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Soil Quality Indicators: The Next Generation

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Soil Quality Indicators: The Next Generation

Report prepared for Land Monitoring Forum of Regional Councils

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1. Executive Summary

This tools project addresses the recommendations made in a review of the soil-quality monitoring programme. Recommendations included the need for an upgrade of target ranges for current indicators to address gaps, expansion of the current indicator list to provide a more complete picture of the state of the land resources, inclusion of additional factors to increase the utility (i.e. link to outcomes) of the soil quality indicators, as well as the quantification of the ecosystem services other than provisioning.

The Land Monitoring Forum, a special interest group consisting of Regional Councils and land and soil scientists, accepted the following recommendations on existing and new indicators following a review by a subgroup of the Forum and a workshop of all forum members. The recommendations included a change in name for anaerobically mineralised nitrogen (N) to "Soil Microbial Health" (measured by AMN) to remove potential misunderstanding with N-leaching, removing the upper targets for AMN because it is not a good indicator of environmental risk, expressing aggregate stability as the average aggregate size distribution, in addition to the mean diameter, to provide a better assessment of erosion risk, inclusion of water content at wilting point to give, along with macroporosity, a measure of water storage services, and a reduction in the upper Olsen P target to the target ranges currently used by the fertiliser and agriculture industries. Further, the Forum should support research on linking the N indicators (AMN and Total N) to a model such as an Overseer® nutrient budget model to assess N-leaching and N_2O emission risks, an investigation to establish aggregate stability targets on different soil types and land uses, establish appropriate macroporosity targets for Podzols and explore adding earthworm diversity and abundance as a biological health indicator. With the core set of soil quality indicators confirmed, the Forum also decided to give greater attention to the assessment of environmental indicators for measuring specific soil issues.

The Land Monitoring Forum explored during a series of workshops over two years the potential use of an ecosystem service framework, which enables links to be drawn between land use, natural capital stocks (i.e. soil properties) and the flow of services (i.e. outcomes), as an approach for adding greater value to the soil quality indicators programme. Soil macroporosity, a proxy for the physical attributes of soil natural capital stocks and also a measure of the "state" of the physical condition of the soil, was selected by the Forum for a closer look. By establishing the flow of ecosystem services from soil natural capital, and how a change in the physical properties of the soil (i.e. as measured by a change in macroporosity) impacts on run-off, P loss and N leaching, a function can be derived, including thresholds or tipping points, that describes the relationship between this soil quality indicator and environment outcomes. In parallel, the implications of a change in this soil quality indicator on economic returns can also be calculated.

The authors recommend, throughout the discussions with the Land Monitoring Forum, caution in the interpretation of the specific values calculated for ecosystem services, because of limitations in data sets and the ability of process models to describe and quantify key processes in agro-ecosystems. This is also highlighted in the body of this document. We also recommend caution in the use of the economic valuation of ecosystem services. The use of “dollars” provides a common currency in which to compare services and compare different soils under the same and different managements.

Accepting the precautionary words, this study demonstrates the enormous potential an ecosystem service approach has in resource management. The ability to track the provision of ecosystem services over time provides the basis for assessing if the resources in the catchment, (i.e. the natural capital stocks), are being managed in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural wellbeing and for their health and safety while (a) sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and (b) safeguarding the life-supporting capacity of air, water, soil and ecosystems.

In addition to developing a farm and catchment scale case study to investigate the potential utility of an ecosystem service approach, the project has been the start of an on-going learning process between science, policy and operational land management staff. A number of initiatives will ensure the progress made in this study is sustained. This includes a current project AgResearch and Hawke’s Bay Regional Council exploring the use of an ecosystem service approach to estimate the loss of soil services from land affected in the April 2011 storm event that caused a significant amount of soil erosion along a coastal belt in the Region.

2. Introduction

Regional Councils are increasingly using approaches that incorporate socio-economic and environmental components into regional policy. This approach allows values and decision making to consider factors wider than production. For example, soils provide services beyond production, including regulating, filtering and storing nutrients, water and gases, supporting habitats and biodiversity and providing a platform for construction (DEFRA, 2008). Inherent to these ecosystems services are the soil properties and the state of these soil properties (termed soil quality). Changes in soil properties change the ability of the soil to provide these services.

Regional Councils are required by the Resource Management Act 1994 to report on soil quality within their region and appraise whether land uses are sustainable. Since 1995 soil quality monitoring has been undertaken by Regional Councils around New Zealand. During this period provisional target ranges were developed to provide guidelines for sound soil management (Sparling et al., 2003). The resulting target ranges are limited to production and environmental response curves and outcomes at the paddock scale. Taylor (2009) highlights the limitations of these target ranges especially the ranges defined by the environmental component and their utility in informing decisions beyond the site of measurement

2.1 Outline of the environmental issue requiring the tool

In a recent discussion-document on indicator target ranges for soil quality monitoring, Taylor (2009) makes a number of recommendations. These included calling for an upgrade of target ranges for current indicators to address gaps, plus an expansion of the current list of indicators (e.g. heavy metals) to provide a more complete picture of the state of the land resources. These two issues can be addressed easily and would bring immediate benefits.

Taylor (2009) also recommended the inclusion of additional factors to increase the utility of the soil quality indicators (i.e. link to outcomes), as well as the quantification of the ecosystem services beyond the provisioning services. Both are currently weaknesses. There is a general consensus that the use of single-factor soil quality indicators to represent soil services has serious limitations. Each soil service is the product of multiple properties and processes.

Further, each indicator (e.g. soil macroporosity) is linked to a number of provisioning and regulating services that cannot, as yet, be valued directly. It is also difficult to develop a single-factor response curve that captures all the changes (for example in pasture growth, pasture utilisation, surface run-off volumes, sediment discharge loadings and nutrient losses as a consequence of a change in soil macroporosity). Until the single-factor indicators are linked to outcomes at the paddock, farm and catchment scale, their value to land managers and policy agents will continue to be very limited. This limits the utility of the current information collected on the State of the Environment. A review of the current framework that is used for the analysis of the soil quality indicators and State of the Environment reporting is therefore timely, if the full value of the monitoring is to be realised.

This tools project investigates the inclusion of soil quality indicators within a framework developed to quantify the flow of ecosystem services from soils (Dominati et al., 2010a). Adoption of a soil ecosystem service framework in reporting on changes in the soil quality indicators will for the first time provide decision makers with information on the significance of a change in the soil's natural capital stocks for the flow of ecosystem services, enabling an assessment to be made of the significance of a change in the State of the Environment on-farm, catchment and regional scale outcomes.

2.2 Past research on which the tool is based

This research builds on State of the Environment indicators published in *Provisional targets for soil quality indicators in New Zealand* (Sparling et al., 2003), updated by Beare et al. (2007), plus a recent report by Taylor (2009) on indicator target-ranges for soil quality monitoring. The new and innovative aspect of this study is linking these soil quality indicators to outcomes using a framework developed for classifying and quantifying the flow of ecosystem services from soils (Dominati et al., 2010a).

2.3 Target stakeholder groups that will be directly involved/affected by the tool

The tool will allow land managers to provide advice about soil management based on target ranges for soil quality that are linked to the desired outcomes at farm, catchment and regional scales. Policy makers will have a tool that can assist in developing policy instruments that incorporate production and environmental components and can assess the value of different tradeoffs.

2.4 Council commitment to the tools implementation

The tool will increase the value of the soil quality data already being collected through the soil-quality monitoring programme currently used by a number of Regional Councils, by providing a link between the soil quality data and outcomes at the paddock, farm, catchment and regional scale. The National Land Monitoring Forum fully supports this proposal and will be part of a wider group involved in scoping and implementing the project. The two Regional Council champions are provisionally Reece Hill (Environment Waikato) and John Phillips (Hawkes Bay Regional Council).

2.5 Proposal

This tools project addresses the recommendations made in a review of indicator target-ranges for soil-quality monitoring which identified the need for:

1. an upgrade of target ranges for current indicators to address gaps,
2. expansion of the current indicator list (e.g. heavy metals) to provide a more complete picture of the state of the land resources, and
3. development of the linking framework between soil quality indicators and ecosystem service-defined resource outcomes,
4. quantification and valuation of the soil's ecosystem services other than the provisioning services.

Issues 1 and 2 are addressed in Objective 01 of this report, while Issues 3 and 4 are tackled in Objective 02, an investigation into the feasibility of the inclusion of the soil quality indicators within a framework developed recently to values the soil's ecosystem services . The details of the tools project and milestones are listed in Appendix 6.1 and 6.2, respectively. Progress reports are listed in Appendix 6.3

3. Objective 1 Towards Developing Targets for Soil Quality Indicators in New Zealand

3.1 Workshop and Participants

A workshop to review the indicators used in soil quality monitoring and their target ranges in New Zealand, was held at the Greater Wellington Regional Council offices on Friday 6th May 2011. Before this workshop, participants were sent documentation covering some of the current and historic development of these indicators and targets, soil issues identified in practice and some problems with certain indicators. The briefing paper for the review of soil quality indicators prepared by M Taylor is listed in Appendix 6.4.

Attendees at the workshop on Friday 6th May 2011 comprised

Andrew Burton	Fiona Curran-Cournane
Barry Lynch	Peter Clinton
Colin Grey	Bryan Stevenson
Dani Guinto	Anwar Ghani
Jeromy Cuff	Alec Mackay
Matthew Taylor	Mike Beare
Reece Hill	Richard McDowell
Amy Taylor	Brent King
Paul Sorensen	
Saun Burkett	

Other contributions

Four people were unable to attend the workshop but contributed comments, either in the email survey or in commenting on the draft of this report:

Dave Houlbrooke
Marcus Deurer
Craig Ross
Allan Hewitt

3.2 Introduction

Before the workshop an email survey was also conducted to identify the indicators of most concern was also sent to the invitees to help set priorities for the day. At the workshop, participants were reminded of the development history of soil quality monitoring in New Zealand and that the current use was as part of State of the Environment reporting for Regional Councils. Participants were asked to consider:

- Are Indicators evidence-based?
- Are current processes robust?

- Are current indicators correct?
- Are current target ranges correct?
- Are there new indicators that should be considered?
- What new issue does this illustrate or how does this better illustrate a current issue?

For current indicators:

- Should we continue with this indicator or not?
- Should the target ranges stay the same? If not what should they be?
- Are target range critical values reflecting changes in soil function?

After the workshop, the Land Monitoring Forum responded to a list of action points assembled by the workshop participants and provided direction for future progress.

3.3 Email survey

The email survey was to help set priorities for the workshop by identifying the issues and indicators of most concern. Invitees were asked:

- What indicators should we focus on?
- Are there indicators that are serving no use in their current form? – Is there something better correlated to thresholds/changes in soil function?
- Are there indicators that are fine and we do not have to work on?
- Are there indicators that are OK but we need to change the target ranges to better reflect thresholds/changes in soil function?

The results of the email survey are listed below, including the indicator, (number of replies from participants on that indicator in bracket), with the main points summarised below each indicator where fuller replies were received. Most replies were of the nature of “yes this is important to discuss” or “no this is OK so does not need more discussion”. There were polarised views on some indicators before the workshop.

More biological measures of soil health (8)

- To reflect biochemical processes occurring in soils.
- Indicators should be sensitive enough to be “leading indicators” of changes or improvements in soil management initiated by a landowner on his/her property (e.g. reduced tillage, cover cropping, etc.).
- Many of the biological methods are fraught with difficulties of interpretation because of the high temporal and spatial variability involved when quantifying soil biological processes

- Several indicators were proposed including Hot Water Carbon (HWC), Active C as measured by the permanganate test, Soil Respiration Rate and Earthworm Abundance and Diversity.

Anaerobically Mineralised N (AMN) (8)

- Replace with HWC to reduce cost, as there is a good correlation with AMN. This means data collected to date is still relevant
- Retain AMN as we have collected a lot of AMN data nationally as part of 500 Soils and other projects
- Should be retained unless it can be demonstrated that AMN is a useless indicator
- First introduced by Graham Sparling as a surrogate for microbial C
- HWC also strongly correlates with microbial C.
- Anaerobically mineralisable N is OK as long it is perceived as a “potential” to leach
- Regarded as a surrogate for microbial activity or health, rather than anything to do with N leaching

Olsen P (7)

- The 100 mg/kg upper limit is too high
- The upper target limits for Olsen P are described as “high” not “excessive” in the provisional limits and should be corrected for consistency.
- Align with industry ranges

Aggregate stability (6)

- Aggregate stability is also very important for arable soils
- There are problems with meeting the 1.5 mm Mean Weight Diameter target for sandy soils

Total N (6)

- Need to refine target ranges for cropping and horticulture.
- The upper target limits for Total N are described as “high” not “excessive” in the provisional limits and should be corrected for consistency.

Soil Macroporosity (6)

- The target ranges for cropping, horticulture and forestry may need to be refined.
- Not enough evidence to justify a change of the lower target from 10 to 12%?
- Not enough data to make an accurate response curve to environmental performance (storage, transport of water and solutes)

Total carbon (3)

- Could be expressed as % soil organic carbon or soil organic matter
- Organic C particularly useful for arable land use
- Total carbon OK

Native forest land use (2)

- Targets do not necessarily apply to indigenous ecosystems.
- Soil quality values are for reference

The soil pH and bulk density indicators were considered OK as they were. However, another issue applying to all the indicators and soil quality monitoring generally is summarised below:

"An issue since Graham initiated SQ measurements is the restriction of the sampling to 0-10cm. That was based on the rounded metric equivalent of the classical depth of sampling for soil fertility/chemistry testing, 0-3 inches, with associated calibrations for fertilizer applications, although in New Zealand soil sampling for soil fertility in pastoral systems is limited to 0-75 mm. The international standard for soil C accounting is 0-30 cm – based on tillage depth in the Great Plains of America. Most pasture top soils in NZ are 20 to 25 cm deep and the majority of agricultural plant roots extract nutrients and function in the topsoil that are generally about 20 cm deep for NZ soils. There is a case therefore for extending the 0-10cm sampling to include also a 10-20 cm soil sample as part of the "Soil Quality measurements".

There was also a general question on "How does setting soil quality targets relate to the Envirolink-funded project Soil quality indicators: the next generation which appears to be dealing primarily with putting a value on soil ecological functions/services. Can it be used to correlate to thresholds/soil functions"? In answer Alec Mackay indicated "an ecosystem service approach could potentially be used to assist in establishing thresholds for some of the soil quality indicators. By linking the soil quality indicator to the outcome, the opportunity is created to reflect on the threshold and target range for that indicator. While the optimum range for plant growth/ production would not change for the suite of soil quality indicators for the major soil orders and major land uses, the optimum range for an environmental outcome could change (for example) from catchment to catchment, depending on the desired outcome for that catchment. As a first approximation the optimum range for plant growth/production would set the minimum values. It is probably beyond the scope of the meeting on Friday to discuss this in any depth.

Part of the ongoing conversation for the Land Monitoring Forum is how do we better connect the soil indicators to outcomes to increase the value of monitoring to inform future regional policy on the one hand, to evaluate existing policy and enable an ongoing review of the thresholds and optimum ranges of existing and any new indicators.

There was a strong emphasis on the provisioning services in setting the original soil quality indicator targets, while there is now a greater recognition of the wide range and value of environmental services.

As a result of this survey the following topics were set as priorities for discussion:

Assess new indicators including biological indicators, review the existing indicators: AMN, Total N, Total C, Olsen P, Aggregate Stability and macroporosity. A summary of the discussion on each indicator is presented below. Briefing papers for the review of the soil quality indicators are summarised in appendix 7.4, along with additional information on soil invertebrate indicators (appendix 7.5) and upgrade of target ranges of macroporosity and Olsen P indicators (Appendix 7.6).

3.4 The Workshop meeting: A Review of soil quality indicators

The discussions at a review of the indicators used in soil quality monitoring and their target ranges, held at the Greater Wellington Regional Council offices on Friday 6th May 2011, are documented below. These should be read alongside the briefing paper prepared before the meeting (Appendix 7.4).

3.4.1 New Indicators including discussion on biological indicators

Anwar Ghani presented research on Hot Water Extractable Carbon (HWC). This test measures a faction of the soil total C that is associated with other measures of biological activity, and is a more sensitive biological indicator than total C. AMN and aggregate stability also correlate strongly with HWC. HWC is easy to do and cost effective, but sampling time is important. This is because there is a natural flux with weather and soil conditions impacting the amount of C extracted, so early spring or late autumn are usually the best times to collect soil samples for HWC. It is likely that separate targets would be required for different land uses and managements and soil types. On a restricted set of soil types and land uses, Anwar has data showing what could be suitable. This needs to be expanded to include other soil types and land uses.

New issue illustrated: The quality of soil carbon. HWC determination could be used to develop a vulnerability index of carbon in soils but some more work is needed.

Bryan Stevenson presented some of the work he has started looking at different techniques for assessing soil microbiology. Characterisation of microbial communities looks promising but is expensive (about $225 per sample). Quantification of specific microorganism groups (e.g. ammonium oxidising bacteria) is possible using various genetic techniques (e.g. PLFA, 7-RFLP, QPCR). The ratio of archaea to bacteria or the number of gene copies could be used to quantify the active ammonium oxidisers, which may be a measure of the nitrate leaching risk.

Bryan also presented data showing δN^{15} increased with farming intensity. There were soil effects at low intensity, but soil effects were overridden as intensity increased. There was no other land use information.

New issue illustrated: The nitrate leaching risk. Completion of a research project is needed before these techniques could be incorporated as soil quality indicators. The microbial community may only be part of the nitrate story and results may need to be assessed against other factors such as soil C:N ratio, etc. However, a tool to measure nitrate risk would be very welcome by Regional Councils.

Other microorganism indicators discussed included respiration rate and active carbon. Respiration rate seems to be appealing but there is a serious issue of variability. Measurements between replicates on the same day of measurement can vary significantly, not to mention effects of moisture and temperature at the time of sampling. Clearly, some biological indicators are too sensitive and will not make good indicators. Active carbon as described by the permanganate test (Weil et al. 2003 with modifications by Moody and Cong 2008) has been used for estimating a pool of labile soil organic matter. HWC and active carbon should in principle correlate with each other.

Active carbon is an indicator of the fraction of soil organic matter that is readily available as a carbon and energy source (food) for the soil microbes. The soil is mixed with potassium permanganate which is deep purple in colour and as it oxidizes the active carbon, the colour becomes less purple, which can be observed visually, but is very accurately measured with a portable spectrophotometer. Active Carbon is a good "leading indicator" of soil health response to changes in crop and soil management, usually responding to management much sooner (often, years sooner) than total organic matter content. (from Dani Guinto)

Alec Mackay presented Nicole Schon's work on a draft invertebrate indicator for pastoral soils. The indicator aims to add to current understanding of the role soil biota play in the provision of soil services and to give land managers an insight of how their current system is affecting soil biology and the soil processes they contribute to. The elements of the invertebrate indicator include the identification and quantification of selected soil invertebrates, as well as a measure of the food resources and habitable pore space available to the invertebrate community.

Whereas the other biological indicators discussed are associated with microorganisms, this work assesses macro fauna. Macro fauna are slower to respond than microorganisms and are less sensitive to variations in climate and soil characteristics, but are very responsive to changes in land use and management practices making them useful indicators of soil conditions. Land use and management practices influence three key factors that have a major influence on the diversity and abundance of the soil's biological community:

- Food resource
- Physical disturbance
- Habitable space (soil pores)

Work is continuing linking earthworms to soil function (ecosystem services). Both earthworm abundance and diversity are important to the provision of soil services. Peak earthworm activity is just before spring and testing should be at the same time each year. A practical procedure has been developed: Combine 20 cores to identify and count surface and shallow borrowers, and take a couple of cores for deep burrowers. Alec's team have put an earthworm sampling protocol together (appended to this report).

New issue illustrated:
Earthworm diversity and abundance.

Peter Clinton indicated that work on the importance of tree biodiversity compared to monocultures is progressing. Biological indicators that may be of importance to forestry also include wood decay invertebrates and the symbiotic relationships between trees and mycrorrhyiza. However, a major factor not considered with soil quality monitoring is the presence of the litter layer in forestry (the A horizon is sampled, not the Lf one).

It was felt by participants that there are subsets of indicators that may be useful on specific land uses or they could add supplementary information to help explain changes in other indicators.

Markus Deurer was unable to attend the workshop but suggested an indicator tracking the degree of soil hydrophobicity to inform the Regional Councils what they can expect if a drought occurs and monitor if this improves or deteriorates over time. The SLURI group have discussed indicators for soil water repellency, which could prove suitable.

3.4.2 Anaerobically Mineralised Nitrogen

Considerable doubt about the use of AMN as an indicator of N-leaching potential on its own and additional analysis is needed for correct interpretation, i.e. AMN can be used along with other measurements (e.g. C:N ratio, land management data etc.) to put the leaching risk into context. However, 0-10 cm sampling is never going to accurately address functional issues that take place at greater depths.

Production targets are legitimate as low production occurs at low AMN, as a function of microbial biomass. There were questions whether more biomass is better and the need for evidence within each land use system. There was no progress on the information gaps identified in Sparling (2003). Production and environmental health need to be considered simultaneously.

Land Monitoring Forum to consider:

Suggested name change to "Soil Microbial Health" (measured by AMN). Conventionally, Councils would consider soil microbial health an "issue", not an "indicator".

Recommend the lower targets stay the same but remove upper target because it is not a good indicator of environmental risk.

3.4.3 Total N,

There was doubt about Total N as an indicator of N-loss – need to consider C:N ratio, which will give an indication of the quality of SOM. But the lower limit for C:N ratio is not clear.

Some sort of process model may be better, e.g. include a measure of potential mineralisable N + soil conditions + total N and C:N ratio. Using the soil total N as input into a process model to explore the impact of a change on emission to air or water may offer greater utility than investing in more calibration curves.

Can Overseer be adapted to Regional Council purposes?

Land Monitoring Forum to consider:

Funding to fill knowledge gaps and investigate linking the N indicators to a model such as OVERSEER to assess N-leaching and N_2O risks.

3.4.4 Total C

Discussion on an upper limit for Total C as there are data showing reduced productivity in soils containing large amounts of carbon. May be soil order dependent.

The lower target may not apply for some land uses, e.g. viticulture.

Linking the soil C estimate to a process model to predict likely future trends in soil C may help quantify soil C environmental services. Work on valuing soil C environmental services is currently ongoing.

Land Monitoring Forum to consider:
The balance of environmental benefit verse productivity
Funding to fill knowledge gaps around upper targets

3.4.5 Aggregate Stability

Limited information on targets is available. The 1.5 mm MWD only from under alluvial soil, so need to establish critical values for other soils. This is the point where there is risk of production being reduced.

Erosion risk is better assessed completing an average aggregate size distribution. The proportion of soil less than 0.85 mm is the critical value.

Land Monitoring Forum to consider:
Funding to fill knowledge gaps around targets, other soil types and land uses

Recommend expressing aggregate stability as the average aggregate size distribution in addition to the mean diameter to provide a better assessment of erosion risk.

3.4.6 Macroporosity

There is not enough evidence to justify a change in the lower target from 10 to 12%.

A 'case by case' basis may be required when interpreting some parameters for certain soil types and land uses, e.g. a macroporosity value of about 20% may be high for a Pallic soil but low for a Melanic soil. Targets can act as a flag but further explanation as to why results are inside or outside the targets may be needed in reporting the results.

Podzols and Forestry are special cases.

- Some soil orders may never achieve targets, e.g. some Podzols
- May already have information in LCR's soil database on macroporosity under forest/bush for these soils
- Macroporosity has little meaning for forestry production.

Value could be added to this indicator by including water content at wilting point, to give water storage.

Land Monitoring Forum to consider:
Funding to assess the targets for Podzols
Adding water content at wilting point [does this change or is it a soil function, like P-retention]

3.4.7 Olsen P

Olsen P is primarily a production indicator but may also be used in conjunction with the anion storage capacity as an indicator of the risk of P loss. The upper Olsen P target should not be higher than that required for production. Cropping and pasture have similar requirements, while forestry requires lower Olsen P values.

Critical values that are across landscapes remains to be done, e.g. hill country shows little economic return above Olsen P values of 20.

Land use	Soil Type	Suggested Olsen P targets
Pasture, Horticulture and cropping	Volcanic	20-50
Pasture, Horticulture and cropping	Sedimentary and Organic soils	20-40
Pasture, Horticulture and cropping	Raw sands and Podzols with low AEC	5
Pasture, Horticulture and cropping	Raw sands and Podzols with medium and above AEC	15-25
Pasture, Horticulture and cropping	Other soils	20-45
Pasture, Horticulture and cropping	Hill country	15-20
Forestry	All soils	5-30

Alec Mackay showed an interaction between the physical conditions of the soil, Olsen P level and pasture growth. The negative impact of a compacted soil on pasture growth appears to be offset to some degree by lifting the Olsen P value.

Richard McDowell provided suggested targets based on his work that would normally allow 97% of maximum production, while providing more environmental protection than the current limits.

As with N there is merit in using Overseer to explore the link between Olsen P and P loss risk to the environment under different land uses and management practices in setting thresholds or ranges for specific catchments or environments.

Because of the variability in not only the calibration curves between Olsen P and relative pasture production, but in the process of sampling, there is no precise soil P level that will guarantee a particular level of pasture production. The adoption of a range in Olsen P as a guideline for fertiliser recommendations recognises this variation and the fact there are ‘other factors’ influencing pasture productivity on each farm. Adoption of a higher range for farms with production in the top 25% for a locality is a mechanism to reduce the risk of under-fertilising. Current research is investigating the merit of continuing with a single relative response curve and critical Olsen P value for 97% of maximum production regardless of the absolute level of pasture production..

Land Monitoring Forum to consider:
The upper Olsen P target is too high and should be reduced to target ranges currently used by the fertiliser and agriculture industries.

3.4.8 Other issues

The issue of concentration vs volumetric sampling was considered. While there remained research gaps, expressing results on a concentration basis was considered better for all but measuring C stocks. Soil quality results should remain expressed on a concentration basis, while stocks of a soil constituent, such as C or N, is better expressed on a volumetric basis.

Coordinated monitoring on a national scale to better integrate State of the Environment reporting into policy was discussed.

A stock take of soil quality sites was suggested, perhaps by Ministry for Environment to include forestry sustainability plots, pastoral research farms and soil quality.

Any gaps in the coverage of land uses and soil types could be identified leading to wise selection of new sites.

Land Monitoring Forum to consider:
Bring together soil quality data for a "national" report

3.5 Action points

The Land Monitoring Forum need to make decisions on:

- Changing the name for anaerobically mineralised N to "Soil Microbial Health" (measured by AMN) to remove potential misunderstanding around N-leaching
- Removing the upper target for AMN as it is not a good indicator of environmental risk
- Whether to express aggregate stability as the average aggregate size distribution in addition to the mean diameter to provide a better assessment of erosion risk
- Whether to include water content at wilting point to give, along with macroporosity, a measure of water storage services
- Should the upper Olsen P target be reduced to the target ranges currently used by the fertiliser and agriculture industries
- The Land Monitoring Forum should support research by actively seeking funding and/or directly funding work to:
  - Investigate linking the N indicators (AMN and Total N) to a model such as a OVERSEER to assess N-leaching and N_2O emission risks
  - Assess the balance of environmental benefit verse productivity and suitable upper targets for total C
  - Investigate aggregate stability targets on different soil types and land uses
  - Investigate what are appropriate macroporosity targets for Podzols
  - Investigate earthworm diversity and abundance as future soil quality indicators
  - Investigate hot water carbon as future soil quality indicator.

3.6 Response from the Land Monitoring Forum

The Land Monitoring Forum received this report at their meeting held at the Greater Wellington offices, 25-26 September 2011, and considered each of the numbered action points described. Their summarised responses are listed below:

Changing the name for anaerobically mineralised N to "Soil Microbial Health" (measured by AMN) to remove potential misunderstanding around N-leaching:

Confirmed that name should stay but that it should be referenced as an indicator of soil microbial health. The manual needs to be updated.

***Removing the upper targets for AMN as it is not a good indicator of environmental risk*:**

Agreed, the upper indicator targets will be removed and the manual updated.

Whether to express aggregate stability as the average aggregate size distribution in addition to the mean diameter to provide a better assessment of erosion risk:

These are two separate tests highlighting two separate issues. Neither is part of the set of core indicators, but both are considered useful for certain situations. These could be considered another set of "environmental indicators" rather than soil quality ones. While not useful for all councils, they could be developed as part of a toolbox of indicators of environmental issues. This toolbox is an advancement of the soil quality monitoring concept. The toolbox is envisaged as a set of indicators for specific soil issues with appropriate targets tied to ecosystem services and changes in critical soil function. However, councils would utilise those indicators of value to them for limited periods, rather than long-term, continuous monitoring.

Whether to include water content at wilting point to give, along with macroporosity, a measure of water storage services:

Water content at wilting point will not be included as a standard indicator as it is a soil property that is fairly insensitive to ecological impact. Although it provides useful information for irrigation, it requires a separate analysis that would add expense to the core set of indicators. However, it may be useful as part of the proposed toolbox of indicators of environmental issues.

Should the upper Olsen P target be reduced to the target ranges currently used by the fertiliser and agriculture industries?

Agreed, reduce the target range to match the levels used by the agricultural and fertiliser industries. Note that these targets are still based on productivity rather than environmental impacts. Further work on the detail, to include specific soils situations (e.g. raw sands) may be required.

***The Land Monitoring Forum should support research by actively seeking funding and/or directly funding work to*:**

Investigate linking the N indicators (AMN and Total N) to a model such as OVERSEER to assess N-leaching and N_2O emission risks:

This is an environmental indicator rather than soil quality and may be best part of the proposed toolbox of indicators of environmental issues.

Assess the balance of environmental benefit versus productivity and suitable upper targets for total C:

Agreed, this is a research issue that needs investigation to connect the lower C target to soil services. Suggest revisiting Hewitt and McIntosh's soil C report and John Dymond's soil loss on slips study. Do we need an upper limit for C or is more C better as a possible ecosystem services? An upper limit may be better as part of the proposed toolbox of indicators of environmental issues.

***Investigate aggregate stability targets on different soil types and land uses*:**

Agreed, requires a research proposal.

***Investigate what are appropriate macroporosity targets for Podzols*:**

There was no support for finding a separate target for podzols, as this does not appear to be a New Zealand wide issue. Current targets are land use–based and seem to be OK. No special difficulties with podzols meeting these targets noted. Observed Tihoi's and Mamaku's meet targets when under bush or forestry.

Investigate earthworm diversity and abundance as future soil quality indicators:

Earthworms – much discussion about the variable nature of earthworms and how deriving an indicator for monitoring may be difficult. Request that Nicole Schon present her work on earthworms to the Forum.

Further investigation of both these indicators is needed to ascertain if they fully fulfil the function of soil quality indicators, or they may be suitable for the toolbox of indicators of environmental issues.

***Investigate hot water carbon as a future soil quality indicator*:**

Some work already on hot water carbon underway – Reece and Matthew are doing a small study with Anwar from AgResearch. They will report back on results and then discuss again at the next Forum meeting.

3.7 Forming a toolbox of indicators of environmental issues

It is now timely to develop a further group of environmental indicators for measuring specific soil issues, in conjunction with ecosystem services. The toolbox is envisaged as a set of indicators for specific soil issues with appropriate targets tied to ecosystem services and changes in critical soil function. However, councils would utilise those indicators of value to them for specific purposes for limited periods, rather than long-term, continuous monitoring.

Some examples:

- Aggregate stability as an indicator of soil structural stability for cropping land
- Aggregate size distribution as an indicator of erosion risk for cropping land
- Wilting point combined with macroporosity as an indicator of water storage
- Acid recoverable cadmium as an indicator of phosphate fertiliser introduced contaminants.

3.8 The Next Steps

Revise the Land Monitoring Manual.

Initiate a new Envirolink Tools bid to identify and develop indicators of environmental issues for the toolbox.

3.9 Addendum

Since the May workshop an additional issue relating to consistent reporting of Olsen P results has been identified. Research laboratories and organisations, such as Crown Research Institutes; determine Olsen P on a gravimetric (weight) basis, while commercial laboratories determine Olsen P on a volumetric basis. Rajendram et al (2003) concluded Olsen P values are influenced by soil weight. The ratio of soil to solution and the buffering capacity of the soil are critical to the amount of P extracted. Olsen P is not a defined or fixed pool. Its size depends on the conditions of measurement. Olsen P increases with decreasing soil to solution ratio (decreasing bulk density).

Fortunately, results can be converted between gravimetric and volumetric using bulk density. It is important for Regional Councils to identify on what basis soil quality Olsen P results have been reported and to present the data on the agreed basis.

Reference

Rajendram G, Perrott K, Waller J, Kear M, Dewar D (2003) Olsen P Test: Should it be on a Volume or Weight Basis? In 'Tools for nutrient and pollutant management: Applications to agriculture and environmental quality.' (Eds L Currie, J Hanly). (Fertilizer and Lime Research Centre, Massey University, Palmerston North, NZ).

4. Objective 2 Development of the Linking Framework between Soil Quality Indicators and Ecosystem Services

4.1 Introduction

Regional Councils are increasingly using approaches that incorporate socio-economic and environmental components into regional policy. This approach allows decision making to consider factors wider than economy from primary production, while recognising that New Zealand's economy is driven by its primary industries with over 40% of the total land area (10.4 million ha) in pasture and arable cropping land and 7% in exotic forest. Together with its support and processing components, the agriculture industry regularly contributes almost a quarter of New Zealand's GDP. Soils and landscapes (i.e. soil natural capital) and the services they provide are therefore an essential factor in the economic well-being of New Zealand, as they are for the economy of most nations (Daily, 1997). Increasing pressures on agro-ecosystems threaten food security globally, because increasing soil erosion and the expansion of urban areas over elite and versatile soils are making land a commodity scarcer every day (Brown, 2012).

There is a growing realisation that soils provide ecosystem services beyond food production, including regulating, filtering and storing nutrients, water and gases, supporting habitats and biodiversity and providing a platform for construction (DEFRA, 2007). Behind the provision of these ecosystems services are the soil properties (e.g. natural capital stocks) and their state (termed soil quality). Therefore, changes in soil properties change the ability of the soil to provide these ecosystem services. Little attention however, has been given to analysis of the greater value of soils to society coming from regulating ecosystem services which currently have no market value.

Since 1995, soil quality monitoring has been undertaken by Regional Councils around New Zealand. During this period provisional target ranges were developed to provide guidelines for sound soil management (Sparling et al., 2003). The resulting target ranges are limited to production and environmental response curves and outcomes at the paddock scale. In comparison to the production curves the environmental response curves are only weakly defined. Taylor (2009) highlights the limitations of these target ranges, especially the ranges defined by the environmental component and their utility in informing decisions beyond the site of measurement. This part of the tools project tackles these limitations by exploring the merits of using a soil ecosystem service framework developed by Dominati (2011) to:

- Develop a linking framework between soil quality indicators and ecosystem service defined resource outcomes
- Quantify and value soil ecosystem services other than just those contributing to provisioning (i.e. production).

The details of the tools project and milestones are listed in appendix 7.1 and 7.2, respectively.

4.1.1 Outline of the environmental issue requiring the tool

Taylor (2009) recommended the inclusion of additional factors to increase the utility (i.e. link to outcomes) of the soil quality indicators, and the quantification of the ecosystem services other than food production. Both currently represent major weaknesses of the soil reporting framework.

There is a general consensus that the use of single-factor soil quality indicators to represent soil services has serious limitations. Each soil service is the product of multiple properties and processes. Further each indicator (e.g. macroporosity) is linked to a number of provisioning and regulating services that cannot, as yet, be valued directly. It is difficult to develop a single-factor response curve because of how changes in, for example, the soil's macroporosity will impact on pasture growth, pasture utilisation, surface run-off volumes, sediment discharge loadings and nutrient losses. Until the single-factor indicators are linked to outcomes at the paddock, farm and catchment scale, their value to land managers and policy agents in policy development and evaluation will continue to be very limited. Therefore a rethink is required of the current framework that is used for the analysis of the soil quality indicators and State of the Environment reporting. Only then will the utility of the current information being collected be fully realised.

This part of the report investigates the inclusion of soil quality indicators within a soil ecosystem service framework developed by Dominati et al., (2010a), enabling the quantification and valuation of soil services at the farm and wider scales. This innovative approach provides for the first time decision makers with information on the significance of a change in soil natural capital stocks and associated ecosystem services. Soil natural capital stocks are a combination of soil properties (e.g. natural capital stocks) and their state (termed soil quality). Importantly it will enable assessment of economic and environmental outcomes at farm and catchment scales.

4.1.2 Past research on which the tool is based

This research builds on State of the Environment indicators published in *Provisional targets for soil quality indicators in New Zealand* (Sparling et al., 2003), updated by Beare et al. (2007), plus a recent report by Taylor (2009) on indicator target ranges for soil quality monitoring. The innovative aspect is that we will now couple this with a new framework for classifying and quantifying soil natural capital and ecosystems services (Dominati et al., 2010a).

4.1.3 Target stakeholder groups that will be directly involved/affected by the tool

The tool will allow land managers to provide advice about soil management based on target ranges for soil quality that are linked to the desired outcomes at farm and catchment scales. Policy makers will have a tool that can assist in developing policy instruments that incorporate production and environmental components and can assess the value of different tradeoffs.

4.1.4 Council commitment to the tools implementation

The tool will increase the utility of the information being collected through the existing soil quality monitoring programme currently in place by a number of Regional Councils. It will provide a link between the indicator values and outcomes at the paddock, farm, catchment and regional scale. The National Land Monitoring Forum fully supports this proposal and will be part of a wider group involved in scoping and implementing the project. The two Regional Council champions are provisionally Reece Hill (Waikato Regional Council) and John Phillips (Hawke's Bay Regional Council). The four milestones that examine linkages between soil quality indicators and soil processes as they influence soil services and outcomes at a range of scales, are listed in Appendix 7.2

4.2 Background on ecosystem services

4.2.1 International literature

Soil science has been very effective in quantifying the differences in the productive capacity and versatility of soils, but struggles to quantify the wide range of ecosystem services that soils provide to society. Some authors noticed early that soils play key roles beyond production (Daily 1997a; Wall et al. 2004). Daily (1997a, p. 113) noted that soils are a very valuable asset that "takes hundreds to hundreds of thousands of years to build and very few to be wasted away".

The concepts of natural capital and ecosystem services come from the discipline of Ecological Economics. Natural capital extends the economic idea of manufactured capital to include environmental goods and services and has been defined as the "stocks of natural assets that yield a flow of ecosystem goods or services into the future" (Costanza et al. 1992, p.38). The concept of ecosystem services gained real momentum in 1997 thanks to Costanza et al. (1997). In 2005, the Millennium Ecosystem Assessment introduced ecosystem services to the general public as "the benefits people obtain from ecosystems" (MEA 2005). The MEA was very successful in informing people on the different roles of ecosystems and how much human societies depend on them, but it treated soils as a black box.

The range of ecosystem services from soils is often not recognised and generally not well understood and neither are the links between soil natural capital and ecosystem services. While a few authors (Daily *et al.* 1997a; Haygarth *et al.* 2009; Wall *et al.* 2004) have proposed soil specific frameworks for ecosystem services, others (Barrios 2007; Porter *et al.* 2009; Sandhu *et al.* 2008; Swinton *et al.* 2007), have considered the ecosystem services provided by soils while working on wider agro-ecosystems. However these frameworks did not make use of available soil science knowledge and did not integrate the relationships between external drivers like climate and land-use, soil natural capital and ecosystem services, limiting their usability for resource management.

