Land Restoration Fund (LRF)
Soil Health Monitoring Method

DOCUMENT DETAILS

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Author: Queensland Government Department of Environment & Science

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Contact: feedback@accountingfornature.org

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Environmental Condition Accounting Method

Soil Health

As relevant to the Queensland Government Land Restoration Fund for third party verification of Environmental co-benefit classes

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1. Introduction

The Queensland Government's $500 million Land Restoration Fund (LRF) is expanding carbon farming in the state by supporting land carbon projects that deliver emissions reduction alongside environmental, social and economic co-benefits.

Demonstrable environmental co-benefits from carbon farming projects are central to the value proposition of the LRF. Evidence of improvement in soil condition, in the form of third-party certified environmental accounts, is one pathway to verification of environmental co-benefits under the LRF program. Rules about the types of environmental co-benefits that can be generated by projects in the LRF program are specified in the *LRF co-benefits standard*.

To facilitate environmental co-benefit verification, the Queensland Government has developed this method, to be accredited under the *Accounting for Nature* framework, as a basis for third-party certification of measurement and reporting on trends in soil condition. Originally developed by the Wentworth Group of Concerned Scientists, the Accounting for Nature® Framework enables measurement and reporting on the condition of assets (e.g. vegetation, soil, fauna) through the development of a consistent, credible and auditable set of environmental accounts.[1]

This method should be read in conjunction with the **LRF Co-benefits Standard**[2] and the **Accounting for Nature® Standard**[3].

2. Aim and scope

This method steps out a process to develop accounts for soil condition that are fit-for-purpose as a line of evidence for environmental co-benefit verification under the *LRF Co-benefits Standard*. This method sets out procedures and indicators to guide collection and delivery of scientifically robust information, generate quality data, and provide appropriate measures of soil condition that can be aggregated.

This method is intended for use in Queensland, particularly in the context of carbon farming projects claiming environmental co-benefits under the *LRF co-benefit standard*. This method can be applied in Queensland above mean sea level. It applies the Australian Soil Classification (Isbell & NCST 2016) as the core classification for sub-setting the soil asset, with soil Orders as the minimum scale for reporting. Finer scale groupings such as Suborders or local classifications, such as soil types, can be applied, but they should integrate with the Australian Soil Classification.

Why measure soil condition for co-benefits?

Soils play a vital role in primary production, carbon and water cycles, and ecosystem functioning. Understanding soil condition requires an appreciation of soil diversity and the dynamic responses of soils to different forms of land use. It requires an appreciation of history, natural variability and management effects, not only for recent years and decades, but also on longer timescales of centuries and millennia. This is because soil formation is typically very slow, the impact of land-use change is long-lasting, and remediation can take decades (State of Environment 2016).

[1] Wentworth Group of Concerned Scientists, 2018.
2 Land Restoration Fund Co-benefits Standard. V1.2. 28 January 2020. https://www.qld.gov.au/__data/assets/pdf_file/0025/116548/lrf-co-benefits-standard-exposure.pdf
3 Accounting for Nature 2019a Standard for Environmental Condition Accounting

3. Accounting for Nature

Accounting for the condition of environmental assets must address a number of challenges (Cosier and McDonald, 2010):

- no two environmental assets are the same;
- no single indicator can provide a complete picture of ecosystem health;
- often different indicators are needed to describe the same asset in different locations; and
- the cost of data collection creates variation in the quality of information collected

Statements about the condition of any asset must be related to a specific purpose or reference. Accounting for Nature uses 'reference condition benchmarking' to create a common unit of measure for building sets of environmental accounts that are capable of describing the condition of any environmental asset (native vegetation, soil, rivers, fauna, estuaries, etc.), at any scale.

The common unit, an Econd, is an index between 0 and 100, where 100 describes the reference condition of an environmental asset. The standard reference state is one representing an appropriate undegraded condition. Soil is classified as an 'asset', which may be broken into 'sub-assets', such as soil Order or soil type, to provide more details of the asset for reporting. The Econd for the 'soil' asset is calculated as an area-weighted average of the condition of its component 'sub-assets'.

The characteristics of the 'undegraded' state of a soil depends upon its type, and the core classification applied in this method is the Australian Soil Classification, which is a scheme used to group the variety of soils across Australia into broad classes, called soil Orders (https://www.clw.csiro.au/aclep/asc_re_on_line_V2/soilhome.htm). In Australian landscapes, undegraded is often taken to simply mean pre-European, however the concept of 'undegraded' is not inherently tied to a point in time, it is more about the lack of degradation by use.

Reference condition does not necessarily need to equate to the condition at a particular site in 1750 (see Wentworth Group of Concerned Scientists, 2016, p11). Although description of historical vegetation or soil patterns are invaluable, they are not comprehensive or quantitative, so benchmarks for undegraded condition must often be assembled from observations of contemporary soils that have been subject to limited modification by management practices known to degrade soils, such as excavation, urbanisation, continuous grazing, mechanical cultivation or clearing.

The Accounting for Nature Standard requires that condition methods should use one of the following approaches to the determination of reference condition benchmarks.

a) Observation at sites in reference condition (i.e. undegraded).
b) Historical record of the undegraded condition of the environmental asset.
c) A robust model that estimates the undegraded condition of the environmental asset.
d) Expert opinion on the undegraded condition of the environmental asset.

Different combinations of these approaches are recommended for the indicators prescribed in this method. They are detailed in section 6.

Definition of terms:

Reference condition is the benchmark against which change in any indicator is measured, it represents the soil's characteristics in the absence of degradation.

Baseline condition is the condition of the soil asset determined at a point in time in order to assess change going forward. Baseline condition could be the condition in which the soil asset is at the time of a soil carbon project starting.

Target condition captures the goal of management, ideally over an explicit time interval. It is not necessary for target condition to be the same as reference condition.

