Manaaki Whenua
Landcare Research

Review of approaches to setting target values for evaluating soil quality indicators for state of the environment reporting

Envirolink Advice Grant: 2224-ESRC506

Prepared for: Environment Southland and Horizons Regional Council

June 2022

Review of approaches to setting target values for evaluating soil quality indicators for state of the environment reporting

Contract Report: LC4148

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Introduction and Background

Regional soil quality monitoring (SQM) for State of the Environment reporting has been ongoing for the past 25 years. While target values developed in the early 2000s have undergone some modification, it was deemed necessary to review the indicator target system value approach before a review of the target values (as revision of indicator target values is needed to better inform the balance between production versus environmental outcomes). Environment Southland and Horizons Regional Council sponsored this project through Envirolink funding (Envirolink Advice Grant 2224-ESRC506) on behalf of all participating councils.

Objectives and Methods

The project was a co-innovation approach with Councils and representatives from central government (MfE and Stats NZ). The objectives of the project were to:

- Review the approach to setting soil quality target values including its terminology.
- Conduct a literature review of several of the different international approaches and compare the current New Zealand approach to those used internationally.
- Hold a workshop (with invited attendees from Councils, MfE, and Stats NZ) to elicit feedback on the current system and alternative target value approaches.
- Integrate workshop feedback.
- Make specific recommendations for an Envirolink tools project to implement changes to evaluation of soil quality target values.

Background information was compiled via an initial literature review. The background material was incorporated into a questionnaire (sent to select individuals within councils and central government) to elicit feedback on whether the soil quality monitoring goals were still relevant and the extent to which change in the current systems was desired. The questionnaire results were discussed in focus group meetings that informed workshop sessions on specific topics. Workshop material was then summarized, and specific recommendations were synthesised from workshop material and further reviewed by the focus group.

Recommendations

Based on feedback from councils and central government (MfE and Stats NZ) during the workshop, a phased approach was suggested to address shortcomings in the target value approach and more broadly, modifications to the soil quality programme itself. We would suggest that an Envirolink Tools proposal focus on modifying the target value approach in addition to reviewing the indicator target values themselves as detailed below. In the longer term it was felt a broader soil health programme that incorporates concepts such as ecosystem services and soil security, and acknowledges a Mātauranga Māori perspective was needed. A staged approach was suggested to implement the broader programme with initial steps part of the Tools proposal above.

Short term, the project should aim to:

- review the evidence for the balance between production versus environmental outcomes for each indicator.
- include and develop a scoring methodology for subdivisions within target ranges. (such as those noted in Sparling et al. (2008)) to better track where indicator values are within target ranges.
- assist councils and central government to better communicate soil quality results in relation to target values for the general public and technical audiences, and to develop improved communication of the impact of the monitoring.

Longer-term objectives could be to:

- evaluate how SQM nationally is performing to detect trends over time. This could include, for example, recent and current work on the trends for Wellington region and current draft work on national trends.
- consider integration of SQM with other soil resources (e.g. S-map) for more complete soil information that can better inform land management choices.
- consider frameworks from the review and other suggestions at the workshop, for longer-term development. Better description of soil functions and/or ecosystem services from a New Zealand perspective, what works and what does not work from each system.
- assist councils and central government to develop improved and more standardised reporting of soil quality data and results, where not covered by the National Environmental Monitoring Standards (NEMS) (while acknowledging that different councils have different aims and resources).
- suggest guidance on statistical approaches and requirements for soil quality trend monitoring.
- consider how best to incorporate a Te ao Māori viewpoint into soil quality reporting.
- explore the reference site concept for comparison to change in indicator values. A reference state would likely need to be adopted for each land use (although for some indicators such as trace elements, comparison to background levels or 'natural states' are useful). This may be useful in platforms such as SINDI, or to improve communication and impact, particularly for production vs environment.
- consider platforms such as SINDI or LAWA to better display soil quality trends; however, a mechanism for continued update and technical upgrades to the system would be required.

1 Introduction

The Resource Management Act 1991 (RMA) was the initial driver for regional soil quality monitoring and created the momentum for the 500 Soils programme (Sparling et al. 2004). The programme trialled soil quality indicators and recommended seven of these as a minimum data set for national soil quality monitoring (pH, total carbon (TC), total nitrogen (TN), anaerobic mineralizable nitrogen (AMN), Olsen P, bulk density, and macroporosity). During a series of workshops (2000–2001), target values were defined for each indicator, largely based on, and ultimately published in, the Sparling et al. document 'Provisional targets for soil quality indicators in New Zealand' (originally published in 2003 and republished in 2008). Trace elements have also often been analysed in addition to the seven primary soil quality indicators, and soil guideline values for the assessment of soil quality in relation to trace element concentrations have been developed separately (Cavanagh 2019; Cavanagh & Harmsworth 2022).

While there have been efforts to review and update target values of the primary soil quality indicators (e.g. Mackay et al. 2013), the target value approach has remained largely unchanged since its inception. Revision of indicator target values is needed to better inform the balance between production versus environmental outcomes, but a review of the target value-setting approach was deemed necessary before a full review of the target values themselves occurred. Environment Southland and Horizons Regional Council sponsored this project through Envirolink funding (Envirolink Advice Grant 2224-ESRC506) on behalf of all participating councils.

The objectives of the project are to:

- review the approach to setting soil quality target values including its terminology
- conduct a literature review of several of the different international approaches and compare the current New Zealand approach to those used internationally.
- hold a workshop (with invited attendees from Councils, MfE, and Stats NZ) to elicit feedback on the current system and alternative target value approaches.
- integrate workshop feedback.
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Background information was compiled via an initial literature review. The background material was incorporated into a questionnaire (sent to select individuals within councils and central government) to get feedback on whether the soil quality monitoring goals were still relevant and the extent to which change in the current systems was desired. The questionnaire results, along with further literature review material, were discussed in focus group meetings that informed workshop sessions on specific topics. Workshop material was then summarized, and specific recommendations synthesised from workshop material and further reviewed by the focus group.

2 Background on soil quality target value approach and alternatives

2.1 Objectives behind regional soil quality monitoring

The approach by which indicators are evaluated should help achieve the overall objectives of the soil quality monitoring programme. Hill et al. (2003, 2009) considered the primary regional objectives for soil quality monitoring to be to:

- provide an early-warning system to identify the negative effects of primary land uses on long-term soil productivity (physical, chemical, biological).
- track specific, identified issues relating to the effects of land use on long-term soil productivity (which may also be district/area specific).
- utilise these results for State of the Environment (SoE) reporting and policy development.
- integrate with other regional monitoring (e.g. water, especially groundwater).

The current system has largely met the original goals as it has provided 'early warning' and tracking of several issues related to land use intensification (e.g. increased nutrients, and low microporosity values under dairy and intensive drystock) and has been used both for regional and national (e.g. MfE & Stats NZ 2018; 2021, for Our Land 2018, Our Land 2021) SoE reporting. However, more quantifiable ways of assessing the state of the environment and how it changes over time are now desired.

2.2 Current system and methods of target value determination

The current target ranges were arrived at through a series of workshops in 2000–2001. The original intent of the target value system was a Warrant of Fitness approach. If an indicator for a site was within that target value range, it received a 'pass' and if outside, a 'fail'. The number of sites that meet all target values for each land use (or do not meet 1, 2 or 3 or more indicator target values) could then be summed (either on a regional or national basis) as well as determining the percentage of sites that failed a particular indicator by land use. This system has worked well as an early warning system as it has signalled several important land use trends, such as the low macroporosity values under dairy and intensive drystock systems, but the system does have obvious shortcomings. The approach has been refined over time; for instance, sites above vs below target values can also be shown as well as those simply outside target values.

Indicators are generally considered under three broad scenarios (Arshad & Martin 2002): less is better (e.g. contaminants), optimal (or acceptable) range (e.g. nutrients), and more is better (e.g. soil carbon). Except for total carbon, the other six original indicators fall into the optimal range category. Even for total carbon, there has been some discussion on whether an upper range is warranted. Thus, an acceptable range of values needs to be determined and these ranges generally must balance production concerns with environmental outcomes, as the indicators are mostly applied to production land. Several different approaches were used to develop the Sparling et al. (2003, 2008) target ranges (e.g. statistical data from the National Soils Database), which culminated in workshops where expert opinion was used to finalise the accepted target ranges. Taylor (2021) listed a number of possible approaches for target value derivation and evaluated the strengths and weaknesses of each (Table 1). He concluded that each indicator would likely require a combination of approaches and that an expert panel would be needed to synthesise and finalise recommended ranges in order to avoid biases in any one approach.