Despite these limitations the ecosystem service approach has gained considerable traction globally in the last 10 years. DEFRA in the UK has adopted an ecosystem service approach to inform resource management (Beddington 2010; Defra 2007) . International initiatives advocating the urgent need to link economic growth and environmental sustainability, such as the Millennium Ecosystem Assessment (MEA 2005), The Economics of Ecosystems and Biodiversity (TEEB 2010) or the United Nations initiative "The Economics of Land Degradation" (September 2011) all use the concepts of natural capital and ecosystem services as their tool of choice. In 2007, the European Commission published the Thematic Strategy for Soil Protection, which identified a specific policy need to address the threats to soils and the essential ecosystem services that they provide. A number of international projects are now working on strategies to embed ecosystem services into decision making and policy frameworks (SoilTrEC www.soiltrec.eu, EcoFinders http://ecofinders.dmu.dk). DEFRA in the UK has adopted an ecosystem service approach to inform resource management (Beddington 2010; Defra 2007; Defra 2011). The UK just released the "UK National Ecosystem Assessment", which advertises for new ways of estimating national wealth (Watson *et al.* 2011).

As a land-based economy, New Zealand needs to embrace and invest in this new domain of science since it represents the future direction of land and resource management, as argued recently in Nature (Banwart 2011).

4.2.2 New Zealand Application

New Zealand's continued wealth generation is more than ever highly dependent on its soils. Green growth is about pairing economic growth with environmental sustainability. New Zealand's economy is driven by its primary industries with over 40% of the total land area (10.4 million ha) in pasture and arable cropping land and 7% in exotic forest. Therefore understanding the biological systems that underpin these industries and ensuring that economic growth does not **deplete finite natural resources** is **crucial** if society is to make informed choices on its future. To do this, we need to understand how human activities impact on ecosystems and what are the **trade-offs** between environmental, economic, social and cultural outcomes. For the last 100 years the growth of the primary industry sector has been based on a strategy that has two main elements: increase the per hectare production through investments in innovations and new technologies, and expansion on to new land. We can continue with the first, as indicated by the recent announcement by government for support for irrigation to address water shortages and lift primary production on 350,000 ha. However the second is becoming less of an option, because the competition for land and, by default, the ecosystems services provided by soils that underpin our economy and the health of our living environment, intensifies amongst a growing number of users. The debates in New Zealand on the level of sustainable economic development possible using our natural capital assets are **invariably flawed** because they do not take into consideration the full costs of impacts of development on intangibles such as the provisioning, regulating and cultural ecosystem services provided by soils and how they may be compromised or enhanced.

At present, analysis of current and potential use of the country's finite land resource and its value to the economy is limited largely to its productive capacity. Over the last 20 years, agriculture and forestry land has contracted from approximately 4.8 ha per capita to 2.8 ha. Approximately 730,000 ha (3%) of New Zealand's total land area is now taken up by urban areas, with a further 160,000 ha taken up by transportation networks. Over the past 25 years, the rate of urban expansion has been of the order of between 4% and 5% per year (40,000 ha/yr). Approximately 70,000 ha of New Zealand are used intensively by the horticultural industry, which is looking to expand. The huge demand for increased dairy production driven by strong commodity prices is resulting in increased conversion of land to dairy grazing. Expansion of these three land uses comes at the expense of the sheep and beef and forestry sectors, which are being relegated to less versatile land and landscapes of lower resilience, exposing these sectors to more challenges.

A recent paper (Mackay et al., 2011) developed from information presented at the 'Collision of Land Use Forum' in 2010 made a number of recommendations including the establishment of a national Land Management Forum, a review of current guidelines for land use management and the accommodation of natural capital and ecosystem services considerations in land use management processes. Education of the importance of soil and land use in terms of economy and environment at all levels was also promoted, as was the importance of science based policy, in recognition of the current weakness in land policy development in New Zealand.

For New Zealand society to make informed choices on its future and the sustainability of economic development, it needs to understand the trade-offs between environmental, economic, social and cultural outcomes. The international interest on ecosystem services has not gone unnoticed in New Zealand: a green paper on the emerging issues on ecosystem services and an assessment of ecosystem services research in New Zealand was released in August 2011 by the Royal Society of New Zealand (Weston 2011).

4.2.3 Ecosystem Services and Regional Policy Statements

Regional Councils are the organisations responsible for land management in New Zealand in accordance with the requirements of the Resource Management Act (RMA) 1991 (MfE, 1991). The RMA sets out legislation on how to manage the environment in New Zealand.

In the RMA "sustainable management" is defined as "managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural wellbeing and for their health and safety while -

(a) Sustaining the *potential of natural and physical resources* (excluding minerals) to meet the reasonably foreseeable needs of future generations; and

(b) Safeguarding the *life-supporting capacity of air, water, soil and ecosystems*; and

(c) Avoiding, remedying or mitigating any adverse effects on the environment"

Safeguarding the life-supporting capacity of air, water, soil and ecosystems refers broadly to natural capital stocks and the provision of ecosystem services. Regional Councils are starting to use these concepts to inform land management by including these concepts in Regional Policy Statements.

In a New Zealand first, Horizons Regional Council in releasing in August 2010 its "One Plan", a new regional plan to guide the management of natural resources in the Manawatu-Wanganui region, limits on nitrogen emissions from soils were defined to sustain the life-supporting capacity of water. The nitrogen leaching allowed from intensive pastoral agriculture was based on soil natural capital, using Land Use Capability (LUC) classes of land (Lynn et al., 2009) as a proxy for natural capital. At that time no framework was available to quantify and value soil natural capital and ecosystem services. This approach is independent of current land use allowing policy development to focus on sustaining the natural resources in the region without the need to regulate land use or practices. The recent decision by the Environment Court's Judge Thompson [5-113] concluded that "We find the evidence strongly supports the use of the LUC approach as a tool for allocating N limits for all land uses." http://www.horizons.govt.nz/about-us/one-plan/appeals-to-the-proposed-one-plan-as-amended-by-decisions-august-2010/environment-court-decisions/ advances the use of a natural capital-based approach for resource management in this country.

The Waikato Regional Council has recently produced its first revision of its "Regional Policy Statement" which has also been developed in accordance with the requirements of the RMA (MfE, 1991). This Regional Policy Statement provides an overview of the resource management issues in the region and policies and methods to achieve integrated management of natural and physical resources. This statement seeks a more integrated planning approach, with clear connections between air, land, water, and coastal resource management, based on new scientific research underpinning new policy and rules. The work realised in this study will be considered and potentially used by the Waikato Regional Council to inform their new policies.

4.2.4 New soil natural capital and ecosystem services framework

The framework developed by Dominati et al. (2010a) to classify and quantify soil natural capital and ecosystem services provides a broader and more holistic approach than previous attempts to identify soil ecosystem services by linking soil services to soil natural capital, but also to external drivers and their impacts on processes underpinning soil's provisioning, regulating and cultural services. Moreover, Dominati et al., (2010) developed and tested the new approach for the quantification and economic valuation of individual soil services. Such methodologies bridge the gap between the concept of ecosystem services and its application at different scales, and enables land valuation to be detached from productive capacity or versatility. The framework is being used to progress the objectives of this study.

In the following sections, the presentations, discussions and decisions made during meetings of the members of the Land Monitoring Forum in September 2010, February 2011, September 2011, February 2012 and August 2012 (Appendix 7.7) are presented and discussed. The purpose of the meetings was to obtain agreement on the soil quality indicators to examine, the elements of the framework, and the details of the methodology for the farm scale and catchment scale cases. The details leading to the development of the dairy case in Waikato (Milestone 2.1 and 2.3) are presented, along with the limitations of the methodology. The development of the catchment case (Milestone 2.2 and 2.4) in the Waikato region is also discussed.

4.3 Introducing the soil natural capital and ecosystem services framework

At the bi-annual Land Monitoring Forum meeting in September 2010 in Wellington, Estelle Dominati presented the progress made on a framework developed in linking soil quality indicator and soil processes as they influence soil services and outcomes at the farm scale as agreed in Objective 2 of the programme. The presentation focused on the elements that make up the ecosystem service framework and the approach and methods adopted to implement the framework at the farm scale for a pasture-based dairy system.

4.3.1 Details of framework for quantifying and valuing ecosystem services provided by soils

The theoretical basis of the developed framework builds on general frameworks developed previously including those by Costanza et al. (1997), de Groot et al. (2002) and the Millennium Ecosystem Assessment (2005), and soil-specific frameworks like the ones developed by Daily at al. (1997b), Wall et al. (2004) and Robinson et al. (2009). Each of the general frameworks contained a number of common limitations including:

- They do not inform in detail the part played by soils in the provision of ecosystem services
- They do not link ecosystem services back to natural capital stocks,
- Consequently they are difficult to implement practically for resource management.

The new framework for soil natural capital and ecosystem services (Dominati *et al.* 2010a) has addressed these limitations and provides a pathway of how Ecological Economics concepts can be integrated with Soil Science in the quantification and economic valuation of ecosystems services. It provides a broader and more holistic approach than previous attempts to identify soil ecosystem services by linking soil services to soil natural capital. The conceptual framework shows how external drivers impact on processes that underpin soil natural capital and ecosystem services and how soil ecosystem services contribute to human well-being.

The framework consists of five main interconnected components:

(1) Soils as natural capital embodied by inherent or manageable soil properties;

(2) Natural capital formation, maintenance and degradation processes;

(3) Natural and anthropogenic drivers of soil processes;

(4) Provisioning, regulating and cultural soil ecosystem services; and

(5) Human needs fulfilled by soil services.

The services detailed by this framework are listed in Table 1.

Table 1: Soil ecosystem services considered in the framework

Service		**Definition**
Provisioning services	Provision of food, wood and fibre	Soils physically support plants and supply them with nutrients and water. By enabling plants to grow, soils enable humans to use plants for a diversity of purposes.
	Provision of raw materials*	Soils can be sources of raw materials (peat, clay), but renewability of these stocks is questionable.
	Provision of support for human infrastructures and animals.	Soils represent the physical base on which human infrastructures and animals (e.g. livestock) stand.
Regulating services	Flood mitigation	Soils have the capacity to store and retain water, thereby mitigating flooding.
	Filtering of nutrients and contaminants	Soils can absorb and retain nutrients (N, P) and contaminants (E-coli, pesticides) and avoid their release in water bodies.
	Carbon storage and greenhouse gases regulation	Soils have the ability to store C and regulate their production of greenhouse gases such as nitrous oxide and methane.
	Detoxification and the recycling of wastes	Soils can absorb (physically) or destroy harmful compounds. Soil biota degrades and decomposes dead organic matter thereby recycling wastes.
	Regulation of pests and diseases populations	By providing habitat to beneficial species, soils can control the proliferation of pests (crops, animals or humans) and harmful disease vectors (viruses, bacteria).
Cultural services*	Spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences	Soils, as part of landscapes and support to vegetation, provide to many cultures a source of aesthetic experiences, spiritual enrichment, and recreation. The earth and its sacredness are referred to by many deities and religious belief. Soils have a diversity of cultural uses across the globe, from being a place to bury the deceased, a material from which to build houses and a place to store and/or cook food.

*These services were not considered in this study.

The main features of the framework (Dominati et al. 2010a) include (Fig. 1) :

- The definition of soil natural capital as stocks, embodied by soil properties. The difference between inherent and manageable soil natural capital was recognised. This distinction is well known to soil scientists and land managers but was never used within an ecosystem services framework before.
- The definition of soil ecosystem services as flows coming from soil natural capital stocks fulfilling human needs. Making the difference between natural capital stocks and ecosystem services flows is critical for land managers if they are to understand how climate and land uses impact on land resources, and the ecosystem services they provide.
- The establishment of the difference between soil processes and ecosystem services: the difference was made for the first time between supporting (e.g. soil formation) and degradation (e.g. erosion) processes and ecosystem services. Such a distinction is critical in linking soil science knowledge to the concepts of natural capital and ecosystem services. The distinction between processes and services is also important when it comes to valuation, because it prevents overlaps and double counting.
- The establishment of the place of external drivers within a natural capital and ecosystem services framework: external drivers such as climate, geomorphology or land use impact on natural capital stocks and thereby on the provision of ecosystem services.

Numerous authors (Daily, 1999; de Groot, 1992; de Groot, 2006; de Groot et al., 2002; Ekins et al., 2003a; MEA, 2005) highlight that ecosystems fulfil both physical and non-physical human-needs. The non-material benefits people obtain from ecosystems are referred by the Millennium Ecosystem Assessment (2005) as “cultural services”. They include spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences.

Cultural services provided by soils at the farm scale include the aesthetics associated with the farm landscape, the opportunity for on-farm recreation, the spiritual and religious values associated with the farm location and particular soil types, the educational and social opportunities of the farming system, through to the cultural heritage value of the farm site or farming practices.

Cultural services cannot be measured in biophysical terms in the same way as provisioning and regulating services, although the valuation of provisioning and regulating services can utilise some of the tools and methodologies developed for the valuation of cultural services.

To fully inform the provision of ecosystem services from soils, cultural services should be considered and included in the valuation scheme. In this project, quantification and valuation does not extend to cultural services, but is limited to the provisioning and regulating services, as a first assessment of the framework described above.

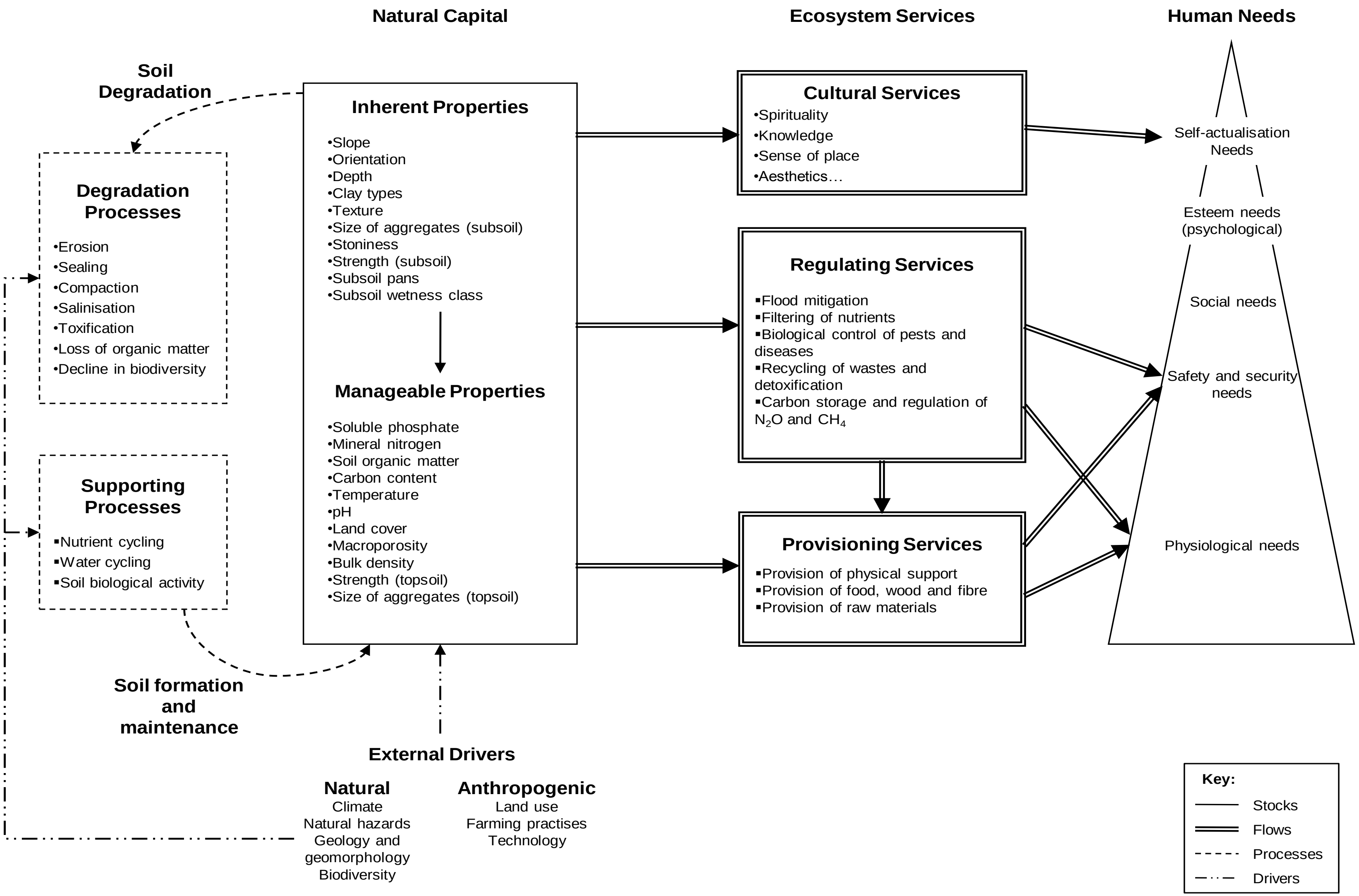

Figure 1: Framework for the provision of ecosystem services from soil natural capital (Dominati et al., 2010a)

4.3.2 Details of the framework for quantifying and valuing the ecosystem services provided by soils

A number of methods were developed to implement the framework at the farm scale:

Identification of the key soil properties and processes behind each soil service

The soil properties and processes at the origin of the provision of each soil service were identified. This information is specific to dairy-grazed systems and the farm scale, but the methodology is applicable to any land use and at a range of scales.

Identification of where and how external drivers impact on the provision of each soil service.

The impacts of external drivers like climate and land use on soil natural capital embodied by soil properties and their current state, and how they affect the provision of soil services, were determined. Again this methodology is applicable to any land use and at a range of scales. This approach will allow land managers to explore the impacts of management practices or a land use on outcomes at different scales including the provision of soil services by linking the impacts on natural capital stocks (soil properties) to those outcomes.

Quantification of ecosystem services

For each soil service a proxy was defined to quantify the service. Each proxy was based on one or more soil properties (natural capital stock) at the origin of the provision of the service. These proxies are specific to a dairy-grazed system and to the farm scale, but the methodology is applicable to any land use and at a range of scales. Each proxy was then calculated from the outputs of a model and/or using data from the literature. Field data can also be used to calculate the proxies, and thereby measure the provision of soil services.

Modelling the provision of ecosystem services from soils

The SPASMO model from Plant and Food Research (Green *et al.* 2003) was used to capture the dynamic attributes of some of the soil properties. SPASMO is a soil-plant-atmosphere system model, which describes soil processes, plant growth and can explore the influence of farm management on these processes. Supporting and degradation processes make up the core of the SPASMO model. The model uses mathematical functions to describe each of the soil, plant, water and nutrient (N and P) processes and links them dynamically to each other and to soil properties using daily time steps. The model uses, as inputs, soil type (soil properties) and external drivers like climate, land use and management practises. It outputs daily measures of chosen soil properties and their dynamics according to these drivers and keeps stock of the flows of nutrients, matter and water. Simple allometric relationships are used to describe the feed, energy and nutrient budgets for the grazing animals, and to parameterize the returns of dung and urine to the grazed pasture.

Valuation of soil ecosystem services at the farm scale

A methodology was developed to value each soil service at the farm scale, under a dairy operation, based on a suite of chosen proxies. The quantitative information on each service was valued using a range of neo-classical economic valuation techniques (Pearce *et al.* 2006) including:

- market prices when available,
- replacement costs approach: costs of restoring the service in situ,
- provision costs approach: provide the service by other means,
- defensive expenditure approach: spend money to avoid an environmental bad (mitigation costs).

Basing economic valuation on dynamic proxies is an innovative and powerful technique to apply the concepts of ecosystem services. Once again, the methodology could be used for different land uses and at a range of scales. Tools like the OVERSEER® nutrients budget were used to generate data for the economic valuation.

Separating the value of soil natural capital stocks from the value of soil ecosystem services

A distinction needs to be made between the value of soil natural capital stocks and the value of soil ecosystem services. Such a distinction is critical to value ecosystem services rigorously. In the literature (Costanza *et al.*, 1997) these are not always separated and clearly defined. For example built infrastructure is often used as a proxy for the value of ecosystem services, which, in our opinion, is not in line with good accounting and economic theory. While a value can be placed on the ecosystem services from soil under a land use, it does not automatically provide an indication of the value of the natural capital stocks. It does provide an indication of the value that can be extracted from the use of the natural capital stocks under that use. A change in land use will see a corresponding change in the value of the services obtained. In our opinion there is more to be gained from understanding how the flow of services change with a change in land use, rather than attempting to put a value on the natural capital stocks.

Implementation of the framework at the farm scale

The framework was implemented at the farm scale on a well drained Horotiu silt loam under a typical Waikato dairy farming operation. The studied farm covers 100 ha, and runs 330 milking cows producing 900 kg MS/ha/yr. Fertiliser N use is 100 kg N/ha/yr. Fertiliser P is 39 kg P/ha/yr. The farm does not have a stand-off pad.

In September 2012, the work in progress was presented to the Land Monitoring Forum. It included:

- Completing the customization of the SPASMO model to capture the influence of livestock treading on soil properties.
- Complete the design of the economic valuation of all services,
- Run scenarios for different stocking rates,
- Run scenarios for two soils
  - Horotiu silt loam: a well drained Allophanic soil,
  - Te Kowhai silt loam: a poorly drained Gley soil,
- Run scenarios with and without a stand-off pad.

Options for future use of the methodologies developed were also discussed including:

- Look at other land uses.
- Scale the study up to a catchment → a region → New Zealand.
- Look at the impacts of land use changes on the provision of soil services.
- Inform land use suitability.
- Use soil ecosystem services values under a land use to complete a cost-benefit analysis (CBA) for policy making.
- A basis for future land valuation.

After the presentation the group was very satisfied with the progress. After discussing the options, the decision was made to focus on one soil quality indicator, macroporosity, to illustrate implementation of the framework and the links between the indicator and outcomes at the farm scale, especially focusing on the measurement and economic value of soil ecosystem services. The underlying principles developed as part of the methodology to quantify and value the ecosystem services at the farm scale will also be used at the catchment scale, with recognition that some of the proxies to measure services will change with scale as will the techniques to value the services. This is particularly true for the filtering of nutrients and contaminants and flood mitigation services, which require different measurement techniques at the farm and catchment scales.

4.4 Implementation of the Framework

At the bi-annual Land Monitoring Forum meeting in Wellington in February 2011 Estelle Dominati presented progress made on implementation of the framework developed to link soil quality indicators and soil processes as they influence soil services and outcomes at the farm scale, as stated in milestone 2.1 of the LMF programme.

The presentation focused on the details of the framework applied to macroporosity (Appendix 7.6). Details of the implementation of the framework at the farm scale were also presented for two ecosystem services, namely flood mitigation and the provision of support to animals. The quantification and economic valuation of these two services was strongly influenced by macroporosity. This was discussed at some length.

4.4.1 General methodology

Detailed below is the methodology for the quantification of soil services. It presents general principles that are valid across land-uses.

The implementation of the framework requires several steps:

1 - Differentiate soil services from the supporting processes behind the formation and maintenance of soil natural capital stocks. It is important in the quantification of ecosystem services that the benefits derived from the service are linked directly to human needs and well-being, as opposed to processes underlying soil functioning and sustaining soil natural capital stocks.

2 - Identify the key soil properties and processes behind each soil service: To determine how soils provide ecosystem services, the soil properties and processes at the origin of the provision of each soil service were described and detailed. Where services depend on dynamic soil properties, the processes driving the changes should be understood. External drivers like climate and land use impact on both soil properties and processes and thereby on the flows of soil services. Separating these impacts is important to establish if natural capital stocks are being sustained or degraded. The impacts of climate and land use on soil natural capital embodied by soil properties also need to be established to be able to quantify the influence of external drivers on the provision of soil services.

3 - Analyse the impact of degradation processes on soil natural capital and ecosystem services: Many processes degrade soil natural capital stocks and thereby affect the flows of soil ecosystem services. Knowing where and how degradation processes impact soil natural capital is essential to determine their impact on soil services. Degradation processes include erosion, compaction, pugging, sealing and crusting, hydrophobicity, loss of soil organic matter (OM), loss of biota, leaching, chemical processes like salinisation or acidification, and the accumulation of chemicals such as heavy metals. The occurrence and intensity of some of these degradation processes is determined by management.

4 - Differentiate between natural capital and added or built capital when defining proxies to quantify soil ecosystem services: The definition of each service is crucial to determine an appropriate proxy to measure it. The proxies used to measure each service require capturing the dynamics associated with the use of soils natural capital stock in the provision of the service. It is argued here that services not only need to be rigorously identified and defined, but one should differentiate the part of the service coming from soil natural capital, from that which comes from added or built capital (e.g. infrastructures, inputs such as fertilisers or irrigation water), enabling the contribution of each to be calculated. Proxies to measure each service based on dynamic soil properties need to be based on the part played by the soil in the provision of the service. Moreover, the soil properties chosen as proxies should be easily measurable and data should be available.

4.4.2 Presentation of the implementation of the framework at the farm scale

At the September 2010 Land Monitoring Forum meeting, the group decided to focus on macroporosity as the example to evaluate the potential value of an ecosystem service approach. The links between macroporosity and the key soil properties and processes behind each service provided by soils and where and how external drivers impact on macroporosity were presented in some detail at the February 2011 meeting (Appendix 7.8).

As an example of the implementation of the framework, the quantification and economic valuation of two services strongly dependent on macroporosity, namely flood mitigation and the provision of support to animals were detailed. The example presented was for the quantification and valuation of these two services from a Horotiu silt loam on a Waikato dairy farm running three cows/ha, no stand-off pad, and with 100 kg N/ha and 35kg P/ha applied each year.

The quantification of the soil's services was based on specific proxies designed for each service, calculated using the SPASMO model (Soil Plant Atmosphere Simulation Model) from Plant and Food Research (Green *et al.* 2003), and OVERSEER® nutrient budget model (Wheeler *et al*., 2008). The economic valuation of the services was realised using neo-classical economics valuation techniques including market prices, replacement costs, provision costs, and defensive expenditures (mitigation costs).

In order to model a dairy farm and gather all the data needed to calculate the proxies behind each soil service, extra-functionality was added to the SPASMO model. This included functions describing the impact of soil water content on pasture utilisation, the impacts of grazing regime on soil structure (macroporosity) (Fig. 2) and pasture growth (rate and recovery) (Fig. 3) during each grazing rotation (Betteridge et al. 2003), the use of standoff-pads, and extra routines to describe the P cycle.

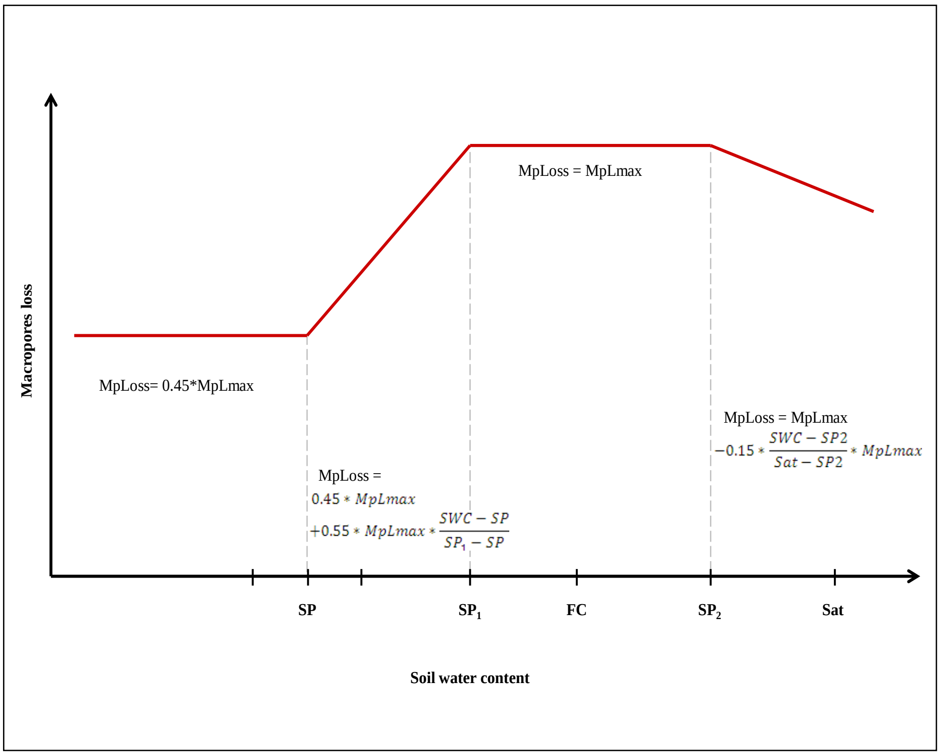

Figure 2: Functions calculating the macropore loss after a treading event in relation to soil water content.

The SPASMO model was used to explore the dynamics of soil properties and processes regulating each of the soil services and to quantify each service for each of 35 years using climate records from Waikato from 1975-2009. The impacts of cattle treading were examined but the same methodology could be used to inform the impacts of e.g. erosion or hydrophobicity at a larger scale.

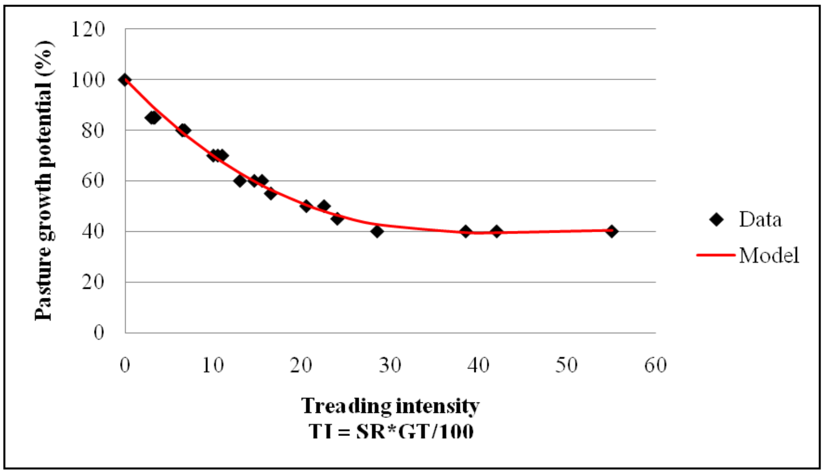

Figure 3: Loss of pasture growth potential depending on treading intensity (TI): Data and model fit.

4.4.2.1 Provision of support to animals

To quantify the provision of support to animals, volumetric soil water content (SWC) was modelled daily with SPASMO. The number of days between May and October when soil water content is between field capacity and saturation (sat) (SWC <(FC+Sat)/2) was calculated (number of wet days). A measure of the service was then defined as the difference between the total number of days between May and October (184 days) and the number of wet days. This measure represents the number of days between May and October when the soil can support animals without damage to soil structure.

To value the provision of support to animals, the provision cost method was used. To avoid treading damage, New Zealand farmers often use off-pasture standing areas, such as feed pads or stand-off pads when the soil is too wet and fails to provide adequate support to the animals. The value of the support provided by soils to animals can be determined by considering that if the cows cannot stand on the paddock because the soil is too wet, they have to be transferred to, for example, a stand-off pad. The construction and maintenance of a stand-off pad is another way to provide the service. The size and construction and maintenance costs of the stand-off pad ($/ha/yr) that would be needed if the soil did not provide the service were calculated. The value of the provision of support to animals in $/ha/yr was then calculated by adding the annualised construction costs of the pad to the annual maintenance costs of the pad for the number of days between May and October when the soil can support the animals.

4.4.2.2 Flood mitigation

To quantify flood mitigation, it was assumed that in the worst case all the rain falling in a year could potentially runoff, as would be the case on an impermeable surface (e.g. concrete). The difference between rainfall and the amount of water that runs off the land is the amount of water absorbed by the soil, or the flood mitigation service. The flood mitigation service is defined as the difference between rainfall (RF) and runoff (RO) for each day, which is the amount of water that could potentially runoff, but does not because of the soil's water absorption and retention capacity. Daily soil water content and runoff were modelled using SPASMO.

The provision cost valuation method was used to value flood mitigation. If the soil had no retention capacity, another way of reducing flood risk at the farm scale would be to build dams to store the water presently stored by the soil in order to delay the flood peak. The value of flood mitigation from soils can therefore be assessed by determining the costs of building water-retention dams, on the farm, to store the water that would otherwise run off. It was assumed that such a retention dam should be big enough to store the annual maximum of seven consecutive days worth of water stored by the soil, which is rainfall minus runoff. This is to mimic the retention of water by the soil profile. This period could be increased or decreased depending on the attributes of a given catchment or specifications of any flood control scheme. For each year, the maximum amount for seven consecutive days of water stored by the soil was calculated using SPASMO. This measure was used to calculate the size of the dam (volume of storage needed) in m^3/ha. The cost of construction of a water storage dam was determined and then annualised using a discount rate of 10 % and a depreciation time line of 20 years to calculate the annual value of the service in $/ha/yr.

4.4.3 Summary of quantification and valuation

The value of soil services has been calculated here using either market prices, when available, or the construction and maintenance costs of built infrastructures which could provide the services concerned. Construction costs of built infrastructures were annualised in order to represent the annual value of the flows of services provided each year, using discount rate of 10% or 3%. Changing from a 10% discount rate to a 3% discount rate when calculating annualisation decreased the value of the services by a quarter.

The total value of the ecosystem services provided by the soil under that use is calculated by summing the value of all services (Table 2). The average value of soil services from a Horotiu silt loam under a dairy operation over 35 years was $15,777/ha/yr, ranging from $11,737/ha/yr to $21,455/ha/yr, using a 10 % discount rate for annualisation. The range in the value of the services reflects the interaction between climate and soil properties for the 35 years of continuous weather records used in SPASMO to quantify the soil services.

Summing the values of each service could be criticised because of the issues of joint production and double-counting. By using the costs of built infrastructures like a stand-off pad or effluent pond, to value soil services, the values obtained are subject to joint production, as the use of infrastructures, such as a stand-off pad impacts on a number of soil properties (Mp, OM content, nutrients contents) and thereby on a number of soil services. The use of the costs of built infrastructures to value the provision of specific services could potentially result in an overestimation of the value of the services.

The study showed that regulating services have a much greater value than provisioning services. Of these the filtering (63% of the total value of services) and flood mitigation (8% of the total value of services) services had the highest value (Table 2).

Loss of these services would have a major impact on the wider environment and the community by increasing flood risk and the risk of contaminants entering the ground and surface water. Land management at present has a strong focus on maximising use of the provisioning services, such as the provision of food and physical support. This is not surprising because these are the services that are recognised and valued by the market.

While the provision of support for animals is not marketed as such, it is increasingly valued indirectly through the recognition of the additional costs incurred on soils where the service is poor. Inclusion of the regulating services in the analysis adds a new dimension when exploring the interaction between land use and resource management.

It should be noted that the value of the ecosystem services provided by soils (annual flows) is different from the value of soil natural capital (stocks). These should not be confused. An ecosystem services valuation estimates the value of the flows from the use of natural capital stocks, but by no means indicates the value of the stocks. A good example would be the differences in value between soil C stocks and flows.

It could be argued that the non-annualised costs of infrastructures correspond to the value of the natural capital stocks they replace. Inclusion of insurance to protect an infrastructure investment, rates adjustments associated with capital investments and the opportunity cost of money could also be included as part of cost structure. However, even with these additions the values tend to be at the lower bound estimate since built infrastructures are in no way as dynamic, renewable and inter-connected as natural capital stocks. However, the “lump sum” value of built infrastructure is often used as a proxy for ecosystem services valuation. This is not in line with accounting and economic theory, where lump sum value should be amortised or annualised.

Valuing the filtering of P was more challenging. The amounts of simulated P lost were very large which shows how strongly some soils retain P. However, since no techniques exist to mitigate losses of P >5 kg/ha/yr, it makes it very difficult to value this service.

Table 2: Different dollar values of soil services for the Horotiu silt loam, under a dairy operation, and capital values.

Soil services	Average dollar value of service (10% discount rate)		Average value of service (3% discount rate)
	Average	%[1]	
Provision of food Quantity	4,155	26	4,155
Provision of food Quality	38	0.2	38
Provision of support for human infrastructures	17	0.1	12
Provision of support for farm animals	112	0.7	89
Provision of raw materials	NC	NC	NC
Flood mitigation	1,196	7.6	685
Filtering of N	554	3.5	529
Filtering of P	2,924	18.5	2,426
Filtering of contaminants	6,513	41	3,424
Recycling of wastes	78	0.5	63
Carbon flows	-36	-0.2	-36
N_2O regulation	15	0.1	15
CH_4 oxidation	0.47	0.003	0.47
Regulation of pest and disease populations	210	1.3	210
TOTAL value ES/ha/yr	15,777		11,610

NC: not considered, [1]Percentage of the total value of services , Land in Waikato in 2010 was valued around $45,000/ha for a dairy farm. Farm infrastructures are generally worth, new, about $15,000/ha (Table 3), which values the land at $30,000/ha. Every year this land provides ecosystem services worth around $15,777/ha. The present value of such perpetuity is $525,900 (using a 3% discount rate), therefore, it is safe to say that the actual market value of farm land is currently on the low side.

Table 3: Value of a dairy farm infrastructure

Asset	Price	Measure for 110 ha	Value ($)
Fonterra shares	$4,52/kg MS	99000 kg MS	447,480
Fences	$15/linear meter	25 km	375,000
Tracks	$16/m	2,5 km	40,000
Milking shed (complete shed including rotary milking system)	$14000/bail	50 bails	700,000
Stand-off pad	$25/m^2	2000 m^2	50,000
Irrigation system for effluents			15,000
Effluent pond	$15/m^3	3000 m^3	45,000
Troughs (water for animals)	$600/trough	22	13,200
Total		**$ for 110 ha**	1,685,680
		$/ha	15,324[1]

[1]Does not include insurance costs

4.4.4 Limitations of the quantification

Some of the limitations could be addressed in future extensions of this research. These are discussed briefly here.

The method used to measure each soil service has been developed for the purpose of this study that is, specific to the measurement of ecosystem services from the soils on a dairy farm. Not all of the proxies used here to measure each service are necessarily transferable to other land uses.

Some uncertainty exists in the quantification of ecosystem services from soils, from gaps in our knowledge of soil processes.

Uncertainty also surrounds the outputs from process-based models. For example the modelling of cattle treading in the SPASMO model used in this study was conservative, e.g. the decrease in macroporosity found in the field after treading is greater than model outputs. If time and resources are available, it will be worth trying to improve this part of the model with more field data to obtain better description of the actual impact of treading.

There has been no accounting for differences in behaviour of different soil types when calculating variables such as the maximum macro-pore loss, macroporosity recovery rate or the actual loss of pasture growth. The spatial component is also missing from this study and is part of the next step of the analysis.

Provision of food Quantity: The method used to determine the part of the pasture yield due to natural capital is robust, because it is based on currently used technical advice on pasture nutrient requirements. However, for different land uses, the provision of marketed goods is embodied by different products (trees, fruits, crops) and therefore the method to determine the part of the yield coming from natural capital would need to be adapted to that land use.

Provision of food Quality: The provision of trace elements from soils can affect any agricultural activity; therefore determining the impacts of trace element deficiencies on yields for different land uses is a robust method.

Provision of support for human infrastructures: In this study soil's bulk density was used as a proxy to measure the provision of support for human infrastructures, which is relevant at the farm scale. However, if looking at a different scale (Paddock, Catchment or Region), position and association of soils in the landscape would have to be considered in addition to bulk density, as well as the nature of soil's deep horizons and underlying regolith.

Provision of support for farm animals: Using soil water content as a proxy for soil physical resistance to loading is robust at the farm scale. It is in fact used by farmers on a regular basis to make decisions on the management of wet soils. At a different scale, the shape of a landscape and the position of soil types in this landscape would have to be considered.

Provision of raw materials: This service was not quantified here because it was considered non-relevant at the farm scale. However at a different scale (catchment, region or country), it would be necessary to quantify it by considering the net flows of raw materials from soils and their renewability and the sustainability of their use.

Flood mitigation: The method used to quantify flood mitigation (RF-RO) is fairly robust. However, at a different scale, landscape and most importantly slope and vegetation would have to be considered since on steep land, during heavy rainfall, water runs off before having time to infiltrate even if soil's water storage capacity is available. Similarly, the influence of hydrophobicity, a degradation process, on this service, has not been investigated but should be included since it can have a major impact on this service.

