil resource
- There are four key pressures impacting on the soil resource, including: Intensification, Land use change, Climatic change and Legacy effects. These pressures result in a range of proximal (effect on soil stocks including availability and condition) and distal (effect of the loss of soil functions and services on other resources) impacts
- The scale (national, regional or local) and magnitude (high, medium or low) of these impacts varies according to the ability to mitigate or reverse the impact and the social acceptability of impacts
- In agreement with past reviews, that the most highly ranking pressures in today's operating landscape are:

  - Intensification – particularly irrigation, the addition of more chemicals and inadequate vegetation cover

  - Land use change – especially the rising trend towards fragmentation and urban expansion, as well as poor matching of land use to inherent capacity

  - Legacy – most notably the impact of past deforestation and pests and diseases
- A key dependency in ensuring New Zealand's readiness to address these pressures and impacts will be building appropriate capability within and outside of the science system
- That readiness will also require addressing significant gaps in coverage, scale or utility of nationally-agreed underpinning resource information and ensuring it is easily accessible to a range of users
- That there are opportunities to ensure ongoing readiness including securing stable investment for underpinning resource information, protecting long-term trials and engaging in foresight projects.

Phase 2 identifies the extent to which current practice, and our policy and planning framework, addresses these pressures and opportunities, as well as looking overseas for examples of how others have addressed priority pressures and impacts, identifying:

- The complexity in the governance of soil in New Zealand, reflecting the close links we all have with our land and its ownership and at the same time the involvement of a diverse range of organizations, sectors and individuals in decision-making
- That many of the priority pressures identified in Phase 1 (*poor matching of land use to inherent capabilities; inadequate vegetation cover; irrigation; addition of chemicals*) are identified as issues and addressed to some degree within primary sector practice; it is however, difficult to ascertain uptake or effectiveness
- Some priority pressures are accommodated within the current policy and planning framework through a range of regulatory and non-regulatory approaches, but policy looking specifically at sustaining soils functional capacity has yet to emerge
- Attention is needed to ensure:

  - Pressures associated with poor matching of land use to inherent capability and fragmentation of land and loss of elite soils are better dealt with, particularly given the finite nature of the soil resource

  - Pressures associated with emergent land uses (e.g. brought about by access to irrigation water and/or new technologies) are understood and incorporated within policy

  - An optimal mix of regulation and non-regulatory measures are developed to ensure the full range of services provided by soils is sustained into the future

  - The full potential of New Zealand's soil is unlocked and realised
- That as a small, biologically-based country New Zealand has the ability and agility to develop the partnerships and integrated measures to realize enduring economic, ecological and social value from its soils for the benefit of the nation

Phase 3 promotes a guiding vision for New Zealand soils and highlights the need for the following future requirements for soil management:

1. Establish a National Soil Management Group to develop national soil strategy; provide leadership; inform and advise policy and practice; provide a national perspective on research; promote and monitor a capability growth strategy; and ultimately act as an advocate for soils.
2. Develop a National Soil (and land) Management Strategy to set direction on the use, policies, capabilities and research on soil.
3. Profile the importance of land and soil to the New Zealand economy and society by quantifying the actual and total potentially realisable economic value of our soils.
4. Undertake a foresight exercise to explore risks to future economy and environment by examining how soils are and might be used into the future.
5. Undertake a national prioritisation of soil research to support the national science challenges, sectors and government agencies and guide investment in R&D.
6. Agree a national suite of underpinning soil and land resource information required to inform policy and decision-making on soil management, agreeing development priorities and stable funding.
7. Create an inventory of the current and projected skills and capability in central and regional government and industry, including current and projected graduate numbers, and identify a strategy for priming the capability system, including improving competencies for extension and adoption.
8. Develop an evaluation and monitoring framework to determine the effectiveness of soil management practices, non-regulatory approaches, and policies in achieving soil management goals.
9. Investigate the form of an integrated regulatory and/or non-regulatory framework that explicitly recognises and protects soil functions from current and future pressures and gains highest value from them.

This is our opportunity to unlock and realise the full potential of New Zealand's soil – and this is the call to action.

What are the current and emerging pressures to New Zealand's soil resource? How well is the knowledge and capability primed to meet these pressures?

Future Requirements for Soil Management in New Zealand

Phase 1: **Looking back**

Future requirements for soil management in New Zealand. Phase 1: Looking Back.

Contract Report number: LC 2077

Project number: 17004

Suggested citation: 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. National Land Resource Centre, Palmerston North.

Professor Mark Kibblewhite – peer review
Justine Daw – approved for release

Steering Group

Gary Bedford, Taranaki Regional Council
James Palmer, Ministry for the Environment
Mark Ross, Federated Farmers
Nick Pyke, Foundation for Arable Research
Oliver Hendrickson & Gerald Rys, Ministry for Primary Industries

December 2014

National Land Resource Centre, c/o Landcare Research, Massey University, Private Bag 11052, Palmerston North 4442, New Zealand.

What are the current and emerging pressures to New Zealand's soil resource? How well is the knowledge and capability primed to meet these pressures?

Future Requirements for Soil Management in New Zealand

Phase 1: **Looking back**

Led by Alison Collins and Alec Mackay

With expert contributions from:

Les Basher – climate change impacts, erosion

Louis Schipper – drainage, nutrients

Sam Carrick – irrigation, land fragmentation

Andrew Manderson - intensification

Jo Cavanagh – pesticides, waste

Brent Clothier – intensification, land fragmentation

Emily Weeks – capacity, information

Paul Newton – carbon fluxes

Contents

Summary

This report is the first in a three phase project to inform future policy formulation in government, planning and regulation in regional councils, as well as good practice principles and sector strategies for business and industry. Phase 1 sets the direction by identifying the pressures and impacts on New Zealand's soil resource and related environments (such as freshwater).

This report identifies:

a. The importance of soil to the environment and economy, as well as its non-renewable and finite nature as a natural resource

b. The continuing expectation of economic growth from the primary sector, but the emergent shift towards high value products and recognition of the critical role of Māori a new paradigm for natural resource management

c. That globally recognition is building around the need for appropriate soil governance and nationally around the need for choices to be made so natural resources such as soil are not degraded

d. Socio-economic factors are the 'driving force' that underpins the long-proud tradition we have in land development and highly productive land based industries. However these same factors also give rise to the pressures of today and tomorrow, as well as influence the scale and severity of impacts on the soil resource

e. There are four key pressures impacting on the soil resource, including: Intensification, Land use change, Climatic change and Legacy effects. These pressures result in a range of proximal (effect on soil stocks including availability and condition) and distal (effect of the loss of soil functions and services on other resources) impacts

f. The scale (national, regional or local) and magnitude (high, medium or low) of these impacts varies according to the ability to mitigate or reverse the impact and the social acceptability of impacts

g. In agreement with past reviews, that the most highly ranking pressures in today's operating landscape are:
   a. Intensification – particularly irrigation, the addition of more chemicals and inadequate vegetation cover
   b. Land use change – especially the rising trend towards fragmentation and urban expansion, as well as poor matching of land use to inherent capacity
   c. Legacy – most notably the impact of past deforestation and pests and diseases

h. A key dependency in ensuring New Zealand's readiness to address these pressures and impacts will be building appropriate capability within and outside of the science system

i. That readiness will also require addressing significant gaps in coverage, scale or utility of nationally-agreed underpinning resource information and ensuring it is easily accessible to a range of users

j. That there are opportunities to ensure ongoing readiness including securing stable investment for underpinning resource information, protecting long-term trials and engaging in foresight projects.

k. Further recommendations will be informed by Phase 2 and reported in Phase 3.

1

direction of travel

Project genesis and purpose

This project sets out to determine the state of soil management in New Zealand, how to optimise the use of our land resources, and the readiness of the knowledge and capability to support better stewardship. Appropriate stewardship has the potential to retain land use flexibility, realise enduring economic value from New Zealand's soils, reduce the loss of high class soils for primary sector use and support the implementation of the freshwater reforms.

Much of the evidence required for New Zealand to make the best decisions on its land and soil management sits within the science, primary and resource sectors either in the form of publications, reports, strategies or anecdotal knowledge. Extracting greater value from this collective evidence-base requires an approach that captures, integrates and synthesizes this disparate knowledge. This report is the first of three phases of work:

1) Looking back: What are the current and emerging pressures to New Zealand's soil resource? How well is the knowledge and capability primed to meet these pressures? (Phase 1)

2) Looking out: What are we doing in regard to soil management, is it enough and can we learn anything from international case studies? (Phase 2)

3) Looking forward: What do we want from New Zealand soils? What policy, practice, science and institutional shifts can we make to get there? (Phase 3)
Phase 1 will provide the direction or lens for the phases that follow – setting down the key pressures and impacts against to provide the context to identify gaps and opportunities. Phase 2 will identify how well we doing across practice, policy and planning and look overseas for examples of how others have addressed priority pressures and impacts. While collectively these three phases of work will inform future policy formulation in government, planning and regulation in regional councils, as well as good practice principles and sector strategies for business and industry, the key opportunities, gaps and recommendations will be the domain of Phase 3 (Looking Forward).

Soil and land – their importance and availability

Soil is essential to life on earth. It is part of the 'ecological infrastructure' or 'natural capital' that underpins food, feed, fibre and fuel production (Clothier, 2014). As well as provisioning services the soil also regulates to ensure clean water, nutrient cycling and carbon storage, while hosting more than one quarter of the world's biodiversity.

Soils are formed through the complex of interaction of factors such as climate, parent material, vegetation, fauna, man, topography but most of all time. 'Pedogenesis' can take thousands of years, so that soil is essentially a non-renewable resource in a human lifetime. Climate, primary production, cities and infrastructure as well as the legacy of our past actions all impact upon the soil resource and its ability to provide life-supporting ecosystem services. A recent New Zealand study showed the economic value of the services provided by soil dropped by 65% when the topsoil was lost in a single instance of shallow mass movement. Fifty years after erosion, the ecosystem services only recovered to 61% of the un-eroded value (Dominati & Mackay, 2014).

The 'Land Use Collision Forum' (23 August 2010, Massey University, Palmerston North) held under the aegis of the Royal Society of New Zealand and involving practitioners, industry, and policy makers at regional and national level along with scientists, academics and students raised the increasingly real notion that New Zealand was facing a 'land use collision' (Mackay et al., 2011). New Zealand ranks 3rd out of OECD countries for 'land per capita' however there is considerable pressure on the availability of land, and in particular 'versatile' soils. The New Zealand Initiative forecast that the decline in land per capita from 4.8 hectares per person in 1990 to 2.8 in 2010 will continue towards 2.4 hectares per capita in 2030. Population growth and urban expansion are two of the primary pressures on land availability, such that between 2001 and 2006, urban development in the Auckland region replaced prime agriculture land at a rate of about 333 hectares per year (Curran-Cournane et al., 2014). With only 15% of land classified as 'versatile' (Classes 1–3) and 33.4% of land legally protected for conservation (Rutledge et al., 2010) productive soils are therefore in limited supply.

New Zealand is highly dependent on a 'biological economy', which is fundamentally underpinned by the availability and condition of its soil resource. Agriculture; food, beverage and tobacco manufacturing; forestry and fishing provide approximately 12% of New Zealand's GDP, with a further 9% generated from the tourism sector (Jones, 2012). The conundrum underlying the growth in the global demand for food is that at the current rate of production, there is not enough arable land available to meet projected demand. In many countries primary producers are facing increasingly strict environmental limits within which they need to operate to meet consumer and public expectations and care for the environment. New Zealand is increasingly implementing environmental regulations in response to this. Conflict over resource allocations, sustainable limits and competing uses are playing out on land and in coastal areas (MPI, 2014).

As the health of the nation's water bodies depends on what is done on the land (LAWF, 2012), appropriate soil management and land use also plays a critical role in preventing further deterioration of water quality and the stretching of water demand beyond supply capacity. The introduction of the National Policy Statement for Freshwater in 2013 (MfE 2013) calls for demonstrable improvement in freshwater quality and highlights the critical role of soil and land use decisions in achieving that.

Today's operating landscape

Over the past 25 years, productivity in the primary sectors has rapidly grown with the Ministry for Primary Industries. Since 2011, the value of agriculture, fisheries and forestry exports has grown from $31.9 billion to an estimated $37.7 billion for the year ended 31 June 2014, and is forecast to continue growing to reach $40.8 billion in 2018 (MPI, 2014). Further growth will be required to meet the ambitious aims of doubling export value by 2025 as set out in the government's Business Growth Agenda (MBIE 2013). Increasing demands for food and fuel from a growing global population that is forecast to reach 9 billion by 2050 as well as growth of emerging market economies in Asia is likely to further drive intensification, putting increasing pressure on our young and fragile soils.

Practicing and reporting excellent land and soil management has important potential to add value to the NZ brand and support premium prices in global markets. Traditional high-volume commodity production is subject to rapidly developing competition with economies that produce the same primary products cheaper and closer to market. A shift, therefore, towards 'high value', discerning food and beverage products and the 'development of value chains that enhance the integrity, value and delivery of New Zealand products', based upon a model of increased sustainability and product integrity offers a feasible competitive strategy (Marshall et al., 2012).

This direction is supported by the independent Māori Economic Development Panel, which has set out a blueprint for Māori economic development to 2040 based on a productive, innovative, and export orientated Māori. Raising the productivity of Māori owned land assets is critical to this transformation, but in a sustainable way (in line with principles of kaitiakitanga and whanaungatanga) and using this as part of Brand Māori and Brand New Zealand (Māori Economic Development Panel, 2012). Māori will play an active ongoing and enduring role in the sustainable management of natural resources in New Zealand.

As our soil and land resources come under increasing pressure, hard choices will need to be made so that resources are not degraded or tipping points reached (MfE, 2014). Decisions made today will affect the prosperity and well-being of future generations. Critical to better decision making by officials, businesses and the general public is clarity on the existing and emergent pressures, threats, opportunities and impacts (both proximal and distal) on the soil and associated natural resources. This is recognised globally and reflected in the establishment of the United Nations 'Global Soil Partnership' in 2011 and the 'Intergovernmental Technical Panel on Soils (ITPS)' in 2013. Both aim to ensure sharing of appropriate science and technical advice and move towards global governance of soil assets.

The analysis that follows, based on expert opinion from across science, resource and primary sectors, attempts to rank priorities for New Zealand soils building upon previous reviews, in particular 'Reporting on soil at the national level' (SLUA, 2012). This highlighted the loss of soil and its services to urban and peri-urban development; the impacts of erosion and intensification; how contaminants can limit future land use options; the impacts of land use on the freshwater and marine environments.

This first phase analysis focuses on the readiness of New Zealand's capability, information and knowledge to address priority pressures, threats and opportunities relating to land and soil. To determine 'readiness' we review existing material including the 2014 review of capability needs in the primary industries (Grimmond et al., 2014) and the landmark Environmental Domain Plan (Statistics NZ et al., 2013), integrating these with activities and discussions occurring in the wider science-policy ecosystem for example the formulation of the national science challenge 'Our Land and Water'.

Key findings

Reflecting on today's operating landscape it is evident of the:

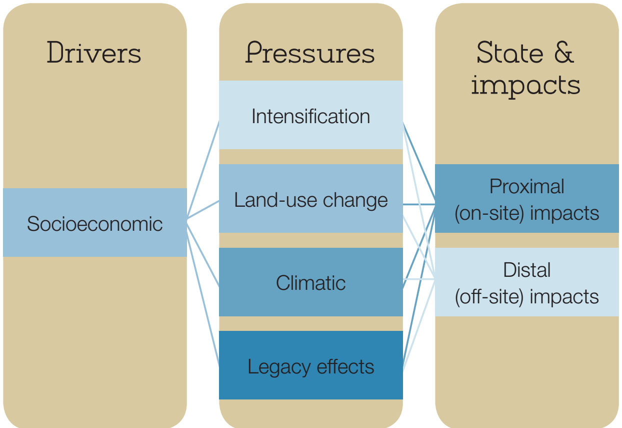
- Importance of soil to the environment and economy, as well as its non-renewable and finite nature as a natural resource
- Continuing expectation of economic growth from the primary sector, but the emergent shift towards high value products and recognition of the critical role of Māori in a new paradigm for natural resource management
- Global recognition building for appropriate soil governance and nationally around the need for choices to be made so natural resources such as soil are not degraded.

2

drivers, pressures and impacts

Framework of drivers, pressures and impacts

In order to systematically work through the range of pressures on the New Zealand's soil resource we consider a series of drivers, pressures and impacts.



Framework of drivers, pressures and impacts

Social, economic and cultural drivers are the 'driving force' that underpins the long-proud tradition we have in land development and highly productive land based industries. However these same factors also give rise to the pressures of today and tomorrow, as well as influence the scale and severity of impacts on the soil resource. There are many factors contributing to the attitudes and behaviours surrounding land and its use. For example, the nature and characteristics of farming operation, the current configuration of the primary sector (i.e., milk, beef, sheep, deer, etc.), farm size, level of debt on-farm, current level of intensification, numbers of livestock farmed, farm and off-farm income, identification of a successor, diversity of farming operations, through to the local availability of specialist services and resources are just some factors that 'lock-in' current or legacy systems (Oscar et al., 2014) and associated pressures.

Table of drivers

DRIVER	LINK TO PRESSURES	TREND AND OPPORTUNITY
Social & societal - attitudes & behaviours, ownership & societal pressures (pg 21)	Has built the productive capacity of much of the national soil resource for a diversity of land uses. However, the ongoing pressure on the intactness of many soils (e.g. risk of erosion), physical integrity, nutrient content, biology, organic matter content and the build-up of unwanted elements has the potential to limit function.	Major determining factor in the choices that are made about land use and associated practices and therefore the likelihood of all other pressures occurring. Increasing societal pressure for change (social license to operate) will likely shift the deeply embedded views on the use of our land.
Economic - primary industry growth models, demand for land & international positioning (pg 21)	Ongoing and increasing pressure to produce more from the land resulting in variety of threats. Shift to added value also brings with it some challenges.	Already significant and is likely to grow (e.g. with price of land, current industry strategy) but could be moderated by focusing more on value-add and global markets.
Policy & practice - policy & regulation & technological interventions (pg 22)	Technologies to date have focused on overcoming limitations in provisioning services, while policy has been retrospective enabling not preventing many of the other pressures.	Significant – with challenge now in regaining lost ground – possible and emergent approaches include a greater focus on natural capital and recognition of the link between land and water.
Cultural values – Māori principles and land characteristics (pg 22)	Significant potential economic value of large areas of Māori owned land has yet to be realised with 80% of that land in LUC class 4 to 7 and >50% in <3ha blocks.	The opportunity exists within the principles of kaitiakitanga & whanaungatanga to realise the potential economic opportunity from extensive Māori land holdings as well as apply these concepts more generally. This aligns with a large number of Treaty settlements and the Māori Economic Development Strategy.

Collectively these drivers generate a suite of four pressures:

1. Intensification: Agricultural intensification, typically defined as a production increase per unit area, achieved through greater use of inputs (e.g. feed, fertiliser, labour), lifting system inefficiencies (e.g. via improved technology, management, genetics) or outright system modification (e.g. clearance, drainage, irrigation, stocking) has been instrumental in the development of an array of highly productive, efficient and innovative primary industries at the very backbone of our economy. But, in parallel the pressures of intensification are causing a range of impacts on both our fragile soils and vulnerable receiving environments.

2. Land use change: The competition for land is reflected in urban expansion on high class soils; large-scale conversion from dry-land sheep to intensive irrigated dairy through the increased availability of water, often on leaky soils or hilly terrain; through to poor land use choices on sloping or highly erodible land, such as increased stocking, cropping and plantation forestry.

3. Climatic pressures: Climate change has the potential to increase erosion rates through hotter, drier conditions that make soils more susceptible to wind erosion, as well as intense rainfall events triggering surficial erosion and shallow landslides. Sea-level rise is likely to cause readjustment of catchment equilibrium driving erosion, while flux in carbon dioxide will alter biogeochemical cycling and microbial processes within soils.

4. Legacy effects: Agriculture in New Zealand is the largest sector of the tradable economy – a position supported by 150 years of agricultural development and innovation (Brazil, 2008). The biologically-dependent economy has resulted in significant modification of land and soils such as forest clearance, land development including drainage and the addition of chemicals to control pests and increase production, contributing legacy effects on the soil resource which continue to impact today. Collectively, this range of pressures is likely to have an effect on the quality and integrity of today's soils and their ability to provide life-supporting and provisioning ecosystem services (*proximal impacts*).

In addition, given that soil also provides a number of regulating services – i.e. nutrient cycling, water regulation, carbon sequestration - any damage will also impact on the quality and integrity of other natural resources such as water and air (*distal impacts*). The range of pressures, their proximal and distal impacts as well as the scale and severity of these impacts are summarised in Table 1. More detailed case notes for each pressure, compiled from the literature and with key references are presented in Appendix A.

KEY PRESSURES	THREATS (pressures affecting soil functions)	PROXIMAL IMPACTS (effect on stocks such as - availability & condition for service provision)	DISTIL IMPACTS (effect of loss of function/services on other resources)	SCALE (extent)	SEVERITY (size of problem)
INTENSIFICATION (increasing inputs of some shape or form with the intent of increasing outputs)					
Irrigation (more water) (pg 24)	Amongst the opportunities are increases in land use options, lifts productivity, reduces drought risk and increases economic growth. However the application of irrigation may change soil biophysical integrity.	Increases the net availability of soils for high productivity use. Loss of physical integrity and function; reduced ability to buffer and filter.	Increased expansion onto soils with lower natural capital e.g. stony soils, and sloping land (LUC classes 4–6) can result in increased nutrient leakage into rivers and groundwater as a result of increased drainage & runoff and increased height of water table.	**Regional** Little is known about the long-term implications to soil function. 722K ha is currently under irrigation with a further 350+K ha planned.	**High** Driven by the increasing distal impacts from the on-going expansion of irrigation in soils with little natural capital.
More chemicals (fertilisers, pesticides, animal welfare products) (pg 23)	Steady build-up of the fertility (phosphorus, sulphur and nitrogen) in soils. Potential for nitrogen saturation. Trace element accumulation also a threat (e.g. Cd, U, F in pasture soils, Cu in horticultural soils), as are other agrichemical additives.	Reduced ability of the soil to filter and retain nutrients. Depletion of base cations as a consequence of increased leaching of anions also a risk.	Decrease in water quality due to increased risk of nutrient leakage into rivers and groundwater. Increased greenhouse gas production specifically increased nitrous oxide emissions.	**Regional** Associated with the highly developed pasture systems (such as in Waikato and Taranaki). Localised in horticultural soils in regards to trace element accumula-tion.	**High** The ongoing inputs of large amounts of maintenance fertiliser in large parts of the country and the increasing use of supplementary feed (another source of nutrients) will see macronutrient and unwanted elements loadings continue to increase in soils. Similarly with other agrichemicals. There is urgency, because of our limited understand-ing, to raise the profile of this topic.
Waste water, effluent & storm water (pg 25)	Application of effluent or grey water can result in the accumulation of nutrients & unwanted elements in soil. New wastewater constituents can also effect soil physical & biogeochemical health.	Addition of effluents and grey water can increase versatility, but unwanted elements will affect soil biota and a range of soil functions. Longer-term application of effluent can reduce future land use options.	Potential increase in nutrient and contaminant flows impacting water quality – especially where loadings exceed the soils capacity to filter and buffer.	**Regional** In all parts of the country where there are significant dairy farming operations. Increasing on-site sewage disposal associated with urban expansion into lifestyle blocks.	**Medium to high** Urban expansion into lifestyle blocks will increase the amount of land under treatment. Impacts on receiving environments highly variable and dependent on soil capacity, but manageable with limits in place. Emerging contaminants represent a knowledge gap.
Loadings (more livestock, wheel traffic) (pg 23)	Increased utilisation of grown forages. Increased levels of compaction and pugging resulting in reduced plant growth increased runoff and erosion. Overstocking of sloping land increases risk of broaching. Compaction as a consequence of wheel traffic.	Damage to the physical structure and biology of the soils. Impacts negatively on a wider range of services, resulting in lower annual and seasonal production and higher emissions to receiving environments.	Decrease in water quality due to increased sediment, P and pathogens input to surface water bodies. Potential for increase nitrous oxide emissions from pugged or physically damaged soils.	**Regional** Associated with recent, gley, pallic and brown soils and increasing number of soils in rolling and hill land in Northland, Waikato, Horizons, Wellington, Otago and Southland.	**High** Impact will be greater with the increasing use of less versatile soils for intensive livestock activities. Greater use of feed pads and standing areas offer options for reducing pressure on lowland soils and receiving environments.
Inadequate vegetative cover (pg 25)	Substantial and ongoing risk of soil erosion and sediment loss in highly eroding hill land, high country and fragile lowland soils under cultivation, due to poor vegetation management.	Loss of large amounts of natural capital as a result of erosion. Loss of all the ecosystems services.	Decrease in water quality due to increased sediment input to freshwater and coastal ecosystems. Loadings in river beds limit flood capacity, adding to infrastructure costs.	**National** Ongoing issues in nearly all regions of the country.	**High** Ongoing capital and operational costs associated with soil conservation and flood control infrastructure found throughout the country. Climate change predications could exacerbate ero-sion.
Cultivation (pg 26)	Continuous cropping results in a loss of organic matter and associated soil structure.	Loss of soil aggregate size and stability, biology and organic matter impacts on a wide range of soil services. No-till, direct drill technologies, precision agriculture, controlled wheel traffic technology limits physical damage.	Loss of sediment and phosphorus in overland flow, soil loss through wind erosion and increased N leaching following cultivation.	**Local** An issue on recent and weakly struc-tured soils.	**Medium** Short-term loss of function and relatively small land area affected.
Drainage (including peat or gley soils) (pg 24)	• Increased production and land use options • Surface height loss increases greenhouse gas emission in agricultural peat soils • Alteration of carbon stocks in mineral soils • Reduced run-off, but more rapid movement of contaminants through soil • Biodiversity threat through altered hydrology	• In mineral soils improvements in soil structure, provisioning and some regulating services • Loss of nutrients to below the root zone • Damage to infrastructure/increased pumping costs on peats • Loss of organic matter in peats and potentially Gleys • Decrease in biodiversity in adjacent wetlands to drained peats	• Losses of contaminants to receiving environments (e.g. N, P, pathogens, organic matter and micro-contaminants) from all artificially drained land) • Increased CO_2 and N_2O emissions from peats • Impact on adjacent biodiversity in peats	**Local** Potential estimated land under artificial drainage 1.09 million ha (includes peat).	**High** Negative impact on surface water quality will continue to increase if drainage water is left untreated. Ongoing subsidence and C and N losses from peats.
LAND USE CHANGE (pressures resulting from a change in land use)					
Fragmentation of land & spill-over (pg 26)	Major threat where urban expansion occurs on high class soils (LUC Class 1 & 2). Spill over effects the use of adjacent land.	Complete loss of soil function under asphalt/tarseal. Loss of services including filtering and flood mitigation and food production.	When tar-sealed little to no soil functional capacity.	**Regional** Rate of urban expansion estimated at 4–5% p.a. particularly concerning in Auckland, Canterbury, Waikato, Hawkes Bay and Manawatu regions.	**High** Disproportionate loss of versatile and elite soils. Spill over effect on adjacent land expands the area of influence. Knock-on effect of increasing intensification on lower class land to compensate.
Irrigation-driven land use change (pg 27)	Large-scale on less versatile, poorly or coarsely-structured soils and on rolling and hill land.	Increases the productive capacity and versatility of soils. However can also damage the physical structure of soils and have unknown impacts on biological cycling in soil. Loss of soil by erosion under irrigation on sloping land.	Decrease in water quality due to increases in phosphorus and sediment input to freshwater and coastal ecosystems and nitrogen leaching.	**Regional** Canterbury, with proposed expansion in the Hawkes Bay, Wairarapa, Waikato, Coastal Manawatu, Hawkes.	**Medium** Little is in fact known about implications of irrigation practices on the long-term health and integrity of soils.
Poor matching of land use to inherent capability (e.g. intensive use on fragile land) (pg 28)	The intensive use of fragile and sloping land, including production forestry on steep, highly erodible land increases the risk of erosion, land-sliding runoff and sediment loss.	Physical loss of soil as a result of erosion. Reduces the natural capital stocks and the provision of all services for hundreds of years.	Decrease in water quality due to increased sediment, P, N and contaminant input to freshwater and coastal ecosystems.	**National** 95% of soils are unsuitable for horti-culture, 65% of soils have a physical limitation to pasture agriculture.	**High** The lack of recognition of inherent weaknesses in soils, combined with the ongoing development of technologies to overcome limitations and competition for land is increasing the physical pressure on more soils and associated receiving water bodies.

KEY PRESSURES	THREATS (pressures affecting soil functions)	PROXIMAL IMPACTS (effect on stocks such as - availability & condition for service provision)	DISTIL IMPACTS (effect of loss of function/services on other resources)	SCALE (extent)	SEVERITY (size of problem)
LAND USE CHANGE (pressures resulting from a change in land use) continued					
Restoration and introduction of diversity (pg 28)	Retirement of the high country, protection of wetlands and native forest fragments and the planting of extensive riparian margins on water courses in intensive livestock operations are all actions to protect land, indigenous biodiversity and associated water bodies.	Positive influence on biodiversity, soil structure, organic matter and ecosystem services.	Positive influence on receiving environments.	**National** Activities found throughout the country on a wide range of landscapes and land uses.	**High** Potential to address the inappropriate use of land and impacts on receiving environments. But efforts can be fragmented and benefits overstated.
CLIMATIC (pressures as a result of climate change)					
Increased soil temperature and moisture (pg 28)	Accelerated biogeochemical cycling creates imbalances in stocks and flows of nutrients and carbon.	Altered supply of nutrients to plants. Unknown increases or decreases in carbon stocks that underpin soil quality.	Potential alteration in nutrient losses CO_2 release/sequestration from atmosphere.	**National** Associated with where average temperature increases or variability changes.	**Medium** Significant proximal and distal impacts into the future.
Changing moisture (flood, drought) (pg 29)	Increased susceptibility to landslides, runoff and/or wind erosion.	Loss of stocks and reduction in productivity.	Decrease in water quality due to increased sediment input to freshwater and coastal ecosystems.	**National** Variable in terms of degree of change.	**Medium** Significant proximal and distal impacts.
Sea level rise (pg 29)	Readjustment in of catchment equilibrium resulting in increased erosion.	Loss of stocks and decline in function.	Decrease in water quality due to increased sediment loss to freshwater.	**National** Coastal and some elite soils. High value land use and dense population.	**Low-medium** Small areas, but high value, with time to adjust.
Increased volatility/ storminess (pg 29)	Increased susceptibility to landslides, runoff and/or wind erosion.	Loss of stocks and reduction in productivity.	Decrease in water quality due to increased sediment input to freshwater and coastal ecosystems.	**Regional** Potential in some parts of the country.	**Medium** Significant proximal and distal impacts into the future.
Changing CO_2 (pg 29)	Change in the quality and quantity of plant inputs leading to changes in biogeochemical cycling and microbial function such as an increasing importance of heterotrophic processes.	Reduced supply of nutrients to plants.	Greater potential for N_2O emissions; increased sequestration of carbon; changes (probably reduction) in hydrophobicity.	**National** Particularly in low input systems.	**Medium** Significant proximal and distal impacts into the future.
LEGACY EFFECTS (pressures resulting from past practices and choices)					
Pesticides (including dips) (pg 29)	Impacts associated with historic use of persistent pesticides in broad-acre and localised (dips) activities.	Loss of stock condition (soil health), may lead to reduction in productivity or food quality, impacts on human health (DDE in milk).	Decrease in surface and ground water quality due to contaminants input from these point sources.	**Local** Limited to some soils in some districts under some specific land uses and practices.	**Low-medium** Due to the impacts on human health and overseas trade the significance of these impacts can be significant. Risk likely to be exposed in cases of land use change – particularly urban expansion – or land put back into production (e.g. cattle in Southland grazing on land leased from a rifle club).
Waste (including landfills, dumps) (pg 29)	Chemical or physical threats associated with historic waste disposal.	Loss of stock condition (soil health), may lead to reduction in productivity, impacts on human health.	Decrease in surface and ground water quality due to micro-contaminants input from these point sources.	**Local** Limited to small areas across the country.	
Mining and extraction (pg 29)	Chemical or physical threats associated with mining for coal, metals and minerals.	Loss of stock condition (soil health), may lead to reduction in productivity, impacts on human health. Loss in versatility for restoration or rehabilitation of ecosystems.	Decrease in surface and ground water quality due to micro-contaminants input.	**Local** Limited number.	**Low** Well documented, localised and usually subject to monitoring and rehabilitation.
Deforestation (pg 30)	Māori reduced the amount of forest cover with the use of fire from 85% down to 56% by 1840. In 2010 the forest cover was at 31%, slowly but steadily rising since 1998. Development of agricultural, horticultural and production forestry on very large tracks of land.Associated with the loss of the forest cover was wide spread soil erosion and sediment losses to water bodies.	Loss of large amounts of natural capital as a result of erosion and reduction in all ecosystems services. Continuing erosions in some parts of the country. Some evidence of soil organic matter recovery on hill country pastures from early clearance.	Decrease in water quality due to increased sediment input to freshwater and coastal ecosystems. Loadings in river beds limit flood capacity, adding to infrastructure costs.	**National** Ongoing legacy issues in nearly all regions of the country.	**High** Ongoing capital and operational costs associated with the management of millions of hectares. Ongoing capital and operational costs associated with the flood control infrastructure found throughout the country. Climate change predications will exacerbate issues.
Pests and diseases (pg 31)	Pests (e.g. deer, possums, rabbits) and disease (PSA) impact directly by increasing the risk of soil erosion and indirectly through treatment (e.g. Zn for facial eczema, Cu for PSA) add unwanted elements and compounds.	Loss of large amounts of natural capital as a result of erosion. Loss of stock condition (soil health), may lead to reduction in productivity or food quality.	Decrease in surface and ground water quality due to micro-contaminants input. Loadings in river beds limit flood capacity, adding to infrastructure costs.	**National** Ongoing legacy issues in many parts of the country.	**High** Ongoing capital and operational costs associated with the management of pests and control of diseases.
Modification of soils (pg 31)	Increased excess nutrients that are vulnerable to loss. Nitrogen and phosphorus saturation. Alteration carbon cycling. Nutrient enrichment alters potential habitat.	Loss of nutrients from soils. Changes in carbon stocks. Loss in versatility for restoration of ecosystems. Accumulation of Cd, U F in pasture soils and Cu in horticultural soils.	Increased inputs of nitrogen and phosphorus into waterways and nitrous oxide production.Increases/ decreases in carbon stocks.	**Regional** Potentially large for nutrient saturation in the most developed parts of the country.	**High** Ongoing development of agricultural soils throughout the country places more and more pressure on both the soil and wider environments.
Drainage systems/ regimes (pg 33)	Range of threats including peat subsidence, soil carbon loss, compaction and pugging.	Loss of stocks and decline in function.	Decrease in water quality due to increased sediment loss to freshwater, impacts on biodiversity and threatened ecosystems.	**Local**	**High** The concerns about peat subsidence in some districts (Thames), and loss of carbon threaten the ongoing capability of these soils to produce food, filter contaminants and regulate water.

Footnote: Scale is divided into three categories: National, regional or local. Magnitude divided into three levels: low, medium or high.

Determining the scale and magnitude of pressures

The scale of these impacts varies according to:

- geographical extent of the impact (local, regional, national)
- the relationship with other impacts (noting climatic pressures may exacerbate many of the other pressures)
- the nature of the impact (proximal and/or distal)
- the ability to mitigate or reverse the impact
- And finally, the social acceptability of the impact, which in turn depends on who is an affected and public perception of risk.

Key findings

Socio-economic factors are the 'driving force' that underpins the long-proud tradition we have in land development and highly productive land based industries. However these same factors also give rise to the pressures of today and tomorrow, as well as influence the scale and severity of impacts on the soil resource.

The most significant pressures on the soil resource in New Zealand include:

- Irrigation both because of the rapid expansion of application on soils with little natural capital (such as stony soils or hilly terrain) and because very little is known about the long-term implications of irrigation on soil function.

- Addition of chemicals as more of our pasture systems intensify. This poses significant threat to freshwater quality and is becoming socially unacceptable (the triennial 'Public Perceptions of New Zealand's Environment: 2013 Survey' found water-related issues were perceived to be the most important problem facing the environment (Hughey et al., 2013)).

- Inadequate vegetation cover, resulting in erosion and sediment transfer to freshwater particularly in vulnerable hill country and on fragile lowland soils under cultivation. An estimated 1.14 million hectares of hill country is classified as erosion-prone in New Zealand, with erosion estimated to cost $100-150 million per annum in loss of nutrients, production, damage to infrastructure and aquatic habitat (MfE, 2007).

- Fragmentation of land and spill-over from urban expansion reducing the availability of versatile and elite soils. The rate of urban expansion (estimated at 5% per annum), the irreversible nature of the impact and the knock-on effect triggering intensification elsewhere confirm this pressure as high magnitude in the New Zealand.

- Poor matching of land use to inherent capability is a widespread problem with cropping on fragile or sloping land or production forestry on steep, highly erodible land. 65% of soils have a physical limitation to pastoral agriculture and 95% are unsuitable for horticulture and yet the pressure to develop these soils is increasing.

- Past deforestation is still having an impact on the erodibility of today's national landscape. The cost of erosion together with likelihood of increased erosion with climate change suggests this as one of the highest priority pressures.

3

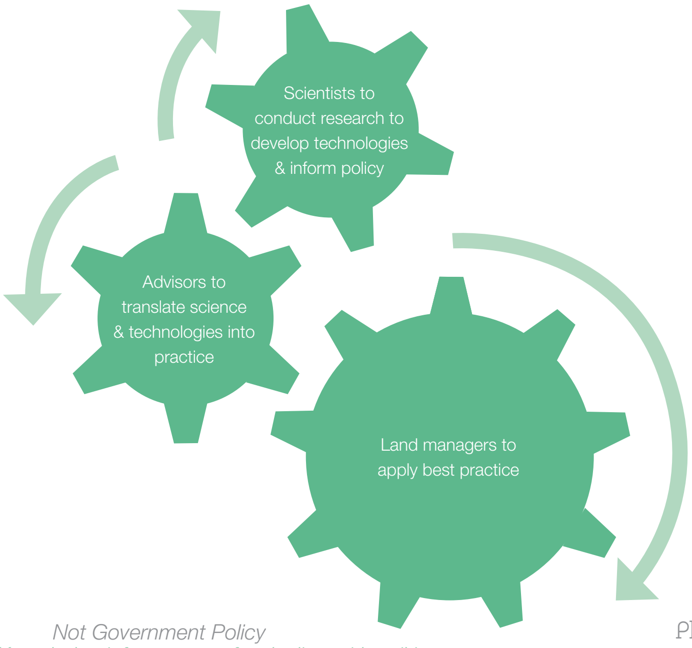
readiness

Securing our land-based economy demands ongoing investment in sustainable management of the soil resource. This in turn, requires a state of 'readiness' comprising appropriate capability, robust and comprehensive resource information, as well as specific knowledge and research to understand and respond to individual pressures and impacts; made available in a way that is accessible and usable by those that need it most.

How well primed is our capability?

The capability to respond to the pressures is in its simplest form a linear flow of knowledge from research conception through to the development of knowledge for end use. However a well-functioning system is far more complex and interactive (Kibblewhite et al., 2010) comprising the efforts of three primary agents:

- Scientists to conduct research to develop technologies & inform policy
- Advisors to translate science & technologies into practice
- Land managers to apply best practice



Scientists to conduct research to develop technologies & inform policy: At present, Crown Research Institutes (CRIs) account for a significant proportion of New Zealand's overall research effort. They employ a combined staff of 4,400 (CRI Taskforce Report 2010) of which includes a number of soil scientists spread across the CRIs (AgResearch, Landcare Research, Plant & Food Research, GNS, ESR and Scion). According to MBIE estimates, the number of agricultural/horticultural scientists (which includes soil scientists) rose by about 8% between 2010 and 2012; despite this it is acknowledged there are still too few scientists to fill available vacancies. Employers emphasised scientists with skills in specialist areas, such as soil science, are particularly hard to find (MBIE2012). Recognising that a large proportion of these experts are approaching retirement was part of the rationale for forming the 'Soil and Land Use Alliance' (SLUA) in 2011. Increasingly, there is also need for scientists across domains (e.g. with biologists) to work with traditional soil scientists to provide a more comprehensive understanding of soil functioning and impacts.

Building capability in soil science involves both formal education and on-the job training. At present there are three primary tertiary institutes that provide degrees in soil science – Lincoln University, Massey University and the University of Waikato. Enrolment in these programmes remains low compared to social sciences, information technology and business. In 2009, 1% of Bachelors' degrees specialised in Agriculture and Environmental Studies compared to 27% in Management and Commerce (Scott 2009).

The 2013 Environmental Domain Plan (Statistics New Zealand et al., 2013) identified skills beyond but relevant to soil science including capability relating to data creation, management and use, 'spatial literacy' as well as the interpretation of data for evidence-based policy. The Plan noted that 'carrying out a national strategy to improve these skills is essential to New Zealand's future understanding of land and soils'

Advisors to translate science & technologies into practice: Advisors, in contrast to researchers and developers, consist of a community of people with diverse levels of ability and application ranging from general advisors through to highly specialized advisors (Kibblewhite et al., 2010) that are able to 'translate' the findings from research and development into tools and best practice for land managers. As such they are a critical 'cog' in the capability system with 'increased translation of science into more useable form, simplification of management software tools, and increasing the numbers of experienced advisors for land managers' recognised as the most significant opportunity in a recent review of nutrient management in New Zealand (Payn et al., 2013). Up until the mid-1980s the Advisory Services Division of the then Ministry for Agriculture and Forestry (MAF) was the primary provider of extension and advice to the rural sector on a non-chargeable basis. In 1985, the new government directed Advisory Services Division to become fully user pays. Since that time regional councils, sector groups and consultants assumed an informal or partial extension and advisory role in New Zealand. The MPI review of Future capability needs for primary industries (Grimmond et al., 2014) identifies 'more accredited rural professionals/providers to transfer new techniques and knowledge' to land managers as a critical need.