Table 1. Approaches for derivation of target values and strengths and weaknesses of each approach (adapted from Taylor 2021)

Approach	Strengths	Weaknesses
1) Expert panel The panel specialists arrive at conclusions and recommendations through consensus (EU Evaluation Unit 2017 [Expert panel | Capacity4dev (europa.eu)])	Experts have knowledge of the subject. Quick to assemble. Cost effectiveness. Credibility of the conclusions. Adaptability to a variety of situations encountered in evaluation. Can be used to establish standard non-linear scoring functions.	Requires experts with recognised expertise in the area of interest. Requires objectivity as results can be distorted by lobbyists or a 'dominant' expert who is over influential. Consensus tends to eliminate minority views and tone down conclusions. Experts tend to go beyond their area of expertise.
2) Percentiles A percentile is a value below which a certain proportion of observations fall	Can separate typical behaviour from unusual behaviour. Not strongly influenced by outliers. Can use non-normally distributed data. Informs where a score stands relative to other scores. allows continuing evolution of the system. Used as a substitute where critical values are absent (Gil-Sotres et al. 2005). Gives a relative assessment.	Oversimplification of underlying physical-chemical processes. Represent rank order only as it only informs where a score stands relative to other scores – Little on the degree of soil quality. e.g., Dutch soil quality monitoring target values are based on median values of the monitoring network.
3) The Natural state i.e. The outer limit of background variation (Kowalska et al. 2018). This usually takes a percentile as the target	Distinguishes natural state from unusual, normal from anomalous, usually in relation to contamination.	No information on the quality of soil, does not consider the impact of the parameters measured on soil properties. The reference may not be at an optimum for all parameters. Background soils may not be suitable for productive use so of limited comparison value.
4) Reference soils The same type and properties of the studied soil. (Kaufmann et al. 2009; Kowalska et al. 2018; Bünemann et al. 2018).	Distinguishes normal from anomalous. Can provide direct comparisons for soil quality parameters.	Needs to be the type and properties of the studied soil, otherwise this brings in uncertainty. Not all monitored soils have suitable reference sites.

Approach	Strengths	Weaknesses
Sampled same time or once as a baseline. A reference soil is in equilibrium with all the components of the environment; soils capable of maintaining high productivity and of causing the minimum of environmental distortion.		Reference properties can change if monitored at same time as the studied soil (Iturri et al. 2016). Ideal reference will not always match maximum standards of Quality.
5) Calibration to risk, a risk index or threshold of contamination	Established toxicological critical values for most common contaminants (most commonly applied to trace elements/ contaminants).	Complex, depends on test organism and component: e.g. several exposure routes should be considered (Fernández et al. 2006) Emerging and uncommon contaminants may lack toxicological critical values (Cavanagh & Harmsworth, 2022).
6) Agronomic optimums	Fertility well established.	Referenced to small plot trials, which adds uncertainty when comparing to SQM representative sampling. Values depend on crop and species grown, not soil function or environmental outcome
7) Comparison with field observations, e.g. Visual Soil Assessment (VSA)	Field methodology relatively quick and simple. Direct relationship with some soil properties demonstrating unfavourable changes in soil structure (Shepherd 2003; Moncada et al. 2014). The expected range for each indicator will vary according to site-specific controlling factors with threshold values of the indicators overcome when the grouping of the soils is based on the classes of the soil structure status (visually evaluated) as a response variable (Moncada et al. 2014).	Subject to operator bias (e.g. in comparing results from different operators either temporally or spatially). Applicable largely to physical measures. Qualitative or semi-quantitative not quantitative. Cohesive, sandy, and peaty soils present problems Lack of research into the influence of soil moisture content on VSA criteria.
8) Demarcation of critical thresholds or triggers for specific soil functions	Would signify significant change to soil functioning	While there are some data for critical values for specific plants or organisms (particularly for contaminants), there is little data for many soil functions. Additionally, many indicators affect different functions in different ways.
9) Biological indicator approach using the behaviour and activities of soil microorganisms (or other soil organisms)	Communities are strongly impacted by changes in soil conditions. They are also ubiquitous and can predict soil physico-chemical characteristics.	Response models, thresholds, and critical values yet to be developed.

2.3 Examples of international approaches to indicator evaluation

Bunneman et. al. (2018) reviewed a number of soil quality programmes internationally and listed the most common methods for interpreting indicator results as target values and/or thresholds and trigger values, trend analysis, and scoring curves and/or indices. Apart from trend analysis, methods to evaluate indicators will require specified approaches to derive the targets, indices or scoring curves. Some of the methods detailed in Table 1 can be applied to other forms of indicator evaluation such as scoring curves, indices and trigger values. Bunneman et al. (2018) list references for each method but specific details on how methodologies are arrived at, as opposed to what indicators are used, are often sparse for these (and other) references listed.

There are several programmes in Australia that use a very similar indicator evaluation methodology to that of NZ (e.g. Cotching & Kidd 2010; Queensland Government Department of Environment & Science 2020); however, many international programmes are different in scope and purpose. Lenka et al. (2022) reviewed four indexing methods including principal components analysis (PCA), soil functions (based on expert opinion with regard to their established role in the soil production), percentiles, and maximum and minimum values. They found that a soil function approach along with percentiles provided the best correlation to crop yield but did not specifically address environmental outcomes. Armenise et al. (2013) used a weight additive soil quality index generated from PCA of soil attributes and although they did find differences in crop management, did not find a significant correlation to crop yield. Haney et al. (2018) devised a soil health test, asserting the tool is 'an integrative soil testing approach that measures inorganic N, P, and K with a soil extractant comprised of organic acids. It also estimates potentially mineralizable N and P as influenced by water extractable organic C and N and microbial soil respiration'. While the test does contain some attributes of soil biology (e.g. soil respiration), it is unclear how the different components of the test are evaluated. The authors did find highly significant correlations of components of the test to production for the soil N test, though r^2 values (i.e., the amount of variation explained by the tests) were low, ranging from 0.06 to 0.20 for different crops

Often, indices are constructed that best differentiate between land uses or land management to identify a specific threat. For instance, Raiesi and Beheshti (2022) used factor analysis and neural network analysis of 16 soil attributes from cropland and forest. Indices for both methods were sensitive to changes in soil organic carbon and able to differentiate deforestation, but other than that stated goal, the authors did not attempt to discern correlation to either production or other environmental outcomes. In a similar study, Raiesi and Pejman (2021) were able to differentiate burned forested areas from unburned. Zhang et al. (2021) used a minimum data set of soil indicators and utilised a non-linear scoring system to differentiate sites disturbed and/or revegetated that could serve as a baseline for areas disturbed during the Winter Olympic Games in China. Such indices are likely to be highly specific to location, however.

Many programmes vary in scale, from on-farm-scale attributes to others with very broad potential international application. Because of the wide variety of programmes, we have selected several alternatives that provide distinct differences in their approach (including alteration of the current programme). These are summarised below.

2.3.1 Modification of existing target value system by utilising subdivisions within target value ranges

The original target value document (Sparling et al. 2003) contains graphs and tables that further categorise indicator values as very low (or very depleted), low (or depleted), adequate/optimal, high, excessive, etc. (see Fig. 2 for an example for anaerobic mineralizable N).

These subdivisions could be refined and incorporated into the target range system (for instance by incorporating sub scores within divisions). While this does not rise to a true quantitative metric (the sub-scores would be categorical variable instead of continuous, which does have some statistical considerations), it would potentially be the easiest alternative to implement.

Whereas the current system does not distinguish where a value is inside the target range, this could allow for better tracking of the progressions of soil quality indicators both within and outside of target ranges. Aggregate scores could also potentially describe whether regional or national trends are moving towards optimum values or away.

Pasture	25	**50**	100	200	200	**250**	300
Forestry	5	**20**	40	120	150	**175**	200
Cropping & horticulture	5	**20**	100	150	150	**200**	225

Very low	Low	Adequate	Ample	High	Excessive

Figure 1. Example of the subdivisions within original target ranges for anaerobic mineralizable nitrogen. The bolded numbers represent the adopted target range (from: Sparling et al. 2003).

2.3.2 Wageningen ISQAPER/SQAPP the soil quality

Although much broader in scope and scale (covering a wider range of soil attributes and attempting international coverage), the Wageningen Interactive 'Soil Quality Assessment in Europe and China for Agricultural Productivity and Resilience' (ISQAPER) project developed the soil quality app (SQAPP) that integrates soil quality information with other soil and climate data. The approach combined commonly used indicators of soil quality with those associated with identified soils threats (e.g. desertification, soil pollution, erosion). Because the steps taken to initiate the programme are clearly defined, we have shown these steps in full below (from: Building SQAPP (isqaper-is.eu))

1 Selecting soil quality indicators; based on the review of soil quality indicators in »Soil quality - a critical review, a selection of the most commonly used was made. For these indicators, we examined availability in terms of global datasets. All relevant indicators for which maps existed were retained as input data layers. Similarly, maps of soil threats were reviewed. Here, available global datasets were used; in Europe some

further soil threats were included based on soil threat maps with European coverage. »Soil indicators

2 Defining pedo-climatic zones; as one of the principles underpinning SQAPP is a relative assessment of soil indicators, appropriate zones with similar conditions need to be defined. Within iSQAPER pedo-climatic zones were developed for both Europe and China (»Pedo-climatic zones of Europe and »Pedo-climatic zones of China). As the basic climate zones distinguished in these classifications were not comparable and because there were some conversion issues to reclassify Chinese soil types to WRB (World Reference Base) soil types, the resulting pedo-climatic zones in Europe and China were not directly comparable, and moreover, did not cover other areas of the world. This became an issue for calculating relative soil indicator scores at global level. To resolve this issue, a new pedo-climatic zonation was produced for the purpose of calculating consistent data layers for the app.
»Defining pedo-climatic zones