Filtering of Nitrogen: The method used here for the quantification of the filtering of N was enabled by modifying the dynamic model (SPASMO) in order to determine N leaching for a soil with very low anion storage capacity. The method used was not ideal since lower anion storage capacity also means less pasture grown and therefore fewer wastes deposited on the paddock.

Filtering of Phosphorus: The method used to quantify the filtering of P was enabled by the existence of a dynamic model (SPASMO) which was modified in order to determine P runoff and leaching for a soil with very low anion storage capacity. The amounts of simulated P lost for the volcanic soil studied were very large which shows how strongly some soils retain P. No techniques exist to mitigate losses of P >5 kg/ha/yr. This creates difficulty in the valuation.

Filtering of contaminants: To measure the filtering of contaminants, a proxy was used (contaminated runoff) because of a lack of detailed data on relevant contaminants. Instead, if data on the dynamics of each contaminant (E-coli, pesticides, EDCs) were available for the studied soils, the difference between amounts applied and leached could be used to measure the service. Such methodology would be relevant at different scales.

Recycling of wastes: To measure the recycling of wastes, a proxy was used (the amount of dung deposited in unrestricted conditions) because of the complexity of the dynamics of dung decomposition and the recycling and transformation of OM. Instead, if, for the studied soils, more data were available on the recycling of dung pads as a function of the season, Mp and SWC for example, the difference between amounts applied and efficiently decomposed could be used to measure the service. Typically this service would be better informed by using field data than model outputs. Such methodology would be relevant at different scales. Moreover, for scenarios including the use of a stand-off pad, dung was deposited only when SWC<FC, which would have influenced the measure of the service.

Carbon flows: The net flows of C modelled with SPASMO are very sensitive to a number of parameters and , therefore these outputs of the model should be considered with extreme caution. Actual data on measured C flows could be used instead if available for the studied soils. The issue of valuing C stocks was raised, but here it is argued that the service is the net flow of C. If positive, it is truly a service since soils are storing C. If net flows are negative, then they can be considered as a degradation process and the impact of C losses on other soil properties and on the provision of soil services should be investigated.

N_2O regulation: The use of the IPCC methodology to calculate N_2O emissions from soils has been heavily criticised but is still a reference. The methodology used here is inspired from the IPCC methodology. It is argued the use of model outputs (N leaching and SWC) to calculate N_2O emissions and the addition of an extra emission factor taking into account wet soil conditions make the calculation more accurate. For even more accurate calculation a process-based model such as DNDC (Giltrap et al. 2008; Saggar et al. 2007a; Saggar et al. 2007b), specialised in GHG emissions could be used.

CH$_4$ oxidation: At the farm scale, CH_4 oxidation is quite small; therefore it would be more relevant to consider this service at a bigger scale. Our estimation of CH_4 oxidation from soils was based on data from the literature and model outputs (SWC) and is therefore approximate. For more accurate calculation a process-based model such as DNDC (Giltrap *et al.* 2008; Saggar *et al.* 2007a; Saggar *et al.* 2007b), specialised in GHG emissions could be used.

Regulation of pest and disease populations: Following soil conditions to assess pest infestation risk is a robust method used by farmers. However, the information used in this study is quite approximate. The quantification of this service could be improved by access to more data on the impact of soil conditions on the different stages of pests' development. Moreover, animal pests (e.g. parasitic nematodes) were not considered in this study because they pose little threat to mature cows. This would change if investigating a whole dairy system that included grazing calves.

The quantification of some services was limited by the availability or existence of relevant data sets. As our understanding improves the ability to address these challenges will also improve.

4.4.5 Limitations of the economic valuation:

A number of issues are associated with the economic valuation of ecosystem services. They are discussed below.

Joint production: The aggregation of the values of each service can be criticised because of the issues of joint production and double counting. Providing the ecosystem services are entirely independent, adding the values is possible. However, the interconnectivity and interdependencies of ecosystem services may increase the likelihood of double-counting ecosystem services (Barbier *et al.* 1994). Moreover, a number of the methods used here to value soil services are subject to joint production (defensive expenditure, replacement cost, provision costs) (Pearce *et al.* 2006). By using the costs of built infrastructures like a stand-off pad or effluent ponds to value soil services, the values obtained are subject to joint production, as the use of infrastructures, such as a standoff pad, impacts on a number of soil properties (Mp, OM content, nutrient content) and services. The use of the cost of built infrastructures to value the provision of specific services could result in an inflated value of the services.

Lastly, different methods were used to value different services; therefore comparing values of different services or adding values is problematic. This study has not dealt with these issues. Therefore it is recommended when exploring the findings of the analysis that the values of each soil service be examined separately, and that each service be compared between scenarios rather than compare total values.

<u>Annualisation</u>: When valuing ecosystem services, it is desirable to value the flow of services from the natural capital stocks and not the stocks themselves. This is why when using the costs of infrastructures to value ecosystem services one must annualise these costs in order to determine the annual flows of value that can be attributed to flows of ecosystem services. Annualisation is used as a rule in benefit-cost analysis. Nonetheless, in the literature some authors have used the value of built infrastructures for ecosystem services valuation without first annualising the initial investment. This approach is not in line with good accounting and economic theory.

<u>Discount rate</u>: The value of the discount rate used for annualisation is a contentious issue in benefit-cost-analysis. In ecosystem services valuation there is no standard method generally accepted by scholars and the value of the discount rate to use for environmental studies is still highly controversial. In this study, it was shown that changing from a 10% discount rate to a 3% discount rate when calculating annualised costs decreased the value of the service by around a third (Dominati, 2011). Such information could be used to choose an appropriate discount rate depending on the project considered.

<u>Mitigation functions</u>: The mitigation functions built to value the filtering of N and P were constructed with a restricted number of model outputs, and therefore assumed linearity In the future, it is recommended to use a great number of field data, if available, to build the mitigation functions.

The economic values obtained here are a lower bound estimate of ecosystem services from soils because the valuation techniques used are not able to account for the dynamism, renewability and interconnectivity of soil natural capital stocks and the ecosystem services they provide. It would be very interesting to use different economic valuation techniques (such as contingent valuation or group valuation) to compare the results for the values of soil services.

4.5 Guidelines for monitoring the provision of soil ecosystem services at different scales

The following section details how the conceptual framework can be implemented first at the farm scale and then at the catchment scale with presently available data.

4.5.1 Farm scale methodology: Dairy case in the Waikato

The following section retraces the steps taken for the farm case study and presents the methodology used and results.

4.5.2 Farm scale study: Milestones time-scale

Milestone 2.1: Development of the dairy case in Waikato

Jan 2011. Agreement was reached on the ecosystem services for inclusion in the framework to explore the links between soil quality indicators and outcomes beyond the paddock scale at the bi-annual Land Monitoring Forum meeting in Wellington in September 2010. Good progress has been made since that meeting in developing the framework for the case study Waikato dairy farm. An update will be provided to the Bi-annual Land Monitoring Forum meeting in Wellington in February 2011.

June 2011 At the bi-annual Land Monitoring Forum meeting in Wellington in February 2011 a presentation on the links between macroporosity and soil ecosystem services including the provision of food, wood and fibre, provision of raw materials, provision of support for human infrastructures and animals, flood mitigation, filtering of nutrients and contaminants, carbon storage and greenhouse gases regulation, detoxification and the recycling of wastes, and regulation of pests and diseases populations, was made to forum members to obtain more feedback on services of most interest and the preferred currency (bio-physical measures and/or NZ dollars) for reporting on each service.

Summary of feedback from group (February 2011)

The quantification and valuation of soil ecosystem services needs to include determination of thresholds / tipping points in the provision of ecosystem services, in terms of quantity or the point at which service is seriously compromised, as well as economic value. These thresholds can then be compared to contemporary optimal values for soil quality indicators (e.g. a macroporosity of 10%). For what value of macroporosity do we get a maximum provision of ecosystem services and at what value does that service start to decay) and used to confirm or revise the current optimum values. The group also expressed interest about marginal values and comparing the costs of increasing natural capital (with mitigation and investments) to the gain in value of the ecosystem services provided.

The need to link thresholds to the provision of services and outcomes at different scales was also mentioned. The group agreed that the focus should be on the provision of food, flood mitigation, and the filtering of nutrients at the catchment scale. More details about the methodology of quantification and valuation of soil ecosystem services were requested. It was agreed that a document detailing the methodology should be provided to the group, in order to discuss the methodology and adapt it at different scales and land uses. The need to aggregate soil quality indicators into a comprehensive single indicator for e.g. a national statement on the state of the soil resource in New Zealand was also mentioned. Combining the approaches of soil quality indicators and ecosystem services valuation was regarded as the best method to provide evidence for policy making.

Milestone 2.3: Working example at the farm scale of the new reporting framework.

Jan 2012: Agreement was reached on visits for 2012 to the Waikato Regional Council to gather data needed for use of the framework to explore the links between soil quality indicators and outcomes at the farm scale at the bi-annual Land Monitoring Forum meeting in Wellington in September 2011. Good progress has been made since that meeting in developing the framework for the case study on the Waikato dairy farm. An update will be provided to the bi-annual Land Monitoring Forum meeting in Wellington in February 2012.

June 2012: Visits were made to the Waikato Regional Council to gather data needed for use of the framework to explore the links between soil quality indicators and outcomes at the farm scale on 18 and 19th January 2012 and 8 and 9th march 2012. Two farm visits were also made on 9th March 2012 to assess data availability on farm.

At the bi-annual Land Monitoring Forum meeting in Wellington on 16 February 2012, a presentation on links between macroporosity and the provision of soil services at the farm scale, and links between quantification and economic valuation of soil services, was made to forum members to obtain more feedback on preliminary results. The group agreed that the preliminary results on macroporosity were encouraging and that focus should be on using the quantification and valuation of soil ecosystem services to determine thresholds / tipping points in the provision of ecosystem services, in terms of quantity, and economic value.

4.5.3 Farm scale study methodology

For each soil service, the soil properties behind the service and the drivers impacting on the service were identified using wiring diagrams of the relationships between soil properties. These diagrams are presented in Appendix 7.8. From these diagrams, the proxies to measure each service were determined.

Two farm visits were made on the 9th March 2012 to assess data availability on-farm for the quantification of the provision of ecosystem services. The farm plans of the two farms visited were made available by the Waikato Regional Council. The OVERSEER® nutrient budget (version 6.0) was used to generate the data necessary for the quantification of ecosystem services for both farms (Table 4). Data on the maximum nitrogen leached from the farms were obtained by selecting the “no N immobilisation” box in the OVERSEER® nutrient budget model.

The methodology for the quantifying and valuing the soil ecosystem services at the farm scale are detailed in Table 5.

For each soil service, the information used includes (Table 5):

- The proxies considered to measure the service,
- The parameters used at the farm scale,
- The origin of the data,
- The formula used for the quantification, if relevant,
- The valuation method used at the farm scale.

Table 5 details how the information presented in Table 4 was adapted to the dairy case in Waikato.

The high input dairy farm had a higher cow stocking rate and used more fertiliser N, but had a similar milk solids production/ha.

Table 4: Description of the two farms visited in the Little Waipa catchment.

	Farm type							
	Low inputs			**High inputs**				
		Dairy block	**Effluent block**		**Original block**	**Winter crop**	**Effluent block**	**Forestry block**
Soil Order		Allophanic	Allophanic		Allophanic	Allophanic	Allophanic	Allophanic
Soil type		Tirau	Tirau		Tirau	Tirau	Tirau	Tirau
N fertiliser (kgN/ha/yr)	60			150				
P fertiliser (kgP/ha/yr)	10			60				
Stocking rate (cows/ha)	2.22			2.96				
Production (kgMS/ha/yr)	1000			980				
Area (ha)[1]	180	150	30	260	160	10	70	30
Pasture growth (kgDM/ha/yr)[1]		10296	10296		14914	2608	14914	
N leached (kgN/ha/yr)[1]		26	30	39	35	183	37	2
N max (kgN/ha/yr)[1]		63	70		89	183	89	2
P losses (kgP/ha/yr)[1]		0.7	0.7		4.1	2.1	2.3	0.1
Runoff (mm/ha/yr)[1]		75	75	21	21	-	21	0

[1] Overseer nutrient budget version #6.0

Table 5: General methodology for the quantification and valuation of soil ecosystem services at farm scale

Services	Proxies to measure	Parameters used at the farm scale	Origin of the data	Formulas for quantification	Valuation method used at the farm scale
Provision of food quantity	Yield coming from natural capital stocks	Yield/ha or /block N fertiliser kg/ha/yr Native Olsen P by soil type	Overseer / farm plan Farm plan AgResearch database	Measured yield - influence of N - influence of P fertilisers	Market prices of meat, crop, fruits, wood (or added value)
Provision of food quality	Trace-element status	Trace-element levels/block	Farmer / farm plan	Not applicable	Defensive expenditure: cost of mitigation of trace-elements deficiencies
Provision of physical support To humans To animals	Soil structure and sensitivity to damages	Bulk density/block, slope/block Field capacity, Saturation capacity, Soil water content number of wet days	Farm plan Farm plan / soil database	Bulk density Total days - dry days	Replacement cost (costs of farm tracks and fences) Provision cost (construction and maintenance of a standoff pad, feed pad for S&H)
Flood mitigation	Part of rainfall stored	Rainfall and runoff	RF: farm plan RO: Overseer	Max weekly RF-RO/year	Provision cost (costs of building dams)
Filtering of N	Part of N inputs retained	Actual N leaching Potential max N leaching	Modelled Overseer Modelled Overseer	Max N loss- Actual N loss	Defensive expenditure (mitigation costs)
Filtering of P	Part of P inputs retained	Actual P runoff Potential max P runoff	Modelled Overseer Assumption	Max P runoff - Actual P runoff	Defensive expenditure (mitigation costs)
Filtering of contaminants	Part of contaminants inputs retained	Actual E-coli or pesticides losses Potential max E-coli or pesticides losses	Assumption from farmer/farm plan	Volume of rainfall filtered properly	Provision costs (costs of construction of a wetland)
Detoxification and recycling of wastes	Conditions of wastes deposition	SWC slope grazing times	Assumption from farmer/farm plan	Amount of dung deposited in ideal conditions	Provision costs (costs of construction and maintenance of an effluent pond)
C flows	Net C flows	C flows	Modelled from soil	Net C flows	Market prices of C

			database		
Nitrous oxide regulation	Amount of N_2O regulated	SWC and N_2O emission	Modelled from farm plan / farmer	Max N_2O emissions (wet soil)- Modelled N_2O emissions	Market prices of C
Methane regulation	Amount of CH_4 regulated	SWC and CH_4 oxidation	Modelled from farm plan /farmer	Modelled CH_4 oxidation	Market prices of C
Biological control of pests and diseases	Conditions for pest development	Macroporosity SWC	Modelled from farm plan /farmer	Number of days unfavourable to pest development between October and March	Provision cost (costs of pesticides)

Table 6: Measure and value of the soil ecosystem services provided by the two farms surveyed.

Soil Services	Farm Type			
	Low input		High input	
	Quantity	Value ($/ha/yr)	Quantity	Value ($/ha/yr)
Food quantity **(kgDM/ha/yr)**	6,577	2,631	8,865	3,546
Food quality **(trace element deficiencies)**	No def	38.0	No def	38.0
Support to infrastructures	Low	9.0	Low	9.0
Support to animals **(wet days between May & October)**	10	152	20	249
Flood mitigation **(mm/ha/yr)**	1,375	1,615	1,429	1,679
Filtering of N **(kgN/ha/yr)**	37	3,387	54	15,117
Filtering of P **(kgP/ha/yr)**	14.3	2,234	10.9	1,192
Filter of contaminants **(m^3 filtered/ha/yr)**	687	7,980	714	8,294
Decomposition of wastes **(well decomposed effluent m^3/ha/yr)**	11.7	140	15.6	186.7
Net C flows **(Net change in total C on 0-10cm in tC/ha/yr)**	-0.8	-76.3	-0.8	-76.3
N_2O regulation **(kg N_2O/ha/yr)**	2	15.9	2.6	21.2
CH_4 regulation **(kg CH_4/ha/yr)**	0.8	0.4	0.8	0.4
Pests **(favourable days over 6 months)**	64	184	64	184
Total	**NA**	**18,310**	**NA**	**30,440**
Net present value (3% discount rate)		610,340		1,014,678
Net present value (10% discount rate)		183,102		304,403

NA: Not applicable; No def. No deficiency

The measures and value of the soil ecosystem services provided by the pastoral blocks of the two Waikato dairy farms are listed in Table 6. The soil services identified of most interest to the Land Monitoring Forum are the provision of food quantity and quality, flood mitigation and the filtering of nutrients to measure and value these only requires data already reported and available in the farm plans realised by the Waikato Regional Council and outputs of the OVERSEER® nutrient budget model.

In the high input farm there is a greater demand for the soil services, increasing their value. The nutrient loadings and contaminants entering the soil on the high input farm are greater than on the low input farm requiring the soils on the high input farm to filter a greater quantity of nutrients, to limit the increased potential risk of nutrient losses from the system making these soil services more valuable. This increased importance was also reflected in a further increase in the importance of the regulating services in comparison with the provision services of the soil for the high input dairy system.

The mitigation functions built to value the filtering of N and P were constructed with a restricted data set on the efficiency and costs of mitigation techniques. The maximum amount N and P mitigated in the construction of the functions was 20 and 10 kg/ha/yr, respectively. However, the magnitude of the service for N filtered were 37 kgN/ha/yr for the low input farm and 54 kgN/ha/yr for the high input farm (Table 4). Application of these mitigation functions beyond the range of data used to construct the functions is dangerous. As a consequence the value of the services resulting from these calculations needs to be treated with real caution. A more extensive dataset needs to be considered when building these mitigation functions.

The high input farm supports a greater stocking rate on a less hilly landscape. Calculated annual runoff was less, but leaching was higher through the soil profile.

The Net Present Value of the flow of services, treated as a perpetuity, was calculated using a 3% discount rate and was $610,340 for the low input farm and $1,014,678 for the high input farm. Changing the discount rate from 3% to 10% decreased the Net Present Value of the flow of services 3-fold. Again these values need to be treated with caution for the reasons listed above.

The methods used for the economic valuation of each soil services need to be revisited when greater datasets become available to build the mitigation functions.

Because the economic valuation of each service used a different method to value services it is not recommended to add the values of the different services.

The calculation of the Net Present Value of the annual flow of services is very dependent on the discount rate used which is still debated vigorously between the various schools of thought in economic (e.g. neo-classical economists prefer to use 10% whereas ecological economists use smaller rates around 5%).

4.5.4 Influence of a change in macroporosity on the provision of ecosystem services from soils:

The output from the SPASMO model from Plant and Food Research (Green *et al.* 2003) was used to identify trends between macroporosity and the provision of ecosystem services under a dairy land use and a range of management practices on two contrasting soils over 35 years (Dominati et al., 2011). The dairy farm systems investigated included an examination of the influence of three dairy cow stocking rates (3, 4 and 5 cows/ha) with corresponding higher N and P fertiliser inputs, and two pasture management options: 1, Cows on the paddock (cows ON) or 2. Cows are taken off the paddock onto a stand-off pad when the soils are wet (cows OFF) as they influenced both the quality of soil natural capital stocks and the quantity and value of each soil service. Plotting the average annual SPASMO outputs for macroporosity against runoff and pasture yield from natural capital from two soils the Horotiu silt loam and Te Kowhai silt loam, under a total of 12 dairy farm system scenarios across 35 years, runoff decreases as macroporosity increases, whereas the pasture yield from natural capital stocks increases as soil macroporosity improved (Fig.4). For the Horotiu, an allophanic soil, macroporosity values ranging from 6-11%, while the Te Kowhai silt loam, a gley soil with poor physical structure, macroporosity values were all <5%.

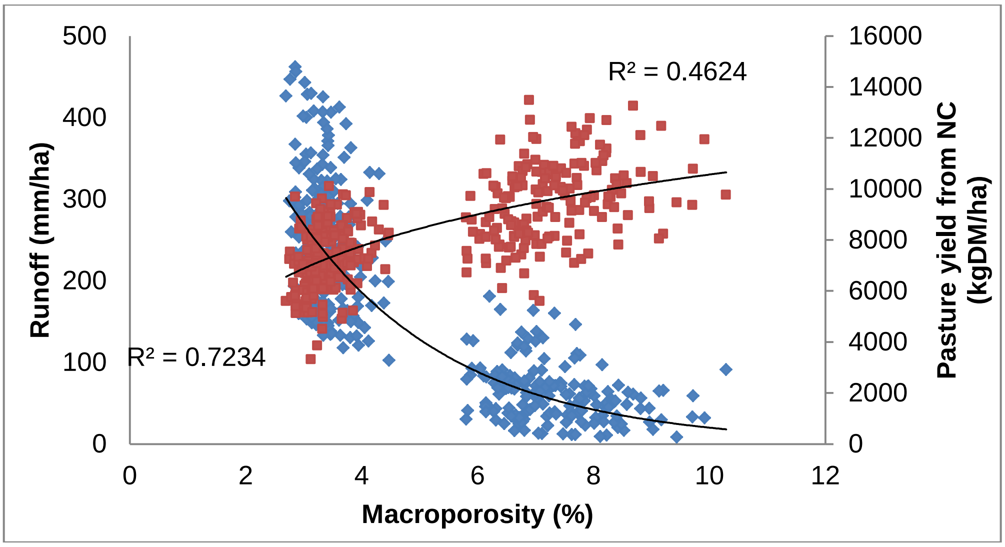

Figure 4: SPASMO Model outputs for macroporosity against runoff (blue) and against pasture yield (red) from natural capital from the two contrasting soils (Horotiu and Te Kowhai) under the 12 dairy farm scenarios over 35 years.

There should be caution in the use of the relationship between macroporosity and runoff and pasture yield because the data for each of the soil types is based on model outputs, data are clustered by soil type and there is not overlap in the data sets between the soils.

Poor relationships were also found when plotting the average annual SPASMO outputs for macroporosity against the risk of P loss and P filtering for these two contrasting soils. Again data were clustered by soil type and there was no overlap in the data sets between the soils.

To observe a net trend between N losses by leaching as nitrate or emissions to air as nitrous oxide, the two soil types had to be considered separately, since the N cycle processes are quite different between a well-drained and a poorly drained soil. Nitrous oxide emissions decreased as macroporosity increased, but the response functions were different between the two soil types (Fig. 5). The relationship between nitrate leaching and macroporosity was less well defined, but again different between the two soil types. The trend observed with models outputs need to be confirmed using field data as more datasets become available.

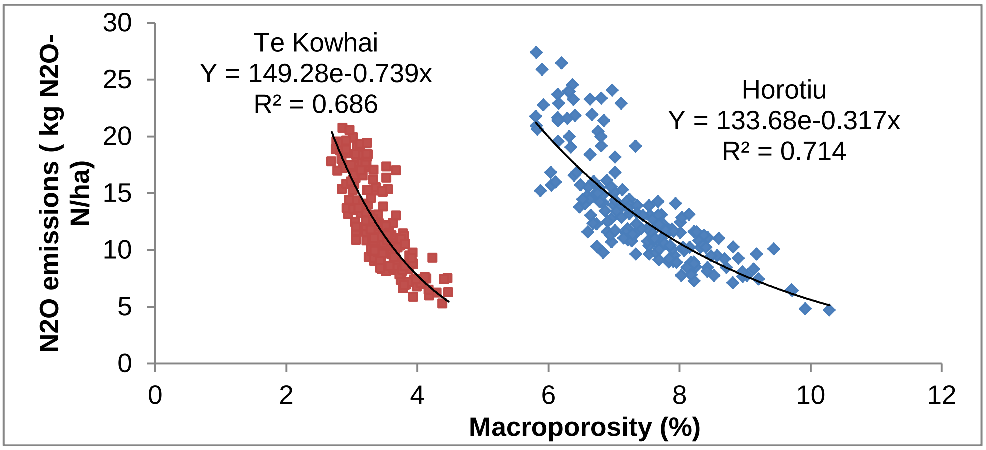

Figure 5: SPASMO Model outputs for the relationship between macroporosity and nitrous oxide emissions (annual averages) from two contrasting soils under the 12 dairy farm scenarios over 35 years

To assess the impact of a decline in macroporosity as a consequence of compaction at the farm scale, a loss of 2% of macroporosity was built into the ecosystem service framework and the flow of services recalculated for the pastoral blocks of the two farms. A summary of these results are presented in Table 7.

Table 7: Changes in the quantification and valuation of soil services after a decline in macroporosity of 2% across the pastoral blocks of two dairy farms.

Farm Type	Change in N loss (kgN/ha)	Change in P loss (kgP/ha)	Change in runoff (mm/ha)	Change in the total value of soil services ($/ha)	Change in the total NPV of soil services ($)
Low input	- 4 (15%)[1]	+ 0.1 (15%)	+ 70 (93%)	+ 707	+ 23,572
High input	- 5 (15%)	+ 8.1 (197%)	+ 70 (330%)	+ 6,608	+ 220,282

[1]Percentage change

These need to be treated with serious caution, because of first, the limited data on the relationship between macroporosity and the soil services of interest and second the nature of the economic valuation. They should be used as some guiding principles for future study.

A decline of macroporosity of 2% in the soil equated to a reduction in drainage and N leaching by 15% in both farm (Table 7). Since the maximum N that could be leached remains unchanged, with less leaching, more of the N is filtered and retained in the soil increasing the value of the filtering service. This equates to an additional $1,429/ha/yr for the low input farm and $8,356/ha/yr for the high input farm (Table 8). The corresponding increase in losses of N as nitrous oxide is in part a function of the increased amount of nitrate-N retained through filtering and in part a function of the reduced macroporosity creating an environment for higher denitrification rates.

A decline in macroporosity of 2% had a dramatic effect on the risk of P losses from the high input farm, with the risk of P losses increasing nearly two-fold (Table 7). The decline in the value of P filtering service amounted to a decrease of $925/ha/yr in the high input farm (Table 8). A decline in macroporosity of 2% also had a dramatic effect on the amount of runoff produced. Runoff increased by 70 mm (or 700 m^3/ha/yr), a 93% increase on the low input farm and 330% increase on the high input farm (Table 7). Increases of these magnitudes would have a significant impact at the catchment scale, because the cumulative effect of increasing quantities of peak run-off was scaled up from the paddock to farm and beyond. At farm scale the value of the service decreased by $82/ha/yr for both farms. The relative difference between measure and value (the measure is great, but not reflected in the value) shows that great caution is needed when dealing with the economic values of ecosystems services.

In summary a loss of macroporosity of 2% decreased the economic value of all soil services, apart from the filtering of N and the regulation of pest populations. Because the N filtering represents 25% of the total value of the soil services for the low input farms and 63% for the high input farm, total value increased with a decrease in macroporosity. Because of the limited reliability of the mitigation function for amounts of N filtered greater than 20kg/ha this finding should be treated with caution. That said it does highlight the danger of limiting the analysis to a change in total value. This hides the loss of individual services with a change in macroporosity that maybe of more interest and importance (Table 8). Once again, these results should be treated with the greatest of caution and should be used as some guiding principles for future study. Converting the provision of each service into dollar values is more about creating the opportunity to examine how all services change with a change in the natural capital stocks, than placing a monetary value on the services.

Table 8: Value of the soil ecosystem services provided by the two farms surveyed before and after compaction with a resulting decrease in macroporosity of 2%.

Soil Services $/ha/yr	**Farm Type** Low input Before compaction	Low input After	High input Before compaction	High input After
Food quantity	2,631	2,343	3,546	3,128
Food quality	38.0	38.0	38.0	38.0
Support to infrastructures	9.0	17.0	9.0	17.0
Support to animals	151.6	146.5	249	241
Flood mitigation	1,615	1,533	1,679	1,596
Filtering of N	3,387	4,816	15,117	23,473
Filtering of P	2,234	2,193	1,192	267
Filter of contaminants	7,980	7,574	8,294	7,888
Decomposition of wastes	140.0	116.7	186.7	156
Net C flows	-76.3	-76.0	-76.3	-76.0
N_2O regulation	15.9	0.0	21.2	5.0
CH_4 regulation	0.4	0.4	0.4	0.4
Pest regulation	184	316	184	316
Total ($/ha/yr)	**18,310**	**19,017**	**30,440**	**37,048**
Net present value ($/ha) (3% discount rate)	**610,340**	**633,911**	**1,014,678**	**1,234,960**

4.6 Catchment scale methodology: Catchment case in Waikato

This section of the project explores the use of an ecosystem service approach at the catchment scale and investigates if the approach offered additional information and insights into the links between soil quality indicators and outcomes at the catchment scale to inform and assist decision making. The following section retraces the steps taken for the catchment case study and presents the methodology and findings.

4.6.1 Catchment scale study: Milestones time-scale

Milestone 2.2: Development of the catchment case

Jan 2011. Agreement was reached on the soil ecosystem services for inclusion in the framework to explore the links between soil quality indicators and outcomes beyond the farm at the Bi-annual Land Monitoring Forum meeting in Wellington in September 2010. Good progress has been made since that meeting in developing the framework for the case study catchment in the Hawke's Bay. An update will be provided to the bi-annual Land Monitoring Forum meeting in Wellington in February 2011.

Jun 2011 At the bi-annual Land Monitoring Forum meeting in Wellington in February 2011 a presentation on links between macroporosity and soil services that include provision of food, wood and fibre, provision of raw materials, provision of support for human infrastructures and animals, flood mitigation, filtering of nutrients and contaminants, carbon storage and greenhouse gases regulation, detoxification and the recycling of wastes, and regulation of pest and disease populations, was made to forum members to obtain more feedback on services of most interest and the preferred currency for reporting on each service (See feedback above from group).

Milestone 2.4 Working example at the catchment scale of the new reporting framework

Jan 2012: Agreement was reached on visits for 2012 to the Waikato Regional Council to gather data needed for the catchment case study testing the usability of an ecosystem services framework to link macroporosity to catchment outcomes at the bi-annual Land Monitoring Forum meeting in Wellington in September 2011. At the meeting, it was also decided that the catchment study will take place in the little Waipa catchment in Waikato instead of Hawke's Bay because of the merits of linking the farm and catchment scale models in the same landscape. Good progress has been made since that meeting in developing the framework for the case study on the little Waipa catchment. An update will be provided to the bi-annual Land Monitoring Forum meeting in Wellington in February 2012.

June 2012: Visits were made to the Waikato Regional Council to gather data needed for use of the framework to explore the links between soil quality indicators and outcomes at the catchment scale on 18 and 19th January 2012 and 8 and 9th March 2012.

At the bi-annual Land Monitoring Forum meeting in Wellington on 16 February 2012, a presentation on adaptation of the farm methodology to the catchment case study was made to forum members to obtain feedback on issues such as scaling up data and tools to use.

4.6.2 Catchment scale methodology:

The general methodology, including proxies, for extending the quantification and the economic valuation of soil services to the catchment scale are summarised in Table 9. These were discussed with the Land Monitoring Forum. As a first step, measures at the catchment scale were obtained by aggregating the farm scale proxies.

For each soil service, the information provided includes

- The proxies considered to measure the service,
- The parameters used at the catchment scale,
- The potential origin of the data,
- The quantification method for the catchment scale,
- The valuation method used at the catchment scale.

This is summarised in Table 9.

Table 9: General methodology for the quantification and valuation of soil ecosystem services at catchment scale.

Services	**Proxies to measure**	**Parameters used at the catchment scale**	**Origin of the data**	**Valuation method used at the catchment scale**
Provision of food quantity	Yield coming from natural capital stocks	Yield/ha or /block N fertiliser kg/ha/yr Native Olsen P by soil type	Overseer / farm plan Farm plan AgResearch database	Market prices of meat, crop, fruits, wood (or added value)
Provision of food quality	Trace element status	Trace element levels/block	Farmer / farm plan	Defensive expenditure: cost of application of trace elements to prevent deficiencies
Provision of physical support humans animals	Soil structure and sensitivity to damages	Bulk density/block, slope/block Field capacity, Saturation capacity, Soil water content number of wet days	Farm plan Farm plan / soil database	Replacement cost Provision cost
Flood mitigation	Part of rainfall stored	Rainfall and runoff	RF: farm plan RO: Overseer	Provision cost
Filtering of Nitrogen	Part of N inputs retained	Actual N leaching Potential max N leaching	Modelled Overseer Modelled Overseer	Defensive expenditure (aggregated mitigation costs)
Filtering of Phosphorus	Part of P inputs retained	Actual P runoff Potential max P runoff	Modelled Overseer Assumption	Defensive expenditure (aggregated mitigation costs)
Filtering of contaminants	Part of contaminants inputs retained	Actual E-coli or pesticides losses Potential max. E-coli or pesticides losses	Assumption from farmer/farm plan	Provision costs (costs of constructed wetland)
Detoxification and recycling of wastes	Conditions of wastes deposition	Soil water content slope grazing times	Assumption from farmer/farm plan	Provision costs (aggregated costs of construction and maintenance of an effluent pond)
Carbon flows Nitrous oxide regulation Methane regulation	Net C flows Amount of N_2O regulated Amount of CH_4 regulated	C flows SWC and Nitrous oxide emission SWC and methane oxidation	Modelled from soil database Modelled from farm plan / farmer Modelled from farm plan /farmer	Aggregated market prices of C Aggregated market prices of C Aggregated market prices of C
Biological control of pests and diseases	Conditions for pest development	Macroporosity Soil Water Content	Modelled from farm plan /farmer	Provision cost (aggregated costs of pesticides)

Data on land use distribution (Table 10) and more detailed information on the area and dominant soil order and soil type (Table 11) of the dairy farms in the Little Waipa catchment were provided by the Waikato Regional Council.

Table 10: Land use distribution of the Little Waipa catchment

Land Use	Area (ha)	% of total catchment area
Dairy	8255	68
Sheep &Beef intensive	2512	21
Arable	775	6
Planted forest	294	2.4
Urban	234	1.9
Sheep & Beef hill	99	0.8
Ungrazed pasture	21	0.2
Native bush	20	0.2
Total	**12210**	**100%**

From the data provided by the Regional Council, five typical dairy farm types were identified to provide a representative sample of dairy farms on the combination of soil type and Land Use Capability (LUC) Classes found in the catchment (Table 11). The five dairy farm types (Table 12) represented 90% of the dairy farms in the catchment. Dairy operations cover 60% of the total area of the catchment.

Table 11: Number and area of each dairy farm with the soil orders and types found in the Little Waipa catchment

Number of dairy farms	Area (ha)	% of total dairy area	Soil order	Soil type
233	5806	70	Pumice	Taupo
82	859	10.4	Allophanic	Tirau
54	757	9.2	Allophanic	Horotiu
58	713	8.6	Podzol	Ngaroma
13	69	0.8	Gley	Topehahae
5	43	0.5	Allophanic	Haupeehi
4	7	0.1	Recent	Esk
Total	**8255**	**100%**		

Each of the five dairy farm systems was modelled using the Overseer® Nutrient Budget version 5.4.11. Outputs were used to quantify the provision of soil ecosystem services from these farm operations. Some of the outputs from the Overseer® Nutrient Budget model are presented in Table 12.

Table 12: Characteristics and outputs from the five dairy farm types used to characterise dairy operations in the Little Waipa catchment.

	Farm Type				
	1a	**1b**	**2a**	**2b**	**3**
Soil Order[1]	Pumice	Pumice	Allophanic	Allophanic	Allophanic
Soil type[1]	Taupo	Taupo	Tirau	Tirau	Horotiu
LUC[1]	4	6	4	6	1-2
Stocking rate (cows/ha)[1]	3	2.5	3	2.5	3
Milk production (MS/ha/yr)[1]	950	900	950	900	950
Area (ha)[1]	2903	2903	430	430	757
Pasture growth (kgDM/ha/yr)[1]	16623	15482	16623	15982	16406
N leached (kgN/ha/yr)[1]	30	26	27	23	27
N max (kgN/ha/yr)[1]	35	31	31	27	32
P losses (kgP/ha/yr)[1]	2.4	3.2	0.7	0.9	0.4
P max (kgP/ha/yr)[2]	15	15	15	15	15
Runoff (mm/ha/yr)[1]	104	201	115	212	67

[1]Input to Overseer®; [2]Authors pers. comm.

The results for the quantification and valuation of ecosystem services from the five farm types considered in the Little Waipa catchment are listed in Table 13. The main differences between the two soil types, Pumice and the Allophanic soil were in the provision of food and the filtering of P. There was a difference of around 1 t DM/ha/yr in the pasture yield sustainable from natural capital stocks, and approximately 2.5 kgP/ha/yr filtered (Table 13).

Table 13: Measure and value of soil ecosystem services for the five farm types considered in the little Waipa catchment

	Farm Type									
	1a		**1b**		**2a**		**2b**		**3**	
	Quantity	Value ($/ha/yr)	Quantity	Value ($/ha/yr)	Quantity	Value ($/ha/yr)	Quantity	Value ($/ha/yr)	Quantity	Value ($/ha/yr)
Food quantity **(kgDM/ha/yr)**	9074	3630	8389	3356	10586	4234	10137	4055	10434	4174
Food quality **(trace element deficiencies)**	cobalt, selenium	32	cobalt, selenium	32	none	38	none	38	none	38
Support to infrastructures	medium	9	0	0	medium	9	0	0	high	17
Support to animals **(wet days between May and October)**	15	123	10	104	20	121	15	102	42	112
Flood mitigation **(mm/ha/yr)**	110	1287	99.9	1173	108.5	1274	98.8	1161	113	1331
Filtering of N **(kgN/ha/yr)**	5	196	5	196	4	186	4	186	5	203
Filtering of P **(kgP/ha/yr)**	12.6	1632	11.8	1408	14.3	2234	14.1	2153	14.6	2362
Filter of contaminants **(m^3 filtered/ha/yr)**	548	6361	499.5	5798	542.5	6297	494	5734	567	6576
Decomposition of wastes **(well decomposed effluent m^3/ha/yr)**	18.4	221	15.3	184	15.8	189	13.1	158	15.8	189
Net C flows **(Net change in total C on 0-10cm in tC/ha/yr)**	-800	-76	-1000	-95	-800	-76	-1000	-95	-800	-76
N_2O regulation **(kg N_2O/ha/yr)**	2.7	21	2.2	18	2.7	21	2.2	18	2.7	21
CH_4 regulation **(kg CH_4/ha/yr)**	0.93	1	0.93	1	0.80	0	0.80	0	0.87	0
Pests **(Favourable days over 6 months)**	18.2	316	18.2	316	63.7	184	63.7	184	63.7	184
Total	NA	13,753	NA	12,491	NA	14,713	NA	13,694	NA	15,130

NA: not applicable

The value of the ecosystem services provided by the soils under dairying in the Little Waipa catchment ranged from $12,491 to $15,130 /ha/yr. When the annual value of the provided ecosystem services, that is perpetuities, are converted to net present value it represents approximately half a million dollars /ha (using a 3% discount rate) (Table 14). The recommended discount rate when dealing with natural assets and ecosystem services is 3%, whereas 10% is the discount rate commonly used for built capital. Changing the discount rate from 3% to 10% reduces the net present value 3-folds (Table 14). We recommend caution in the use of these numbers, because the economic valuation of ecosystem services is still in its infancy and include a number of limitations as discussed earlier. As also indicated earlier, the use of "dollars" provides a common currency in which to compare all the services and also to compare services from different soils under the same or different managements.

Table 14: Total value of soil ecosystem services for the five farm types and impact of discount rate on present value.

Farm Type	Value of soil services ($/ha/yr)	Present value at 3% ($/ha)	Present value at 10% ($/ha)
1a	13,753	458,439	137,532
1b	12,491	416,368	124,910
2a	14,713	490,431	147,129
2b	13,694	456,464	136,939
3	15,130	504,344	151,303

4.7 Link macroporosity to farm and catchment outcomes

In order to link the impacts of compaction and decreased macroporosity at the farm level to outcomes at the catchment scale, the Overseer® Nutrient Budget, version 5.4.11, was ran for the five farm types simulating imperfect drainage. Figures 6 and 7 present the variation in N leaching and P loss outputs from Overseer®. Runoff simulation with Overseer® 5.4.11 wasn't sensitive to a change in drainage class so we simulated the impact of compaction on runoff using the trends observed at the farm scale using the SPASMO model presented in the previous section (Figure 8). It is worth noting that Overseer nutrient budget version 6.0 includes functionality that reflects more closely differences in drainage classes between soils and when there is a change in a soil property influencing drainage.