A national trial of the Accounting for Nature framework at regional scale (Sbrocchi et al., 2015) defined soil condition after Karlen (2004), identifying soil condition measures in relation to a soil's capacity to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. The trial identified chemical, physical and biological indicators to measure the overall condition of soil. Soil condition cannot be assessed by only one indicator. Ideally, soil condition indicators should shed light on aspects of soil function (e.g. ecological productivity), organization (e.g. physical structure) and resilience. Sbrocchi et al. (2015) suggested that ideally soil condition should consider "at least" the following factors: soil acidification, soil organic carbon (SOC), water erosion, wind erosion, salinity, nutrients, physical condition and biological condition. The selection of a suite of indicators to cover all of these factors would be extremely demanding if they all needed to be measured accurately everywhere.

Therefore, this method focusses on indicators for which we have potential to identify an undegraded reference condition, as well as thresholds for some soil properties that can be explicitly linked to soil condition. The following table outlines the indicators selected in this method and how they inform soil condition. An improvement, or halt in decline, in these indicators, relative to the appropriate reference, can be interpreted as having a positive impact on soil condition.

Table 1. Indicators informing the Land Restoration Fund soil condition account. Note that the indicators applied and their associated sampling effort will depend on the confidence level of the account (see Section 4).

Soil condition component	Indicator	How does this inform soil condition?
Soil function/ productivity	Soil organic carbon (SOC) (an integrating measure of aspects of soil nutrition, biological condition and physical resilience of soil)[4]	Soil organic carbon is primarily made up of decomposing organic material. In agricultural systems, the roots, stems and leaves of crops or pasture grasses can be cycled into the soil and broken down, where some remains as soil organic carbon. Management practices that increase the amount of biomass incorporated into the soil, and/or reduce the amount of organic matter that is released from soils, can lead to increases in soil organic carbon levels. Organic carbon is a component soil organic matter, which includes additional elements that are components of organic compounds. Soil organic matter plays a critical role in a range of physical, chemical and biological soils processes (Baldock 2007) as it: • provides energy for biological processes (Fontaine et al. 2003) and nutrients N, P, S • improves soil structure, influences water retention properties, alters thermal properties • contributes to cation exchange capacity, enhances pH buffering and complexes cations.
Soil function/ productivity	Total N	Soil N cycling is an important ecosystem function that affects primary production, plant species richness and biodiversity; some forms of N in soil are highly mobile and management practices can influence the amount and form of reactive N, N transformation processes and N loss pathways. Knowledge of total N can also be helpful in interpreting other indicators such as SOC.
Resilience - acidification	Soil pH*	Soil acidity is a major land degradation issue facing much of Australia. The main onsite effects of acidification include (State of Environment 2016): • loss of, or changes in, soil biota involved in nitrification (which fix nitrogen, a key nutrient, within the soil) • accelerated leaching of plant nutrients (manganese, calcium, magnesium, potassium and anions) • induced nutrient deficiencies or toxicities • breakdown and subsequent loss of clay materials from the soil • reduced net primary productivity • erosion as a result of decreased groundcover that may follow acidification. The potential offsite effects include: • mobilisation of heavy metals into water resources and the food chain • acidification of waterways as a result of leaching of acidic ions • in streams and water bodies - increased siltation (where fine sediments suspended in the water are deposited on the floor) and eutrophication (where a high concentration of nutrients typically triggers excess growth of algae). At the other end of the pH scale, alkalinity can be indicative of potential problems with soil structure, hydraulic conductivity, toxicities and nutrient deficiencies.

Soil condition component	Indicator	How does this inform soil condition?
Resilience – erosion (risk of water and wind erosion)	Ground cover	Water and wind erosion cause soil loss that can far exceed the rates of soil development. The on-site consequences include: • decreasing soil volume available for the plant root to exploit • breaking soil aggregates and preventing water from infiltrating the soils, increasing surface runoff • loss of nutrients and organic matter • decreasing ground cover from loss of surface soil Off-site effects relate to the sedimentation of creeks, rivers, estuaries and reservoirs, increased flooding, eutrophication, the general decline of aquatic environments and off-site reduction in air-quality (State of Environment 2016)
Resilience - salinity	Salt-affected area	Salinity, a measure of the content of salts in soil or water, occurs as two types: primary salinity (large salt deposits that are distributed unevenly throughout the Australian landscape and are a natural feature resulting from rainfall interacting with geographical features over thousands of years) and secondary salinity (additional salt transported to the soil surface or waterways, due to altered land use and which may take the form of 'dryland salinity' or 'irrigation-induced salinity') (Department of Agriculture, Water and the Environment 2017). Secondary dryland salinity has been one of Australia's most costly forms of land degradation. However, the millennium drought appears to have halted the spread of dryland salinity in most of the worst-affected regions (State of Environment 2016) Salinity can have significant impacts on the following: • Agriculture • Water quality • Ecological health of streams • Terrestrial biodiversity • Infrastructure
Resilience - salinity	Soil electrical conductivity (EC)	Identification of saline areas and emerging salinity issues can be assisted by assessment of soil electrical conductivity, a measure of how much electricity moves through a solution. Higher electrical conductivity readings reflect more electricity moving through saltier solutions. The measure may be linked to plant tolerance thresholds as an indicator of salinity effects on plant growth. Since the composition of salts will affect the EC of the solution as a whole, any measure of EC needs to consider whether Gypsum has been applied and its effect on reported EC values and plant growth (The State of Queensland, 2011).
Resilience – physical structure	Bulk density	Soil physical structure is important for provision of physical stability and support, pathways for water and air, solute movement and habitat for soil organisms. Bulk density is a coarse indicator of soil physical condition, particularly relevant to degrading processes such as soil compaction, and threshold values may be applied to bulk density measures to indicate impaired function e.g. to plant or root growth. Bulk density is also a key measure for calculation of SOC stocks from data on SOC as a percentage by mass (State of Environment 2016).

*the measurement of acid sulfate soils (ASS) and potential acid sulfate soils (PASS) are not considered in this method.