3 Ranging soil quality indicators; once indicators are selected and pedo-climatic zones are defined, it is possible to calculate cumulative probability density functions for each indicator in each pedo-climatic zone. These cumulative probability density functions become the basis for the relative assessment of soil quality. Moreover, within each pedo-climatic zone, attention also needs to be paid to the land use/cover, as land use is known to greatly influence the indicator scores of several soil indicators. To account for this issue, separate calculations are made for the minimum and maximum scores of each indicator in each pedo-climatic zone, specific for arable and grazing land respectively.
»Ranging soil quality indicators

4 Scoring indicators; the relative scores of soil property values are considered based on their position on the cumulative probability density curves. That means (considering whether indicators are of the 'more is better' or 'more is worse' type), that the bottom 33% of the frequency distribution are considered as low, and the top 33% as high, with medium the outcome for intermediate values. For soil threats, absolute, expert-based values were considered based on the work conducted in »Calculating the soil quality index in SQAPP.
»Scoring soil quality indicators

5 Assessing indicators; this step concerns the calculation of the potential for soil improvement (percent score) across all soil property indicators, and the calculation of the average soil threat level (on a bar slider between low and high). All poor performing soil property indicators and soil threats are considered as urgent aspects to be addressed.
»Assessing indicators

6 Recommended practices; the final step in the SQAPP is to recommend agricultural management practices based on the overall soil quality score and most urgent soil quality aspects to be addressed. Underlying the recommendations is the development of a large matrix table of the agricultural management practices and a) applicability factors – defining where each of the AMPs is applicable; and b) effectiveness – where the impact on soil property and soil threat indicators of each AMP are scored. The 10 AMPs reaching the highest overall score for the combination of soil properties and

soil threats to be addressed in a given location are presented to the app user. »Recommended practices

2.3.3 SHAPE – Soil Health Assessment Protocol and Evaluation

The Soil Health Assessment Protocol and Evaluation (SHAPE) is an extension of the Soil Management Assessment Framework (SMAF) developed in the United States. The SMAF approach had an initial set of 11 indicators (organic C, microaggregates, microbial biomass carbon, potentially mineralizable nitrogen, pH, extractable phosphorus, microbial quotient (qCO2), bulk density, electrical conductivity, sodium adsorption ratio, and available water content) but there was also a list of potential indicators that could be added. SMAF utilised quantitative scoring (indexed to a 0 to 1 scale where 1 is optimal (Andrews et al. 2004) to gauge the 'health' of each indicator. The nature of the scoring system makes comparisons over time and space more quantitative. Generating these relationships, however, requires extensive field data (often from long-term controlled field trials across different soil types and climates) and development of complex functions to derive the curves (in the current New Zealand system, only soil order and land use are required). The shape of the curves is still likely to be somewhat subjective, particularly when considering environmental outcomes, as much more data are available for productivity than environmental outcomes).

The SMAF approach is well reviewed (Karlen et al. 2019) and is arguably one of the most extensively used systems, having been utilised in the US on pasture and cropping systems (e.g. Karlen et al. 2013; Amorim et al. 2022) but also in South America (Lisboa et al. 2019).

Although certainly more quantitative, these scoring systems are generally more difficult to implement. In the original SMAF approach, soil carbon curves were generated from pedo-transfer functions of measured soil texture values (soil texture was a required measurement as part of the programme). In an extension of the SMAF approach (designated as SHAPE), Nunes et al. (2020) detail at length a more involved process they used to generate such curves for soil organic carbon (Fig. 2). Here the curves were generated from Bayesian model-based estimates of the conditional cumulative distribution function (CDF) for defined soil peer groups reflecting five soil texture and five soil suborder classes adjusted for mean annual temperature and precipitation. In effect, this approach attempts to assess the distribution of soil carbon values under the different soil texture, suborder, and climatic combinations.

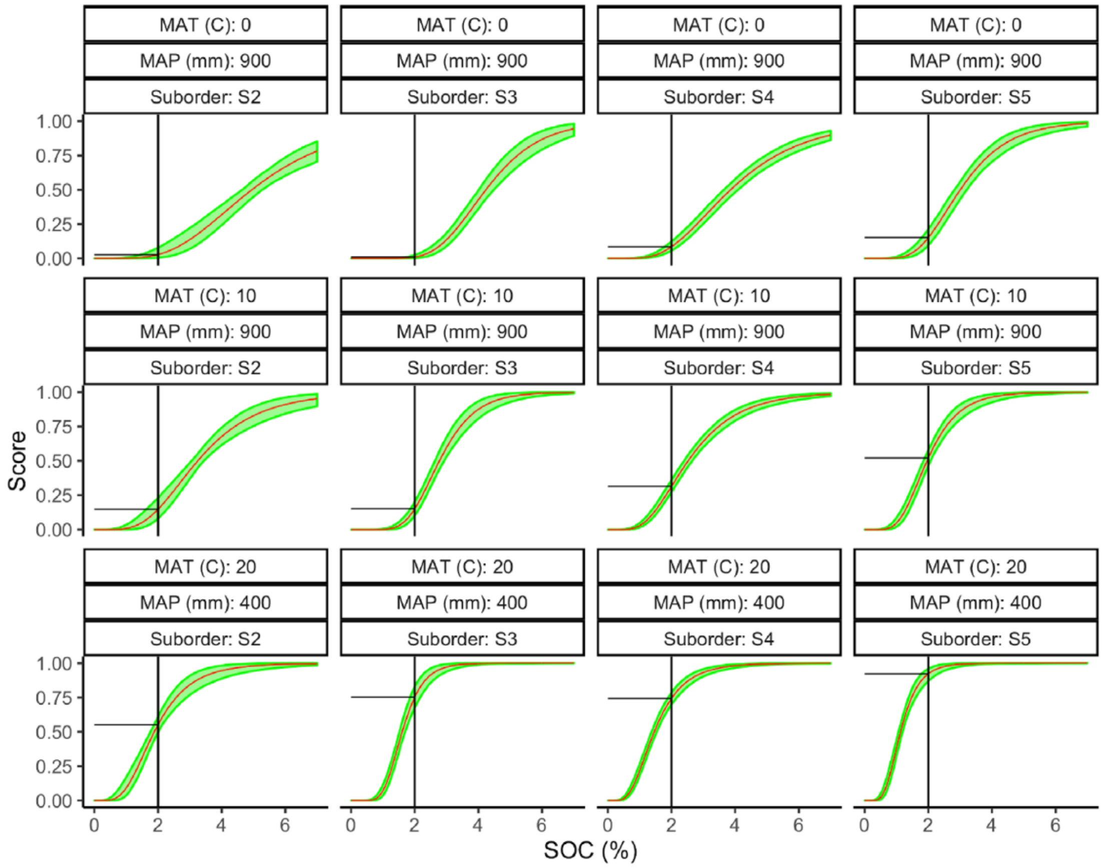

Figure 2. Scoring curves developed for different soil suborders in the US depending on climate and parent material factors (from Nunes et al. 2020).

2.3.4 DEX (Decision Expert Model)

Van Leeuwen et al. (2019), have developed a model that is designed to assess attributes in three categories, soil properties (including soil biological indicators such as worm, nematode, microarthropod and enchytraeid abundance, and species richness), environmental factors, and management practices. Similar to SHAPE, DEX attempts to address the interrelationships between the combinations of properties (e.g. environment/climate × soil properties × management practices).

The breadth of attributes that the model covers is impressive, but the weightings and algorithms used in the model are decided by expert opinion (see Table 2 for an example). The results are arrayed in four subgroups – soil nutrient status, soil biodiversity, soil structure, and soil hydrological status and utilise a variety of scoring methods (e.g. count data for number of species and categorical data for land management). Results from the DEX model compared well with the expert ranking of the data from the Netherlands Soil Monitoring Network (a similar but separate programme) but since the system is designed largely on expert opinion, integrating new data may be difficult. Similarly, the degree of compromise between environmental and production outcomes may not be easily discerned.