A decline in macroporosity of 2% resulted in a slightly lower N leaching loss from all five farm types (Table 15). However, P losses increased especially on Pumice soils. Runoff also increased for all five farm types (Table 15). These trends are in agreement with the literature (Betteridge et al., 2003) and in line with observation by land managers at the farm scale.

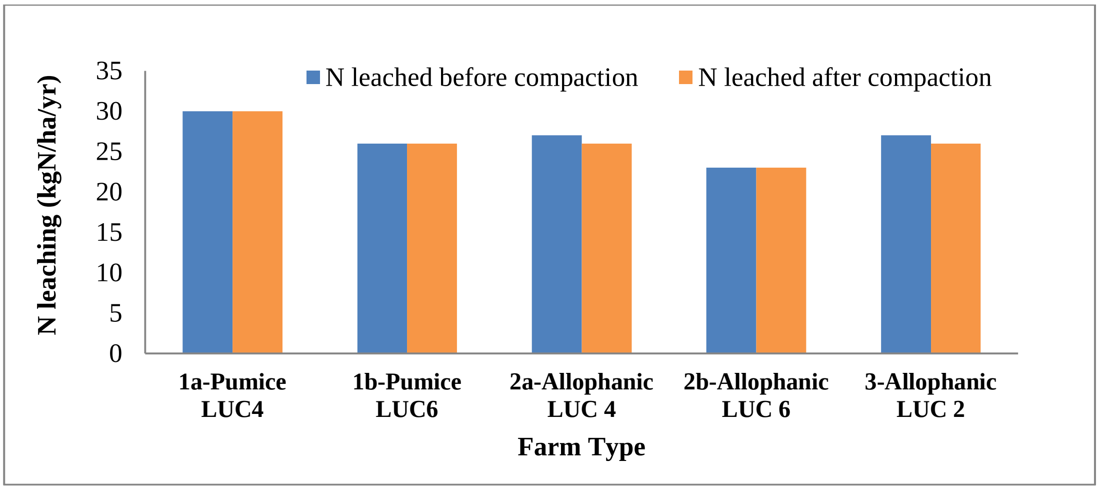

Figure 6: N leaching losses for the 5 dairy farm types in the Little Waipa catchment before and after compaction, calculated using Overseer® 5.4.11.

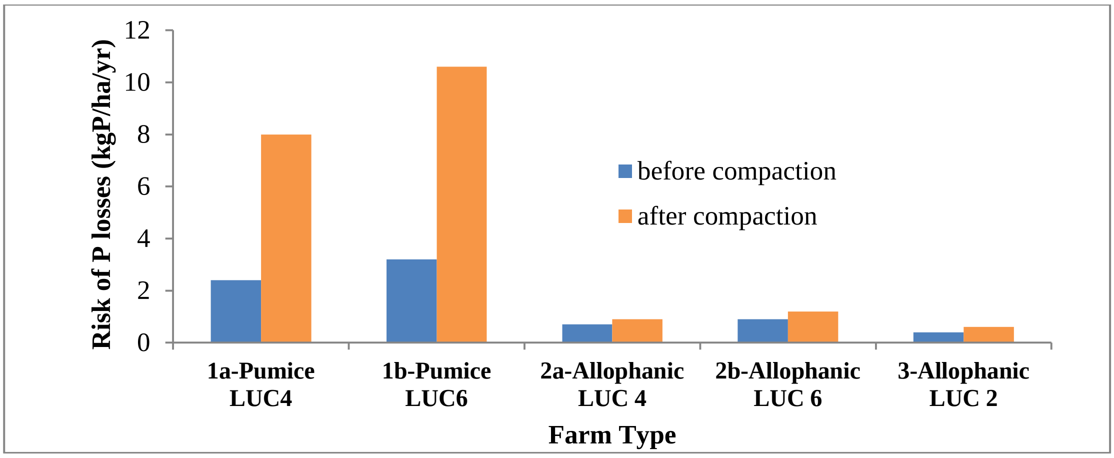

Figure 7: Risk of P losses for the 5 dairy farm types in the Little Waipa catchment before and after compaction, calculated using Overseer® 5.4.11.

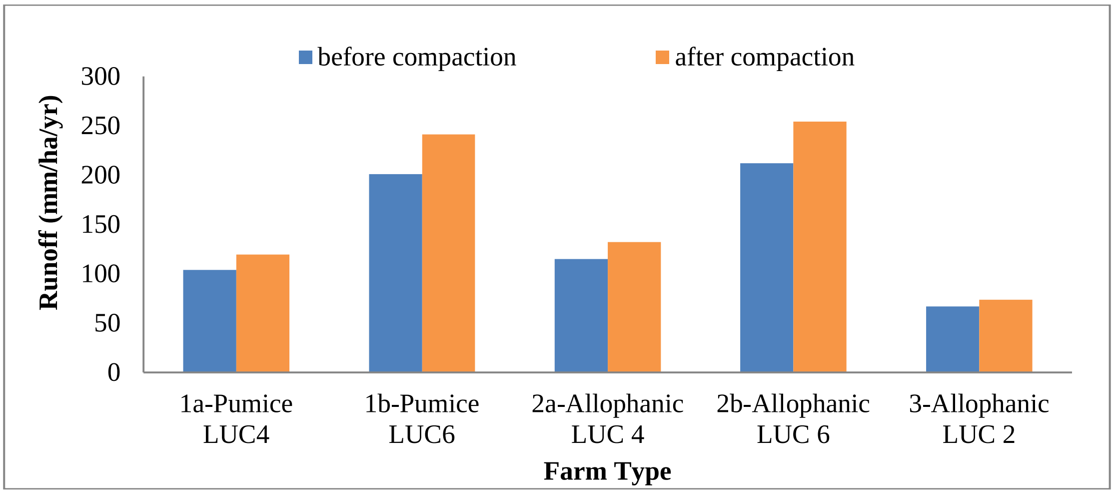

Figure 8: Runoff for the 5 dairy farm types in the Little Waipa catchment before and after compaction, calculated using the SPASMO model.

The impact of compaction at the farm scale on five dairy farm systems is summarised in Table 15. While there was little change in N leaching losses with a change in macroporosity, there was more than a doubling in the risk of P losses and runoff increased by almost 20% (Table 15). Indicative information from the Waikato Regional Council (Bill Vant, pers. comm. 2012) based on monitoring results and various assumptions, indicates that the Little Waipa stream currently transports approximately 70 tonnes N/yr and 4 tonnes P/yr. This translates into a loss per hectare assuming no attenuation of 5.7 kg N/ha/yr and 0.33 kg P/ha/yr. Assuming an N attenuation factor of 0.5 (Clothier et al., 2007) this translates into a root zone N leaching loss of 11.4 kgN/ha/yr, which is very conservative compared to N leaching calculated with Overseer® 5.4.11 (Table 12).

Compaction of all soils on all dairy farms in the catchment would result, in the absence of any attenuation, in an additional 38 tonnes of P into the Little Waipa catchment (Table 15). Such load represents almost 9 times increase on the current load and has the potential to seriously degrade water quality by providing a nutrient source for periphyton growth and eutrophication. In a more realistic scenario, if 5% of the soils under dairying in the catchment were compacted the increase would be, again assuming no attenuation, an additional 1.9 tonnes of P. This still represents nearly a 50% increase on the current loading of 4 tonnes P, highlighting how sensitive the catchment outcomes are to small changes in the physical condition of the soil and the soil services that this soil attribute influences.

A 20% increase in runoff due to compaction (Table 15), which translates into an increase in the volume of water leaving each hectare of 70 to 420m^3/yr depending on farm type, would add additional pressure on the drainage and flood network in the catchment from small streams and their associated crossings (i.e. bridges and coverts) through to structures in the main channel.

Table 15: Aggregation of N leaching, risk of P losses and runoff for the Little Waipa catchment, as a consequence of soil compaction on the five dairy farm types

Farm Type	Extra N loss kgN/ha	Extra N loss for catchment kgN	Extra P loss/ha kgP/ha	Extra P loss for catchment kgP	Extra runoff mm/ha	Extra runoff for catchment mm
1a	0	0	5.6	16,258	16	45,289
1b	0	0	7.4	21,483	40	116,706
2a	-1	-430	0.2	86	17	7,408
2b	0	0	0.3	129	42	18,210
3	-1	-757	0.2	151	7	5,074
Aggregate		-1187		38,107		192,690
Catchment change		-0.6%		+221%		+18%

By linking the changes in macroporosity to farm and catchment specific outcomes through the ecosystem service framework, the optimum range, thresholds, and tipping points can be derived for farm and catchment scales to achieve the outcomes sought by the land owner and also by the community for that catchment. By establishing the links between this soil quality indicator and farm and catchment outcomes, the value of the soil quality data used for State of Environment reporting takes on added value by also providing an insight into the state of the natural capital stocks in the catchment. This approach provides the beginnings of a framework for assessing the effectiveness of other elements of regional policy that are often reported more by activity rather than by outcome.

The loss of value of ecosystem services from soils of the five dairy farm types due to compaction varied from -$1,532 to -$2,629/ha/yr (Table 16). Using a 3% discount rate, this translates into a net present value loss of approximately $460 million in soil services under dairying in the catchment (Table 16). Dairying occupies 60% of the land area within the Little Waipa catchment.

Table 16: Value of soil ecosystem services (SES) before and after compaction and associated loss of net present value (NPV).

Farm Type	Area (ha)	Value of SES before compaction ($/ha/yr)	Value of SES after compaction ($/ha/yr)	Value of SES lost ($/ha/yr)	Loss of NPV[1] ($/ha)	Loss of NPV[1] for all catchment ($)
1a	2903	13,753	12,221	- 1,532	- 51,059	- 148,231,280
1b	2903	12,491	10,615	- 1,876	- 62,534	- 181,546,950
2a	430	14,713	12,422	- 2,291	- 76,376	- 32,803,667
2b	430	13,694	11,065	- 2,629	- 87,633	- 37,638,455
3	757	15,130	12,883	- 2,247	- 74,894	- 56,725,085
Total						- 456,945,437

[1] Net present value was calculated using a 3% discount rate.

The sum of the changes in the value of each of the ecosystem services that are listed in Table 16 provides an indication of the change in the "state" or "quantity" of the natural capital stocks on-farm and aggregated in the catchment under current land uses and practices. Tracking how the "quantity" of the natural capital stocks is changing over time provides the basis for determining if the land resources in the catchment are being degraded, managed or improved. It provides for the first time a methodology to assess if the natural resources in the catchment are being managed in a way that enables people and communities to provide for their social, economic, and cultural wellbeing and for their health and safety, while (a) sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and (b) safeguarding the life-supporting capacity of air, water, soil and ecosystems; and (c) avoiding, remedying or mitigating any adverse effects on the environment as recommended by the Resource Management Act. Again we recommend caution in the use of these numbers, because the economic valuation of ecosystem services is still in its infancy and include a number of limitations as discussed earlier. As also indicated earlier, the use of "dollars" provides a common currency in which to compare all the services and also to compare services from different soils under the same or different managements. This study provides some guiding principles for future research.

5. Key Findings and Lessons

5.1 Soil quality indicators

Several new indicators were discussed including Hot Water Carbon (HWC), characterisation of microbial communities, δN^{15}, active carbon as measured by the permanganate test, soil respiration rate, earthworm diversity and abundance, tree biodiversity, wood decay invertebrates and mycorhiza. Of these, HWC and earthworm diversity and abundance appear closest to being introduced as soil quality indicators in the future.

There was considerable doubt about the use of Anaerobic Mineralisable Nitrogen (AMN), in isolation, as an indicator of N-leaching potential and additional analyses are needed for correct interpretation. A name change to “Soil Microbial Health” was suggested to remove potential misunderstanding around N-leaching. The participants recommended the AMN lower targets stay the same but remove upper target, as it is not a good indicator of environmental risk.

Similar to AMN, there was doubt about the use of total N, in isolation, as an indicator of N loss and it may be better to examine options for linking the indicators to a model such as Overseer® to assess N-leaching and N_2O emission risks. However, this adaption would require research funding to fill knowledge gaps. Participants felt that consideration of the C:N ratio was important in interpreting both total N and AMN results.

Discussion on total C centred on balancing environmental and production benefits. The environmental economics of soil is a current research project and will help understanding of the environmental benefits. There was support for changing the upper Olsen P target becuase it should not be higher than required for production. Suggested target ranges are presented in the body of this report.

Six specific recommendations were submitted to the Land Monitoring Forum Special Interest Group for consideration:

- Changing the name for anaerobically mineralised N to “Soil Microbial Health” (measured by AMN) to remove potential misunderstanding around N-leaching,
- Removing the upper targets for AMN as it is not a good indicator of environmental risk,
- Whether to express aggregate stability as the average aggregate size distribution in addition to the mean diameter to provide a better assessment of erosion risk,
- Whether to include water content at wilting point to give, along with macroporosity, a measure of water storage services,
- Should the upper Olsen P targets be reduced to the target ranges currently used by the fertiliser and agriculture industries,
- The Land Monitoring Forum should support research by actively seeking funding and/or directly funding by council to:
    - Investigate linking the N indicators (AMN and Total N) to a model such as Overseer® to assess N-leaching and N_2O emission risks,

- Assess the balance of environmental benefit versus productivity and suitable upper targets for total C,
- Investigate aggregate stability targets on different soil types and land uses,
- Investigate what are appropriate macroporosity targets for Podzols,
- Investigate earthworm diversity and abundance and hot water carbon as future soil quality indicators.

Finally the Land Monitoring Forum concluded that now that the core set of soil quality indicators are confirmed it is timely to develop a further group of environmental indicators for measuring specific soil issues, in conjunction with ecosystem services for inclusion in the toolbox of indicators of environmental issues.

5.2 Linking soil quality and farm and catchment scale outcomes using an ecosystem service approach

Natural capital stocks, reported using soil quality indicators, are important for so monitoring the state and change of soils. However, flows from these stocks are as important, if more, and also need to be monitored closely. Any monitoring scheme will always be more powerful if both stocks and flows are determined and used to cross check each other in the assessment of change (Robinson et al, 2012).

The application of an ecosystem service approach provides additional utility to the current soil quality indicator programme by linking the indicators (a measure of stocks) to the flows that matter and outcomes at the farm and catchment scale (e.g. run-off, P loss, N leaching, water quality and quantity, etc). Quantification of the natural capital stocks in the catchment is information that could be used to provide a commentary on the current condition of the natural resource base. Further the quantification and economic valuation of soil ecosystem services indicates the “quantity” and/or “state” of the flows from natural capital stocks on-farm or in the catchment under current land uses and practices.

By establishing a link between the soil quality indicators, which in this study was limited to macroporosity (a proxy for the physical attributes of soils natural capital stocks and also a measure of the “state” of the physical condition of the soil), and outcomes at the farm (e.g. run-off, P loss and N leaching and the implications of this to farm performance) and catchment (e.g. Flood peaks, P and N loadings) scales a function can be derived including thresholds or tipping points that describes the relationship between the indicator and environment outcomes. In parallel, the implications of a change in the indicator to economic returns can also be calculated, along with the implications to the “state” and management of the soil natural capital stocks on-farm and in the catchment.

The authors recommend caution because of limitations in data sets and the ability of process models to describe and quantify key processes in agro-ecosystems. This was highlighted throughout discussions with the Land Monitoring Forum and documented in the text For example, the link between macroporosity and ecosystem services needs further investigation and validation, under field conditions as our understanding of the relationship between macroporosity and the soils services of interest is still incomplete. We also recommend caution in the use of the economic valuation of ecosystem services. As indicated in the text, converting each service into dollar values was more about creating the opportunity to examine how services change with a change in the natural capital stocks, than placing a monetary value on the services. The use of “dollars” provides a common currency in which to compare services and compare services from different soils under the same and different managements. The catchment study was also limited to investigating the influence of a change in soil quality indicators under a dairy land use. This analysis could be extended to include the other land uses in the catchment including sheep and beef and forestry. Accepting these precautionary words this study demonstrates the enormous potential this approach has in resource management.

Tracking how the level of provision of ecosystem services is changing over time provides the basis for assessing if the resources in the catchment, e.g. the natural capital stocks, are being managed in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural wellbeing and for their health and safety while (a) sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and (b) safeguarding the life-supporting capacity of air, water, soil and ecosystems; and (c) avoiding, remedying or mitigating any adverse effects on the environment, as recommended by the Resource Management Act. Beyond compliance to the RMA, linking soil quality indicators to the provision of ecosystem services from agro-ecosystems also informs the sustainability of New Zealand agricultural systems.

In addition to developing farm and catchment scale case studies to demonstrate the potential utility of an ecosystem service approach to adding value to soil quality indicators and to future resource management, the project has been the start of an on-going learning process between science, policy and operational land management practices on the potential application of the approach. Over the course of this study, four presentations and discussions were held with the Land Monitoring Forum to first assist in developing the frameworks and then in scoping the farm and catchment case studies. The project has resulted in a number of initiatives to continue the progress made in the utility of an ecosystem service approach in the present study between the Crown Research Institutes and Regional Councils. Examples of these initiatives include:

The Land Monitoring Forum was part of a funding proposal involving the Soil and Land Use Alliance, a partnership between AgResearch, Landcare Research, Scion and Plant and Food Research, submitted to the Ministry of Science and Innovation in the 2012 funding round. The smart idea proposed as part of the proposal was the development of a single integrated agro-ecosystem services framework that would provide a much needed platform to consistently allow rigorous evaluation of green growth investments in this country. This smart idea linked, for the first time, what have been disparate frameworks and their associated methods for valuing ecosystem services provided by NZ agro-ecosystems. The project aimed at identifying the most effective investments in natural capital, and associated built capital, that would lead to increased provision of ecosystem services from agro-ecosystems, and thus true green growth. The projects aimed at growing the skills and knowledge of the key institutions making day-to-day decisions around land and resource management, policy, planning and investment. Key institutions would be involved directly through 'live cases' in the development and implementation of the integrated framework. The live cases included exploring

- The use of natural capital approach in nutrient limiting setting for land as a mechanism in policy for delivery of water quality outcomes. The National Policy Statement for Freshwater Management directs Regional Councils to set water quality limits for freshwater objectives, and where these objectives are not met, time-bound targets for water quality are to be specified and policy and plans implemented to ensure these are met in the future. Policy development to achieve these requirements will require extending current controls around point source discharges, which represent only a very small percentage of total discharges to diffuse losses from agricultural land. In order to understand the full impact of a policy, they need to understand the value of ecosystem services and how these are impacted by current and future land use so that information can be used to see the full cost of development and to bring it into their community deliberations.
- Land policy approaches to assist in balancing the protection of the ecosystem services provided by elite and versatile soils with the need for peri-urban development, by providing much sharper detail as to what the value of ecosystem services are so that planners, policy agents and even Commissioners and Judges can ensure that "versatility and productivity must be assessed in a holistic manner together with environmental factors
- Informing future land management policy and infrastructure investments in eroding hill land,
- Further advancing the utility of an ecosystem service approach to link soil quality indicators to Regional land and water policy objectives.
- Explore the flow of ecosystem services from kiwifruit orchards and examine the eco-efficiency of sheep and beef producers, against other uses of our natural resources.

While the project was not successful in obtaining funding another research proposal has since been developed that draws on the findings of this work. The MBIE proposal "Smarter natural resource management: impacts and dependencies on ecosystem services and biodiversity", if successful will help land managers make better informed, "smarter" natural resource management decisions that preserve options for future resource use and enhance the value derived from NZ's landscapes. We will develop new approaches, including cultural, to link biodiversity to the ecosystem services that underpin human well-being, and provide evidence of how human activities impact on biodiversity and modify ecosystem services. Impacts and trade-offs from competing demands for environmental, economic, social, and cultural outcomes from our natural resources will be identified.

On another front AgResearch and Hawke's Bay Regional Council are currently exploring the use of an ecosystem service approach to estimate the loss of soil services from the land affected in the April 2011 storm event that caused a significant amount of soil erosion along a coast belt in the region.

The study aims to:

- quantify and value the provision of ecosystem services from soils for a model East Coast hill land sheep and beef operation using the Dominati et al., (2010) framework.
- quantify and value the loss in ecosystem services from the land affected by landslides within the 10 km wide, 250 km long coastal belt from Mahia to Porangahau in the Hawke's Bay hill country in April 2011 from the data supplied to Hawke's Bay Regional Council by GNS Science, using Dominati et al. (2010) framework.
- characterise the recovery profile of soils ecosystem services in the 50 years following a landslide event.
- assess the provision of ecosystem services from a soil under a pasture/wide spaced poplars system.
- assess the cost-efficiency (benefit-cost analysis) of an ecological infrastructure investment in soil conservation on hill pasture land at risk from soil erosion using an ecosystems service approach.

Finally the Parliamentary Commissioner for the Environment contracted the Soil and Land Use Alliance to undertake a scoping study on the future reporting on soils as part of National State of the Environment (SoE) reporting. The scoping study includes a brief summary on the current approach to soil reporting in New Zealand, the purpose of monitoring, international frameworks, priorities and issues around soils, options for future reporting, a proposed new framework using ecosystem services for reporting in New Zealand, and the next step. A key resource in that scoping study was the learning from this study with the Land Monitoring Forum.

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7. Appendix

7.1 Envirolink Tools Project Details: Soil quality indicators. The next generation

Tool Project Details:		
Brief Tools Project Title:	Soil quality indicators: The next generation	
Project Duration:	24 Months	Grant Type: Terrestrial
Funds Requested:	$ 208,000 (inc GST)	
Total Project Cost:	$ 280,000 (inc GST)	$ 72,800 in-kind From Regional Councils

Research Organisation Details:		**Project Leader/Contact Person:**	
Organisation:	AgResearch	Full Name:	Dr Alec Mackay
Physical Address:	Tennent Drive Fitzherbert West	Position Held:	Principal Scientist
	Palmerston North	Work Phone Number:	06 351 8009
Postal Address:	Private Bag 11008	Mobile Phone Number:	
	Palmerston North	Fax Number:	06 351 8009
Website Address:	www.agresearch.co.nz	Email Address:	alec.mackay@agresearch.co.nz
		Postal Address:	AgResearch Grasslands Private Bag 11008 Palmerston North

I have the authority to commit the organisation to this project, and I confirm that all information provided is both accurate and current. Contractors nominated in this proposal have agreed to the scope of work required from them and the amount they will be paid to undertake it.

Signature: ____________________________ Position: ______________________________

Name: ____________________________ Date: ______________________________

Please attach electronic signature before emailing to Business Manager. Or sign and mail it to the Foundation.

Section 2.0 Project Overview

The project overview should be no more than 2 pages in length. It is the opportunity for you to give an overview of the proposed tool, who will use it and its potential benefit.

Give an overall description of
The tool to be developed
The project Soil Quality indicators: Next Generation tackles the recommendations made in a recent review (Taylor 2009) of indicator target-ranges for soil-quality monitoring which identified the need for:

- An upgrade of target ranges for current indicators to address gaps,
- expansion of the current indicator list (e.g. heavy metals, hydrophobicity, biological function) to provide a more complete picture of the state of the land resources,
- development of a linking framework between soil quality indicators and ecosystem services to assess resource outcomes, and
- quantification and valuation of the soil's ecosystem services other than just those contributing to provisioning (i.e. production), namely .the supporting, regulating and cultural services provided by soil

The latter two will be addressed by investigation of the inclusion of the soil quality indicators within a framework developed recently (Estelle et al., 2009) to value the soil's ecosystem services.

An outline of the environmental problem requires the tool
Currently, regional council state-of-environment monitoring and reporting for soils quality follows nationally agreed monitoring protocols, including target ranges for soil quality indicators (Hill and Sparling, 2009). The current target ranges are based on those published in *Provisional targets for soil quality indicators in New Zealand* (Sparling et al., 2003). In a recent discussion-document on soil quality indicators and target ranges for soil quality monitoring, Taylor (2009) makes a number of recommendations. These included calling for an upgrade of target ranges for current indicators to address gaps, plus an expansion of the current list of indicators (e.g. heavy metals, biological diversity) to provide a more complete picture of the state of the land resources. These two issues can be addressed easily and would bring immediate benefits.
Taylor (2009) also recommended the inclusion of additional factors to increase the utility (i.e. link to outcomes) of the soil quality indicators, as well as the quantification of the ecosystem services other than provisioning. The current lack of both currently represents major weaknesses in soil quality indicators. There is a general consensus that the use of single-factor soil quality indicators to represent soil services has serious limitations. Each soil

service is the product of multiple properties and processes. The SLURI team were contracted by MfE in 2008 to provide a discussion paper on the use of ecosystem services as a basis for making resource management decisions. The proposed tool will extend and apply this approach to soil quality indicators. Further each indicator (e.g. macroporosity) is linked to a number of provisioning and regulating services that cannot, as yet, be valued directly. It is difficult to develop a single-factor response curve as how changes in, for example, the soil's macroporosity will impact on pasture growth, pasture utilisation, surface run-off volumes, sediment discharge loadings and nutrient losses. Until the single-factor indicators are linked to outcomes at the paddock, farm and catchment scale, their value to land managers and policy agents will continue to be very limited. Therefore, a rethink is required of the current framework that is used for the analysis of the soil quality indicators and state of the environment reporting. Only by establishing the next generation framework will the utility of the current information be fully realised.

Any past research on which the tool is based

This research builds on state-of-the-environment indicators published in *Provisional targets for soil quality indicators in New Zealand* (Sparling et al., 2003), updated by (Beare et al. 2007), plus a recent report by Taylor (2009) on indicator target-ranges for soil quality monitoring. The project will also draw on the paper by Mackay et al., (2009) examining the critical range for Olsen P in high producing systems and Schon et al., (2010) on a draft invertebrate index for pastoral soils. The innovative aspect is that we will now couple this with a new framework for classifying and quantifying the soil's natural capital value and its ecosystems services at the farm (Dominati et al., 2009) and broader scales (Hewitt et al., 2010).

Immediate and future benefits that will result from the use of the tool

Regional Councils are required by the Resource Management Act 1994 to report on soil quality within their region and appraise whether land uses and land-use changes decisions are sustainable. Since 1995 soil quality monitoring has been undertaken by Regional Councils around New Zealand. During this period provisional target ranges were developed to provide guidelines for sound soil management (Sparling et al., 2003). The resulting target ranges are limited to production and environmental response curves and outcomes at the paddock scale. Taylor (2009) highlights the limitations of these target ranges especially the ranges defined by the environmental component. Their utility in informing decisions is limited to the site of measurement. The target ranges were based on the best available data at the time and in the absence of sufficient data, expert knowledge. This was especially so for the environmental response curves.

Any target stakeholder groups that will be directly involved/affected by the tool

The proposed tool will allow land managers to provide advice about soil management based on meaningful target ranges for soil quality that are linked through ecosystem services to the desired outcomes at farm, catchment and regional scales. Regional and national policy makers will then have a tool that can assist in developing policy instruments that incorporate production and environmental components and can assess the value and impact of different tradeoffs.

Council commitment to the tools implementation

The tool advances the utility of information being collected through regional soil-quality monitoring programmes currently implemented by about eight Regional Councils. It will provide a link between the indicator values and outcomes at the paddock, farm, catchment and regional scale. The Land

Monitoring Forum fully supports this proposal and will be part of a wider group involved in scoping and implementing the project. The two regional council champions are provisionally Reece Hill and Matthew Taylor (Environment Waikato).[1]

References

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Taylor M. 2009. Discussion paper on indicators target ranges for soil quality monitoring. Internal report: Environment Waikato. 30.pp.

Section 3.0 Assessment criteria

The Foundation’s generic assessment criteria will be applied. The requirements under each have been adjusted to fit Envirolink. The first two criteria consider potential benefits; the other two consider investment risk. The first and last criteria are given more weight in the Envirolink assessment process; the % weighting is shown in brackets. For further directions in addressing the four criteria, please see the RFP, available online.

Section 3.1 Environmental benefits to New Zealand (30%)

The tool being proposed should help enhance environmental management by one or more regional councils, or it should aid councils to help others carry out environmental management more effectively. Please address the following:

[1] Matthew Taylor (Environment Waikato) replaces John Phillips (HBRC) who has recently moved to MfE

3.1.1Why and for whom is this project a priority?

If the tool is developed or adapted successfully, what are the nature, scope and scale of the environmental benefit to Regional Councils and New Zealand? How will that benefit arise? How big or extensive will the benefit be? (For example. a newly adapted tool might affect decision making for all new urban coastal developments, or it might help councils x and y allocate groundwater resources for over 70% of the South Island's lowland plains, or within 2 years it will remove the need to spend $z dollars per year on air quality monitoring in small towns.)

The soil quality indicators tool assists Regional Councils in managing the soil resource within each Region by providing base data on soil health and assessments of change under different land management practices. Critical to the effectiveness of such a tool is setting relevant, validated thresholds or target ranges for the individual soil quality indicators. Provisional target ranges were set in 2003 and revision of these was intended as further information became available. However, apart from restricted internal reviews of some of the target ranges, no overall review has been carried out. Review of the target ranges for soil quality monitoring shows the provisional targets should be updated. Importantly there are two types of target ranges used in soil quality monitoring, production targets for the efficient production of produce and environmental targets for environmental protection. There is little data on environmental targets and application of production target ranges to non-productive land uses could be misleading. However, application of environmental targets to all land uses is constructive. It is recommended that target ranges should reflect 90% optimum productivity and environmental protection.

1.1 When might the benefits come about, and will the benefits be durable?

The benefits of the project will be realised in the first 12 months as the project builds on the state-of-the-environment indicators published in *Provisional targets for soil quality indicators in New Zealand* (Sparling et al., 2003) used routinely by Councils for monitoring soil quality. This tool project will draw and incorporate the findings of a number of recent studies including the update of Beare et al., (2007) who examined the current target ranges of 4 of the 7 soil quality indicators currently being used, Mackay et al., (2009) examined the critical range for Olsen P in high producing systems, and Taylor (2009) reported on indicator target-ranges for soil quality monitoring, plus Schon et al., (2010) on a draft invertebrate index for pastoral soils. Recent recommended changes to methodologies (e.g. soil depth for soil carbon) will also be added to the protocols. These will be picked up and used immediately. Extending state of the environment reporting beyond current analysis to examine the influence they have on outcomes at the paddock, farm and catchment scale will take longer, requiring significant changes to current reporting protocols. We see this project as part of the ongoing development and evolution of State of the Environment reporting.

1.2 Explain how the tool will stimulate a positive change in how one or more regional councils operate?

The tool project will have four major impacts. The upgrade of target ranges for current indicators to address gaps and provide greater consistency in future reporting. 1) The updated indicator target ranges will be more robust and provide clearer direction to land managers for soil management., 2) The inclusion of additional soil quality indicators (e.g. heavy metals, hydrophobicity, biological function) plus some refinements to current methodology (depth of sampling for soil carbon) will provide a more complete picture of the state of the land resources. 3) The framework for linking the soil indicators to outcomes at the paddock, farm and catchment scale, will result in a total rethink in way we interpret our soil quality indicators and report in the future on the state of the environment. By using and ecosystem services approach it will allow a link to be made between land management and land-use decisions and outcomes at a range of scales. 4) The tool will increase the opportunity for regional policy objectives around land and soil and water quality and quantity to be achieved, especially where objectives encompass the concept of ecosystems services. The framework is the first step towards linking soil and land management with water.

Section 5.2 Science and Technology benefits (20%)

This criterion is primarily about building science-related capacity in Regional Councils. A strong proposal will have this additional type of benefit. We want to see increased abilities to use environmental research-based tools and to engage (individually and collectively) with the science system in the use and strategic planning of research. This capacity might be boosted by commitment of staff to implement the new tool, training initiatives, secondments, and the setting up of networking mechanisms. Please describe:

5.21 How the Regional Councils have been involved in the definition of the tool to be developed and any ongoing contribution during the development of the tool.

As regional council champions, **Environment Waikato** and **Hawke's Bay Regional Council** together with the **Land Monitoring Forum,** have been instrumental in co-development of the proposal. The first part of the proposal builds on the recommendations in the discussion paper on indicators target ranges for soil quality monitoring prepared by Taylor (2009) of Environment Waikato. Regional Council champions and Land Monitoring Forum will contribute staff time as necessary to complete and implement the project. A meeting is planned when funding has been confirmed with the Land Monitoring Forum to finalise the project plan.

5.22 How the use of the tool will extend Regional Council's capacity to incorporate research based tools.

Increasing the regional councils' capacity to incorporate research based tools is a fundamental component of the proposal. Councils are increasingly using approaches that incorporate socio-economic and environmental components into regional policy. This approach allows values and decision making to consider factors wider than just production. For example, soils provide services beyond production, including regulating, filtering and storing nutrients, water and gases, supporting habitats and biodiversity and providing a platform for construction (DEFRA, 2008, Dominati et al., 2009). Inherent to these ecosystems services are the soil properties and the state of these soil properties (termed soil quality). Changes in soil properties change the ability of the soil to provide these services. It also ensures councils are using a common monitoring protocol and interpretation is consistent on a national-scale.

5.23 Any initiatives between councils or with the researchers to facilitate tool uptake and training.

The Land Monitoring Forum will be the primary avenue for providing extension capability. Initially, key council staff will be trained through the National Land Monitoring Forum. Land Monitoring Forum can organise training of participating land owners' and other council staff through individual or combined council workshops or other means as required.

5.24 Any initiatives that are built into the project to boost science-related capacity in regional councils

The upgrade of target ranges for current indicators, expansion of the current indicator list (e.g. heavy metals, biological function) to provide a more complete picture of the state of the land resources, development of the linking framework between soil quality indicators and ecosystem service defined resource outcomes and quantification and valuation of the soil's ecosystem services other than just those contributing to provisioning (i.e. production) will boost science related capacity within Councils. The ongoing council commitment to soil quality research at a national scale ensures continued updating and refinement to the framework. The interaction with project researchers during development will build the capacity of council staff to interpret and make effective use of soil quality indicators in their operations. Members of the LAND MONITORING FORUM will be able to demonstrate and promote the use of the tool to landowners and industry representatives at appropriate workshops.

5.25 The nature and scale of change that might occur as a result of the tool development project (in the context of science and technology benefits and capacity).

The project has the potential to fundamentally change the current approach to reporting on the state of the environment reporting. It lays the foundation for quantifying the soil's natural capital value and its ecosystem services. This has implications for enabling the link between a change in a soil quality indicator with outcomes at the farm and catchment scales. It offers a nationally consistent approach and has the potential to provide Councils with an insight into the link between land practices and catchment outcomes. Quality soil indicator data will enable effective use of sophisticated model-based sustainable-management tools.

Section 5.3 Ability to deliver (20%)

This criterion involves an assessment of the individuals and team developing the tool. We want to be confident an appropriate team has been identified. Do the investigators have access to all the necessary skills and research expertise? Ideally, the team being put forward will also be the best and most appropriate team, but this is not a requirement. (Cost or logistical problems might preclude this). Please demonstrate that:

5.26 The team has a relevant research track record in the field,

Key Personnel:
SLURI team including Dr. Alec Mackay Principal Scientist and Research Leader in SLURI. plus Dr Andrew Manderson Geospatial Analyst AgResearch, Dr Allan Hewitt, Soil Scientist, Landcare Research and Research Leader in SLURI and Dr Brent Clothier Science Group Leader Plant and Food Research , Programme Leader of SLURI

Regional Council:
Dr Reece Hill: Over 10 years post graduate experience as a Soil Scientist. Currently, Scientist and Project Manager for Land and Soil, Resource Information Group at Environment Waikato
Mr Matthew Taylor, Scientist in the Resource Information Group at Environment Waikato, previously research scientist in Landcare Research.
Members of the Land Monitoring Forum; broad range of expertise and experience in land management and monitoring.

5.27 The team has access to all the necessary skills and resources to complete the project,

The key personnel in the project team are drawn from SLURI which brings capability from three CRI to the project team. Research in all three objectives in SLURI will contribute directly to this tools project. The team members and through collaborations have the necessary skills in soils science, soil quality indicators, geospatial manipulation, emerging capabilities in ecosystems service quantification and valuation and long standing experience in project management. The team's long standing working relationship with regional council staff ensures effective interaction and uptake of the information.

5.28 The proposed tool development/adaptation is based on previous research.

This research builds on state-of-the-environment indicators published in *Provisional targets for soil quality indicators in New Zealand* (Sparling et al., 2003), updated by (Beare et al. 2007), plus a recent report by Taylor (2009) on indicator target-ranges for soil quality monitoring. The innovative aspect is that we will now couple this with a new framework for classifying and quantifying the soil's natural capital value and its ecosystems services (Dominati et al., 2009).

5.29 The proposed tool development/adaptation is feasible and realistic within the proposed funding level,

We are confident we can complete an upgrade of target ranges for current indicators to address gaps and expansion on the current indicator list (e.g. heavy metals, hydrophobicity, fauna biological function) to provide a more complete picture of the state of the land resources, within budget, as this builds on a well established platform of work that goes back to the research that lead to the state-of-the-environment indicators published in *Provisional targets for soil quality indicators in New Zealand* (Sparling et al., 2003), updated by (Beare et al. 2007), plus a recent report by Taylor (2009) on indicator target-ranges for soil quality monitoring. Development of the linking framework between soil quality indicators and defined resource outcomes using an ecosystem services approach, plus quantification and valuation of the soil's ecosystem services other than just those contributing to provisioning (i.e. production) offers a greater challenge and so some uncertainties. Development will be dependent on the progress made in advancing the framework we developed recently to values the soil's ecosystem services at the farm (Dominati et al., 2009) and boarder scale (Hewitt et al., 2010) within the work programme of SLURI. Case studies will be used to develop the framework.

5.30 The team has the freedom to operate, e.g. where an overseas patented tool is being adapted to local conditions,

The project team has complete freedom to operate.

5.31 The team is well aware of recent national and international developments in the field, to ensure they are not "re-inventing the wheel".

The National Land monitoring Forum, in conjunction with MfE and national research providers have provided leadership in land monitoring protocol for soil quality and soil stability since 1998 to work towards agreed national monitoring approaches for local authorities. Matthew Taylor visited soil quality researchers in the United Kingdom during 2009 and has ongoing connections with soil quality research and developments to ensure we are not "re-inventing the wheel". A general comment would be that our work has been leading the way and may be the most progressed national soil quality monitoring programmes internationally. Most recently, MfE have used the soil quality monitoring results and interpretation framework to produce a national scorecard for soil quality; http://www.mfe.govt.nz/environmental-reporting/report-cards/soil-health/2010/index.html.

Budget (up to 2 years)

Income	Year 1	Year 2
FRST Funds sought	104,000	104,000
Co- funding (organisational or external)		
Income total		
Expenses		
Personnel	26,500	26,500
Operating expenses	15,600	15,600

Building depreciation		
Overheads	25,370	25,370
Subcontracts	25,000	25,000
Extraordinary expenses		
GST	11,556	11,556
Expenses total	104,026	104,026

Section 5.4 Implementation Pathway (30%)

We want to be confident the new information will be used to influence change and achieve the environmental benefits being sought. We therefore want to see a plausible route or pathway in which the tool will be used, and/or passed on to others for use, e.g. in a new or modified council process, technology, guideline, strategy, protocol or plan. Applicants need to explain and justify their choice of pathways (and there may be more than one). We suggest applicants present a clear implementation plan and address the following:

5.41 Give any critical success factors for the development of a successful tool and what steps are being taken to ensure risks are minimised

Completion of an upgrade of target ranges for current indicators to address gaps and expansion on the current indicator list (e.g. heavy metals, hydrophobicity, biological function) to provide a more complete picture of the state of the land resources, in itself is a relatively straightforward process. The involvement and support of the Land Monitoring Forum will be pivotal in this part of the tools development, helping to facilitate agreement and adoption. Operationalizing the framework linking the soil quality indicators to ecosystem service to enable quantification and valuation of all the soil's ecosystem services, as indicated earlier offers a greater challenge and so some risk. Regular meetings and contact to report on progress and work through the choices with councils to help the project team and them to understand the best options.