Land managers to apply best practice: MPI has recently started working with industry, MBIE, the Ministry of Education and the Tertiary Education Commission to develop action plans around key aspects of attracting, training and retaining talented people in the primary sector (MPI, 2014). This includes better understanding of the skills that are needed, the demand and supply sides of the labour market, as well as ensuring the education and training system is more responsive to the needs of the primary industries. The MPI commissioned report 'Future Capability Needs for the Primary Industries in New Zealand' provides an outlook for primary industry employment based on industry (horticulture, red meat and wool, arable, dairy, seafood, forestry, other primary industries, and support services), occupation, qualification level, field of study, ethnicity, gender, and region. The forecast findings show that across the primary industries there will be a need to have a workforce that has been upskilled in what are traditional primary industry occupations and a growing demand for professional skills such as engineering, science and management (Grimmond et al., 2014). Employment in the sector is projected to increase to 370,000 by 2025 and modelling suggests there will also be an increase in demand for people with higher education and specialized skills. Taking the dairy industry as a specific example, there is a projected demand for science-based capacity around resource efficiency and technologies to reduce environmental impacts (Grimmond et al., 2014).

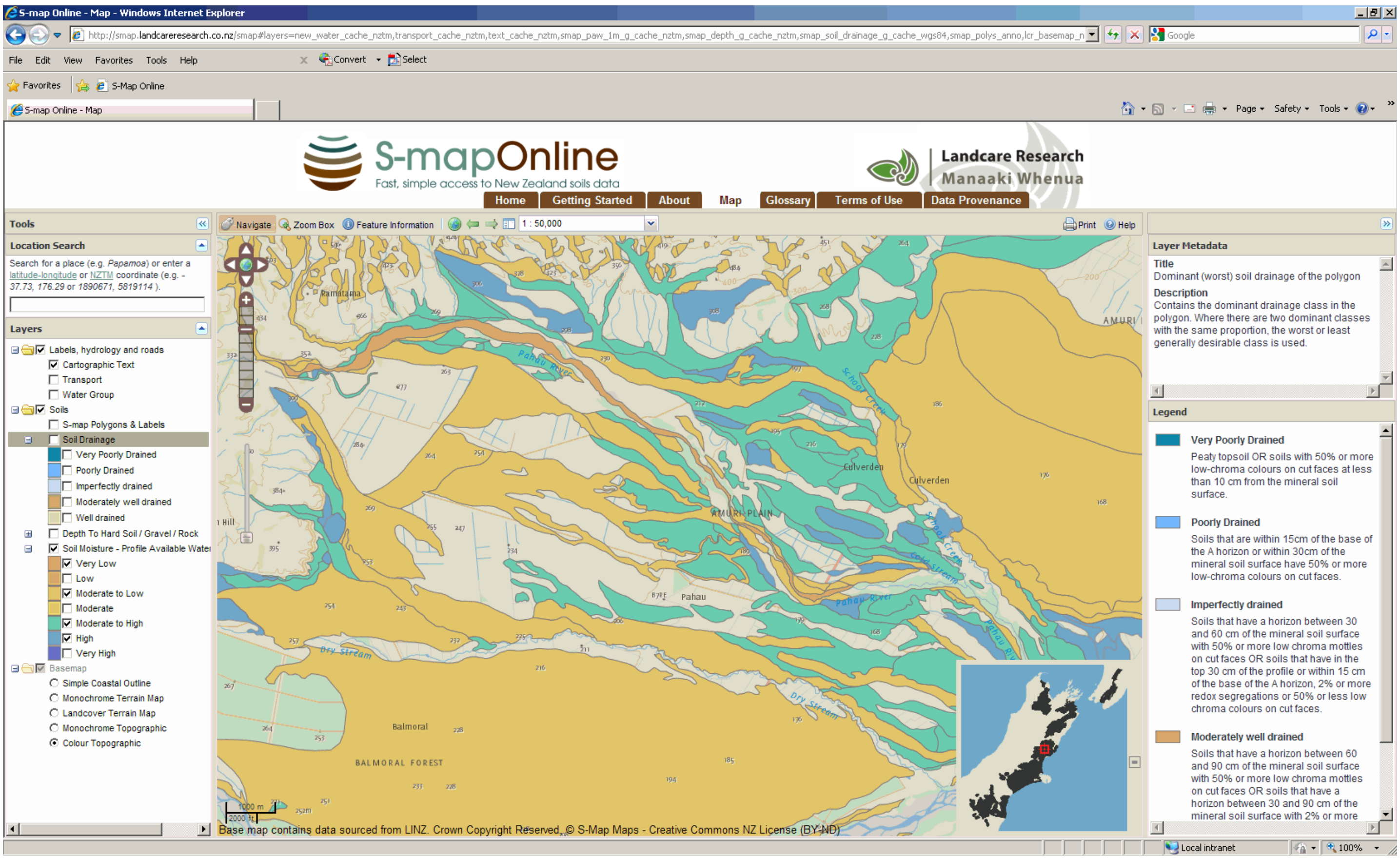
State of underpinning soil and land information

Resource information provides the critical evidence from which to assess state and trend as well as monitor the impact of actions and responses. MfE highlight in their Briefing to the Incoming Minister (2014) the significant opportunity for step change in the management of New Zealand's natural resources through an improvement in the underpinning information and evidence base. The Environmental Reporting Bill, the Regional Council-led Environmental Monitoring and Reporting system (EMaR) and the public-facing information resource Land, Water, Air Aotearoa (LAWA) have been recently identified as initiatives to inform a wide variety of stakeholders about the condition of natural resources, including soil but there remain questions over the completeness of the underpinning data to support these initiatives.

The Environment Domain Plan of 2013 made a landmark assessment of the information available to provide insights on the state of our natural environment. In regards to 'Land' (one of the ten broad domains) it suggested the following enduring question: '*What are our land cover and land use profiles, how are they changing, what is driving these changes, and what is the consequential impact on New Zealand's soils, and natural and cultural landscapes, including urban environments and conservation lands?*'

The status of resource information to answer this enduring question (soil variability, health and quality as well as land use) including its coverage, scale, utility and governance is briefly reviewed below:

- S-map: is the digital soil spatial information system for New Zealand. It comprises the National Soil Database (NSD) with point data on soil attributes,



a modelling and inference system, as well as a number of platforms to deliver soil information to end-users (Lilburne et al. 2012, 2014; Landcare Research 2014). Since its inception 10 years ago S-map has incrementally evolved in response to changes in funding, technology development, and implementation of regional policies and end-user tools (Carrick et al., 2013, 2014). Today it has 26% coverage of the nation, with weighted coverage towards land with multiple use potential (Land Use Capability Classes 1–4), covering 56% of versatile land– largely paid for by investment from regional councils and to a lesser extent the primary industries. A hybrid approach to increasing coverage has been used, focusing on conventional mapping and the use of polygon data for the intensive lowlands, and applying globally recognised (Global Soil Map) digital soil mapping techniques for the hilly terrain.

S-map has been developed to operate at the sub-catchment to regional-scale information to support both primary production and the water reforms. Significant focus is given to providing a good information supply chain such that S-map has been established online, allowing users to access information, free of charge, for their locality, in an easy to understand way (e.g. through factsheets). 21,000 factsheets have been downloaded by the public in the last six months alone. Data is also available for download from a GIS portal by scientists and other GIS users, or streamed directly through web services to support models and tools such as Overseer®. The future aims of S-map include providing complete digital soil map coverage for NZ, with a suite of adaptable soil information interoperable with a suite of key end-user tools. However, current funding for S-map is ad hoc hamstringing the rate at which coverage can be expanded (currently estimated to be at least 20 years). To address these concerns a pan-sector governance group has recently been established to determine strategic priorities and investment options.

- Farm-scale soil information: There is an increasing demand for detailed soil mapping of rural land to determine Farm Dairy Effluent (FDE) soil risk (and subsequent effluent system design), nitrogen-leaching caps, septic field design, irrigation scheduling, nutrient budgeting using Overseer, and the identification of versatile soils to be protected from urban expansion. Currently this demand is partly met through private consultants. However, consultants have no obligation to observe national standards for soil description and classification, nor are they required to have their work checked or validated by peers. Anyone can currently claim to be a 'soil mapper', and few have the capability to provide robust data on soil properties. Consequently, farmers and councils are making substantial investments into detailed soil maps of largely unknown quality (at $1,500 to $5,000 per farm) raising a number of issues over quality and risk, including:

  — Getting it wrong with FDE soil risk, nitrogen-leaching caps, irrigation scheduling, and nutrient budgeting. All have considerable financial, environmental, and compliance-related 'getting it wrong' implications when imperfect soil data are used.

— Not of a standard suitable for inclusion in national datasets (this has been tested).

— Soil data of unknown quality may be discarded if it fails to meet future compliance standards and requirements (not future-proofed).

Research is required to quantify the problem and appropriate accreditation or auditing is urgently required to ensure standards are observed.

- Soil health: Soil quality defines whether soils are in good condition for their current use. The physical, chemical and biological characteristics of different soils vary a great deal, so that different soils are suited to different uses. The indicators selected to assess soil quality (organic carbon, total nitrogen, pH, Olsen P, macro-porosity, mineralizable N and bulk density trace elements) reflect the idea that soil quality is not a single concept, but encompasses aspects of the soil physical structure, chemical fertility, nutrient storage, organic matter resources, and the biological life in the soil. Statistical techniques were used to determine the seven indicators that together describe soil quality. The indicators exclude trace elements which may be important from a contamination or essentiality perspective at this stage. Target ranges have been defined by a small group of experts for each of these indicators on a variety of soil types and land uses. These target ranges form the basis of the graphical interpretation used in 'SINDI' and the 'Soil Quality Database'.

Despite the good temporal richness of the soil quality data in New Zealand there are a few fundamental and limiting flaws including:

— *Omission of key data relating to trend and response:* To date the indicators have focused on soil physicochemical data, with no exploration of microbial health or diversity and limited exploration of the influence of trace elements which may be important from a contamination or essentiality perspective and provide explanations for observed biological responses. Inclusion of a microbial component may provide advances over traditional strategies used by councils to report on the long-term status of New Zealand's natural soil resource. Importantly, the delayed response of soil physicochemical measures to land-use change means current soil monitoring strategies can overlook the onset of serious soil degradation. In contrast, bacterial communities respond very rapidly to environmental change, allowing declines in soil health and fertility to be detected at a far earlier stage, before degradation is severe or perhaps irreversible (Curran-Cournane et al., 2014). Similarly, soil biota such as nematodes and earthworms may also be sensitive indicators of soil degradation and reduced biological functioning.

— *Lack of coverage and consistency:* The soil quality dataset from soil quality monitoring represents a unique regional council asset for regional and national scale environmental reporting. The dataset also represents a significant scientific resource as a number of international peer review journal articles have been published utilising the data. However, not all regions use the same methodology, are regularly reported on or provide reference points across land uses (currently the bias is for pastoral soils). Trace elements are measured inconsistently across regions.

— *Soil quality database no longer fit-for-purpose:* Since the initial inception of the soil quality database project and SINDI upgrade in 2007, new reporting requirements and opportunities have arisen. Upgrade to the database is needed to increase regional council capacity to report on temporal changes in soils, to allow for more automated importation of new data, and for expansion of ancillary environmental data. Enhancing the scope and functionality of soil quality data and increasing reporting features such as ability to integrate data for national scale environmental reporting, is critical to ensure a centralised soil quality dataset with secure storage and increased access.

- Land Use Capability and the NZ Land Resource Inventory: New Zealand's Land Use Capability System (LUC) is based on the New Zealand Land Resource Inventory (NZLRI) which is an assessment of physical factors required for long-term land use and management. It provides the most reliable basis to help managers sustainably manage their land. The 3rd edition of the Land Use Capability Survey Handbook was publication edition in 2009 (Lynn et al., 2009). The 3rd edition contains more quantitative rigour, however work is still required to update the underlying NZLRI information. Recently Barringer et al., (2013) developed a roadmap on the current state of NZLRI. The roadmap points to several key issues that need resolving including improving national consistency (e.g. erosion) and the opportunities to link to contemporary data (e.g. LCDB, S-map). The NZLRI is also based round a "static" approach to data collection and interpretation that makes regular updating extremely costly and there is a need for new developments (making more of these developments, which offer more data and more information at much lower costs than previously). Meeting these needs is challenging due to loss of expertise and institutional knowledge. However, there are several new initiatives that aim to address these needs. This includes the establishment of the LUCCS (Land Use Capability Classification System) governance group.

- Land use information: in New Zealand remains fragmented and in many cases hard to access. Most land use related projects result in combining databases to come up with land use classifications. The main sources of land use information include AgriBase™, Census data, LCDB, LINZ topographic data and Protected Areas DOC layers. AgriBase™ remains the best source of land use information for non-urban areas. It provides rich detail about on-farm crops, horticultural species and animal numbers for many stock types, but it is incomplete both in spatial coverage (not all farms are present) and in the data-fields farm owners have chosen to fill in. Furthermore its spatial detail is limited to whole farm enterprises. New Zealand's Land Use Map (LUM), created as part of the Land Use and Carbon Analysis System (LUCAS), is the most comprehensive source of land use information however it is limited in terms of characterisation/classification and is more of a hybrid land use/cover classification than a true land use classification. Census data and valuation data remain good sources of nationally consistent land use data and dwelling data but tend to be underutilised, most likely due to cost, coordination and privacy issues. DOC layer and LINZ Parcel data are publically accessible. There are other sources, primarily from regional councils, that exist but are quite heterogeneous. QEII and Nga Whenua Rahui hold good data but have controlled access for confidentiality purposes.

The Domain Plan also ranked national information needs, with 'improve access to and use of land use data (including optimising data, improving existing databases and providing open access to publicly funded data)' and 'establish a multi-sector facilitation group' ranking most highly. At present, information on soil, and the capability to commission, generate, interpret, and use it, is distributed across many organisations. This issue was identified in the CRI Taskforce Recommendations but only partly remedied through the shift from a contestable operating environment into one in which CRIs work collaboratively to solve national science challenges. There still remains a need and opportunity to create a single point of entry into the available research and resources, data, and experts. The National Land Resource Centre has made some progress along this pathway creating a presence in the sectors and online (https://www.nlrc.org.nz/home) with Land Information New Zealand and the Geospatial Office working towards a strategy for the development of a more mature and widely used geospatial data infrastructure, bringing benefits to a wide range of users of geospatial information across all sectors of New Zealand society (LINZ, 2014).

Trajectory of today's science system

Investment in soil related research for evidence and innovation occurs through a number of investment mechanisms. MBIE is a major investor through Envirolink (to allow eligible regional councils to access science and science advise), CRI core funding (varying according to CRI and from year to year according to strategic priorities), as well as contestable funding in Environment and Biological Industry appropriations. MPI invests in a number of programmes, including the: Primary Growth Partnership (PGP), Sustainable Farming Fund (SFF), Māori Agribusiness, Irrigation Acceleration Fund and Regional Economic Development initiatives. MfE's investment include the: Community Environment Fund, Waste Minimisation Fund, Fresh Start for Fresh Water fund (concludes 2014) and the Contaminated Sites Remediation Fund. Primary (e.g. Dairy NZ, Beef & Lamb New Zealand, Fonterra etc.) and resource (directly regional council funding) sector groups also invest into targeted and applied research and development. However, without a set of clear national research priorities for soils and also access to a comprehensive database of funded projects across it is difficult to ascertain the quantum of the investment dedicated to soil priorities or evaluate the impact this has in advancing wider economic, social and environmental goals.

The National Science Challenges are designed to take a more strategic approach to the government's science investment by targeting a series of goals, which, if they are achieved, would have major and enduring benefits for New Zealand. The Challenges provide an opportunity to align and focus New Zealand's research on large and complex issues by drawing scientists together from different institutions and across disciplines to achieve a common goal through collaboration. Each Challenge includes both new funding and funds that will become available as current MBIE research contracts mature. Relevant CRI core funding will also be invested in Challenges, where CRIs are part of Challenge collaboration and in time it is hoped that industry and government investments will be aligned. Most relevant to addressing pressures and impacts on the soil and associated receiving environments is the 'Our Land & Water' National Science Challenge.

Opportunities to increase readiness

While many threats to soil and land environments are difficult to anticipate or respond to due to complex responses, there are a number of ways to increase readiness. We provide here a few examples for consideration although this not intended as comprehensive and will be more fully explored in Phase 3.

(i) Stable investment to upgrade and enhance nationally-agreed resource information: Good resource information has unanticipated utility and is an evidence-base that can be called upon to address emergent issues. Land Use Capability and S-map are proven examples of the merit of resource data that allows us to respond to existing and emerging issues. Both resources have and are being used to address productivity and environmental issues/outcomes (e.g. East Coast forest accord to address erosion, Manawatu-Wanganui to develop natural capital based approach, Grow Otago to develop regional economy; developing catchment limits for zone committees in Canterbury; identifying high class soils for protection in Waikato; improving soil inputs in Overseer). Stable investment in this and other underpinning resources would significant increase overall readiness. It is also critical that the ongoing development of our inventories (e.g. attributes, scale, etc) are driven by the current and future requirements of users.

(ii) Securing a number of long-term trials or experiments: Long term phenomena is crucially important, but can be difficult to observe given the drive for rapid results in science. Long-term trials however, generate a temporal dataset that can be used to test hypothesises and look for changes in state or trends. The Winchmore and Ballantrae long-term field experiments are the longest running irrigation and fertiliser grazing field trials of their type in the world, representing a very valuable reserve of information and data.

(iii) Foresight projects: Another opportunity to enhance readiness is to identify tractable problems and explore possible trends and solutions. Asking the 'what if' questions has the advantage of highlighting alternative futures to better prepare for changes and unexpected events. Three examples were worked through by the experts in this project:

— *Peat subsidence – impacts on land use:* Peat heights in the Waikato (and likely other parts of the country) are subsiding at about 2 cm per year (Pronger et al., 2014), which requires farmers to deepen drains and, in some cases, pump water out when farms are below regional water levels and indeed sea level. It is possible that the costs of removing water and maintaining infra-structure will make some existing farming systems uneconomic in decades to come. The extent and timing of this problem could be quantified through a spatial analysis of peat extent, land use, water table and known rates of peat decline and then coupling this decline to predicted economic costs of maintaining land use. This would require close coordination between research providers and regional councils to understand timing and develop strategies to manage likely land use change or implement strategies to decrease subsidence rates.

— *National and regional nutrient use efficiency:* The intensification of land and increased production has often required the addition of nutrients (e.g., N and P) to maximise plant growth. Increased nutrient losses can then become a major environmental issue but it is difficult to determine the fate of nutrients at national and regional scales through time. Parfitt et al (2012) developed a methodology that allowed annual estimation of nitrogen budgets at national and regional scales including nitrogen inputs (e.g., fertiliser, nitrogen fixation, product import) and removal (e.g., products, leaching to surface waters, gaseous losses). These authors presented budgets for 1990, 2001 and 2010. National and regional nutrient use efficiency (NRNUE) can then be calculated as the percentage of nitrogen inputs captured in products. NRNUE could be calculated on an annual basis as a collective indicator of national and regional efficiencies and in fact be determined for the last few decades based on available data. Such as analysis would identify how we are tracking as a national and the regions are improving or regressing.

— *Alternative land uses and crops:* One of the advantages of the weak regulation of New Zealand biological economy is that it is able to respond to market opportunities for new products. Research to explore the potential for new crops or land uses that utilise the inherent capacity of the natural capital resulting in low input, high value and resilient land uses is particularly interesting. It could include exploring how 'infrastructural capital' such as precision technologies can be deployed to ensure soil, land and water are used more efficiently and effectively; as well as what social, human (such as critical mass, knowledge) and financial capital (investment into processing or harvesting technologies) is needed to ensure options are feasible and palatable.

Additionally, the analysis of pressures and impacts (see Previous Section) the state of 'readiness' for each was also assessed, with the following specific gaps identified in terms of research:

- Within the New Zealand context: This includes research on the effects of specific threats e.g. increased soil temperature and moisture or increased volatility; or impacts upon the soil resource that such as biological diversity, soils which have limited biology, reflecting their genesis (under native forest).

- On the long-term implications of relatively emergent pressures and actions: For example research on the long-term implications of irrigation on soil quality and condition or the nitrogen saturation of soils.

- Outside of the traditional 'calibration' areas: Including the implications of intensification on fragile land, given limited focus to date on low productivity land or on drainage where there has been the perception it is very case specific.

Key findings

Securing the land- based economy demands ongoing investment in sustainable management of the soil resource. This in turn, requires a state of 'readiness' comprising:

- Ensuring the 'knowledge infrastructure' or 'capability system' as a whole is primed to address key pressures on the soil resource. This includes building an enduring supply of scientists, advisors and skilled land managers with key competencies and with aspects of 'soil literacy'.
- A set of clear national priorities for soil research with the explicit link to social, economic and environmental goals, together with a comprehensive database of investments and projects to evaluate
- Stable investment to upgrade and enhance nationally-agreed resource information to ensure an evidence-base that can be called upon to address emergent issues and systemic change to make that information more easily accessible to a range of users
- Long-term trials to generate temporal datasets that can be used to test hypothesises and look for changes in state or trends.
- Foresight projects to identify tractable problems and explore possible trends and solutions. Asking the 'what if' questions has the advantage of highlighting alternative futures to better prepare for changes and unexpected events.
- A suite of research that is specifically focused on the New Zealand context, includes long-term and future perspectives and gives due attention to areas previously considered 'outside of calibration'.

Appendix A: expert case notes

Social, economic and cultural

The list of social, economic and cultural drivers below is not exhaustive, but explores what is driving key pressures on the soil resource:

Social and societal: There is a large range of personal factors that have an influence over farmers' attitudes and behaviours and hence the choices made in regards to farming systems and practices (Fairweather and Robertson, 2000). These include, perceptions of social norms, self-efficacy and of behavioural control in a situation. These will vary according to a complex range of variables including: farmer age, education level, family structure, presence or absence of farm successor, lifecycle stage of farm business/farmer (i.e. socialisation, consolidation, expansion, transition, retirement), risk-taking or -aversion, years of experience, innovativeness (i.e. location on innovation continuum); as well as extent of social networks, nearness to other farmers through to the spouses role in decision-making. All these factors will influence the type of farming system, the decisions made and the practices used. Personal beliefs about the extent and meaning of private property rights as well as the current institutional rules are major factors influencing land use and practice. The perception that '*I own the land and will make the decisions*' is still a major factor influencing decision-making. Most human behaviour is driven by habit, so closely aligned with long-term private ownership is the notion that 'we have always done it this way'. Corporation ownership, which trends towards bigger blocks of land, and the demand by the investors for return on investment (both dividend and capital growth) brings more pressure to bear on-farm business performance and the underpinning soil resource. Corporate owners also have money that can be used for things that cannot be justified on a family-owned farm, e.g. training, adoption of monitoring systems that can track resource use (of all types).

More recent in our social history is the notion of 'social license to operate' – a phenomenon that may well be significant enough to change some of the more deeply embedded behaviours. 'Social licence to operate is the ability of an organisation to carry out its business because of the confidence society has that it will behave legitimately, with accountability and in a socially and environmentally responsible way' (Martin et al., 2011). The triennial 'Public Perceptions of New Zealand's Environment: 2013 Survey' found water-related issues were perceived to be the most important problem facing the environment. Respondents indicated that growth in production and consumption, as well as an intensification of activities including farming and forestry were putting increasing pressure on the environment (Hughey et al., 2013). This notion of a social license to farm, particularly to meet society's aspirations around freshwater quality is likely to be influential in the way the land and soil are stewarded. All of these can be described as the 'driving force' that on the one hand underpins the long-proud tradition we have in land development and the establishment of wide diversity of highly productive land based industries uses and gives rise to other pressures such as intensification and land use change, are responsible for the legacy pressures of today and tomorrow, as well as the scale and severity of climate change impacts on the soil resource.

a. Economic: The increasing cost of land is a key driver behind the need to intensify. It explains the trends in larger farms striving for greater profitability, an increase in corporate ownership, as well as a decline in family farming endeavour. Capital gains, urban or rural residential development through to the fact that land is a finite resource, particularly if on the boundary of the farm, are all pressures driving up land price.

A focus on short- or long-term productivity gains, the level of production, return on investments or long-term capital gains, and the balance between production and environmental outcomes and demand for labour, are just a few of the choices decision-makers and land managers must make. The aspirations of the Business Growth Agenda aligns with the current primary industry business models based on sourcing more products for processing and export through a combination of increased production from the existing supply base and through expansion onto new land. The CEO of Fonterra on TV3's The Nation " Believes NZ dairying can continue to expand over the next decade, with 60% of expansion based on conversions and more animals and 40% on more productivity .He said the country had not reached the point of having too many cows. He disagreed with the Environment Commissioner s comments that more dairying means a drop in water quality. NZ dairying could easily grow for the next 10 years by 2–3% per year, "he said. This strategy is placing increasing pressure on land owners' to intensify current activities and extend existing operations to more challenging landscapes.

The opportunity to move towards 'high value', discerning food and beverage products and the 'development of value chains that enhance the integrity, value and delivery of New Zealand products' in order to gain market access, particularly overseas, may reverse this direction and incentive different behaviours in the management of soil and water.

b. Policy and practice: To date best practice and technologies have tended towards overcoming limitations in provisioning services or mitigating impacts. For many there is a belief that there will be a 'technology fix' to overcome constraints on production and environmental limits – with many investing in infrastructural interventions. There is a range of evidence from overseas that landholders can default to a belief that there will be a technological fix, especially given past experience (e.g. new herbicides, pesticides, etc.). Given New Zealand's strong dependency on the biological economy for GDP much of the policy and regulation has also been retrospective and focused on mitigating rather than preventing problems, and as a result, has failed to reduce pressures and in some cases enabled them.

c. Culturally New Zealand has a 'do-it yourself' attitude with 'generations of us have seen a problem and come up with an ingenious way to deal with it – from how to grow warm temperature kumara in a much colder climate to a novel piece of farm equipment put together in the barn' (MBIE et al., 2014). That said, others remain sceptical about scientific models, their application and the use of technologies given uncertainties in the science and the inferential gap between what is known and what needs to be known.

d. Maori Land: Land held by Māori in accordance with tikanga Māori which has the status of Māori customary land comes with its own unique restrictions, protections and challenges. The unique "values" bring different pressures to managers of Māori land. Treaty settlements are likely see the transfer of more land to Iwi with consequences on the way land is managed.

Key pressures and their impact on the soil and associated natural resources

While a precise and overarching definition of intensification is beyond the scope of this study, framing rather than defining intensification is useful in discussing the pressures of our current agricultural systems on soils (Louis Schipper pers. Comm.). Agricultural intensification is typically defined as a production increase per unit area, achieved through greater use of inputs (e.g. feed, fertiliser, labour), or by increasing throughputs by lifting system inefficiencies (e.g. via improved technology, management, genetics, specialisation) or by outright system modification (e.g. land clearance, drainage, irrigation, shelter/housing, increased stocking rate) including land use change. Whether a land use change (e.g., sheep to dairy) is classed as intensification, depends entirely on comparative stocking rates and inputs of both land uses. In New Zealand associated with the conversion of land from forestry or sheep and beef to dairy has been a large increase in external inputs (e.g., nutrients, water, energy and labour). In some regions, like Canterbury that is only been possible with access to water for irrigation. Associated with this "intensification" has come a deterioration in surface water quality (PCE report on intensification) and pressure on the soils resource (Sparling & Schipper, 2004).

While intensification is often framed in terms of an increase in external inputs, and or an impact on the environment through increasingly inefficient use of inputs (nutrients, water, or energy) and/or of increased physical pressure on the land, this depends importantly on the scale of interest. A clear global example of the environmental benefit of intensification was demonstrated by Burney et al. (2010) who modelled the total global greenhouse gas emissions from agriculture for different scenarios. They demonstrate that intensification which has led to greater food production resulted in lower total greenhouse gas production than if the same amount of food lower was produced with lower intensity production associated with increasing land clearance. More generally, the negative environmental impacts of intensification can be moderated by ensuring inputs are efficiently converted into product and limits are set on emissions to protect receiving environments.

NZ agriculture is currently following an upward trend in intensification across all three criteria. Environmental modification was prevalent in the past, and still continues in situations where the modifications are economically viable. Increased used of inputs is considered by some as the greatest single driver of modern-day intensification, particularly for dairying (PCE, 2013). Efficiency gains are regarded as a distinguishing factor between 'top' and 'average' farmers, and can often be claimed as triple positives resulting in reduced inputs, production gains, and reduced environmental impacts.

Increasing the intensity of production from the same area of land can significantly impact on the character, production capability, and ecosystem function of the underlying soil resource. The following discussion focuses on the effects of animal stocking rate, fertiliser inputs, drainage, land management practices and cultivation practices.

a. Animal stocking rate: Livestock numbers in NZ have been steadily decreasing for all major livestock classes accept dairy (Fig. 1), although a reduction in total grassland (down 17%

from 1991 to 2013) has maintained national stocking intensity around 11.3 stock units (su)/ha since 2001. The greatest increases associate with dairy, with a stable net trend of 0.15 SU/ha increase each year since 1982, currently sitting at an average 17.9 su/ha (2.9 cows/ha). Individual farms with particularly high stocking rates may achieve upwards of 28 su/ha (4.5 cows/ha). On a daily grazing basis, actual stocking rates are far higher (200-500 cows/ha/grazing) while break-feeding can result in short term rates equivalent to well over 1000 cows/ha.

Treading damage is the main impact of increased stocking rates, whereby the collective physical weight of many animals concentrated as sizeable force over small hoof areas (~490 kPa/leg for a dairy cow) causing soil compaction and pugging under wet conditions. Treading of wet soils decreases hydraulic conductivity, air permeability and macroporosity, and can increase the proportion of large soil aggregates. This can lead to reduced infiltration, surface ponding, aerobic anoxic conditions, and increased runoff associated with phosphorus, sediment and pathogen transport. Soil damage from treading, in particular the loss of macroporosity, is known to have a negative effect on pasture production. Pande et al., (2000) found a single late winter treading event reduced pasture growth rates from 51 to 33 kg DM/ha/day for the first 7 weeks of spring.

Soils can take months to years to recover, even with spelling and post-damage management. Rotationally grazed dairy farms with year-round grazing may suffer cumulative on-going damage. Restorative practices include mechanical loosening such as subsoiling. Preventative practices include improved wet-soil management such as the use of stand-off pads. Increasing soil fertility is known to offset and mask pasture reductions associated with soil compaction.

The trend of increasing dairy stocking rates is likely to continue, and thus the proximal and distal environmental and production problems associated with treading damage has the potential to further increase. Of particular risk are poorly drained and weakly structured soils (Pallics, Gleys, Podzols), accounting for close to 2 million hectares of NZ's grazed lowlands lowlands and increasingly rolling and hill landscapes as the competition for land use intensifies. A key imperative for future research is to build greater resilience into these soils through modification of aggregate building and strengthening processes. The trend towards more DairyNZ systems 3, 4 and 5 dairy, which includes wintering, feed pads and barns, offers options for reducing the pressure on soils when wet. Schon et al. (2013) found that as livestock live-weight loading increased in a pastoral soil, both the diversity and abundance of the soil biological community declined. This impacts negatively on a wide range of soil ecosystems services, particularly when the diversity of our pastoral soils is low, due to the limited introductions from the Northern hemisphere.

b. Fertiliser inputs: Fertiliser inputs, an essential input for the on-going viability of our agricultural systems, have resulted in the slow, steadily build-up of P and indirectly N levels in our soils. In some pasture soils nitrogen saturation has occurred (Jackman, 1964, Schipper et al., 2014, Schipper et al., 2004). This is going to impact on the capacity of soil to filter and retain additional nitrogen inputs against leaching. Similarly the findings of Wheeler et al. (2004) who reported increases in Olsen P in both dairy and dry stock farms between 1988 and 1995 with many dairy farms having Olsen P values above the upper limit for maximum production and others (Mackay et al., 2009) indicating a higher risk of P losses in run-off to receiving environments. **The absence of longitudinal studies to track the changes in the dynamics of added wanted and unwanted elements in agricultural soils limits our ability to predict with any confidence long-term trends.**

The ongoing accumulation of unwanted elements, including fluorine, cadmium and uranium found in trace amounts in phosphate fertilisers, in soils has the potential to not only put

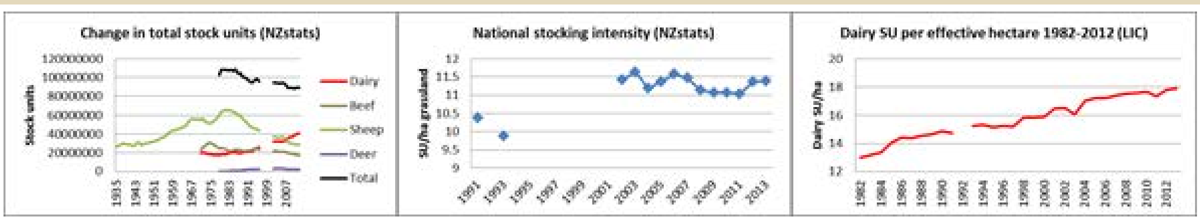


Figure 1 Change in total stock units, national stocking intensity and diary stock units per hectare. (Note: Total stock units from StatsNZ, total stock numbers converted to SU using EW methodology. Grassland area from StatsNZ Dairy SU/eff ha from LIC stats 2013 converted to SU using EW methodology)

human health and receiving environments at risk, but also limit land uses beyond pastoral agriculture into the future and act as a barrier to restrict future access for agricultural exports (MAF 2008). Slowing the accumulation rates of these unwanted elements would address in the short term these concerns, and has potentially already occurred with cadmium (Cavanagh 2014b). Currently there are management guidelines governing cadmium accumulation rates with some soil guideline values of potential effect adopted, but no soil guideline values for uranium and fluorine have been developed for use in New Zealand.

Depletion rates of based cations (K and Mg) above mineral weathering rates as a consequence of higher leaching losses of these two base cations in association with sulphate and nitrate losses by leaching and the ongoing challenge with the supply of trace elements will continue into the future on many soils.

c. Drainage: Total estimated pastoral land 'that potentially could be under artificial drainage' = 982,000 ha or 1.09M ha if peat was included (Muller et al., 2008). Control of water availability to plants is a key to optimising production and in drier regions is controlled by irrigation. However, in wetter soils, surface and subsurface drainage are needed to remove excess water from the near surface to improve trafficability (by either animals or machinery) and increase the aerated zone for root growth. With the exception of peats, as a general rule drainage has a positive impact on most soil functions underpinning ecosystem services. The increases in crop and forage production can be large, as is animal production through increased utilisation of forage. Increases in lamb survival, following drainage of wets soils have also been reported. Drainage also increase land use options. Drainage by increasing the percentage of the soil matrix involved in processes increases the efficiency of use of inputs. Drainage does allow higher physical loadings to be carried potentially risking increased topsoil compaction. This translates into impeded surface process including aeration and drainage. Importantly drainage does open up new land use options.

The single biggest challenge with drained soils is controlling contaminant losses to receiving environments. Limiting the loss of P, N and bugs from drained soils is already an issue in a number of lowlands environments (Houlbrooke et al., 204b, Houlbrooke et al., 2008, Monaghan et al., 2010). With the ongoing pressure to lift output per hectare the area drained is likely to continue to expand, as is the intensity of existing drainage systems. Intersecting land areas and existing and likely future drainage systems with land use and connect this area hydrologically to receiving environments will be critical in quantifying the implication of more drained soils on receiving environments.

d. Irrigation: Hectares in irrigation have been roughly doubling in area every 12 years since the late 1970's. The exact irrigated area is difficult to ascertain. In 2012 it was estimated at 720,000 ha, with two-thirds in the Canterbury region (Irrigation NZ, 2014). The ongoing move away from flood irrigation has been driven by the expansion in groundwater based irrigation, but also recognition that sprinkler irrigation allowed increased yield and productivity per unit of water applied (Heiler, 2012) and limits the adverse effects of excess water application on surface and groundwater quality (Monaghan et al., 2009). Sprinkler irrigation allows less water to be applied more often to greater areas, avoiding large return intervals that necessitate large application depths limiting the ability to adjust irrigation to rainfall events AERU (2012). he reduction in nutrient losses associated with shifting from flood to sprinkler irrigation is greater than the losses associated with the increased production possible with improved water use efficiency with sprinker irrigation. It is estimated that >80% of irrigation is now by spray irrigation systems in Canterbury. Recent years has seen the emergence of precise control over the sprinkler system allowing farmers to respond to varying soil, crop, and climate conditions to make additional gains in water-use efficiency. Land under irrigation is predicted to continue to increase with current plans to expand the irrigated area by 340,000 ha, with almost two-thirds in the Canterbury Region (The Beehive 2013).

In drought prone areas, irrigation has been shown to greatly increase farm production (Irrigation NZ, 2014, Heiler, 2012). Despite the three-fold difference in primary production and associated litter return to the soil ecosystem over an extended period of time, Srinivasan & McDowell (2009) could find no measurable effect of irrigation on the soil moisture holding capacity or the hydraulic conductivity of the soil, indicating little or no "soil development" of attributes linked to the inherent properties of the soil. Fraser et al. (2012) found that apart from macrofauna that are mobile, to a large extent the soil invertebrate community in the long-term irrigation trial at Winchmore was more characteristic of a dryland soil than of a soil in a higher rainfall zone. While there is evidence semi-arid soils under lower annual rainfall accumulated more carbon and had higher soil water capacity following long-term irrigation, findings from Winchmore would suggest otherwise. Recent research on downland soils has shown the irrigated land-use intensification can have significant effects on soil quality, with soil physical properties (e.g. compaction) responding more quickly to land-use change than do biochemical and organic indicators (Houlbrooke et al. 2011). Hedley et al (2013) identifies that further research is needed to refine our understanding of water retention for plant use by different types of soils, e.g. stony soils, and how to optimise irrigation practise for different soil types. Soil water movement is also poorly understood for New Zealand soils, particularly soil infiltration, especially on soils prone to soil-water repellency, or hydrophobicity, which is a key to irrigation design and management (Carrick 2009; MAF 2011).

There are major gaps in our understanding of the long-term implications of keeping soils moist throughout the summer using irrigation on soil structure and the array of services it influences. Drying and cracking is an important process that assists with the restoration of physical structure of a soil. Soils that are irrigated late into the season are also more likely to be at risk from damage by livestock.

Irrigation is more often than not accompanied by increases in fertiliser inputs and livestock numbers. There is likely flow on effects to surface water quality as a consequence of the increased risk of higher N and P losses in leaching and overland flow, respectively. Losses of nutrient as a consequence of irrigation have been reported in the sand country and soils in an around Lake Wairarapa. Environmental models consistently predict stony soils as a hotspot for leaching (Lilburne and Webb 2002; Green and Clothier 2009; Lilburne et al. 2010; Wheeler et al. 2011), although there are limited data (Lilburne et al. 2010; Carrick et al. 2013). Previous research has demonstrated that leaching from stony soils can be reduced by improved management practises, when irrigation was changed from flood to spray irrigation (Di and Cameron 2002a, 2002b, 2007), although given the spatial extent and range of irrigated stony soil types sustainable management practises remain a significant research challenge (Carrick et al. 2013). **The failure to address the growing impact of irrigation on receiving water bodies places the economic opportunities this investment creates at great risk.**

e. Inadequate vegetative cover. The ongoing risk of soil erosion and sediment loss from highly eroding hill land and in the high country and fragile lowland soils under cultivation, due to poor vegetation management is still a major threat to soils throughout the country. The storm events in the Manawatu in 2004 and Hawkes Bay on 2011 are two recent examples of storms that resulted in significant soil erosion and downstream erosion. Associated with the loss of natural capital as a result of erosion is the loss of a wide range of ecosystems services, many of which are not valued (Dominati et al., 2014), a decrease in water quality due to increased sediment input to freshwater and coastal ecosystems, increase in sediment in river beds limiting flood capacity, which adds to infrastructure costs. Erosion is an ongoing issue in nearly all regions of the country, Associated with this are ongoing capital and operational costs in soil conservation and flood control infrastructure. This cannot be underestimated into the future, given the greater volatility of future climates.

f. Wastewater practices: Already widespread in New Zealand, and is likely to continue expanding. Approximately 1.5 billion litres of municipal and domestic wastewater are discharged every day, mostly treated by public wastewater treatment plants, although there are about 270,000 domestic on-site systems in New Zealand, disposing of wastewater for 15–20% of the population. In total, about 30–35% of wastewater is disposed of to land (Ministry for the Environment, 2007). Land application of farm dairy effluent (FDE) is also significant, with 960 million cubic metres of FDE estimated to be produced between 1997 and 2000 (Flemmer and Flemmer, 2008). These activities are all likely to expand into the future. Accumulation on nutrients (e.g. nitrogen, phosphorus, etc.), unwanted elements (e.g. cadmium, uranium, etc.), organic contaminants (e.g. steroid hormones, pharmaceuticals) and bugs (e.g. *E coli*, etc.) are an ongoing challenge, as is limited impacts on receiving environments. It is widely recognised that wastewater irrigation can significantly change soil physical and biogeochemical properties, depending on the soil type and wastewater characteristics (Carrick 2009).

A significant research effort over the last 20 years in south Otago and Southland has demonstrated the vulnerability of downland soils to FDE application to contaminant losses through both overland flow and mole-pipe drain leaching from, but has also developed a suite of good management practices to mitigate this risk (Houlbrooke et al. 2011). The effects of irrigation on total nitrous oxide emissions require constraining. Nitrous oxide is produced by two processes – nitrification and denitrification – and these processes are generally enhanced when the moisture content of soils vary (Luo et al., 2010). Wastewater irrigation remains a significant challenge, with failure rates of onsite domestic systems range from 15–50%, which equates to between 40,000 and 130,000 systems nationally (MFE, 2008). Considerable ongoing research has also been focussed on improving FDE irrigation (Houlbrooke et al. 2004), with adoption of good management practise (Houlbrooke et al. 2011) and irrigation system upgrade being a recent major focus of the dairy industry and regional councils.