Table 2. Weightings developed for different attributes of the DEX model (condensed from van Leeuwen et al. 2019)

Attribute	Grassland		Cropland	
Soil biodiversity and habitat	**Local**	**Global**	**Local**	**Global**
Nutrients	39	39	38	38
pH condition	30	12	31	12
Liming	50	6	50	6
Soil pH	50	6	50	6
Nutrient content	35	14	38	15
Organic matter quantity	50	7	50	7
Soil organic matter	50	3	50	4
Thickness organic-rich layer	50	3	50	4
Organic quality	50	7	50	7
Soil C:N ratio	50	3	57	4
Soil N:P ratio	50	3	43	3
Nutrient inputs	35	14	31	12
Mineral N fertilization	50	7	50	6
Manure type	50	7	50	6
Biology	33	33	29	29
Soil biota	35	11	44	13
Faunal	50	6	50	6
Earthworm diversity	25	1	25	2
Earthworm richness	50	1	50	1
Earthworm abundance	50	1	50	1
Nematode diversity	25	1	25	2
Nematode richness	50	1	50	1
Nematode abundance	50	1	50	1
Microarthropod diversity	25	1	25	2
Microarthropod richness	50	1	50	1
Microarthropod abundance	50	1	50	1
Enchytraeid diversity	25	1	25	2
Enchytraeid richness	50	1	50	1
Enchytraeid abundance	50	1	50	1
Microbial	50	6	50	6
Bacterial biomass	50	3	50	3
Fungal biomass	50	3	50	3
Management*	65	21	NA	NA
Grassland	57	12	NA	NA
Grassland type	32	4	NA	NA
Grassland diversity	36	4	NA	NA
Legume presence	32	4	NA	NA

2.4 Different frameworks and concepts that relate to soil quality/soil health

Council and central government feedback indicated a desire to work towards a broader soil health programme. When considering longer-term goals for soil quality/soil health, it is useful to consider how different frameworks relate to soil quality indicators and how they are evaluated in the context of broader State of the Environment reporting programmes. No single approach is likely to fit New Zealand's specific needs for its reporting (e.g. the balance between production and environmental outcomes and a mechanism for inclusion of Te ao Māori). Here we give an overview of three frameworks that have some similarities but also differ in their approaches to describing aspects of the soil system – the soil ecosystem services model, Soil Security, and a well-being model that integrates the Treasury's Living Standards Framework, and the Waka-Taurua concept.

2.4.1 Soil ecosystem services (natural capital, stock adequacy)

The soil ecosystem services concept (Fig. 3) shows how soil stocks and flows affect ecosystem services. The broader ecosystem services concept acknowledges that **trade-offs** often occur between different services, and it is difficult to optimise for all services. The framework can be used to investigate how natural capital and supporting or degrading processes affect different services. Dominati et al. (2021) used this approach to assess biodiversity enhancements on the financial and environmental performance of mixed livestock farms in New Zealand. Lilburne et al. (2020) used a similar approach (the land resource circle) to explore services and functions provided by soil.

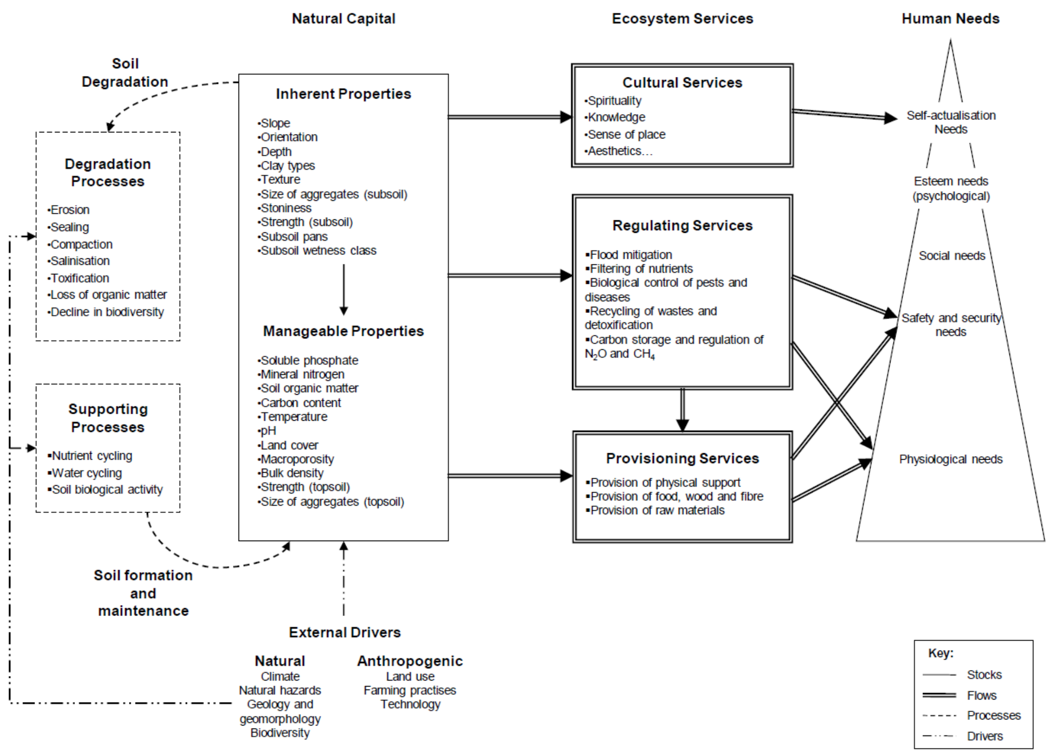

Figure 3. Conceptualisation of soil ecosystem services (from Dominati 2011).

Though the framework explicitly acknowledges cultural services, most of the work in this area has focused on regulating and provisioning services. An argument has also been presented that representation of Te ao Māori (and cultural services in general) should extend through all the services.

2.4.2 Soil security

The soil security concept relates how seven soil functions (biomass production, storing filtering and transforming of nutrients, biodiversity pool, physical and cultural environment, sources of raw materials, acting as a carbon pool and archive of geological and cultural heritage) affect an array of global concerns (Fig. 4).

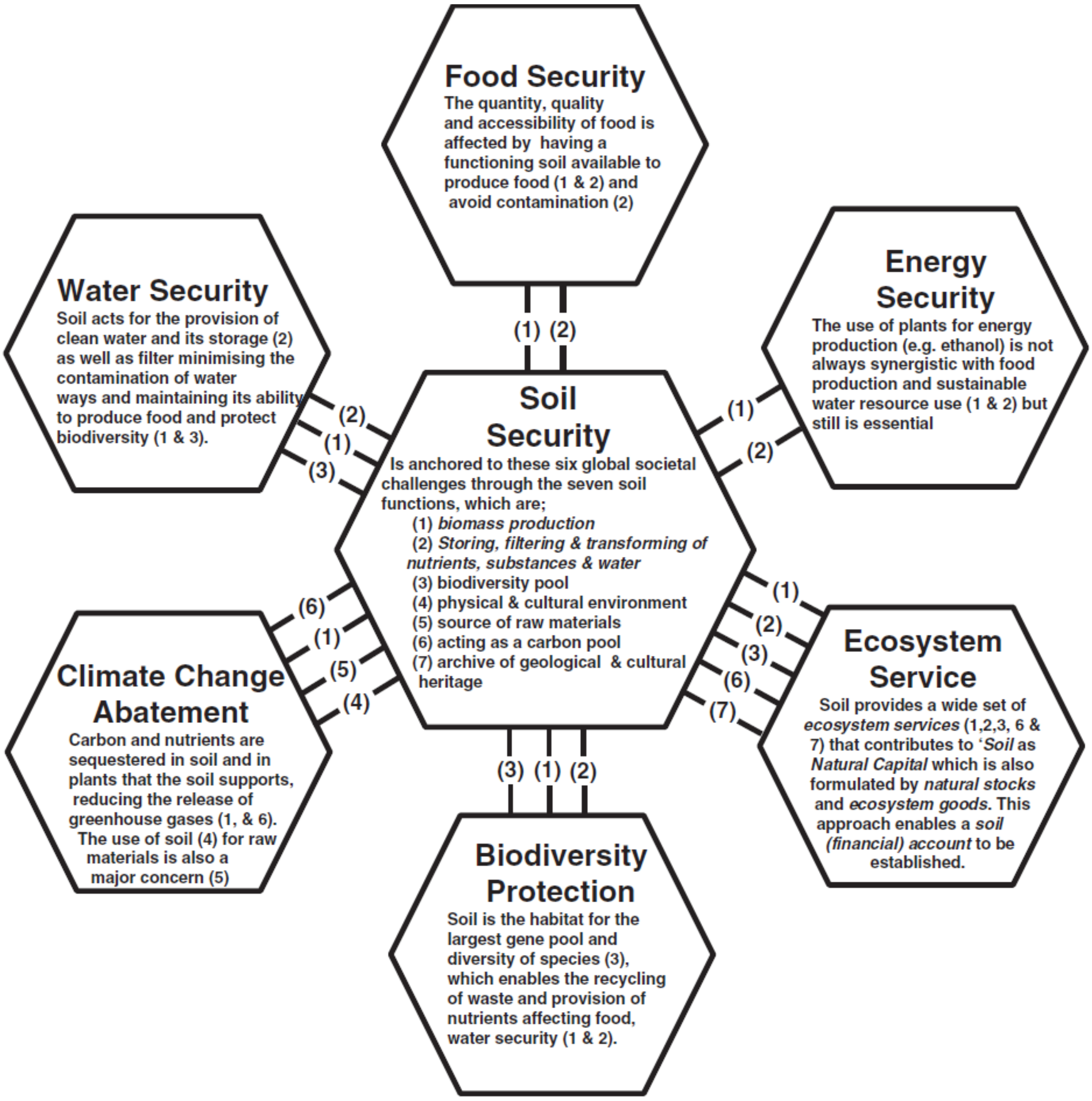

Figure 4. How Soil Security (and soil functions) relate to other societal challenges (from McBratney et al. 2014).