5.42 Describe the approach Regional Councils will take to ensure that the new tool is incorporated into management practise

The majority of regional councils currently conducting soil quality monitoring have indicated (through Land Monitoring Forum support of the project) that the upgrade of target ranges for current indicators will be built into further reporting, as will the inclusion of additional soil quality indicators to provide a more complete picture of the state of the land resources. Just how the framework will be incorporated into management practice requires further discussion with members of the National Land Monitoring Forum. During and on completion of the project Land Monitoring Forum will be used as the vehicle for providing updates and training for land monitoring staff from RC and regional unitary authorities.

5.43 If the tool is of potential use to organisations other than Councils describe how the tool will be made available and its uptake facilitated.

Both the upgrade of target ranges for current indicators and the inclusion of additional soil quality indicators to provide a more complete picture of the state of the land resources will be disseminated widely including industry good organisations and will be available through councils, the Land Monitoring Forum, plus the SLURI and Regional Council websites. It will be presented to forums and workshops by members of the project team and in discussion with the Land Monitoring Forum developed into manual. Access and use of the framework will be worked through with the Land Monitoring Forum and Council. Additionally, the tool developed in this project will be incorporated into the SINDI soil quality interpretation website (a current Envirolink tools project is building a supporting soil quality database and upgrading SINDI) to ensure accessibility and encourage the incorporation of soil quality information into management practices; the SINDI site is publicly accessible. Regional councils currently encourage land managers to use the site for assessing their soil quality results.

5.44 Provide evidence that councils have been heavily involved in proposal development and have an ongoing role and commitment to the project and proposed tool.

Environment Waikato and Hawke's Bay Regional Council were instrumental in the development and writing of this proposal. The first part of the proposal builds on the recommendations in the discussion paper on indicators target ranges for soil quality monitoring prepared by Taylor (2009) of Environment Waikato. Oversight of part one of the project (Upgrade of target ranges for current indicators and expansion of the current indicator list will be directed by the national Land Monitoring Forum, with Matthew Taylor of Environment Waikato in the lead. The Council champions and Land Monitoring Forum staff time will be critical in working through how the framework linking the soil quality indicators to ecosystem service is best used and reported. A subgroup of the forum members will be form to provide regular input into that process.

5.45 What happens next, once the tool is developed? What and who will it influence?

Councils currently conducting soil quality monitoring have indicated that the upgrade of target ranges for current indicators will be built into further reporting, as will the inclusion of additional soil quality indicators to provide a more complete picture of the state of the land resources. This information will feed through immediately to land managers and policy developers from which more informed decisions can be made. As indicated earlier use of the framework that links the soil quality indicators to outcomes will take long to work through with Council.

5.46 What might it lead on to?

Linking soil quality indicators to outcomes at the paddock, farm and catchment scale will increase soil quality monitoring and quantification of soil quality issues at regional and national scales. The soil services valuation framework will make the costs of reduced soil quality and benefits of good soil quality management clear to managers and policy. This will lead to changes in behaviour and will be a string economic driver towards meeting a number of national and regional outcomes. Adoption of environmental accountability and eco-verification of products for shelf-access overseas markets, rapidly gaining momentum and the tool could well go beyond the current purpose to where it could be used as an eco-verification means to secure premium product pricing.

5.47 Who will take it up and has anyone made any commitment to its use?

All members of the Land Monitoring Forum are committed to using the tool in their current soil quality monitoring programs. Other Regional Councils who conduct soil quality monitoring on a regular or semi-regular basis (Waikato, Canterbury, Wellington, Hawke's Bay, Auckland, Bay of Plenty, Tasman and Marlborough) and at a minimum, all regional councils within the LAND MONITORING FORUM will benefit from increased access to the upgrade of the soil quality indicators and the framework linking the soil quality indicators to outcomes.

5.48 Will you be training others in application of the tool?

This upgrade of the soil quality indicators and the framework linking the soil quality indicators to outcomes is to be developed for the benefit of Regional Councils and their operations. Our training and support will be focused primarily on Council staff. The tool will be useful for land managers and it is envisaged Regional Councils will continue extension when the tool is available.

5.49 Have those future users made any commitment to using the tool, and are they aware of it?

There has not been any formal commitment at this stage, some are aware of it, including MfE.

5.50 Have any councils made a commitment to using the tool?

See section 5.47

5.51 If there are barriers to implementation, how are these being overcome, and are you confident they can be overcome? For example, a new system might need extensive or very expensive data collection before it becomes workable.

There are no foreseeable barriers that would impede implementation of the tool. The first part of the project includes an upgrade of the monitoring programme already in place within Councils. As indicated earlier progress on the development of the framework linking the soil quality indicators to outcomes will be dependent to a degree on progress within SLURI and also on the pace at which Councils might be prepared to adopt and evolve current reporting protocols. The Land Monitoring Forum will act as a single point of contact between regional councils and the project team to overcome any barriers should they arise.

Section 6.0 Project Plan

This section focuses on clear identification of the major project plan technical deliverables, milestones, technical objectives and tasks in a way that identifies the risk involved and resources required for each task. Especially important is a clear definition of milestones where the project risks can be evaluated and updated. Each milestone may call for an alternate strategy, e.g. a go/kill or key decision point. Sequencing of work will be provided as an attached GANTT chart. Note that the project will be regularly measured against the project plan to form the basis of the quarterly and final reports. Also note that the project plan can be varied under clauses in the funding contract should that become necessary.

6.1 Provide an overview of your team's overall approach to the R&D work and any quality standards observed:

The soil quality indicators: Next generation project tackles the recommendations made in a recent review (Taylor 2009) of indicator target-ranges for soil-quality monitoring which identified the need for:

- An upgrade of target ranges for current indicators to address gaps,
- Expansion of the current indicator list (e.g. heavy metals, hydrophobicity, biological function) to provide a more complete picture of the state of the land resources,
- Development of the linking framework between soil quality indicators and ecosystem service defined resource outcomes, and
- Quantification and valuation of the soil's ecosystem services other than just those contributing to provisioning (i.e. production).

The first two issues can be addressed easily and would bring immediate benefits. The latter two will be addressed by investigation of the inclusion of the soil quality indicators within a framework we have developed recently (Dominati et al., 2009) to values the soil's ecosystem services.

6.2 Technical Objectives*: The significant technical challenges in the project.*

Objective Name	Specific Achievement Measure
Upgrade of existing target ranges of existing indicators and addition of new indicators	Agree on new target ranges of existing indicators, on refines to current methodologies and on new indicators and the inclusion of these update in the state of the environment reporting protocols.
Development of the linking framework between soil quality indicators and ecosystem service	A farm scale (Waikato) and catchment scale (Hawke's Bay) case will be developed and available for Councils to use as a working example of the new reporting framework.

6.3 Project Milestones: *Populate the table with milestones that show the essential steps that must be achieved to deliver the individual technical objectives. A separate table should be prepared for each objective. Technical and reference points marking a major event in the project that may or may not be aligned to project phases or technical deliverables. These may also be decision (Go/Kill) points in the project. Milestones must be specific, measurable and time bound.*

Milestones description	Milestone sequence	Performance measure Go/Kill point?	Completion date
Upgrade of existing target ranges of existing indicators	1.1	Availability of appropriate science and Council personnel and Council agreement	December 2010
Refinements to existing methodologies	1.2	Availability of appropriate science and Council personnel and Council agreement	December 2010
Identification of new indicators	1.3	Availability of appropriate science and Council personnel and Council agreement	December 2010
Draft version of soil quality indicators manual	1.4	Approved by participating councils	June 2011

Milestones description	Milestone sequence	Performance measure Go/Kill point?	Completion date
Development of the dairy case in the Waikato	2.1	Availability of appropriate science and Council personnel Agreement by Council of the approach and the case	June 2011
Development of the catchment case in the Hawke's Bay	2.2	Availability of appropriate science and council staff and access to data sets Agreement by Council of the approach	June 2011

		and the case	
Working example at the farm scale of the new reporting framework.	2.3	Availability of appropriate science and council staff and access to data sets Agreement by Council of the approach and the case	June 2012
Working example at the catchment scale of the new reporting framework.	2.4	Availability of appropriate science and council staff and access to data sets Agreement by Council of the approach and the case	June 2012

6.4 Cash flow Forecast: *Please provide details of the anticipated total spending for this project and the projected drawdown of funds until the end of the project. Briefly outline the stages of the project during each time period. Expand the number of quarters as necessary. Please note that the maximum length for the project is 2 years.*

Project Period	Activities/stage of project	Anticipated total spend
First quarter (Sept 2010)	Agree on new target ranges of existing indicators, on refines to current methodologies and on new indicators and the inclusion of these update in the state of the environment reporting protocols.	20,000
Second quarter	Upgrade of existing target ranges of existing indicators Refinements to existing methodologies Identification of new indicators	32,000
Third quarter	Progress report to councils	20,000
Fourth quarter	Draft version of soil quality indicators manual Development of the dairy case in the Waikato Development of the dairy case in the Waikato	32,000
First quarter (Sept 2011)	Agree on scope of the working examples	20,000
Second quarter	Presentation on the working cases	30,000
Third quarter	Working example at the farm scale of the new reporting framework.	44,000

	Working example at the catchment scale of the new reporting framework	
Fourth quarter	Final reporting	10,000

7.2 Schedule of work. Objectives and milestones

Technical Objective Sequence #	1 – Upgrade of target ranges of existing indicators and addition of new indicators
Objective Text	In a recent discussion-document on soil quality indicators and target ranges for soil quality monitoring, Taylor (2009) makes a number of recommendations. These included calling for an upgrade of target ranges for current indicators, identify those target ranges that remain poorly validated and developing a process to improve validation, refinements to current methodologies, plus expansion of the current list of indicators (e.g. heavy metals, biological diversity) to provide a more complete picture of the state of our land resources.
Objective Final Milestone	Agree on new target ranges of existing indicators, processes to address gaps, improve validation, on refinements to current methodologies and on new indicators and the inclusion of these in the Land Monitoring Forum guidelines
Start Date	August 2010
End Date	June 2012
Milestone #	1.1 Upgrade of target ranges of existing indicators and identify those target ranges that remain poorly validated.
Description	Current target ranges are based on those published in *Provisional targets for soil quality indicators in New Zealand* (Sparling et al., 2003). Several refinements have been made in target ranges since that time, but gaps remain (e.g. poor defined N, Olsen P, AMN, macroporosity @ -10kPa targets for cropping & horticulture and for different land use categories for annual tillage and perennial crops (orchards))
Start date	August 2010
Finish date	December 2010
Achievement Measure	Agree on new target ranges of existing indicators, develop a process to improve validation were target ranges are poorly defined and the time scale for their inclusion in the Land Monitoring Forum guidelines
Milestone Dependent on	
Milestone Contributes to	1.4

Milestone #	1.2 Refinements to existing methodologies
Description	Refinements to current methodology (e.g. depth of sampling for soil carbon) will provide a more complete picture of the state of the land resources
Start date	August 2010

Finish date	December 2010
Achievement Measure	Agree on refinements to current methodologies and the time scale for their inclusion in the Land Monitoring Forum guidelines.
Milestone Dependent on	
Milestone Contributes to	1.4

Milestone #	1.3 Identification of new indicators
Description	The inclusion of additional soil quality indicators (e.g. heavy metals, hydrophobicity, biological-function) will provide a more complete picture of the state of the land resources. To justify inclusion for State of the Environment reporting and policy development the new indicators will need to be practicable and cost-effective
Start date	August 2010
Finish date	June 2011
Achievement Measure	Agree on new indicators and the time scale for their inclusion in the Land Monitoring Forum guidelines.
Milestone Dependent on	
Milestone Contributes to	1.4
Milestone #	1.4 Update of the Land Monitoring Forum guidelines
Description	Inclusion of the 1.1, Upgrade of existing target ranges of existing indicators 1.2 Refinements to existing methodologies and 1.3 New indicators in the soil quality indicators manual will ensure all Regional Councils are working towards the same set of state of environment reporting guidelines.
Start date	July 2011
Finish date	June 2012
Achievement Measure	Completion of the update of the Land Monitoring Forum guidelines (Land and Soil Monitoring: a guide for State of the Environment and Regional council reporting).
Milestone Dependent on	1.1, 1.2, 1.3.
Milestone Contributes to	
Technical Objective Sequence #	2 Development of the linking framework between soil quality indicators and ecosystem service
Objective Text	The inclusion of additional factors to increase the utility (i.e. link to outcomes) of the soil quality indicators has been the subject of much discussion, but little action. The recent development of an ecosystem services approach that includes for the first time soils, enables a link to be made between soil quality indicator and soil processes as they influence soil services and outcomes at a range of scales.
Objective Final Milestone	A farm scale (Waikato Dairy farm) and catchment scale (Hawke's Bay) case will be developed and available for Councils to use as a working example of the new framework.
Start Date	September 2010

End Date	June 2012
Milestone #	2.1 Development of the dairy case in the Waikato
Description	Recent study has successfully linked soil quality indicators (i.e. soil attributes) to soil processes to enable the influence of land use on soil services to be quantified at a farm scale. The approach offers promise as a tool for adding utility to soil quality indicators for reporting on outcomes at the farm scale.
Start date	October 2010
Finish date	June 2011
Achievement Measure	Agree on the soil services for inclusion in the framework to explore the links between soil quality indicators and outcomes beyond the paddock scale
Milestone Dependent on	
Milestone Contributes to	2.3
Milestone #	2.2 Development of the catchment case in the Hawke's Bay
Description	Recent study has successfully linked soil quality indicators (i.e. soil attributes) to soil processes to enable the influence of land use on soil services to be quantified at a farm scale. Extending that approach to the catchment scale requires inclusion of additional attributes to add utility to soil quality indicators for reporting on outcomes at the catchment scale.
Start date	October 2010
Finish date	June 2011
Achievement Measure	Agree on the soil services for inclusion in the framework to explore the links between soil quality indicators and outcomes beyond the farm.
Milestone Dependent on	
Milestone Contributes to	2.4
Milestone #	2.3 Working example at the farm scale of the new reporting framework.
Description	Test the ecosystems service framework with the agreed soil services (2.1) on Waikato Dairy farm to demonstrate the value of the approach for linking soil quality indicators to farm outcomes
Start date	July 2011
Finish date	June 2012
Achievement Measure	Provide a written report covering the Waikato Dairy farm case to the Land monitoring forum and obtain agreement from the forum on the merit or otherwise of advancing the approach to further cases or services.
Milestone Dependent on	2.1
Milestone Contributes to	
Milestone #	2.4 Working example at the catchment scale of the new reporting framework.
Description	Test the ecosystems service framework with the agreed soil services (2.2) in Catchment in the Hawke's Bay to demonstrate

	the value of the approach for linking soil quality indicators to catchment outcomes.
Start date	July 2011
Finish date	June 2012
Achievement Measure	Provide a written report covering the Hawke's Bay Catchment case to the Land monitoring forum and obtain agreement from the forum on the merit or otherwise of advancing the approach to further cases or services
Milestone Dependent on	2.2
Milestone Contributes to	

7.3 Evaluation Reporting Format for Envirolink Tools Projects

Project Title: Soil quality indicators: The next generation

Contract Number: AGRX1001

Local Govt Champion: Reece Hill (Environment Waikato)

Completion Date of Project: June 2012

Project Aim:

The project Soil Quality indicators: Next Generation tackles the recommendations made in a recent review (Taylor, 2009) of indicator target-ranges for soil-quality monitoring which identified the need for:

- An upgrade of target ranges for current indicators to address gaps,
- Expansion of the current indicator list (e.g. heavy metals, hydrophobicity, biological function) to provide a more complete picture of the state of the land resources,
- Development of a linking framework between soil quality indicators and ecosystem services to assess resource outcomes,
- Quantification and economic valuation of the soil's ecosystem services other than just those contributing to production, namely the provisioning, regulating and cultural services provided by soils.

The latter two will be addressed by investigation of the inclusion of the soil quality indicators within a framework developed recently (Dominati et al., 2010) to quantify and value soil ecosystem services.

Project timelines:

Objective 01
Upgrade of target ranges of existing indicators and addition of new indicators June 2012

Objective 02
Development of the linking framework between soil quality indicators and soil ecosystem services June 2012

Milestone 1.1
Jan 2011. Discussion were held on likely new target ranges of existing indicators, a process to improve validation were target ranges are poorly defined and the time scale for their inclusion in the Land Monitoring Forum guidelines at the Bi-annual Land Monitoring Forum meeting in Wellington in September 2010. These will be finalised and advanced at a meeting of "experts" planned for the end of April 2011.

June 2011. Further discussion was held with members of the land monitoring forum at the Bi-annual Land Monitoring Forum meeting in Wellington in February 2011. Milestone 1.1 was the subject of a special workshop to review the current soil quality indicators held on the 6^{th} of May 2011 in Wellington, and attended by Regional Council and MfE staff and scientists from a number of institutions. A draft report "Towards Developing Targets for Soil Quality Indicators in New Zealand" has been prepared and will be circulated for comment in July 2011.

Milestone 1.2

Jan 2011. Discussion on refinements to current methodologies and the time scale for their inclusion in the Land Monitoring Forum guidelines were held at the Bi-annual Land Monitoring Forum meeting in Wellington in September 2010. These will be finalised and advanced at a meeting of "experts" planned for the end of April 2011.

June 2011. Further discussion was held with members of the land monitoring forum at the Bi-annual Land Monitoring Forum meeting in Wellington in February 2011. Milestone 1.2 was the subject of a special workshop to review the current soil quality indicators held on the 6th of May 2011 in Wellington, attended by Regional Council and MfE staff and scientists from a number of institutions. A draft report "Towards Developing Targets for Soil Quality Indicators in New Zealand" has been prepared and will be circulated for comment in July 2011.

Milestone 1.3

June 2011. The inclusion of additional soil quality indicators (e.g. heavy metals, hydrophobicity, biological-function) was discussed at the special workshop to review the current soil quality indicators held on the 6th of May 2011 in Wellington, attended by Regional Council and MfE staff and scientists from a number of institutions. In the draft report "Towards Developing Targets for Soil Quality Indicators in New Zealand: there is some discussion on "addition" of possible new indicators. This will be the subject of further discussion. The draft report will be circulated in July 2011.

Milestone 2.1

Jan 2011. Agreement was reached on the ecosystem services for inclusion in the framework to explore the links between soil quality indicators and outcomes beyond the paddock scale at the Bi-annual Land Monitoring Forum meeting in Wellington in September 2010. Good progress has been made since that meeting in developing the framework for the case study Waikato Dairy farm. An update will be provided to the Bi-annual Land Monitoring Forum meeting in Wellington in February 2011.

June 2011 At the Bi-annual Land Monitoring Forum meeting in Wellington in February 2011 a presentation on links between macroporosity and soil ecosystem services that include provision of food, wood and fibre, provision of raw materials, provision of support for human infrastructures and animals, flood mitigation, filtering of nutrients and contaminants, carbon storage and greenhouse gases regulation, detoxification and the recycling of wastes, and regulation of pests and diseases populations, was made to forum members to obtain more feedback on services of most interest and the preferred currency (bio-physical measures and/or NZ dollars) for reporting on each service.
Summary of feedback from group (February 2011) The quantification and valuation of soil ecosystem services needs to focus on determining thresholds / tipping points in the provision of ecosystem services, in terms of quantity, as well as economic value. These thresholds can then be compared to what is regarded at the moment as the optimal values for soil quality indicators (e.g. a macroporosity of 10%. For what value of macroporosity do we get a maximum provision of ecosystem services) and used to confirm or revise the current optimum values. The group also expressed interest about marginal values and comparing the costs of increasing natural capital (with mitigation and investments) to the gain in value of the ecosystem services provided. The need to link thresholds to the provision of services and outcomes at different scales was also mentioned. The group agreed that the focus should be on the provision of food, flood mitigation, and the filtering of nutrients, at the catchment scale. More details about the methodology of quantification and valuation of soil ecosystem services were demanded. It was agreed that a document detailing the methodology should be provided to the group, in order to discuss the methodology and adapt it at different scales and land uses. The need to aggregate soil quality indicators into a comprehensive single indicator for e.g. a national statement on the state of the soil resource in New Zealand was

also mentioned. Combining the approaches of soil quality indicators and ecosystem services valuation was regarded as the way to go to provide evidence for policy making.

Milestone 2.2

Jan 2011. Agreement was reached on the soil ecosystem services for inclusion in the framework to explore the links between soil quality indicators and outcomes beyond the farm at the Bi-annual Land Monitoring Forum meeting in Wellington in September 2010. Good progress has been made since that meeting in developing the framework for the case study Catchment in the Hawke's Bay. An update will be provided to the Bi-annual Land Monitoring Forum meeting in Wellington in February 2011.

Jun 2011 At the Bi-annual Land Monitoring Forum meeting in Wellington in February 2011 a presentation on links between macroporosity and soil services that include provision of food, wood and fibre, provision of raw materials, provision of support for human infrastructures and animals, flood mitigation, filtering of nutrients and contaminants, carbon storage and greenhouse gases regulation, detoxification and the recycling of wastes, and regulation of pests and diseases populations, was made to forum members to obtain more feedback on services of most interest and the preferred currency for reporting on each service. (See feedback above from group).

Budget & EDS forecast:

Date (Month/Year)	Expected Amount to be Claimed Quarterly with an invoice and report (includes GST)
30/09/2010	$ 23,400
31/12/2010	$ 23,400
31/03/2011	$ 23,400
30/06/2011	$ 23,400
30/09/2011	$ 23,400
31/12/2011	$ 23,400
31/03/2012	$ 23,400
30/06/2012	$ 23,400
15/08/2012	$ 20,800
Total	$ 208,000
	Please ensure that the final payment is not less than 10% of the approved funding

Critical Performance Indicators:

Programme Management

On target and track: Project is operating within financial and time limits.

Milestones (work programme)

On track: see Milestone comments above.

Key Personnel

Alec Mackay, Matthew Taylor, Estelle Dominati and Andrew Manderson.

Ethnical & regulatory

Nothing to report.

Audit Compliance

Nothing to report.

Contract conditions

Nothing to report.
Contract highlights
Jan 2011. Presentations were made on the project followed by excellent discussion with the members of the Land monitoring forum on current methodologies, likely new target ranges of existing indicators, a process to improve validation were target ranges are poorly defined, the time scale for their inclusion in the Land Monitoring Forum guidelines, a brief history on ecosystems services and its potential application in resource management and finally on the soil ecosystem services for inclusion in the framework.

June 2011. Good progress has been made towards the goals of the project which includes the review of target ranges for current indicators, exploring the possible expansion of the current indicator list and the development of a linking framework between soil quality indicators and ecosystem services to assess resource outcomes. Following the special workshop to review the current soil quality indicators, held in May 2011, a draft report "Towards Developing Targets for Soil Quality Indicators in New Zealand" was prepared. It includes an analysis of current target ranges and some comment on "addition" of possible new indicators. In advancing the development of the framework for linking soil quality indicators and ecosystem services there has been good engagement and feedback from forum members including the need to focus on determining thresholds or tipping points in the provision of ecosystem services, in terms of quantity, as well as economic value and linking the thresholds to the provision of services and outcomes at different scales. The group agreed that the focus should be on the provision of food, flood mitigation, the filtering of nutrients, at the catchment scale and expressed interest in learning more details about the methodology of quantification and valuation of soil ecosystem services.

Exec Summary of evaluation and lessons learned:

[Include details of any issues with project progress or other concerns]

ALL REPORTS MUST BE SIGNED BY THE RESEARCH ORGANISATION

<u>Notes for Completing the Final Report</u>

This report should capture the learning and outcomes of the project and ***should be signed by the Research Organisation, the Council Champion and Regional Council Governance Committee***

Evaluation Reporting Format for Envirolink Tools Projects

Project Title: Soil quality indicators: The next generation
Contract Number: AGRX1001
Local Govt Champion: Reece Hill (Environment Waikato)
Completion Date of Project: June 2012

Project Aim:

The project Soil Quality indicators: Next Generation tackles the need for:

An upgrade of target ranges for current indicators to address gaps,

The expansion of the current indicator list (e.g. heavy metals, hydrophobicity, biological function) to provide a more complete picture of the state of the land resources,

The development of a linking framework between soil quality indicators and ecosystem services to assess resource outcomes,

The quantification and economic valuation of the soil's ecosystem services other than just those contributing to production, namely the provisioning, regulating and cultural services provided by soils.

The latter two will be addressed by investigation of the inclusion of the soil quality indicators within a framework developed recently (Dominati et al., 2010) to quantify and value soil ecosystem services. The project builds incorporates recent research on soil quality indicator target ranges into an upgraded monitoring tool. It will benefit regional councils and MfE. It will contribute to the ongoing development and evolution of State of the Environment reporting.

Project timelines:

Objective 01 Upgrade of target ranges of existing indicators and addition of new indicators June 2012

Objective 02 development of the linking framework between soil quality indicators and soil ecosystem services June 2012

Budget & EDS forecast:

Date (Month/Year)	Expected Amount to be Claimed Quarterly with an invoice and report (includes GST)
30/09/2010	$ 23,400
31/12/2010	$ 23,400
31/03/2011	$ 23,400
30/06/2011	$ 23,400
30/09/2011	$ 23,400
31/12/2011	$ 23,400
31/03/2012	$ 23,400
30/06/2012	$ 23,400
15/08/2012	$ 20,800
Total	$ 208,000

Critical Performance Indicators:

Programme Management

On target and track: Project is operating within financial and time limits.

Milestones (work programme)
On track

Milestone 1.1: Upgrade of target ranges of existing indicators and identify those target ranges that remain poorly validated.
Jan 2011. Discussion were held on likely new target ranges of existing indicators, a process to improve validation were target ranges are poorly defined and the time scale for their inclusion in the Land Monitoring Forum guidelines at the Bi-annual Land Monitoring Forum meeting in Wellington in September 2010. These will be finalised and advanced at a meeting of "experts" planned for the end of April 2011.
June 2011. Further discussion was held with members of the land monitoring forum at the Bi-annual Land Monitoring Forum meeting in Wellington in February 2011. Milestone 1.1 was the subject of a special workshop to review the current soil quality indicators held on the 6th of May 2011 in Wellington, and attended by Regional Council and MfE staff and scientists from a number of institutions. A draft report "Towards Developing Targets for Soil Quality Indicators in New Zealand" has been prepared and will be circulated for comment in July 2011.
Milestone 1.2: Refinements to existing methodologies
Jan 2011. Discussion on refinements to current methodologies and the time scale for their inclusion in the Land Monitoring Forum guidelines were held at the Bi-annual Land Monitoring Forum meeting in Wellington in September 2010. These will be finalised and advanced at a meeting of "experts" planned for the end of April 2011.
June 2011. Further discussion was held with members of the land monitoring forum at the Bi-annual Land Monitoring Forum meeting in Wellington in February 2011. Milestone 1.2 was the subject of a special workshop to review the current soil quality indicators held on the 6th of May 2011 in Wellington, attended by Regional Council and MfE staff and scientists from a number of institutions. A draft report "Towards Developing Targets for Soil Quality Indicators in New Zealand" has been prepared and will be circulated for comment in July 2011.
Milestone 1.3: Identification of new indicators
June 2011. The inclusion of additional soil quality indicators (e.g. heavy metals, hydrophobicity, biological-function) was discussed at the special workshop to review the current soil quality indicators held on the 6th of May 2011 in Wellington, attended by Regional Council and MfE staff and scientists from a number of institutions. In the draft report "Towards Developing Targets for Soil Quality Indicators in New Zealand: there is some discussion on "addition" of possible new indicators. This will be the subject of further discussion. The draft report will be circulated in July 2011.
Milestone 1.4: Update of the Land Monitoring Forum guidelines
June 2012 Since the special workshop in May 2011, Draft 1.2 "Targets for Soil Quality Indicators in New Zealand" has been produced for the Land Monitoring Forum. The draft has been circulated and revised, and after further discussion at both the September meeting in 2011 and February meeting in 2012 will be sign off at the September meeting in 2012 and the Final reported produced "Towards Developing Targets for Soil Quality Indicators in New Zealand: Final report". This report will guide future developments of the soil quality indicators used by Regional Councils for State of the environment monitoring and reporting
Milestone 2.1: Development of the dairy case in the Waikato
Jan 2011. Agreement was reached on the ecosystem services for inclusion in the framework to explore the links between soil quality indicators and outcomes beyond the paddock scale at the Bi-annual Land Monitoring Forum meeting in Wellington in September 2010. Good progress has been made since that meeting in developing the framework for the case study Waikato Dairy farm. An update will be provided to the Bi-annual Land Monitoring Forum meeting in Wellington in February 2011.

June 2011 At the Bi-annual Land Monitoring Forum meeting in Wellington in February 2011 a presentation on links between macroporosity and soil ecosystem services that include provision of food, wood and fibre, provision of raw materials, provision of support for human infrastructures and animals, flood mitigation, filtering of nutrients and contaminants, carbon storage and greenhouse gases regulation, detoxification and the recycling of wastes, and regulation of pests and diseases populations, was made to forum members to obtain more feedback on services of most interest and the preferred currency (bio-physical measures and/or NZ dollars) for reporting on each service.
Summary of feedback from group (February 2011) The quantification and valuation of soil ecosystem services needs to focus on determining thresholds / tipping points in the provision of ecosystem services, in terms of quantity, as well as economic value. These thresholds can then be compared to what is regarded at the moment as the optimal values for soil quality indicators (e.g. a macroporosity of 10%. For what value of macroporosity do we get a maximum provision of ecosystem services) and used to confirm or revise the current optimum values. The group also expressed interest about marginal values and comparing the costs of increasing natural capital (with mitigation and investments) to the gain in value of the ecosystem services provided. The need to link thresholds to the provision of services and outcomes at different scales was also mentioned. The group agreed that the focus should be on the provision of food, flood mitigation, and the filtering of nutrients, at the catchment scale. More details about the methodology of quantification and valuation of soil ecosystem services were demanded. It was agreed that a document detailing the methodology should be provided to the group, in order to discuss the methodology and adapt it at different scales and land uses. The need to aggregate soil quality indicators into a comprehensive single indicator for e.g. a national statement on the state of the soil resource in New Zealand was also mentioned. Combining the approaches of soil quality indicators and ecosystem services valuation was regarded as the way to go to provide evidence for policy making.

Milestone 2.2: Development of the catchment case in the Hawke's Bay
Jan 2011. Agreement was reached on the soil ecosystem services for inclusion in the framework to explore the links between soil quality indicators and outcomes beyond the farm at the Bi-annual Land Monitoring Forum meeting in Wellington in September 2010. Good progress has been made since that meeting in developing the framework for the case study Catchment in the Hawke's Bay. An update will be provided to the Bi-annual Land Monitoring Forum meeting in Wellington in February 2011.

Jun 2011 At the Bi-annual Land Monitoring Forum meeting in Wellington in February 2011 a presentation on links between macroporosity and soil services that include provision of food, wood and fibre, provision of raw materials, provision of support for human infrastructures and animals, flood mitigation, filtering of nutrients and contaminants, carbon storage and greenhouse gases regulation, detoxification and the recycling of wastes, and regulation of pests and diseases populations, was made to forum members to obtain more feedback on services of most interest and the preferred currency for reporting on each service. (See feedback above from group).
Due June 2011

Milestone 2.3: Working example at the farm scale of the new reporting framework.
Test the ecosystems service framework with the agreed soil services (2.1) on Waikato Dairy farm to demonstrate the value of the approach for linking soil quality indicators to farm outcomes.
Start date -July 2011, Finish date -June 2012.
Achievement Measure: Provide a written report covering the Waikato Dairy farm case to the Land monitoring forum and obtain agreement from the forum on the merit or otherwise of advancing the approach to further cases or services.

Due June 2012
Jan 2012:
Agreement was reached on visits for 2012 to the Waikato Regional Council to gather data needed for use of the framework to explore the links between soil quality indicators and outcomes at the farm scale at the Bi-annual Land Monitoring Forum meeting in Wellington in September 2011. Good progress has been made since that meeting in developing the framework for the case study on the Waikato Dairy farm. An update will be provided to the Bi-annual Land Monitoring Forum meeting in Wellington in February 2012.

June 2012:
Visits were made to the Waikato Regional Council to gather data needed for use of the framework to explore the links between soil quality indicators and outcomes at the farm scale on the 18-19th January 2012 and again on the 8-9th march 2012. Two farm visits were also made on the 9th March to assess data availability on farm.
At the Bi-annual Land Monitoring Forum meeting in Wellington on 16 February 2012, a presentation on links between macroporosity and the provision of soil services at the farm scale, as well as links between quantification and economic valuation of soil services was made to forum members to obtain more feedback on preliminary results. The group agreed that the preliminary results on macroporosity were encouraging and that focus should be on using the quantification and valuation of soil ecosystem services to determine thresholds / tipping points in the provision of ecosystem services, in terms of quantity, as well as economic value.
A written report covering the Waikato dairy farm case study testing the usability of an ecosystem services framework to link macroporosity to farm outcomes has been prepared and will be circulated for comment in July 2012 and presented for sign off at the September 2012 Forum meeting.

Milestone 2.4 Working example at the catchment scale of the new reporting framework.
Test the ecosystems service framework with the agreed soil services (2.2) in Catchment in the Hawke's Bay to demonstrate the value of the approach for linking soil quality indicators to catchment outcomes.
Start date - July 2011, Finish date - June 2012
Achievement Measure: Provide a written report covering the Hawke's Bay Catchment case to the Land monitoring forum and obtain agreement from the forum on the merit or otherwise of advancing the approach to further cases or services.

Due June 2012
Jan 2012:
Agreement was reached on visits for 2012 to the Waikato Regional Council to gather data needed for the catchment case study testing the usability of an ecosystem services framework to link macroporosity to catchment outcomes at the Bi-annual Land Monitoring Forum meeting in Wellington in September 2011. At the meeting, it was also decided that the catchment study will take place in the little Waipa catchment in the Waikato instead of Hawke's Bay, in part because of data availability buts more importantly direct links could be made between the farm and catchment scales by working in the same District.
Good progress has been made since that meeting in developing the framework for the case study on the little Waipa catchment. An update will be provided to the Bi-annual Land Monitoring Forum meeting in Wellington in February 2012.

June 2012:
Visits were made to the Waikato Regional Council to gather data needed for use of the framework to explore the links between soil quality indicators and outcomes at the catchment scale on the 18-19th January 2012 and the 8-9th march 2012.

At the Bi-annual Land Monitoring Forum meeting in Wellington on 16 th February 2012, a presentation on adaptation of the farm methodology to the catchment case study was made to forum members to obtain feedback on issues such as scaling up data and tools to use. Working at the catchment scale has been a little more challenging than the farm scale. At both scales collecting the required data has not been easy, as has developing proxies to substitute where data are not available.
A written report covering the little Waipa catchment case study testing the usability of an ecosystem services framework to link macroporosity to catchment outcomes has been prepared and will be circulated for comment in July 2012 and presented for sign off at the September 2012 Forum meeting.

Comment on variation
Testing of the framework has been more of a challenge that expected because of the challenge of finding the required data sets and where data are not available developing a suitable proxy that still has the required sensitivity to capture the dynamics of the ecosystem.

Key Personnel
No Change
Alec Mackay, AgResearch, project manager
Matthew Taylor: Waikato Regional Council
Estelle Dominati, AgResearch
Andrew Manderson, AgResearch

Ethnical & regulatory
Nothing to report.
Audit Compliance
Nothing to report.
Contract conditions
Nothing to report.

Contract highlights
Jan 2011: Presentations were made on the project followed by excellent discussion with the members of the Land monitoring forum on current methodologies, likely new target ranges of existing indicators, a process to improve validation were target ranges are poorly defined, the time scale for their inclusion in the Land Monitoring Forum guidelines, a brief history on ecosystems services and its potential application in resource management and finally on the soil ecosystem services for inclusion in the framework.

June 2011: Good progress has been made towards the goals of the project which includes the review of target ranges for current indicators, exploring the possible expansion of the current indicator list and the development of a linking framework between soil quality indicators and ecosystem services to assess resource outcomes. Following the special workshop to review the current soil quality indicators, held in May 2011, a draft report “Towards Developing Targets for Soil Quality Indicators in New Zealand” was prepared. It includes an analysis of current target ranges and some comment on “addition” of possible new indicators. In advancing the development of the framework for linking soil quality indicators and ecosystem services there has been good engagement and feedback from forum members including the need to focus on determining thresholds or tipping points in the provision of ecosystem services, in terms of quantity, as well as economic value and linking the thresholds to the provision of services and outcomes at different scales. The group agreed that the focus should be on the provision of food, flood mitigation, the filtering of nutrients, at the catchment scale and expressed interest in learning more details about the methodology of quantification and valuation of soil ecosystem services.

Jan 2012:

Since the special workshop in May 2011, Draft 1.2 "Targets for Soil Quality Indicators in New Zealand" has been produced for the Land Monitoring Forum. The draft has been circulated and revised and was discussed further at the Bi-annual Land Monitoring Forum meeting in Wellington in September 2011.

Good progress has been made since the Bi-annual Land Monitoring Forum meeting in Wellington in September 2011 in developing the framework for the case studies on the Waikato Dairy farm and the little Waipa catchment. Agreement was reached on visits for 2012 to the Waikato Regional Council to gather data needed for both case studies. The project was presented at an international conference, the Wageningen Conference on applied Soil Science: Soil Science in a changing world, September 2011, Wageningen, Netherlands. The initiative and methods used gathered high praises from international experts.

June 2012:

The draft 1.2 "Targets for Soil Quality Indicators in New Zealand" was again discussed at the February meeting and will be sign off at the September meeting in 2012 and the Final reported produced "Towards Developing Targets for Soil Quality Indicators in New Zealand: Final report". This report will guide future developments of the soil quality indicators used by Regional Councils for State of the environment monitoring and reporting

At the February meeting Forum members gave their support for a Ministry Science Innovation Smart Idea bid ***–"Through the looking glass"*** that will link the disparate frameworks for valuing ecosystem services to develop a decision-support tool to account for the contribution of natural capital and built capital on the flow of ecosystem services across productive environments. The forum is very keen to continue the development of an ecosystem service approach to resource management. In addition to the Forum, three Regional Councils and one District Council are also supporting the MSI bid as part of their own assessment of the approach. Since the start of this project the concepts of ecosystem services has been pickup and used by a number of the forum members. The concept is being used by one Council to allocate a nutrient discharge limit to land. In addition to these initiatives this project has been very instrumental in initiating a review currently being conducted by SLURI for the PCE.

Matthew Taylor from Waikato Regional Council presented a paper on the use of an ecosystem service approach in advancing soil quality indicators on behalf of the team at the European Geosciences Union meeting in Vienna in April. The paper was certainly ahead of much of what was presented, which was still very much around the theory rather than the practical application of the approach.

Visits were made to the Waikato Regional Council and two farms of the little Waipa catchment to gather data needed for use of the ecosystem services framework to explore the links between soil quality indicators and outcomes at the farm and catchment scale on the 18-19th January 2012 and the 8-9th march 2012. A written report covering both case studies testing the usability of an ecosystem services framework to link macroporosity to farm and catchment outcomes has been prepared and will be circulated for comment in July 2012.

The Envirolink tools project has attracted the interest of an international initiative The Economics of Land Degradation (ELD): This is a global study lead by the United Nations and the European Union, to make the economics of land degradation an integral part of policy strategies and decision-making. Ultimately, ELD aims to raise sustainable land management to a higher level of priority on global and national agendas and establish a global standard for land degradation. The Envirolink tools project is of particular interest because the methods used to quantify and value ecosystem services to link soil quality indicators to outcomes at the farm and catchment scale is similar to the method used by the ELD.