Disposal of urban storm water to land has become an integral component of urban development in New Zealand (Christchurch City Council, 2008; NZWERF, 2004). The change from a rural to lifestyle land use increases the density of onsite domestic sewage disposal. It was estimated there were 270, 000 domestic on-site sewage disposal systems in 2007 (Ministry for the Environment, 2007). This changes the nature, loading, and location of contaminants to land, compared to what would occur under rural land use. Despite the increasing use of ground soakage there appears to be little published research on its effectiveness under New Zealand conditions. The exception is some site-specific research in the Auckland region (Carrick 2009) A report on potential loadings from lifestyle blocks in the Horowhenua which resulted in the developers investing in a reticulation system. The Ministry for the Environment estimates that the failure rates of onsite systems range from 15–50%, which equates to between 40,000 and 130,000 systems nationally. The primary reason for failure is because the hydraulic loads do not match the drainage properties of the soil in the disposal field (Leonard and Gilpin, 2006; Ministry for the Environment, 2008).

g. Management practices: There are a wide range of practices in pastoral, horticultural, arable and forestry systems that result in additives, in addition to fertiliser to soils. In addition to legacy issues there are the ongoing concerns with the use of copper in kiwifruit orchard soils, zinc in facial eczema management, and ongoing use of CCA-treated posts in agricultural and horticultural systems.

h. Cultivation: In the last 20–30 years we have seen the adoption of no-till and direct drill technologies, precision agriculture, controlled wheel traffic technology, self-drive equipment, cultivation onto increasing sloping land and the also the emergence of spray and pray on what was previously uncultivable land. All these activities expose soils to greater pressures. In pastoral systems over 200,000 ha arecultivated in some way each year. This is likely to increase with the pressure on to produce more forage of higher quality for more of the year.

Land use and Change

a. Land fragmentation and spill-over: A disproportionate amount of the limited land that has high versatility for food production has been under threat from urban and rural-residential development for many years. Mackay et al. (2011) reported there were 175,000 lifestyle blocks covering 873,000ha in 2011, an area equivalent to the current irrigated

area of NZ. In comparison. Urban areas cover approximately 221,000 ha (Andrew and Dymond 2013). Over the last 25 years Mackay et al. (2011) estimate the rate of urban and lifestyle block expansion to be 4–5% per annum. By 2040 the population of Auckland is forecast to increase from 1.5 to 2.5 million, raising concerns about the pressure on the regions limited soil resource (Curran-Cournane et al. 2014). Ongoing pressure of urban and lifestyle block expansion on the land resource has raised concerns about the loss of high class land. High class land has been defined as Land Use Capability (LUC) classes 1–2 (Rutledge et al 2011) or LUC classes 1–3 (Curran-Cournane et al. 2014). The class 1–2 land represents 5% of the NZ land area, and classes 1–3 represent 14% (Rutledge et al. 2010). The increasing recognition of land fragmentation and the potential threat to high classes has led to recommendations that the following are urgently required: (1) national monitoring of rural land fragmentation; (2) analysis of the economic and ecosystem services impact of urban/lifestyle block expansion; (3) establishment of a national Land Management Forum(4) a national policy statement prioritising NZ's best agricultural lands for productive uses (Rutledge et al. 2010, Mackay et al. 2011, Clothier et al. 2012, Andrew and Dymond, 2013, Curran-Cournane et al. 2014).

There is a general observation that lifestyle owners do not engage in high levels of production (Fairweather and Robertson 2000, De Luca 2009) and surveys have shown that few owners of lifestyle blocks obtain the majority of their income from the property. Despite the large area occupied by lifestyle blocks there are little data on the condition of soils on lifestyle blocks.

Andrew and Dymond (2013) identify that an important consideration of urban/lifestyle block expansion is that an additional area is also affected by proximity factors such as 'reverse sensitivity and social consequences. To accommodate urban neighbours, farmers can be faced with new challenges including regulations that impact on routine farming operations such as time constraints on machinery operation and restrictions on pesticide and fertiliser application options (Curran-Cournane et al. 2014). Collectively urban and lifestyle block expansion is disproportionately impacting on the national and regional stocks of high class land. If recent trends in expansion continue, a large percentage of high class land could be lost to agricultural land over the next 50-–00 years (Rutledge et al 2010). Lifestyle blocks occupy 10% of NZ high-class land, with 35% of the high class land in the Auckland region already occupied by lifestyle blocks. While urbanisation between 1990 and 2008 occupied 0.5% of high class land, 29% of this new urban land occurred on high-class land (Andrew and Dymond, 2013). Urbanisation expansion rates tend to be highest for LUC Class 1 (5.6%) and Class 2 (3.96%) compared with <0.01 to 2.0% for LUC Classes 3–8 (Rutledge et al. 2010). One consequence of the loss of high-class land is an increase in broad-acre production from lower class land, which to achieve similar productivity is generally less efficient, requires more inputs and increased risk of environmental impact (Mackay et al. 2011, Andrew and Dymond, 2013). Concerns have been raised that the complete value of rural land is not being accounted for when permitting urban and lifestyle block expansion. Rural land contributes a wide range of provisioning, regulating and cultural ecosystem services to both human and ecological communities that urgently needs to be evaluated to inform the long-term economic, environmental and cultural cost:benefit's of land planning decision making (Mackay et al. 2011, Curran-Cournane et al. 2014).

b. Irrigation-driven land use change: We have a good understanding of what future water demands are likely to be, as a result of climate change. We have only a poor idea of what river flows and groundwater recharges (the supply) will look like. Irrigated driven land-use change is also expanding onto new land types. The 232,000 ha of dairy operations under irrigation on stony soils in 2012, was nearly double the hectares in 2000 (Carrick et al. 2013). It is estimated that there is approximately 60,000ha of irrigated hill country (around 8% of the total irrigated area), with another 60,000ha is consented for irrigation and more in the pipeline. Little is understood of the implications of these practices on hill slopes, the soil surface structure and function. Efficient irrigation on both stony soils and hill country has proven to be a significant challenge, and will continue to do so as irrigation area expands on both land types and the increasing need to operate within nutrient discharge limits.

The recent focus on "improving hill country irrigation" technologies is another aspect of water availability changing land use. There is heightened awareness of the challenges of irrigating sloping land and the associated difficulties in managing runoff, even using sprinkler irrigation (MAF, 2011). Limited research has been completed evaluating the effect of different sprinkler irrigation systems on leaching, and has been limited to a few soil types.

The large changes in production associated with irrigation results in increases in inputs of organic matter inputs into soil, this is coupled to increase in soil respiration rates and decomposition when moisture limitation is alleviated (Kelliher et al., 2012, Schipper et al., 2013, Scott et al., 2012). The net effect of increased inputs and decomposition may alter the total organic matter stocks of irrigated soils but these net effects are very poorly known in New Zealand or indeed globally (Conant et al., 2001). Furthermore, this net effect (positive or negative) is likely dependent on the precise timing and amount of irrigation, which has had little to no research. Many soil services are dependent on organic matter stocks.

c. Restoration and introduction of diversity: Retirement of the high country, protection of wetlands and native forest fragments and the planting of extensive riparian margins on water courses in intensive livestock operations (Dairy clean streams accord) are all actions that protect land, indigenous biodiversity and associated water bodies. This has a positive influence on soil structure, organic matter, ecosystem services and receiving environments. Potential to address the inappropriate use of land and impacts on receiving environments throughout the country.

d. Poor matching of land use to inherent capability (e.g. intensive use of fragile land):. The intensive use of fragile and sloping land, for livestock and horticulture and production forestry on steep highly erodible land increases the risk of erosion, land-sliding runoff and sediment loss.

Livestock: Land use intensification on sloping lands. Growth in primary production is likely to see continued expansion of dairying, some of which is likely to spread more on to steeper slopes with the availability of irrigation. We are also likely to see continued intensification of land use in sloping downland areas with heavier stocking of cows and sheep. Heavy grazing can cause an increase the pressure on the soil surface and physical integrity of the soils pore structure and function and increase surface runoff and sediment generation by sheet erosion (Elliott et al. 2002, Elliott and Carlson 2004). Many of the downland soils are formed from loess which have weak soil structure readily prone to degradation, compaction and erosion under intensive livestock uses (Watt 1972, Houlbrooke et al. 2011).

Arable and horticultural: Sloping land used for intensive cropping sheet erosion can experience severe erosion (Basher and Ross 2002, Basher et al. 2004). Compacted areas are particularly important in causing runoff and erosion (Basher and Ross 2001). Similarly intensive cropping in the east of the country can cause severe wind erosion (Basher and Painter 1997). As population grows an increasing area of cropland is likely and unless well managed there is potential for erosion to increase.

Production forestry: About one third of the New Zealand plantation forest estate is located on erodible steeplands and many of these forests, originally planted for erosion control, are now maturing for harvest. When forests are harvested, land-sliding risk increases considerably (Philips et al. 2012). There is a long history of landslides and debris flows associated with rainstorms following forest harvesting in New Zealand, especially in Northland, Coromandel, Bay of Plenty, Gisborne-East Coast, and Nelson-Marlborough. These events also occur in pastoral farmland and indigenous vegetation. The trigger for these events is rainstorms typically with a >10–20 year annual recurrence interval. It is likely that post-harvest landsliding and debris flows will remain an issue for the forestry industry and it is likely to become worse with the predicted increase in storminess as a result of climate change. There is a question about how much of this steep eroding land is replanted into production forestry?

The lack of recognition of inherent weaknesses in soils (i.e. 95% of soils are unsuitable for horticulture and 65% of soils have a physical limitation to pasture agriculture), combined with the ongoing development of technologies to overcome limitations and increasing competition for land is increasing the physical pressure on many soils and associated receiving water bodies.

Climatic drivers and pressures

Climate change is projected to cause changes in temperature, rainfall, drought and wind patterns that will have direct impacts on soil processes and indirect impacts via changes in land use and practices that affect soil management. The predictions are summarised in MfE (2008), Tait (2011) and the latest (5th) IPCC assessment is on the New Zealand Climate Change Centre Web site (http://www.nzclimatechangecentre.org/sites/nzclimatechangecentre.org/files/images/research/NZCCC%20Summary_IPCC%20AR5%20NZ%20Findings_April%202014%20WEB.pdf) and pressures likely to include:

a. Temperature: New Zealand has warmed by about 0.9°C since 1900 and temperature is expected to rise in the next century by between c.0.8°C (if stringent measures to limit greenhouse gas emissions are implemented quickly) and 3.5°C (under a high carbon scenario) above the 1986–2005 average. The area of land that will be frost-free in spring and autumn is expected to at least triple by the 2080s. Up to 60 more hot days per year (over 25°C) are expected in northern areas by 2090. A rise in air temperature will lead to warmer soils and changed rates in key soil processes, including soil respiration with an elevated risk of soil carbon loss (Luke & Cox, 2011)

b. Moisture: There will be lower annual average rainfall in the northeast South Island and northern and eastern districts of the North Island (2.5–7.5%), with higher annual average rainfall (5–15%) elsewhere. The annual pattern of rainfall change is dominated by the changes in winter and spring, with projected changes to rainfall in summer and autumn being less significant and quite different to the annual pattern. These seasonal rainfall differences are related to the projected changes to the seasonal wind flow patterns over the country. The time spent in drought in eastern and northern New Zealand is projected to double or triple by 2040. By the end of this century much of New Zealand will experience some increase in drought, even under milder emission scenarios. Whether this increased demand can be met via irrigation from rivers or groundwaters is unclear, and it is likely that water storage schemes will be required to maintain primary productivity.

c. Variability and Volatility: An increase in the frequency and intensity of extreme rainfall, especially in places where mean annual rainfall is also expected to increase. Increases to extreme rainfall for New Zealand of approximately 8% are projected for each 1°C increase in temperature, but with significant regional variations. The present-day 24-hour extreme rainfall with a 100-year average recurrence interval (ARI) will increase and is projected to occur about twice as often by 2080–2099. There is likely to be a reduction in the number and intensity of extra-tropical cyclones over the North Island and to the east of the country in winter, but there may be an increase in summer over the Tasman Sea. Basher et al. (2012) analysed the likely impacts of climate change on erosion processes and suggested the main features of climate change that will affect erosion are changes in annual rainfall patterns (an increase in the west and south of the country and a decrease in the east and north) and a reduction in extreme storm rainfall return periods, increases in temperature affecting plant water use and soil water balance, and increased windiness and incidence of drought, particularly in the east.

There will be shifts in wind speed and direction. By 2090, the annual mean westerly component of wind flow across New Zealand is projected to increase by up to 10%. This increase is most prominent in winter (>50% by 2090) and spring (around 20% by 2090), with decreased westerly airflow in summer and autumn (around 20% by 2090). The frequency of westerly days is projected to increase in winter and spring, and the frequency of easterly days to increase in summer and autumn. There is likely to be up to 10% increase in strong winds by 2090, with more storminess possible and the frequency of extreme winds likely to increase in almost all regions of New Zealand in winter. This increase in intensity will increase the risks of soil loss by erosion.

d. Carbon dioxide: Rising carbon dioxide levels in the atmosphere will result in changes in the quality and quantity of plant inputs leading to changes in biogeochemical cycling and microbial function such as an increasing importance of heterotrophic process. The net effect will be a reduction in the supply of nutrients to plants. There will be a greater potential for N_2O emissions under elevated CO_2; increased sequestration of carbon in the soil and changes (probably reduction) in hydrophobicity. Our understanding of the implication of the combination of a change in temperature, moisture and elevated CO_2 remains incomplete.

Legacy

a. Pesticides (including dips), waste (including landfills, dumps), mining and extraction: Managed land, and in particular production land, invariably requires the use of chemicals to assist with production or the control of pests and may lead to contamination of the soil. Historical use of persistent pesticides, such as lead arsenate or the organochlorine pesticide DDT, have led to wide-spread low levels of contamination of agricultural land, while usage of persistent pesticides for ectoparasite control has resulted in localised high levels of contamination (e.g. sheep dips).

Historical use of arsenic based pesticides in sheep-dips has resulted in an estimated 50,000 sites contaminated with arsenic and persistent organic pollutants such as dieldrin (Robinson et al. 2004). As well, past pesticide practices in agriculture and horticulture employed arsenic-based compounds. Recent sampling of previously productive soils has uncovered high levels of arsenic in some soils. Changes in land-use, particularly sub-division for residential land-use, increases the significance of such localised areas of contamination for human health as the relative area of the contamination increases, increasing the potential exposure of people using the site. Modern pesticides are intended to have less environmental impact and may be less persistent in the environment, more targeted modes of action, and be effective a lower concentrations. However the presence of co-occurring contaminants, such as copper or DDT may slow the degradation rate, or degradation products may be more toxic than the parent compound and resulting in unanticipated environmental effects.

Disposal of wastes such as biosolids, drilling mud wastes to land may also result in contamination including pathogens and chemical contaminants that can contaminate soils. Land leasing provides a previously unrecognised contamination risk for production systems and was highlighted by the recent poisoning of cattle in Southland grazed on land leased from a rifle club.

However, there is a dearth of New Zealand studies that demonstrate environmental impacts arising from diffuse contamination, in particular, or even point source concentrations e.g. sheep dips, simply because relevant studies, ie those that provide a measure of biological or ecological impact have not been undertaken. Rather, concentrations of contaminants are used to infer the potential level of impact, primarily based on international data, if it exists. Furthermore, the effects arising from chemical contamination may be subtle such as endocrine disruption, increased antibiotic resistance, and not easily determined. Finally, while a biological response may be observed at one level, it may be difficult to translate or determine if this response is significant. Even for cadmium, which is a comparatively well-known contaminant there remains limited knowledge of the actual risk or effects in the New Zealand environment.

Offsite movement of contaminants may result in negative impacts in aquatic systems, and arguably there has been greater focus on evaluating the effect of soil contamination on water quality, than the effect of soil contamination on terrestrial systems in New Zealand (e.g. Tremblay et al 2011, Macleod et al 2013), although internationally there may be a broader focus e.g. Arnold et al (2014). The potential for offsite movement, depends on the contaminant, e.g. it's persistence, association with soil particles, degree of water solubility; and land-use practices e.g. cultivation, irrigation. Some unexpected situations arise in predicting off-site losses, for example it has been assumed the surface run-off of cadmium could be estimated by sediment loss, however, analyses of surface run-off from irrigated pastures found that cadmium was present primarily in the dissolved fraction and surface run-off losses were in the same order of magnitude as leaching losses (McDowell 2010).

b. Deforestation: Māori reduced the amount of forest cover with the use of fire from 85% down to 56% by 1840. In 2010 the forest cover was at 31%, slowly but steadily rising since 1998. Forest clearing enabled the development of agricultural, horticultural and production forestry on very large track s of land. Associated with the loss of the forest cover has been wide spread soil erosion and sediment losses to water bodies. While soil properties recover following erosion they never fully recover to pre-landslide levels and there is a permanent impact on soil properties and loss of productivity (Rosser and Ross 2011).

The Water and Soil Conservation Act was passed in New Zealand in 1941 to address hill country erosion associated with post-European settlement and deforestation. Catchment Boards, directed by central government policies, were tasked with soil and water conservation until 1988. In 1988, Catchment Boards were absorbed into Regional or Unitary Councils responsible for broader natural resource management, including soil erosion and flood control under the Resource Management Act (RMA) of 1991. Each-year erosion in hill country is estimated to cost between NZD100 to 150 million (Eastwood et al., 2001). Part of this is through lost pasture production and nutrients (MfE, 2007), but does not include an estimate of the loss of soil natural capital stocks (Dominati et al., 2010). The investment in soil conservation continues today, as erosion remains a challenge threatening the long-term sustain- ability of agro-ecosystems. This is not unique to New Zealand but a threat to food security in many regions of the world (McBratney et al., 2014), heightened by uncertainties surrounding future weather patterns The impacts of storms such as Cyclone Bola (March 1988) and the lower North Island storm in February 2004 has led to schemes such as the East Coast Forestry Project (Phillips and Marden 2005) and the Sustainable Land Use Initiative (SLUI) (Manderson et al. 2013) to put more trees on highly erodible land. The government also funds the Sustainable Land Management Hill Country Erosion Programme as a targeted intervention to deal with hill country erosion in parts of Northland, Gisborne, Hawke's Bay, Wellington, Manawatu-Wanganui, Taranaki, Eastern Bay of Plenty and Waikato regions. However these programmes have had limited uptake and effectiveness and have only partly addressed the problem of susceptibility of large tracts of hill country to erosion, and its effect on productivity and soil properties. An estimated 1.14 million hectares of hill country pasture is classed as erosion prone, much of which remains to be treated for erosion control and erosion of this land is estimated to cost New Zealand between $100–150 million each year through the loss of soil and nutrients, loss of production, damage to houses, fences, roads, phone and power lines, and damage to waterways and aquatic habitat (Ministry for the Environment 2007). Treatment of erodible hill country for erosion control would reduce the long-term cost of post-storm recovery measures, ensure sustainable production on hill country properties, and reduce off-site effects of erosion on streams and estuaries.

c. Land development: Fundamental alteration of the New Zealand soils and the landscape began about 800 years ago with burning of native vegetation following the arrival of Māori. In the last 150 years, agricultural production has increased through greater inputs of nutrients (e.g., phosphorus, nitrogen), lime, chemicals, irrigation and energy (e.g., cultivation, irrigation) (MacLeod & Moller, 2006). These changes can be collectively referred to as land/soil development which supported higher stocking rates and increased crop and fibre production. Initially, phosphorus fertiliser was applied with the added benefit of increasing nitrogen fixation by clover; specific regions in New Zealand also benefited from addition of a range of other macro and micro-nutrients. Additions of lime increased soil pH and availability of some key nutrients (e.g., phosphorus and molybdenum). This was followed by addition of nitrogen fertilisers starting in about the late 1980s. These changes were not small; national phosphorus fertiliser inputs in 2001/02 were 211 Gg (Parfitt et al., 2008). The sum of nitrogen fertiliser, nitrogen fixation and in feed imports have increased 574 (1990) to 784 (2001) and finally to 822 Gg N in 2010 (Parfitt et al., 2012). These very high loadings have supported greater production and have resulted in large and essentially irreversible changes in the chemical and biological cycling in soils used for production and receiving environments with surface water quality a major environmental issues in the is country. In comparison to indigenous ecosystems many soils developed for agriculture now have higher total nitrogen and phosphorus contents, are less acidic, have unwanted trace elements and less biological diversity. For example, as part of the 500 soils project average (SE) total nitrogen in indigenous forest was 3.48 mg cm^{-3} ± 0.16 (n=58) while in dairy pastures was 5.92 ± 0.12 (n=127) (Sparling & Schipper, 2004); it is important to acknowledge that some of this difference was likely due to differences in sampled soil types. In some pasture soils nitrogen saturation has occurred (Jackman, 1964, Schipper et al., 2014, Schipper et al., 2004), impacting on the capacity of soil to filter and retain additional nitrogen inputs There is less information on changes in total phosphorus stocks, but Olsen P values in indigenous forest was 11 ± 2 µg cm^{-3} g-1 (n=58) while in dairy pastures was 44 ± 3 µg cm^{-3} (n=127) (Sparling & Schipper, 2004). Lambert et al., (2000) highlighted the accumulation of P in the topsoil following long-term superphosphate application, as did Wheeler et al. (2004) who reported increases in Olsen P in both dairy than dry stock farms between 1988 and 1995 with many dairy farms having Olsen P values above the upper limit for maximum production. Repeat application of P fertilisers over many years' has also resulted in the trace amounts of cadmium, uranium and fluorine gradually accumulating in soils to reach levels above typical natural background levels (Loganathan et al., 1995, Schipper et al., 2011, McDowell 2012). Syers et al., (1986) found in a study comparing 10 phosphate rock sources, including five reactive phosphate rocks, the concentration of cadmium varied from as little as 2 mg/kg in Chatham Rise Phosphorite to 100 mg/kg in Nauru Island (used extensively in the past in NZ for superphosphate manufacture) and the concentration of uranium varied from 69 mg/kg in North Carolina to 153 mg/kg in Arad. Land development legacy issues have changed for the future:

- **Land use versatility:** Increased nutrient content of soils generally means that production from land increases and will sustain production for a limited time period without continuous fertiliser inputs. This allows additional flexibility to land managers, but in some instances might reduce the versatility for productive land use. The high nutrient status is not necessarily beneficial for all land uses. For example in viticulture, it causes excessive leaf growth. It is also unlikely that soils with substantially increased fertility could be restored back to previously occurring indigenous vegetation, which is adapted to low nutrient status. Given that the most threatened ecosystems are more likely to be originally on developed lowlands, nutrient enrichment decreases the likelihood of being able to reverse the decline in the remaining natural ecosystems. The accumulation of unwanted trace elements (e.g. cadmium, uranium and fluorine) to date in soils also has the potential to reduce the future versatility of productive land uses. Recognition of the potential effects arising this source has led to changes in fertiliser production, most notably specified limits, and reduced cadmium content of fertilisers. Surprisingly little thought has been given to the setting of background soil cadmium concentrations based on the future land use options as determined by soil type.

II Carbon dynamics: Transformation of forest soils to pastures has resulted in an increase in soil carbon (Tate et al., 2003, Tate et al., 2005). Conversion to cropped land decreases carbon contents generally but this varies depending on soil and cropping management (Poeplau et al., 2011). Losses of soil carbon have been reported for Gley and Allophanic soil under pasture on flat land the last few decades with gains occurring on hill country sites (Schipper et al., 2014). Whether these changes are ongoing is not known but have important effects on soil quality and ecosystem services (Sparling et al., 2003, Sparling et al., 2006). Rising temperatures will also have an effect.

III Physical integrity: There have been large changes in soil physical properties due to animal compaction and likely decreased earthworm mixing that allows soils to recover compaction events (see below). The alteration of physical structure can decrease production (Drewry, 2006, Drewry et al., 2008) but also lead to short-circuiting of contaminant transport through bypass flow (McLeod et al., 2008). Bypass flow can be beneficial in protecting nitrogen naturally mineralised in the soil's matrix from leaching, but it can lead to deleterious impact with surface-applied solutes like stock urine and pesticides (Robinson et al. 2013)

IV Soil biodiversity: Soil development with increased nutrients and alteration in plant litter inputs has altered soil biology (e.g., Stevenson et al., 2004), with the loss of biological diversity (Schon et al. 2008). For example of indigenous earthworm fauna (Megascolecidae) found in forest ecosystems in New Zealand which number 178 species (Glasby et al. 2009), are largely absent from pastoral soils because Megascolecidae did not evolve under grazed pastures (Springett et al. 1998). As a consequence earthworm functional diversity is naturally low in pastoral agricultural soils in New Zealand, with one (anecic) of the three recognised earthworm functional groups (Paoletti, 1999), the deep burrowing anecic earthworm often absent (Schon et al., 2011). Earthworm species that thrive under farmed pasture soils are exotic and were unintentionally introduced during European colonisation. These introduced species survived the long ship journey within the soil of potted plants and ships ballast from the United Kingdom and Europe (Smith 1893). Because there has been no systematic release of exotic earthworms, the number of species introduced is limited compared to the species diversity found in European farmland soils. The lack of earthworm species diversity was reflected in a nationwide survey in 1984–85 that revealed the presence of epigeic *Lumbricus* (L.) *rubellus* and endogeic *Aporrectodea caliginosa* in the majority of farm soils, while anecic earthworms, *A. longa* and *L. terrestris* were rarely found (Springett 1992). Schon et al., (2011) estimated there are 6.5 million hectares of pastoral land in New Zealand where anecic earthworms are absent. They suggested that the introduction of anecic earthworms to pastures where they are absent may provide greater resilience in the face of more pressures (e.g. live-weight loading, more volatile, climate).

V Nutrient enrichment: Large changes in nutrient status of soil have increased production but there are also environmental off-site consequences. Nitrogen saturation has occurred in some pasture soils (Jackman, 1964, Schipper et al., 2014, Schipper et al., 2004), which will impact on the capacity of soil to buffer ongoing nitrogen inputs. For example, an important setting in Overseer ® is N immobilisation potential. This capacity is initially high when forest/scrub are converted to pasture because C:N ratio are high (Hedley et al., 2009, Schipper & Sparling, 2011, Sparling et al., 2014) but decrease as soils develop and measures of recent changes suggest that for many flat pastures ongoing net nitrogen immobilisation is now not occurring (Schipper et al., 2014). The implications for other nitrogen loss pathways are not clear but suggest that these losses will increase. The appropriate setting in Overseer ® is poorly understood but has large implications for predicted nitrate leaching and other loss pathways including nitrous oxide losses.

Increases in Olsen P and presumably total P will increase vulnerability to losses mainly through surface runoff, but potentially through vertical flow in soils with low anion storage capacity or macro-pore flow (McDowell & Condron, 2004, McDowell et al., 2003). Edwards et al (1994) found in a Wharekohe podzol with an anion storage capacity of <10% that only about half the phosphorus that had been applied as fertiliser could be recovered. Significant amounts were found (10% of applied) where found to leach. Elevated soil P levels in a podzols, pallic or sand represent a significant risk to receiving environments.

VI Base Cation depletion: Nitrate formation and leaching is also the major mechanism for acidification of pasture soils (de Klein et al., 1997), that requires correction with regular additions of lime.With increased nitrate leaching comes the associated losses of cations such as calcium, potassium and magnesium. This is reflected in the need for potash soon after converting a sheep and beef operation to dairy. Within a few year of conversion the need to supplement dairy cows with magnesium due to the depletion in exchangeable magnesium in the topsoil because of the losses of magnesium associated with nitrate leaching exceeds the magnesium released through mineral weathering. What goes unnoticed is the losses of base cations associated with the leaching of not just Nitrogen but also the loss of sulphate sulphur (Sakadaven et al.1993), and the long-term implications of the grazing animal redistributing nutrients across landscapes. Building an understanding of the long-term changes in the balance of the base cations in the topsoil and depletion rates is a gap.

Of the phosphate rocks used in the past for superphosphate manufacture, Nauru with 100 mg/kg was one of the highest (Syers et al. 1986). The introduction of limits on Cadmium accumulate in soils is a consequence of past practice, but to date no limits have been suggested for either uranium and fluorine.

d. Management practices: In addition to unwanted elements in fertiliser, a wider range of additives and chemicals used in agriculture accumulate in soils. Livestock themselves are source of contaminants, through excretion of animal health remedies (e.g. zinc for facial eczema treatment, anitbiotics) or hormones (natural or synthetic) in urine or manure (Sarmah et al 2006, Macleod et al 2013). Application of dairy shed effluent to land may also result in contamination including pathogens and chemical contaminants that can contaminate soils DDE a breakdown product of DDT arsenic based pesticides and elevated copper levels in orchard soils, are further examples of contaminants that have been found to accumulate in soils. Current research has found DDE at concentrations that may conceivably have a detrimental effect in Australasian harriers from the Canterbury region, despite the soil concentrations of DDE and degradation products anticipated to being low. This demonstrates that bioaccumulation can be an important pathway of exposure to contamination in a New Zealand context. Soils associated with the production and use of Copper-Chromium-Arsenic (CCA) treated timber also exhibit elevated arsenic concentrations. Wood-waste and timber-treatment sites often contain arsenic hot spots that present a risk to groundwater. The extensive use of CCA-treated posts in agricultural and horticultural systems will lead to the long-term arsenic contamination of New Zealand's productive soils (Robinson et al, 2006).

e. Drainage: In understanding the size of the legacy issues associated with field drainage methods, which includes peat subsidence, soil carbon loss from mineral soils and compaction and pugging, it is also important to also intersect the area of drained soils with land use and connect this area hydrologically

to receiving environments as part of the wider analysis of the impact of drainage on air and water quality, water balance and threatened ecosystems:

I Peat subsidence: There are some 166,000 ha of peat lands in New Zealand (Daveron, 1978) much of which has been drained, mainly for grazing in the Waikato (94,000 ha) and Southland, large areas are more than 8 m deep. There are smaller areas in the Manawatu and other regions of the country. It is well recognised that following drainage, oxidation of surface organic matter and subsidence occurs as pores are dewatered. Pronger et al (2014) showed that NZ farmed peatlands are subsiding at about 20 mm y^{-1}. Farmers respond by digging drains deeper and re-contouring land restarting the cycle. In low lying areas, such as the Hauraki plains, some farms are already below sea-level, which is rising, and water must be pumped up and out. As long as peat is drained it will continue to lose surface elevation and pumping costs will increase, some peats are sufficiently high so that they can be gravity drained to the base. Where, when and what the consequences of this peat surface height loss will have on supporting infrastructure (including ongoing need to drainage), farm profitability and continued land use is not clear. While it is unlikely that subsidence can be stopped, mitigation strategies to decrease the rate of subsidence are needed.

II Soil carbon loss from mineral soils: Schipper et al. (2014) demonstrated that Gley soils had lost soil C during the past 2 to 3 decades (average of 7.8 t ha^{-1} in top 0.3 m) and suggested that this loss was due to drainage enhancing oxygenation that increased organic matter turnover. Whether these losses are continuing and what the effects on soil quality (e.g., structure, nutrient storage) is not known but losses of soil organic matter are generally more rapid than regaining organic matter. Greater losses of soil carbon were reported for drained pastures in Belgium where losses of between 20 and 40 t ha^{-1} (Meersmans et al., 2009, van Wesemael et al., 2010).

III Compaction and pugging risk: Drainage of saturated soils can results in large gains in per hectare production through a combination of increase forage and crop production, utilisation and animal performance. Associated with the higher animal performance is the increased risk of soil compaction from the higher more frequent grazing pressure, as these soils are often weakly developed, with poor aggregate stability. Importantly, while excess water is removed rapidly by the artificial drainage system, the soils are still wet and hence vulnerable to compaction and pugging. An interesting observation is artificially drained soils still have the appearance of the undrained parent, indicating artificial drainage systems are only particularly successful in removing the excess water.

IV Greenhouse gas production: A proportion of the peat subsidence is due to increased decomposition releasing large amounts of CO_2. The rate of CO_2 loss from New Zealand drained peats is very poorly constrained but has been estimated at about 1–4 t C ha^{-1} yr^{-1} (Nieveen et al., 2005, Schipper & McLeod, 2002) (Campbell et al. submitted). Extrapolating these rates to estimated peat area of the drained peat in the Waikato (75,000 ha) alone gives a national annual CO_2-C flux of between 0.075–0.3 Tg C y^{-1}. Assuming a total drained peat area for NZ of 149,400 ha gives an annual C flux of between 0.15–0.6 TgC y^{-1}. For comparison, Baisden and Manning (2011) estimated fossil fuel emissions contributed 9.7 Tg C y^{-1}, while Kyoto forest removed 4.6 Tg. Internationally, CO_2 losses from agricultural have been reported higher but New Zealand peats are formed from unique restiad plants in a generally much warmer climate and so data from overseas peats are unlikely to be transferable. Nitrous oxide emissions from grazed peats might be expected to be high since the soil conditions (anaerobic with high organic matter contents) would likely promote denitrification. However, there have been few measurements of N_2O emissions from agricultural peats soils in New Zealand (de Klein et al., 2003) (Kelliher et al in preparation). Kelliher et al (in preparation) measured a mean background N_2O flux of 1.6 kg N ha^{-1} y^{-1} from a peat soil, while the median from mineral soils was ~0.3 kg N ha^{-1} y^{-1}. The effects of urine and fertiliser input on peat N_2O flux have been estimated from a single study and had a lower emission factor than mineral soils (de Klein et al., 2003).

V Short-circuiting of pollutants to surface waters: Surface and subsurface drainage is designed to rapidly remove water and where cracks or macro-pores occur. The water and entrained pollutants effectively bypass the soil matrix (McLeod et al., 2008, McLeod et al., 2003). Surface applied pollutants such as pathogens, phosphorus and organic nitrogen, are normally removed by through sorption and filtering processes as they pass through the soil matrix, limiting the losses below the root zone to receiving environments (e.g., Monaghan et al., 2002, Monaghan

& Smith, 2004). This is particularly true for soil irrigated with farm dairy effluent (e.g., Houlbrooke et al., 2008), with bypass or preferential flows of effluent from irrigators effectively transporting the applied effluent directly to the tile.

VI Effects on biodiversity and threatened ecosystems: Some of New Zealand's most threatened ecosystems have naturally high water tables and are now surrounded by drained agriculture and the impacts of this drainage on ecosystem resilience is not well known. Drainage can lower the water table of these adjacent ecosystems dramatically altering local conditions that support the unique plant assemblages. An obvious example is that of wetlands, of which only 10% remain nationally (Ausseil et al., 2011) where drainage has adversely affected plant community composition (Ausseil et al., 2011, Clarkson et al., 2004, Myers et al., 2013, van Bodegom et al., 2006). The vulnerability of other native ecosystems to alteration of hydrology is poorly defined, such as Kahikatea forest stands of the lowland Waikato.

VII Changed Hydrology: Drainage of agricultural also alters hydrological flows in receiving waterways and wetlands which may have adverse effects on biota. For example, the Ramsar-designated wetland Whangamarino receives floodwaters on occasion of high rainfall which deposits sediments and nutrients into an internally recognised oligotrophic ecosystem changing plant community composition (Blyth et al., 2013). Drainage of wet soils by changing the water flow regulating service from the soil, also changes the hydrological characteristics of the landscape.

f. Irrigation: New Zealand has a long history of irrigation, with irrigation trials starting as early as 1880. Large scale irrigation development didn't expand until the 1910–1930 period. Irrigation development initially occurred in the drought prone Otago and Canterbury regions, and prior to the 1980's was central government funded schemes. Since the 1980's ownership has transferred back to farmers, and most subsequent schemes have occurred through private funding, either as individual farmers or as collective schemes. Most early irrigation was by flood irrigation methods, but by the early 2000's sprinkler systems had become predominant. The move away from flood irrigation is in part recognition of the adverse effects of excess water application on surface and groundwater quality (Carey et al., 2004; Close et al., 2008; McDowell and Rowley, 2008; Monaghan et al., 2009). Wastewater irrigation is also widespread in New Zealand and is likely to continue expanding placing pressure on soils and receiving environments. The first effects of irrigation on the wider environment were recognised in the water and Soil Conservation Act 1967, with the need recognised to restrict over extraction to maintain minimum flow constraints on certain rivers (Heiler, 2012). Over-extraction of groundwater also arose in Canterbury in the early 2000's, with implantation of zone limitations by the Regional Council. A number of the recent irrigation schemes have been developed to address historical river and stream flow issues, at the same time providing irrigation, e.g. the Opuha dam in South Canterbury has improved water flows in the Opihi River, and the Central Plains scheme in mid Canterbury will reduce groundwater extraction, improving stream flows into Te Waihora Lake (Irrigation NZ, 2014). The pathway to building new storage-based irrigation schemes will likely be fraught, especially with the NPS on Freshwater – as in the case of the Ruataniwha, likely to place limits on emissions.

References

AgriOpticsNZ 2013. VRI Case Study 1 – Greenvale pastures. http://www.agrioptics.co.nz/wp-content/uploads/2013/03/AONZ-VRI-Case-Study-1.pdf [Accessed October 2014]

Andrew, R, and 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 Vol. 43(3), 128–140. http://dx.doi.org/10.1080/03036758.2012.736392

Arnold KE, Brown AR, Ankley GT, Sumpter JS 2014. Theme Issue 'Assessing risks and impacts of pharmaceuticals in the environment on wildlife and ecosystems. 369 (1656).

Ausseil AGE, Chadderton WL, Gerbeaux P, Stephens RTT, Leathwick JR 2011. Applying systematic conservation planning principles to palustrine and inland saline wetlands of New Zealand. Freshwater Biology, 56, 142–161.

Baisden WT, Manning MR 2011. Editorial: The New Zealand carbon cycle: from regional budget to global cycle. Biogeochemistry, 104, 1–4.

Barringer JRF, Lynn IH, Basher LR 2013. Report on the 'Roadmap for the New Zealand Land Resource Inventory / Land Use Capability' Workshop, 9 October 2012. Landcare Research contract report; LC1197. Landcare Research. 15 p. http://www.envirolink.govt.nz/Envirolink-reports/1-NLCC1/1243-GSDC106/

Barringer JRF, Lynn IH, Basher LR, Medyckyj-Scott D. 2013. NZLRI/LUC Roadmap. unpublished Landcare Research Internal Report, p48.

Basher L, Lynn I, Barringer J 2014. Peer review of the process proposed to update the Erosion Susceptibility Classification for the National Environmental Standard for Plantation Forestry. Landcare Research Contract Report LC1877 for Ministry for Primary Industries.

Basher LR, Botha N, Dodd MB, Douglas GB, Lynn I, Marden M, McIvor IR, Smith W 2008. Hill country erosion: a review of knowledge on erosion processes, mitigation options, social learning and their long-term effectiveness in the management of hill country erosion. Landcare Research Contract Report LC0708/081.

Basher LR, Douglas G, Elliott S, Hughes A, Jones H, McIvor I, Page M, Rosser B, Tait A 2012. The impacts of climate change on erosion and erosion control methods – a critical review. MPI Technical Paper No. 2012/45, Ministry of Primary Industries, Wellington.

Basher LR, Painter DJ 1997. Wind erosion in New Zealand. In Proceedings of the International Symposium on Wind Erosion, Manhattan, Kansas, 3–5 June 1997, USDA-ARS, Manhattan. Available at http://www.weru.ksu.edu/symposium/proceed.htm

Basher LR, Ross CW 2001. Role of wheel tracks in runoff and sediment generation under vegetable production on clay loam, strongly structured soils at Pukekohe, New Zealand. Soil and Tillage Research 62,117–130.

Basher, L., Ross, CW 2002. Soil erosion rates under intensive vegetable production on clay loam, strongly structured soils at Pukekohe, New Zealand. Australian Journal of Soil Research 40, 947–961

Basher, LR, Ross, CW, Dando, J 2004. Impacts of carrot growing on volcanic ash soils in the Ohakune area, New Zealand. Australian Journal of Soil Research 42, 259–72.

Blyth JM, Campbell DI, Schipper LA 2013. Utilizing soil indicators to explain historical vegetation changes of a peatland subjected to flood inundation. Ecohydrology, 6, 104–116.

Bowler D.G. 1980. The Drainage of Wet Soils. Edition, illustrated. Publisher, Hodder & Stoughton, 1980. ISBN, 0340256907, 9780340256909.

Brazil, S (ed) 2008. New Zealand Official Yearbook. Statistics New Zealand. p357. ISBN 978-1-86953-717-3

Burney JA, Davis SJ, Lobell DB 2010. Greenhouse gas mitigation by agricultural intensification. Proceedings of the National Academy of Sciences of the United States of America, 107, 12052-12057.

Cadmium Working Group 2011. Cadmium and New Zealand Agriculture and Horticulture: a strategy for long term risk management. Http// www.maf.govt.nz/news-resources/publications.aspx

Campell, DI, Wall, AA, Nieveen, JP, Schipper LA (submitted) Variations in CO_2 exchange for dairy farms with year-round rotational grazing on peat soils. Agriculture, Ecosystems and Environment.

Carey PL, Drewry JJ, Muirhead RW, Monaghan RM 2004. Potential for nutrient and faecal bacteria losses from a dairy pasture under border-dyke irrigation: a case study. Proceedings of the New Zealand Grassland Association 66, 141–149.

Carrick S, Hainsworth S, Lilburne L, Fraser S 2013. S-map @ The Farm-Scale? Towards A National Protocol For Soil Mapping For Farm Nutrient Budgets. Fertilizer & Lime Research Centre Workshop. Massey University.

Carrick S, Lilburne L, Webb T, Hewitt A, Lynn I, Fraser S, Hainsworth S, Palmer D, McLeaod M, Barringer J, Medyckyj-Scott D 2014. S-map 2014 and Beyond. NZSSS 2014 Conference.

Carrick ST 2009. The dynamic interplay of mechanisms governing infiltration into structured and layered soil columns. PhD thesis, Lincoln University, Canterbury, New Zealand. Available from URL: http://hdl.handle.net/10182/1328.

Cavanagh JE 2014. Methodologies for deriving cadmium soil guideline values for the protection of ecological receptors and food standards. Landcare Research Contract Report LC1713 for Fertiliser Association of New Zealand and the Ministry for Primary Industry.