The five interconnected dimensions of soil security are defined as **capability, condition, capitol, connectivity, and codification**. Threats to each of these dimensions are listed in Table 2. Soil health is closely aligned with the condition (and capability) of a soil but is explicitly defined in comparison to a reference state. In New Zealand, Codification (laws and governance) has arguably affected development of soil quality (and natural capital) concepts through the Resource Management Act. Connectivity (relationship to society) is also affecting our view on soils, particularly from a Māori perspective.

McBratney et al. (2014) state that 'For each one of those dimensions there are some burning questions. For example, Capability & condition, how can we arrive at an agreed methodology for defining the reference state?'

Table 3. Threats to the dimensions of Soil Security (from McBratney et al. 2014)

Dimension	Threat to soil security
Capability	Erosion, landslides, sealing by infrastructure, source of raw materials
Condition	Contamination, loss of organic matter, compaction and other physical soil degradation, salinization, floods
Capitol	Inadequate assessment of the value of the soil asset, soil stock, and the processes that: support (e.g. nutrient & water cycling, biological activity), degrade (e.g acidification, salinization, loss of organic matter, compaction), and regulate (flood mitigation, erosion, control soil pests, and disease, & greenhouse gas abatement) Indiscriminate treatment of soil as a renewable resource
Connectivity	Inadequate soil knowledge of land managers, lack of recognition of soil services and soil goods by society
Codification	Incomplete policy framework Inadequate or poorly designed legislation

2.4.3 Well-being/Nature Futures Framework incorporating the Treasury Living Standards Framework and Waka-Taurua concept

The Natures Futures Framework acknowledges that there are different sets of values we need to account for – instrumental, intrinsic and relational (as defined in Fig. 5), and each of these values underlie the various benefits that other frameworks define.

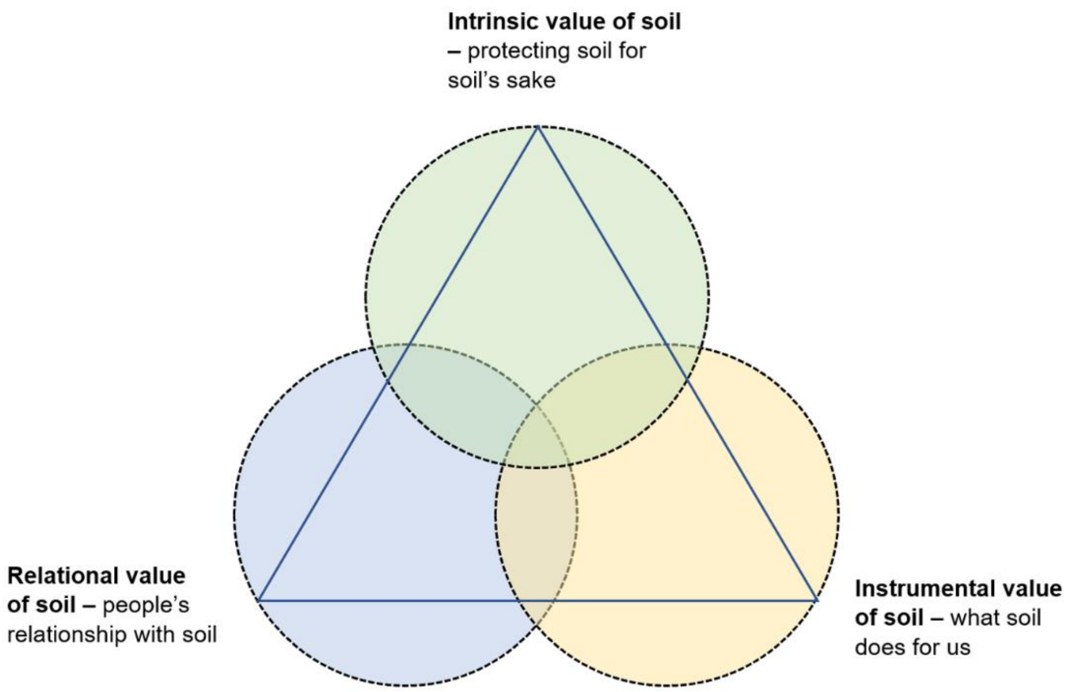

Figure 5. Application of the Natures Futures Framework to how we value soil. From: Stronge et al. Submitted.

The well-being framework put forth by Stronge et al. (Fig. 6) incorporates the different values defined in the Natures Futures Framework with aspects of the Treasury's Living Standards Framework (inclusion of social, human and natural capital as well as financial and physical capital) and the Waka-Taurua concept (the connection of overlapping goals with a Te ao Māori through a papanoho (bridge) (Maxwell et al. 2020) to explicitly acknowledge a Māori world view in addition to a western science approach and broader societal view.

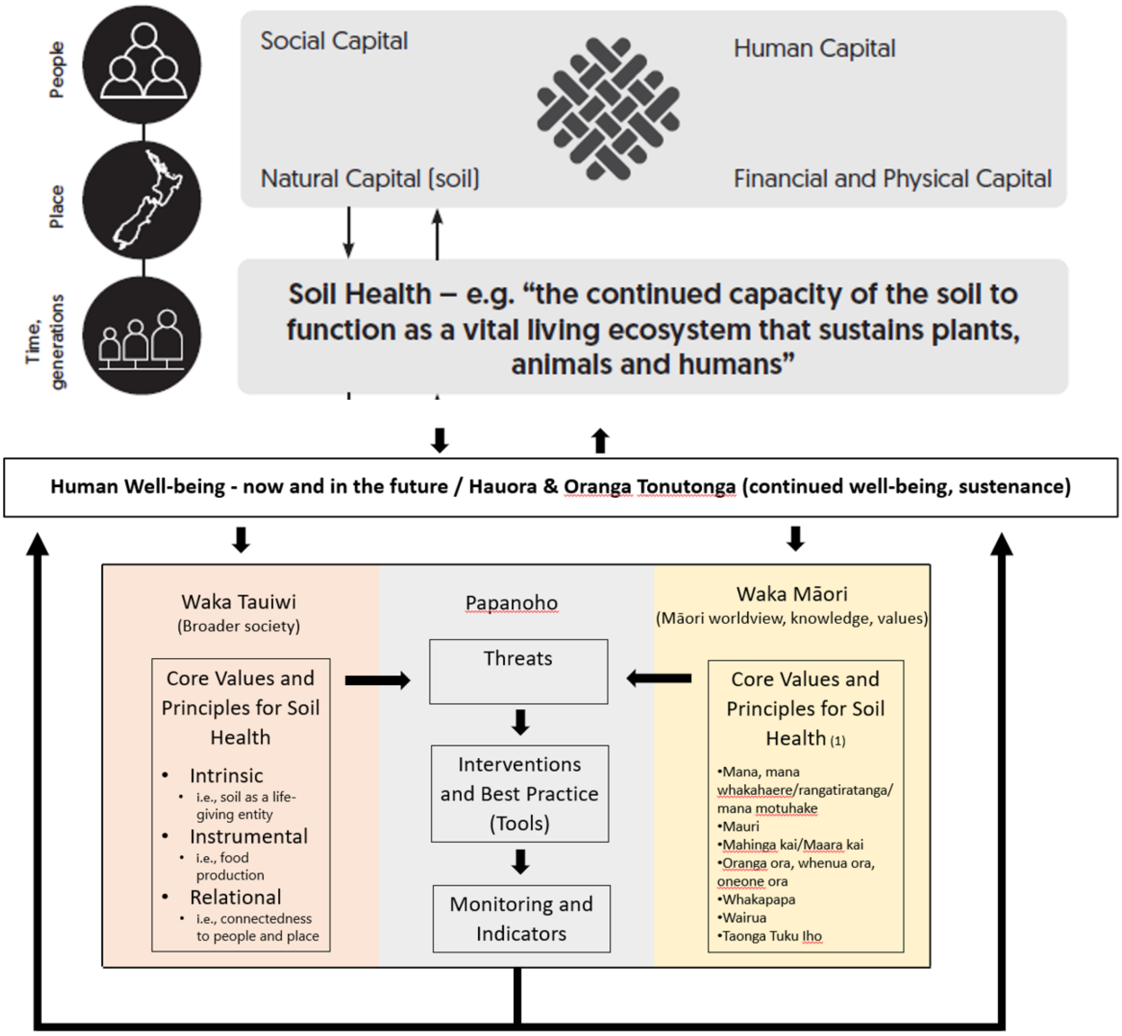

Figure 6. A well-being framework for soil health in Aotearoa/New Zealand (from Stronge et al. submitted).

3 Questionnaire and Focus Group responses

The background material was initially condensed into a questionnaire format and specific questions posed to a small group of council and central government respondents to gauge perceived strengths and weaknesses of the current approach and the extent to which change was desired. A copy of the questionnaire can be found in Appendix 1. Here we present a summation of how the Focus Group organised responses into different groups. These response groups formed the basis for the workshop sessions in Section 5.

- Goals of soil quality monitoring programme still relevant
- General agreement on the need for (at least) some change to target value system, but a variety of opinions on how much change needed
- What is the best approach for suggesting changes to the current system?
    - More 'depth' behind the targets, what they mean, what if not met?