Land use change and potential impacts on soil condition

Accounting for Nature explicitly applies the 'undegraded' state as the default reference against which indicators are assessed to measure condition. Defining a reference for soil condition or an 'undegraded' state can be problematic because there is limited evidence about the soil's physical, chemical and biological condition at times when they were not already under a modified land use (e.g. pre-European baseline). There is however, an understanding of soil changes associated with land clearing, particular land management techniques and conversion to alternate land uses. Appendix 4 provides a generalised guide of how land use change (that are likely to occur within projects contracted by the Land Restoration Fund) might affect the soil indicators utilised in the method. This table can be used to gauge whether a project is likely to generate a soil condition co-benefit under the LRF and it also influences the level of sampling required for a confidence level 2 account. It must be noted however that this is general guidance and that changes in soil condition are site specific.

4. Confidence Levels

Accounts generated by this method must opt for one of two confidence levels, the levels are referred to as level 1 or level 2 under the Accounting for Nature® Standard, which describes the levels as follows:

> A **Level 1 (Very High)** confidence level applies to Methods that include a comprehensive set of indicators and are likely to have <u>very high accuracy</u> (≥95%) when measuring the condition of environmental assets and detecting change in their condition through time.
>
> A **Level 2 (High)** confidence level applies to Methods that include a relatively comprehensive set of indicators and are likely to <u>have high accuracy</u> (≥90%) when measuring the condition of environmental assets and detecting change in their condition through time.

For confidence level 1, the method employs the suite of indicators specified in section 6 of this document. Confidence level 2 requires collection of fewer indicators through on ground survey (Table 5). Both levels require classification of the accounting area into assessment units, which are unified by similarity in dominant soil order and broad land use history, and the standardised collection of soil condition indicators through field survey.

5. What does an account look like?

The AfN Format requires accounts to have three components:

1. An Environmental Account Summary;
2. An Information Statement; and
3. The body of the account, containing the Asset Tables (detailing condition of the components of the asset) and Data Tables (recording observations).

Upon certification of an account, the Information Statement and Environmental Account Summary will be published in the AfN Certification Register. The body of the account details the condition of specific components of the overall soil asset. These components are referred to as sub-assets, and they are the classes for which condition data must be collected. Please refer to the Accounting for Nature® Standard for more details[4].

[4] Available from: www.accountingfornature.org

6. Overview of process

Implementing this method involves the following steps:

- Step 1. Define accounting area
- Step 2. Compile existing data
- Step 3. Stratify accounting area into assessment units
- Step 4. Design field surveys, including provisions for seasonality and materiality
- Step 5. Locate, mark and monitor plots
- Step 6. Calculate indicator condition scores and Econds for assessment units
- Step 7. Calculate area-weighted average Econd for sub-assets (from assessment units) and the overall Econd for the soil asset account
- Step 8. Compile account, including information statement, and submit for accreditation

If the purpose of the account is related to co-benefits from a planned carbon farming project, steps 1 to 4 are common to the requirements of establishing a carbon project, and could be done in parallel to reduce costs. A detailed description of these steps is outlined below.

Step 1. Define accounting area

An account's purpose is the primary consideration when defining the spatial scope of soil assets to be included. Whether accounts of soil condition should be assembled for an entire business, a property or a paddock depends on the purpose of the account. For the purpose of verification of co-benefits under the Land Restoration Fund standard, the scope of assets must include the extent of all assets within the project area relevant to the co-benefit class that the accounts are intended to verify, which is defined in the LRF co-benefit standard.

Proponents may opt to include other parts of the project or surrounding areas under their management within the account boundary, but in such cases they must identify areas relevant to specific co-benefits, and also distinguish sub-assets within the project from those beyond it during spatial stratification in step 3. Only areas where it is conservative to assign a condition score of zero should be excluded from the 'current extent' at the start of the accounting time-series. For example, areas that are intensively cultivated or dominated by infrastructure, where land-use change is not planned and will not materially affect soil condition, can be excluded.

For simplicity, and to be conservative in terms of improvements through time, this method requires accounts to maintain a consistent geographical extent of "soils assets" through time. That is, the extent should not increase or decrease.

The output from step 1 will be polygon features defining the accounting area within a spatial data file compatible with geographical information systems, such as a shapefile, in a commonly applied 'static' datum such as the Geographic Datum of Australia 1994.

Step 2. Compile existing data and identify sub-assets and component soil types

There are existing data available which may help to determine the distribution of sub-assets for soil types (and soil orders) in the project area. Proponents will also need to develop a baseline of particular indicators or the extent of the assessment units required in order calculate an environmental account. Table 2 provides some useful resources for soil condition assessment.

Table 2. Available resources for determination of sub-assets (and soil orders) in the project area for assessment of soil condition.

Data	Description	How do I access this?
Existing soil sites in and around project area	There may have been soil sites sampled with morphological and chemical analysis measured. *This may assist in providing a baseline value for indicators.*	Queensland Globe https://qldglobe.information.qld.gov.au/ • Search for lot/plan • Layer > Add layers > Geoscientific information > Soil > Soil sites • Download PDF of site • Can print a map of the soil sites
Existing soil mapping in project area	Soil surveys have been conducted at various scales across parts of Queensland. The soils mapping produced may intersect with a project area. Associated reports may also provide additional information. *This may help to determine assessment units.*	Queensland Globe https://qldglobe.information.qld.gov.au/ • Search for lot/plan • Layer > Add layers > Geoscientific information >Soil > Soil mapping • Can print a map of the soil mapping
Indicative Grazing Land Management Types map	The report shows the current version of Grazing Land Management (GLM) land type mapping and the approximate area of each land type with the selected area. *This may help to determine assessment units.*	Forage – map request https://www.longpaddock.qld.gov.au/forage/ Land Type Information sheets https://futurebeef.com.au/knowledge-centre/land-types-of-queensland/ *An example of the type of information on soils provided in the Land Type information sheets is outlined in Appendix 1.*
Ground Cover map	The Ground Cover report shows a ground cover and minimum ground cover map for the selected Lot or Lots on Plan generated from satellite imagery. It also shows a regional comparison. *This may help when considering and developing land management plans.*	Forage – map request https://www.longpaddock.qld.gov.au/forage/report-information/ground-cover/
Regional Ecosystem – pre-clearing and remnant	Vegetation patterns often align with soil patterns, and REs can also be used for reference values for ground cover	Queensland Globe https://qldglobe.information.qld.gov.au/ • Search for lot/plan • Layer > Add layers > Biota (Flora & Fauna) • Regional Ecosystem mapping > Regional ecosystem (RE) mapping > Biodiversity status - preclear

Step 3. Stratify accounting area into assessment units, develop monitoring plan

Assessment units are mapped entities that break the account area into consistent sub-units to direct sampling and provide appropriate detail in reporting.