Cavanagh JE 2014b. Status of cadmium in New Zealand soils: 2014. Landcare Research Contract Report LC1857 for Fertiliser Association of New Zealand and the Ministry for Primary Industry.

Christchurch City Council. 2008. Draft south-west Christchurch area plan. Christchurch City Council, Christchurch, N.Z.

Clarkson BR, Schipper LA, Lehmann A 2004. Vegetation and peat characteristics in the development of lowland restiad peat bogs, North Island, New Zealand. Wetlands, 24, 133–151.

Close, M., R. Dann, A. Ball, R. Pirie, M. Savill, Z. Smith 2008. Microbial groundwater quality and its health implications for a border-strip irrigated dairy farm catchment, South Island, New Zealand. Journal of Water and Health 6, 83–98.

Clothier BE, Green S, Müller K, Gentile R, Herath I, Mason K, Holmes A 2013. Orchard ecosystem services: Bounty from the fruit bowl. Chapter 1.7 in Dymond JR ed. Ecosystem services in NewZealand – conditions and trends. Lincoln, Manaaki Whenua Press. Pp. 94–101.

Clothier B, Mackay A, Dominati E 2012 Natural capital and New Zealand's Resource Management Act (1991). Paper presented at the 2012 NZARES Conference Tahuna Conference Centre – Nelson, New Zealand. August 30–31, 2012.

Conant RT, Paustian K, Elliott ET 2001. Grassland management and conversion into grassland: Effects on soil carbon. Ecological Applications, 11, 343–355.

Cossens GG, Rickard DS 1966. Irrigation investigations in Otago, New Zealand. New Zealand Journal of Agricultural Research, 9(2), 197–217. doi: 10.1080/00288233.1966.10420774.

Cossens GG, Rickard DS 1969. Irrigation investigations in Otago, New Zealand. New Zealand Journal of Agricultural Research, 12(1), 193–213. doi: 10.1080/00288233.1969.10427089.

Crown Research Institute Task Force 2010. How to enhance the value of New Zealand's investment in Crown Research Institutes . Report of the Crown Research Institute Taskforce.

Curran-Cournane F, Vaughan M, Memon A, Fredrickson C 2014. Trade-offs between high class land and development: Recent and future pressures on Aucklands valuable soil resources. Land Use Policy (2014). http://dx.doi.org/10.1016/j.landusepol.2014.02.020

Daveron A 1978. A survey of New Zealand peat resources. University of Waikato (For the National Water and Soil Conservation Organisation) , Hamilton, New Zealand.

De Klein CaM, Barton L, Sherlock RR, Li Z, Littlejohn RP 2003. Estimating a nitrous oxide emission factor for animal urine from some New Zealand pastoral soils. Australian Journal of Soil Research, 41, 381–399.

De Klein CaM, Monaghan RM, Sinclair AG 1997. Soil acidification: a provisional model for New Zealand pastoral systems. New Zealand Journal of Agricultural Research, 40, 541–557.

De Luca R 2009. District plan review planner's report: section 16-rural-general strategy. Report prepared for Western Bay of Plenty District Council, Russell De Luca Consultancy. 20 p.

Dominati, E, Patterson M, Mackay A 2010. A framework for classifying and quantifying the natural capital and ecosystem services of soils Ecological Economics 69,1858–1868

Dominati E, Mackay A, Lynch B, Heath N, Millner I 2014. An ecosystem services approach to the quantification of shallow mass movement erosion and the value of soil conservation practices. Ecosystem Services 9, 204–215

Dominati E, MacKay A 2014. Using an ecosystem services approach to assess the cost of soil erosion. Soil Horizons, Issue 23, November 2014. National Land Resource Centre.

Drewry JJ 2006. Natural recovery of soil physical properties from treading damage of pastoral soils in New Zealand and Australia: A review. Agriculture Ecosystems & Environment, 114, 159–169.

Drewry JJ, Cameron KC, Buchan GD 2008. Pasture yield and soil physical property responses to soil compaction from treading and grazing - a review. Australian Journal of Soil Research, 46, 237–256.

Elliott A, Carlson W 2004. Effects of sheep grazing episodes on sediment and nutrient loss in overland flow. Australian Journal of Soil Research 42, 213–220.

Elliott A, Tian Y, Rutherford J, Carlson W 2002. Effect of cattle treading on interrill erosion from hill pasture: modelling concepts and analysis of rainfall simulator data. Australian Journal of Soil Research 40: 963v976.

Fairweather JR, Robertson NJ 2000. Smallholders in Canterbury: characteristics, motivations, land use and intentions to move. Research Report No.245. Lincoln University, New Zealand, Agribusinessand Economics Research Unit. 55 p.

FAR 2011. Variable rate irrigation case study. In: Combined FAR fieldday and Balance Farm Environment Awards Supreme Winners Field day handout, Rangitata Holdings, Wakanui, Canterbury, New Zealand. Field day pamphlet. Pp 8–11.

Flemmer CL, RC Flemmer 2008. Water effluent from New Zealand dairy farms from 1997 to 2000. New Zealand Journal of Agricultural Research 51,181–189.

Fraser PM, Schon NL, Piercy JE, Mackay AD, Minor MA 2012. Influence of summer irrigation on soil invertebrate populations in a long-term sheep irrigation trial at Winchmore (Canterbury). New Zealand Journal Agricultural Research 55(2), 165–180.

Green S, Clothier B 2009. Nitrate leaching under various land uses in Canterbury. A report prepared by Plant & Food Research. Environment Canterbury report no. R09/8, September 2009.

Greven M, Green S, Robinson B, Clothier B, Vogeler I, Agnew R, Neal S, Sivakumaran S 2007. The impact of CCA-treated posts in vineyards on soil and ground water Water Science & Technology Vol 56 No 2 pp 161–168 © IWA Publishing 2007 doi:10.2166/wst.2007.485

Grimmond D, Bell B, Yap M 2014. Future capability needs for the primary industries in New Zealand. Ministry for Primary Industry. Wellington, NZ.

Harmsworth GR, Page MJ 2009. Correlation of Land Use Capability (LUC) Units into a Single LUC Classification for the Horizons Regional Council Area, Landcare Research Contract Report: LC0809/082, Manaaki Whenua - Landcare Research , Private Bag 11052, Palmerston North, New Zealand.

Hedley CB, Kusumo BH, Hedley MJ, Tuohy MP, Hawke M 2009. Soil C and N sequestration and fertility development under land recently converted from plantation forest to pastoral farming. New Zealand Journal of Agricultural Research, 52, 443–453.

Hedley C, Craige R, Bradbury S 2013, 2012. Variable rate irrigation for improved water use efficiency. . Final Report Sustainable farming Fund project 10/111: 2010-2013. Landcare Research contract report LC 1592 http://maxa.maf.govt.nz/sff/about-projects/search/10-111/report.pdf [Accessed October 2014].

Hedley C, Yule I, Bradbury 2010. Analysis of potential benefits of precision irrigation for variable soils at five pastoral and arable production sites in New Zealand. Proceedings of the 19th World Congress of Soil Science: Soil solutions for a changing world, Brisbane, Australia, 1–6 August 2010.

Heiler, T 2012. 'Irrigation and drainage - Beginnings of irrigation', Te Ara - the Encyclopedia of New Zealand, updated 13-Jul-12 URL: http://www.TeAra.govt.nz/en/irrigation-and-drainage/page-2 [Accessed October 2014].

Houlbrooke D, Laurenson S, Carrick S 2011. Categorising the environmental risk from land application of liquid wastes based on soil properties. AgResearch report (961MLDC610 for Envirolink. http://www.envirolink.govt.nz/Envirolink-reports/ [Accessed 10 March 2014].

Houlbrooke D, Paton R, Littlejohn R, Morton J 2011. Land-use intensification in New Zealand: effects on soil properties and pasture production. The Journal of agricultural Science 149(3), 337–349.

Houlbrooke DJ, Horne DJ, Hedley MJ, Snow VO, Hanly JA 2008. Land application of farm dairy effluent to a mole and pipe drained soil: implications for nutrient enrichment of winter-spring drainage. Australian Journal of Soil Research, 46, 45–52.

Houlbrooke DJ, Paton RJ, Littlejohn RP, Morton JD 2011. Land-use intensification in New Zealand: effects on soil properties and pasture production. Journal of Agricultural Science, 149, 337–349.

Hughey KFD. Kerr GN, Cullen R 2013. Public Perceptions of New Zealand's Environment: 2013. EOS Ecology, Christchurch. vi+115 pp. ISSN 2230-4967

IPCC (Intergovernmental Panel on Climate Change) 2003. Chapter 3 LUCF Sector Good Practice Guidance, in: Good Practice Guidance for Land Use, Land-Use Change and Forestry, Edited by: J Penman, M Gytarsky, T Hiraishi, T Krug, D Kruger, R Pipatti, L Buendia, K Miwa, T Ngara, K Tanabe and F Wagner, IPCC National Greenhouse Gas Inventories Programme, Published by the Institute for Global Environmental Strategies (IGES) for the IPCC, http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.htm

IrrigationNZ 2014. New Zealand irrigation information. http://irrigationnz.co.nz/about-us/irrigation-facts/ [Accessed October 2014].

Jackman RH 1964. Accumulation of organic matter in some New Zealand soils under permanent pasture New Zealand Journal of Agricultural Research, 7, 445–471.

Jones, D 2012.The Role of Agriculture and Farm Households in the Rural Economy. Main findings of a report prepared for the OECD Trade and Agriculture Directorate.

Kelliher FM, Condron LM, Cook FJ, Black A 2012. Sixty years of seasonal irrigation affects carbon storage in soils beneath pasture grazed by sheep. Agriculture Ecosystems & Environment, 148, 29–36.

Kibblewhite MG, Deeks LK, Clarke MA 2010. A Gap Analysis on the Future Requirements of Soil and Water Management in England. Practice with Science Group, Royal Agricultural Society of England.

Lambert MG, Clark DA, Mackay AD, Costall DA 2000. Effects of fertiliser application on nutrient status and organic matter content of hill soils. N.Z. J. Agric. Sci. 43, 127–138.

Land and Water Forum 2012. Third Report of the Land and Water Forum: Managing Water Quality and Allocating Water. Wellington, Ministry for the Environment.

Landcare Research 2014. http://smap.landcareresearch.co.nz/home [Accessed 20 February 2014].

Landcare Research. The Formation of New Zealand Soils: http://soils.landcareresearch.co.nz/contents/SoilNames_NZSoilClassification_SoilFormation.aspx

Lawton M, Barton J 2002. Framework Report on the Development of the National Carbon Monitoring System (PDF 290 KB); also on LUCAS site in HTML format.

Leonard M, Gilpin B 2006. Potential impacts of on-site sewage disposal. ESR Client report CSC 0603, prepared for Gisborne District Council. [Online] http://www.envirolink.govt.nz/reports/documents/92-Gsdc1-SepticTankContaminationOfGroundwater.pdf (verified February 2009).

Lilburne L, Webb T, McNeil 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. Fertilizer & Lime Research Centre Workshop. Massey University.

Lilburne LR, Hewitt AE, Webb TH 2012. Soil and informatics science combine to develop S-map: a new generation soil information system for New Zealand. Geoderma 170, 232–238.

Lilburne LR, Trevor TH, Ford R, Bidwell V 2010. Estimating nitrate nitrogen leaching rates under rural land uses in Canterbury. Environment Canterbury report no. R10/127. 37 p. ISBN 978-1-927137-76-5 (printed version) ISBN 978-1-927137-77-2 (electronic version).

Loganathan P, Hedley M J, Grace ND, Lee J, Cronin SJ, Bolan NS, Zanders JM 2003. "Fertiliser contaminants in New Zealand grazed pasture with special reference to cadmium and fluorine: a review." Soil Research 41(3), 501–532.

Loganathan P, Mackay AD, Lee J,Hedley MJ 1994. Cadmium distribution in grazed hill pastures as influenced by 20 years of phosphate fertiliser application. Aust. J. Soil Res. 33, 859–871.

Luke CM, Cox PM 2011. Soil carbon and climate change: from the Jenkinson effect to the compost-bomb instability. European Journal of Soil Science 62, 5–12.

Luo J, De Klein CaM, Ledgard SF, Saggar S 2010. Management options to reduce nitrous oxide emissions from intensively grazed pastures: A review. Agriculture Ecosystems & Environment, 136, 282–291.

Lyn IH, Manderson AK, Page MJ, Harmsworth GR, Eyless GO, Douglas GB, Mackay AD, Newsome PJF 2009. Land Use Capability Survey Handbook – a new handbook for the classification of land 3rd ed. Hamilton. AgResearch; Lincoln, Landcare Research; Lower Hutt, GNS Science. 163 p.

Mackay AD, Gillingham A, Smith C, Budding P, Sprosen M, Johnstone P 2009. Phosphorus fertilizer requirements of high producing dairy pastures SIDE Proceedings "Resilient SIDE" 22-24th June 2009, Lincoln University, Canterbury pp. 153–161.

Mackay AD, Stokes S, Penrose M, Clothier BE, Goldson SL, Rowarth JS 2011. Land: Competition for future use. New Zealand Science Review 68, 67–71.

MacLeod CJ, Moller H 2006. Intensification and diversification of New Zealand agriculture since 1960: An evaluation of current indicators of land use change. Agriculture Ecosystems & Environment, 115, 201–218.

MAF, 2011. Hill Country Irrigation – SFF project 11/118 summary. http://maxa.maf.govt.nz/sff/about-projects/search/11-118/index.htm. [Accessed October 2014]

Maori Economic Development Panel 2012. He kai kei aku ringa - Crown-Māori Economic Growth Partnership: Strategy to 2040.

Marshall K, Avery G, Ballard R, Johns D 2012. A Call to Arms: A Contribution to a New Zealand Agri-Food Strategy. Report from the Riddet Institute Agri-Food Thought Leadership Team. Massey University.

Martin, Paul and Williams, Jacqueline, eds.2011, Defending the Social Licence of Farming: issues, Challenges and News Directions for Agriculture, CSIRO Publishing <http://books.google.co.nz/

McDowell R 2010. Is cadmium loss in surface runoff significant for soil and surface water quality: a study of flood-irrigated pastures? Water Air and Soil Pollution 209, 133–142.

McDowell RW, Condron LM 2004. Estimating phosphorus loss from New Zealand grassland soils. New Zealand Journal of Agricultural Research 47, 137–145.

McDowell RW, Monaghan RM, Morton J 2003. Soil phosphorus concentrations to minimise potential P loss to surface waters in Southland. New Zealand Journal of Agricultural Research, 46, 239–253.

McDowell, RW 2012. "The rate of accumulation of cadmium and uranium in a long-term grazed pasture: implications for soil quality." New Zealand Journal of Agricultural Research 55(2), 133–146.

McDowell RW, Rowley D 2008. The fate of phosphorus under contrasting border-check irrigation regimes. Australian Journal of Soil Research 46, 309–314.

McLeod M, Aislabie J, Ryburn J, McGill A 2008. Regionalizing potential for microbial bypass flow through New Zealand soils. Journal of Environmental Quality 37, 1959–1967.

McLeod M, Aislabie J, Ryburn J, McGill A, Taylor M 2003. Microbial and chemical tracer movement through two Southland soils, New Zealand. Australian Journal of Soil Research, 41, 1163–1169.

MacLeod M, Aislabie J, Hewitt A, Northcott G 2013. The fate of biological and organic contaminants in New Zealand soils. Landcare Research Contract Report LC1250 for NZ Land Treatment Collective, Rotorua.

Meersmans J, Van Wesemael B, De Ridder F, Dotti MF, De Baets S, Van Molle M 2009. Changes in organic carbon distribution with depth in agricultural soils in northern Belgium, 1960-2006. Global Change Biology, 15, 2739–2750.

Ministry for Business, Innovation and Employment 2013. The Business Growth Agenda. Wellington, Ministry for Business, Innovation and Employment.

Ministry for the Environment 2008. Climate change effects and impacts assessment: a guidance manual for local government in New Zealand. 2nd edn. Mullan B, Wratt D, Dean S, Hollis M, Allan S, Williams T, Kenny G, MfE eds. Wellington, Ministry for the Environment. xviii + 149 p.

Ministry for the Environment 2013. Freshwater Reform 2013 and beyond. Wellington, Ministry for the Environment.

Ministry for the Environment 2007. Environment New Zealand 2007 [Online]. Available by Ministry for the Environment, Wellington, N.Z. http://www.mfe.govt.nz/publications/ser/enz07-dec07/index.html (verified February 2009).

Ministry for the Environment 2008. Proposed national environmental standard for on-site wastewater systems: discussion document [Online]. Available by Ministry for the Environment, Wellington, N.Z. http://www.mfe.govt.nz/laws/standards/wastewater-systems-standards.html (verified February 2009).

Ministry of Agriculture and Forestry 2011. Technical Paper: Review of, and recommendations for, the proposed New Zealand Cadmium Management Strategy and Tiered Fertiliser Management System. MAF Technical Paper No. 2011/03. http://www.mpi.govt.nz/news-resources/publications

Ministry of Agriculture and Forestry 2008. Report one: Cadmium in New Zealand Agriculture. Report of the Cadmium working party August 2008. 85 p. http://maxa.maf.govt.nz/mafnet/rural-nz/sustainable-resource-use/land-management/cadmium-in-nz/report-one/cadmium-report-1.pdf

Ministry of Business and Innovation 2012. 2003–2013 Occupation Data prepared for Careers New Zealand. Ministry of Business and Innovation. Wellington, NZ.

Ministry of Business and Innovation 2014. Knowledge Intensive Services. The New Zealand Sectors Report 2014. Ministry of Business and Innovation. Wellington, NZ.

Monaghan RM, Paton RJ, Drewry JJ 2002. Nitrogen and phosphorus losses in mole and tile drainage from a cattle-grazed pasture in eastern Southland. New Zealand Journal of Agricultural Research, 45, 197–205.

Monaghan RM, Smith LC 2004. Minimising surface water pollution resulting from farm-dairy effluent application to mole-pipe drained soils. II. The contribution of preferential flow of effluent to whole-farm pollutant losses in subsurface drainage from a West Otago dairy farm. New Zealand Journal of Agricultural Research, 47, 417–428.

Monaghan R.M, Carey PL, Wilcock RJ, Drewry JJ, Houlbrooke DJ, Quinn JM, Thorrold BS 2009. Linkages between land management activities and stream water quality in a border dyke-irrigated pastoral catchment. Agriculture, Ecosystems & Environment 129, 201–211.

Monaghan RM, Houlbrooke DJ, Smith LC 2010. The use of low-rate sprinkler application systems for applying Farm dairy effluent to land. New Zealand Journal of Agricultural Research 53, 389–402

Monaghan RM, Carey PL, Wilcock RJ, Drewry JJ, Houlbrooke DJ, Quinn JM, Thorrold BS 2009. Linkages between land management activities and stream water quality in a border dyke-irrigated pastoral catchment. Agriculture, Ecosystems & Environment 129, 201–211.

Morgan F, Rutledge D, Price R 2010. Envirolink Tools - Land Use Database Project Gap Analysis and Prioritisation Report. Landcare Research Report LC0910-147 prepared for Envirolink. 75 p.

MPI 2011. Situation and Outlook for New Zealand Agriculture and Forestry (SONZAF) 2011. Wellington, Ministry for Primary Industries.

MPI 2012. Working towards New Zealand risk-based soil guideline values for the management of cadmium accumulation on productive land. Landcare Research Report LC965 for the Ministry for Primary Industry. MPI Technical Paper No: 2012/06.

MPI 2014. Briefing to the Incoming Ministers 2014. Wellington, Ministry for Primary Industries

Müller K, Manderson A, van den Dijssel C, Vogeler I, Clothier BE 2008. Relevance of EU focus surface and groundwater scenarios to New Zealand. Client report to ERMA New Zealand. Newsome PJF, Wilde RH, Willoughby EJ 2008. Land Resource Information System Spatial Data Layers: Data Dictionary, Landcare Research, Private Bag 11052, Palmerston North, New Zealand.

Myers SC, Clarkson BR, Reeves PN, Clarkson BD 2013. Wetland management in New Zealand: Are current approaches and policies sustaining wetland ecosystems in agricultural landscapes? Ecological Engineering, 56, 107–120.

Newton PCD, Carran RA, Lawrence EJ 2003. Reduced water repellency of a grassland soil under elevated atmospheric CO_2. Global Change Biology, 10(1), 1–4. doi: 10.1111/j.1365-2486.2003.00715.x

Newton PCD, Lieffering M, Bowatte WMSD, Brock SC, Hunt CL, Theobald PW, Ross DJ 2010. The rate of progression and stability of progressive nitrogen limitation at elevated atmospheric CO_2 in a grazed grassland over 11 years of Free Air CO_2 enrichment. Plant and Soil, 336(1), 433–441. doi: 10.1007/s11104-010-0493-0

Nieveen JP, Campbell DI, Schipper LA, Blair IJ 2005. Carbon exchange of grazed pasture on a drained peat soil. Global Change Biology, 11, 607–618.

NZWERF. 2004. On-site stormwater management guideline. New Zealand Water Environment Research Foundation, Wellington, New Zealand.

Pande TA, Valentine I, Betteridge K, Mackay AD, Horne D. 2000. Pasture damage and regrowth from cattle treading. N.Z. Grsslds. Assoc. 62, 155–160

Page MJ, Trustrum NA, Gomez B 2000. Implications of a century of anthropogenic erosion for future land use in the Gisborne-East Coast region of New Zealand. New Zealand Geographer 56(2), 13–24.

Parfitt RL, Baisden WT, Elliott AH 2008. Phosphorus inputs and outputs for New Zealand in 2001 at national and regional scales. Journal of the Royal Society of New Zealand, 38, 37–50.

Parfitt RL, Stevenson BA, Dymond JR, Schipper LA, Baisden WT, Ballantine DJ 2012. Nitrogen inputs and outputs for New Zealand from 1990 to 2010 at national and regional scales. New Zealand Journal of Agricultural Research, 55, 241–262.

Parfitt RL, Stevenson BA, Ross C, Fraser S 2014. Changes in pH, bicarbonate-extractable P, carbon and nitrogen over 5 to 30 yrs for soils under pasture. New Zealand J of Agricultural Research. 57, 216–227. DOI: 10.1080/00288233.2014.924536

Payn TW, Beare M, Shepherd M, Bayne K, Botha N, Collins A, Curtin D, Davis M, Fraser P, Hedley C, Hoogendoorn C, Johnstone P, Lucci G,Parfi tt R, Xue J 2013. Nutrient management science – state of knowledge, use and uptake in New Zealand. Ministry for Primary Industries Technical Paper No: 2013/XX. Soil and Land Use Alliance. 439 p.

Phillips C, Marden M, Basher L 2012. Plantation forest harvesting and landscape response – what we know and what we need to know. New Zealand Journal of Forestry 56, 4–12.

Phillips CJ, Marden M 2005. Reforestation schemes to manage regional landslide risk. In: Glade T, Anderson M, Crozier MJ eds Landslide hazard and risk. Chichester, UK, Wiley. Pp. 517–547.

Poeplau C, Don A, Vesterdal L, Leifeld J, Van Wesemael B, Schumacher J, Gensior A 2011. Temporal dynamics of soil organic carbon after land-use change in the temperate zone - carbon response functions as a model approach. Global Change Biology 17, 2415–2427.

Pronger J,Schipper LA, Hill R, Campbell DI, Mcleod M. 2014. Subsidence rates of drained agricultural peatlands in New Zealand and the relationship with time since drainage. Journal of Environmental Quality 43, 1442–1449.

Rickard DS,Cossens GG 1967. Irrigation Investigations in Otago New Zealand. New Zealand Journal of Agricultural Research, 11(3), 701–732. doi: 10.1080/00288233.1968.10422448

Robinson B, Clothier B, Bolan N, Mahimairaja S, Greven M, Moni C, Marchetti M, van den Dijssel C, Milne G 2004. Arsenic in the New Zealand environment 2004. 1HortResearch, Private Bag 11 030, Palmerston North, New Zealand.

Robinson BH, Greven MM, Green SR, Sivakumaran S, Davidson P, Clothier BE 2006. Leaching of copper, chromium and arsenic from treated timber vineyard posts in Marlborough, New Zealand, Science of the Total Environment 364,113–123.

Robinson DA, Jackson BM, Clothier BE, Dominati EJ, Marchant SC, Cooper DM, Bristow KL 2013. Advances in soil ecosystem services: Concepts, models and applications for Earth System Life Support. Vadose Zone Journal doi:10.2136/vzj2013.01.0027

Rosser BJ, Ross CW 2011. Recovery of pasture productivity and soil properties on soil slip scars in erodible siltstone hill country, Wairarapa, New Zealand. New Zealand Journal of Agricultural Research 54, 23–44.

Rutledge DT, 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 ofthe New Zealand Grassland Association 72, 241–246.

Rütting T, Clough TJ, Muller C, Lieffering M, Newton PCD 2010. Ten years of elevated atmospheric carbon dioxide alters soil nitrogen transformations in a sheep-grazed pasture. Global Change Biology, 16(9), 2530–2542.

Sarmah A, Meyer MT, Boxhall A 2006. A global perspective on the use, sales, exposure pathways, occurrence, fate and e ects of veterinary antibiotics (VAs) in the environment. Science of the Total Environment: 65, 725–759.

Schipper L 2004. Soil quality monitoring in New Zealand: trends and issues arising from a broad-scale survey. Agriculture Ecosystems & Environment, 104, 545–552.

Schipper LA, Dodd MB, Pronger J, Mudge PL, Upsdell M, Moss RA 2013. Decadal Changes in Soil Carbon and Nitrogen under a Range of Irrigation and Phosphorus Fertilizer Treatments. Soil Science Society of America Journal, 77, 246–256.

Schipper LA, Mcleod M 2002. Subsidence rates and carbon loss in peat soils following conversion to pasture in the Waikato Region, New Zealand. Soil Use and Management, 18, 91–93.

Schipper LA, Parfitt RL, Fraser S, Littler RA, Baisden WT, Ross C 2014. Soil order and grazing management effects on changes in soil C and N in New Zealand pastures. Agriculture Ecosystems & Environment, 184, 67–75.

Schipper LA, Percival HJ, Sparling GP 2004. An approach for estimating when soils will reach maximum nitrogen storage. Soil Use and Management, 20, 281–286.

Schipper LA, Sparling GP 2011. Accumulation of soil organic C and change in C:N ratio after establishment of pastures on reverted scrubland in New Zealand. Biogeochemistry, 104, 49–58.

Schipper LA, Sparling GP, Fisk LM, Dodd MB, Power IL, Littler RA 2011. "Rates of accumulation of cadmium and uranium in a New Zealand hill farm soil as a result of long-term use of phosphate fertilizer." Agriculture Ecosystems & Environment 144(1), 95–101.

Scott D 2009. Trends in fields of study of bachelor's degree graduates in New Zealand. Ministry of Education.

Scott JT, Stewart DPC, Metherell AK 2012. Alteration of pasture root carbon turnover in response to superphosphate and irrigation at Winchmore New Zealand. New Zealand Journal of Agricultural Research, 55, 147–159.

Soil and Land Use Alliance 2012 Reporting on soils at the national level. Report prepared for the Parliamentary Commissioner for the Environment, November 2012.

Sparling G, Parfitt RL, Hewitt AE, Schipper LA 2003. Three approaches to define desired soil organic matter contents. Journal of Environmental Quality, 32, 760–766.

Sparling G, Schipper L 2004. Soil quality monitoring in New Zealand: trends and issues arising from a broad-scale survey. Agriculture Ecosystems & Environment, 104, 545–552.

Sparling GP, Lewis R, Schipper LA, Mudge P, Balks M 2014. Changes in soil total C and N contents at three chronosequences after conversion from plantation pine forest to dairy pasture on a New Zealand Pumice soil. Soil Research, 52, 38–45.

Sparling GP, Wheeler D, Vesely ET, Schipper LA(2006. What is soil organic matter worth? Journal of Environmental Quality, 35, 548–557.

Srinivasan MS, McDowell RW, 2009. Irrigation and soil physical quality: an investigation at a long-term irrigation site. N. Z. Journal Agric. Res. 52, pp 113–121.

Statistics New Zealand, Ministry for the Environment, Department of Conservation 2013. Environment domain plan 2013: Initiatives to address our environmental information needs. www.stats.govt.nz. ISBN 978-0-478-40832-4 (online) Published 4 July 2013.

Stevenson BA, McNeill S, Hewitt AH 2015. Characterizing soil quality clusters in relation to land use and soil order in New Zealand: an application of the phenoform concept. Geoderma 239–240, 135–142.

Stevenson BA, Sparling GP, Schipper LA, Degens BP, Duncan LC 2004. Pasture and forest soil microbial communities show distinct patterns in their catabolic respiration responses at a landscape scale. Soil Biology & Biochemistry, 36, 49–55.

Stevenson BA, Parfitt, RL, Schipper LA, Baisden, WT, Mudge P 2010. Relationship between soil 15N, C/N and N losses across land uses in New Zealand. Agriculture, Ecosystems & Environment. 139, 736–741.

Syers JK, Mackay AD, Brown MW, Currie LD 1986. Chemical and physical characteristics of phosphate rock materials of varying reactivity. J. Sci. Food Agric. 37, 1057–1064.

Tait A 2011. Climate change projections for New Zealand – a literature review. NIWA Client Report WLG2011-48, for Landcare Research. 43 p.

Tate KR, Scott NA, Saggar S et al. 2003. Land-use change alters New Zealand's terrestrial carbon budget: Uncertainties associated with estimates of soil carbon change between 1990-2000. Tellus Series B-Chemical and Physical Meteorology, 55, 364–377.

Tate KR, Wilde RH, Giltrap DJ et al. 2005. Soil organic carbon stocks and flows in New Zealand: System development, measurement and modelling. Canadian Journal of Soil Science, 85, 481–489.

The Beehive 2013. http://www.beehive.govt.nz/sites/all/files/Irrigation%20Funding%20-%20Factsheet.pdf [Accessed 20 February 2013].

Tremblay LA, Stewart M, Peake BM, Gadd JB, Northcott GL 2011. Review of the Risks of Emerging Organic Contaminants and Potential Impacts to Hawke's Bay. Prepared for Hawke's Bay Regional Council. Cawthron Report No. 1973. 39 p.

Van Bodegom PM, Grootjans AP, Sorrell BK, Bekker RM, Bakker C, Ozinga WA 2006 . Plant traits in response to raising groundwater levels in wetland restoration: evidence from three case studies. Applied Vegetation Science, 9, 251–260.

Van Wesemael B, Paustian K, Meersmans J, Goidts E, Barancikova G, Easter M 2010. Agricultural management explains historic changes in regional soil carbon stocks. Proceedings of the National Academy of Sciences of the United States of America, 107, 14926–14930.

Watt JPC (ed.) 1972. Loess soils: problems of land use on the downlands of the South Island, New Zealand. Otago Catchment Board Publication No. 4. Dunedin, New Zealand.

Weeks E, Collins A 2013. Alignment of Land Special Interest Groups and the Naitonal Land Resource Centre Priorities. National Land Resource Centre Report LC1474 prepared for Envirolink. 34 p.

Weeks ES, Medyckyj-Scott D,Collins A 2013. A preliminary review of capacity building needs in the land resource sector. National Land Resource Centre. Palmerston North.

Wheeler D, Cichota R, Snow V, Shepherd M 2011. A revised leaching model for Overseer ® nutrient budgets. In: Adding to the knowledge base for the nutrient manager. (Eds LD Currie and CL Christensen). Occasional Report 24. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. http://flrc.massey.ac.nz/publications.html.

Wheeler DM, Sparling GP, Roberts AHC 2004. Trends in some soil test data over a 14-year period in New Zealand. New Zealand Journal of Agricultural Research, 47, 155–166.

Ministry for Primary Industries
Manatū Ahu Matua

NATIONAL
LAND RESOURCE
CENTRE

Landcare Research
Manaaki Whenua

THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

agresearch

Plant & Food
RESEARCH
RANGAHAU AHUMĀRA KAI

SCION
forests · products · innovation

What are we doing about soil management within the sectors? To what extent is soil protection/management provided for in our policies and plans? How do we measure up with our international peers and can we learn anything from them?

Future Requirements for Soil Management in New Zealand

Phase 2: **Looking out**

Future requirements for soil management in New Zealand. Phase 2: Looking Out.

Contract Report number: LC 2179

Project number: 17004

Suggested citation: Collins A, Mackay A, Thomas S, Garrett L, Weeks E, Johnstone P, Laurenson S, Dyck B, Payn T, Gentile R, 2015. Phase 2: Looking Out. Future requirements for soil management in New Zealand. National Land Resource Centre, Palmerston North.

Justine Daw – approved for release

Steering Group

Gary Bedford, Taranaki Regional Council
James Palmer, Ministry for the Environment
Lisa Harper, Federated Farmers
Nick Pyke, Foundation for Arable Research
Oliver Hendrickson & Gerald Rys, Ministry for Primary Industries

Design and layout by Nicolette Faville, Landcare Research

December 2014

National Land Resource Centre, c/o Landcare Research, Massey University, Private Bag 11052, Palmerston North 4442, New Zealand.

What are we doing about soil management within the sectors? To what extent is soil protection/management provided for in our policies and plans? How do we measure up with our international peers and can we learn anything from them?

Future Requirements for Soil Management in New Zealand

Phase 2: **Looking out**

Led by Alison Collins, Alec Mackay and Steve Thomas with:

Bill Dyck
Loretta Garrett
Roberta Gentile
Paul Johnstone
Seth Laurenson
Tim Payn
Emily Weeks

Contributions made by:

Nick Pyke – Arable and potato
Chris Keenan – Vegetable
Alistair Mowat – Kiwifruit
Tim Herman - Pipfruit
Alvaro Vidiella – Avocado
Mike Scarsbrock – Dairy
Nathan Heath and Simon Stokes – Regional councils
Victoria Lamb, Geoff Ridley and Matt Harcombe – Sheep and beef
Lindcay Fung – Deer
Kit Richards, Kelvin Meredith and Peter Weir – Forestry
Helen Marr and Lucy Cooper – Perception Planning

Contents

Summary

This report is the second in a three-phase project to inform both future policy formulation and good practice principles to take advantage of New Zealand's land and soil resource and maximise its productivity and value.

Phase 1 sets direction by identifying the pressures and impacts on New Zealand's soil resource. Phase 2 identifies the extent to which current practice, and our policy and planning framework, addresses these pressures and opportunities, as well as looking overseas for examples of how others have addressed priority pressures and impacts.

This report identifies:

- The complexity in the governance of soil in New Zealand, reflects the close links we all have with our land and its ownership and at the same time the involvement of a diverse range of organizations, sectors and individuals in decision-making. A co-ordinated approach to governance to utilize our natural advantage is overdue.
- That many of the priority pressures identified in Phase 1 (*poor matching of land use to inherent capabilities; inadequate vegetation cover; irrigation; addition of chemicals*) are identified as issues and addressed to some degree within primary sector practice; it is however, difficult to ascertain uptake or effectiveness.
- Some priority pressures are accommodated within the current policy and planning framework through a range of regulatory and non-regulatory approaches, but policy looking specifically at sustaining soils functional capacity has yet to emerge.
- Attention is needed to ensure:

  - Pressures associated with *poor matching of land use to inherent capability and fragmentation of land and loss of elite soils* are better dealt with, particularly given the finite nature of the soil resource

  - Pressures associated with emergent land uses (e.g. brought about by access to irrigation water and/or new technologies) are understood and incorporated within policy

  - An optimal mix of regulation and non-regulatory measures are developed to ensure the full range of services provided by soils is sustained into the future

  - The full potential of New Zealand's soil is unlocked and realised
- That as a small, biologically-based country New Zealand has the ability and agility to develop the partnerships and integrated measures to realize enduring economic, ecological and social value from its soils for the benefit of the nation

1

behind the wheel

Project genesis and purpose

This project sets out to determine the state of soil management in New Zealand, how to optimise the use of our land resources, and the readiness of the knowledge and capability to develop policy and support progressive stewardship. Appropriate policy and stewardship has the potential to retain land use flexibility, realise enduring economic value from New Zealand's soils, reduce the loss of high class soils for primary sector use, as well as support the implementation of the freshwater reforms.

Much of the evidence required for New Zealand to make informed decisions on its land and soil management sits within the science, primary and resource sectors either in the form of publications, reports, strategies, models and decision-support tools or anecdotal knowledge. To extract greater value from this collective evidence-base requires an approach that captures, integrates, and synthesizes this disparate knowledge. This report is the second of three phases of work:

1) Looking back: What are the current and emerging pressures to New Zealand's soil resource? How well is the knowledge and capability primed to meet these pressures? (Phase 1)

2) Looking out: What are we doing in regard to soil management, is it enough, and can we learn anything from international case studies? (Phase 2)

3) Looking forward: What do we want from New Zealand soils? What policy, practice, science, and institutional shifts can we make to get there? (Phase 3)

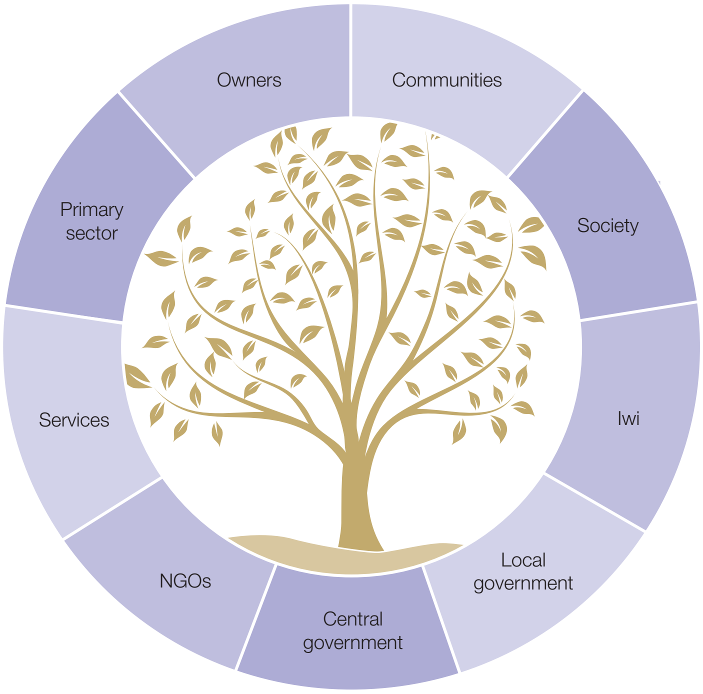


Fig 1.1: Main stakeholders with an interest in soil and land in New Zealand

Phase 1 provided the direction or lens for the phases that follow – setting down the key pressures and impacts. This phase (Phase 2) identifies how well we are doing across practice, policy, and planning and looks overseas for examples of how others have addressed priority pressures and impacts. While collectively these three phases of work will inform future policy formulation in government, planning and regulation in regional councils, as well as good practice principles and sector strategies for business and industry, the key opportunities, gaps and recommendations will be the domain of Phase 3 (Looking Forward).

Who is behind the wheel?

Because of its close link with land and its ownership, the governance of soil in New Zealand is highly complex, involving a diverse range of organisations, sectors, and individuals. The 'stakeholders' in the domains of soil and land are represented in Figure 1.1 and include:

- Māori: The legal definition of Māori land is provided by section 129 Te Ture Whenua Māori Act 1993 and includes a variety of titles including Māori Customary and Māori Freehold Land, General Land

Owned by Māori, Crown Land Reserved for Māori, and some treaty settlement reserves, mahingā kai, and fishing rights areas (Land Information New Zealand).

Around 1.5 million hectares of land in New Zealand is Māori land (around 5% of New Zealand's total land area). Of this, 750 187 hectares (or 49.5% of Māori land) is administered by ahuwhenua trusts, and 207 157 hectares (or 13.7% of Māori land) is administered by Māori incorporations. The remaining 300 000 hectares or 20% of Māori land is not administered by trusts or incorporations (Tē Ara).

Through the Treaty of Waitangi Negotiations Māori have sought redress for breaches by the Crown of the guarantees set out in the Treaty of Waitangi. This has resulted in settlement packages including compensation and the transfer of significant land holdings. There have been 52 such settlements since between 1990 and 2014 (Office of Treaty Settlements), with more expected in coming years, emphasising the very critical role of Māori in the future management and governance of New Zealand's soil resource.

Almost all incorporations, and a significant proportion of the ahuwhenua trusts, have an interest in agriculture, horticulture and forestry. In 2007 it was estimated that the asset value of these organisations was around $3.2 billion. This figure does not include the assets of Māori who privately own agricultural farms or forestry lands. Eighty percent of Māori owned land is in LUC (Land Capability Classification) classes 4–7 (reduced versatility) and more than 50% is divided into blocks three hectares or less. The potential of large areas of Māori owned land has therefore yet to be realised. Raising the productivity of these land assets is an aspiration of the Māori Economic Development Panel in line with the principles of kaitiakitanga and whanaungatanga.

- Central government:

  - *The Ministry for Primary Industries* (MPI) focuses on five main areas under its 'Strategy 2030': helping maximise export opportunities for primary industries; improving sector productivity; ensuring food is safe, increasing sustainable resource use, and protecting New Zealand from biological risk. While MPI is responsible for administering legislation that covers a wide range of sectors as regards the soil, it functions less as a regulator and focuses more on supporting and working with primary industries (MPI 2015) through partnerships and investment (such as East Coast Forestry Programme, Irrigation Acceleration Fund, Primary Growth Partnership, Restoring the Waiapu Catchment, Sustainable Land Management, Sustainable Farming Fund & Hill Country Erosion Programme).

  - *The Ministry for Environment's* (MfE) mission is focused on environmental stewardship for a prosperous New Zealand. As highlighted in Section 3: *In plans and policies*, MfE plays a critical role in both regulatory and non-regulatory approaches governing natural resources, including those that directly (e.g. Soil Conservation and Rivers Control Act 1941) and indirectly (e.g. National Policy Statement for Freshwater 2014) influence the decisions made on soil and land resource. MfE is also responsible for reporting on the state of land through six national environmental indicators: land cover, land use, soil health, soil erosion risk, area of native land cover, and distribution of seven selected native species. Like MPI, MfE is also an enabler, partner and investor for others managing land such as Contaminated Sites Remediation and Community Environment Funds.