  - We have more data now to evaluate.
  - Larger more diverse audience (and different audiences, e.g. industry bodies, environmental bottom lines).
  - Staged approach useful to outline in project.
  - Short- and long-term options useful.
    – What do we want soil quality monitoring to look like in 20 years?
    – What can it show us in 20 years?
- Regional and Central Govt Reporting Issues
  - Simple (but statistically robust) results desired on National level
  - More willingness to experiment with design and interpretation at regional level(?)
  - Quantifiability – what does that look like for regional vs national (back to ratings level of SoE indicators)?
  - How do we better detect and represent trends?
  - While some regions have relatively large programmes, others do not. Leads to disparity in what can be done on a region by region basis.
  - More direction and leadership (and funding) from Central Gov on what specific reporting they want to do.
  - Better feeding up of issues identified at regional level to national level.
- How to better relate/explain the data with respect to environmental outcomes
  - Environmental impact is the key (but sustainable production vis a vis RMA still relevant).
  - Relate better to catchments/water quality issues – but sampling strategies may differ. Current design is broad soil order/land use stratification whereas water quality is thought to be more specifically impacted by critical source areas. General relationships of soil quality and water quality being explored in current OLW project.
  - Better interpretation for off-site vs on-site impacts?
  - Balance between production and environment – dis-entangle to better inform/explain environmental component.
  - How do we better separate production and environment for more impact to audience?
  - Can the current system be fitted into an ES/Natural capital framework?
  - Put issues/drivers and impacts together.
- How do we define Soil Health and what do we measure it against?
  - Definition of soil health?
  - Consider natural or reference state?
  - Where do the soils 'fit'?
  - Should target values be more aspirational (i.e. measuring movement toward some aspirational level)?
  - Indigenous land useful for contaminant issues (Eco-SGVs approach for contaminants).

    - Methods? Consider DOC data but different methods (could be used to help determine better native sites).
- Indicator Evaluation and improved communication of impact messages
    - What do the values mean?
    - Go back to (or perhaps modify) original indicator groupings – organic status, acidity, fertility, physical status.
    - How can we get better information out?
    - Link more directly to key land management practices?
    - Interconnection between the issues.
    - Better way of communicating the data?
    - Improve the potential for what is used.
    - Who are the various audiences?
    - Key messages needed to them.
    - Is something having serious impact or not?
    - Scaling of the impact of indicator values by (a) current aerial extent of land, and/or (b) change in land area of land uses.
- Individual indicators and approaches
    - What do we know most about each indicator?
    - What do we know least about each indicator?
    - What do we want to know on future indicators?
    - VSA?
    - eDNA/DNA as a regular indicator?
    - New potential indicators could be a separate Tools project.
    - Re-incorporate bare ground as an indicator? Potentially now available from remotely sensed data.

4 Workshop summary

The following is a summary of the workshop with the Land Monitoring Forum members, MfE and StatsNZ on 13 May 2022. As discussed in previous section, the Focus Group summation of questionnaire responses formed the basis for the workshop sessions, which included: regional and central government reporting priorities; short- and long-term goals for the soil quality monitoring programme; concepts and frameworks (how do these affect long-term goals); and a final session on what an Envirolink Tools proposal could look like.

4.1 Regional and central government reporting priorities

MfE gave an update on their priorities regarding land and reporting. These are broadly summarised as:

- Clarify purpose of environmental reporting, national EMRS.

- Inconsistent and deficient data. Core indicator list to be established and soil quality will likely be one.
- Te Tiriti under-recognised.
- Targets and limits – resource management. Need to be consistent with what's been done over last 20 years of monitoring.

There should also be awareness of Resource Management Act reform, particularly in reference to the Natural and Built Environment Act (NBEA) and proposed actions around the concept of ecological integrity (see: Highlights from the proposed Natural and Built Environments Act (buddlefindlay.com)

StatsNZ gave an update on their priorities regarding land and reporting. These are broadly summarised as:

- Recent expansions to environmental reporting are now adding drivers and outlooks to pressure state and impacts. Now includes Mātauranga Māori.
- Current soil/land domain topics include impact of soil quality on human health and soil health.
- Core indicators – process for selecting these and then to establish.
- Guidelines for establishing core indicators. Agreement is required on guidelines. They are essential for providing context to the data and need to be trusted by a reader as much as the data.

Participant responses for the topic of regional and central government reporting priorities were broadly summarised into the following themes:

- Discussion and comments suggested the SQM needs more guidance on method, such as consistent soil monitoring site selection, statistical robustness, with more guidance on frequency, etc. to detect trends.
- Discussion and comments suggested the SQM needs targets that relate to changes in soil function or properties, and LMF should consider targets defined internationally. Guidance on how to use the criteria for national reporting, policy outcomes, and potential actions would be worthwhile.
- Discussion and comments suggested the SQM should have a minimum parameter set nationally (currently 7) and across all councils (some councils do yet not monitor SQM). Locally relevant indicators for councils, biological indicators, and ecosystem service ones were discussed as potentially useful.
- Messaging and communication was a strong theme, with suggestions to keep messaging simple, include production vs environmental information clear, but to include actions for more impact, especially for policy. Some caution with 'grouping' the indicators may need to be applied, but a strong message was to use consistent terminology nationally for target ranges/limits/guidelines, and for soil quality vs soil health.

4.2 Short- and long-term goals

Participant responses for this topic were broadly summarised into the following themes:

4.2.1 Short-term goals

As mentioned in Section 5.1, discussion and comments suggest that SQM needs more guidance on method, such as standardising samples spatially, providing guidance on the most important for impacts. The 'Soil Quality and Trace Element National Environmental Monitoring Standards' (NEMS; Hill 2022) should help to alleviate some sampling questions, but others could be addressed in the next review.

Messaging and communication should be clearer to public vs technical readers, with a mix of simplicity and complexity for various audiences (land-owners, industry bodies, regional and central policy makers). Consistent terminology as described previously was recommended. Messaging around targets needs to be clear, for example, not reaching a target – what does that mean to risk or potential action.

Indicator targets could relate better to changes in how the soil functions, or services it provides.

4.2.2 Longer-term (3 specific questions were posed)

<u>How soil quality (SQ) relates to other SoE monitoring</u>

Messaging and robustness

Better relate SQ trends with trends in water quality indicators, link with GHG fluxes and carbon stock. Relationship with land use and intensity of land use. Effectiveness monitoring – knowing if the land use and management mitigations are making a difference. Better relate to drivers and outcomes and health, socio-economic reporting, and well-being.

As an environmental warning:

Foresee SQ issues, indicators provide 'robustness' around what we say. Link measurements with issues identified and actions for mitigations (including policy).

Guidance:

Site selection determined and managed at a national level (similar to the soil C). Statistically sound national approach. All measurements at sites to see interrelationships. Environmental targets (e.g. Olsen P) to align with water quality monitoring. Sites need to be spatially aligned with catchments to relate to other SoE indicators.

How will SQ monitoring data be used in 20 years?

Participant responses for this question were broadly summarised into the following themes:

- Land management drivers and impacts established for each SQ issue. Drivers instead of land uses may be useful for trends. Relate Olsen P or soil N to DRP, TIN or weed in waterways, and other SoE monitoring. Clustering. To inform best management practices with policy to achieve improved outcomes (both environmental and production). Resilience, more use of structural vulnerability.
- As a reliable record of the change in soil health, quality, and biodiversity. As evidence of failure to protect or of success for more sustainable land management. Need strategies or actions. Need better knowledge about what a result means for some indicators.
- Ideally data to be made available. Data privacy issues will need to be resolved. Ideally, it will be used as the most reliable, quantitative long-term database for the state of soil (and its change over time) in Aotearoa New Zealand.

What do we want the SQ monitoring programme to look like in 20 years?

Participant responses for this question were broadly summarised into the following themes:

- Have a nationally consistent SoE monitoring programme for all physical factors in the environment, with a national agency overviewing monitoring activities, setting the standards and guidelines, data storage, analysis and communication. Have a programme that is valued and used by all sectors, users, primary industry sectors and industry etc. SIGs now have a shared Teams platform for sharing which could be used more.
- Landowners will want to monitor their soils. Monitoring will be more widespread and openly shared, and rather than develop regulations it will serve to determine best land use and management.

4.3 Concepts and frameworks

Participant responses for this topic were broadly summarised into the following themes:

- Discussion and comments acknowledged that each framework can contribute to a New Zealand approach to soils and soil quality. Further comparative analysis on the utility of each framework for SQ reporting will be useful, clearly disentangling productive from environmental concerns will be important. Need more clarity on how the different frameworks might be applied and used (and this ideally would come from a central government approach). Conceptual frameworks have strengths and weaknesses, e.g. ecosystem framework may be inside the two waka? Plus any important ideas from the other frameworks as needed. Agreed to include Māori soil indicators in a 'new' NZ-matched framework.