Exec Summary of evaluation and lessons learned:
[Include details of any issues with project progress or other concerns]

ALL REPORTS MUST BE SIGNED BY THE RESEARCH ORGANISATION

Notes for Completing the Final Report

This report should capture the learning and outcomes of the project and ***should be signed by the Research Organisation, the Council Champion and Regional Council Governance Committee***

7.4 Briefing paper for the Review of Soil Quality Indicators, 6 May 2011

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Highlights

- Soil quality indicators highlight current and emerging resource management issues
- Several soil quality indicator target ranges should be updated to include advances in research
- Soil quality indicators need to include the value of soil ecosystem services other than productivity

ISSUES to DISCUSS:

- Are current processes robust?
- Are current indicators correct?
- Are current target ranges correct?
- Are there new indicators that should be considered?

Abstract

Soil quality monitoring in New Zealand has become an important State of the Environment reporting tool. Critical to the effectiveness of such a tool is setting relevant, validated thresholds or target ranges for the individual soil quality indicators. Provisional target ranges for individual soil indicators in New Zealand were set in 2003 (Sparling et al., 2003) and revision of these was intended as further information became available. However, apart from restricted internal reviews of some of the target ranges, no overall review has been carried out since 2004. Hence a review of the soil quality indicators for State of the Environment reporting by established experts and regional council scientists is to take place in May. Subsequently, a chapter is to be added to the Land Soil Monitoring Manual, documenting soil quality indicators, target ranges and their justification.

As part of the provision of back ground information for the participants in May, this paper compares results with the original published target data, response curves and newly published data, and reviews the performance of soil quality indicators targets by the Waikato Regional Council. The existing indicators used in New Zealand for soil quality assessment are soil pH, total carbon, total nitrogen, anaerobically mineralised nitrogen, Olsen P, bulk density, macroporosity @-10kPa and aggregate stability.

7.4.1 Background

Regional councils are responsible for managing the long-term sustainable management of resources (air, water, soil etc). Carrying out this responsibility requires accurate information on the current state of the environment (State of the Environment reporting or SOE). Soil quality monitoring provides such data and indicators of soil quality have provided early warning of developing issues before they become serious allowing implementation of resource management techniques such as soil conservation. Resource management issues highlighted by soil quality monitoring include non-point sources of water contamination, assessment of excessive or insufficient nutrients, soil compaction, loss of soil organic matter, erosion and accumulation of contaminants (Taylor et al 2010).

Soil quality monitoring in New Zealand started an innovative research program with Regional Councils playing a supporting role (Sparling et al 2004). Preliminary work started as far back as 1995 but most of the research was carried out 2000-2003. After 2003, the research contract finished but many regional councils chose to continue monitoring as the programme provided base data on the quality of the soil resource under different land management practices.

Critical to the effectiveness of soil quality monitoring are rigorous sampling and measurement protocols and the setting of relevant, validated thresholds or target ranges. Provisional production target ranges were set in a workshop in 2003 using expert opinion and data on production responses. At the time there was little information available for setting environmental criteria (Sparling et al., 2003). In addition, many soil indicators interact with each other, and thus, the value of one is affected by one or more of the selected parameters (Arshad & Martin 2002). Revision of these target ranges were intended as further information became available (Lilburne et al 2004), but that review has been restricted to internal reports on some of the target ranges (e.g. Beare et al 2007, Mackay 2006). A comprehensive review has not been carried out the workshop in 2003 (Sparling et al., 2004). A number of these targets, for total C and N, Olsen P and anaerobically mineralised N, were changed without notification. These revised targets have not been formally vetted by the science community or submitted for publication in a referred journal. This has created two difficulties in the governance for user:

- Policy based on the revised target cannot be supported by documentation
- Some confusion may exist due to the lack of documentation to reference target ranges.

The lack of documentation has serious implications for sustaining consistency in state of the environment reporting. as the reasons for the changes may not be clear. Documentation is particularly important in the New Zealand situation where many soils researchers are of retiring age and there exists a considerable risk of loss of Institutional knowledge. Some of the difficulties currently facing practitioner is in part due to the evolution of the purpose of the State of the Environment reporting and the original objectives of the 500 Soils Programme (Table 1).

Table 1 Comparison of 500 Soils and Regional Council Soil Quality Monitoring Programmes.

500 Soils Programme	**Regional Council Soil Quality Monitoring Programme**
Research programme	State of the Environment reporting
Output focused	Procedure and assessment focused
Funded by MfE and councils - Funding ceased ~2003	Funded by individual Councils
Updated methodologies in response to developing knowledge	Consistency in procedures to provide meaningful comparisons over time
Updated functions in response to developing knowledge	Consistency in targets to provide meaningful comparisons over time
Primarily production orientated on a 5 year timeframe	Production and environmentally orientated on a 50 year timeframe
National scale	Regional scale
~500 sites nationally	~1000 sites nationally (thus far)

To obtain consistency across Regional Councils and to document methods and procedures, Regional Councils, through the Land Monitoring Forum, produced the Land and Soil Monitoring Manual. A further chapter is to be added to this manual, documenting soil quality indicators, target ranges and their justification, giving opportunity for a review by established experts and regional council scientists. This group will need to consider a wide range of factors during the review including:

- The requirements for Regional Council State of the Environment reporting
- Target ranges for indicators of soil quality have traditionally been limited to production outcomes. To meet the needs for Regional Council's State of the Environment reporting must also includes environmental outcomes
- For some current soil quality indicators there is still a poor understanding and hence definition of what is the desirable range for a soil.
- Although based on response curves, inconsistent application of the data to derive existing indicator targets confuses the issue, e.g. lower limits of a target vary between 50-90% of optimum production without any obvious reason (such as an impact on an environmental service other than production), rather than setting a target based on, for example 90% of optimum.
- Research continues requiring the update of the target range of several indicators.
- Soil quality issues have arisen that were not covered in the original set of indicators.
- Additional indicators could provide valuable management and reporting information.

7.4.2 Typical Methodology for Soil Quality Monitoring

Soil quality monitoring sites are chosen and sampled according to the Land and Soil Monitoring Manual (Hill & Sparling 2009). Samples consist of a composite of 50 soil cores (0-100 mm) taken over a 50 m transect and three 100mm wide by 80 mm deep cores for physical analysis. Sites are classified according to land use. Dairy are long-term pasture with milking cows, dry stock were all other long-term pasture, cropping are sites that are tilled annually, horticulture are sites with perennial vines bushes and trees have not been tilled since establishment, forestry are production pine forests and indigenous are native New Zealand forest and wetlands. Samples from cropping land uses are sampled just before harvest (about February), when the soil is at its most stable. All other land uses are sampled at the end of spring (about November), while they were close to but did not exceed field capacity, and swelling clays were at their wettest. Soils are classified according to the New Zealand Soil Classification (Hewitt et al., 2003)

Samples are analysed for pH (in water), total C, total N, Olsen P, anaerobically mineralised N, bulk density, macroporosity (-10kPa) and aggregate stability. All analyses are carried out at IANZ-accredited laboratories (Landcare Research and Plant & Food Research) according to the Land and Soil Monitoring Manual (Hill & Sparling 2009). All results and target ranges are presented on a gravimetric basis. Summary statistics are calculated using Data Desk version 6. The data was log-transformed to make a normal distribution for significance testing where necessary.

7.4.3 Individual indicators

7.4.3.1 Soil pH in water

In many parts of the world, including New Zealand, soil acidity is an important constraint to agriculture (Fageria 2009). This constraint is usually overcome by liming. There is an optimum pH range for plant growth and animal performance, assessed by a production response curve. Similarly, an environmental response curve can be made to assess the target range for environmental goals. Target ranges are given in Sparling et al (2003) for pasture, cropping and horticulture, and forestry on mineral and organic Soils (Table 2). These target ranges are based on a combination of measured-production and estimated by expert committee-environmental response curves.

Table 2.Target ranges for pH

Land use	Current Target	Suggested Target
Pasture on all soils except Organic Soils	5.0-6.6	Same as current
Pasture on Organic Soils	4.5-7.0	Same as current
Cropping & horticulture on all soils except Organic Soils	5.0-7.6	Same as current
Cropping & horticulture on Organic Soils	4.5-7.6	Same as current
Forestry on all soils except Organic Soils	3.5-7.6	Same as current
Forestry on Organic Soils	Exclusion	3.5-7.6
Indigenous	None	Exclusion

No targets are provided for indigenous sites as soil pH is determined by parent material and specialised indigenous plants grow in the various environments created. Indigenous sites can, however, provide useful background measurements and verification of environmental targets. Changes in indigenous sites, particularly trends in data, can also identify unexpected anthropogenic and natural impacts (e.g. acid rain).

An assessment of the scientific literature provides little reason to significantly change target ranges. Beare et al (2004) collated data from 4 New Zealand studies to generate tables for optimum soil pH for arable and pastoral crops, while Reid et al (2006a, 2006b and 2006c) produced best management practices for tomatoes, maize and sweet corn. Grapevines have a very wide optimum pH range, depending on the type of rootstock (Cooperative Research Centre for Viticulture 2006, Caspari 1996). These data are summarised in Table 3. No target was given for forestry on Organic Soils but this does occur in other parts of the world and could arise in New Zealand. It seems sensible to include a target range for forestry for these soils.

Table 3. Update. Optimum soil pH range for selected crops

Crop	Optimum soil pH
Tomatoes	>5.0
Oats	5.1-6.5
Swedes and Turnips	5.4-6.7
Sweet Corn	5.5-7.0
Grapevines	5.5-7.5
Wheat	5.6-6.2
Grass/Clover pasture	5.6-6.3
Maize and Corn	5.7-6.2
Grain Maize	>5.0
Most Grasses	5.8-6.0
Barley	5.8-6.5
Peas	6.0-6.5
Lucerne and Clover	6.0-7.0
Forestry	???

Looking at the data from the Waikato Regional Council soil quality monitoring programme no sites were found with soil pH outside the current and suggested target ranges. No trends in soil pH values were identified in the latest sampling in the Waikato Region. These results are consistent with farmers managing well acidity in their soils and the low acid rain forming potential of industry in New Zealand. This indicator appears to be working well in the Waikato region and would only appear to require an update to extend the number of crop types included in the indicator table.

There seems little need to make changes target ranges? Is this the case in the rest of New Zealand?

7.4.3.2 Total Carbon

New Zealand soils, generally, have high levels of total C and very low concentrations of carbonate, so total C is a good representation of Soil Organic Matter (SOM) in New Zealand soils. Tillage and erosion have been shown to greatly affect soil carbon, with rapid decline in carbon concentrations when native soils are tilled, while erosion can selectively move carbon off-site, and deposit it elsewhere in the landscape. Soils with low SOM have reduced productivity and are more susceptible to erosion. Aggregates can detach and erosion increase once a threshold clay/SOM ratio is passed (Wuddivira et al 2009). Soil structure decreases rapidly once soil carbon drops to below 2.5% (Reid et al 2006a, b, c).

Organic Soils form by a completely difference process to that for mineral soils and accumulate carbon in different ways, e.g. C in peat soils is protected from oxidation by high water tables, while C in mineral soil is protected from oxidation by binding soil clays. When peat is drained, the surface decomposes at about 1 cm per year (Schipper & McLeod 2002) and the annual net loss of carbon measured at about 1000 kg/ha (Nieveen et al., 2005). Organic Soils must have > 18% total C w/w by definition (Hewitt, 2003), so the current targets are not useful for this soil order. Organic soils may therefore require a different set of soil quality indicators compared with mineral soils to achieve meaningful results. If so, would that target range look like?

Soil carbon in mineral soils is influenced by both the soils mineralogy and the climate. Sparling et al., (2003) divided soil orders into three distinct groups (Table 4). As the response curves were asymptotic and reaching a plateau anywhere above, but between 2-6%, more was considered better and no upper target was set for total carbon in the 2003 workshop (Sparling 2003). The lower targets are based on a combination of production and environmental response curves In contrast, Reynolds et al (2008) after assessing indicator soil properties in Canada, gives a critical upper limit of <6%, above which the soil may be excessively prone to compaction and/or absorption of pesticides. Reynolds et al (2008) also gives a lower target of >2.3% below which tillage-induced loss of soil structure may occur. This value is similar to the lower target value from Sparling et al (2003) of >2-3% (depending on the soil type).

This lower target is considerably below the optimum for maximum production. The suggestion here is to define the lower targets, based on 90% of the higher of the environmental or the production response curve of Sparling et al (2003). This gives lower targets for total carbon of >5.5% for the Allophanic Soils, >2.5% for Pallic, Pumice and Recent Soils and >3.5% for all other soil orders except Organic Soils, which as explained above, is excluded.

Table 4. Target ranges for Total Carbon (%)

Soil Order	**Current Target**	**Suggested Target**
Allophanic Soils	3	5.5
Semiarid, Pallic & Recent Soils	2	2.5
Other soil orders except Organic Soils	2.5	3.5
Organic Soils	Exclusion	To be investigated

The economic benefits of C and N storage in soil are discussed together as these are intricately linked together. The economic benefits of simple C and N sequestration in soil have been shown to outweigh the benefits to production by 1-2 orders of magnitude (Sparling et al 2006).

Table 5. Percent of soil samples outside current and suggested updated target limits for total C by soil and land use in the Waikato Region

Land use	Current Target %w/w Allophanic >3% Semiarid, Pallic & Recent > 2% Other >2.5%	Suggested Target w/v Allophanic >30 kg m^{-3} Semiarid, Pallic, raw & Recent > 2 kg m^{-3} Organic >100 kg m^{-3} Other >25 kg m^{-3}	Suggested Target %w/w Allophanic >5.5% Semiarid, Pallic & Recent > 2.5% Other >3.5% Organic Excluded
Dairy	3	0	3
Dry stock	0	0	0
Cropping & Horticulture	6	6	34
Forestry	0	0	0
Indigenous	0	9	Exclusion

The economic value of the ecosystem services from soil are very much greater as environmental services, such as flood mitigation, GHG regulation, filtering of nutrients and contaminants detoxification and the recycling of wastes and the regulation of pests and disease populations, than production or provision services such as the provision of water and nutrients and physical support (Dominati et al., 2011) In setting the original targets, only the provisioning services were considered (Sparling et al., 2006).

Applying the current total C targets to the Waikato Regional Council soil quality monitoring results showed about 6 % of cropping and horticulture sites, along with 3% of the dairy sites were below the indicator target (Table 5). The proportion of sites meeting/not meeting the indicator target has remained fairly static over the period of monitoring and no trend is apparent (Taylor 2010). However, there has been a considerable decline in soil C concentrations in the monitoring data (average 9.9% in 2003 to average 9.4% in 2009), and therefore SOM (Taylor 2010). This decline was most strongly pronounced in soils under arable land use, but some dairy soils were reported as losing more C and N than dry stock and hill country areas and dairy farms on non-Allophanic Soils. Schipper et al., (2007) reported losses an average of up to approximately one tonne of soil C per hectare per year in some parts of the country. Relying on threshold values, such as indicator targets, may be insufficient to accurately represent the state of the soil environment for carbon and assessment of trends from actual concentrations may also be necessary. Two new suggested targets applied to the Waikato Regional Council soil quality results in Table 5 would indicate that raising the threshold for total C seems to better reflect field observations of loss of SOM in soil under cropping. The loss of carbon from cropping land may result in a lessoning ability to hold N. The total C indicator appears to provide useful information for SOE reporting but the target ranges may need to include environmental services other than production. Linking the soil C estimate to a process model to explore the likely possible future trends in soil C may offer another option going forward.

7.4.3.3 Total Nitrogen

High concentrations of total N in soil may be a source for NO_3, from mineralization which can be leached to ground or surface waters and cause eutrophication, or N_2O, a greenhouse gas. The current levels of total nitrogen in soil associated with intensive pasture agriculture are also linked to degrading water quality as nitrogen concentrations in streams, seen in long-term records of river water quality in the Waikato Region, continue to increase at about 1% of the median value per year (Vant, 2008). Total soil N by plant productivity response curves were only produced for pasture and forestry land uses due to insufficient data for other land uses (Sparling et al 2003). Maximum production was seen at 0.7 % N for pastoral soils and 0.3 % N for forestry soils. No differentiation was made between soil types or orders. Current target ranges are 0.25 – 0.70 % for pasture and 0.10-0.70 % for forestry. Total N is typically associated with SOM as organic N usually comprises more than 90% of the total N. Soils with high SOM content can potentially hold more N than those with less SOM. N availability may differ between different soil types, e.g. a separate target range may be required for Organic Soils.

For the sake of argument if the 0.7% N upper limit is applied to all soils and land uses in the Waikato Regional Council soil quality monitoring results some interesting discrepancy are found. A fifth of indigenous forest (on high C soils, with high C:N ratios) exceeded 0.70% total N, and several pasture farming sites on Organic Soils exceeded 0.70% total N, with C:N ratios of around 20. Converting results and targets to a weight/volume basis may overcome this discrepancy as they effectively take the C content of the soil into account in the conversion using bulk density. Possible target indicators ranges for total N on a weight/volume basis (Brian Stevenson, Landcare Research, pers. comm.) and the proportion of samples above 0.7% total N (weight/weight) are presented for comparison (Table 6). Clearly, the proportion of samples meeting/not meeting targets varies depending which target is used but the volumetric targets appear more rational than the gravimetric ones on an empirical basis. Would it be better if results and targets are converted to a volumetric measure? Some cropping sites had low total N values between 0.10% and 0.25% and could be limited in production but there is no target range for this land use

Table 6. Percent of soil samples exceeding target limits for total N by land use in the Waikato Region

Land use	Current Target Forestry 0.10-0.70% Pasture 0.25-0.70%	% samples exceeding 0.70% N	Spreadsheet Target Pasture 2.5-7 kg m^{-3} All other land uses 1-7 kg m^{-3}
Dairy	50	50	18
Dry stock	64	64	39
Cropping & horticulture	Exclusion	13	3
Forestry	18	18	0
Indigenous	No target	18	0

Contrary to the results for total C, soil total N concentrations in the monitoring data have trended upwards (average 0.68% in 2003 to average 0.71% in 2009, Taylor 2010),reflecting the ongoing lifts in soil fertility through increased inputs of P and N as fertilisers and supplements. Similar to total C, assessment of trends from actual concentrations may also need to be included, as well as meeting threshold values, to more accurately represent the state of the soil environment for soil N. This indicator seems to have some limitations in assessing excessive or deficient soil nitrogen levels. Using the soil total N as input into a process model to explore the impact of a change on emission to air or water may offer greater utility than investing in more calibration curves. Further discussion on the complexity of nitrogen behaviour in soil is presented towards the end of this paper.

7.4.3.4 Anaerobically Mineralised Nitrogen (AMN)

This is a laboratory measure of the amount of N that can be mineralised through the decomposition of organic matter. Like total N, low concentrations of AMN tend to reflect soils with low available N for production and high concentrations are of potential environmental concern as they can indicate a large source of NO_3 for leaching or N_2O for gaseous losses. Andersson et al., (2002) found enhanced N leaching only detectable at sites with high net N mineralisation and low C:N ratio. They showed the net N mineralisation rate in a given soil horizon was strongly dependent on the C:N ratio, despite large differences between sites associated with climate, land use and mode of N addition (deposition or fertilisation). The existing targets recognise the greater organic N (and C) contents of soils under some land uses, but not the same greater organic N and C contents for Organic Soils, nor the influence of the C:N ratio. Converting results and targets to a weight/volume basis may help in some way to take these factors into account as describe for total N above.

AMN Response curves were produced for pasture and forestry land uses, while the response curves for cropping and horticulture land uses were poorly defined (Sparling et al., 2003). No differentiation was made between soil types. Differences in characteristics and behaviour between mineral soils and Organic Soils may require separate target ranges under the different land uses. The current target ranges are 50 –

250 mg/kg for pasture, 20 -175 mg/kg for forestry, and 20 – 200 mg/kg for cropping and horticulture.

Applying the targets to the Waikato Regional Council soil quality dataset showed that most soils under cropping tend to have low concentrations of AMN (Table 7). Conversely, soils under pastoral land uses tended to have higher concentrations of AMN with about 20% of sites above target. Evaluated on a weight/volume basis all pastoral sites met indicators ranges for AMN (Brian Stevenson, Landcare Research, pers. comm.). Further discussion on the complexity of soil N behaviour is presented in a later section. Does AMN provide additional information not obtainable from other indicators?

Table 7. Percent of soil samples not meeting target limits on a weight and volume basis for anaerobically mineralised N by land use in the Waikato Region

Land use	Current Target Forestry 20-175 mg kg^{-1} Pasture 50-250 mg kg^{-1} Cropping & Hort 20-200 mg kg^{-1}	Possible Volumetric Target Indigenous, Forestry 20-175 mg cm^{-3} Pasture 50-250 mg cm^{-3} Cropping & Hort 20-200 mg cm^{-3}
Dairy	15	0
Dry stock	22	0
Cropping & horticulture	3	3
Forestry	5	0
Indigenous	No target	0

The AMN indicator is strongly correlated with Total N (r=0.726, n=244) and aggregate stability (r=0.724, n=90) (Table 8)

Table 8. Correlations between Total C, N, AMN, macroporosity and aggregate stability

	n	Total C	Total N	AMN	Bulk Density	Macroporosity	Aggregate stability
Total C	244	1					
Total N	244	**0.866**	1				
AMN	244	**0.655**	**0.726**	1			
Bulk density	244	**-0.767**	-0.555	-0.414	1		
Macroporosity	242	0.092	-0.214	-0.255	-0.505	1	
Aggregate stability	90	0.560	**0.593**	0.724	-0.311	-0.208	1

7.4.3.5 Olsen P

The soil Olsen P test was developed as a measure of plant available P. It is an empirical measure of soil P that has been calibrated in numerous field studies examining the relationship between Olsen P and pasture growth over the last 40+ years to provide an indicator of plant available P (Roberts and Morton 1999). It is used primarily as a production indicator, but is also used along with anion storage capacity as an indicator of the risk of soil P loss in surface run-off to the wider environment. Low Olsen P values indicate conditions where soil P is limiting pasture growth, while high Olsen P concentrations increases the risk of P transfer in surface run-off to surface water and possibly leaching. Avoiding extremes is important in ensuring efficient use of P inputs to retaining optimum conditions for plant growth, while minimising the risk of potential increases of P losses in surface run-off.

Separate Olsen P relative pasture yield calibration curves have been derived for different soil orders (Roberts and Morton 1999) and land uses (Sparling et al 2003). The current industry standard for the critical soil Olsen P for 97% of maximum pasture production are 20 and 22 µgP/ml for a sedimentary and volcanic ash soil, respectively (Roberts & Morton 2009). Because of the variability in the calibration curves between Olsen P and relative pasture production, and also in soil test results, Roberts & Morton (2009) point out there is no precise soil P level that will guarantee a particular level of pasture production. The reason for the wide scatter of relative yield (RY) points with any Olsen P value can be related to variability in the effects of unrecorded 'other factors', such as moisture and N availability, affecting pasture growth. The adoption of a range in Olsen P values as a guideline for fertiliser recommendations is recognition of the effects of these unrecorded 'other factors' on pasture growth on each farm.

Roberts & Morton (2009) recommend that to reduce the risk of under-fertilising pastures for sites that may fall below the average curve, two target ranges should be added, with the range based on production of milk solids/ha. For both sedimentary and volcanic ash soils the target Olsen P range is 20-30 µgP/ml where milk solids production/ha is near the average for the local supply area, and 30-40 µgP/ml if production is in the top 25% for the local supply area (Roberts & Morton 2009). At the other extreme, when comparing results from 0-20 and 30-40 degree slopes in Waikato hill pasture, Gillingham *et al.* (1984) found that near maximum pasture production from summer-dry steep slopes was at an Olsen P of 10 µgP/ml, whereas maximum production from gentle slopes was two-fold higher with an Olsen P of 15 µgP/ml. This finding suggests that as the constraints to the expression of pasture response to added P decreased the critical Olsen P value increased.

Table 9. Olsen P concentration required to achieve 97% maximum production for pasture (derived from Edmeades et al 2006)

New Zealand Soil Order	97% max Olsen P mg/kg
Raw Soils (Sands)	12
Recent Soils and Podzols	25
Allophanic, Oxidic and Granular Soils	32
Organic Soils	40
Pumice Soils	50
Other Soils	30

In a review of the soil P database on which the calibration curves of Roberts & Morton (2009) were based, Edmeades *et al.* (2006) derived higher critical Olsen P levels for 97% maximum pasture production for all soil groups. They re-examined the 2255 soil P field trial data base that had been used earlier by Roberts and Morton (1999) finding there was little, if any, increase in relative pasture production ($P < 0.05$) at an

Olsen P of 50 mg/kg. The Olsen P concentration required to achieve 97% maximum production for pasture ranged from 12 – 50 mg/kg, depending on the soil type (Table 9).

It is important to note that the soil quality samples are taken to a depth of 100mm whereas the Edmeades et al (2006) study was based on samples taken to a depth of 75mm. Using these figures for soil quality targets then builds in a conservative safety factor to ensure production. This data has been reworked in Table 9 to fit the New Zealand Soil Classification (Hewitt 2003). The higher critical Olsen P values reported by Edmeades et al., (2006) compared with the earlier study of Roberts and Morton (1999) can be explained in part by the application of a more rigorous protocol in the selection of the soil P field trial data sets for inclusion in their analysis. In addition, whereas Edmeades et al., (2006) reports Olsen P values on a weight basis, Roberts and Morton (1999) reports Olsen P values on a volume measure.

In a recent study by Mackay et al., (2010) exploring the P requirements of high producing perennial ryegrass (*Lolium perenne*) and tall fescue (*Festuca arundinacea*)-based pastures, at field sites in the Waikato, Manawatu, Canterbury and Southland where the constraints to pasture growth and associated P uptake imposed by low nitrogen (N) availability and soil moisture over summer-autumn and poor physical condition of the soil have been removed indicate that the critical Olsen P level for near maximum (97%) pasture production is greater than current industry standard. It is important to note that a different model- fitting approach was used to calculate the critical Olsen P value in the studies of Roberts & Morton (2009) and Edmeades *et al.* (2006). This may explain in part the difference in the derived critical Olsen P values. It is also important to note however that over 70% of the soil P field data base on which the production function between Olsen P and RY for the major soil groups is based, came from permanent pastures producing <10 000 kg DM/ha/yr. Little fertiliser N was applied in these studies and few were irrigated. It is also worth noting that compared the critical Olsen P values found in the study of Mackay et al., (2010), Gillingham *et al.* (1984) found near maximum pasture production at a critical Olsen P level of 15 µgP/ml or less, and Gillingham *et al.* (2007) found near maximum pasture production at a critical Olsen P level <20 µgP/ml for sheep and beef pastures located on the East Coast of both Islands.

The field sites of both of Gillingham's studies were characterised by old resident pastures, where frequent seasonal moisture deficits occurred. Pastures were grass-dominant and overall levels of production low, due to the combination of limited soil N availability from poor legume growth and moisture. This contrasts sharply with the characteristics of the field sites of Mackay et al., (2010). It raises the question of the merit of continuing with a single relative response curve and critical Olsen P value for 97% of maximum production regardless of the absolute level of pasture production. It also suggests that as constraints are removed and production increases, so does the critical Olsen P value.

Aligning or exploring trade-offs' between the critical Olsen P value for maximum pasture production and water quality outcomes requires adding the soils anion storage capacity. Assessing the risk of P losses in run-off with Overseer allows inclusion of other variables that are likely to influence the risk of P losses by run-off as Olsen P values increase. We know that soil P concentration influences stream P concentrations (McDowell et al. 2001) and about 77% of P entering streams is attributable to pastoral farming (Environment Waikato 2008). Soil P concentrations are increasing in the Waikato and are likely to be responsible for the increased P concentrations in surface waters. As a consequence the current upper target range boundary does not seem to be protecting water quality as P concentrations in streams, seen in long-term records of river water quality in the Waikato Region, as the Olsen P values are increasing at about 1% of the median value per year (Vant 2008). In drawing that conclusion an examination of the Olsen P values from the Ravensdown Fertiliser Company data base finds that over 20% and 40% of the dairy farms on sedimentary and volcanic soils, respectively, have Olsen P values beyond the upper target range (>40 ug/ml) recommended for those producers with milk solids production/ha in the top 25% for the supply area or who intended to increase milk production to that level.

Table 10. Target ranges for Olsen P in mg kg^{-1}

Land use	Current Target	Revised Target*
Forestry on all soils	5-100	5-50
Celery, Leeks, Winter Lettuce, Onions, Early Potatoes, Winter Spinach on Recent and Pallic Soils	20-100	45-55
Celery, Leeks, Winter Lettuce, Onions, Early Potatoes, Winter Spinach on Brown, Gley, Melanic, Organic, Pumice, Semi arid and Ultic Soils	20-100 or 25 -100	55-75
Celery, Leeks, Winter Lettuce, Onions, Early Potatoes, Winter Spinach on Allophanic, Granular and Oxidic Soils	20-100	75-90
Pasture, other cropping and horticulture on Andisols	15-100 or 25-100	35-60
Pasture, other cropping and horticulture on Pumice Soils	15-100 or 25-100	35-60
Pasture, other cropping and horticulture on Organic Soils	15-100 or 25-100	35-50
Pasture, other cropping and horticulture on Recent Soils and Podzols	15-100 or 20-100	20-50
Pasture, other cropping and horticulture on Raw Soils	none	10-25
Pasture, other cropping and horticulture on other soil orders	15-100 or 20-100	25-50
Indigenous	none	Exclusion-50

***Note** . This is for a soil sample 0-10 cm.

Watts et al., (2008) showed there was little, if any, increase in relative forestry production above Olsen P of 25 mg/kg, while considerable work has also been done on P requirements for most crops grown in New Zealand (Beare et al., 2004, Reid et al., 2006a, b, c, HortResearch, 1995). Olsen P targets are based on crop type and the anion storage capacity of the soil.

Of crops commonly grown in New Zealand, potatoes and members of the onion family seem to have the highest requirements for P fertiliser and can have yield responses at high Olsen P values – if the grower gets everything else correct, e.g. “For growing potatoes in a soil of field bulk density 0.7 and lab bulk density of 0.8 g/ml (not unusual for the Waikato Region) if the maximum yield is

- 80 t/ha (good spring sown crop, no drought, other nutrients and disease not limiting) then the optimal Olsen P is about 88 µg/ml
- 40 t/ha (winter crop, no drought, other nutrients and disease not limiting) then the optimal Olsen P is about 44 µg/ml.

Close to the optimum there is very much a law of diminishing returns" (Jeff Reid, Plant and Food Research, pers. comm..).

Some suggested target ranges, base on available literature are presented in Table 10 and impacts on samples meeting/not meeting targets are presented in Table 11. Applying the current and suggested targets to the current Waikato Regional Council soil quality dataset showed many sites did not meet the targets. There was about a 50:50 split in the sites not meeting targets with half were above the upper target and half were below the lower one. A far greater number of sites are not meeting the suggested target compared with the current targets and this may reflect an opportunity for improved efficiency of phosphate fertiliser use. This indicator seems to require revised target ranges to be more useful as a tool for SOE reporting.

Table 11. Percent of soil samples not meeting target limits for Olsen P by land use in the Waikato Region

Land Use	**Current Target** Forestry 5-100 mg kg^{-1} Pasture 15-100 mg kg^{-1} Cropping & Hort Organic & Pumice Soils 25-100 mg kg^{-1} Other soils Cropping & Hort 20-100 mg kg^{-1}		**Revised Target** See Table 10	
	Below lower limit	Above upper limit	Below lower limit	Above upper limit
Dairy	0	16	8	58
Dry stock	28	10	54	24
Cropping & Horticulture	0	11	18	34
Forestry	12	0	12	0
Indigenous	No target	No target	Excluded	Excluded

7.4.3.6 Bulk Density

Bulk density often exhibits complex, soil specific or site specific interactions that are not consistent or predictable (Reynolds et al 2008), making development of target ranges challenging. Separate production response curves for bulk density were described based on soil order, but insufficient data were available to differentiate between land use categories (Sparling et al 2003). Target ranges are broad and may need to be tightened up to make this indicator more meaningful. Recently, Watt et al (2008) presented a production response curve for bulk density in soil under forestry. Productivity declined above 1.25 g/cm^3, and below 0.92 g/cm^3. However, the decline in productivity below 0.92 g/cm^3 was attributed to concurrent increased P-retention within these sites, not to bulk density itself. Beare et al (2004) showed arable cropping yields decreased as bulk density increased and bulk density should be maintained below 1.1 g/cm^3 to reduce the risk of production losses. Setting target indicators for bulk density is complicated by the influence of other soil and non-soil parameters. For example Parent et al (2008) showed silage maize appeared to be more sensitive to changes in bulk density in clay soils than in sandy soils while the bulk density upper limit favourable to silage maize was found to be 0.99 g/cm^3 in a clay soil during a wet year in Quebec (330 mm of rainfall in June, July and August) compared to 1.13 g/cm^3 in average years, whereas an increase of 0.14 g/cm^3 in bulk density resulted in large yield losses across years (McKyes, 1985, quoted in Parent et al 2008). In comparison, a bulk density optimum of 1.40 g/cm^3 in a sandy loam and a dramatic drop in silage maize yield when bulk density exceeded 1.45 g/cm^3 was also reported by McKyes (1985). Reynolds et al (2008) used structural regression to predict an optimal range of 1.10 - 1.23 g/cm^3 for a clay loam and compare that with an optimal bulk density range of 0.9 -1.2 g/cm^3 for medium-fine textured soils. At the high end, a critical upper bulk density value of 1.60 g/cm^3 has been found in Belgian sandy loams (Vrindts et al 2005).

Applying the current targets to the current Waikato Regional Council soil quality dataset showed no sites had bulk density above the upper target, while 55% of indigenous, 43 % of forestry, 3 % of dairy and 3 % of cropping and horticulture sites had low bulk density and may be prone to erosion. Many soils within the region are very light and with ash and pumice, making them vulnerable to erosion. The large proportion of indigenous and production forestry sites not meeting the lower bulk density target reflects the management practice to leave erosion prone soils in native bush or planted in production forestry as trees reduce the amount of rain impacting the ground, thus reducing erosion risk, while bare ground has a higher erosion risk. The bulk density indicator is providing warning that care is needed at harvest or conversion of such land to another land use. Note that bulk density would need to be measured if volumetric measurements were used for total C, total N AMN or Olsen P or other, new indicators.

7.4.3.7 Macroporosity @-10kPa

Soils with low macroporosity have reduced soil aeration and living space for beneficial soil organisms, and decreased productivity when the soil is wet for prolonged periods, while high macroporosity infers loose soil, which is vulnerable to erosion and has poor water capillary.

Table 12. Target ranges for Macroporosity @ -10 kPa in %

	Current Target	Revised Target
Pasture, cropping and horticulture	10-30	12-30
Forestry on Ultic Podzol and Gley Soils (Ultisols, Spodosols, Aquepts & Aquents)	8-30	22-40
Forestry in low rainfall environments	8-30	8-30
Forestry on other soils	8-30	8-36
Indigenous	No target	Exclusion

Two response curves were initially produced, one for forestry and one for pasture, cropping and horticulture (Sparling et al 2003). Mackay et al., (2006) reviewed and updated macroporosity targets and these are now the current targets of Table 12. Targets should also recognise the impact of imperfect drainage combined with high rainfall for certain soil types (Mackay et al 2006). Suggested targets reflecting the higher of 90% optimum productivity and environmental protection from Sparling (2003) and Mackay et al., (2006) are presented in Table 12.

Applying the current targets to the Waikato Regional Council soil quality dataset showed a large proportion of sites below targets (Table 13) and this proportion is even greater if the suggested targets are applied. These results suggest surface compaction is a larger issue than previously thought and there are potential production benefits to be made if it can be reduced. There are also large environmental gains, by increasing the proportion of rainfall that infiltrates the soil rather than runs off. Conversely, similar proportions of sites were above targets for both the current and suggested targets reflecting the management practice to leave erosion prone soils in native bush or planted in production forestry. Care is needed at harvest or conversion of such land to another land use as trees reduce the amount of rain impacting the ground, thus reducing erosion risk, while bare ground has a higher erosion risk. Special care is needed when harvesting forests or changing land use on these sites.

Table 13. Percent of soil samples not meeting target limits for macroporosity @-10 kPa by land use in the Waikato Region

Land Use	**Current Target**		Revised Target (Table 12)	
	Below lower limit	Above upper limit	Below lower limit	Above upper limit
Dairy	56	3	70	0
Dry stock	42	6	84	4
Cropping & Horticulture	13	13	21	11
Forestry	0	48	0	41
Indigenous	No target	No target	Exclusion	9

The macroporosity indicator seems to be providing useful information on surface soil compaction and on identification of areas of high potential erosion risk.
In some recent study Mackay et al.,(2010) has found an interaction between the physical condition of the soil, Olsen P level and pasture growth. There initial findings suggest that the Olsen P x pasture RY function is modified by the physical condition of the soil. The negative impact of a compacted soil on pasture growth appears to be offset to some degree by lifting the Olsen P value. Inclusion of a measure of soil physical condition in either the derivation of relative P response curves or in the interpretation of the Olsen P test value would appear to warrant further study, given the increasing cost of this nutrient, and the potential impact that soil with limited pore function and elevated Olsen P could have on surface water quality.

7.4.3.8 Aggregate stability

Aggregate stability, the ability of soil aggregates to resist disruption when outside forces (e.g. cultivation, raindrop impact) are applied, is commonly measured on soils used for cropping. A loose assemblage of aggregates between 0.35-12 mm allows unimpeded root growth (Tardieu et al 1992) and their easy access to air, water and nutrients, while decreased aggregate size may increase P leaching risk (McDowell et al 2006). Also, aggregates with low structural stability have increased risk of erosion by water or wind and lower crop yield (Beare et al. 2005).

The aggregate stability indicator has less experimental data behind it validation than the other soil quality indicators. A production response curve for aggregate stability WMD for cropping and horticulture on Recent and Pallic Soils was presented in the appendix of Sparling et al (2003). Production maximum was at 2.5 mm MWD and 95% was at 1.7 mm MWD, while Beare (2005) showed the level at which production decreased is 1.5 mm MWD. This is a production target. No data for other soil types or land uses were presented.

Aggregate stability has been carried out on 90 sites in the Waikato region soil quality dataset (Table 14). Applying the 1.5 mm MWD target showed 30 % of cropping sites did not meet this target, consistent with field observations of low structural stability and high erosion risk for these soils. Surprisingly, 43% of recent conversions from forestry to pasture on pumice soils also did not meet the 1.5 mm MWD target. This result is consistent with field observations of very low aggregate formation in these soils, probably due to the loss of SOM.

Table 14. of soil samples not meeting target limits for aggregate stability by land use in the Waikato Region

Landuse	<1.5mm MWD
Annual Cropping	70
Horticulture	100
Forestry	100
Dairy Pasture	100
Conversion pasture	57
Other Pasture	97

It was expected there may be interdependent interactions between aggregate stability, macroporosity and SOM, e.g. sequestering soil carbon was shown to increase macroporosity and aggregate stability (Deuwer et al 2009), and the stability of the aggregates positively influences the stability of macropores networks (Le Bissonais & Arrouays, 1997). Indeed, the dataset showed a significant ($p < 0.0001$) correlation between aggregate stability and total C ($r = 0.560$, $n = 90$, Table 8) but not between aggregate stability and macroporosity ($R=-0.208$). A possible reason for the low correlations between macroporosity and aggregate stability (and macroporosity and total C) is the impact of land use is dominating. Most of the low macroporosity sites are under animal grazing and these sites are being compacted regardless of their aggregate stability or total C content. Thus, aggregate stability is not a useful indicator of compaction.

Measuring the rate of rewetting after air drying may be also useful in interpreting aggregate stability measurements. Eynard et al., (2006) showed hydrophilic organic components deposited along a network of inter-connected pores strengthened natural aggregate structure under grass. If water entered aggregates faster than intra-aggregate pore stability can withstand, soil structure could be disrupted and water infiltration hindered by pore sealing, but a relatively high rate of water uptake at low water tension could take place within aggregates with stable intra-aggregate pore structure.