- *Land Information New Zealand* (LINZ) retains maps, land records, land registration, and survey information to support others in managing land. It also manages the licensing, leasing, and tenure review of Crown pastoral land.

- *The Department of Conservation* (DOC) is charged with the conservation of New Zealand's natural and historical heritage As a consequence of the Conservation Act, all Crown land in New Zealand designated for conservation and protection became managed by the Department of Conservation. The DOC estate covers about 30% of New Zealand's land area or about 8 million hectares of native forests, tussock-lands, alpine areas, wetlands, dune-lands, estuaries, lakes and islands, national forests, maritime parks, marine reserves, nearly 4000 reserves, river margins, some coastline, and many offshore islands. All the land under its control is protected for conservation, ecological, scenic, scientific, historic or cultural reasons, as well as for recreation. It is not, however, bound by the 1991 Resource Management Act.

- Local government: New Zealand is divided into sixteen regions for devolved local government. Eleven are administered by regional councils (the top tier of local government), and five are administered by unitary authorities, which are territorial authorities (the second tier of local government) that also perform the functions of regional councils. The boundaries of the regions are based largely on catchments – anticipating the responsibilities required under the 1991 Resource Management Act. Regional authorities are primarily responsible for the integrated management of natural and physical resources; planning for regionally significant land uses; as well as soil conservation, water quality and quantity, water ecosystems, natural hazards, and hazardous substances. Regional authorities also manage flood and river control under the 1941 Soil Conservation and Rivers Control Act.

  Territorial authorities are responsible for local-level land-use management (urban and rural planning); network utility services such as water, sewerage, storm water and solid waste management; local roads; libraries; parks and reserves; and community development. Property rates (land taxes) are used to fund both regional and territorial government activities. There is a high degree of cooperation between regional and territorial councils, given their complementary roles.

- Communities: range from local residents in a catchment who unite over a particular issue; groups that come together in an activity (sometimes accessing funds such as the Community Environment Funds (previously Sustainable Management Fund), e.g. planting, restoration or establishing a best practice), and often in partnership with others such as the Landcare Trust; through to structured and formal initiatives such as Community Land Trusts that acquire and hold land for the benefit of community (e.g. for creating affordable housing). Implementation of the Freshwater Reforms is likely to elevate the role of communities in making decisions about land use, including planning and the setting of limits.

- Society: play an important role in determining the management of the soil resource. The triennial 'Public Perceptions of New Zealand's Environment: 2013 Survey' found water-related issues were perceived to be the most important problem facing the environment (Hughey et al. 2013), no doubt contributing to the ratification of the National Policy Statement on Freshwater. Society also plays a role providing primary producers with a 'social license to operate' and authenticating brand (Martin et al. 2011).

- Non-governmental organisations: are of relevance to soil management, and represent a range of organisations committed to environmental and/or recreational outcomes. NGOs perform a variety of roles including campaigning, raising awareness and engaging (e.g. Environmental Defence Society), providing advice and partnering (e.g. Landcare Trust), developing scientific understanding (e.g. Ecologic), conservation and land management projects (e.g. Forest & Bird), and actively managing recreational land and adjacent waterways (e.g. Fish & Game). In directly the involvement by a number of these NGO's in plans changes to address declining water quality (e.g. Taupo, Rotorua, Canterbury) have by default drawn them into the debate on the regulation of land.

- Service organisations: play a critical role in supporting primary industries in their endeavours. This includes generating research and development, providing access to innovation and advice, and ensuring the effective transfer of best practice guidelines, tools, technologies, and codes. Such agencies are funded through membership, industry levies and/or grants; they include, but are not limited, to: Foundation for Arable Research, Horticulture NZ, Fertiliser Association of NZ, Deer Industry NZ, NZ Winegrowers, Zespri, Pipfuit NZ, NZ Avocados, Irrigation NZ, Federated Farmers, Fertiliser Association of NZ, Business NZ, etc.)

- Primary sector: spans agriculture (sheep and beef, wool, deer, dairy, pork, poultry, arable and horticulture), fishing, and forestry. New Zealand's land area comprises approximately 43% pasture and arable; 27% other non-forested; 6% plantation forestry and 24% natural forest (MfE 2015). There is considerable variation in the intensity of land use within each of these classes. The sector comprises broad-spectrum industry groups and organisations such as Federated Farmers, representing the collective interests of the production sectors, cooperatively owned companies such as Fonterra and Zespri, through to individual producers and growers. Each production sector (i.e. forestry or arable) is made up of a range of producers and growers, each varying in the scale of operations, intensification, investment and adoption of tools and technologies. Collectively, the primary sector plays a significant role in the stewardship of New Zealand's soil and land, and by nature, is the sector with the largest impact on these resources.

Organic farming began on a commercial scale in the 1980s and now represents an increasing segment of the market. The New Zealand Biological Producers and Consumers Council (BioGro) was formed in 1983 to support producers, and to certify produce to BioGro standards and international regulations. A number of agencies supporting and servicing the organic farming movement have been established, particularly in areas of soil biological health and productivity.

- Owners: this final stakeholder grouping is perhaps where most complexity lies. Land owners can be Maori, Maori agribusiness owners, or other owners who form part of agribusiness or other primary sector segments. Land owners can be residential or industrial and will make decisions influenced by a wide range of factors such as market forces, cultural values, or societal perceptions. Decisions, such as how they use the land, whether it is leased, how much they invest in it, will have a significant effect on the condition of the underlying soil resource and associated receiving environments.

Partnership – the new vehicle for change?

The stakeholders described above do not operate in isolation. At times they may have conflicting perspectives, at other times they may be well aligned and working in collaboration. Given the complexities of the challenge, property rights (private and public), competing resource use (production within environmental limits), governance (ownership, use and guardianship), and the demands and variety of stakeholders for the finite services the land provides and their scales of operation, achieving better alignment between these groups is critical to ensure progressive stewardship of the soil resource into the future.

The establishment of the Land & Water Forum (LAWF), bringing together 62 organisations across industry groups, electricity generators, environmental and recreational NGOs, iwi, scientists, central and local government to develop a common direction for freshwater management in New Zealand demonstrates both the appetite for, and the potential of, collaboration in the pursuit of nationally agreed outcomes. The theme of collaboration and partnership emerges throughout the following sections of this Phase 2 report.

'On the Ground' reviews how the primary sector perceives key pressures and, most important, how it is responding to them. The review reveals the longstanding partnerships between the primary sector and service sector to develop and embed best practice soil management guides, tools, technologies, and codes.

'In plans and policies' explores the policy framework in New Zealand, including the range of regulatory and non-regulatory approaches and their relevance to address key soil pressures. This section also identifies the partnership and interdependency between central and regional government as well as the gains made through bringing regulatory and non-regulatory approaches together in addressing key pressures.

'Measuring up' reviews what approaches our international peers have taken to increase awareness, close knowledge gaps, integrate soil management into policy and planning, develop specific legislation, and/or manage soil pressures. As in the previous sections, partnership and collaborative action emerges as a necessary and common element.

Key findings

- The governance of soil in New Zealand, because of its close link with land and its ownership, is highly complex and involves a diverse range of organizations, sectors and individuals

- Stakeholders of the soil and land resource do not operate in isolation, at times having conflicting perspectives and at other times being well-aligned and working in collaboration.

- The establishment of the Land & Water Forum (LAWF), bringing together 62 organisations, demonstrates both the appetite for, and the potential of, collaboration in the pursuit of nationally agreed outcomes.

2

on the ground

Understanding sector pressures and responses

This section explores how the primary sector currently perceives and manages key pressures. Collectively, the primary sector plays a significant role in the stewardship of New Zealand's soil and land.

As highlighted in the previous section, the primary sector is diverse, comprising broad-spectrum industry groups that represent the collective interests of the production sectors, cooperatively owned companies, through to individual producers and growers. Within the primary sector the constituent producers and growers vary in scale of operation, access to investment, and therefore in their ability to adopt and use tools and technologies. To understand the extent of this variability, tables were pre-populated by sector project teams (e.g. Scion for forestry) using a combination of expert knowledge of their sector and review of sector strategies. Tables were then tested with key individuals or groups through interviews, committee meetings, and workshops to identify the:

- Pressures and relative priorities: Using the Phase 1 framework (key pressures on soils, scale/extent and severity/size of problem) pressures were rated as local, regional or national, and low, medium or high severity

- Initiatives used in response to these pressures: Including best practice soil management guides, tools, technologies and codes

- Relative uptake and adoption of initiatives, as well as their effectiveness: Where this is monitored and evaluated by the sector

- Drivers of adoption: From the industry perspective and including reference to relevant reviews such as Survey of Rural Decision Makers (vetted by Regional Councils; NZIER; Beef & Lamb New Zealand (B+LNZ), DairyNZ, Horticulture New Zealand (HortNZ), Rural Support Trust and Hawke's Bay Wine Growers Association).

Care was taken to reference industry-accepted good practice, strategies, and papers and to consult with the sectors; however due to the size and scope of the project this is by no means comprehensive. A summary of this analysis is presented in Table 2.1 with more detailed sector profiles presented Appendix A.

Overall, the analysis suggests individual sectors (within the wider primary sector) perceive a similar set of pressures to those identified in Phase 1. The relative importance of pressures, however, varies by sector (e.g. forestry v dairy), reflecting both the type of land and soil (typically the Land Use Capability Class) managed by the sector and the pressures generated by the practices employed.

Most sectors are actively managing threats, particularly those that affect their productivity and profitability. Of particular note in terms of emergent pressures is increasing cultivation due to the greater reliance on short-rotation forage crops in pasture agriculture, cultivation on fragile landscapes, increased loadings on the soil due to high stocking rates and use of larger

Table 2.1

MAIN PRIORITIES (in terms of pressures from Phase 1)	SCALE & SEVERITY	THREATS & OPPORTUNITIES (How these pressures manifest)	INITIATIVES	UPTAKE / ADOPTION & EFFECTIVENESS (What is level of uptake and how effective is the initiative?)	DRIVERS OF ADOPTION
PLANTED FORESTRY SECTOR					
Intensification – Inadequate vegetation cover/harvesting	National, high	Erosion and loss of topsoil	Forest Stewardship Council (FSC) (New Zealand Forest Owners Association 2011/2012). FSC certification requires best management practices and independent 3rd party auditing of practice to be undertaken to ensure compliance. There is also an Environmental Code of Practice and a number of guidelines, handbooks and codes to help implement Best Management Practices (e.g. Forest Road Engineering Manual; FOA Harvesting Manual)	50% of planted forest area is now certified (with a bias towards large/corporate forest owners). A 20% increase in the area of forest certified over the past decade is a clear indication of a management preference	Market forces (FSC provides market access). The National Environmental Standard for Planted Forest under development may provide regulatory drivers for future adoption of initiatives
Land use change – poor matching of land use to capability	National, high	Erosion and loss of topsoil			
Climatic – increased vitality/ storminess	National, medium	Erosion and loss of topsoil			
Legacy – modification of soils	National, medium	Maintaining productivity over multiple rotations	Retirement of land where not environmental or economically viable	Only large forest growers – and where it is unviable	Market forces. The National Environmental Standard for Planted Forest under development may provide regulatory drivers for future adoption of initiatives
DAIRY SECTOR					
Intensification – Irrigation	Regional, high	Nutrient leakage (especially expansion to stony/sloping soils) Increases productivity and reduces drought risk	Irrigation scheduling tools (e.g. neutron probe scheduling, consultants). More efficient irrigation systems. Effective design, maintenance (including link to irrigation NZ standards)	Driver for irrigation is increased production and reduced risk	Limits on water takes. Restriction on takes during dry conditions. Nutrient caps/limits imposed through regulation
Intensification – Wastewater	National, medium	Increased risk of nutrient leakage under poorly designed/managed systems. Human & animal health. GHG emissions	Sustainable Dairying: Water Accord (2013) DairyNZ Farm Dairy Effluent design code of practice. Various forms of compliance monitoring by councils, including New Zealand Environmental Farm Plans Fonterra Every Farm Every Year Programme DairyNZ WOF scheme and code of Practice	Fonterra Sustainable Dairying Advisors /Area Managers and DairyNZ regional consultants involved in monitoring and advising	Condition of supply to dairy companies. Source of nutrients rather than a cost to the business. Regulatory back stop of the Resource Management Act/Regional Council requirements (various)
Intensification – Loadings rate	National, high	Water quality impacts. Soil structure (runoff, WHC, soil quality inc. biological, physical and chemical) Increased GHG emissions	Sustainable Dairying: Water Accord (2013). Fonterra Nitrogen Programme. Farm nutrient budgets (inc OVERSEER). Farm Management plans	Fonterra Sustainable Dairying Advisors /Area Managers and DairyNZ regional consultants involved in monitoring and advising	Loss of pasture production. Higher costs of production if not managed. Caps/limits on emissions
Land use change – poor matching of land use to capability	National, high	Podzols, Gleys Pallic, Gravels, Sands, pumice, soils. All these soils are weakly structured and have low sorption capacities. Soil erosion Increased nutrient leakage (e.g. stony or sloping soils).	Dairy Sector Strategy: Making Dairy Farming Work for Everyone. Strategy for Sustainable Dairy Farming 2013–2020. Based around 10 main objectives. Specific targets relating to each objective. Key sector strategy: Proactive environmental stewardship and wise use of natural resources (including soil). Resource consent process overseen by regional councils	Fonterra Sustainable Dairying Advisors /Area Managers and DairyNZ regional consultants involved in monitoring and advising	Combined pressure of the drive for more milk and limiting impacts on receiving environments
Land use change – Irrigation-driven land use change	Local, high	Can cause damage to marginal land and fragile soils, but also can reduce drought risk and lift productivity. Off-site impacts such as deteriorating water quality		Limited	Investment in the sector
Land use change – Restoration and introduction of diversity	National, high	On-going pressure on few lowland indigenous habitats/ecosystems remaining	Previous clean stream accord and current Sustainable Dairying: Water Accord (2013). DairyNZ WOF scheme and code of Practice. Specific initiatives such as riparian plantings of stream margins	Fonterra Sustainable Dairying Advisors /Area Managers and DairyNZ regional consultants involved in monitoring and advising	Condition of supply to dairy companies. Regulatory back stop of the Resource Management Act / Regional Council requirements (various)
SHEEP & BEEF SECTOR					
Intensification – Inadequate vegetation cover / harvesting	National, high	Erosion, reduction in soil/intactness and loss of natural soil capital. Loss of elite soils to urban and restrictions. Pressure on fragile soils from on-going intensification. Protection and restoration of indigenous fragments	Wide promotion of the Land & Environment Planning (LEP) toolkit (3 levels of detail), raising awareness through field days, and a comprehensive and regularly updated website on environmental and other challenges. Land Use Capability Handbook (3rd edn) and classification system, and inclusion of its well-founded principles in the LEP Toolkit. Participation in regional schemes such as Sustainable Land Use Initiative (SLUI) with Horizons RC. Poplar and willow wide-spaced plantings for erosion control on pastoral hill country	In the last 15–20 years all monitor farms have included an environmental plan of some kind. Established, healthy, wide-spaced trees reduce shallow landslides on pastoral land by 70–95%. LEP Toolkits (level 3) provide a whole-farm plan similar to those used by regional councils, providing documented knowledge of the farm's resources and strategies to address important environmental and other issues. In the last 12 months B+LNZ has held 60+ LEP level-1 workshops throughout the country to increase the number of farms with formal plans. The sector goal is adoption of a Level 1 working towards an LEP level 2 by all sheep and beef farmers. However, no statistics on actual use of the LEPs	Ability to access capability and funding through schemes such as SLUI, SLMACC and the Hill Country Erosion Fund particularly for soil conservation. Access to capacity in regional councils through partnership programmes also seen as critical. Regulations relating to freshwater limits also likely to impact on adoption
Land use change – fragmentation of land & spill-over poor matching of land use to capability.	National, medium National, high National, medium				
Legacy effects – pests and diseases	National, medium				
VEGETABLE SECTOR					
Intensification – irrigation	National, high	New land use opportunities but also threat to soil biophysical integrity	Irrigation NZ Guidelines & Code of Practice	Highly variable depending on level of investment from grower and the type of initiative irrigation e.g. drip irrigation vs. variable rate irrigation	Improvement in yield is major driver. Access to capital is variable across growers – smaller growers may not be able to afford latest technologies. Also depends if land is leased or owned – as investment is long term

Table 2.1 (continued)

MAIN PRIORITIES (in terms of pressures from Phase 1)	SCALE & SEVERITY	THREATS & OPPORTUNITIES (How these pressures manifest)	INITIATIVES	UPTAKE / ADOPTION & EFFECTIVENESS (What is level of uptake and how effective is the initiative?)	DRIVERS OF ADOPTION
Intensification – more chemicals	National, high	Nutrient leakage & over use of fertilisers	Nitrogen and Phosphorus recorded and agronomists/ fertiliser representatives advise – Good & Best Management Practices developed. (http://www.hortnz.co.nz/assets/Uploads/Auckland-Waikato-ES-Control-Guide-lines-1-1.pdf)	Good – with most growers adopting good & best management practices	Awareness of freshwater issues rising with the National Policy Statement for Freshwater and subsequent policy frameworks to calculate nitrogen loads of catchments and on-farm leaching levels
Intensification – cultivation	Regional, high	Erosion & sediment loss	Range of techniques: Wheel-track dyking, sediment traps, earth bunds, raised headlands, paddock contouring. Broad-scale support for catchment initiatives, including the Franklin Sustainability Project, The Lake Horowhenua Accord, and other projects looking at coordination of drainage systems and production of land contouring alongside catchment-scale sediment controls	Good uptake based on Code of Practice. This code has been revised three times. It now forms the basis of cropping management in three key regions (Horizons, Canterbury, Auckland / Waikato and adopts a new Risk Based Assessment format. The Code is now being made a national code, and will form the basis of a module on soil management in NZGAP	Meeting sector good and best practice and gaining market access (NZGAP)
Intensification – cultivation	National, medium	Soil organic matter & soil structure	Development of programmes to support advanced farming systems and precision agriculture. Support for Landwise programmes. Advice produced in A Guide to Smart Farming (2011)	Survey data for Franklin show broad adoption of a range of the practices. But the effectiveness of techniques is not quantified from a mass balance perspective (desktop studies have suggested effectiveness but not proved this). In the medium term we have an SFF project application in to start on this work	Ensuring crop health and ongoing cropping – very practical driver
Land use change – fragmentation of land/spill over	National, high	Loss of elite soils	Main activity providing input to plans to protect high class soils from subdivision and urbanisation on a large scale (~30 plan changes over the last 5 years). Intervention has focussed on managing growth through structure plans, protection of production land values including soil/climate/water/infrastructure, protection of rural character, reverse sensitivity and subdivision methods, setbacks, etc. Seeking recognition in RMA reform of the finite characteristics of versatile soil and land (section 6–7 reform)	Current efforts are focussed in Auckland where the land supply issue is causing major land pressure. Auckland processes have prevented significant urbanisation over the last 7 years, including Rodney PC 132 and Franklin PC14. Our methods have had high success in many areas; in other areas less so. We are very limited by the level of resourcing we can provide at any one time	Market driven issue – with growers being encouraged to sub-divide. Good rating practice from local councils is necessary (rates rebates and amendments to valuation techniques to rate land on the actual use as opposed to the potential use)
Legacy effects – pesticides, waste	National, high	Heavy metal accumulation	Production of a wide range of training, guidance and modelling support through the GROWSAFE initiatives and NZS:8409 Safe Management of Agrichemicals	High as cohesive certification and training programmes wired in as critical non-compliances in GAP programmes	
ARABLE (including potato)					
Intensification – cultivation	National, medium	Loss of soil organic matter and soil structure. Loss of production. Increased risk of soil loss through erosion	Increasing use of minimum, no-till or strip till practices. Increasing use of precision agriculture and mapping technology	Between 2006 and 2011, the number of growers ploughing after grass has fallen from c. 60 to 50%. Cropping Sequences Surveys 2006 and 2011. Information provided to all levy paying growers. Extension information and demonstration of practices on farm and via research	Positive: Farm economics Profitability and reduced costs Negative (lack of adoption): Perceived risk of negative outcome following change Cost of introducing new management or equipment
Intensification – Loadings	National, high	Compaction. Increased risk from larger harvest machinery. Compaction from heavier livestock grazing crops	Reduced tillage to retain soil structure	See cultivation above	Negative (lack of adoption): Problem of critical timing of harvesting coinciding with risk of compaction
Intensification – Soil borne diseases	National, high	Loss of productivity	Research to identify disease/pathogen drivers and to enable development of management options	Likely to be high due to the potentially large production losses	Profitability will be a key-driver when controls are found
Climatic – increased vitality/ storminess	Regional, high	Loss of production due to storms and flooding	Changing of planting times to avoid periods of flood risk and increase range of harvest windows		
Legacy effects – pests and diseases	National, high	Weed incursion and proliferation. New species and herbicide resistance	Lacking. Cultivation, herbicide use and burning are main management options. Cultivation and burning is reducing	Uptake is likely to be high as it is an important issue	Driven largely by farm economics
KIWI FRUIT					
Intensification – more chemicals	Regional, medium	Nutrient leakage	Tools such as SPASMO, OVERSEER and industry research projects have helped quantify the risks of nitrogen leaching. Research projects have defined practices to minimise leaching	Leaching of nitrogen in regions with high rainfall and deep, well-drained or light soils is recognised as a risk by the kiwifruit industry but as yet growers are not limited by regulation on nitrogen applications or timing. Grower use of practices, such as rates, timing and application method, are therefore voluntary and not monitored	Market access. Research demonstrating that fruit quality can be improved and vine pruning costs can be reduced through lower rates of nitrogen application are resulting in a reduction of nitrogen applied to kiwifruit orchards
Legacy effects – pests & diseases, pesticides	Regional, medium	Loss of soil biological activity due to copper contaminant associated with the PSA disease control	Developing integrated PSA disease control methods are part of the broader PSA management programme. Good practice is expected to be achieved through greater use of products and control methods that have a lower impact on soil biological function than copper-based control methods	Low (as primary focus for growers has been on controlling PSA disease on kiwifruit). Adoption will increase as viable alternatives to copper become available for PSA disease control. Research investment is in place to develop more integrated PSA control programmes	As cost-competitive alternatives to copper become available, kiwifruit growers are expected to reduce their dependency on copper and reduce the risks of soil contamination from copper
PIPFRUIT					
Intensification – more chemicals (fertilisers)	National, high	Nutrient leakage & over use of fertilisers	NZ Pipfruit IFP Manual provides guidelines for nutrient management practise. Minimum requirements include record keeping and soil nutrient analysis every 3 years. Industry factsheets on nutrient management, soil and plant nutrient analysis sampling	Good. Most growers following recommendations	Market access and documentation of good practices for buyers
Intensification – more chemicals (pesticides)	National, medium	Loss of organic matter and associated soil structure. Loss of soil biota	NZ Pipfruit IFP Manual provides guidelines for soil organic matter management. Recommend monitoring every 5 years	Good. Most growers following recommendations	Market access and documentation of good practices. Concerns about soil quality and maintaining good soil structure and drainage

machinery and changing temperatures (increasing the spread of weeds and pests and the risk of drought).

There are a number of sector-specific initiatives used to manage soils as well as practices that are common across the sectors including:

- Codes of practice, manuals and management guidelines (e.g. specifying options for managing effluent, irrigation, cropping or roading)
- Farm planning approaches (e.g. Land and Environment Plans)
- Nutrient budgeting tools in particular OVERSEER
- Smart or precision agriculture (e.g. reduced tillage, variable rate irrigation, and precision fertiliser application).

Partnerships between the primary sector and the 'service sector' (e.g. Irrigation NZ, Foundation for Arable Research, HortNZ, and Fertiliser Association of New Zealand etc.) have been successful, providing education and extension, as well as driving the development and embedding of initiatives and practices. Supporting and working with primary industries through partnerships and investmen (e.g. East Coast Forestry Project, – see Section 3: *In plans and policies*) have also been responsible for significant improvements in soil management, more often as a way to meet national or regional policy objectives (erosion control, water quality improvements).

Uptake and adoption of practices varies according to a range of factors including access to investment, education, maturity of sector, and strength of the partnership with related service sectors. For the forestry, pipfruit, and kiwifruit sectors, particularly for large or corporate growers, demonstrating compliance to environmental codes of practice or wise use of soil is driven by gaining access to (largely overseas) markets. In the dairy, beef and lamb, vegetable, and arable sectors the adoption of soil management initiatives is more often voluntary and typically a response used to increase production, profitability or reduce risk and costs. Most of these sectors, however, are aware that meeting water quality targets set as part of the implementation of the freshwater reforms is likely to become a significant driver of good practice, particularly for controlling nutrient and sediment loss.

A major gap across all sectors is lack of monitoring and evaluation of the use and uptake of soil management measures. There is also little in the way of comprehensive assessment of the effectiveness of measures – although some initiatives are underway to remedy this.

Table 2.2

PHASE 1 PRESSURES (TOP SIX)	RELATIVE AWARENESS OF PRESSURES AND INITIATIVES IN PLACE TO MANAGE THEM, BY SECTOR							IS IT ENOUGH GIVEN PRIORITY OF PRESSURE?
	Planted forestry	Dairy	Sheep, beef & deer	Vegetable	Arable	Kiwifruit	Pipfruit	
Irrigation	Not an issue for this sector	Range of initiatives in place to manage irrigation pressures (e.g. effective design, irrigation standards, scheduling tools)	Not an issue for this sector	Range of initiatives in place to manage irrigation pressures	Not identified as an issue for this sector	Not identified as an issue for this sector	Not identified as an issue for this sector	Managed but still significant opportunities to increase water use efficiency and better consider the impacts on soil function
More chemicals	Very low levels of chemicals used but high awareness of market pressure to reduce amount and understand/ manage potential impacts on waterways	Range of initiatives in place to manage pressure (codes of practice, accords)	Good and best management practices in place and supported by service sector (e.g. fertiliser, agrichemical companies)	Good and best management practices in place and supported by service sector (e.g. fertiliser, horticulture)	Good and best management practices in place and supported by service sector (e.g. fertiliser, agrichemical companies)	Not identified as a major pressure but practices in place to minimise leaching	Guidelines for nutrient management and industry factsheets	Managed but limits that consider soil function needed
Inadequate vegetation cover	Long standing awareness of the pressures by the sector with Environmental Code of Practice and other initiatives such as National Environmental Standard and FSC guiding good practice	Not identified as an issue for this sector	Wide promotion of Land & Environmental Plans (LEPs) to address this issue	Not identified as an issue for this sector	Not identified as an issue for this sector	Not identified as an issue for this sector	Not identified as an issue for this sector	Managed but question over whether emerging issues (annual crops, short rotation pastures etc.) are adequately covered
Fragmentation of land & spill over	Not identified as an issue for this sector	Not identified as an issue for this sector	Awareness but other than LEPs nothing in place	Very aware however activity limited to provision of information and to planning input	Concerned about the issue, but no activity in place	Concerned about the issue, but no activity in place	Not identified as an issue for this sector	Limited opportunity for sectors to manage this high priority pressure
Poor matching of land use to inherent capability	Long standing awareness of the pressures by the sector with FSC and other initiatives guiding good practice	Awareness of the issue particularly on weakly structured soils with low sorption capacities – while in the Dairy Sector Strategy, there remain gaps	Wide promotion of Land & Environmental Plans (LEPs) to address this issue but continuing pressure to intensify on fragile land	Not identified as an issue for this sector – except where elite soils are being used to support urban expansion	Not identified as an issue for this sector	Not identified as an issue for this sector	Not identified as an issue for this sector	Difficult to manage given scale and pace change and complexity of drivers
Pests and diseases	Awareness of risks high but plant focused, small emerging threat of soil borne diseases	Awareness of the issue and covered in sustainable milk plans	Awareness of the issue and part of the LEPs	Addresses indirectly	Awareness of the issue but more the threat of emerging soil-borne diseases	Practices in place to replace copper-based control methods that impact on soil biological function	Not identified as an issue for this sector	Managed but need to mindful of the potential impact of new control methods/treatments on soil functional capacity

Is it enough?

Phase 1 reviewed the pressures on the soil and other natural resources identifying six priorities based on the scale of impact, ability to mitigate or reverse the impact and the social acceptability of impact. Our analysis suggests that the sectors are both aware and have initiatives in place to address these pressures. However there remains a question over whether the current initiatives are effective enough to actively reduce these pressures. A more systemic view of how each pressure is managed across the sectors is presented in Table 2.2 and highlights:

1. Irrigation as part of intensification ranks highly as a pressure; both because of the rapid expansion in irrigated land and as very little is known about the long-term implications on soil function. The management of irrigation pressures by the sectors is driven by likely gains in product yield and quality, profitability, improvements in water use efficiency, and cost-savings. The freshwater reforms are also requiring better irrigation practices but targeted at protecting against impacts on water quality and allocation, and not specifically soil function. Despite the range of good practices there are still significant opportunities to increase water use efficiency through wider adoption, better irrigation management practices and in some cases investment in technology.

2. Addition of chemicals as part of intensification is a major pressure, given the effects on soil functional capacity and freshwater quality. Affected sectors are actively managing these pressures, driven by a combination of conditions of supply, market access and regulation through the freshwater reforms. However existing limits on losses are defined on the basis of freshwater quality, with no specific limits on nutrients or contaminants (e.g. cadmium, fluoride, uranium, copper, and zinc) in soils.

3. Inadequate vegetation cover as a result of intensification causes erosion and sediment transfer to freshwater as well as loss of productive soils. Affected sectors have developed strong partnerships to proactively manage the problems, particularly in erodible hill country. An emerging risk however is the increased use of annual crops, short rotation pastures and forage crops, increasing the risk of soil loss during periods when soils are bare.

4. Fragmentation of land and spillover from urban expansion as part of land use change can reduce the availability of versatile and elite soils. While there is awareness of the pressure and related impacts across the sectors, all are limited in their ability to manage or reduce these when land prices and market forces encourage fragmentation and there is little in the way of regulatory backstop. More infrequent but as important is the fragmentation of Maori land, particularly remote forest blocks that can be uneconomical to harvest if disconnected from other forest blocks. Overall our analysis suggests not enough is being done to manage this high priority pressure.

5. Poor matching of land use to inherent capability has resulted in soils being used beyond their functional capacity. The scale and speed of some land use change is a major concern such as the rapid expansion of dairying onto shallow soils in

Canterbury, humping, hollowing and flipping on the West Coast, and dairy conversions from forestry in pumice soils.

While the New Zealand Land Use Capability Classification System (Lynn et al., 2009) helps define use of land (and is the basis of many farm planning approaches), it is not always the primary determinant of how land is used or managed. This is due to the complexities of landownership, governance (see Section 1: Behind the wheel) and day-to-day decision-making (e.g. market conditions, regional rules, farmer knowledge and risk tolerance), that collectively affect the way land is used and make it difficult to realise the full potential of soil. As a consequence of this complexity and without clear leadership beyond the sectors, not enough is being done to manage this increasingly critical pressure.

6. Pests and diseases impact directly by increasing the risk of soil erosion and indirectly through the addition of unwanted elements and compounds from control treatments. At present these pressures are managed well by the sectors, with the Kiwifruit sector for example, reducing copper-based PSA (Pseudomonas syringae) control methods to prevent impact on soil biological function. While we have characterised this pressure as under control, it is important to remain mindful of the potential impact of new control methods and treatments on soil functional capacity.

Key findings

The primary sector plays a significant role in the stewardship of New Zealand's soil and land, and by nature, is the sector with the largest impact on these resources. In general the wider sector:

- Recognises the range of pressures on the soil and manages them through both sector-specific practices and common initiatives (e.g. codes of practice, guidelines, farm planning, nutrient budgeting as well as smart or precision agriculture).

- Has variable uptake and adoption of practices according to a range of factors (e.g. access to capital or farmer knowledge) and driven by demonstrating compliance for market access, increasing productivity and profitability or reducing risks and costs.

- Recognises many of the priority pressures identified in Phase 1 (*poor matching of land use to inherent capabilities; inadequate vegetation cover; irrigation; addition of chemicals*) as issues and address to some degree within primary sector practice; it is however, difficult to ascertain uptake or effectiveness.

- Are cognisant and responsive to the implementation of the freshwater regulations and the importance of soil management practices to meet freshwater limits and targets. However without defined limits to protect soil functional capacity not all issues will be addressed.

- Are not well-equipped to deal with *fragmentation of land and spillover from urban expansion* and its impact on the availability of versatile and elite soils. This is due to the overriding influence of land prices, government response to liberate land for housing supply and little to no regulation.

- Is unable to do enough to address the pressures of *poor matching of land use to inherent capability* or realise the full potential of soil, given the complexities of landownership, governance (see Section 1: *Behind the wheel)* and day-to-day decision-making (e.g. market conditions, regional rules, farmer knowledge and risk tolerance).

3

in plans and policies

The policy and planning framework in New Zealand

New Zealand develops a range of policy, legislative, economic, and voluntary measures to foster economic growth and ensure environmental well-being. The Resource Management Act 1991 (RMA) is New Zealand's main piece of legislation governing the use and development of environment. Central government administers the RMA and provides national direction using instruments such as National Environmental Standards and National Policy Statements. Other than setting national direction, decision-making under the RMA is generally the responsibility of local authorities (regional, district and unitary councils). A range of non-regulatory approaches and reporting frameworks are used to complement and inform the regulatory framework, as presented in Figure 3.1

Central government regulation

At the national level there is a range of regulatory instruments of relevance to soil, providing some direct or indirect protection of soils. These policies tend towards regulating activities rather than ensuring outcomes, and where the policy or legislation relates to soil, the extent is generally limited to the protection of a specific impact of that soil, as summarized in Table 3.1.

- The Resource Management Act (RMA) promotes the sustainable management of natural and physical resources such as land, air and water. At the time it was introduced (1991) it was revolutionary, establishing one integrated framework replacing a number of resource-use regimes such as land use, forestry, pollution, air and water, which were previously fragmented across agencies and

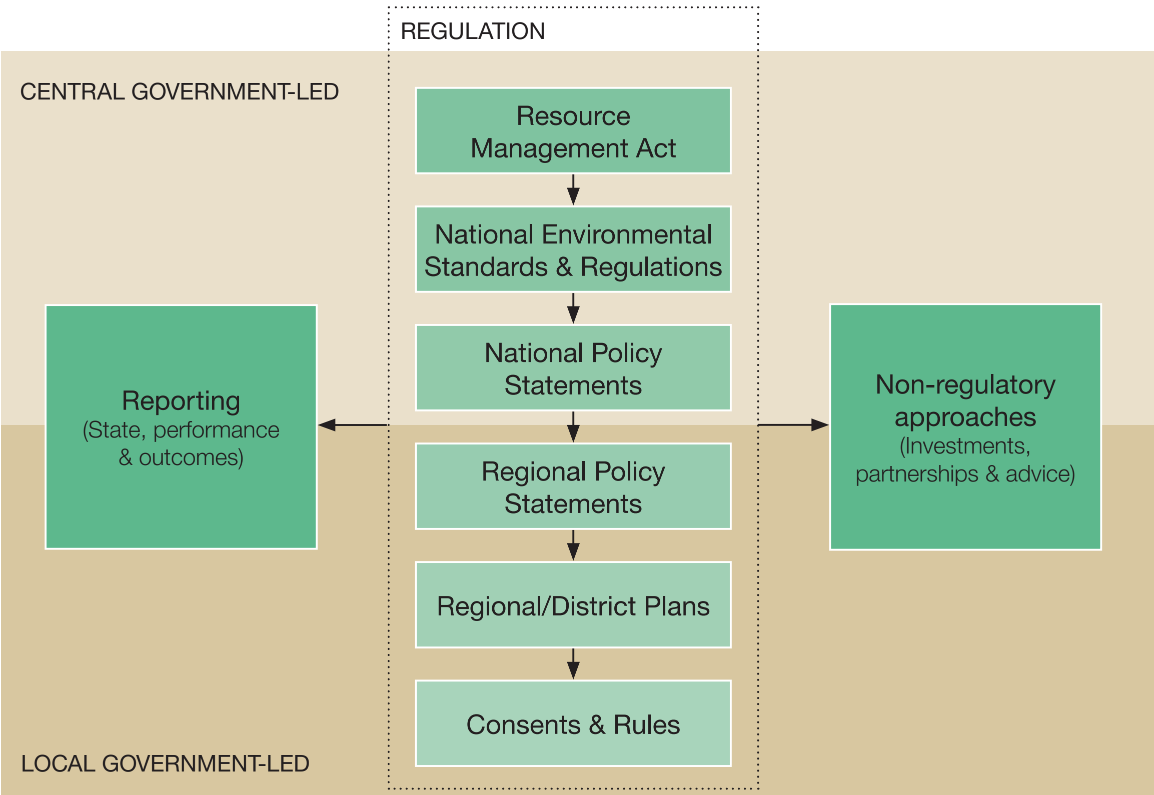


Fig 3.1: Environmental policy and planning framework in New Zealand.

Table 3.1

INSTRUMENT / CASE	IDENTIFIED PRESSURES	GAPS & OPPORTUNITIES	REGULATORY RESPONSE
Resource Management Act (1991)	Theoretically all key pressures but currently not specific on any	RMA is extremely prescriptive in legal processes but not in terms of environmental quality standards – it is more of an enabling legislation. While the RMA requires monitoring of the state of the environment, it does not provide a monitoring protocol or interpretive framework (note this is challenged in the Environmental Reporting Bill and initiatives such as Environmental Monitoring and Reporting).	RMA allows for land management to be regulated through regional and/or district plans and through granting resource consents. Policies are required to achieve integrated management of the natural resources. Consistency must be maintained between national, regional, and district policies with any inconsistences to be taken to an Environment Court for resolution.
National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health (2014)	**Legacy effects** – pesticides, waste; mining & extraction	Again, not designed to specifically address the range of soil pressures; only those pressures relating to contaminated land.	Each territorial and unitary authority implements this NES in accordance with their section 31 functions under the Resource Management Act 1991 (RMA) relating to contaminated land, specifically section 31(b) (iia) "the prevention or mitigation of any adverse effects of the development, subdivision, or use of contaminated land".
Proposed National Environmental Standard for Planted Forests	**Intensification** – inadequate vegetation cover, cultivation/ harvesting **Land-use change** – poor matching of land use **Legacy effects** – deforestation, modification of soils	This work overlaps with the water reforms being considered, however, MPI and MfE have worked closely to ensure that the proposed NES for Plantation Forestry aligns with the National Policy Statement for Freshwater management. If ratified the NES will address land use effects on water quality, particularly sedimentation effects from harvesting and earthworks, the proposed NES-PF is expected to contribute to improved water quality outcomes	The proposed NES comprises rules for eight activities related to forestry, across four erosion susceptibility classes, which would largely override rules in district and regional plans. Some of the proposed NES regulation addresses land-use effects on water quality, particularly sedimentation effects arising from harvesting and earthworks.
National Policy Statement for Freshwater (2014)	**Intensification** – more chemicals; waste water effluent & storm water	The NPS FW seeks to address many of the pressures identified in Phase 1 as they affect key water quality and quantity attributes only Does not recognise land as a finite resource Any monitoring or evaluation will not examine the impact on reducing soil pressures/impacts (proximal) but the distal or offsite impacts on freshwater.	Policy A3 requiring regional councils where permissible, to make rules for the adoption of the best practicable option to prevent or minimise any actual or likely adverse effect on the environment of any discharge of a contaminant into fresh water, or onto or into land in circumstances that may result in that contamination.
	Intensification – all **Land use change** – all **Legacy effects** – all		Policy C1 requiring every regional council to manage fresh water and land use and development in catchments in an integrated and sustainable way, so as to avoid, remedy or mitigate adverse effects, including cumulative effects.
	Intensification – all **Land use change** – all **Legacy effects** – all		Policy C2 requiring every regional council to make or change regional policy statements to the extent needed to provide for the integrated management of the effects of the use and development of land on fresh water, including encouraging the coordination and sequencing of regional and/or urban growth, land use and development and the provision of infrastructure.
Soil Conservation and Rivers Control Act (1941)	**Intensification** – inadequate vegetation cover **Legacy effects** –deforestation, modification of soils	The Act was developed to prevent the damage caused by erosion and sediment transfer, so is limited in the pressures it deals with and focused more on the offsite impacts. However, under Section 16 of the Act MfE holds a small number of Soil Conservation Reserves (Wharekiri and Waerenga-o-kuri in Gisborne, Tangoio near Napier, and Wither Hills, adjacent to Blenheim), which effectively takes fragile land out of production.	Place vulnerable land under regional council control and into Crown ownership.
Hazardous Substances and New Organisms Act (1999)	**Legacy effects** – hazardous substances	There are 22 regulations under this Act covering a broad scope of controls, very few of relevance to the soil. The Act focuses primarily on protecting the health and safety of people by preventing or managing the adverse effects of hazardous substances and new organisms. It does not focus on ensuring soil quality.	Most relevant are Sections 25, 25a and 25b 25AA, which restrict the import, manufacture, development, field testing, or release of hazardous substances; prohibit the import, manufacture, or use of persistent organic pollutants; and prohibit the storage of persistent organic pollutants.

sectors. The RMA allows for land management to be regulated through regional and/or district plans and through the resource consent process.

- National Environmental Standards (NES) are regulations issued by the government under sections 43 of the RMA and apply nationally. There are two NES of relevance to soil (one in force, the other still in development): the *NES for Assessing and Managing Contaminants in Soil to Protect Human Health* (2012), and the proposed N*ES for Plantation Forestry*. The NES for Contaminants provides regulates specific activities on land where there is potential contamination and seeks to enable the safe use of affected land. The standard does not explicitly focus on the protection of soil resource. The proposed NES for Plantation Forestry would use the Erosion Suseptibility Classification (ESC) to categorize the risk of erosion on land. As the risk of erosion increases the controls applied to forestry activities will increase.