- There is a perception that an ecosystem services approach has not yet been accepted at a central government level. Start the intent of high policy framework and then look at the indicators in that. Connect with international reporting where possible. Ecosystem services concepts are useful but needs to be further refined for New Zealand's policy framework. Consider inviting the scientists that are working on these frameworks to provide some input or advice.
- Discussion and comments suggested a whole framework for our soil quality programme would give great context. Need to consider special attention on drivers-scale and land management drivers, and land use. Move away from soil scientist-relevant properties and towards public issue-relevant properties such as vulnerabilities of soils. For where we see the monitoring in 20 years' time, it would be nice to frame a vision into a framework. Questions arose on how an existing monitoring programme would be fitted into frameworks, and on modifying frameworks to match our needs.
- There were some comments on adapting international approaches, with some example frameworks given (see below). Though different international approaches may prove useful, caution is needed as these may not necessarily fit New Zealand's goals and specific intent. Being able to relate soil quality data to the UN Sustainable Development Goals (SDGs) would be useful although respondents suggested the SDGs are a very broad framework with little direction on how to report on the different SDGs.

Some specific examples provided in the workshop by respondents were:

- New Zealand example matching soil SoE data within a soil resilience framework: https://www.mdpi.com/2071-1050/14/3/1808
- EU wide ecosystem service mapping https://publications.jrc.ec.europa.eu/repository/handle/JRC120383
- EU soil health law (https://ec.europa.eu/environment/strategy/soil-strategy_en), which can affect New Zealand, e.g. https://www.rnz.co.nz/news/country/465939/spray-free-orchards-project-wins-7-point-4m-government-grant
- Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services: 'Assessment Report on Land Degradation and Restoration' https://ipbes.net/assessment-reports/ldr

Other discussion comments were broadly summarised:

- A framework may be useful for communication to integrate better with other domains. Start with what we need for policy (New Zealand and international). Use the framework to understand the data and communicate it. Different indicators are helpful in different frameworks, but are indicators designed around the framework, or connected later?
- An ecosystem services framework has not been picked up at national level so needs national acceptance. There can be problems with targeting indicators to ecosystem services such as being less useful for measurement-oriented applications, but useful for reporting.

4.4 What should a tools proposal on target value evaluation contain?

Participant responses for this topic were broadly summarised into the following themes:

Guidance and method:

Need a documented framework and process for reviewing and adopting indicators and defining targets (containing evidence basis for why it is being included, method, and the derivation of soil target ranges and how they are to be interpreted). Consider NEMS (Hill 2022) and link with S-map siblings.

Messaging and communication:

Consider a land manager's point of view. Relate results to resilience or damage, and drivers (e.g. cultivation, fertiliser use), and impacts, e.g. reduction of 10% macroporosity can get less crop growth and more runoff. Improve messaging to help people understand what it means if for example 50% of sites 'failed' to meet the soil quality target.

SINDI and/or S-map:

SINDI (soil indicators) is a MWLR web-based tool designed to help interpret the quality or health of a soil, and is available at https://sindi.landcareresearch.co.nz/

Suggestions included communicate SINDI more and possibly refurbish the website such as building on SINDI, adding interpretative information, or automating updates including adding new soil quality data collected for S-map, etc. Consider Goggle maps and connect to S-map. A question was raised that do soil quality sites need S-map soil sibling matches?

Targets:

Discussion and comments indicated the need to devise targets in a transparent way to show targets for productivity and targets for environmental protection, as these are concepts people generally understand, but to keep the targets largely as is. Use the gradation words more, e.g. 'ample'. There were responses to provide the research basis for the target values and research gaps identified to further refine values.

There were responses about the need to define our overall objective and vision, and what we would like to achieve in the future, with clear definition of what a target value means, and its application. More context is needed around where the natural range and capability is for a soil, e.g. its natural range values, the range under land management, and the range needed to maintain it sustainably.

5 Recommendations

The overall objective of the project was to make recommendations that could form the basis of an Envirolink Tools proposal. Though there was significant diversity in opinions on the degree of change needed, most respondents felt that the target range system should be kept (at least in the short term), but that a degree of modification was needed to address current shortcomings of the system. Longer term, it was felt there was a need to more fully address how SQM related to soil functions. The relevance of the term 'target range' was discussed, but there was no definitive decision on alternative phrasing to better describe the 'acceptable ranges' in which an indicator should fall, so for the present we have kept that terminology.

Envirolink Tools Stage 1 Proposal applications are to be submitted to the LMF in October. We would suggest a draft be prepared by mid-September 2022 for LMF (and central government) to review before formal submission in October. As per the Envirolink webpage, the proposal should contain:

- Outline of the environmental problem requiring the tool
- Alignment with research priorities, strategy and national policy
- Past research upon which the tool is based
- Project team
- Council commitment to the tools implementation
- Budget details

Based on feedback from Councils and central government (MfE and Stats NZ), we suggest that an Envirolink Tools proposal should not only focus on the short-term changes to the target value system but should also develop a longer-term staged approach to a broader soil health programme that incorporates concepts such as ecosystem services and soil security, and acknowledges a Mātauranga Māori perspective.

Short-term the project should aim to:

- review the evidence for the balance between production versus environmental outcomes for each indicator.
- include and develop a scoring methodology for subdivisions within target ranges (such as those noted in Sparling et al. 2008) to better track where indicator values are within target ranges
- assist councils and central government to better communicate soil quality results in relation to target values for the general public and technical audiences, and develop improved communication of the impact of the monitoring.

Longer-term objectives could be to:

- evaluate how SQM nationally is performing to detect trends over time. This could include, for example, recent and current work on the trends for Wellington region and current draft work on national trends.
- consider integration of SQM with other soil resources (e.g., S-map) for more complete soil information that can better inform land management choices.
- consider frameworks from the review and other suggestions at the workshop, for longer term development. Better description of soil functions and/or ecosystem services from a New Zealand perspective, what works and what does not work from each system.

- assist councils and central government to develop improved and more standardised reporting of soil quality data and results, where not covered by NEMS (while acknowledging that different councils have different aims and resources).
- suggest guidance on statistical approaches and requirements for soil quality trend monitoring.
- consider how best to incorporate a Te ao Māori viewpoint into SQ reporting.
- explore the reference site concept for comparison to change in indicator values. A reference state would likely need to be adopted for each land use (although for some indicators such as trace elements, comparison to background levels or 'natural states' are useful. This may be useful in platforms such as SINDI, or to improve communication and impact, particularly for production vs environment.
- consider platforms such as SINDI or LAWA to better display soil quality trends (a mechanism for continued update and technical upgrades to the system however would be required).

6 Acknowledgements

We thank Environment Southland and Horizons Regional Council for sponsoring this grant, and councils, Land Management Forum and representatives from MfE and Stats NZ for their engagement in this project.

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Appendix 1 – Questionnaire

1. Objectives behind Regional Soil Quality monitoring

The approach by which indicators are evaluated should assist in achieving the overall objectives of the soil quality monitoring programme. Hill et al. (2003, 2009) considered the primary regional objectives for soil quality monitoring to be to:

- provide an early-warning system to identify the negative effects of primary land uses on long-term soil productivity (physical, chemical, biological).
- track specific, identified issues relating to the effects of land use on long-term soil productivity (which may also be district/area specific).
- utilise these results for State of the Environment (SoE) reporting and policy development.
- integrate with other regional monitoring (e.g. water, especially groundwater).

While the original system has generally been used as an 'early warning' for potential problems, more quantifiable ways of assessing the state of the environment are now desired.

Are the original objectives still valid/important? What other objectives need to be considered, and why (please list below)?

2. Indicator Evaluation

Indicators are generally considered under three broad scenarios (Arshad & Martin 2002): less is better (e.g. contaminants), optimal (or acceptable) range (e.g. nutrients), and more is better (e.g. soil carbon). Except for total carbon, the other six original indicators fall into the optimal range category. Even for total carbon, there has been some discussion on whether an upper range is warranted. Thus, an acceptable range of values needs to be determined and these ranges generally must balance production concerns with environmental outcomes. As previously mentioned, the current target ranges were arrived at through a series of workshops in 2000–2001.

The original intent of the target value system was a Warrant of Fitness approach. If an indicator for a site was within that target value range, it received a "pass" and if outside a "fail". The number of sites that meet all target values for each land use (or do not meet 1, 2 or 3 or more indicator target values) could then be totalled as well as the percentage of sites that failed a particular indicator by land use. This system has worked well as an early warning system as it has signalled several important land use trends, such as the low macroporosity values under dairy, but the system does have obvious shortcomings. This approach has been somewhat modified over time; for instance, sites above vs below target values can also be shown as well as those simply outside target values.

Pros:

- Pragmatic approach that is easy to understand
- Relatively easy to implement
- Generates easily interpretable data
- Works well as an early warning system
- **Others (please list below)**

Cons:

- Not very sensitive for monitoring change over time (no error associated with number of sites meeting targets, etc.) per sampling interval and assumes land use classes reported on are represented by adequate site numbers
- Deemed too simplistic (or not quantitative enough) – no sense of how close or far away from targets an indicator is: two sites may have similar indicator values but if one is just inside a target range vs one just outside, one is deemed to be fine, the other "of concern"
- Apart from overall statistic on meeting vs not meeting target values, little indication of direction of change
- **Others (please list below)**

1.1 Alternative indicator assessment frameworks to consider

- Utilising subdivisions within target ranges. The original target value document contains graphs and tables that further categorise indicator values as very low (or very depleted), low (or depleted), adequate/optimal, high, excessive, etc. (see Figure 1 for an example). These subdivisions could be refined and better incorporated into the target range system.