Mapping the account area into assessment units may build on the spatial data requirements for a carbon project. For example, projects implementing area-based carbon farming will require stratification of the project area into Carbon Estimation Areas (CEAs). Stratification of CEAs is typically based on things such as vegetation, bio-physical characteristics (e.g. soil types), management, and land-use history. Readers are referred to the Commonwealth's CFI mapping guidelines[5] for further information on spatial data for carbon projects. The Climate Solutions Fund user guide for measured soil carbon projects "Understanding your soil carbon – Simple method guide" is also a good resource[6] for information on soil carbon project concepts such as CEAs as is the guideline on sampling for the measured soil carbon method[7].

Assessment units should spatially divide the account area into relatively uniform subsets. They should be defined by intersecting maps of the chosen soil sub-assets (e.g. soil Orders or soil types within Orders, perhaps divided by wetland classes; see LRF co-benefit standard for classifications required for specific co-benefit classes) with a map of landuse or broad current condition classes (e.g. cropping, pasture, regrowth, remnant vegetation). Assessment units do not need to be composed of a single contiguous area. They can be composed of multiple isolated areas, but all should generally be larger than one hectare. The extent of each assessment unit must be described within a spatial data file compatible with geographical information systems, such as a shapefile, in a commonly applied static datum such as the Geographic Datum of Australia 1994.

Creating assessment units from a carbon estimation area map may require splitting or amalgamating CEAs into several assessment units, based upon the level of variation in condition which is present. Assessment units may be further subdivided into administrative classes, such as paddocks or project boundaries, for reporting if necessary. For Land Restoration Fund projects, if the account includes any 'non-project' areas (See example Figure 1) they must be separate assessment units, so that no assessment unit crosses the project boundary and the account for the project can easily be extracted.

Similarly, areas related to specific co-benefits should be identifiable in the account and would therefore need specific assessment units for sampling.

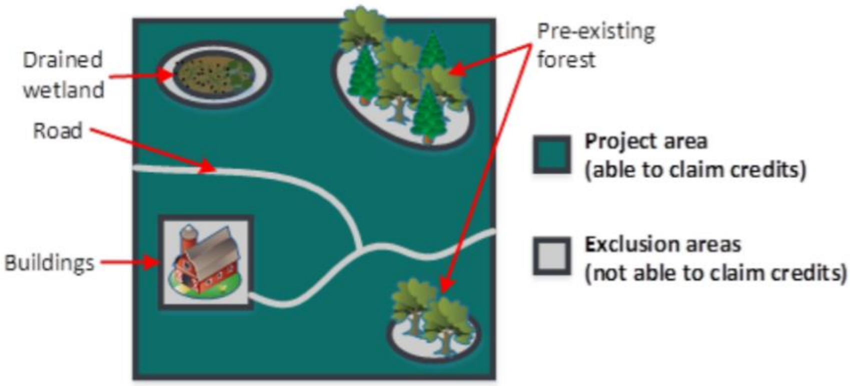

Figure 1. Project areas and exclusions (source "Understanding your soil carbon project – Simple method guide"[8]).

[5] https://www.environment.gov.au/climate-change/government/emissions-reduction-fund/publications/cfi-mapping-guidelines
[6] http://www.cleanenergyregulator.gov.au/DocumentAssets/Pages/Understanding-your-soil-carbon-project---Simple-method-guide.aspx
[7] https://environment.gov.au/system/files/pages/b341ae7a-5ddf-4725-a3fe-1b17ead2fa8a/files/cfi-soil-sampling-design-method-and-guidelines.pdf

Step 4. Design field surveys, including provisions for seasonality and materiality

Each assessment unit requires field sampling at locations referred to as sample sites. Sites are initially randomly located for the first survey, using a technique detailed in step 5. Subsequent surveys will sample at locations determined by applying a 5m offset along a random compass bearing from each of the sites sampled in the first survey. This approach aligns with the technique described in the guideline for the measured soil carbon method[8].

If a sample site is found to clearly belong to a soil Order other than the dominant soil Order for the relevant sub-asset the assessment unit is meant to be representing, then it should still be sampled, but it should not be bulked with other samples for analysis.

Sampling should occur in a consistent season. Winter to late spring are suitable because ground cover is relatively low across much of Queensland, which better reflects erosion risk. Sample site locations for the first sampling should be based on random selection of intersections in a grid overlayed on each assessment unit, following specification from the carbon method for *Reforestation by Environmental or Mallee Plantings—FullCAM* (see division 3.6, “Establishing a grid overlay”), which are paraphrased in below:

- The grid must consist of square cells.
- There must be at least 10 grid intersects within each assessment unit being sampled.
- An anchor point for the grid must be established by randomly selecting easting and northing coordinates within the ranges of easting and northing coordinates for the project area. Noting that a project may require more than one grid anchor point to be established.
- The easting and northing coordinates referred to in subsection (3) must be from the Map Grid of Australia, known as MGA94, or any Australian standard that replaces MGA94.
- The orientation of one axis of the grid must be either north-south (aligned to the datum being used in the project’s spatial data), or along an azimuth determined by randomly selecting a whole number angle within the range of zero and 89 degrees inclusive, where zero degrees is true north.
- Each grid intersect must be assigned a unique identifier.
- Actual plot locations must be located within 10 metres of each intended plot location.