- National Policy Statements (NPS) are instruments available to the government under the RMA to provide direction on matters of national significance. The *NPS for Freshwater Management* (NPSFM) (2014) will have a significant impact on future land use and soil management through its aims to improve freshwater. The NPSFM directs regional councils to establish objectives and set limits for freshwater in their regional plans. As with the NES' identified above, the NPSFM is focused on addressing those pressures identified in Phase 1, but only as they affect key water quality and quantity attributes. There is no provision within the NPS to recognise land as a finite resource, nor regulate to prevent impacts on the soil resource.

- Other acts, statutes, and instruments have been established over the decades to protect natural resources and ecosystems. Of those most relevant to soil are the *Soil Conservation and Rivers Control Act 1941; Drainage Act 1908 (amended 1952); Biosecurity Act 1993;* reserves vested in regional councils under the *Reserves Act 1977*, and hazardous waste under the *Hazardous Substances and New Organisms (HSNO) Act 1996*.

Local government regulation

The purpose of a *Regional Policy Statement (RPS)* is to set policy to achieve integrated management within a region. Every region must have an RPS, and the RPS must give effect to the relevant NES and NPS. The RPS provides an overview of the significant resource management issues facing the region and sets out the objectives, policies and methods to address them. The extent to which RPS recognise and prioritise the range of pressures varies according to the characteristics of land and soil, the predominant land use within the regions as well as the priorities identified by the community through the consultation process.

Regional Plans and *District Plans* give effect to the direction set in the RPS and may include regulatory approaches and rules to achieve objectives and address key resource management issues. Some regions still use a number of single-issue plans (e.g. Land and Vegetation Plan, River or Catchment Plan, Coastal Resource Plan) within the region, while others, such as Horizons Regional Council, are taking a second generation approach, combining the Regional Policy Statement, Regional Coastal Plan, and regional plans within one.

We reviewed five RPS documents, each at different stages of maturity (1998 through to 2014), from regions with different soils, landscapes, land use characteristics and communities (and hence pressures). The case studies included three regional authorities (Horizons, Canterbury and Otago) and two unitary authorities (Gisborne and Auckland).

For each case study, the RPS was analysed against each of the soil management challenges identified in the report, *Future Requirements for Soil Management in New Zealand – Phase 1: Looking Back*. An assessment was then undertaken to determine whether, and to what degree, the soil management challenges are identified as resource management issues in the RPS documents. The responses proposed in each RPS to address Phase 1 pressures are also identified. It should be noted that only 5 out of 13 RPS were reviewed and no regional or district plans.

Table 3.2 illustrates the findings of the RPS review, which includes:

- Intensification pressures: this set of pressures includes irrigation, cultivation and inadequate vegetation cover. There is some consistency across the five case studies in that each region has identified most of the aspects of intensification as resource management issues. The range of intensification pressures is most comprehensively dealt with by Horizons Regional Council. Horizons One Plan was the only case study to identify resource management issues that either directly or indirectly addressed all the intensification pressures identified in Phase 1.

  With the implementation of the NPS for Freshwater intensification pressures resulting from increased irrigation, more chemicals and wastewater/effluent disposal are likely to gain greater prominence.

- Land use issues include fragmentation of land and spillover, poor matching of land use to inherent capability and irrigation-driven land use change. Canterbury and Horizons are the two case study RPS documents that include resource management issues that either directly or indirectly address all of the land use challenges identified in Phase 1. In the case of Horizons, Issue 3 - Unsustainable Hill Country Land Use - identifies unsustainable pasture-based farming practices in the region's steeper hill-country as resulting in damage to soil structure and accelerating erosion. The issue pertaining to poor matching of land use to inherent capability is addressed by objective 4-1 within the One Plan requires that by 2017 50% of all hill country farms will have in place farm-wide sustainability practices (through a farm plan).

  While the 16 regional councils in the 'Land Monitoring Forum' have collectively identified land fragmentation as a high priority (Collins et al. 2014), only the Gisborne District and Canterbury RPS case studies include direction to develop rules in district plans to manage the pressures on the soil resource resulting from sub-division and settlement. These include regulatory responses such as rules in the Gisborne District Plan preserving highly versatile and productive lands for agricultural production on the Poverty Bay flats, with lifestyle and rural development zoned restricted to the less versatile soils close to Gisborne City.

Table 3.2

Pressures (under key categories from Phase 1)	Horizons One Plan (2014)		Otago RPS (1998, new expected 2015)		Gisborne RPS (2002)		Canterbury RPS (2013)		Auckland Unitary Plan (2013)	
	Regulatory	Non-Regulatory	Regulatory	Non-Regulatory	Regulatory	Non-Regulatory	Regulatory	Non-Regulatory	Regulatory	Non-Regulatory
Intensification										
Irrigation										
More chemicals										
Wastewater, effluent and stormwater										
Loadings (livestock and traffic)										
Inadequate vegetative cover										
Cultivation										
Drainage										
Land Use										
Fragmentation of land and spillover										
Irrigation-driven land-use change										
Poor matching of land use to inherent capability										
Restoration and introduction of diversity										
Climatic										
Increase soil temp and moisture										
Changing moisture (e.g. drought, flood)										
Increased volatility/storminess										
Changing CO_2										
Legacy										
Pesticides (including dips)										
Waste (including landfill, dumps)										
Mining and extraction										
Deforestation										
Pests and disease										
Modification of soils										
Drainage systems/regimes										

Idenitified as a pressure, with a response in place

Idenitified as a pressure, but no response in place

Not idenitified as a pressure

- Climatic pressures as identified in the Phase 1 report are the least well identified across the case studies. Few climatic pressures were identified within the RPS frameworks, except for Gisborne, which in section 2.3 of the Land Chapter identifies climate change, sea level rise, and increased storminess as pressures. Landslides and slope erosion are also identified as an issue and associated with the region's large tracts of hill country. This inclusion with the District Plan owes its origin to the devastating impact of Cyclone Bola in 1988, which caused widespread damage to land and infrastructure costing more than $82M (O'Loughlin 1991).

- Legacy pressures were identified in the resource management issues of all five case studies. The pressure of pests and diseases on the soil resource was identified in the resource management issues of four out of the five RPS. While the primary aim of pest control tends towards the protection of biodiversity and productivity, both Gisborne and Canterbury RPS direct regulatory responses to be developed in the relevant regional and district plans, with the focus being to control pests that contribute to erosion or impact on the effectiveness of soil conservation measures.

Non-regulatory approaches

Table 3.3 identifies the non-regulatory as well as the regulatory approaches developed through the RPS process to address resource management issues that pertain to the soil resource. In many cases they are intended to complement the regulatory framework, and often involve partnership between regional and central government, as well as rely on the support of industry bodies, such as Fonterra and HortNZ (e.g. Method 5-9 of Horizons One Plan to address water quality).

The development and implementation of codes of best practice are key non-regulatory features promoted in the Horizons Otago, Gisborne and Canterbury RPS examples to address resource management issues that relate to the Phase 1 pressures of intensification, land use change and legacy issues. Plans and accords also feature in many council programmes; examples include the Manawatu River Forum, Lake Horowhenua Accord and the Waipa Plan by Waikato Regional Council. Advocacy and education programmes are also featured, particularly in the Auckland RPS example and include educating land managers on soil and land, including factsheets, field days, formal discussion groups, training centres (e.g. Smedley Station and Cadet Training Farm) as well as the more informal but frequent engagement between councils and farmers. The release and use of the 'Visual Soil Assessment', a simple tool to assess and monitor soil quality, and 'Soils Underpinning Business Success', skills and knowledge to identify and map soils on farms to inform stock and land management practices, are both good examples of these education-based approaches.

Gisborne RPS includes a non-regulatory method that commits the regional council to identifying whether it is feasible and appropriate to extend the existing controls which apply to vegetation removal and earthworks and operate an "eroder pays" principle whereby those carrying out an activity contributing to accelerated soil erosion pay compensation towards ameliorating the effects. This is an example of a non-regulatory method being used to provide the justification for a more directive, regulatory approach as part of the plan monitoring and review process. Gisborne RPS also provides an interesting example of the deployment of non-regulatory research based methods in respect of the pressure of cultivation to the soil resource. Non-regulatory method 2.5.3.4 states that the council will consider the adoption of measures to protect soil fertility and structure if evidence develops that these are being adversely affected by cropping practices.

Central government is also supportive of codes of practice or good practice initiatives that are consistent with the RMA, NPS, and RPS, are prepared by the users for the users, and reduce compliance monitoring (especially where the codes of practice or other good practice initiatives include a component of independent audit).

Non-regulatory approaches range from accords (e.g. NZ Forest Accord 1991; National Pest Plant Accord, 1993), financial assistance for a broad range of projects (e.g. MfE's Community Environment Fund, MPI's Sustainable Farming Fund and Primary Growth Partnership) and specific issues (e.g. MPI's Hill Country Erosion Fund) through to governance, research, monitoring and management activities (e.g. Cadmium Management Strategy and the work of the Cadmium Management Group).

To date most non-regulatory efforts have focused on addressing pressures of intensification, land-use change, and climate as related to erodible hill country, including schemes such as the Afforestation Grant Scheme (AGS), the East Coast Forestry Project (ECFP), and the Hill Country Erosion Fund. These efforts, together with the Emissions Trading Scheme (ETS) and Permanent Forest Sinks Initiatives (PFSI), have taken some fragile land out of agricultural use and into exotic or indigenous forestry (for example PFSI has over 15,000 ha of forest registered for permanent management under covenant with the Crown; previous AGS resulted in 12,000 ha of new forest with the new AGS expected to deliver 15,000 ha; and ECFP has delivered over 40,000 ha of new planting since its inception in 1992). A number of reviews (Bayfield & Meister 2005; Barnard et al. 2012) suggest progress has been made, however since the uptake of treatment is largely voluntary (except in areas where it is required e.g. under the Gisborne Combined Regional Land and District Plan – Land Overlay 3A), these schemes are vulnerable to market forces such as fluctuating carbon prices or the relative profitability of pastoral agriculture. These forces have resulted in variable uptake of new grants, suggesting further progress may well require a regulatory backstop to increase the rate of uptake (Bayfield & Meister 2005).

A further concern is the extent to which current non-regulatory approaches deal with the full range of pressures. The Sustainable Dairy Water Accord (previously *the Dairying and Clean Stream Accord*) and the efforts of the Primary Sector Water Partnership, replaced by the Land Water Partnership (setting pan-sector targets for nutrient management, sediment and microbial management and water efficiency) suggest other soil pressures, particularly those relating to the offsite impacts on freshwater, are however likely to become more commonplace.

Table 3.3

SCHEME	IDENTIFIED PRESSURES	KEY FEATURES	PARTNERS INVOLVED	RESULTS
Sustainable Dairying Water Accord (2013)	**Intensification** – all **Land use change** – irrigation-driven land use change; poor matching of land use to capability; restoration & introduction of diversity	A set of national good management practice benchmarks aimed at lifting environmental performance on dairy farms. Includes commitments to targeted riparian planting plans, effluent management, comprehensive standards for new dairy farms and measures to improve the efficiency of water and nutrient use on farms	Dairy NZ, dairy companies, Fertiliser Association NZ, Ravensdown, Ballance, Federated Farmers, NZ Institute of Primary Industry Management, Irrigation NZ, regional councils, MPI, MfE and the Federation of Māori Authorities	Builds on the Dairying and Clean Stream Accord, one of the first major industry efforts to extend beyond regulatory bottom-lines, engage with other stakeholders, and take responsibility for doing better. It seeks further significant improvement in the management of risks to waterways posed by dairying
Sustainable Land Management Initiative (2005)	**Intensification** – more chemicals; loadings; inadequate vegetation cover **Land use change** – poor matching of land use to capability	Focused primarily on improving management of highly erodible land to protect the soil resource and ensure downstream flood and water quality control. A variety of tools have been identified as necessary for successful performance of SLUI but the development of Whole Farm Plans with individual farmers is a key component	Horizons Regional Council, ratepayers and MPI	Flooding across much of the Manawatu in February 2004 prompted Horizons Regional Council to work with Government, community representatives and farmers on a plan to address the source of much of the sediment finding its way into our rivers and streams. By 2012, 369,280,441 hectares had farm plans (28% of hill country farmland); over 85% of these plans are active (works are being undertaken); 5,171,000 million trees; and 280 km of fencing erected
Afforestation Grant Scheme (2008)	**Intensification** –inadequate vegetation cover **Land use change** –poor matching of land use to capability **Climatic** – increased volatility & storminess	A contestable fund designed to encourage the establishment of new forests. Designed to improve land-use productivity and regional economic development, new forests will also generate environmental benefits, including reducing soil erosion, storing carbon, and improving water quality	MPI and regional councils	The Afforestation Grants Scheme is expected to deliver 15,000 hectares of new forest planted by 2020, with applications prioritised according to their contribution to environmental co-benefits such as reducing soil erosion. The scheme complements work already undertaken in this area, including the Permanent Forest Sink Initiative, the Erosion Control Funding Programme on the East Coast, and the Hill Country Erosion Fund
Hill Country Erosion Fund (2007)	**Intensification** –inadequate vegetation cover **Land use change** –poor matching of land use to capability **Climatic** – increased volatility & storminess	Aimed at protecting erosion-prone hill country by providing leadership and targeted support to regional and unitary councils. Funding is available to strengthen the knowledge of regional council land sustainability officers. These officers have a critical role in providing information on land management practices to land owners and managers. Funding is also available for establishing or enhancing catchment facilitation groups. The programme supports these groups by funding facilitators through relevant regional councils	MPI and regional councils	Funded a range of initiatives including: • Horizons Regional Council: Sustainable Land Use Initiative • Plant & Food Research: Poplar and willow breeding programme • Hawke's Bay Regional Council: Wairoa Sediment Reduction Initiative and Catchment Facilitation Programme • Taranaki Regional Council: South Taranaki Regional Erosion Support Scheme • Wellington Regional Council: Wellington Regional Erosion Control Initiative • Gisborne District Council: Waipaoa River Catchment Works Facilitation
East Coast Forestry Project / Erosion Control Funding Programme (1992)	**Intensification** –inadequate vegetation cover **Land use change** –poor matching of land use to capability **Climatic** – increased volatility & storminess	Grants provision to landowners to fund treatments that control erosion on the worst eroding or erosion-prone land in the district (target land). Landholders can use the grants to pay for planting trees or encouraging natural reversion to native bush	MPI and Gisborne District Council	A review in 2005 found that after 13 years the Project had planted >31K trees with 60% of total area of target land treated
Emissions Trading Scheme (2008)	**Climatic** – primarily land use in response to climate related pressures	The ETS puts a price on emissions and therefore creates a financial incentive for all New Zealanders – especially businesses and consumers – to change behaviour. The NZ ETS provides an incentive to: reduce emissions, invest in clean technology and renewable power generation, and plant trees	Government and business sectors	A review was carried out under Section 160 of the Climate Change Response Act
Permanent Forest Sink Initiative	**Climatic** – primarily land use (forestry) in response to climate related pressures	The PFSI is favoured for programmes with native tree species and for projects where maintenance of permanent forest cover is valued for environmental reasons such as enhancement of biodiversity, soil conservation, water quality improvement, and flood control	Government and landowners	The PFSI is an alternative to the ETS. Through PFSI forests must be maintained as continuous cover canopy forests for 99 years, and harvesting is only permitted on the basis of low intensity individual tree removals

Is it enough?

As with Section 2: *On the ground,* we took the six priority pressures from Phase 1 and explored how well they were provided for within New Zealand's current policy and planning framework (comprising both regulatory and non-regulatory approaches). The analysis, presented in Table 3.4 overleaf highlights:

1. Irrigation is likely to increase in prominence as a pressure and become more regulated as councils move to second generation RPS and the freshwater reforms are implemented.

2. Addition of chemicals is well-provided for in both regulatory and non-regulatory approaches from a water quality perspective. There is doubt however, whether enough is being done to protect soil functional capacity given that the freshwater reforms will be focused on setting limits to protect freshwater and not extend to defining the impacts, or protecting against, threats to soil functional capacity.

3. Inadequate vegetation cover and reducing erosion susceptibility has been the single largest focus of environmental regulation and non-regulatory approaches in New Zealand to date. The Erosion Susceptibility Classification (ESC) developed for application in the NES for plantation forestry classifies 554,000 ha as having very high erosion susceptibility (this excludes DoC land, towns and queries) only 108,000 ha of this is currently under plantation forest. Therefore there are still tracts of land outside of major schemes at risk of erosion, suggesting we should not reduce attention to this pressure in the medium-term. There are also emergent pressures outside of highly erodible hill country including where there is an increased use of annual crops; winter grazed forages and short rotation pastures in pastoral systems. These systems are all subject to increased risk of soil loss during periods when soils are the bare and vulnerable to the increased storminess associated with climate change scenarios.

4. Provision for the fragmentation of land and spillover from urban expansion is a gap in the current framework. This is particularly concerning given that currently land prices and market forces are incentivising fragmentation particularly around major urban centres. The light touch on this pressure within the planning and policy framework is a significant concern given the two-fold impacts: loss of finite and elite soils in most cases; and removal of high quality land from productive use, increasing the pressure on what remains (which may have greater risk and vulnerability).

5. Poor matching of land use to inherent capability. While highly erodible land is generally provided for within the current policy framework, other constraints such as poorly or coarsely structured soils and rolling land are not. A further concern is that we are not doing enough with our soils, i.e. realising the potential of some soils to yield greater value land uses and products. An additional concern is that while access to additional resources and technologies enables land uses beyond inherent capabilities, the policy framework may not be geared to the pressures that might arise as a result. This risks the creation of enduring legacy

issues (as has been the case with the pressures resulting from large-scale European deforestation) that are difficult to reverse or address through regulating retrospectively.

6. Pests and diseases. The indirect impacts resulting from pest and disease control (contamination, pesticides) are provided for within the *NES for Assessing and Managing Contaminants in soil* and HSNO Act. Many councils also have rules in place to deal with the direct and indirect effects of pests and diseases, while the sectors (see previous section) control pests and diseases to protect productivity and profitability.

While the RMA creates the headroom for soil protection to be provided for within the policy and planning framework it is perhaps not given attention due to the lack of information to support decision-making. Better information has the potential help understand the cause of the pressures; determine how well they are being addressed, and evaluate the effectiveness of policy and planning initiatives. Similarly, the Resource Management Amendment Act 2013 brings a fundamental shift from regulating activities to regulating 'for outcomes', and with it a requirement under Section 32 to identify the extent to which plans and policies will achieve outcomes. This will require improving the evidential basis upon which policy development and ultimately planning decisions are made.

There are a number of initiatives, most under development at the time of writing, that might therefore help with answering the 'are we doing enough' question, including:

- National environmental reporting: The consolidated *State of Environment* reports published by MfE in 1997 and 2007 provided a narrative about environmental performance, but lacked temporal or spatial detail. In 2014 the Environmental Report Bill (MfE 2014) proposed the creation of a national-level environmental reporting system to ensure reporting on the environment occurs on a regular basis (rather than discretionary outputs) is nationally and temporally consistent (i.e. between reports), and is based on the best available information. The environmental reporting framework includes three main types of information: pressures, states, and impacts, with a report specifically focusing on the 'Land Domain' likely to be developed in the next few years.

- Local government environmental monitoring under section 35(2) (a) of the RMA: While local authorities must monitor their environment, and make the results publicly available at least every five years, they are not legally required to report on its state. Since the late 1990s, however, considerable effort has been made to develop a set of soil quality measures to support the assessment of the effectiveness of regional policy on key soil functions (Lilburne et al. 2002; Land Monitoring Forum 2009; Drewry et al. 2015).

- Environmental Monitoring and Reporting (EMaR) Framework: Regional councils, in partnership with MfE are developing the EMaR initiative to integrate regional/national environmental data collection networks and to ensure reporting platforms are more widely accessible. EMaR will be focused on understanding current land cover and land use

Table 3.4

PHASE 1 PRESSURES (TOP SEVEN)	PROVISIONS IN PLACE FOR KEY PRESSURES BY SCALE AND APPROACH				IS IT ENOUGH GIVEN PRIORITY OF PRESSURE?
	National regulations	Regional regulations	Non-regulatory approaches	Reporting initiatives	
Irrigation	Likely to be highly regulated under the NPS-FW but focused on the impact on freshwater not soil functional capacity	Water is already regulated in second-generation plans councils; however, this is more focused on protecting water resources than soil functional capacity	Sectors and service organisations (such as IrrigationNZ) provide advice and extension Irrigation Acceleration Fund provides funding support for regional rural water infrastructure schemes, strategic water management studies and community irrigation schemes	Not currently, but could feature as a pressure in the Environmental Reporting Framework and Environmental Monitoring and Reporting (EMaR) initiatives through land use characterisation	Dealt with in second generation RPS and the implementation of NPS-FW; no regulation for impacts on soil function, given effects are unknown
More chemicals	Likely to be well-provided for in the NPS-FW but may not extend to protecting against the threats to soil functional capacity, i.e. there are no limits on nutrient (P and N) or contaminants (Cd, F, U, Cu, Zn, etc.) in soils	Cover in some plans but not all, although most councils are aware of this as a pressure	Sustainable Dairying Accord addresses this pressure, but again more from the perspective of freshwater quality. Other sectors also have in place various initiatives (see Section 2)	Likely to feature as a pressure (from land use indicators) in Environmental Reporting Framework. EMaR may well include measures of impact on soil health	Well covered from the freshwater quality perspective concerns around whether enough is being done to protect soil functional capacity
Inadequate vegetation cover	National regulatory system geared to protecting highly erodible land and hill country. The Erosion Susceptibility Classification (ESC) developed for application in the NES for plantation forestry classifies 554,000 ha as having very high erosion susceptibility (this excludes DoC land, towns and queries) only 108,000 ha of this is currently under plantation forest. Therefore there are still tracts of land outside of major schemes at risk of erosion. The NES for Plantation Forestry also likely to address if it goes through, but will be limited to the forestry sector. The NPS-FW will give effect to regional plans to deal with this pressure through its focus on reducing downstream sediment	Well-provided for within most plans at a broad scale but unclear about the areas not defined or recognised as highly erodible	Major focus for New Zealand, dating back many years. However, unclear on the effectiveness of initiatives or the amount of land outside of key initiatives	Erosion is likely to feature in both Environmental Reporting Framework and EMaR initiatives as a state and impact indicator	Requires ongoing effort as well as attention to emergent issues (e.g. bare soil associated with winter grazed forages)
Fragmentation of land & spill over	Not currently provided for within national regulation	Not well-provided for within most RPS (Gisborne and Canterbury are exceptions)	Not provided for, indeed all incentives are encouraging fragmentation particularly around major urban centres	May feature in both Environmental Reporting Framework and EMaR initiatives as a pressure indicator	Significant gap in current policy and planning framework and requires regulatory backstop
Poor matching of land use to inherent capability	While the regulatory system offers provision for dealing with erosion other aspects of soil inherent capability are directly catered for	Well-provided for within most RPS and certainly a dominant feature of second-generation RPS	Range of non-regulatory approaches especially for highly erodible land and hill country	Likely to feature in both Environmental Reporting Framework and EMaR initiatives as a pressure indicator and captured through land use characterisation	While highly erodible land is generally provided for within the current policy framework focus, other aspects of soil inherent capability are not. Also areas where potential of soils not being realised
Pests and diseases	Indirect impacts resulting from pest and disease control (contamination, pesticides) are provided for within the NES for Assessing and Managing Contaminants in soil and HSNO	Most councils appear to have rules in place to deal with the direct and indirect effects of pests and diseases	Well provided for in the extent that most sectors wish to control pests and diseases to protect biosecurity, productivity and profitability	Not clear – may possibly come through a different 'domain' such as biodiversity or biosecurity and therefore not apply well in this context	On balance probably well provided for within the current policy framework with regulations focusing on limiting the indirect impacts and non-regulatory and the sectors focusing on limiting the direct impacts

profiles, how are they changing, what is driving these changes, and what is the consequential impact on New Zealand's soils and landscapes (Statistics New Zealand et al. 2013). To this extent significant effort will be targeted at ensuring effective data is available to identify the pressures relating to current land uses (including intensification and land use change) and the impacts on soil quality, trace elements, and soil stability. The EMaR project team for the Land Domain is currently determining the extent to which monitoring of soils is currently undertaken in accordance with available national guidelines across New Zealand and identifying gaps that will need to be addressed.

Key findings

New Zealand develops a range of regulatory and non-regulatory measures to foster economic growth and ensure environmental well-being. The current policy and planning framework:

- At the national level, has a range of regulatory instruments of relevance to soil, providing some direct or indirect protection of soils. However these policies tend towards regulating activities rather than ensuring outcomes, do not recognize the finite nature of soils and where the policy or legislation relates to soil, the extent is generally limited to the protection of a specific impact on that soil.

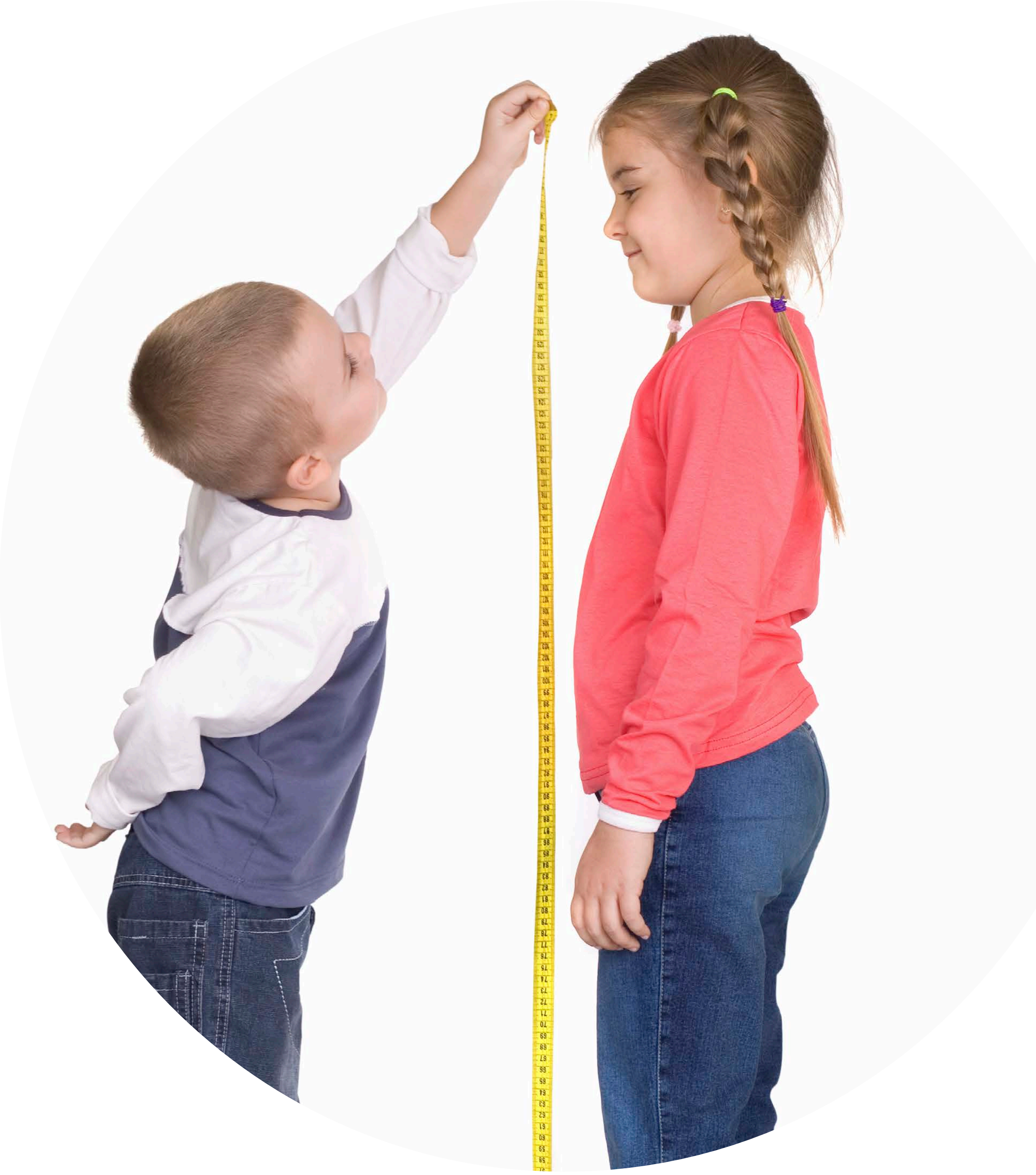
- At the regional level, has rules and regulations to address pressures but these vary from region to region, with intensification pressures most recognised and climatic pressures least well identified or addressed.

- Includes a range of non-regulatory initiatives and approaches, including schemes, education programmes and partnerships. To date most non-regulatory efforts have focused on addressing pressures of intensification, land-use change, and climate as they relate to erodible hill country.

- Collectively these non-regulatory efforts have had the effect of taking fragile land out of agricultural use and into exotic or indigenous forestry; but uptake is susceptible to market forces (such as carbon prices or sector profitability).

- Is not currently geared towards ensuring soil functional capacity, or recognising the importance of matching of land use to inherent capability and limiting fragmentation due to urban expansion. This is a concern given the finite nature of the soil resource, and suggests there are opportunities lost as we are not realising the full potential of New Zealand soils.

- Should better anticipate the pressures arising from emergent land uses brought about by access to irrigation water and new technologies, and account for them within policy development.



4

Measuring up

International comparisons

To evaluate New Zealand's stewardship of soils and identify potential areas for improvement, the performance of six international peers was reviewed. Case studies were selected to span soil pressures and economies, but have relevance and application to the New Zealand context (e.g. similar climate, active sectors, primary products, or aspirations), including:

- United States and Canada – both are significant economies and among the largest agricultural producers and exporters in the world. Agricultural production is focused on arable and red meat and has increased by an average of 5% each year since 1990, despite decreasing agricultural subsidies (MacDonald 2013).

  In both case studies key pressures on the soil resource have intensified as part of the drive to increase yields and contribute to global food security (Acton & Gregorich 1995). The pressures from intensification manifest as greater loading on soils from machinery, inadequate vegetation cover resulting in soil erosion (Standing Senate Committee on Agriculture, Fisheries and Forestry 1984), and cultivation impacting on soil organic matter. The economic impact of soil erosion alone is estimated at $37.6 billion per annum in productivity losses in the US (Pimental & Burgess 2013).

- Australia – 61% of Australia's land mass is in agricultural production, contributing 12% of national GDP, with the largest sectors arable and red meat (National Farmers Federation, 2012). However challenging climatic conditions and nutrient deficient soils have resulted in large-scale intensification (PMSEIC 2010), increasing the application of more chemicals and irrigation. These pressures, together with large swaths of woody vegetation substantially contribute towards salinization being one of the biggest issues facing Australian soils (Campbell, 2008).

- England, Wales, and Scotland – Agriculture in the United Kingdom uses around 60% of the country's land area but contributes less than 0.7% GDP, with the UK producing less than 60% of the food it eats. Despite fertile soil, significant investment in research and development as well as subsidies, which primarily come from the European Union, farm earnings are relatively low (due to low prices at the farm gate). Fewer young people are able to afford the rising capital cost of entry into farming and are discouraged by low earnings which, together with competition for land, have resulted in a declining agricultural sector (DEFRA, 2015).

  With a limited amount of land available for agriculture in England and Wales, focus is given to ensuring it remains productive, can help regulate climate change and freshwater impacts, does not get sealed through urban development, and the historic legacy of contamination is managed. Key pressures as identified in 'Safeguarding our Soils: A Strategy for England' (DEFRA 2009) primarily derive from intensification including the effects of inadequate vegetation cover (erosion), increasing loadings (compaction) and cultivation (organic matter decline).

  While Scotland is part of the UK, its legal system has remained separate from those of England and Wales. For this reason, we have benchmarked Scotland independently from England and Wales. In contrast to the other case studies, under the Scottish Soil Framework, all soil pressures are given attention due to the underpinning role that functioning soils play in sustainable development. Ensuring soil function, by managing the impacts of climate change and reversing the loss of organic matter are therefore major priorities for Scotland. Sealing of soils through urban expansion (total loss of function) and the unknown impact of the loss of soil biodiversity on soil function also rate highly (Scottish Government 2009).

- Denmark – is a net agricultural exporter, with 60% of its land in primary production. While grain and pork production dominate, Denmark is growing its dairy sector (Danish Agriculture and Food Council 2014). Denmark is renowned for its advanced technology and infrastructure (credited to high levels of investment in education and research), and commitment to organic production. Given this backdrop, it is not surprising that legacy effects, particularly those relating to pesticides, waste, mining, and other manufacturing practices, and the impact these have on human health and market access for primary products, are the major concern.

Measuring performance: a benchmarking framework?

To compare the stewardship performance of our international peers we created a benchmarking framework. Based on the key actions needed to steward soils, it combines elements of the action plans of *European Union (EU) Thematic Strategy for Soil Protection* and *United Nations Food and Agriculture Organization (UN FAO) Global Soil Partnership.*

In 2006 the European Commission submitted a communication to the council of the European Parliament, the European Economic and Social Committee and the Committee of the Regions calling for a comprehensive EU strategy for soil protection (COM(2006) 232). The EU Thematic Strategy for Soil Protection sets out common principles for protecting soils across the EU, including four pillars of action:

- *Dedicated legislative* action to protect against key threats to soil function, in particular erosion, contamination and sealing
- *Prioritized research* to close knowledge gaps
- *Integration of soil protection into other policy areas* (e.g. agriculture, regional development and transport)
- *Awareness-raising* to improve technical knowledge exchange and promote the importance of soil within society.

In 2012, the UN FAO established a *Global Soil Partnership* in recognition of the need for a unified and authoritative voice across sectors and bring together initiatives such as the UN Convention to Combat Desertification (UNCCD), and the UN Framework Convention on Climate Change (UNFCCC). As part of the establishment of the international governance body, five pillars of action were identified:

- Promote *sustainable management* of soil resources for soil protection, conservation and sustainable productivity

- *Encourage investment, technical cooperation, policy, education awareness and extension* in soil

- *Promote targeted soil research* and development focusing on identified gaps and priorities and synergies with related productive, environmental and social development actions

- *Enhance the quantity and quality of soil data and information:* data collection (generation), analysis, validation, reporting, monitoring and integration with other disciplines

- *Harmonization of methods, measurements and indicators* for the sustainable management and protection of soil resources.

This framework is consistent with the Scottish Soil Framework, which describes key pressures on soils, relevant policies to combat those threats, and the research agenda to underpin efforts (Scottish Government 2006) and Managing Australia's Soils: A policy discussion paper (Campbell 2008). The benchmarking framework is represented in Figure 4.1 opposite.

Performance of international peers

Despite the varying viability of agriculture, the size of the export sector, and soil pressures in each of these countries, there were a number of commonalities

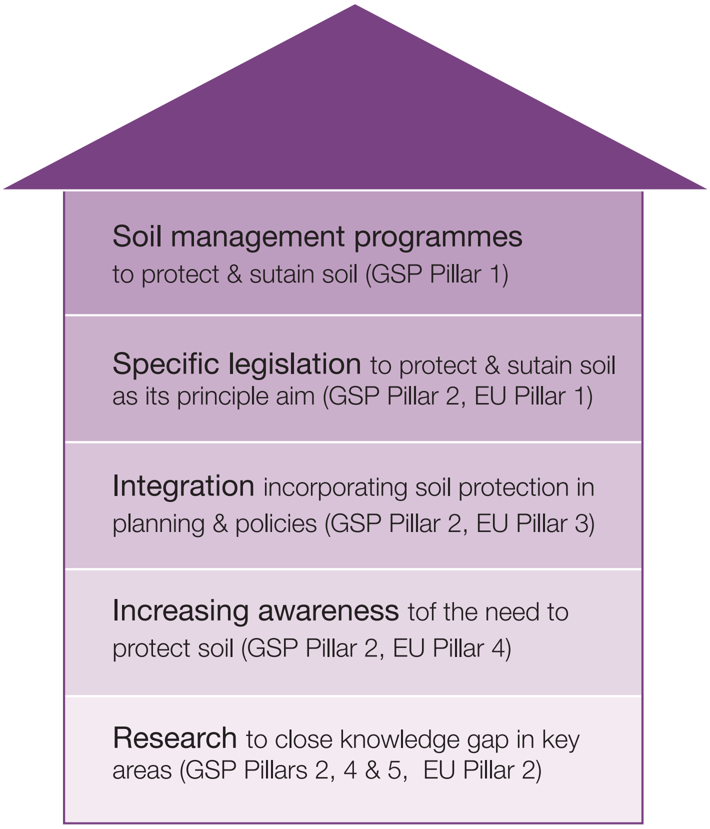


Fig 4.1: Benchmarking framework to assess national performance in soil stewardship

in the responses that had been used to address key soil pressures. Table 4.1 summarizes the performance of each country in each of the five areas of the benchmarking framework, with the following observations:

- Increasing awareness: All countries rely on their soil science societies raise awareness and educate society on the importance of soil. Activity in most countries has ramped up as a result of the 68th UN General Assembly declaration of 2015 as the *International Year of Soils* (A/RES/68/232). Other initiatives of note include a *European Network on Soil Awareness,* initiated following the "Education in Soil Science and Raising Public Awareness" symposium at the Eurosoil Conference in Vienna

Table 4.1

COUNTRY	CONTEXT – KEY PRESSURES	INCREASING AWARENESS	RESEARCH TO CLOSE KNOWLEDGE GAPS	INTEGRATING INTO POLICY & PLANNING	SPECIFIC LEGISLATION	SOIL MANAGEMENT PROGRAMMES
US	Intensification – particularly how to increase yields and contribute to global food security without undermining the soil resource. Managing erosion and drainage remain key issues.	The Natural Resources Conservation Service makes available extensive soil information (e.g. Web Soil Survey) and has a soil health awareness programme (http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/soils/health/) The Soil Science Society of America promotes awareness and educational opportunities	The Office of the Chief Scientist (OCS) coordinates USDA research, education, and Extension with scientists and researchers across the federal government and university and private partners, to make the best use of taxpayer investments. In 2012, OCS continued focus on the Research, Education and Economics Action Plan including sustainable natural resource use. United States Department of Agriculture (USDA) Strategy Plan for R&D: Water, Air and Soil 2011–2016 Agriculture Research Service Strategic Plan 2012–2017 USDA also has specific soil focused labs across the country e.g. National Soil Erosion Research Lab & Sedimentation Lab.	The 'Farm Bill' is the primary agricultural and food policy tool of the federal government. The comprehensive omnibus bill is passed every 5 years or so by the United States Congress and deals with both agriculture and all other affairs (including the Agricultural Act 2014) under the purview of the United States Department of Agriculture. The Environmental Protection Agency (EPA) is primarily responsible for implementing federal law to remediate contaminated land Land-use planning lies primarily with local authorities. (e.g. Louisiana Soil & Water Conservation Commission)	Soil Conservation and Domestic Allotment Act 1936 Soil and Water Resources Conservation Act of 1977	Comprehensive suite of soil management programmes advised by key agencies and adopted by land owners. Very strong focus on soil conservation, soil-water and nutrient management. Through the Farm Bill, funding is provided to farmers and ranchers for conservation, for programmes that prevent soil erosion, preserve and restore wetlands, clean the air and water, and enhance wildlife.
Canada	Intensification – particularly how to increase yields and contribute to global food security without undermining the soil resource. As with the US managing erosion and drainage remain key issues.	The landmark Senate report of 1984, 'Soil at risk: Canada's eroding future' raised national awareness of the soil resource and its role in Canada's future well-being. Canadian Society of Soil Science (CSSS), in 2014 established a Soil Education Committee to raise awareness of soils in Canada. Soil Conservation Council of Canada is an NGO that was formed in 1987 to provide a non-partisan forum to speak and act at the national level for soil conservation.	'The Health of Our Soils' 1995 provided a national strategy for research, development, and extension that included cross-sector collaboration. It is difficult to identify any large-scale research priority-setting initiative since then.	The Agricultural Growth Act of 2015 aims to modernize and strengthen federal agriculture legislation, support innovation in the Canadian agriculture industry and enhance global market opportunities. Some parts of the Act could stimulate good soil management, but others may force the opposite (ambitious export targets) Growing Forward 2 (GF2) is a 5-year (2013–2018) policy framework for Canada's agricultural and agri-food sector. GF2 is a $3 billion dollar investment by federal, provincial, and territorial (FPT) governments and the foundation for government agricultural programs and services. National Environmental Farm Planning Initiative.	1989 National Agriculture Strategy was agreed to support the transition from conventional to sustainable agriculture. However, it has been limited by the absence of a comprehensive conceptual framework for identifying the most critical policies, programmes, and regulations	As with others, to date Canada has had extensive programmes around soil conservation, stewardship and water management. Of particular relevance to the NZ context is Canada's 2009 National Environmental Farm Planning Initiative that helped Canada's agricultural producers develop and implement environmental farm plans (EFPs) through provincially delivered EFP programmes.
Australia	Intensification – due to the large proportion of desert and unproductive soils, there is considerable pressure to increase yield on the remaining soils. Managing soils to reduce salinization and increase water and nutrients are key issues.	An active Soil Science Australia society, with Australia also nominating 'state soils' (akin to a flower or emblem for each state). Has an active programme around International Year of Soils. Healthy Soils Australia (HSA) is a not for profit volunteer organisation concerned with reconnecting healthy soil and human health.	The 2014 'Securing Australia's soil for profitable industries and healthy landscapes. The national soil research, development and extension strategy' provides a national strategy for research, development and extension which includes cross-sector collaboration. Australia also has two CSIRO Flagships of relevance to soil: Land & Water; Sustainable Agriculture.	The 2008 'Managing Australia's soils: a policy discussion paper' explores the policy context in Australia. It notes there are no clear lines of policy at a national level for soil. Some jurisdictions within the Australian Federation have already begun working towards a State Soil Policy. NSW, led by the Department of Lands, has made considerable progress in this area with the publication of a draft soils framework titled 'Looking forward, Acting now' (NSW State Soil Policy Working Group 2008), and the Victorian Soil Health Strategy.	Soil and Land Conservation Act 1945	A range of programmes, focused on priority issues about salinization and soil degradation. Australia Soil Management works with land managers to develop more profitable and sustainable soil management practices. The National Landcare Programme merges previous funding initiatives into one simple programme that puts landcare back at the centre of natural resource management.
England & Wales	Intensification, climatic and legacy effects – with a small amount of land available for agriculture in England and Wales, the focus is on ensuring it remains productive, can help regulate climate-change impacts, does not get sealed through urban development, and the historic legacy of contamination is managed. Managing erosion, compaction and organic matter decline are the three primary concerns.	Very active British Society of Soil Science with an Education Committee promoting Soil Science through a range of activities such as developing education resources and grant funding. Also active in social media (videos, tweets, Facebook). Participants in the European Network on Soil Awareness and contributors to EU Joint Research Centre (JRC) 'Soil – the hidden treasure' initiative.	The Department for Environment, Food and Rural Affairs' (DEFRA) 2003 Audit of UK Soil Research and 2009 'Safeguarding our soils: a strategy for England', and the Royal Agricultural Society of England's 2010 'A Gap analysis on the future requirements of soil and water management in England' all detail research priorities to support sustainable soil management. Research is also coordinated out of Cranfield University's National Soil Research Institute.	Soil protection policy devolved in the UK but since many of the pressures on soil are common across the UK, Defra is working closely with the Devolved Administrations to share knowledge and to adopt a coordinated approach where appropriate. Water Frameworks Directive that includes measures to prevent erosion and run-off. Waste and Resource Action Programme (WRAP) works with industry partners to develop standards and quality protocols. Regulatory legislation includes the England Catchment Sensitive Farming Delivery Initiative and the use of Water Protection Zones. Implementation is carried through River Basin Management Plans. 2003 EU Common Agriculture Policy reform. Code of Practice for Agricultural Use of Sewage Sludge 1996.	Environment Protection Act 1990 Agriculture Land (Removal of Surface Soil) Act 1953	A range of English and Welsh initiatives at various scales. Also participates in EU soil management programmes including: • Contaminated Land Capital Projects • Waste and Resource Action Programme (WRAP) works with industry partners to develop standards and quality protocols. • Common Agriculture Payment (CAP) cross compliance, Code of Good Agriculture Practice and Environmental Stewardship.