Pasture	25	**50**	100	200	200	**250**	300
Forestry	5	**20**	40	120	150	**175**	200
Cropping & horticulture	5	**20**	100	150	150	**200**	225

Very low	Low	Adequate	Ample	High	Excessive

Figure 1. Example of the subdivisions within original target ranges for anaerobic mineralizable nitrogen. The bolded numbers represent the adopted target range (from, Sparling et al. 2008).

- Quantitative scoring systems create curves where an actual quantitative score can be derived from an indicator value. Generating these relationships requires extensive field data and development of complex functions to derive the curves (in the current system, only soil order and land use are required). The shape of the curves is still likely to be somewhat subjective, particularly when considering environmental outcomes, as curves are generally built around productivity. Thus, although much more quantitative, quantitative scoring systems are generally much more difficult to implement.

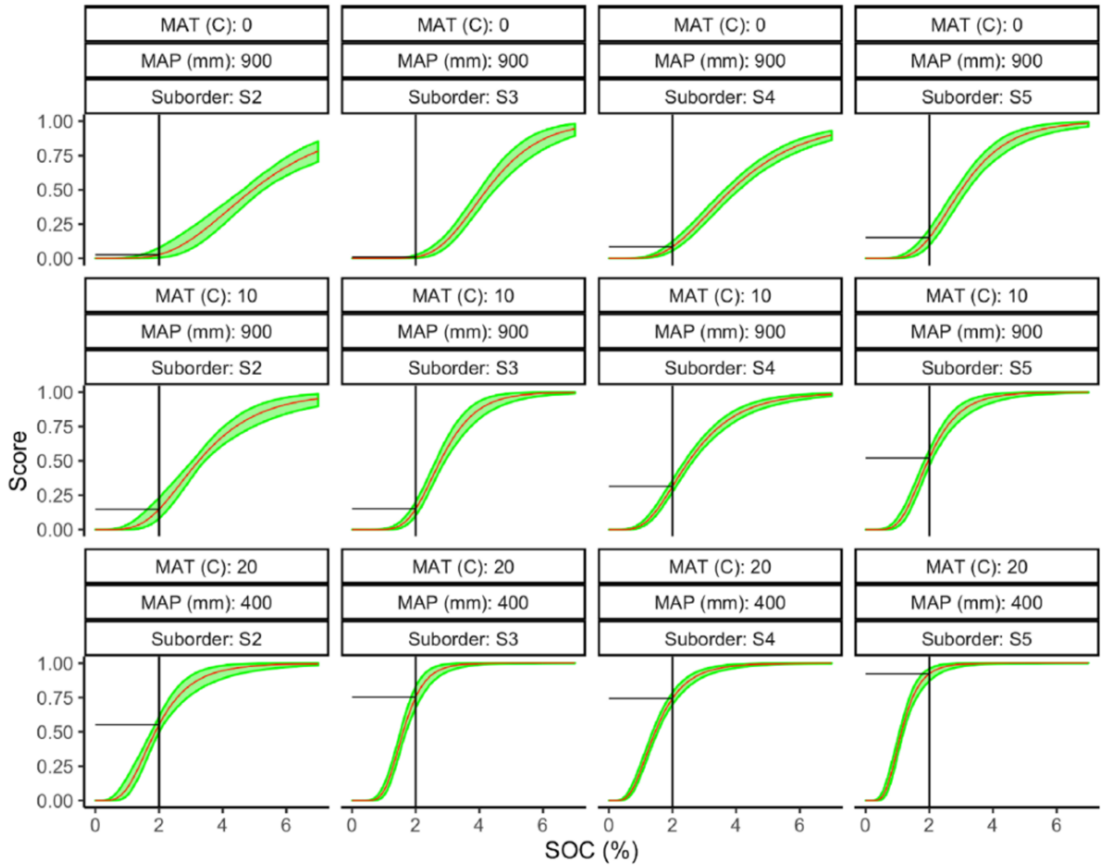

Figure 2. Scoring curves developed for different soil suborders in the US depending on climate and parent material factors (from Nunes et al. 2020).

- **Other approaches (please list below if applicable):**

Given your feedback from the previous information, would your initial preference be to:

________ keep the target range system as is (potentially with minor changes)

________ keep the target value system but with major changes (e.g. addition of subdivisions within the target value range

________ go to a more quantitative system (such as a scoring curve)

________other (please explain below):

3. Approaches to setting ranges

Any method to evaluate soil quality ranges (or scores) will require specified approaches to derive them. Several different approaches were used to develop the Sparling et al. (2003) target ranges (e.g. statistical data from the National Soils Database), which culminated in workshops where expert opinion was used to finalise the accepted target ranges. Taylor (2021) expanded the list of possible approaches and evaluated the strengths and weaknesses of each. He concluded that each indicator would likely require a combination of approaches and that an expert panel would be needed to synthesise and finalise recommended ranges in order to avoid biases in any one approach.

Table 1. Approaches for derivation of target values and strengths and weaknesses of each approach (adapted from Taylor, 2021)

Approach	Strengths	Weaknesses
1) Expert panel The panel specialists arrive at conclusions and recommendations through consensus (EU Evaluation Unit 2017 [Expert panel | Capacity4dev (europa.eu)])	Experts have knowledge of the subject. Quick to assemble. Cost effectiveness. Credibility of the conclusions. Adaptability to a variety of situations encountered in evaluation. Can be used to establish standard non-linear scoring functions.	Requires experts with recognised expertise in the area of interest. Requires objectivity as results can be distorted by lobbyists or a 'dominant' expert who is over influential. Consensus tends to eliminate minority views and tone down conclusions. Experts tend to go beyond their area of expertise.
2) Percentiles A percentile is a value below which a certain proportion of observations fall	Can separate typical behaviour from unusual behaviour. Not strongly influenced by outliers. Can use non-normally distributed data. Informs where a score stands relative to other scores. allows continuing evolution of the system. Used as a substitute where critical values are absent (Gil-Sotres et al. 2005). Gives a relative assessment.	Oversimplification of underlying physical-chemical processes. Represent rank order only as it only informs where a score stands relative to other scores – Little on the degree of soil quality. e.g., Dutch soil quality monitoring target values are based on median values of the monitoring network.
3) The Natural state i.e. The outer limit of background variation (Kowalska et al. 2018). This usually takes a percentile as the target	Distinguishes natural state from unusual, normal from anomalous, usually in relation to contamination.	No information on the quality of soil, does not consider the impact of the parameters measured on soil properties. The reference may not be at an optimum for all parameters. Background soils may not be suitable for productive use so of limited comparison value.

4) Reference soils The same type and properties of the studied soil. (Kowalska et al. 2018; Bünemann et al. 2018; Kaufmann et al. 2009). Sampled same time Or once as a baseline. A reference soil is in equilibrium with all the components of the environment; soils capable of maintaining high productivity and of causing the minimum of environmental distortion.	Distinguishes normal from anomalous. Can provide direct comparisons for soil quality parameters.	Needs to be the type and properties of the studied soil, otherwise this brings in uncertainty. Not all monitored soils have suitable reference sites. Reference properties can change if monitored at same time as the studied soil (Iturri et al. 2016). Ideal reference will not always match maximum standards of Quality.
5) Calibration to risk, a risk index or threshold of contamination	Established toxicological critical values for most common contaminants.	Complex, depends on test organism and component: e.g. several exposure routes should be considered (Fernández et al. 2006) Emerging and uncommon contaminants may lack toxicological critical values
6) Near agronomic optimums	Fertility well established.	Referenced to small plot trials, which adds uncertainty when comparing to SQM representative sampling. Values depend on crop and species grown, not soil function or environmental outcome
7) Comparison with field observations, e.g. Visual Soil Assessment (VSA)	Quick and simple. Direct relationship with some soil properties demonstrating unfavourable changes in soil structure (Moncada et al. 2014, Shepherd 2003). The expected range for each indicator will vary according to site-specific controlling factors with threshold values of the indicators overcome when the grouping of the soils is based on the classes of the soil structure status (visually evaluated) as a response variable (Moncada et al. 2014).	Subject to operator bias. Applicable largely to physical measures. Qualitative or semi-quantitative not quantitative. Cohesive, sandy and peaty soils present problems Lack of research into the influence of soil moisture content on VSA criteria.
8) Biological indicator approach using the behaviour and activities of soil microorganisms (or other soil organisms)	Communities are strongly impacted by changes in soil conditions. They are also ubiquitous and can predict soil physico-chemical characteristics.	Response models, thresholds, and critical values yet to be developed.

Do you have any additional comments on (or disagree with) strengths or weaknesses of the approaches noted in Table 1, and do you think any of these approaches are not acceptable for deriving ranges for regional or national SoE reporting? If so, please note your comments below (referring by number to those approaches listed in Table 1).

Are there any additional approaches you would recommend?

Do you represent:

___________A regional authority

___________Central Govt

___________Other (Please indicate):