Site locations that are randomly selected but are within 25 m of infrastructure such as a road or a dam can be moved so that they are centred 50 m from the infrastructure. Site orientation should be along the contour (i.e. across the slope) unless they need to be oriented otherwise to stay within the assessment unit or to stay more than 25 m away from infrastructure such as roads or dams.

The output from step 4 will be a list of sampling locations (spatial coordinates in the relevant datum) for each of the assessment areas output from step 3, which will meet sampling requirements for soil condition indicators set out in Tables 3 and 4.

Table 3 Minimum numbers of sites for third party assurance. Larger assessment units require more sites.

Assessment unit area	Minimum number of sites per assessment unit for sampling of site-based indicators (see Table 4 for further detail)
1-2 ha	3
>2 and ≤20 ha	6
>20 and ≤60 ha	9
>60 and ≤500 ha	12
>500 ha	15

[8] https://environment.gov.au/system/files/pages/b341ae7a-5ddf-4725-a3fe-1b17ead2fa8a/files/cfi-soil-sampling-design-method-and-guidelines.pdf

Table 4. Soil indicators and approaches to identify their confidence level and benchmark score

Indicator	Approach for confidence level 1	Approach for confidence level 2	Identifying Indicator Reference condition
Soil organic carbon (SOC)	Sampling and analysis must follow the sampling guidelines for the Carbon Farming Initiative—Measurement of Soil Carbon Sequestration in Agricultural Systems Methodology Determination 2018, where each assessment unit is treated as is described for a CEA in the sampling guidelines. Total numbers of sites sampled per assessment unit must be at least the number specified in Table 3. Stratification of assessment units (or CEAs) by groundcover is recommended. Measurement of bulk density is required, but SOC may be presented as a percentage by weight for the purpose of accounting.	SOC is to be measured as a percentage, meaning that it does not require bulk density measurement to accompany the soil sampled at a specified depth. Minimum requirement is to sample 0-30cm depth as a single interval, but sampling of sub-intervals such as 0-10 and 10-30cm is also recommended, and sampling may also include deeper layers. Minimum number of samples per assessment unit follows Table 3. Samples at each nominated soil depth (or 0-30cm if treated as single interval) may be bulked (composited) together to provide one representative laboratory sample from triplets of three randomly selected samples within each assessment unit. That is, the number of laboratory samples can be as few as one for every three sample sites (Table 3).	Upper 95% confidence interval for the mean SOC in relevant depth interval from at least 3 samples from uncleared native vegetation in good condition for the same soil sub-asset (e.g. soil order) within 50 km of the project area. If sufficient suitable sample sites for local reference are not available, use local soil site data and mapping held in the Queensland Globe (https://qldglobe.information.qld.gov.au/) to reference these values. If local soils mapping and soil site information is inadequate, use the Soil and Landscape Grid of Australia (https://aclep.csiro.au/aclep/soillandscapegrid/) to report the maximum % soil organic carbon for the relevant depth interval(s) (e.g. a weighted average SOC % for 0-30cm) within the project area as the reference condition value.

Indicator	Approach for confidence level 1	Approach for confidence level 2	Identifying Indicator Reference condition
Soil pH	Minimum requirement is to sample 0-30cm depth as a single interval, but sampling of sub-intervals such as 0-10 and 10-30cm is encouraged. Sampling may also include deeper layers but must be differentiated from 0-30cm. Minimum number of samples per assessment unit follows Table 3, so pH should use the same sample effort and locations as for SOC. Samples at each nominated soil depth (or 0-30cm if treated as single interval) may be bulked (composited) together to provide one representative analytical sample from triplets of three randomly selected samples within each assessment unit. That is, the number of analytical samples can be as few as one for every three field sites. pH to be measured in laboratory using 1:5 soil water suspension. Option for measuring soil pH would be to add this as an additional laboratory measurement when sending samples in for soil carbon. (e.g. Rayment and Lyons 2011 methods 4A1 and 4B1)	As per level 1, although field measurement of pH may be considered.	The mean pH for the relevant depth interval(s) from at least 3 samples from uncleared native vegetation in good condition for the same soil sub-asset (e.g. soil Order). If sufficient suitable sample sites for local reference are not available, use local soil site data and mapping held in the Queensland Globe (https://qldglobe.information.qld.gov.au/) to reference these values. If local soils mapping and soil site information is inadequate, use the Soil and Landscape Grid of Australia (https://aclep.csiro.au/aclep/soillandscapegrid/) to report the median value for pH (using relevant depth layers, e.g. weighted average pH in data layers for soil 0-5, 5-15, 15-30cm if sampling 0-30cm as single interval).

Indicator	Approach for confidence level 1	Approach for confidence level 2	Identifying Indicator Reference condition
Ground cover	Average of visual estimates for combined cover of litter and plants (record separately) in at least five 1x1m quadrats along a straight 50m transect line centred on the sample sites for SOC.	As per level 1	Indicator reference is determined by sum of Regional Ecosystem conditions for litter and plant cover in ground layer. If no published reference condition exists, sample at least three sites more than 200m apart in remnant native vegetation in good land condition for the same soil sub-asset (e.g. soil Order) as close as practicable to the account area, preferably within it.

Indicator	Approach for confidence level 1	Approach for confidence level 2	Identifying Indicator Reference condition
Saline extent	Calculate (i.e. map) extent of land within each assessment unit in the following classes as a percentage of total assessment unit: 1. Not affected: land showing no signs of salt scalding 2. Slightly affected: Land showing a reduction in non-salt-tolerant plant vigour, some salt-tolerant plants, seasonally or permanently shallow watertable, and perhaps small bare areas 3. Moderately affected: Land showing a significant loss of non salt-tolerant plants, salt-tolerant plants are common, seasonally or permanently shallow watertable, bare areas up to about 50m^2 in size, some erosion present 4. Severely affected: Land showing an absence of non salt-tolerant plants, permanently shallow watertable, large bare areas (>50 m^2), which are often badly eroded	As per level 1	Reference saline extent is assumed to be zero in most situations. Do not apply this indicator to naturally saline ecosystems, which can be identified by dominance of halophytic vegetation and/or historical records indicating long term presence.