Table 4.1 (continued)

COUNTRY	CONTEXT – KEY PRESSURES	INCREASING AWARENESS	RESEARCH TO CLOSE KNOWLEDGE GAPS	INTEGRATING INTO POLICY & PLANNING	SPECIFIC LEGISLATION	SOIL MANAGEMENT PROGRAMMES
Scotland	All pressures are a concern under the Scottish Soil Framework, given the critical role that Scotland perceives soil to play in sustainable development. Managing the impacts of climate change and reversing the loss of organic matter are the two primary concerns for Scotland. Sealing of soils through urban expansion (total loss of function) and the unknown impact of the loss of soil biodiversity also rate highly.	Very active British Society of Soil Science with an Education Committee promoting Soil Science through a range of activities such as developing education resources and grant funding. Also active in social media (videos, tweets, Facebook). Soil Association campaigns relating to sustainable land management for soil conservation.	Scottish Government funds a substantial research portfolio 'Protecting the Nation's Soils'. Key research providers include the James Hutton Institute and a 'Soils Research Consultative Group'.	The Scottish Environmental Protection Agency plays a proactive role in protecting Scottish soils. Key policies of relevance to soils include: Climate Change (Scotland) Act 2009 (including the Land Use Strategy); Water Environment and Water Services (Scotland) Act 2003 (including River Basin Management Planning); and Flood Risk Management (Scotland) Act 2009. Many in common with England & Wales.	Sludge (Use in Agriculture) Regulations (1989) Waste Management Licensing (Scotland) Regulations 2011 Water Environment (Controlled Activities) (Scotland) Regulations 2011 Pollution Prevention and Control (Scotland) Regulations 2012	Range of schemes to protect and manage soils. Scottish Environmental Protection Agency collaborates with Northern Ireland to provide advice through NetRegs – Land and soil management for agricultural businesses.
Denmark	Legacy effects are the key focus in Denmark, particularly those relating to pesticides, waste, mining, and other manufacturing practices. Managing soil contamination and pollution is the primary focus.	Danish Soil Partnership is a platform for all actors in the soil remediation sector – EPA, local government, consultants, contractors, technology developers, and research institutions – to raise awareness and address soil contamination.	Danish Soil Partnership Strategy has developed a research component. Capacity is focused in research institutes and centres (e.g. Regional Information Centre on Contaminated Soils).	The Ministry of the Environment is in charge of administrative and research tasks for environmental protection and planning. At regional and local level, much of the administrative responsibility has been delegated to local governments in counties and municipalities. The Danish Environmental Protection Agency enforces any national regulation. European policy such as Water Frameworks Directive which includes measures to prevent erosion and run-off and the 2003 EU Common Agriculture Policy reform also apply.	Act on Contaminated Soils 2000 amended in 2007 and 2014 The Act on Chemical Waste Deposits 1984 Danish Act on Soil Pollution 1999	Range of public–private partnerships focusing on soil remediation.
New Zealand	Intensification, land use change, and legacy effects are the pressures perceived as most significant in New Zealand. New Zealand is focused on driving export growth while ensuring freshwater quality; as a result irrigation, nutrients, inadequate vegetation cover, poor matching of land use to inherent capacity, as well as the legacy of past deforestation are major concerns. Managing erosion and nutrient leakage are the prevailing issues, with the protection of elite soils an emerging issue.	The NZ Society of Soil Science plays an active role in promoting the importance of soil. The society has a communications and education mandate and has a programme focused on International Year of Soils. A variety of CRI and university initiatives focus on raising the profile of soils, including the National Land Resource Centre. New Zealand participates in the Global Soil Partnership and was instrumental in establishing the Pacific Soil Partnership.	Owing to the economic importance of soils in New Zealand, many organisations are actively interested in various branches of soil science. Some national coordination is occurring through the National Science Challenge 'Our Land and Water', and a stocktake produced under Phase 1 of this report. No national soil research strategy currently exists.	The Resource Management Act 1991 is New Zealand's main piece of legislation for governing the environment. Within this policy framework there are National Environmental Standards and National Policy Statements focusing on reducing the off site or distal impacts of poor soil management (e.g. as they effect human health or freshwater quality) as well as other acts, statutes and instruments. Regional Policy Statements identify key pressures and provide a broad direction for regional management, while regional plans put in place rules and regulations to address the pressures.	Soil Conservation and Rivers Control Act 1941	Range of schemes across primary sector, often in partnership with the service sector or regional councils.

in August 2008, to identify mechanisms to ensure soil protection in Europe through 'soil awareness' (Broll 2010); the EU Joint Research Centre 'Soil the hidden treasure' initiative; the US Natural Resources Conservation Service 'soil health awareness programme'; and Australia's programme of 'state soils'.

- Research to close knowledge gaps: All countries reviewed have research capacity focused on varying aspects of soil science, with critical mass established through national centres or flagships (e.g. US Department of Agriculture (USDA) National Erosion Research and National Sedimentation Laboratories; Commonwealth Scientific and Industrial Research Organisation (CSIRO) Land and Water Flagship; UK National Soil Research Institute).

  The US, and Australia, as well as England and Wales, have all undertaken national stock takes and priority-setting exercises for soils in the last 15 years to target research efforts (e.g. USDA Strategy Plan for R&D: Water, air and soil 2011–16; Australia's Department of Agriculture, Forestry and Fisheries 2014 'National Soil Research, Development and Extension Strategy, Securing Australia's Soil, for profitable industries and healthy landscapes'; and the UK Department of Agriculture, Food and Rural Affairs 2003 Audit of UK Soil Research, 2009 'Safeguarding our Soils: A Strategy for England', and the Royal Agricultural Society of England's 2010 'A Gap analysis on the future requirements of soil and water management in England'). Scotland has taken a slightly different approach, establishing a national research portfolio 'Protecting the Nation's Soils' and a 'Soils Research Consultative Group' to advise on research priorities.

- Integrating into policy and planning: Due to the diverse but underpinning role soil plays (e.g. sustaining agriculture, ensuring freshwater quality, moderating climate change impacts) in all countries there are a range of existing policies that make a contribution to soil protection, but each focuses on a particular function of the soil, rather than on the soil itself. Because of this fragmented nature, existing policies are limited in their combined effectiveness to protect soils (Scottish Government 2009). As a specific example, the EU Water Framework Directive (WFD) (Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy) is an EU directive which commits EU member states to achieve good qualitative and quantitative status of all water bodies. Soil degradation, erosion and contamination are identified as pressures within the policy framework, however with the focus on protecting water quality there remain many gaps around soil protection.

- Specific legislation: The case studies reveal that while there is a significant body of policy in place relevant to soils, providing some direct or indirect protection of soils, most countries do not have a legislative or policy tool that has been developed specifically with the protection of soil in mind. Where policy or legislation does relate to soil, the extent is generally limited to the protection of a specific impact or function of that soil, typically erosion (e.g. US Soil and Water Resources Conservation

Act 1977; Australian Soil and Land Conservation Act 1945) or contamination (e.g. Scotland's Sludge Use in Agriculture Regulations 1989; Denmark's Act on Contaminated Soils 2000/2007/2014).

- Soil management programmes: For the case studies reviewed, this is an area where most success has been achieved. As for New Zealand, there are a range of soil management programmes, supported through non-regulatory approaches (e.g. funding through the US Farm Bill for programmes in soil erosion control and wetland restoration; Canada's 2009 National Farm Planning Initiative; Australia's National Landcare Programme; and the EU's Common Agricultural Policy for cross-compliance) to sustain soils. In all cases, science, primary, and service sectors play a critical role in both the design and implementation of practices, with significant recognition on the importance of extension and capability to increase uptake and adoption (Kibblewhite et al. 2010; DAFF 2011).

New Zealand – how do we measure up?

Using the benchmarking framework we can compare our performance to our international peers:

- Increasing awareness: The New Zealand Society of Soil Science plays an active role in promoting the importance of soil and has a programme in place to support the aims of International Year of Soil. With just over 400 local and international members, the society's activities are limited by scale and funding compared with its international equivalents. Government funding through the national science challenges and Ministry for Business, Innovation and Employment (MBIE) 'Unlocking Curious Minds' offers future potential to upscale soil literacy and awareness raising efforts.

- Research to close knowledge gaps: Unlike our international peers, research capability in soils and related areas is fragmented across a significant number of Crown Research Institutes, universities and other agencies. While there has been significant public and private sector investment in soil-related research and development in the last two decades there is currently no nationally agreed prioritization of needs or research strategy for soils, as there has been for water (FRST & MfE 2009).

- Integrating into policy and planning: The New Zealand policy and planning framework (see Section 3) allows for land management to be regulated through regional and/or district plans through the resource consent process. While soil degradation is often identified as a pressure for water quality and human health under the RMA, the impact on soil health and function is not well provided for. Significant opportunity currently exists, however, to incorporate provisions to both support water quality and soil function as part of the implementation of the National Policy Statement for Freshwater.

- Specific legislation: In common with our international peers, New Zealand does not have a legislative tool specifically focused on soil protection, and where existing legislation relates to soil, the extent is generally limited to the protection of a specific impact or function of that soil, in New Zealand most notably erosion.

- Soil management programmes: As identified in Section 2 of this report, longstanding partnerships between the primary sector and service sector to develop and embed best practice soil management guides, tools, technologies and codes are clearly evident; however, widespread uncertainty about the effectiveness or uptake of many of these responses remains an issue. While the potential of large areas of Māori owned land has yet to be realised, a potential opportunity is to embed the principles of kaitiakitanga and whanaungatanga more widely in soil management and enhance the concept of 'guardianship'.

On reflection, there are opportunities for New Zealand to learn from it peers and improve its stewardship of the soil resource. These include increasing the focus on raising awareness; developing a national soil research strategy; building on the momentum and regulatory tools establishing through the freshwater reforms; and exploring the relationship between the Crown and Maori to enhance guardianship, enact the principles of kaitiakitanga and whanaungatanga, and leverage from their growing role as land owners.

New Zealand is not behind its global peers, however. If anything, as a small, biologically based country New Zealand, has the ability and agility to bring together disparate measures into an integrated framework and develop the partnerships to realize enduring economic value from its soils. This will not only offer benefits for the protection of other natural resources such as freshwater, but provide an exemplar for other countries.

Key findings

Review of international experience suggests:

- There are five key areas necessary for better governance of the soil resource: increasing awareness; closing of knowledge gaps; integrating soil management into policy and planning; developing specific legislation; and managing soil pressures.

- US, Canada, Australia, England & Wales, Scotland, and Denmark have an idea of the knowledge gaps, have soil referenced within their policy frameworks and have existing practices to manage key soil pressures. None have legislative tools specifically focused on soil protection, and where existing legislation relates to soil, the extent is generally limited to the protection of a specific impact or function of that soil.

- While New Zealand is not behind its international peers a more co-ordinated approach to soil governance is needed to utilize our natural advantage.

- As a small, biologically-based country New Zealand has the ability and agility to develop the partnerships and integrated measures to realize enduring economic, ecological and social value from its soils for the benefit of the nation.

Appendix A: sector case notes

Planted forests

Pressures: Erosion and sediment loss are the most significant pressures identified by the forestry sector, particularly where planted forests are on steep, highly erodible land and exacerbated during harvesting. Extreme rainfall events and their predicted increasing frequency under climate change were seen as high threats to erosion-prone country.

. It can take considerable time to rebuild eroded soils naturally and forest productivity on degraded soils has been shown to be ~10% less (Heaphy et al., 2014). The increase of harvesting on steeplands that will occur in the next decade plus the sector's emphasis on doubling production of future forests will also increase the pressure on these soils. Increased productivity can come from either a higher number of trees per hectare or shortening of the rotation. The former could have impacts on soil nutrient levels, and the latter on soil intactness due to increased frequency of harvesting or higher risk of erosion..

Responses: About 50% of the forest estate is managed by large corporate growers; smaller growers make up the remainder. The risks presented by both increased erosion and intensification are seen to be higher for smaller growers than for the large corporates who tend to have greater resources, access to technology, and knowledge of good practice.

The planted forest sector has a number of good management practices to ensure sustainable forest management, central to which is the Forest Stewardship Council (FSC) certification, which allows access to markets. Over 50% of planted forest land is certified by the FSC (New Zealand Forest Owners Association 2011/2012). FSC certification requires good or best management practices to be undertaken and independent third party auditing of practice to ensure compliance. A 20% increase in the percentage of forest area certified over the past decade is a clear indication that certification is likely to remain a management preference. Moreover, the Environmental Code of Practice NZFOA 2012has been adopted by all corporate forestry companies (about 50% of planted forest area – effectively the certified area). A number of other handbooks and codes, such as the Road Engineering manual (NZFOA, 2012), also help the implementation of best management practice.

Protection of soil natural capital is perceived by the sector as increasingly important, with a few larger forest growers retiring areas that are not economically or environmentally viable to harvest due to erosion risk. Moreover, as an example, in the Gisborne Region resource consents for forest harvesting require that areas be replanted at a minimum density To further reduce the risk of erosion in the sector, enhanced focus on small growers and forestry contractors is needed to bring them up to the standard of larger corporate companies. This has been discussed as part of the development of the proposed National Environmental Standard for Plantation Forestry.

When the economics of forestry plus its associated ecosystem services are considered there is an opportunity to move forestry onto a better land class and thus mitigate some of these risks The transition of what was planted production forestry on to conservation forestry where the erosion susceptibility classification is an issue that is actively being addressedconsidered by some companies.

Dairy

Pressures: The most significant pressures in today's dairy sector relate to intensification, with animal loading (stocking), nutrient management, waste water management (national, medium) cultivation (regional, low) and irrigation (regional, high) ranking highly for the sector.

The matching of land use to soil or land capability is a major issue for the sector. The appropriateness of intensive dairying on certain soil or land classes is a concern, for example, irrigation has led to intensification of dairying on the Canterbury Plains and North Otago, where the major issue is the soil's ability to filter or buffer large nutrient inputs. The intensification of dairying on hill slopes in some regions, for example, South Canterbury and North Otago, is another area of concern, given this land use may increase the risk of soil erosion, nutrient losses, and sedimentation. Large-scale land conversion (e.g. forestry conversions in the Waikato or humps and hollowing or flipping on the West Coast) generally requires large inputs of nutrients to "develop" soils that were previously of low fertility.

Soil compaction, as a result of treading damage and machinery, has been widely publicised within the sector. Widespread soil damage under winter grazing of pasture and crops when soils are wet is an important issue. Nationally, there is general understanding that soil damage is associated with increased runoff from land and the loss of nutrients, faecal microbes, and sediments.

Adaptation to climate variability is seen as an issue of moderate importance for the sector (e.g. erosion caused by storms), as is loss of productivity during drought and flooding. Greenhouse gas emissions, such as nitrous oxide and methane, are affected by changes in soil structure (whether increasing or decreasing). While this was a key research area in 2010, it has recently had limited resourcing by the dairy industry. However, it is expected such issues will become increasingly important with the introduction of carbon foot-printing and the possibility of an emissions trading scheme. An emerging issue is the risk that changing temperature and rainfall may produce new pest and weed problems. Methods for increasing farmer "resilience" to these pressures will be required.

Responses: Intensification, land-use change, and legacy pressures can all lead to water quality impacts. Therefore, the most important environmental focus for this sector is reducing farming impacts on water quality. Soil management and nutrient management are acknowledged as a key element to achieving improved water quality goals. The responses to pressures in the dairy sector are still largely voluntary, with condition of supply indirectly influencing behaviour. Adoption of improved soil management is often a response to other drivers such as increased production, profitability, and/or cost and risk reduction. For example, better pasture management focused on improved feed utilisation may lead to reduced loadings at times when soils are vulnerable to compaction.

Farmer responses to the risk of compaction include the use of restricted grazing, and off-paddock confinement facilities such as stand-off pads, feed pads and barn housing. These systems have become increasingly common, particularly in regions prone to soil damage (due to a combination of soil type, landscape features and climate).

There is widespread (national) adoption of effluent management practices that better match the soils capability with the given effluent load (with respect to rate and depth of application). Best practice methods are provided or supported by the Sustainable Dairying Water Accord (www.dairynz.co.nz/wateraccord), the DairyNZ Dairy Effluent Code of Practice, design tools, and a range of extension methods and groups (e.g. DairyNZ, dairy companies). Regional consultants (provided under a milk levy administered by DairyNZ) help farmers with monitoring and system design. The DairyNZ code of practice, 2012, provided a series of standards that effluent system designers must meet. In 2014, the DairyNZ 'WOF' scheme was established, which provides an assessment framework for existing effluent management systems on farm. Regional council policies also stipulate a framework within which effluent application can occur, and the dairy industry is committed to achieving compliance with such policies for 365 days of the year. In 2012, 73% of farms met the compliance standards outlined in the Sustainable Dairying: Water Accord.

Improvement of pasture and crop nutrient management have been a key focus for reducing excess nutrient loadings to soils. Issues are primarily the build up and losses of soil N and P, with direct consequences for water quality, the build up of potassium from the application of dairy effluent, which can have adverse animal health effects, and the build up of cadmium from phosphate-based fertilisers.

The sector is also a major user of the OVERSEER nutrient budgeting, increasingly accepted as an environmental policy compliance tool. The use of fertiliser guidelines, limits to cadmium concentration in phosphate rock, and an industry working group set up to limit cadmium accumulation are also supported by the sector.

Voluntary initiatives such as the Upper Waikato Sustainable Milk Project (DairyNZ) led by Dairy NZ and supported by the wider dairy industry (www.dairynz.co.nz/sustainablemilk) are in place to reduce contaminants into the Waikato River. The project involves 700 farmers in the Upper Waikato catchment. The Fonterra Nitrogen Management Programme is another example of an industry-led initiative aimed at increasing the efficiency of nitrogen use. Partly in response to nutrient contamination of water bodies and recognition of the value of wetlands for nutrient attenuation, there has also been a reduction in the drainage of wetland areas and instead concentration on wetland restoration and the construction of new wetlands. The use of managed drainage to overcome "over-drained soils" is an approach to combat drought conditions. Reduction of stream bank erosion is a performance target of the Sustainable Dairying: Water Accord (2013), the target being to exclude dairy cattle (exclusive of Westland Region) from 90% of waterways by 2012 and from 100% by 2016. This has, by and large, been achieved primarily through voluntary leadership shown by industry. In the recent changes to the Water Accord, Westland Milk Products sought inclusion of farms on the West Coast.

Extension of best management practices is generally provided by a range of on-farm consultants – private, DairyNZ, Fonterra, fertiliser and seed companies, CRIs, and universities. The milk companies (e.g. Fonterra Sustainable Dairying Advisors and Area Managers) and DairyNZ (Regional consulting officers) have consultants charged with implementing better management practices at the farm level. Information is also provided through other media such as popular articles in the Dairy Exporter, rural newspapers, and through local and national field days.

Sheep and beef

Pressures: The most significant pressures judged in this sector were inadequate vegetation cover (national, high), poor matching of land use to inherent capability (national, medium/high), restoration and introduction of diversity (national, medium/high), legacy issues associated with deforestation (national, high), and pests and diseases (national, high). These pressures impact directly on the physical integrity of soil. The risk of erosion of pastoral land, and therefore its control, is a high priority for the sector. Inadequate vegetation cover, a consequence of the increasing hectares under cultivation and spray and pray, is an emerging challenge.

"More chemicals" was considered a local–scale, low severity problem because of the generally heavy involvement between the sector and other agencies, e.g. regional councils, fertiliser companies, to ensure that effects on water quality are minimised.

Emerging issues include inadequate vegetation cover, particularly for forage cropping and specialty pasture species, cultivation on sloping land, and pressure on fragile landscapes, not so much from erosion, but rather from livestock and cropping pressures.

Also likely to have an increased influence on the future use and condition of millions of hectares of land currently used for sheep and beef operations, is the approach government takes in addressing the poor surface water quality found in many lowland lakes and rivers. Policy linked directly to current land uses (e.g. Taupo, Selwyn Te Waihora and Hurunui in ECAN) and not the underlying land resource (Horizons, Hawke's Bay Regional Councils) could seriously constrain future innovations and development, by grand-parenting landowners to current emissions. The ramifications of current and proposed policy to protect the water quality of future land-use options on landscapes currently in sheep and beef require further investigation.

Responses: Key good practices used by the sector to address these soil management issues/pressures include the wide promotion of the Land & Environment Planning (LEP) toolkit (3 levels of detail), raising awareness through field days and a comprehensive and regularly updated website on environmental and other challenges, support for the Land Use Capability Handbook (3rd) and classification system, and inclusion of its well-founded principles in the LEP Toolkit.

Beef & Lamb New Zealand (B+LNZ) collaborates with agencies on regional issues that affect its members, such as the high profile Sustainable Land Use Initiative (SLUI) of Horizons Regional Council. There are links with the NZ Poplar & Willow Research Trust, charged with the development and promotion of poplar and willow wide-spaced plantings for erosion control on pastoral hill country. In the last 15–20 years all monitored farms have included an environmental plan of some kind. The practices are highly effective in managing the significant pressures on the soil, for example, established, healthy, wide-spaced trees reduce shallow landslides on pastoral land by 70–95%.

LEP Toolkits (level 3) provide a Whole Farm Plan similar to those used by regional councils, providing documented knowledge of the farm's resources and strategies to address important environmental and other issues.

In the last 12 months B+LNZ has held more than 60 LEP level-1 workshops throughout the country to increase the number of farms with formal plans. The sector goal is adoption of a Level 1 working towards an LEP level 2 by all sheep and beef farmers. The purpose of the tool kit is the greater integration of resource information into future decision making, rather than just a plan to address existing environmental challenges. Increasing the awareness and interest in treating a farm as a collection of different land management units, each with its own requirements, rather than the use of average values in decision making, is also one of purposes of the tool kit.

Within regions with outstanding soil erosion challenges, some progress has been made in recent years through a diversity of national (East Coast Forest Scheme) and regional sustainable land management programmes (e.g. Hill Country Erosion Fund). As an example, in the Horizons Region over the last 8 years the Sustainable Land Use Initiative established following the 2004 flood (part funded by the regional council, MPI and land owners) has developed and implemented over 500 SLUI whole farm plans covering more than 400 000 ha of eroding hill country. There is increasing awareness of the effectiveness of vegetation management for erosion control and the need for implementation to reduce sediment and nutrient loss on- and off-farm.

As a footnote, the importance of existing programme (e.g. Animal Health Boards, Regional Council land management programmes, etc.) to ensure legacy issues continue to be actively managed, cannot be underestimated.

Deer

Pressures: The comments on the key pressures on soils under sheep and beef also initially apply to the Deer sector. Pressures in this area include inadequate vegetation cover, poor matching of land use to inherent capability, restoration and introduction of diversity, deforestation, and pests and diseases. An additional loading pressure relates directly to the behaviour of deer (i.e. fence pacing and wallowing). Fence pacing by deer leads to a breakdown in the intactness of the soil and therefore to erosion. In addition to the loss of natural capital, productive capability, and a range of other ecosystem services, the loss of intactness increases the risk of sediment and P losses to waterways. Wallowing leads to a direct degradation of the waterways and has negative impacts on water quality through greater sediment and phosphorus loadings. Both challenges are well understood by the sector and are more typical of the intensive farmed lowlands, than of extensive high country operations.

Responses: In response, the industry offers deer producers packages (based on the LEP toolkit) and manuals (Deer Farmers Land Care Manual) to address key pressures, along with the wider resource challenges facing the sector. Like the sheep and beef sector, the LEP are as much about positioning the sector for the future as addressing existing or legacy challenges. Over the last 12 months a number of LEP workshops have been run for deer farmers by the Landcare Trust. However, as with the sheep and beef industry, the number of deer farmers with an LEP is not known.

Equine

A small, but highly visible livestock sector, often found close to population centres and generally on high-class soils. The sector has distinct segments, including stud operations with brood mares, racing stables, to equestrian, which in itself ranges from commercial operations to the pony in the horse paddock by the house of a significant proportion of lifestyle blocks. While large and heavy horses are generally run at low stocking rates, this can result in physical damage to soils. The use of break-feeding to limit intake creates bare ground and at times increases the risk of sediment and P losses to receiving environments. It is worth noting there has not been a comprehensive review of the impact of this sector on soils.

Other small or emerging animal sectors

The goat milking industry is limited largely to the Waikato. Features of the industry include the cut and carry of fresh forage to the goats, housing of animals indoors year round, and the return of manure to pastures. If not well managed during periods when soils are wet, the machinery used for cutting and carrying forage has the potential to cause soil compaction and subsequent losses of soil services. As a result, in winter and early spring when soils are wet the cut and carry operation is often suspended to protect the soils from physical damage. Understanding the long-term changes to soils under cut and carry is a research gap not limited to the goat milking sector, but is also an emerging question for the dairy industry. The result of nutrients returned in manure is another area in need of research, if the levels of imported feeds into the milking increase over current levels.

The sheep milking industry, in comparison, is still in its infancy, but has the potential to be a significant future land use. Unlike the goat industry, sheep milking has all the characteristics of the dairy cow industry, with ewes grazing pastures in situ walked to the milking parlour for milking. This requires infrastructure to and from the shed and the facility to collect and apply effluent to pastures. Ewe stocking rates on the milking platform may be higher than found currently during the spring in lamb production units, but across the whole farm may not be any different. The sector has the potential to expand onto land currently under a sheep and beef operation and to replace dairy cow operations on fragile soils or in catchments with water quality problems. There would appear to be few immediate challenges to the sector. The proximity of both these emerging industries to population centres may limit some practices.

Outdoor pig farming is suited to areas with free-draining soils, low rainfall, and a moderate climate, such as Canterbury, where large numbers of pigs are farmed outdoors. The pork industry has a code of practice that considers such things as welfare, feeding, indoor and outdoor conditions, cleaning, manure collection, drainage, aesthetics, noise, and odour. The behaviour of pigs results in soils damage and an increased risk of contaminant losses to receiving environments.

Free-range poultry still represents a small part of the industry, with the control of contaminants to receiving environments a potential future challenge if it was to expand.

Aquaculture in New Zealand occupies in excess of 15 000 ha of coastal waters is expanding in area. In fresh water, aquaculture is limited to a few raceways located in several Canterbury rivers (Clutha and Waimakariri) and in hydroelectric canals in the Mackenzie Basin (Ohau and Tekapo canals). There is one small-scale freshwater prawn farm at Wairakei, near Taupo, producing tropical giant river prawns using heat from a geothermal source. Again, the link to soil management is very limited.

Vegetable

Pressures: The most significant pressures for the vegetable sector were the change to soil structure, organic matter, nutrient losses resulting from irrigation and intensification; cultivation and associated effects on soil erosion and productivity; land sterilisation fragmentation, loss of diversity and loss of high class soils to urbanisation; and the legacy of heavy metal contamination.

In recent years there has been increased scrutiny on the potential impacts related to intensification. In particular, considerable effort has been invested in understanding the effects of a range of land uses on nutrient losses and irrigation efficiency and in developing farming practices that meet the needs of industry, regulatory, and community stakeholders. Work in this area continues to be a significant focus for the vegetable sector to ensure farming remains profitable within agreed environmental limits.

An emerging issue in the sector is land fragmentation and loss of high class soils to urbanisation. Historically, vegetables have been grown on highly productive soils close to major urban centres. As the population in these centres expands there is increasing pressure to create more housing on land currently used for cropping. The risk to the sector is that growers are forced onto more marginal land that is less versatile and naturally less productive, requiring more inputs to optimise yields. This can also result in greater nutrient leakage and poorer efficiencies. The sector is actively engaged in plan change hearings in high-risk regions to ensure the protection of high-class soils is considered. In some cases there have been good outcomes, in others less so.

Legacy effects related to agrichemical and heavy metal (especially cadmium) contamination are also seen as a potential issue in the future. The scope and scale are not yet well defined, but the sector is working proactively with other groups to ensure the risks are minimised and little land has to be retired in the future. Relevant best practice and GAP (Good Agricultural Practice, formerly the New Zealand Fresh Produce Approved Supplier Programme) programmes used in the sector also contribute to reduce this risk as they outline a range of accepted practices, particularly in relation to agrichemical use and disposal.

Responses: Responses to soil management issues in the vegetable sector tend to be voluntary, with the exception of those that affect regulatory compliance and/or market access. Horticulture NZ and its various product groups invest in grower levies to address important issues, and extension is delivered through a variety of guides, on-farm research and demonstration trials, workshops and conferences. The vegetable and arable sectors often work closely together on these issues as they are relevant across a range of crops and farming enterprises. Other extension is provided through consultants and a range of research providers. The MPI Sustainable Farming Fund (SFF) has provided funding for a wide range of projects to help the sector respond to pressures on the soil resource.

As in the arable sector, there is widespread awareness of the impacts of long-term cultivation causing loss of soil structure and soil organic matter, which, in turn, results in an increased risk of soil erosion and loss of productive capacity. A range of minimum- or no-till practices have been considered for selected crops in the sector, but in some cases these are not suitable for establishing crops that require a fine seed bed. Where possible, growers look to incorporate green crops in their rotations to add organic matter back into the soil and in some cases use controlled traffic systems to reduce compaction and subsequent cultivation requirements. In addition to these efforts, a wide range of mitigation options have been identified to reduce soil losses in erosion prone regions. These are now well documented in industry codes of practice, though further work is required to demonstrate the ongoing efficacy of these methods across a wide range of circumstances to ensure widespread adoption. Extension has been provided by a range of partners, primarily through short-term applied SFF projects led by industry.

Key drivers of the adoption of good management practices in the vegetable sector are profitability and cost reduction, and to a lesser extent regulatory compliance and market access. For example, less cultivation can produce large cost reductions. Lack of adoption of the same practices may be risk averseness; growers are satisfied that their current practices are effective, or that change may have negative impacts on other facets of their farm system or profitability.

Arable (including Potatoes)

Pressures: For this sector the pressures judged to be the most significant were cultivation, machinery loadings, weeds and diseases, as well as storms and flooding. As with vegetables, this sector is also concerned about the loss of arable land to other uses such as urban encroachment on to high-class soils.

An emerging concern is the use of increasingly larger and heavier machinery that may counteract the benefit of reduced tillage. A specific concern is the use of large, heavy harvesting machines when soils are wet and have less resilience to compaction. Farmers are faced with the (economic) problem of removing a crop within a small harvest window when wet soils are likely to compact.

Soil-borne diseases and weeds are another emerging or growing threat for the arable sector. There has recently been an increased focus on soil-borne diseases due to their contribution to sometimes large "yield gaps" in high value crops, in particular potatoes. Potential responses to this issue are likely to be in the form of bio-control and bio-fumigants, modification of irrigation, and cultivation practices. Two types of weed issue are emerging or poorly quantified: first, new or different weed species are proliferating; and second, some species may become herbicide resistant. Changes in weed populations may reflect the changes in management such as reduced cultivation and reduced burning to manage stubble.

Likely emerging pressures include access to reliable irrigation supply, especially in systems that may have seasonal restriction. A related issue is the efficient utilisation of irrigation water through improved application technology, crop and soil management. Extreme weather events are a concern but currently a low priority. Responses include increasing the use of shelter belts, and crop timing to spread the harvest window to reduce the risk of crop losses. Locally, flooding following storm events is a risk in some areas (e.g. Gisborne). Some responses include adjusting planting time to reduce risk of flooding and precision methods to locate and run mole drains more accurately.
Although the impact on water quality is considered low when best management crop rotation, fertiliser and cultivation practices are used, there is concern about the implementation of blanket Regional Policy rules. It is a high priority for the sector to provide policy-makers with appropriate data. This said, there is concern about the winter grazing of forage crops and fertiliser inputs to some high value crops (e.g. potatoes).

Responses: There is widespread sector awareness of the impacts of long-term cultivation causing loss of soil structure, loss of soil organic matter, increased risk of erosion, and loss of productive capacity. In response to the effect of intensive cultivation on soil function, there has been a large reduction in the use of intensive cultivation (e.g. inversion ploughing). There is also awareness of farm machinery causing compaction and loss of a range of soil services. Minimum, no-tillage, and other practices such as controlled traffic and strip tillage have become more common. The use of reduced tillage practices, which retains better soil integrity, has reduced the impact of compaction on regulating and provisioning services. These changes have occurred through demonstration of the benefits of reduced tillage for retaining soil organic matter, soil intactness, and crop productivity.

Erosion is actively managed with shelter belts and improvement in cultivation and soil management practices; however, the sector is still battling localised areas of intensive cultivation and low frequency of restorative phases in rotations, for example, intensive potato and other vegetable cropping that have led to soil erosion and sedimentation in the Pukekohe area. Responses include best crop and soil management guides and research trials to inform better practices (e.g. Franklin Sustainability Project). Examples of mechanisms that have been used to bring about change include the development and extension of best management guides, country-wide on-farm demonstrations, and research trials. Between 2006 and 2011 the use of ploughing after a grass phase in crop rotations fell from 60 to 50%. The threat of soil erosion and soil nutrient losses through leaching has reduced through improved timing of crops reducing fallow periods.

In general the arable sector responses to soil management issues tend to be voluntary. The Foundation of Arable Research, funded mainly by farmer levies, provides much of the sector-wide extension information through a variety of guides, on-farm research and demonstration trials, workshops and conferences. Other extension is provided through Landwise and from the Crown Research Institutes and universities. The MPI SFF has provided funding for a wide range of projects to help the sector respond to pressures on the soil resource. There is increasing interest in the use of precision agriculture and monitoring tools to use soil resources more efficiently and effectively (e.g. EM mapping, yield mapping, precision application of fertiliser, mapping of soil organic matter and pH, variable rate irrigation).

Kiwifruit

Pressures: Significant pressures on the sector were identified as more chemicals and the legacy effects of disease control. Application of copper to control the PSA disease was also identified as having a potential impact, particularly on soil biological activity.

Compaction of heavy soils or excessive irrigation leading to waterlogging was identified as a pressure of local scale and medium severity. The bulk of the industry produces kiwifruit on well-drained soils and the issues of water logging are expected to stay a local issue for the medium term. Best practices, guided by past research, include improving drainage or, if that is not possible, by removing vines and retiring those parts of the orchard prone to water logging. Orchards on heavy soil types have had guidance on the water requirement for kiwifruit so that they can better balance water application rates to water requirements and soil drainage characteristics. Growers dependent on rainfall can have fewer options to manage water supply. Techniques such as soil electrical conductivity mapping are starting to provide growers with an assessment of variation in soil properties, including compaction and drainage.

Responses: Good practices for the sector addressing these soil management issues include nutrient budget tools, and development of integrated disease control methods. Tools such as SPASMO, OVERSEER, and industry research projects have helped quantify the risks of nitrogen leaching, and previous research has defined management practices to minimise nutrient leaching. Good practice for disease control is expected to be achieved through greater use of products and control methods that have a lower impact on soil biological function than copper-based control methods.

Leaching of nitrogen in regions with high rainfall and deep, well-drained or light soils is recognised as a risk by the kiwifruit industry but as yet growers are not limited by regulation of nitrogen applications or timing. Grower use of practices such as rates, timing and application method are therefore voluntary and not monitored. Opportunities for mitigating these issues include development of best practices through a consultative process and more research on competitive disease control alternatives to copper. Development and adoption of best practices for nitrogen management need to occur through a consultative process involving growers, technical representatives, and plant nutrition consultants as a diversity of opinion exists in industry regarding optimal nitrogen management practices. Regional councils and marketers also have a role in providing future signals relating to community and customer stakeholder environmental impact risks.

Uptake and effectiveness of integrated disease control methods are low as primary focus for growers has been on controlling PSA disease on kiwifruit. Adoption will increase as viable alternatives to copper become available for PSA disease control. Research investment is in place to develop more integrated PSA control programmes.

The ley driver of adoption is market access. However, research demonstrating that fruit quality can be improved and vine pruning costs reduced through lower rates of nitrogen application are resulting in a reduction of nitrogen applied to kiwifruit orchards. As cost-competitive alternatives to copper become available, kiwifruit growers are expected to reduce their dependency on copper and thus the risks of soil contamination from copper.

Pipfruit

Pressures: Most significant for this sector were pressures of more fertiliser (national, high) and pesticide (national, medium) chemicals. Pesticide use can decrease soil organic matter by maintaining a vegetation-free herbicide strip along tree rows, and decrease soil biota.

Compaction from wheel traffic was identified as of local scale and medium severity. This pressure occurred in orchards with heavy soils when traffic was required during wet periods. Research is examining alternatives to wheel traffic to mitigate compaction problems.

Cultivation was identified as of local scale and low severity. Some organic orchards are adopting cultivation for pest control of bronze beetle, which results in loss of soil organic matter and nutrient flushes. This may become a more extensive issue if the pest pressure spreads. Research is ongoing to improve management practices.

Responses: The New Zealand Pipfruit Integrated Fruit Production (IFP) Manual outlines key good practices for the sector to address these soil management pressures. For nutrient management, minimum requirements include record keeping and soil nutrient analyses every 3 years. Monitoring soil organic matter content is recommended. Strategies to improve soil organic matter concentrations are included in the manual. Factsheets on good soil management practices (e.g. how to sample soils and plants for nutrient analyses) are also available from NZ Pipfruit.

Uptake of good practice initiatives is high, and growers are generally following IFP Manual recommendations. Drivers of this adoption include market access and the need for documentation of good practice to comply with market requirements. Additionally, growers are aware that losses in soil organic matter can have further negative impacts for soil structure and drainage.

Gaps in effectiveness include ensuring that current industry nutrient recommendations are suited to local growing conditions. Incorporating soil organic matter maintenance as a positive component of orchard nutrient management strategies could increase recognition of soil health.

Avocado

Pressures: No pressures from Phase I were identified as knowingly being of national or regional scale and high or medium severity. The threats or opportunities of chemical applications in the sector are unknown and are under research. Ongoing projects include an intensive survey of grower information, including fertiliser use practices, to quantify current management practices. Current New Zealand Avocado nutrient management guidelines provide conservative recommendations for nutrient requirements.

Drainage presents a significant opportunity of local scale and high severity in some avocado growing areas, such as in the Far North. Soil physical properties impede drainage restricting plant growth, and physical manipulations are required for fruit production. Initiatives include breaking clay pans with an excavator pre-planting, installing drainage systems, or planting on humps to avoid root water-logging. Adoption of these practices is high in these locations and they are mostly effective or tree production fails. Research is examining the potential role of water-logging and aeration on tree decline in these areas.

References

Acton DF, Gregorich LJ eds 1995. The health of our soils: Toward sustainable agriculture in Canada. Ottawa. Canada, Centre for Land and Biological Resources Research, Research Branch, Agriculture and Agri-Food Canada. Publication 1906/E. 138 p.

Barnard T, Barry L, Garrett L, Harrison D, Jones H, Moore D, Page M, Rosser B, Porou T, Fitzgerald G, Bloomberg M, Morgenroth J, Peacock D 2012. Waiapu River Catchment Study: Final Report. Report to Ministry of Agriculture and Forestry, Wellington.

Bayfield M, Meister A 2005. East Coast Forestry Project Review. Report to Ministry of Agriculture and Forestry, Wellington.

Broll G 2010. European network on soil awareness. 19th World Congress of Soil Science, Soil Solutions for a Changing World 1 – 6 August 2010, Brisbane, Australia.

Campbell A 2008. Managing Australia's soils: a policy discussion paper, prepared for the National Committee on Soil and Terrain through the Natural Resource Management Ministerial Council, Canberra.

Collins A, Weeks E, Leckie C, Stokes S, Hill R 2014. Strategic Roadmap for Land & Water Research. National Land Resource Centre Report LC 1866.

Department of Agriculture, Fisheries and Forestry 2011. A stocktake of Australia's current investment in soils research, development and extension: a snapshot for 2010-11. Prepared by the Soils Research, Development and Extension Working Group for the Department of Agriculture, Fisheries and Forestry, Canberra, available at daff.gov.au/natural-resources/soils/stocktake-of-australias-investment-in-soils-rde

Department of Agriculture, Fisheries and Forestry 2014. The National Soil Research, Development and Extension Strategy, securing Australia's Soil for profitable industries and healthy landscapes, Canberra.