The aggregate stability indicator seems useful for indicating loss of soil stability and increased erosion risk. However, its usefulness seems limited to cropping soils and recent conversions from forestry to pasture on Pumice Soils. Future work could focus on confirming the production response curve for the range of soil orders and land uses and developing environmental response curves, possibly focused on erosion potential.

7.4.4 The Complexity of Nitrogen and the identification of an indicator

The complexity of N transformations in soils and transport will require assessment of several indicators and measurements, e.g. total N, C:N ratio, rooting depth, stoniness, anaerobically mineralised N measurements, the soils potential for bypass flow, nitrate reduction and denitrification to be able to link the existing indicators (Total N and C and AMN) to outcomes (e.g. nitrate leaching) .

For example high concentrations of total N create a potential source for nitrate leaching or nitrous oxide gas (Sparling 2003). Dise et al., (2009) found the most consistent and useful indicators of NO_3^- leaching were nitrogen deposition, C:N ratio and mean annual temperature. Andersson et al., (2002) found a threshold value for leaching at about 90 kg N ha^{-1} per year for inputs of N-fertiliser + N-mineralisation but enhanced NO_3^- leaching was only detected at sites with high net N mineralisation.

The soil C:N ratio controls nitrogen availability (Figeria 2009), e.g. net N mineralisation rate has been shown to correlate with the soil C:N ratio (Andersson et al., 2002) and higher C concentrations can lead to greater mineralisation and increased leaching (Lilburne & Webb 2002). However, soils with a large proportion of recalcitrant carbon are likely to begin leaching nitrate at a higher C/N value than soils with more labile carbon (Rowe et al 2006). The C:N ratio threshold values have also been measured for carbon dioxide emission (Thomsen et al 2008). A narrow C:N ratio is advantageous for productivity but a wide ratio is advantageous for environmental outcomes. Productivity drops off with increased C:N ratio, in the absence of added N fertiliser, as competition for N by micro-organisms and plants increases, which may lead to N deficiency. Conversely, reports indicate a threshold for N leaching has been seen when the C:N ratio drops below 25 (Gundersen et al., 2006, Macdonald et al., 2002), or 27 for deciduous woodland and acid grassland and 50 for coniferous woodland and heathland (Rowe et al 2006). Soils may have little capacity to hold further N once the C:N ratio drops below 10 (Schipper et al 2004). Also, strong negative relationship between soil C:N ratio and emission of nitrous oxide (Klemedtssen et al 2006), and maximum carbon dioxide emission at a C:N ratio of 9.7-10.8 (Thomsen et al 2008) have been reported. There is general agreement that the more N that is applied to soil the greater the risk of leaching. For any given value of C:N, the level of nitrate leaching was higher at high N-deposition sites than at intermediate N-deposition sites (Dise et al., 1998).

Varying proportions between C and N in the different pools with different turnover times may be the reason why the C:N ratio better describes SOM decomposability than the actual C concentration. Also, the C:N ratio is less affected by soil bulk density as the impact of soil carbon is self correcting. The C: N ratio has likewise been found to relate better to N mineralisation than the total N concentrations (Springob and Kirchmann 2003). Determination of C and N is simple and the relation between C: N ratio and SOM decomposability appears to be valid across a wider range of soil types independent of the length of incubation period. An increase in the C: N ratio from 10 to about 14 (Thomsen et al 2008) or 16 (data from Springob and Kirchmann 2002) reduces the CO_2-C evolution by 50%.

More NO_3^- is leached in shallow soils (< 45 cm to gravels) and in stony soils (7-35% stones) than in moderately deep to deep and non-stony soils (Lilburne & Webb 2002, Webb & Lilburne 2005). Soils with a drainage impediment or those with well developed soil structure have a high potential for bypass flow, whereas soils from tephra and soils with less developed, porous, soil structure have a low potential for bypass flow (McLeod et al 2008). Conversely, soils with a drainage impediment or prolonged wetness are conducive to denitrification, as they have restricted O_2 availability and provide electron donors (Stenger et al 2008), while free draining soils have a relatively low denitrification capacity (Barkle et al 2002).

There are a number of questions that need to be answered before the behaviour of N in a soil system is characterised and an indicator set that enables a connection to be made between the soil quality indicator and outcomes :

- How much N is being put into the system?
- Is there a shortage of N in the system so that any added N is scavenged by micro-organisms and plants before it can be lost?
- How active are the micro-organisms in decomposing organic matter?
- How much available N is currently in the soil?
- Are there risk factors, such as a high potential for bypass flow, shallow soils or stoniness that increase the risk of N losses?
- Are there mitigating factors, such as a high potential for denitrification?

An option that has considerable merit is to use the current soil quality indicators as input data into model frameworks (ecosystem service framework) and tools (Overseer nutrient budget model) for predicting and or estimating the implications of a change in total N or C or AMN to assist in defining target ranges etc.

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7.5 Invertebrate indicator for pastoral soil

Soil invertebrates (macrofauna, mesofauna, nematodes) play an important role in a wide range of soil processes. Soil invertebrates represent a highly dynamic natural capital stock whose activity has enormous consequences on soil nutrients fertility and nutrients cycle and thereby on plant growth and the provision of other services.
Soil biota, by recycling dead OM (wastes or plant litter), is a main agent in nutrients cycling. The species and number of animals vary greatly between soils. Micro-organisms and earthworms make the bulk of the soil fauna biomass.
Each organism has a different role in nutrients cycling and takes a different part in the decomposition of OM and wastes. The amount and quality of inputs to the soil impact on the type and abundance of trophic groups and therefore on decomposition pathways and the efficiency of decomposition and nutrients cycling.

Macrofauna species (body diameter >2 mm) like earthworms constitute an important group for nutrients cycling. They require reasonably moist conditions, satisfactory aeration, and depend on a constant supply of OM and calcium. They play an important role in the initial incorporation and mixing of surface applied material including dead plant roots, plant litter and animal dung, which they digest or mix, thereby starting the recycling of nutrients. Their burrowing activity has important effects on the physical properties of the soil. It promotes aeration and drainage. They are often referred to as ecosystem engineers.

An Invertebrate Indicator for Pastoral Soils would aim to add to current understanding of the role soil biota play in the provision of soil ecosystem services. Such indicator would provide land managers with an insight of how their current system is affecting soil biology and the soil processes they contribute to.
A study was conducted between 2007 and 2010 by Schon et al., (2010, 2011, 2013) to build such an indicator. The study included five sampling sites:

- Waikato: dairy at different intensities, sheep at low and high phosphorus and ungrazed Olsen P trial.
- Taranaki: dairy at different intensities.
- Manawatu: sheep at different intensities, sheep with and without N, sheep organic, dairy organic, ungrazed Olsen P trial.
- Canterbury: sheep irrigated, dairy irrigated.
- Southland: ungrazed Olsen P trial.

Schon et al., (2013) showed that the factors that influence soil invertebrates under a pastoral use are:

- Food availability (pasture production, supplements),
- Physical disturbance (livestock type and density),
- Habitable pore space (treading pressure).

There are three earthworms’ functional groups (Fig. 1). Epigeic earthworms feed on plant litter and dung on the soil surface and do not form permanent burrows. Endogeic earthworms inhabit the mineral soil horizons and ingest soil, feeding on the humified organic material within. They form semi-permanent burrows in the topsoil which have few openings to the soil surface, as they don’t feed on the surface. Anecic earthworms draw plant litter and dung from the soil surface into their burrows and feed on it underground. Their burrows are deep and permanent or semi-permanent. Epigeic and anecic earthworms are particularly useful in organic matter incorporation. Endogeic and anecic earthworms are important for soil structure and porosity. Earthworms casts have an extremely stable structure, contain an intimate mixture of organic and mineral matter, and are extremely rich in soluble nutrients that can return to soil solution and available for plants (Syers *et al.* 1979).

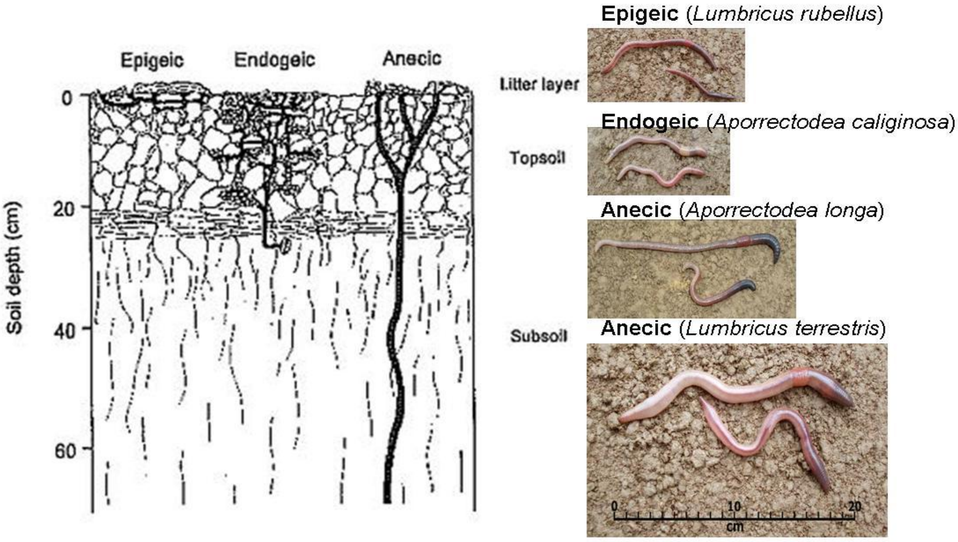


Figure 1: Depth of activity of the three functional earthworm groups.

Influence of stock treading on earthworm abundance and diversity

Schon et al. (2010b) showed the importance of initial diversity of functional groups in providing resilience to increasing external pressures. They showed that anecic earthworms (deep burrowers) can substitute litter-incorporating epigeic earthworms (surface burrowers) vulnerable to treading in intensively managed pastoral systems by taking on the incorporation of litter, as well as being important soil engineers (Fig. 2 and 3).

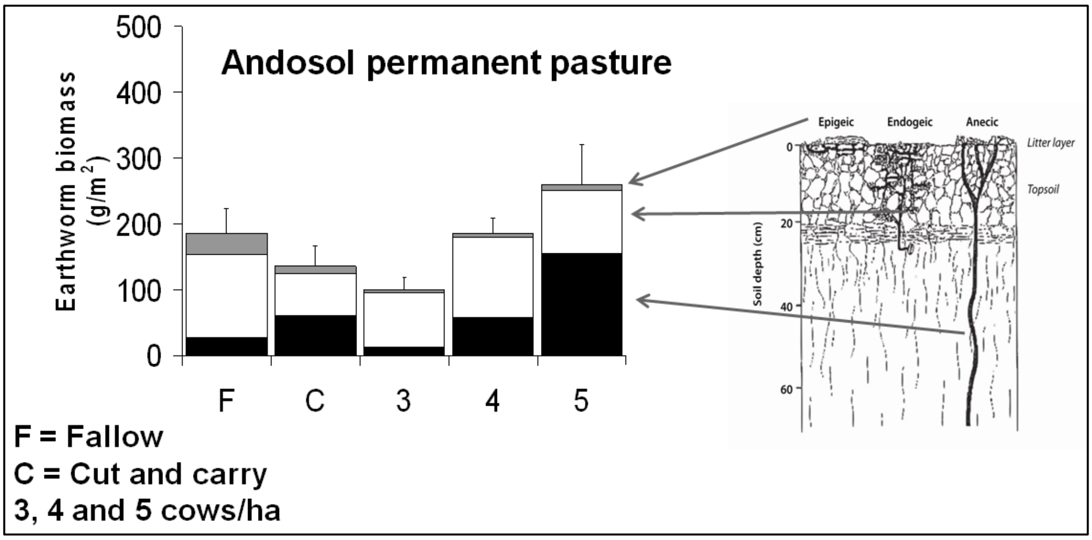


Figure 2: Influence of stock treading on earthworm abundance and diversity (Schon et al., 2010).

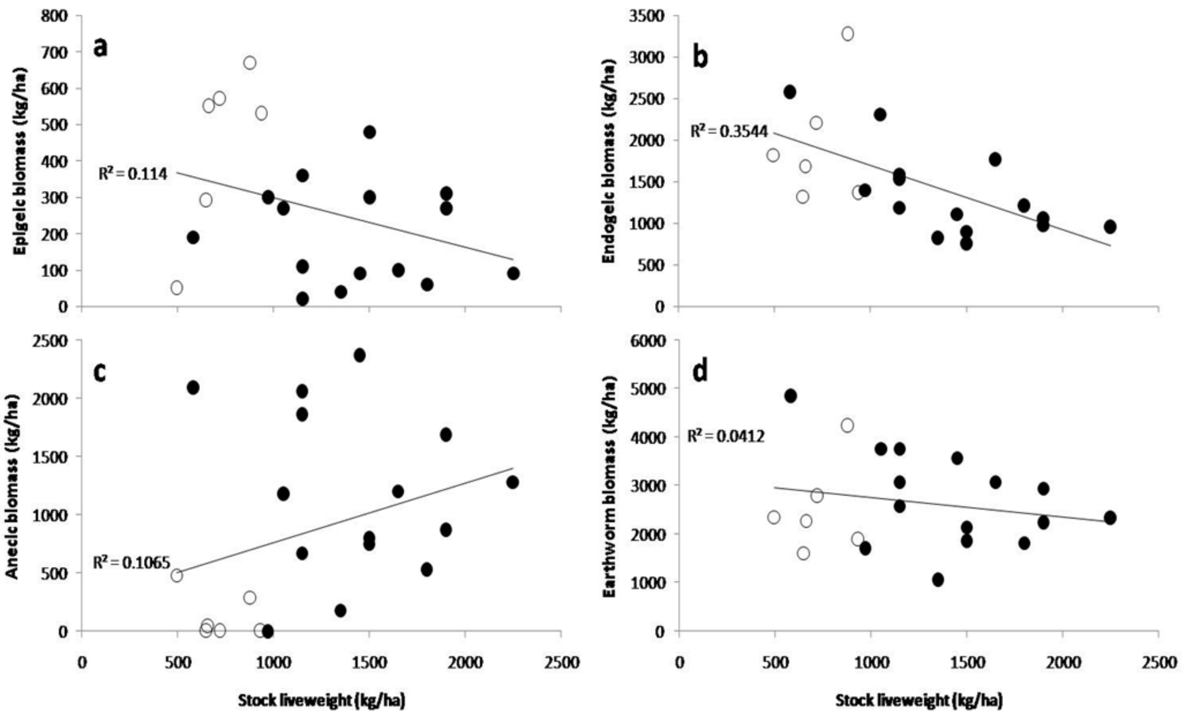


Figure 3: Relationship between stock liveweight loading and earthworm biomass. (a) Epigeic, (b) endogeic, (c) anecic and (d) total earthworm biomass. Open circles represent sheep-grazed pastures; closed circles represent dairy-grazed pastures (Schon *et al.* 2010a).

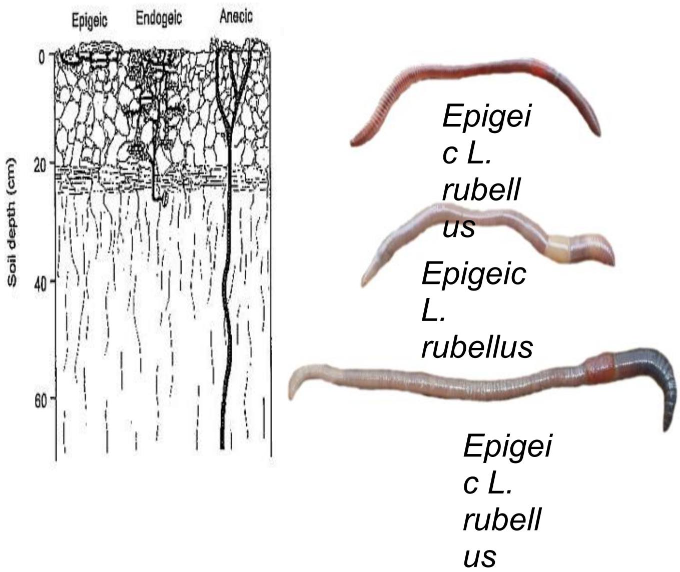
From this data, Schon et al., (2013) developed a invertebrate threshold indicator for pasture soils based on invertebrate species, numbers and land use. Invertebrate numbers are linked to the efficiency of soil processes (Table 1).

Table 1: Invertebrate Threshold indicator for pasture soils.

Soil processes (contributing to a service/disservice)	Important invertebrates	Low	High	Sheep (Fig 1A)	Dairy (Fig 1B)
Water and air movement					
- creation of soil pores	Endogeic earthworm[1]	250	500	516	278
	Anecic earthworm[1]	0	150	0	18
- sensitive to treading pressures	Oribatid mite[1]	65	21 100	17 100	8 100
Nutrient cycling					
- litter incorporation	Anecic earthworm[1]	0	150	0	18
	Epigeic earthworm[1]	10	125	132	8
- nutrient rich faecal pellets	Oribatid mite[1]	65	21 100	17 100	8 100
- controlling other populations	Nematode[1]	550 000	1 180 000	881 200	985 300
- dominant food web pathway	Nematode Channel Ratio	0.72	0.93	0.94	0.87
- plant growth	Nematode Plant Parasite Indicator	0.60	1.55	0.88	1.44
	Herbivorous macrofauna[1]	5	325	106	71
Green house gas regulation					
- carbon storage	Anecic earthworm[1]	0	150	0	18
	Epigeic earthworm[1]	10	125	132	8
- nitrous oxide production	Endogeic earthworm[1]	250	500	516	278
	Anecic earthworm[1]	0	150	0	18

7.5.1 Field sampling and identification protocol for earthworms

Earthworms burrow through the soil and feed on organic matter, improving the movement of air, water and nutrients through the soil. Considering that the liveweight of earthworms living in the soil is similar to the liveweight of stock aboveground, their contribution to these ecosystem services are not to be dismissed.



Earthworm functional groups

Epigeic earthworms (i.e. *Lumbricus rubellus*) feed on organic matter on the soil surface and do not form permanent burrows.

Endogeic earthworms (i.e. *Aporrectodea caliginosa*) ingest topsoil and its associated organic matter, forming semi permanent burrows.

Anecic earthworms (i.e. *Aporrectodea longa*) draw organic matter from the soil surface into their deep, permanent burrows to feed on. Figure from Fraser and Boag (1998), photos of common earthworms courtesy of R. Gray.

Earthworms are not all the same, with different species having different burrowing and feeding behaviours in the soil. The three main groups which can be distinguished are the epigeic and endogeic species living in the topsoil and the deeper-burrowing anecic species. The deep burrowing anecic earthworms have a particularly patchy distribution in New Zealand pastures, being absent from large areas of grassland. However, where they are present they appear to be positively correlated with increased pasture productivity and stocking rates.

Field sampling protocol for earthworms in pasture soils

For each pasture site five turf samples are collected using a spade (e.g. 20 x 20 cm surface area) to a soil depth of 40 cm (Fraser *et al.* 1996; Mackay *et al.* 2010; Springett 1985). Each of the samples need to hand-sorted by finely crumbling the soil onto a plastic sheet in the field and removing all earthworms detected. Earthworms tend to be concentrated near the soil surface so care needs to be taken in sorting the earthworms among the roots. An option is to take the topsoil which includes the turf layer back to the laboratory in a plastic bag for a closer inspection. Earthworm sorted in the field should be placed in a plastic bag with a handful of soil for transport to the laboratory. Once back in the laboratory all earthworms should be placed in water overnight, before counting and identification of species. Within a species the ratio of juveniles to mature earthworms can also be determined. Fresh weight of earthworms is determined after removing surface water with a paper towel. To convert to individuals/m^2 and fresh weight g/m^2 multiply the count data from each spade sample (20cm x20 cm) by 25.

Identification of earthworm species

A decision tree is described in Appendix I for the identification of the earthworm species common in pasture soils in New Zealand

Linking earthworm number to soil services

An invertebrate threshold indicator has been proposed (Schon *et al.* 2011) that includes thresholds below which the invertebrate abundance could become a major factor limiting the delivery of the following soil services

1. Nutrient supply (organic matter incorporation)
2. Water and air movement /supply (creation of soil pores)
3. Physical support (aggregate size and strength)
4. Green house gas regulation (carbon storage)
5. Green house gas regulation (nitrous oxide production)
6. Flood mitigation (water infiltration)

Provisional thresholds, at which the abundance of the three earthworm functional groups might limit the delivery of the provisioning and regulating services listed above for pastoral agricultural soils under sheep and dairy management are presented below.

Soil service/process	Important invertebrates	Limiting (ind./m^2)
1, 4,	**Epigeic earthworms**	**<25**
2, 3, 5, 6	**Endogeic earthworms**	**<350**
1, 2, 3, 4, 5, 6	**Anecic earthworms**	**<20**

More back ground information on the proposed soil invertebrate threshold indicator is available in Schon et al., (2013).

7.5.2 Earthworm identification: Common pasture species in New Zealand

Earthworm morphology

Earthworm key (modified from (Springett 1985), photos Ross Gray)

Is the worm dark or pale? (Check this at the head end, i.e. on the first few segments in front of the saddle.) Dark worms have a paler underside. In pale worms the upper and undersides are the same colour.

If dark: go to 2
If pale: go to 11

Dark worms

Is the worm a red-brown colour with a purple sheen and iridescent in bright light?

If yes: go to 5
If no: go to 3

Is the worm a dark grey-brown or green-brown colour?

If yes: go to 7
If no: go to 4

Is the worm bright red with yellow bands (visible when the worm stretches out) merging to a yellowish tail?

If yes: *Eisenia fetida, Eisenia andrei* or *Dendrodrilus rubidus rubidus*

Eisenia fetida **Length: 30-130 mm** **Type: Epigeic**	Commonly known as the 'tiger worm' it is often found in compost.

Eisenia andrei **Length: 30-130 mm** **Type: Epigeic**	*E. fetida* is lighter in colour than *E. andrei.*
Dendrodrilus rubidus **Length: 20-100** **Type: Epigeic**	Yellow colouring concentrated at the tail end (last 3-8 segments).

If no: start again

Is the worm very large, 90-300 mm.

If yes: *Lumbricus terrestris*

Lumbricus terrestris **Length: 90-300 mm** **Type: Anecic**	Resides in a deep burrow which is marked by a large worm cast with leaves and twigs pulled into it. Tail distinctly flattened.

If no: go to 6

Is it an active red-brown worm, 25-150 mm long?

If yes: *Lumbricus rubellus*

Lumbricus rubellus **Length: 25-150 mm** **Type: Epigeic**	A very active worm with a distinctly flattened tail and a reddish saddle.
www.earthwormsoc.org.uk	
Lumbricus castaneus **Length: 30-70 mm** **Type: Epigeic**	Rare species. They have an orange saddle and are darker in colour to *L. rubellus*. On their underside they are a darker brown-yellow.

If no: start again

Is the worm green-brown with a tail square in cross section?

If yes: *Eiseniella tetraedra*

Eiseniella tetraedra **Length: 30-60 mm**	Body quadrangular. Usually found under stones on stream bottoms or in swampy ground.

Type:	

If no: go to 8

Is the worm dark grey-brown without a square cross section tail?

If yes: *Aporrectodea longa* or *Aporrectodea trapezoides*

***Aporrectodea longa* Length: 90-120 mm** **Type: Anecic**	Dark grey-brown worm particularly at head end which can be almost black; tail end is distinctly paler and slightly flattened. There is no reliable way of distinguishing *A. longa* and *A. trapezoides* while alive, but dary grey-brown worms over 100 mm are likely to be *A. longa*.
Aporrectodea trapezoides **Length: 40-90 mm** **Type: Endogeic**	Same size as *A. caliginosa* (see 12) specimens from the same soil with pigmentation extremely similar to *A. longa*.

If no: go to 9

Is it a dark greenish brown, long (up to 130 mm), slender worm which writhes like a snake when disturbed?

If yes: *Amynthas corticis*

***Amynthas corticis* Length: 70-180 mm** **Type:**	Slender for its length. Writhes like a snake when disturbed and has quite a leathery skin.

If no: go to 10

Is the worm pale greenish brown, coiling stiffly when disturbed?

If yes: *Allolobophora chlorotica*

www.earthwormsoc.org.uk

Allolobophora chlorotica **Length: 40-70 mm** **Type: Endogeic**	Rare species.

If no: start again

Pale worms

Is the worm pale grey with a distinct yellow tip to the tail and a thin bright yellow collar (sometime not visible) between the saddle and the head?

If yes: *Octolasion cyaneum*

Octolasion cyaneum **Length: 65-180 mm** **Type: Endogeic**	A very soft bodied worm and the species most often seen on urban footpaths after sudden, heavy rail. Fairly common under pastures of low to medium fertility.
Octolasion tyrtaeum **Length: 25-130 mm** **Type: Endogeic**	**??? No yellow tail???**

If no: go to 12

Is the worm pink or grey with a pink head and a pale cream section and glandular bumps on the underside between the head and the saddle?

If yes: *Aporrectodea caliginosa, Aporrectodea rosea* or *Aporrectodea tuberculata.*

Aporrectodea caliginosa **Length: 40-100 mm** **Type: Endogeic**	Most common and widespread worm in New Zealand pastures. Colour can vary considerably.

Aporrectodea rosea **Length: 25-85 mm** **Type: Endogeic**	*A. rosea* may be more pink (than *A. caliginosa*) and have a dark pink-orange slightly flattened saddle and a pale tail.
Aporrectodea tuberculata **Length: 90-150 mm** **Type: Endogeic**	*A. tuberculata* is uncommon and cannot be readily distinguished from *A. caliginosa*.

If no: go to 13

Is the worm pink or grey with the saddle near the head end with no glandular bumps or pale areas on the underside between the saddle and the head?

If yes: native species

Native species...
Nearly 200 native species vary considerably in size and colour. All have the saddle near the head end and no glandular areas underneath. Distribution mostly confined to native bush, scrub and some hill land soils. Not found in high fertility, intensively farmed pasture systems.

If no: go to 14

Is the worm pale greenish brown, coiling stiffly when disturbed?

If yes: *Allolobophora chlorotica* (see 10).

If no: start again

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7.6 Upgrade of target ranges of existing indicators

New scientific data on two of the existing soil quality indicators, macroporosity and Olsen P, was presented at the forum in May 2011 by Mackay (2011)

7.6.1 Macroporosity:

Soil is more than sand, silt and clay. It is a porous material. Half the volume can be voids. The size, connectivity, and shape of voids is known as porosity. Porosity influences soil water storage, air permeability, gaseous diffusion, drainage, root penetration and habitat for soil organisms.

Macropores (>30 µm) generally represent space around soil aggregates and are usually air filled, containing water for only short periods. Macropores must be drained for optimum plant growth.

Micropores (<30 µm) are responsible for water storage in soil and are usually found within, rather than between, soil aggregates.

Macroporosity determines the movements of water and gases in soils, influences heat exchange and root growth and distribution, as well as nutrients uptake processes. Macropores also provide habitat for a range of species.

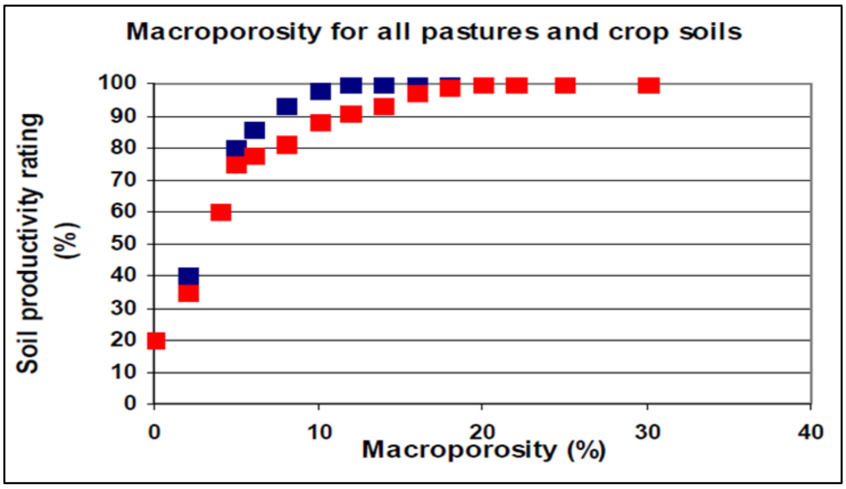

Figure 1: The provisional soil productivity response curve for macroporosity (blue) in pasture and cropping soils based on expert opinion, and the revised curve (red) based on production responses recorded to macroporosity values >10%. The curves are based on macroporosity measures at -10 kPa (Beare *et al.* 2007).

Low macroporosity means reduced soil aeration and drainage and a reduction in surface water infiltration and drainage leading to increased surface run-off. Extended water-logged conditions due to low macroporosity also leads to an increase in gaseous losses of C (increased methane emissions and reduced methanotrophy) and N (nitrous oxide emissions), and less root and plant growth.

Therefore macroporosity is a useful indicator to assess the changes in soil physical condition under different land-uses including pasture, cropping horticulture and forestry. It is worth noting that measuring macroporosity is difficult for soils with a large proportion of stones where the obtaining of an intact soil core is problematic.

Soil productivity response curves for macroporosity were revised for pasture and crops soils (Fig. 1) and forests soils (Fig. 2) based on recorded production responses (Beare *et al.* 2007).

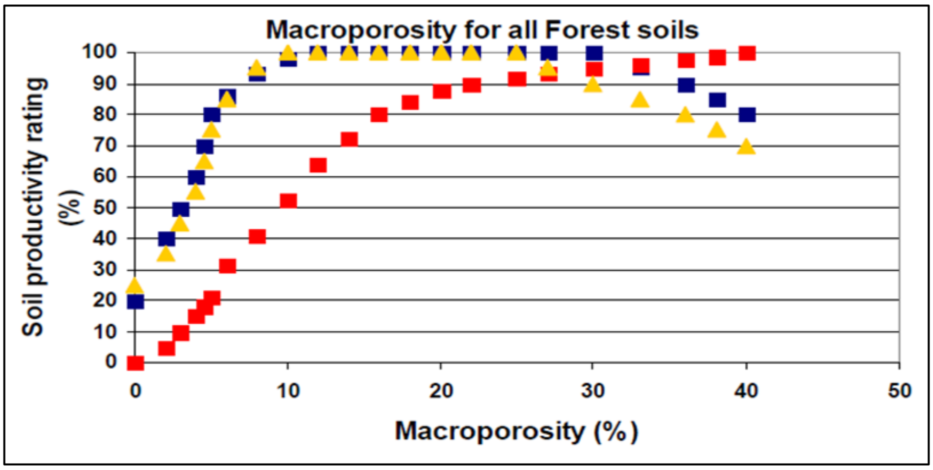

Figure 2: The provisional soil productivity response curve for macroporosity (blue) in forest soils based on expert opinion. The response curve for imperfect to poorly drained soils is shown in red. This recognises the negative impact that poor drainage and high water tables have on pine seedling root growth. The curve for low rainfall environments is given in yellow. All curves are based on macroporosity measures at -10 kPa (Beare *et al.* 2007).

7.6.2 Soil Olsen P:

The current industry standard for the critical soil Olsen P for 97% of maximum pasture production are 20 and 22 µgP/ml for a sedimentary and volcanic ash soil, respectively (Roberts & Morton 2009). Because of the variability in the calibration curves between Olsen P and relative pasture production, and also in soil test results, Roberts & Morton (2009) point out there is no precise soil P level that will guarantee a particular level of pasture production (Fig. 1). The reason for the wide scatter of relative yield (RY) points associated with any Olsen P value (Fig. 1) can be related to variability in the effects of unrecorded 'other factors', such as moisture and N availability, affecting pasture growth. The adoption of a range in Olsen P as a guideline for fertiliser recommendations is recognition of the effects of these unrecorded 'other factors' on pasture productivity on each farm (Table 1).

Table 1: Target ranges for optimum Olsen P levels by soil type.

Soil	97% max	Target range	Top 25% in area
Sedimentary	20	20-30	30-40
Volcanic	22	20-30	30-40
Pumice	38	34-45	45-55

Roberts & Morton (2009) recommend that to reduce the risk of under-fertilising pastures for sites that may fall below the average curve (Fig. 1), two target ranges should be added, with the range based on production of milksolids/ha. For both sedimentary and volcanic ash soils the target Olsen P range is 20-30 µgP/ml where milksolids production/ha is near the average for the local supply area, and 30-40 µgP/ml if production is in the top 25% for the local supply area (Fig.2)..

At the other extreme, when comparing results from 0-20 and 30-40 degree slopes in Waikato hill pasture, Gillingham *et al.* (1984) found that near maximum pasture production from summer-dry steep slopes was at an Olsen P of 10 µgP/ml, whereas maximum production from gentle slopes was two-fold higher with an Olsen P of 15 µgP/ml. This finding suggests that as the constraints to the expression of pasture response to added P decreased the critical Olsen P value increased.

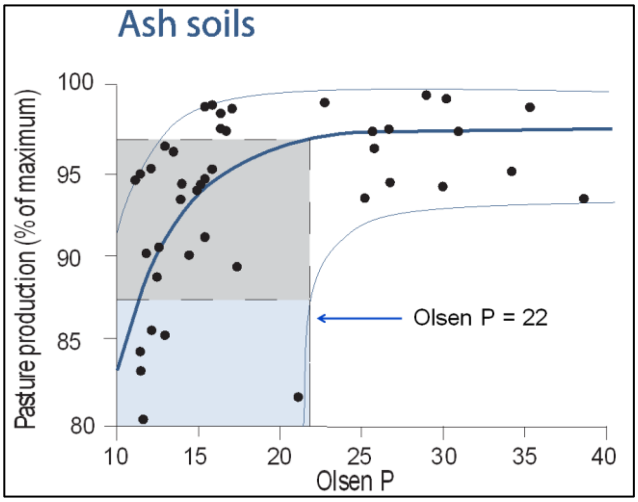

Figure 1: Relative pasture yield as a function of Olsen P for an Ash soil (Roberts & Morton (2009).

In a review of the soil P database on which the calibration curves of Roberts & Morton (2009) were based, Edmeades *et al.* (2006) derived higher critical Olsen P levels for 97% maximum pasture production for all soil groups. The most likely reason for this finding was the application of a more rigorous protocol in the selection of the P field trial results for inclusion in the analysis. Over 70% of the large data base of P field trials on which the production function between Olsen P and RY for the major soil groups was based, came from permanent pastures producing <10 000 kg DM/ha/yr. Little fertiliser N was applied in these studies and few were irrigated.

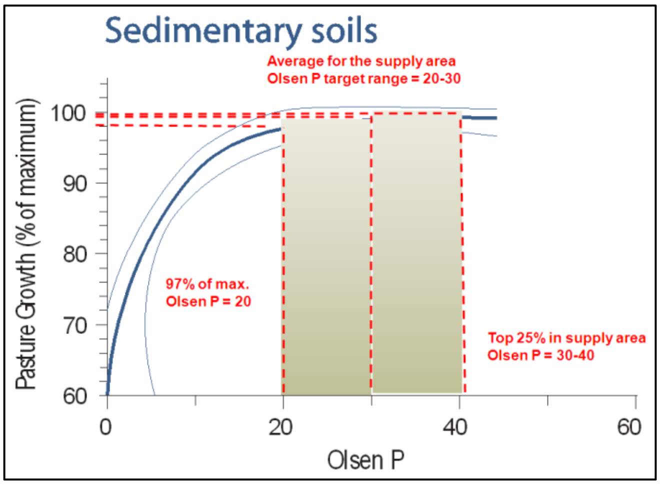

Figure 2: Relative pasture yield as a function of Olsen P for a sedimentary soil (Macaky pers.com.).

This situation has changed in the last two decades with a greater emphasis on pasture renewal with new germplasm, increasing use of N fertiliser and increasing hectares under irrigation. The overall nutrient status of dairy pasture soils has also increased (Wheeler 2004). This raises the question as to how representative are the currently recommended critical Olsen P values for today's pastures when the constraints to growth have been progressively removed.

The Pasture 21 research programme is assessing if current recommended Olsen P target ranges are appropriate for our high producing dairy pastures.

The features of high producing dairy pastures include:

- Higher production levels 15-20+ tonnes DM/ha/yr,
- Increased use of new plant germplasm and species,
- Improved pasture management,
- Greater use of nitrogen (N) fertilizer,
- Expansion of irrigation, including effluent application,
- Soils have higher nutrient (N,<C:N) status,
- Soils have declining organic matter contents and macroporosity values.

The Pasture 21 research programme is exploring P requirements of pasture where growth constraints imposed by low N availability and soil moisture over summer-autumn have been removed. The programme tests the hypothesis that, as constraints to pasture growth are removed and production increases so does the critical Olsen P value (for 97% of max relative yield).

The Pasture 21 programme includes a total of 9 field studies including 7 pasture response studies, with 5 sites water is non-limiting at 5 locations. Data have been collected for up to 5 years, building 34 data sets.

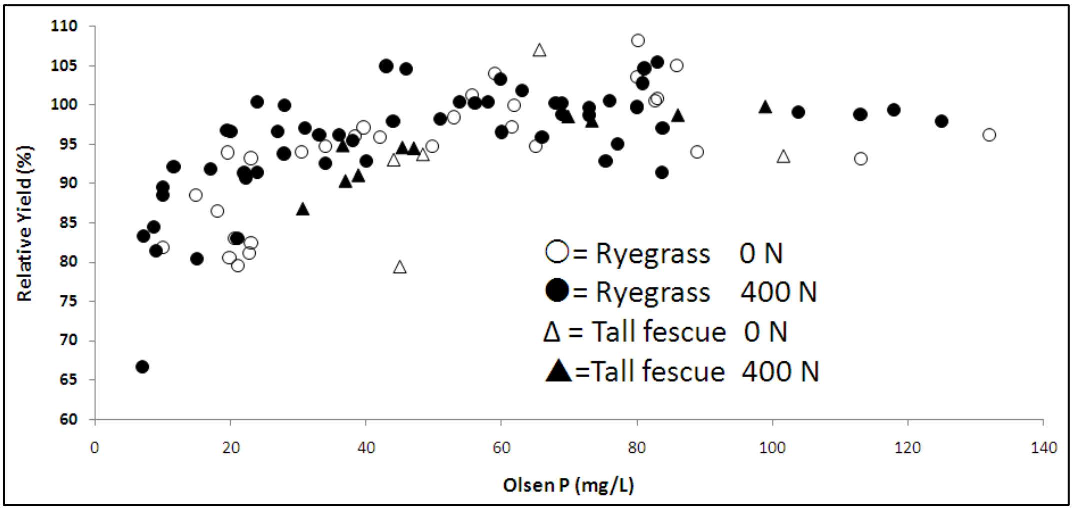

Figure 3: Relationship between Olsen P and relative yield (2005-2009) where an asymptote could be established: RY (%) = 99.606 – 32.47x0.941$^{\text{Olsen P}}$; r^2 = 0.521 ; Critical Olsen P (97%) = 41 µgP/ml.

The results from this study support the contingency recommendation suggested by Roberts & Morton (2009) to increase the soil Olsen P level in dairy farms that are operating at higher than average production levels. The recommended soil Olsen P level of 41µgP/ml for 97% of maximum production (Fig. 3). This is similar to the upper end of the range suggested by Roberts & Morton (2009).

There is a good case therefor e for reducing the target ranges for soil Olsen P values currently in the soil quality indicators tables to values that more closely align with the industry values.

The negative impact of a compacted soil on pasture growth appears to be offset to some degree by lifting the Olsen P value (Fig.4). Inclusion of a measure of soil

physical condition in either the derivation of relative P response curves or in the interpretation of the Olsen P test value would appear to warrant further study, given the increasing cost of this nutrient, and the potential impact that soil with limited pore function and elevated Olsen P could have on surface water quality.
This is a good example of the need to examine the soil quality indicators together rather than in isolation.