Indicator	Approach for confidence level 1	Approach for confidence level 2	Identifying Indicator Reference condition
Soil $EC_{1:5}$ at 0-30cm	Measure electrical conductivity (EC) at the same locations as utilised for SOC to at least 30cm depth by 1:5 soil/water extract (EC1:5). Option for measuring soil EC would be to add this as an additional laboratory measurement when sending samples in for soil carbon. (e.g. Rayment and Lyons 2011 methods 3A1 and 14B1)	Not required for level 2	The mean EC for the relevant depth interval(s) from at least 3 samples from uncleared native vegetation in good land condition for the same soil sub-asset (e.g. soil Order) as close as practicable to the account area, preferably within it. If sufficient suitable sites for local reference are not available, use local soil site data and mapping held in the Queensland Globe (https://qldglobe.information.qld.gov.au/) to reference these values.

Indicator	Approach for confidence level 1	Approach for confidence level 2	Identifying Indicator Reference condition
Total soil N	Measure at the same locations as utilised for SOC. Laboratory analysis of total soil N in at least the top 30cm for samples analysed for SOC. Option would be to add this as an additional laboratory measurement when sending samples in for soil carbon (e.g. Rayment and Lyons method 7A5)	Not required for level 2.	The mean total N for the relevant depth interval(s) from at least 3 samples from uncleared native vegetation in good land condition for the same soil sub-asset (e.g. soil order) as close as practicable to the account area, preferably within it. If sufficient suitable sites for local reference are not available, use local soil site data and mapping held in the Queensland Globe (https://qldglobe.information.qld.gov.au/) to reference these values. If local soils mapping and soil site information is inadequate, use the Soil and Landscape Grid of Australia (https://aclep.csiro.au/aclep/soillandscapegrid/) to report the median value for total N (using relevant depth layers, e.g. weighted average total N in data layers for soil 0-5, 5-15, 15-30cm if sampling 0-30cm as single interval).

Indicator	Approach for confidence level 1	Approach for confidence level 2	Identifying Indicator Reference condition
Bulk density	Soil bulk density is determined following The Supplement to the Carbon Credits (Carbon Farming Initiative—Measurement of Soil Carbon Sequestration in Agricultural Systems) Methodology Determination 2018 for the same samples as assessed for SOC.	Not required for level 2.	The mean bulk density for the relevant depth interval(s) measured from at least 3 sites in uncleared native vegetation in good land condition for the same soil sub-asset (e.g. soil order) as close as practicable to the account area, preferably within it. If sufficient suitable sites for local reference are not available, use local soil site data and mapping held in the Queensland Globe (https://qldglobe.information.qld.gov.au/) to reference these values. If local soils mapping and soil site information is inadequate, use the Soil and Landscape Grid of Australia (https://aclep.csiro.au/aclep/soilandlandscapegrid/) to report the median value for bulk density (using relevant depth layers, e.g. weighted average bulk density in data layers for soil 0-5, 5-15, 15-30cm if sampling 0-30cm as single interval).

Step 5. Locate and mark plots, measure attributes

Plots must be permanently marked, for example with a steel picket at the origin. Their location should be within 10m of the location determined by selection of grid intersections from step 4, unless the site location was moved to accommodate infrastructure as described in step 4.

The output from Step 5 will be a table of Site data for each assessment unit, in a format similar to that described in Table 5. Indicators must be compared to reference values to create indicator condition scores.

Table 5. Example data table: site data capture (one table per assessment unit per survey). If multiple depth intervals are sampled one table per depth may be necessary.

	Site 1: Identifier	Site 2: Identifier	Site 3: Identifier
Assessment unit			
Sub-asset (e.g. soil order or soil type)			
Sample depths			
Photo IDs			
Coordinates			
Date sampled			
Soil carbon sample ID(s) (bulked)			
Soil pH sample ID(s)			
Soil total N sample ID(s)			
Soil EC sample ID(s)			
Soil bulk density sample ID(s)			
Plant cover			
Litter cover			
Bare ground			

Surveys subsequent to the first survey should locate sample sites using a uniform offset distance of 5m from the last location (marked by star picket) on a random bearing. After measurement the star picket locating the site should be moved to the most recent sample location.

Step 6. Calculate indicator condition scores and Econds for assessment units

Each sampled indicator must be compared with its relevant reference value to generate indicator condition scores (ICS). This should be done for each assessment unit and for each indicator by first calculating an average of the measured values of the indicator over the assessment unit, and then calculating the corresponding ICS value. The Econd for the assessment unit is then calculated as the minimum indicator condition score for the assessment unit, representing the most-limiting factor to soil condition (Sbrocchi et al., 2015). Table 6 sets out the indicator condition scoring system to be applied for each indicator. Appendix 5 notes further details and shows plots of the functions in Table 6 for calculating indicator condition scores.

Table 6. Indicator condition score calculation for soil condition indicators. The subscript acc indicated the measurement of an indicator for the time of the account, while a subscript ref indicates the associated reference value.