Danish Agriculture and Food Council 2014. Danish Agriculture and Food: Facts and figures. http://www.agricultureandfood.dk/

Department for Environment, Food and Rural Affairs 2003. Audit of UK soil research. London, Department for Environment, Food and Rural Affairs. http://archive.defra.gov.uk/environment/quality/land/soil/documents/audit-report.pdf

Department for Environment, Food and Rural Affairs 2009. Safeguarding our soils: a strategy for England. London, Department for Environment, Food and Rural Affairs. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69261/pb13297-soil-strategy-090910.pdf

Department of Environment, Food and Rural Affairs 2015. Structure of the agricultural industry in England and the UK. Statistical data set. https://www.gov.uk/government/statistical-data-sets/structure-of-the-agricultural-industry-in-england-and-the-uk-at-june

Department of Sustainability and Environment 2007. Land and biodiversity at a time of climate change.http://www.dse.vic.gov.au/CA256F310024B628/0/3BEF611031D56535CA2572C3001DE765/$File/Consultation+doc+final+20070426.pdf

Drewry J, Curran-Cournane F, Taylor M, Lynch B 2015. Soil quality monitoring across land uses in four regions: implications for reducing nutrient losses and national reporting. Paper presented at 28th Fertiliser and Lime Research Centre Workshop, Massey University, Palmerston North.

European Commission 2006. Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions – thematic strategy for soil protection [SEC(2006)620] [SEC(2006)1165].

Foundation for Research Science and Technology and Ministry for the Environment 2009. Water research strategy. Wellington, Ministry for the Environment. http://www.mfe.govt.nz/publications/water/water-research-strategy/water-researchstrategy.pdf

Heaphy, M., Lowe, D. J., Palmer, D. J., Jones, H. S., Gielen, G. J. H. P., Oliver, G. R., & Pearce, S. H. (2014). Assessing drivers of plantation forest productivity on eroded and non-eroded soils in hilly and steep land in eastern North Island, New Zealand. New Zealand Journal of Forestry Science, 44, 24.

Kibblewhite MG, Deeks L, Clarke M 2010. A gap analysis on the future requirements of soil and water management in England: report commissioned by Royal Agricultural Society of England. Stoneleigh Park, Warwickshire, UK, RASE. http://www.soils.org.uk/media/uploads/regional_groups/wsdg/LDeekes.pdf

Land and Water Forum 2010. Report of the Land and Water Forum: A fresh start. Wellington, Ministry for the Environment. http://www.landandwater.org.nz/Site/Resources.aspx#H126743-8

Land and Water Forum 2012. Third Report of the Land and Water Forum: Managing water quality and allocating water. Wellington, Ministry for the Environment. http://www.landandwater.org.nz/Site/Resources.aspx#H126743-8

Land Monitoring Forum 2009. Land and soil monitoring: A guide for SoE and regional council reporting. Wellington, Land Monitoring Forum.

Lilburne LR, Hewitt AE, Sparling GP, Selvarajah N 2002. Soil quality in New Zealand: policy and the science response. Journal of Environmental Quality 31:1768–1773.

Lynn IH, Manderson AK, Page MJ, Harmsworth GR, Eyles GO, Mackay AD, Newsome PJF 2009. Land Use Capability Survey Handbook – a New Zealand handbook for the classification of land 3rd ed. Hamilton, AgResearch; Lincoln, Landcare Research; Lower Hutt, GNS Science. 163p.

MacDonald S ed. 2013. Latest U.S. agricultural trade data. USDA Economic Research Service. USDA, 4 Sept. 2013. Web. 28 Sept. 2013.<http://www.ers.usda.gov/data-products/foreign-agricultural-trade-of-the-united-states-(fatus)/latest-us-agricultural-trade-data.aspx#.UkckR_Pn-M8

Ministry for the Environment 2010. Resource Management Act 1991 (RMA). Ministry for the Environment. Retrieved 14 September 2011.

Ministry for the Environment 2014. A framework for environmental reporting in New Zealand. Wellington, Ministry for the Environment.

National Farmers Federation 2012. NFF farm facts: 2012. www.nff.org.au Kingston, Australia.

NCST 2013. Establishing the Australian Soil Assessment Program: supporting Australia's sustainable future through improved knowledge of Australian soils and their responses to land management, Prepared by the National Committee on Soil and Terrain for the National Soil Research Development and Extension Strategy Reference Group, Canberra.

O'Loughlin CL 1991. Priority setting for government investment in forestry conservation schemes – an example from New Zealand. Washington DC, USDA Forest Service.

Pimental D, Burgess M 2013. Soil erosion threatens food production. Agriculture 3: 443–463; doi: 10.3390/agriculture3030443

PMSEIC 2010, Australia and food security in a changing world, a report by The Prime Minister's Science, Engineering and Innovation Council, Canberra, Australia, available at chiefscientist.gov.au/wp-content/uploads/FoodSecurity_web.pdf (pdf 3.75mb).

Scottish Government 2009. The Scottish Soil Framework. ISBN 978 0 7559 9013 9 (Web only publication). http://www.gov.scot/Publications/2009/05/20145602/0

Smith G 1997. The Resource Management Act 1991 – 'A biophysical bottom line' vs 'a more liberal regime'; a dichotomy? Canterbury Law Review 6: 499–538, p 501.

Soil and Land Use Alliance 2012. Reporting on soils at the national level. Report prepared for the Parliamentary Commissioner for the Environment. Palmerston North.

Standing Senate Committee on Agriculture, Fisheries and Forestry, Hon. HO Sparrow, Chair. 1984. Soil at risk-Canada's eroding future. Ottawa, Senate of Canada. 129 p.

Statistics New Zealand, Ministry for the Environment, Department of Conservation 2013. Environment Domain Plan 2013: Initiatives to address our environmental information needs. Wellington, Statistics New Zealand, Ministry for the Environment, Department of Conservation. http://www.stats.govt.nz/browse_for_stats/environment/environmental-economicaccounts/environment-domain-plan.aspx

United Nations Global Soil Partnership http://www.fao.org/globalsoilpartnership/the-5-pillars-of-action/en/ http://ec.europa.eu/environment/soil/three_en.htm

Victorian Government Department of Sustainability and Environment (DSE), 2005. Our Environment: Our Future. Melbourne, Australia, DSE.

Key links

Land Information New Zealand http://www.linz.govt.nz/land/land-records/search-for-land-records/m%C4%81ori-land-records-%E2%80%93-te-ketu-k%C5%8Drero-wh%C4%93nua-m%C4%81ori/what

Māori Land Online http://www.maorilandonline.govt.nz/gis/home.htm

Ministry for Environment http://www.mfe.govt.nz/

Ministry for Primary Industries https://mpi.govt.nz/about-mpi/our-strategy-2030/

Office of Treaty Settlements http://www.ots.govt.nz/

Te Ara – The Encyclopaedia of New Zealand http://www.teara.govt.nz/en/ahuwhenua-maori-land-and-agriculture/page-2

Ministry for Primary Industries
Manatū Ahu Matua

NATIONAL
LAND RESOURCE
CENTRE

Landcare Research
Manaaki Whenua

agresearch

Plant & Food
RESEARCH
RANGAHAU AHUMĀRA KAI

SCION
forests · products · innovation

What do we want for New Zealand soils? What policy, practice, science, and institutional shifts can we make to get there?

Future Requirements for Soil Management in New Zealand

Phase 3: **Looking forward**

Future requirements for soil management in New Zealand. Phase 3: Looking Forward.

Contract Report number: LC 2369

Project number: 17004

Suggested citation: Collins A, Mackay A, Hill R, Thomas S, Dyck B, Payn T, Stokes S. 2015 Phase 3: Looking Forward. Future requirements for soil management in New Zealand. National Land Resource Centre, Palmerston North.

Justine Daw – approved for release

Steering Group

Gary Bedford, Taranaki Regional Council
James Palmer, Ministry for the Environment
Lisa Harper, Federated Farmers
Nick Pyke, Foundation for Arable Research
Oliver Hendrickson & Gerald Rys, Ministry for Primary Industries

Design and layout by Nicolette Faville, Landcare Research

December 2014

National Land Resource Centre, c/o Landcare Research, Massey University, Private Bag 11052, Palmerston North 4442, New Zealand.

What do we want for New Zealand soils? What policy, practice, science, and institutional shifts can we make to get there?

Future Requirements for Soil Management in New Zealand

Phase 3: **Looking forward**

Led by **Alison Collins, Alec Mackay, Reece Hill, Steve Thomas, Bill Dyck, Tim Payn and Simon Stokes.**

Contributions made by:

Alison Fordyce – MBIE

Andrew Curtis – Irrigation New Zealand

Ants Roberts – Ravensdown

Ben O'Brien – Beef & Lamb New Zealand

Bridget Fraser – MfE

Bruce Thorrold – DairyNZ

Chris Keenan – Horticulture New Zealand

Dan Bloomer – Page Bloomer

Gary Bedford – Taranaki Regional Council

Gerald Rys – MPI

Ian McKenzie – Federated Farmers

Jacqueline Rowarth – University of Waikato

James Palmer – MfE

John Phillips – MfE

Kevin Steel – MPI

Lisa Harper – Federated Farmers

Liz Wedderburn – AgResearch

Louis Schipper – University of Waikato

Martin Workman – MPI

Myles Guy – MPI

Naomi Parker – MPI

Nick Pyke – Foundation for Arable Research

Oliver Hendrickson – MPI

Sharon Adamson – MPI

Stuart Miller – MPI

Tony Rhodes – PGG Wrightsons

Contents

Summary

This report represents the findings of the final phase of a three-phase project to inform future policy and good practice principles to protect and realise the full potential of New Zealand's soil resource. The report is informed by Phases 1 and 2 and a formative workshop with leading strategic thinkers in June 2015.

The report promotes a guiding vision for New Zealand soils:

To recognise and explicitly manage our fragile, finite and precious soils to ensure productive and protective functions for all society

The report also highlights the need for a national *Soil Framework for Resilience and Growth* with the following key actions:

1. Establish a National Soil Management Group to develop national soil strategy; provide leadership; inform and advise policy and practice; provide a national perspective on research; promote and monitor a capability growth strategy; and ultimately act as an advocate for soils.
2. Develop a National Soil (and land) Management Strategy to set direction on the use, policies, capabilities and research on soil.
3. Profile the importance of land and soil to the New Zealand economy and society by quantifying the actual and total potentially realisable economic value of our soils.
4. Undertake a foresight exercise to explore risks to future economy and environment by examining how soils are and might be used into the future.
5. Undertake a national prioritisation of soil research to support the national science challenges, sectors and government agencies and guide investment in R&D.
6. Agree a national suite of underpinning soil and land resource information required to inform policy and decision-making on soil management, agreeing development priorities and stable funding.
7. Create an inventory of the current and projected skills and capability in central and regional government and industry, including current and projected graduate numbers, and identify a strategy for priming the capability system, including improving competencies for extension and adoption.
8. Develop an evaluation and monitoring framework to determine the effectiveness of soil management practices, non-regulatory approaches, and policies in achieving soil management goals.
9. Investigate the form of an integrated regulatory and/or non-regulatory framework that explicitly recognises and protects soil functions from current and future pressures and gains highest value from them.

This is our opportunity to unlock and realise the full potential of New Zealand's soil – and this report represents the call to action.

1

orientation

Project genesis and purpose

This project sets out to determine the state of soil management in New Zealand, how to optimise the use of our land resources, and the readiness of the current knowledge and capability to develop policy and support progressive stewardship. Appropriate policy and stewardship have the potential to retain land-use flexibility, realise enduring economic value from New Zealand's soils, reduce the loss of high class soils from primary sector use, and support the implementation of the freshwater reforms.

Much of the evidence required for New Zealand to make informed land and soil management decisions sits within the science, primary, and resource sectors in the form of publications, reports, strategies, models, and decision-support tools or in anecdotal knowledge. Extracting greater value and synthesising this collective evidence-base was the focus of the first two phases of this project:

1) Looking back: What are the current and emerging pressures to New Zealand's soil resource? How well is the knowledge and capability primed to meet these pressures? (Phase 1, Collins et al. 2014)

2) Looking out: What are we doing in regard to soil management, is it enough, and can we learn anything from international case studies? (Phase 2, Collins et al. 2015)

This report is the final in the series of three phases of work:

3) Looking forward: What do we want from New Zealand soils? What policy, practice, science, and institutional shifts can we make to get there? (Phase 3)

This final phase aims to provide advice on where to next for soil management in New Zealand. This report draws on both the evidence assembled in the first two phases and a workshop bringing together New Zealand's leading strategic thinkers to:

- validate the findings from Phase 1 and 2 (*Where do we stand*)
- guide a discussion on where we want to be in regards to the management of our soils (*Destination*)
- recommend future requirements for New Zealand Soil Management (*Future requirements*).

Lessons from the journey

Phases 1 and 2 explored and established:

- the operating context in which soil is managed in New Zealand (*Phase 1 – Direction of travel*). This includes the continuing expectation of economic growth from the primary sector, but the emergent shift towards high value, sustainably produced primary products
- the complexity of soil governance in New Zealand, reflecting the close links we all have with our land and land ownership, but at the same time the diversity of interests. This suggests a more

coordinated approach to governance to utilise our natural advantage is needed (*Phase 2 – Behind the wheel*)

- the socio-economic factors and the pressures on the soil resource and other natural resources to which they give rise (*Phase 1 – Drivers, pressures and impacts; Phase 2 – On the ground*), including intensification, land-use change, climatic change, and legacy effects

- the range of responses within the sectors and policy planning frameworks and whether they are enough to address these pressures (*Phase 2 – On the ground; In plans & policies*). We conclude that many of the pressures are addressed within primary sector practice and the policy and planning frameworks; however, it is difficult to ascertain uptake or effectiveness of practices given a general lack of monitoring and evaluation

- how we measure up to our international peers in terms of soil management (*Phase 2 – Measuring up*) reveals that as a small biologically-based country, New Zealand has the ability and agility to develop the partnerships and integrated measures to realise enduring economic, ecological and social value from its soils – but we aren't there yet

A summary of these key findings is presented in Table 1.1

Where do we stand?

Taking the findings from Phases 1 and 2, and from discussions at a workshop of leading strategic thinkers, we determine where New Zealand is now in terms of soil management, where New Zealand needs to be to optimise the sustainable use of its land resources, and how well the knowledge and capability that supports this transition is able to respond.:

Could we manage our soil resource better as a country?

Working with the primary sector in Phase 2 it is apparent that there still significant opportunities for better soil management to address pressures, particularly in response to new technologies that bring currently unknown effects. Greater monitoring and evaluation of soil management initiatives to understand levels of uptake and effectiveness were also seen as critical to establishing if we could manage our soils better.

The loss of our best soils and land to subdivision (essentially removing it from primary production) was recognised in Phases 1 and 2, and through the workshop emerges as a critical issue. In recent years, New Zealand's population has grown at one of the fastest rates in the OECD (New Zealand Productivity Commission 2015). Most of this growth has been concentrated in cities, especially Auckland. Growing populations need more housing, yet New Zealand cities have struggled to provide enough land to meet this demand, turning towards rezoning and bringing rural land to the market. For example, between 2001 and 2006, urban development in the Auckland region replaced prime agriculture land at a rate of about 333 hectares per year (Curran-Cournane et al. 2014). With only 15% of land classified as 'versatile' (Classes 1–3) and 33.4% of land legally protected for conservation (Rutledge et al. 2010) productive soils are therefore in limited supply.

Table 1.1

Theme	Key findings	Source /Reference
Direction & value	**Importance of soil to the environment, economy and well-being**	Phase 1, Section 1, page 4
	Continuing expectation of economic growth from primary sector but need to protect natural resources	Phase 1, Section 1, page 5
Pressures & opportunities	**Complex soil governance with a range of socio-economic factors giving rise to pressures**	Phase 1, Section 2, page 9
	The most significant pressures: • ***Intensification*: irrigation, more chemicals & inadequate vegetation cover** • ***Land use change:* land fragmentation/loss of soils, poor matching of land use** • ***Legacy*: past deforestation, pests & diseases**	Phase 1, Section 2, page 11
	Scale (national, regional, local) and magnitude (high, medium, low) of impacts varies according to the ability to mitigate or reverse the impact and the social acceptability of impacts	Phase 1, Section 2, page 12
Requirements	Greater focus on capability-building, including extension/uptake	Phase 1, Section 3, pages 14–15
	Closing of significant gaps in scale, coverage &/or utility of underpinning resource information through strategic prioritisation and stable funding	Phase 1, Section 3, pages 16–20
	Priming of RS&T system with more long-term trials, foresight projects and a nationally agreed set of priorities to better respond to identified pressures	Phase 1, Section 3, pages 22–23
	Greater monitoring and evaluation of soil management initiatives within sectors and the policy framework to understand levels of uptake and effectiveness	Phase 2, Section 2, pages 10–14
	Extension of the range of non-regulatory approaches to greater range of pressures (beyond just intensification and land use change in erodible hill country)	Phase 2, Section 3, page 27
	More regulatory attention to prevent poor matching of land use to suitability	
	Stronger regulatory back stop to protect versatile soils from land fragmentation/ urban spill over	
	Greater focus on unlocking and realising the full potential of New Zealand's soil to increase land productivity	Phase 2, Section 4, pages 35–36
	More of a nationally coordinated approach to utilise natural advantage	

This 'land use collision' (Mackay et al. 2011) can be characterised as a 'wicked problem' with complexity in protecting against the loss of productive soils, ensuring supply of land for housing, and landowners' property rights. Unfortunately, the unintended consequences (e.g. damage to soils, tar-sealing) of policy or market-based decisions frequently occur as soil does not rank highly in the decision-making agenda. This is in part due to the fact that changes to soil health or state can be insidious, gradual, and not clearly visible, as well as complicated by the tensions of freehold title over land (this contrasts with water which is seen as a public good).

Do we understand enough about our soils?

Understanding the interconnections between people, soils, plants, and animals in agricultural and horticultural production, and the ways in which both practices impact on the environment and can be used to sustain or enhance it, is critical to reducing pressures and realising opportunities. While there has been significant investment in soil and land-based research in New Zealand through government, regional councils, and the primary sector (see *Trajectory of New Zealand Science System*, page 21, Phase 1 report), there has been little attempt to nationally prioritise needs. This has resulted in gaps in understanding, particularly about the long-term implications of relatively emergent pressures and actions and for areas outside the traditional 'calibration' areas. Resource information (e.g. soil mapping – see *State of underpinning soil and land information*, page 16, Phase 1 report) is another apparent gap. While critical in providing evidence from which to assess state and trend as well as monitor the impact of actions and responses, this type of understanding is often not seen as valuable science endeavour and can therefore fall through funding cracks.

To secure New Zealand's soil resource also requires a well-connected and functioning knowledge infrastructure comprising not only scientists to conduct research to develop technologies and inform policy but also advisors to translate science and technologies into practice, and land managers to apply best practice (Kibblewhite et al. 2010). Workshop discussions identified deep concerns regarding gaps in capability, particularly science literacy, typically beginning with a lack of students willing to engage with, and commit to, science training. This was seen to be confounded by a lack of stable and consolidated investment in soil science leading to uncertain and risky careers. Collectively these issues contribute to a society less than adequately informed on either the value of soils or the importance of good soil management. The lack of knowledge flows through all levels of decision making. The discussions identified the critical need for:

- an enduring pipeline of scientists, advisors, policy-makers, and land managers with key competencies and aspects of soil literacy that begin at school age
- a measure of value and amount of services (provided by soil) that are lost as a result of different threats (e.g. to urban and pre-urbanisation) as well as the actual and potentially realisable value from our soils
- the filling of critical gaps (in coverage and scale) of nationally agreed resource information through stable and long-term investment

Are we getting enough from our soils?

Land productivity rose rapidly in the period 1950 to the early 2000s as science contributed to the identification of high-yielding varieties, and the primary sectors led the development of low input, high output management initiatives. However, as theoretical limits are approached it is becoming more difficult to sustain a continuing volume increase for many of our primary products, which, together with competition for land, necessitates a different approach to the way our soils are used.

An alternative approach is needed that includes a long-term view to avoid making rapid decisions on land use that can have long-lasting or irreversible impacts on the ability of soils to provide services, as well as recognising and managing soils according to their diversity and maintaining flexibility for future uses. Such a shift in approach could not only result in a reduction in key pressures (identified in Phases 1 and 2) but could also unlock and realise the full potential of New Zealand's soil.

Key reflections

1. Gaps in the understanding and underpinning of resource information and capabilities (across the capability pipeline) in regards to soils. As a consequence, society is informed neither of the importance of soils to their well-being and economy, nor of the criticality of wise soil management

2. The lack of broad societal emotional connection to, or awareness of, the need to protect soil, given the insidious, gradual, and not clearly visible changes to soil health and the tension of freehold title over land

3. The need to manage our soils better as a country, including moving from our current policy approach of focusing on a single issue, to recognising soils more explicitly in decision-making agendas to prevent soil becoming a casualty of unintended consequences

4. The perceived margin to realize greater potential from our soils, including raising land productivity, by recognizing and managing according to the diversity of soils and maintenance of future flexibility.

2

destination

Attributes of our soils

Throughout the workshop a common theme on the human perspectives of soils – and specifically the lack of understanding, appreciation and respect – emerged. The ideas promoted through the *New Zealand Society of Soil Science International Year of Soils Campaign (Te Ohomauri o Te Whenua),* in particular the concept of soils being fragile, finite, and precious, appear relevant (refer to Fig. 1), including recognising the:

- Fragility of our soils better through the provision of a more holistic policy that includes explicit focus on soils so that unintended consequences of decision-making do not result in soil as a casualty
- Finite and limited nature of the soil, exacerbated by soil taking hundreds to thousands of years to form just a few centimetres. This means our future must include an informed debate and protection measures to prevent long-lasting (e.g. degradation in soil quality) and irreversible impacts on soil (e.g. loss to urban development and sealing)
- Precious nature of soil, given it hosts more than 25% of the world's biodiversity, stores and filters water, improves resilience to flood and drought, and regulates carbon, oxygen, and plant nutrient cycles. Soils must be recognised and valued for their diversity and the services they provide. For many, this means preserving inter-generational

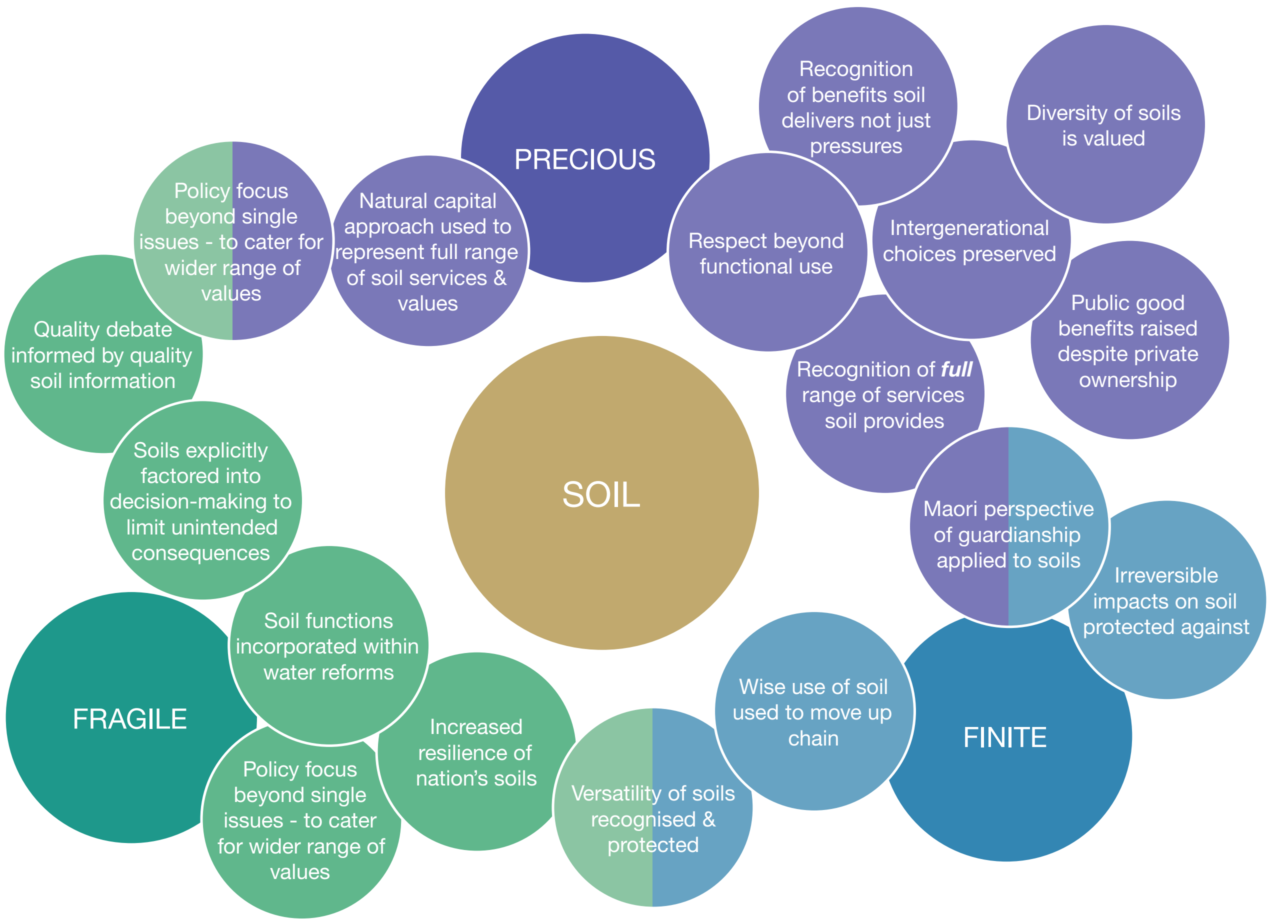


Fig 1: Aspirations for New Zealand soils, recognising their fragile, finite and precious (from workshop whiteboard exercise).

choices and is most likely achievable through embedding Māori perspectives on guardianship in future soil management; using a natural capital or ecosystem services approach; and adopting approaches that move our primary products up the value chain.

Where do we want to be?

This phase of the project focuses on looking forward, envisioning possibilities, and enlisting others in a shared view of the future. Through the workshop we identified that the desired destination is a time and place where government, industry, community, and Māori coordinate to use the natural advantage provided by our soils, and where the full potential of those soils is unlocked and realised to increase land productivity and primary product value. This includes working to the following vision for New Zealand soils:

Recognise and manage explicitly our fragile, finite, and precious soils to ensure productive and protective functions for the value of all society.

However, to do this requires resolving the following barriers:

- A wicked problem? As a biological-based economy we depend on soils, and yet the housing crisis and development agenda in some of our key cities (with the 10 high growth areas being Whangarei, Auckland, Tauranga, Hamilton, Waikato, Wellington, Christchurch, Selwyn, Waimakariri, and Queenstown Lakes; New Zealand Productivity Commission 2015) are irreversibly locking up some of our most versatile soils. This competition for land not only affects these versatile soils but also encourages the compensatory action of intensification of marginal lands.

- Playing in the wrong place? Another perceived issue was the intensification required to hold a position and deliver a return in the high volume commodities market. Despite the best efforts in the 'New Zealand Story' (an initiative that defines the attributes that make us unique and provides a framework for communicating value to the world) we have not yet committed to moving up the value chain through premium products and robust environmental credentials. The challenge, therefore, is that if we continue along current trajectories (housing and commodities) without informed debate we risk not meeting current business growth targets and reducing future flexibility.

- Too many disconnects? Part of the problem are the disconnections between the landscape-scale spatial context of our soils and the property scale of management; the temporal scale of soil processes (sometimes geological) and the day-to-day management at the property scale (managing for the issues of the day); and freehold title over land and the public good of soil services. One potential way to reconcile these disconnections is to change how we approach soil management – to the perspective that we do not 'own' soils but are their stewards for future generations. This is consistent with the Māori view of natural resources, where resources are physically and spiritually entities in their own right.

Key reflections

Through the findings of Phase 1 and 2 and discussions with leading strategic thinkers, we reflect on the importance of:

1. Enhancing the understanding, attitudes, and behaviour towards the soil resource, as well as bridging those key disconnections that prevent us from realising the full potential of our soils

2. Developing and sharing in a vision for future soil management that is informed by both the risks to be avoided and the opportunities to be realised

3. A guiding vision to *'recognise and manage explicitly our fragile, finite and precious soils to ensure productive and protective functions for all society'*

3

future requirements

Appropriate policy and stewardship has the potential to retain land-use flexibility, realise enduring economic value from New Zealand's soils, reduce the loss of high class soils from primary sector use, as well as support the implementation of the freshwater reforms. In this final section we take account of both the findings on the state of soil management in New Zealand and the readiness of current knowledge and capability, and recommend future requirements for soil management in New Zealand.

Key pathways

Taking into account the recommendations resulting from Phases 1 and 2 and the workshop, we propose a *Soil Framework for Resilience and Growth* focused on the following pathways: *Leadership and partnership; Readiness and recognition; Measures and management; and Integrated Frameworks.*

Fig 2:. Proposed New Zealand Soil Framework for resilience and growth

Call to action

Findings and recommendations from Phase 1 and 2 of the project were categorised under each of these four pathways and discussed during the workshop. Table 2.1 identifies key actions for each of these pathways, explained more fully in the next section.

Leadership and partnership

A common theme emerged throughout the project: to do things differently so that we increase the resilience of the soil and realise new opportunities (such as lifting land productivity). This in turn requires encouraging society to think differently about soil and work together to identify a set of national actions and changes.

Ultimately, action by all sectors is essential to create the visibility and urgency needed to focus society on the issues and challenges for soil: the endorsement that the issues are important; the direction that better outcomes for soil are required; and that changes are needed now.

Government has a wide range of instruments and mechanisms for facilitating and managing natural resources, including working parties, national policy statements, national environmental standards, or national objective frameworks. There are several precedents of pan-sector alliances forming to tackle a nationally significant issue (e.g. Land And Water Forum – LAWF; National Cadmium Working Group) and draft a direction and strategy to guide a shift in practice (e.g. National Cadmium Management Strategy; Rys 2011). Success, however, depends on ensuring membership that balances representation, interest, and continuity and embedding the leadership group into the wider operating system, with the appropriate 'levers' to create change.

RECOMMENDATION 1: Establish a National Soil Management Group to develop national soil strategy; provide leadership; inform and advise policy and practice; provide a national perspective on research; promote and monitor a capability growth strategy; and ultimately act as an advocate for soils.

RECOMMENDATION 2: Develop a National Soil (and land) Management Strategy to set direction on the use, policies, capabilities, and research on soil. This strategy should be underpinned by partnership across government, sectors, and science; be driven by the principles of kaitiakitanga and whanaungatanga; and recognise the role of soils in land productivity and the integrity of natural resources (including freshwater).

Recognition and readiness

The majority of society thinks in terms of land, rather than soil, not appreciating the range of life-supporting provisioning and regulating services soil provides. To remedy this we recommend quantifying both the actual and potentially realisable economic value derived from our soils in respect of the services they provide. Such an exercise, building on globally standardised approaches (e.g. System of Environmental-Economic Accounting (SEEA)), would increase the visibility of the value of our soil resource in a currency that society and government understands.

As we seek to lift the level of awareness about sustainable soil management, and with that the need for better planning, management, and practice, the tension of freehold title over land is likely to create barriers to change as the prospect emerges of new limits and restriction on practices. To cut through this we need to shift this perspective from *owning* soils to *stewarding* them for future generations. This is consistent with the Māori view of natural resources, where resources are an entity in their own right, physically and spiritually.

Making this paradigm shift requires a greater focus on the future and speculation as to what the future might look like by presenting a range of scenarios, including likely future land-use patterns based on current policy and practice settings. As a result we recommend scenario planning to assess the impact of decisions on the future and inform policies and strategy-setting.

RECOMMENDATION 3: Profile the importance of land and soil to the New Zealand economy and society by quantifying the actual and total potentially realisable economic value of our soils.

RECOMMENDATION 4: Undertake a foresight exercise to explore risks to the future economy and environment by examining how soils are and might be used into the future.

To respond to pressures and trends, and realise opportunities, requires clarity on priorities for research and knowledge generation. Currently, investment in soil-related research for evidence and innovation occurs through a number of investment mechanisms, from a variety of investors (e.g. MBIE, MPI, MfE, Dairy NZ, Beef & Lamb New Zealand, Fonterra, etc.), with complexity even within individual investors (e.g. MBIE: Envirolink, core and contestable funding; MPI: Primary Growth Partnership (PGP), Sustainable Farming Fund (SFF), Māori Agribusiness, Irrigation Acceleration Fund and Regional Economic Development initiatives). However, without both a set of clear national research priorities for soils and access to a comprehensive database of funded projects across it, is difficult either to ascertain the quantum of the investment dedicated to soil priorities or to evaluate the impact this has in advancing wider economic, social, and environmental goals. We therefore recommend creating a national landscape of soil research and undertaking a national prioritisation to support the national science challenges, sectors, and government agencies and guide investment in R&D.

Resource information provides the critical evidence from which to assess state and trend as well as monitor the impact of actions and responses. MfE highlight in their Briefing to the Incoming Minister (2014) the significant opportunity for step change in the management of New Zealand's natural resources through an improvement in the underpinning information and evidence base. The completeness and accuracy of existing resource information remains a concern, as does the lack of an agreed suite of consistently used and authoritative resources. To prevent a continuing proliferation of models, tools, and the data on which they depend, we recommend agreeing on a suite of national tools and the resource information needed to support trend analysis, underpin models and tools, and guide decision-making. Once agreed, effort will be needed to establish development priorities (to address questions of scale, coverage and utility) and stable funding required to ensure gap-filling proceeds.

Finally, the capability to understand, manage, and realise opportunity from our soils requires lifting. This calls for both a unified capability-building strategy specifically targeted at increasing soil literacy (and leveraging available funding streams where possible), and a nationally concerted effort to increase the supply of scientists, advisors, and skilled land managers. The latter requires going right back to the beginning of the capability pipeline to encourage students in schools to engage with science.

RECOMMENDATION 5: Undertake a national prioritisation of soil research to support the national science challenges, sectors, and government agencies and guide investment in R&D.

RECOMMENDATION 6: Agree on the national suite of underpinning soil and land resource information required to inform policy and decision-making on soil management, as well as on development priorities and stable funding.

RECOMMENDATION 7: Create an inventory of the current and projected skills and capability in central and regional government and industry, including current and projected graduate numbers, and identify a strategy to prime the capability system, including improving competencies for extension and adoption.

Measures and management

Many of the pressures affecting New Zealand soils can be accommodated for and addressed within sector practice and the policy and planning framework.

However, the analysis in Phase 2 of this project identified that there is very little information either in the sectors or in regional government on the uptake and effectiveness of soil management initiatives and measures, particularly over the long term. With the Resource Management Amendment Act of 2013 generating a shift from regulating activities to regulating for outcomes (Section 32), it will be critical to improve the evidential basis on which policy and planning decisions are made.

RECOMMENDATION 8: Develop an evaluation and monitoring framework to determine the effectiveness of soil management practices, non-regulatory approaches and policies in achieving soil management goals.

Integrated framework

While the RMA creates the headroom for soil protection to be incorporated into planning and policy, there are still gaps in providing adequate regulatory bite for key pressures (such as spill-over resulting in the loss of versatile soils), or using non-regulatory levers for a wider range of pressures. We therefore recommend identifying the levers for government, and evaluating and taking forward appropriate policy options that explicitly recognise and protect soil functions against current and future pressures as well as gain highest value from soils. This requires a toolbox of measures – both regulatory and non-regulatory approaches – both to reduce current pressures and proactively address emerging pressures.

RECOMMENDATION 9: Investigate the form of an integrated regulatory and/or non-regulatory framework, which explicitly recognises and protects soil functions against current and future pressures and gains highest value from them.

Table 2.1

Pathways for change	Near sight		Across the horizon	
	2015–16	2016–17	2017–18	2018–19
LEADERSHIP & PARTNERSHIP				
Establish a lead agency or set of champions • Formalise a 'coalition of the willing' or National Soil Management Group (NSMG) to advocate and develop a common direction for soil management				
• Harness existing relationships and networks to highlight work of NSMG – including regional sector, Natural Resource Sector (through Chief Executives Environment Forum) and the primary sector (through Sustainable Business Council, LAWF) and bring soil management through as an action relevant initiatives e.g. regional growth strategies				
Develop a national soil strategy • Develop through the NSMG a government-mandated National Soil (and land) Management Strategy driven by the principles of kaitiakitanga and whanaungatanga, while recognising the role of soils in the government's aspirations for the economy and our freshwater resources				
RECOGNITION & READINESS				
Raise awareness of the value soils • Raise awareness of this MPI commissioned project and the NSMG through promotion at relevant workshops, conferences (e.g. Fertiliser & Lime Research Centre Annual Workshop, Grasslands Conference, NZARM etc.) and websites				
• Profile the importance of land and soil in the New Zealand context, including a clear statement of the actual and potentially realisable economic value of our soils (map of soils with actual and potential economic productivity values)				
• Map the landscape (through NZSSS and NLRC) of who is a 'stakeholder' in soil and produce a set of stories or messages that have meaning and relevance to them				
• Fund a foresight project to explore risks to future economy and environment by examining how soils are and might be used in to future (e.g. continuing unchallenged vs no regulation vs new land use)				
Prime New Zealand's research and knowledge infrastructure • Specifically engage with Our Land & Water and Bio-Heritage Challenges to ensure soil is factored into systems research and that soil information is given attention as a key enabling platform.				
• In partnership with MBIE and the National Soil Management Group, undertake a national prioritisation of soil research to support OLW, sectors, and government agencies in their R&D investment strategy – drawing where possible on existing research strategies (e.g. regional council Land & Water Strategic Roadmap)				
• Agree on a national suite of underpinning soil and land resource information required to inform policy and decision-making on soil management; agree on development priorities and stable funding				
Lift national soil capabilities • Create an inventory of the current and projected skills and capability in central and regional government and industry, including current and projected graduate numbers				
• Identify a strategy to prime the capability system and increasing the supply of scientists, advisors, and skill land managers and improve competencies in extension and adoption				
MEASURES & MANAGEMENT				
Evaluate the effectiveness of soil management • Map the institutions and organisations active in soil management and the range of tools, models, and initiatives that are being used as a baseline for evaluation (and to share best practice)				
• Develop an evaluation and monitoring framework to determine the effectiveness of soil management practices, non-regulatory approaches and policies in achieving soil management goals and use across the NSMG				
INTEGRATED FRAMEWORKS				
Integrate regulatory and non-regulatory frameworks • Ensure regional and community discussions on the implementation of the NPS-FW are informed on soils and the implication of policy on future land use options and flexibility are modelled and part of the decision making process				
• Scope the mechanisms and instruments available to Government, including soil-specific legislation, working parties, national policy statements, national environmental standards, national objective frameworks, Land and Water Forum type processes for lifting attention and providing a mandate for action to address issues on soil management				
• Support decision-making, policy, and practice frameworks by providing science-based evidence on key soil pressures (e.g. loss of elite and versatile soils to peri-urban spread, chemical and physical loadings, and tipping points)				
• Investigate policy options that explicitly recognise and protect soil functions against current and future pressures and gain highest value for elite and versatile soils				

Key reflections

A coalition of the willing emerged from the workshop. They responded to the call for action, prioritising the follow critical next-steps to secure the future for, and realise the full potential of, New Zealand's soils:

1. Establish a National Soil Management Group to develop national soil strategy; provide leadership; inform and advise policy and practice; provide a national perspective on research; promote and monitor a capability growth strategy; and ultimately act as an advocate for soils.

2. Develop a National Soil (and land) Management Strategy to set direction on the use, policies, capabilities, and research on soil.

3. Profile the importance of land and soil to the New Zealand economy and society by quantifying the actual and total potentially realisable economic value of our soils.

4. Undertake a foresight exercise to explore risks to future economy and environment by examining how soils are and might be used into the future.

5. Undertake a national prioritisation of soil research both to support the national science challenges, sectors, and government agencies and to guide investment in R&D.

6. Agree both on a national suite of underpinning soil and land resource information required to inform policy and decision-making on soil management, and on development priorities and stable funding.

7. Create an inventory of the current and projected skills and capability in central and regional government and industry, including current and projected graduate numbers, and identify a strategy for priming the capability system, including improving competencies for extension and adoption.

8. Develop an evaluation and monitoring framework to determine the effectiveness of soil management practices, non-regulatory approaches and policies in achieving soil management goals.

9. Investigate the form of an integrated regulatory and/or non-regulatory framework that explicitly recognises and protects soil functions against current and future pressures and gains highest value from them.

References

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. National Land Resource Centre, Palmerston North.

Collins A, Mackay A, Thomas S, Garrett L, Weeks E, Johnstone P, Laurenson S, Dyck B, Payn T, Gentile R 2015. Phase 2: Looking Out. Future requirements for soil management in New Zealand. National Land Resource Centre, Palmerston North.

Curran-Cournane F, Vaughan M, Memon A, Fredrickson C 2014. Trade-offs between high class land and development: Recent and future pressures on Auckland's valuable soil resources. Land Use Policy (2014). http://dx.doi.org/10.1016/j.landusepol.2014.02.020

Kibblewhite MG, Deeks LK, Clarke MA 2010. A Gap analysis on the future requirements of soil and water management in England. Practice with Science Group, Royal Agricultural Society of England.

Mackay AD, Stokes S, Penrose M, Clothier BE, Goldson SL, Rowarth JS 2011. Land: Competition for future use. New Zealand Science Review 68, 67–71.

Ministry for the Environment 2014. Briefing to the incoming Minister for the Environment and Minister for Climate Change Issues 20. Wellington, Ministry for the Environment. November 2014.

New Zealand Productivity Commission 2015. Using land for housing Draft report. June 2015, Wellington

Rutledge DT, 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.

Rys, G 2011. A national cadmium management strategy for New Zealand agriculture. In: Adding to the knowledge base for the nutrient manager: Occasional Report No. 24. Fertilizer and Lime Research Centre, Massey University, Palmerston North. February 2011. http://www.massey.ac.nz/~flrc/publications.html.

Ministry for Primary Industries
Manatū Ahu Matua

NATIONAL
LAND RESOURCE
CENTRE

Landcare Research
Manaaki Whenua

agresearch

Plant & Food
RESEARCH
RANGAHAU AHUMĀRA KAI

SCION
forests · products · innovation