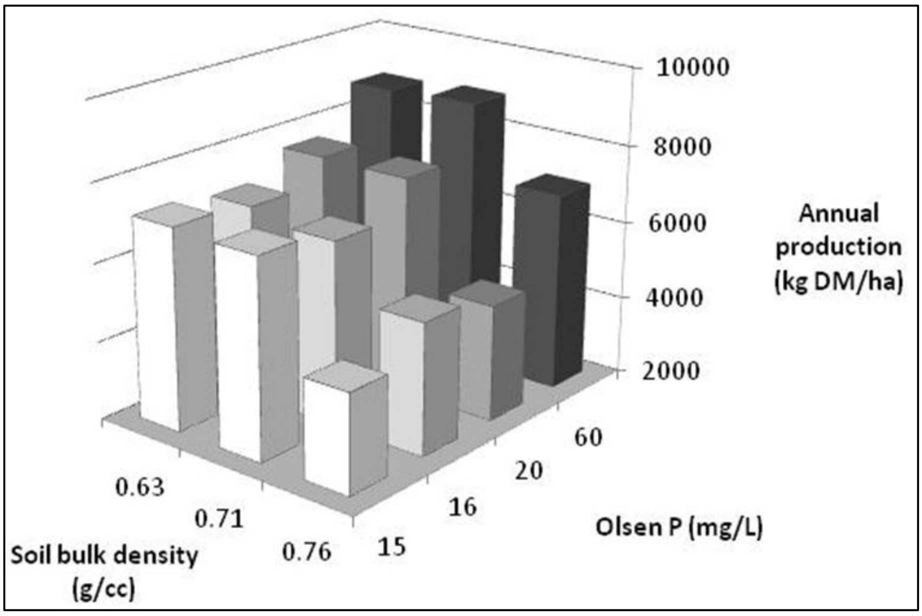

Figure 4: Effect of soil physical condition on nutrient requirements (Mackay *et al.* 2010).

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7.7 Land monitoring forum meetings and agendas

LAND MONITORING Forum

Agenda of the Bi-annual Land Monitoring Forum

Wellington Regional Council, 142 Wakefield Street, Wellington.

Thursday September 9th, 2010

Time	Item	Presenter/Chair
9.00am	*Attendees turn up – morning tea*	
9.30 – 10.00am	Introductions, apologies Last minute agenda additions Actions from last meeting	Reece
10.00 – 10.15am	**General business** LMF - SIG	 Reece/Amy
10.15am -12.15pm	**Policy and strategy session** Regional Policy Statement "Collisions forum" FRST Freshwater funding Regional Council Research Strategy	Chair? All (15 mins) Reece/others (10 mins) Bill (15 mins) Bill Dyck / All
12.15 – 1.00pm	Lunch	
1.00 - 3.00pm	**Technical session – Land use** MFE LUCAS presentation GDC – Hill country erosion issues Horizons –SLUI Plans Land intensification	Chair? Nelson Gapare Shaun Burkett Malcolm Todd Reece Hill
3.00 – 3.30am	Afternoon tea	
3.30 - 5.00pm	**Technical session - Soil Quality** Soil Quality update Soil Ecosystem Services Envirolink potential projects? -discussion	Chair? Matt Taylor Estelle Dominati All

Friday September 10th, 2010

Time	Item	Presenter/Chair
8.00am - 8.30am	*Coffee etc*	
8.30am – 10.00am	**Envirolink: Projects** SINDI Soil Quality Indicators	Chair? Amy Alec McKay
10.00 – 10.30am	Morning tea	
10.30am – 12.30pm	**Envirolink: Projects continued** S-Map LUDB	Chair? Allan Hewitt Daniel Rutledge
12.30pm – 1.15pm	Lunch	

1.15pm – 2.00pm	MAF presentation	Chris Arbuckle
2.00pm – 3.00pm	**Regional Roundup**	All
3.00pm – 3.30pm	**Other business and Wrap up** Other business Actions from meeting Next meeting	Amy
3.30pm	Meeting closed	

Attendees: Reece Hill (EW), Mathew Taylor (EW), Amy Taylor (ARC), Paul Sorensen (GW), Shaun Burkett (GDC), Barry Lynch (HBRC), Malcom Todd (Horizions), Colin Gray (MDC), Dani Guinto (EBOP)
Guests: Bill Dyck, Nelson Gapare, Daniel Rutledge, Allan Hewitt, Estelle Dominati, Alec McKay, Chris Arbuckle
Apologies: Jim Risk (ES), Don Sherman (TRC), Jeromy Cuff (ECan), Nick Kim (EW), Wayne Teal (NRC), Susie McKeague (ORC), Andrew Burton (TDC),

LAND MONITORING
FORUM

Bi-annual meeting

Thursday/Friday, February 17th/18th, 2011

Greater Wellington Regional Council, Wellington

Objectives

Soil Strategy NZ update
Land and soil guidelines - Riparian Characteristics monitoring
Envirolink Tools updates and discussion
Envirolink Tools project list
Define next actions for Land Monitoring Forum
Set date and place for the next meeting – Christchurch?

Thursday 17th February

9:30am **Meet Royal Society of NZ (4 Halswell St, Thorndon)**
9:30am - 10.15am **Introduction/Agenda of LMF before "What on Earth"**
10:25am – 12:35pm "What on Earth" (Royal Society)
12.35pm – 1.00pm Lunch
1:00pm – 1:30pm Travel to GW
1:30pm –2:30pm **Scion – national mapping (Dave Palmer)**
2:30pm – 3:30pm **R C's role in Soil Strategy/ R C's Research Strategy (Reece)**
3:30pm – 3:45pm Coffee/tea break
3:45pm – 5:00pm **Roundtable R C's**

Friday 18th February

9:00am – 9:30am **Envirolink Tools project sub-committees**
9.30am – 10.30am **Session 1 – Envirolink Tools updates**
SINDI and S-Map
10:30am – 10:45am Morning tea
10:45am – 11:45am **Session 2 – Envirolink Tools updates cont.**
Soil Quality and LUDB
11:45am – 12:15pm **Riparian Characteristics monitoring**
12:15pm – 12:45pm Lunch
12:45pm – 1:45pm **Envirolink Tools discussion**
1:45pm – 2:00pm **Meeting Close – actions and next meeting**

LAND MONITORING FORUM

Bi-annual meeting

Thursday/Friday, February 16th/17th, 2012
Ministry for the Environment, Wellington

Objectives
Update of proposed work/projects for 2012 from councils
Envirolink Tools updates and feedback on finished projects
Envirolink Tools projects new
Set date and place for the next meeting

Thursday 16th February

9:00am – 9:15am **Introductions, agenda, items etc** Reece
9:15am – 10:30am **Roundtable R C's** All
10:30am – 11:00am *Morning Tea*
11:00am – 12:30pm **Session 1 – Ecosystem Services** Estelle and Alec (AgR)
ICM catchment case study
Core funding discussion
12:30pm – 1:15pm *Lunch*
1:15pm – 3:00pm **Session 2 – Soil Quality**
Hot water carbon Anwar (AgR)
Soil indicators Matt/Reece
Defining what background means? Matt/Reece
3:00pm – 3:15pm *Coffee/tea break*
3:15pm – 3:45pm **Proposed Envirolink**
– Review of 500 now 1000 soils Reece
3:45pm – 4:30pm **Shared workspace MfE** Amy/Brent

Friday 17th February

8:45am **Arrive day 2**
9:00am – 10:00am **LUDB testing and feedback** Amy
10:00am – 10:30am *Morning tea*
10:30am – 12:00pm **Landcare Research** Alison Collins (LCR)
Soil and Land Resource centre
Core funding
12:00pm – 12:45pm *Lunch*
12:45pm – 1:30pm **Soil Strategy** Reece
1:30pm – 2:00pm **Envirolink New Tool – land fragmentation** Amy/Reece
2:00pm – 2.30pm **Land and soils guidelines - funding** Reece
2:30pm – 3:00pm **Actions and next meeting** Amy

LAND MONITORING FORUM

Bi-annual meeting

Thursday/Friday, August 16th/17th, 2012
Greater Wellington, Wellington

Objectives
LMF contributions to soil and land strategy
Update of proposed work/projects for 2012 from councils
Envirolink Tools updates and feedback on finished projects

Thursday 16th February

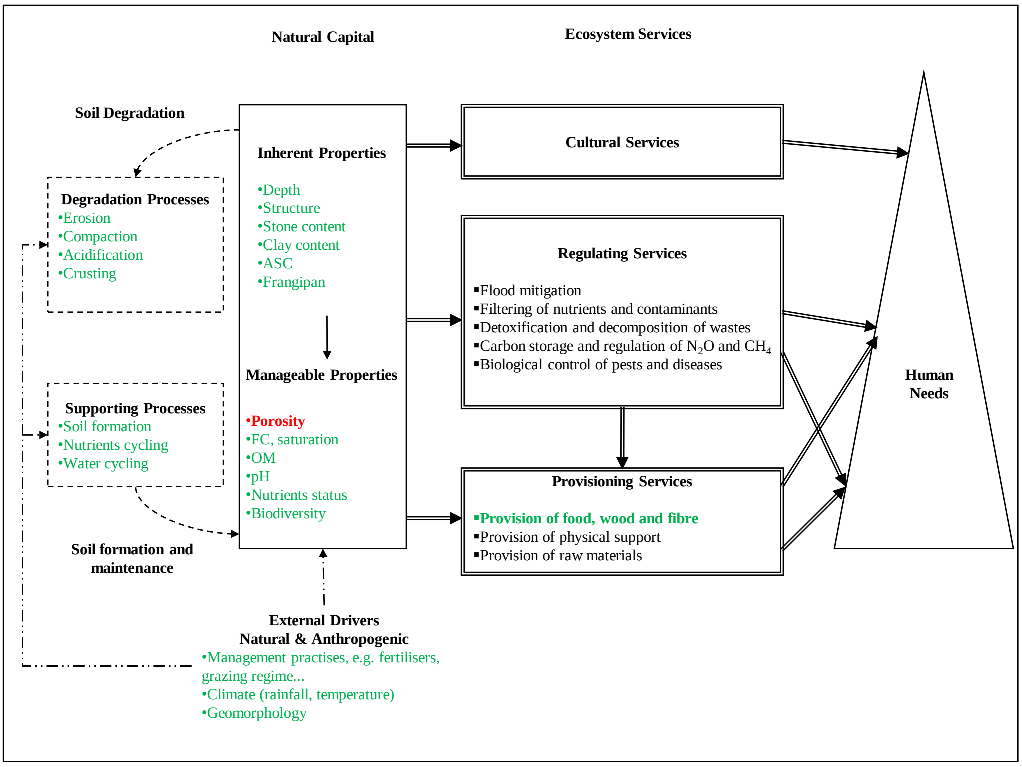
9:00am	**Arrive day 1**	
9:00am – 9:30am	**Confirm agenda, Minutes, Introductions**	Reece
9:30am – 10:30am	**Roundtable council updates (5 mins/pp)**	All
10:30am – 11:00am	*Morning Tea*	
11:00am – 12:30pm	**Session 1 – LMF strategy**	Bill Dyck
12:30pm – 1:15pm	*Lunch*	
1:15pm – 3:00pm	**Session 2 – Soil Quality**	
Hot water carbon update		Matt
Olsen P		John
Envirolink project (NRC/ES)		Matt
3:00pm – 3:15pm	*Afternoon Tea*	
3:15pm – 4:30pm	**Envirolink projects**	All
Project updates and feedback		
New projects		
4:30pm – 4:45pm	**MfE/Central government update**	Brent King (MfE)

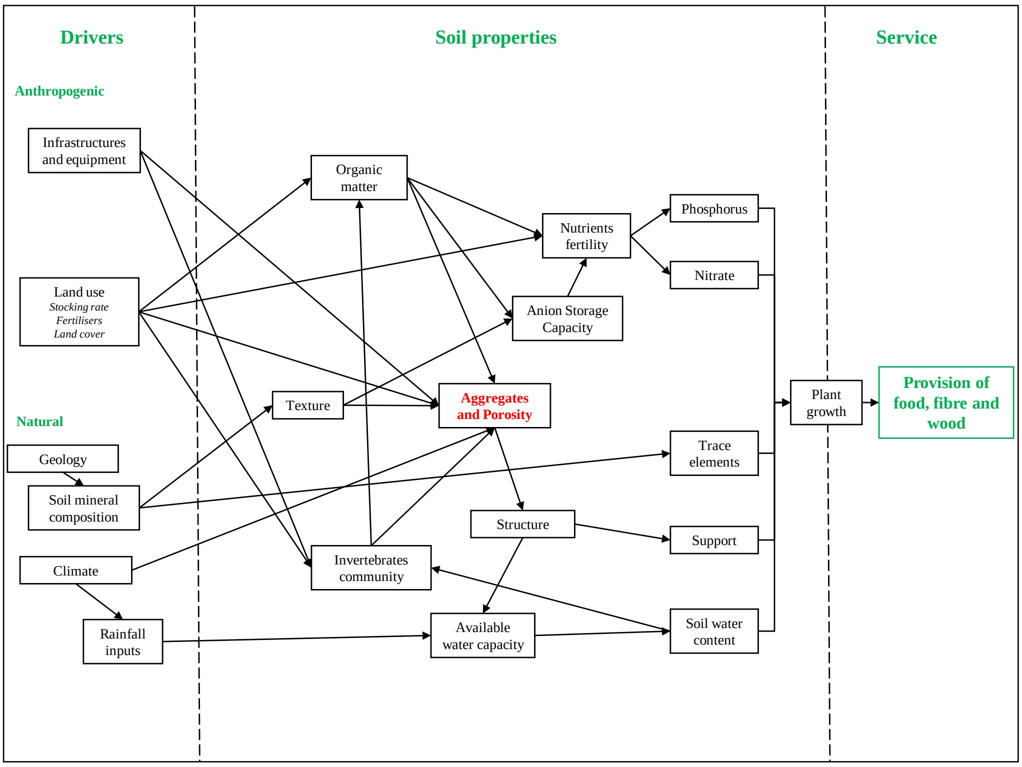
Friday 17th February

9:00am	**Arrive day 2**	
9:00am – 10:15am	**Session 1 – S-map update**	Allan Hewitt (LCR)
	NLRC	
10:15am – 10:45am	*Morning tea*	
10:45am – 12:00pm	**Soil Ecosystem Services**	Estelle Dominati (AgR)
Update and new ideas		
12:00pm – 12:45pm	*Lunch*	
12:45pm – 1:15pm	**LMF guidelines**	Reece/Matt
1:15pm – 2:00pm	**LMF roles**	Reece
2:00pm – 2.30pm	**Roundtable - summary**	All
2:30pm – 3:00pm	**Actions/Next meeting/Close**	All

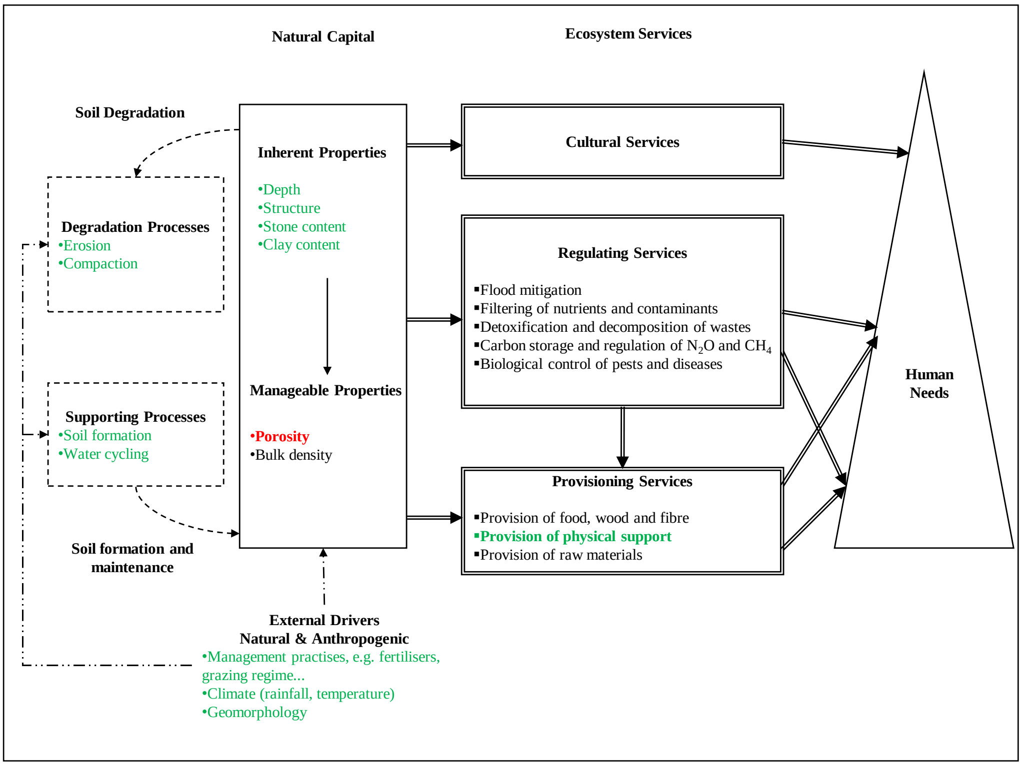
7.8 Details of the framework for each soil service in relation to macroporosity

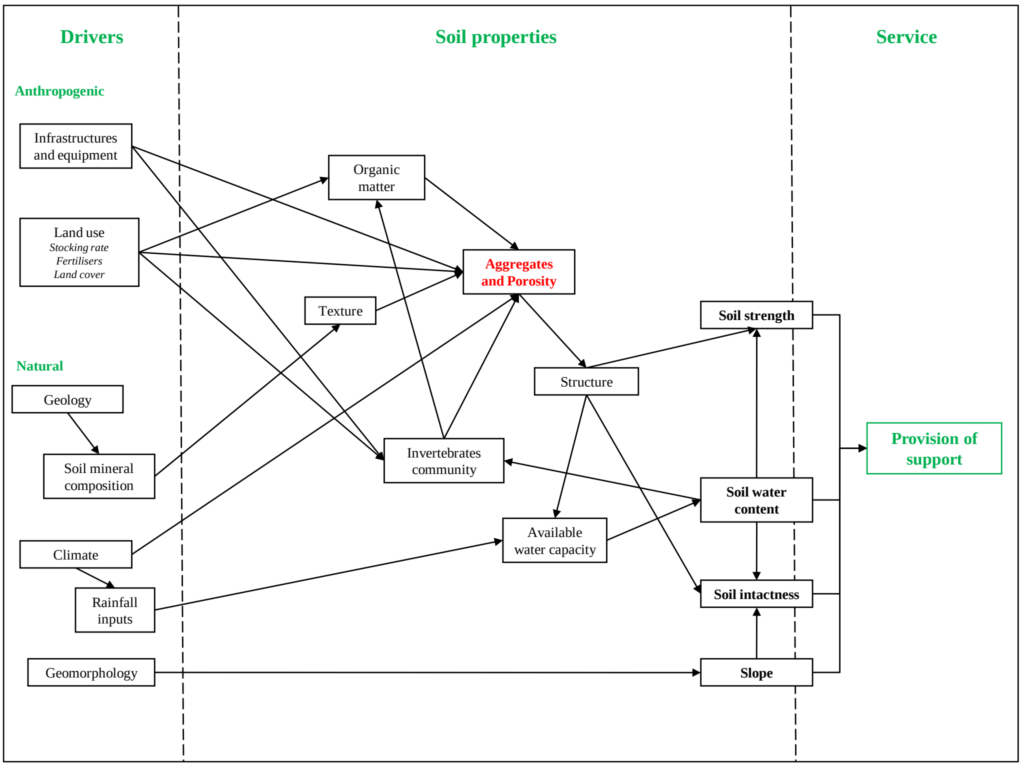
1. PROVISION OF FOOD, WOOD AND FIBRE



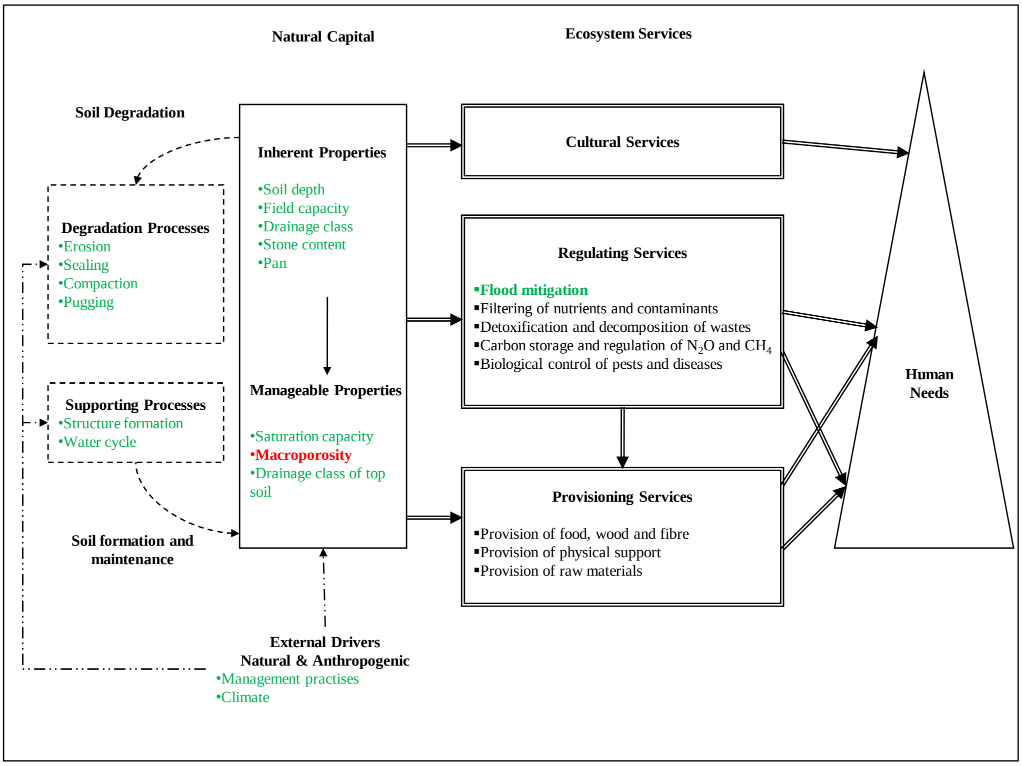


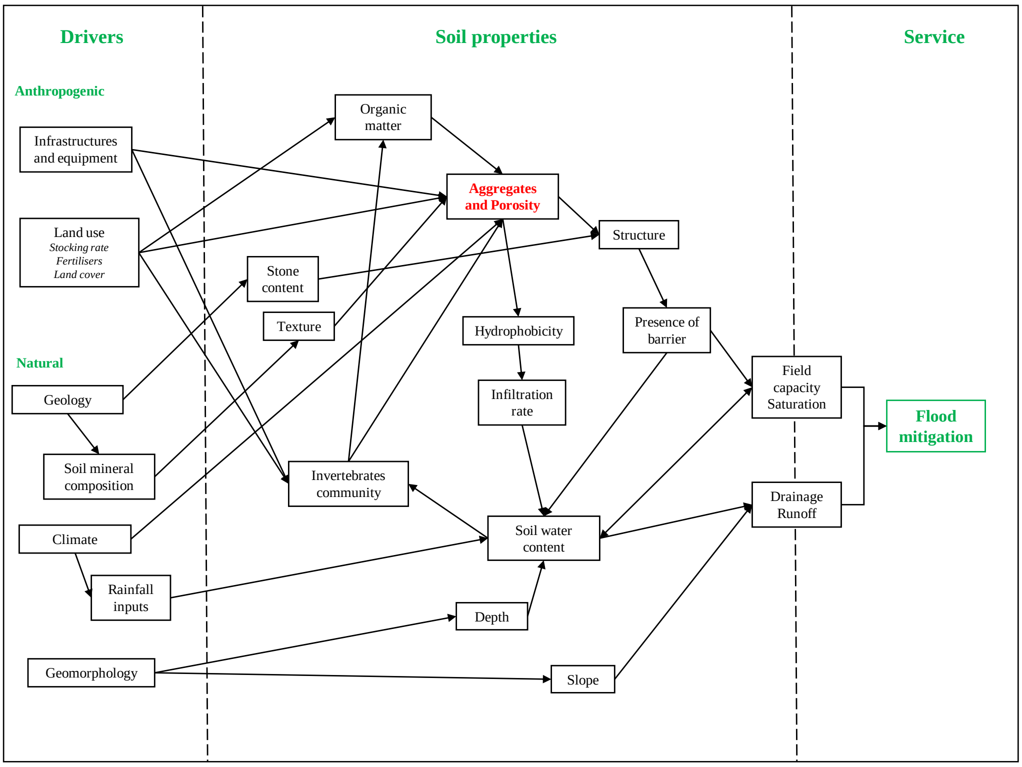
2. PROVISION OF PHYSICAL SUPPORT



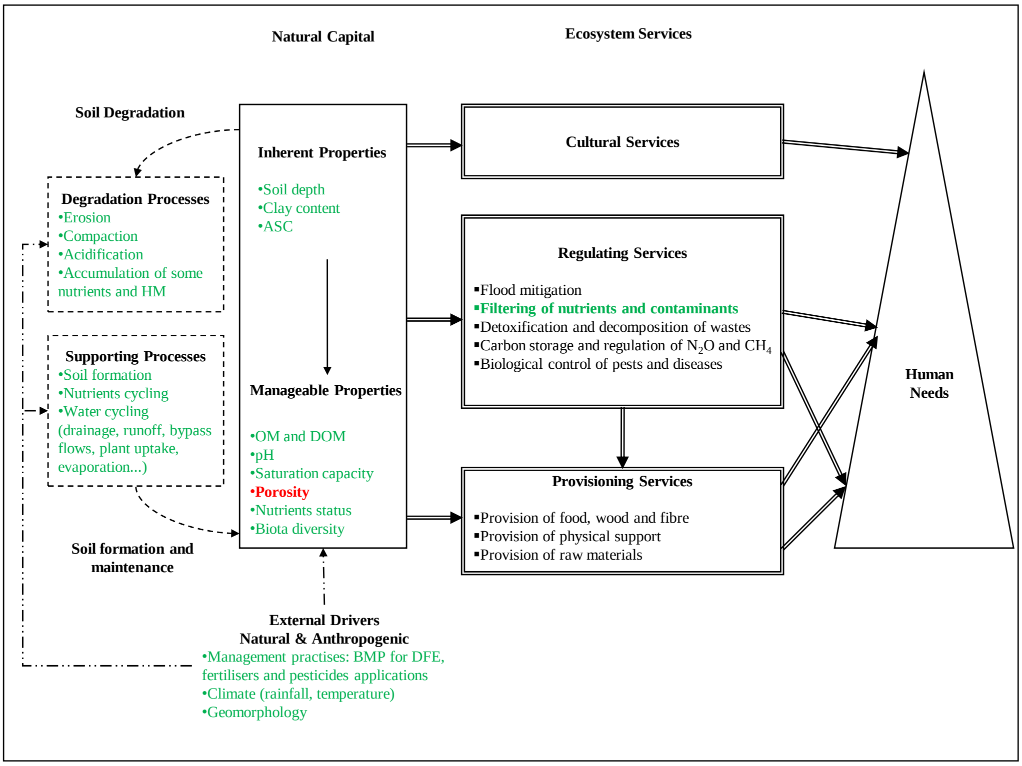


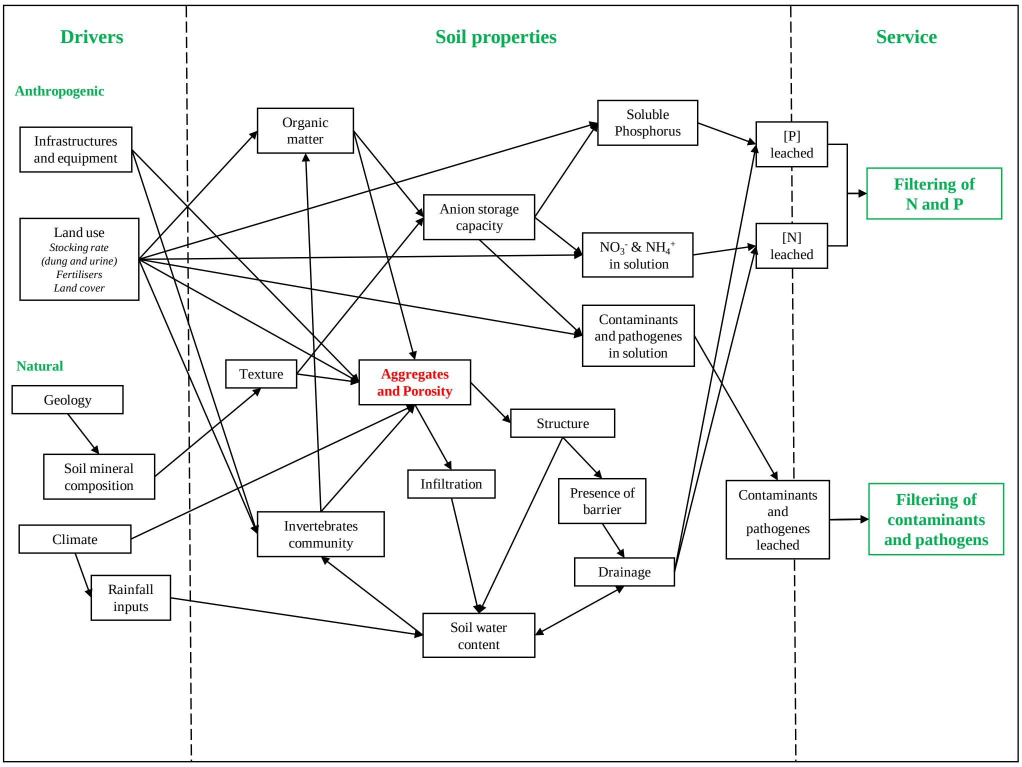
3. FLOOD MITIGATION



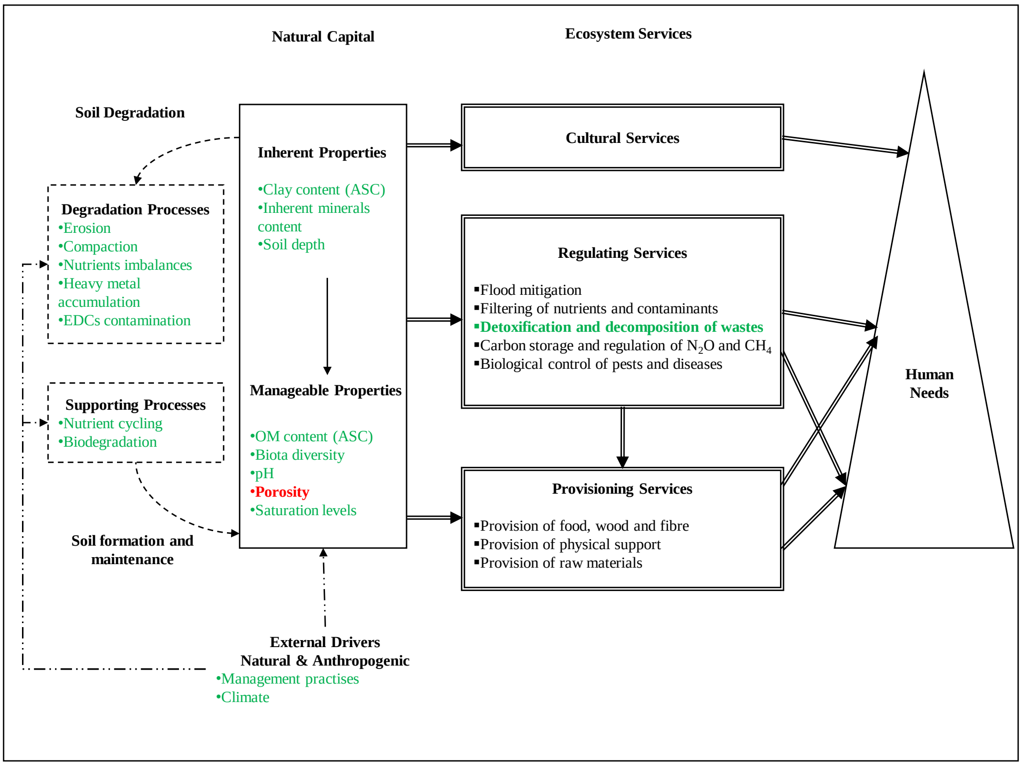


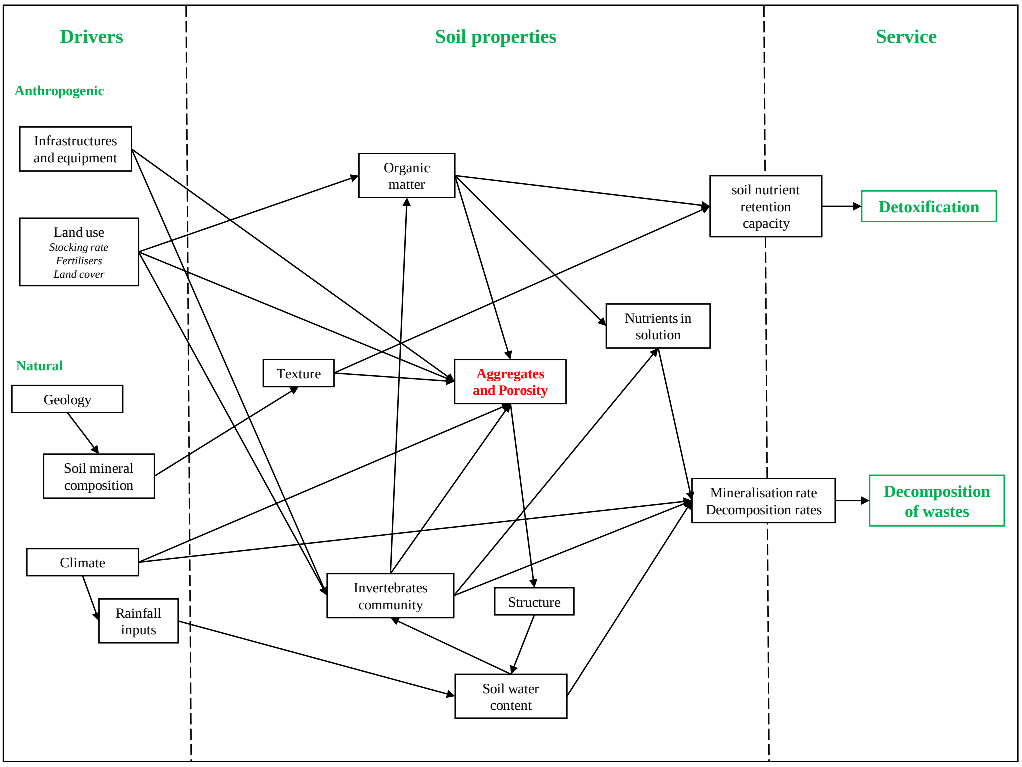
4. FILTERING OF NUTRIENTS AND CONTAMINANTS



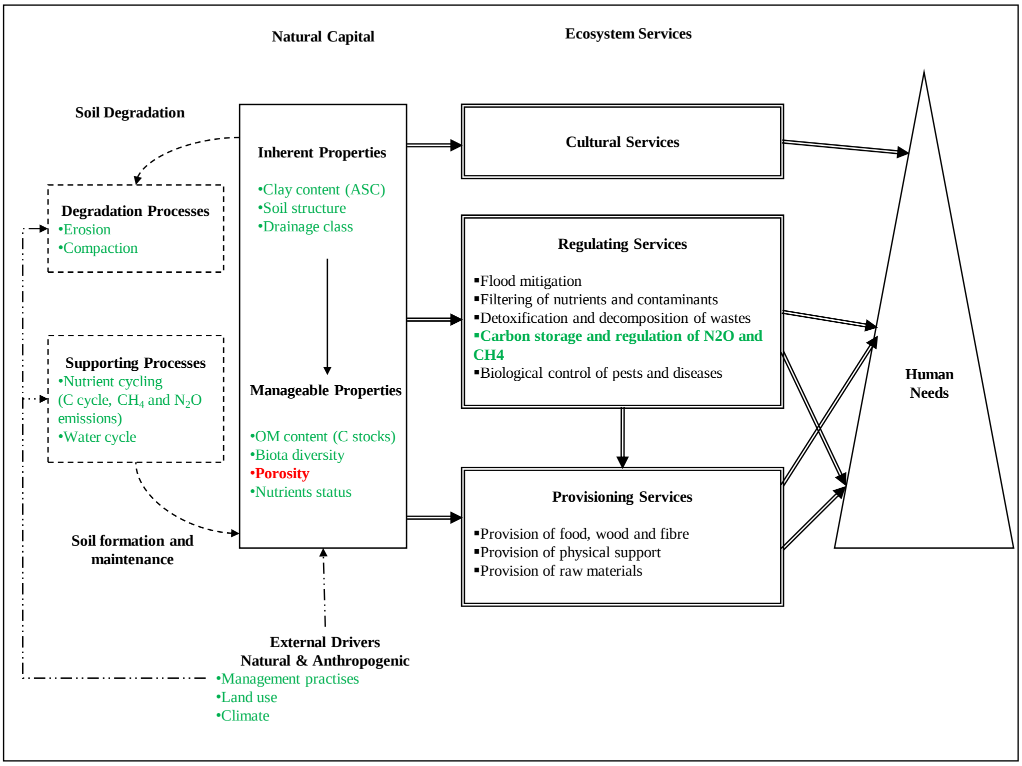


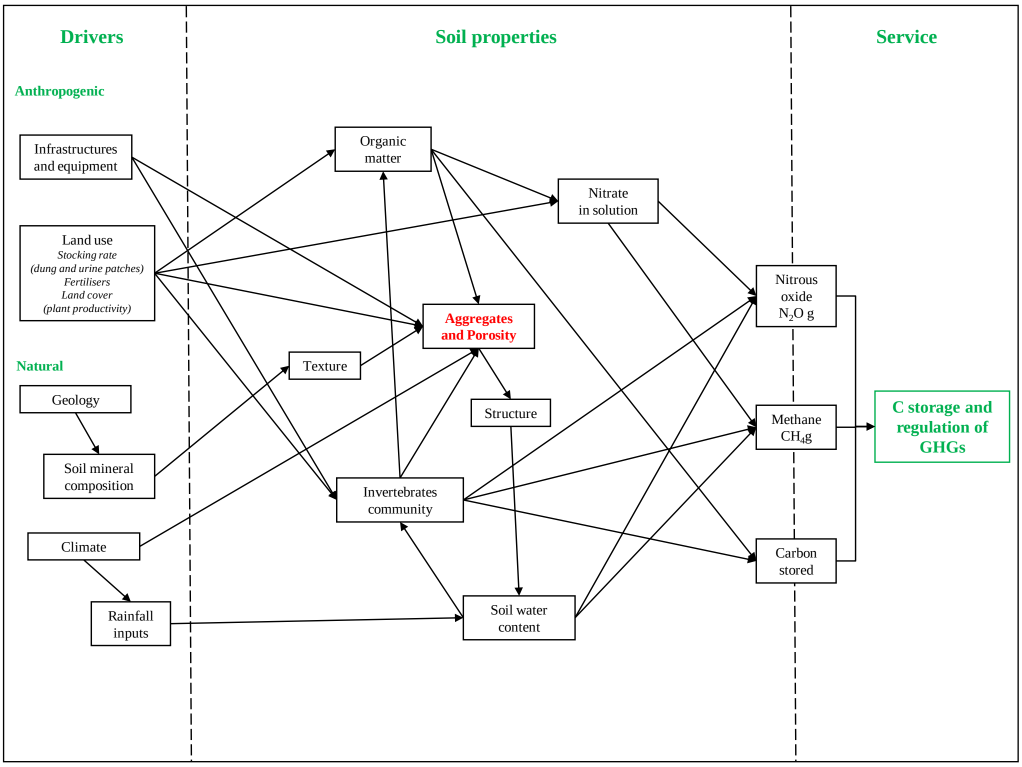
5. DETOXIFICATION AND DECOMPOSITION OF WASTES





6. CARBON STORAGE AND REGULATION OF N_2O AND CH_4





7. BIOLOGICAL CONTROL OF PESTS AND DISEASES