Soil condition indicator	Indicator condition score (ICS)
SOC	$ICS = \begin{cases} 100 & \text{if } SOC_{acc} \geq SOC_{ref} \\ 100 * \dfrac{SOC_{acc}}{SOC_{ref}} & \text{if } SOC_{acc} < SOC_{ref} \end{cases}$
pH	Define pH_A as $\min[pH_{ref} - 0.5\ , 6.0]$ and pH_B as $\max[pH_{ref} + 0.5\ , 7.9]$. Then: $ICS = \begin{cases} 0 & \text{if } pH_{acc} < 3.0 \\ 100 * \dfrac{(pH_{acc} - 3.0)}{(pH_A - 3.0)} & \text{if } pH_{acc} \geq 3.0 \ \&\ pH_{acc} < pH_A \\ 100 & \text{if } pH_{acc} \geq pH_A \ \&\ pH_{acc} < pH_B \\ 100 * \dfrac{(11.0 - pH_{acc})}{(11.0 - pH_B)} & \text{if } pH_{acc} \geq pH_B \ \&\ pH_{acc} < 11.0 \\ 0 & \text{if } pH_{acc} \geq 11.0 \end{cases}$ See Appendix 5, Figure 2
Ground cover	$ICS = \begin{cases} 100 & \text{if } cover_{acc} \geq cover_{ref} \\ 100 * \dfrac{41 - runoff_{acc}}{41 - runoff_{ref}} & \text{if } cover_{acc} < cover_{ref} \end{cases}$ where $runoff = \begin{cases} 41 & \text{if } cover < 10 \\ 2 + 39 * \exp\left\{-\dfrac{(cover - 10)^{0.68}}{6.2}\right\} & \text{if } cover \geq 10 \end{cases}$ See Appendix 5, Figure 3
Saline extent	$ICS = \max\left[100 * \left(1 - \dfrac{area_2 + area_3 * 2 + area_4 * 3}{area_{Tot}}\right), 0\right]$ where $area_2$, $area_3$ and $area_4$ are the areas of the assessment unit in salinity classes 2, 3 and 4, and $area_{Tot}$ is the total area of the assessment unit.
Electrical conductivity (EC)	$ICS = \begin{cases} 100 & \text{if } EC_{acc} < EC_{ref} \\ 100 * \left[1 - \dfrac{1}{4}\left(\dfrac{EC_{acc} - EC_{ref}}{EC_{ref}}\right)^2\right] & \text{if } EC_{acc} \geq EC_{ref} \ \&\ EC_{acc} < 3 * EC_{ref} \\ 0 & \text{if } EC_{acc} \geq 3 * EC_{ref} \end{cases}$ where any reference values of EC (1:5 soil:water) below 0.2 dS/m should be put equal to 0.2 dS/m. See Appendix 5, Figure 4
Total N	Define TN_A as $TN_{ref} - 0.1 * TN_{ref}$ and TN_B as $TN_{ref} + 0.1 * TN_{ref}$. Then: $ICS = \begin{cases} 100 * \dfrac{TN_{acc}}{TN_A} & \text{if } TN_{acc} < TN_A \\ 100 & \text{if } TN_{acc} \geq TN_A \ \&\ TN_{acc} < TN_B \\ 100 * \left(1 - \dfrac{TN_{acc} - TN_B}{2 * TN_{ref} - TN_B}\right) & \text{if } TN_{acc} \geq TN_B \ \&\ TN_{acc} < 2 * TN_{ref} \\ 0 & \text{if } TN_{acc} \geq 2 * TN_{ref} \end{cases}$ See Appendix 5, Figure 5
Bulk density	$ICS = \begin{cases} 100 & \text{if } BD_{acc} < BD_{ref} \\ 100 * \left(\dfrac{2 - BD_{acc}}{2 - BD_{ref}}\right) & \text{if } BD_{acc} \geq BD_{ref} \ \&\ BD_{acc} < 2 \\ 0 & \text{if } BD_{acc} \geq 2 \end{cases}$ where any reference values of BD below 1.6 g/cm^3 should be put equal to 1.6 g/cm^3. See Appendix 5, Figure 6

Proponents must also calculate the standard error of the measurements for each indicator for each assessment unit (standard deviation of measurements divided by square root of number of samples; not required for saline extent). The output from step 6 will be an assessment unit table, in the format shown in Table 7.

Table 7. Example data table: Assessment unit summary (one table per sub-asset)

Sub-asset	Assessment unit ID	Area (ha)	Component soil types	Broad condition	Number of sites	Site IDs	Econd	Standard error
			List soil types	*e.g. remnant, regrowth, pasture, cropping*				

Step 7. Calculate Econd for each sub-asset and for the accounting area

Econds must be calculated for all sub-assets within the account as the area-weighted average of the Econds calculated for the assessment units containing each sub-asset. Condition scores for sub-assets must be recorded within the asset table, in the format shown in Table 8.

Table 8. Example data table: Sub-asset summary

Sub-asset	Short description	Component soil types	Co-benefit classes	Present in assessment units	Total area (ha)	Econd
		List soil types	*List relevant co-benefit classes from LRF standard*	*List relevant assessment units*		

The overall condition score must then then be calculated as the area weighted average of scores for each sub-asset.

Step 8. Compile account and submit for accreditation

Steps five to eight should be repeated at regular intervals (up to 5 years) to establish trend. It is recommended that sampling for some of the more dynamic indicators such as cover, and collection of ancillary data such as photopoints, should occur annually even if accounts are certified at the maximum five yearly interval. Regular monitoring will assist in identifying trends in condition within the natural variability in indicators that can arise due to variability in weather and other factors. A well-developed account of soil asset change will provide contextual information on seasonal conditions and their impact on indicators such as ground cover in and around the accounting area. Such information can be very useful to place variation in observed condition in appropriate context.

7. References

Accounting for Nature (2019) *Accounting for Nature® Standard Version 2.1.* https://www.accountingfornature.org/the-afn-standard

Baldock J.A. (2007) Composition and Cycling of Organic Carbon in Soil. In: Marschner P., Rengel Z. (eds) Nutrient Cycling in Terrestrial Ecosystems. *Soil Biology*, vol 10. Springer, Berlin, Heidelberg. DOI: 10.1007/978-3-540-68027-7_1.

Caritat P., Cooper M., and Wilford J. (2011) The pH of Australian soils: field results from a national survey. *Soil Research* 49, 173-182. https://www.publish.csiro.au/SR/pdf/SR10121

Cosier P., and McDonald J. (2010) A common currency for building environmental (ecosystem) accounts. In: 16th Meeting of the London Group on Environmental Accounting.

Fontaine S., Mariotti A., and Abbadie L. (2003) The priming effect of organic matter: a question of microbial competition? *Soil Biology and Biochemistry* 35: 837-843

McKenzie N.J., Grundy M.J., Webster R., and Ringrose-Voase, A.J. (2008). Guidelines for Surveying Soil and Land Resources. Australia: CSIRO Publishing.

O'Brien L.E., and Thomas E. 2018. Soil constraints mapping to inform nutrient management in the cropping industries – RP155C: Soil Constraints Report. Brisbane: Department of Environment and Science, Queensland Government.

Rayment G.E., and Lyons D.J. (2011) 'Soil chemical methods – Australasia'. Melbourne: CSIRO Publishing.

Sbrocchi C., Cosier P., Davis R., Grundy M., Harding R., Hillman T., Mount R., Possingham H., Saunders D.A., Smith T., Thackway R., Thom B., and Williams J. (2015) *Australian Regional Environmental Accounts Trial: Technical Analysis.* Wentworth Group of Concerned Scientists in association with NRM Regions Australia, Sydney. pp 34-64.

Silburn D.M., Carroll C., Ciesiolka C.A.A., deVoil R.C., and Burger P. (2011) Hillslope runoff and erosion on duplex soils in grazing lands in semi-arid Central Queensland I. Influences of cover, slope and soil. *Soil Research* 49, 105-117.

State of the Environment (2016) Soil: Understanding [Accessed 10/02/2020] https://soe.environment.gov.au/theme/land/topic/2016/soil-understanding.

The State of Qld Department of Environment and Resource Management. 2011. Salinity Management Handbook second edition ISBN 0 7242 7412 X [Accessed 10/02/2020) https://www.publications.qld.gov.au/dataset/5f866f8d-d47a-430e-aa9f-c97f7c4147d7/resource/265de065-02d3-4dad-8360-7033b3f40a94/fs_download/salinity-management-handbook-ch05.pdf.

Wentworth Group of Concerned Scientists (2016) *Accounting for Nature: A scientific method for constructing environmental asset condition accounts.* https://wentworthgroup.org/wp-content/uploads/2017/07/Wentworth-Group-2016-Accounting-for-Nature.pdf

Appendix 1. Example soil information for GLM land types

Accessed through the Future Beef website - https://futurebeef.com.au/knowledge-centre/land-types-of-queensland/

Hard mulga

Landform	Gently undulating to undulating plains with variable stone and gravel cover (slopes 1–6%). Often occur on scarp retreats and back slopes of residuals.
Woody vegetation	Sparse mulga shrublands to mulga low woodlands, some areas associated with poplar box, bastard mulga and western bloodwood, and variable shrubby understorey of cassia, hopbush or turkey bushes. Areas of heathlands and spinifex patches occur on ridges.
Expected pasture composition	** Denotes non native 'Expected Pasture Composition' species.*
Preferred	Cotton panic, mulga oats, kangaroo grass, mulga Mitchell.
Intermediate	Dwarf mulga grass, bottlewasher grasses, purple lovegrass, woollybutt wanderrie grass, mountain wanderrie grass, five-minute grass.
Non-preferred	Wiregrasses (e.g. Jericho, brush threeawn, dark, erect kerosene).
Annual grasses	Hairy armgrass, button grass, pretty wanderrie grass, rare panic. Bunched kerosene (non-preferred).
Common forbs	Caustic vine, daisy burrs, silvertail, green pussytail, green crumbweed, burrs, smooth goodenia, hill hibiscus, sidas (e.g. corrugated, ridge), mulga nettle, soft roly poly (western form), potato bushes.
Suitable sown pastures	Not suitable for sown pastures.
Introduced weeds	None of significance known to occur.

Land types of Queensland
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Version 3.1

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Soil	Shallow to moderately deep (30–90 cm), stony or gravely loamy red earths with areas of ironstone and stone throughout the profile.
Description	***Surface***: Loamy hard surfaces; ***Surface texture***: Sandy clay loam to clay loam; ***Subsoil texture***: Clay content may increase down profile to light clay; ironstone gravel common throughout profile.
Features	Hard-setting; high runoff zone.
Water availability	Low to medium.
Rooting depth	Shallow
Fertility	Very low to low (phosphorus, nitrogen, carbon).
Salinity	Very low
Sodicity	Non-sodic
pH	Very acid to slightly acid throughout profile.
Utilisation	15%
Enterprise	Mixed dry sheep and cattle, or adult wethers only.
Land use and management recommendations	• Stock lightly during dry periods and post drought to maintain ground cover. • Mulga fodder provides drought protein reserves. • Wiregrasses often predominate in areas cleared of mulga. • Opportunistic use of fire as management tool to control woody weeds (e.g. turkey bush, hopbush, cassias and mint bush). • Maintain ground cover to minimise water and wind erosion and maximise rainfall capture. Any grass cover is better than none. • Strip clearing is preferable to clearing of large areas to minimise erosion and degradation.
Land use limitations	• Fragile grazing lands. • Difficult to reclaim if degraded by either soil erosion or woody weed domination. • Poor surface structure, soil acidity and stoniness limit mechanical treatment options.
Conservation features and related management	• These areas provide potential habitat for rare and threatened fauna (pink cockatoo, red-throat, yellow-footed rock-wallaby, woma python) and flora (climbing caustic, *Euphorbia sarcostemmoides*). • Maintenance of ground cover will minimise extensive loss of topsoil and degradation of these areas.
Regional ecosystems	6.7.9, 6.7.10, 6.7.11, 6.7.12, 6.5.16, 6.5.16a.

Land types of Queensland
Mulga Region
Version 3.1

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Appendix 2. Recommended equipment and resources

The following equipment is desirable for undertaking a soil condition assessment in an assessment area:

- 100 m transect tape
- 50 m transect tape (optional)
- 1 x 1 m quadrat for measuring ground cover (or some 1 m long sticks)
- Compass (to lay out the site)
- Star pickets, with caps, for the 0 m and 50 m point along the transect for relocating the site (corner locations should also be captured as back-up for star pickets).
- Diameter tape or a smaller measuring tape
- The BioCondition manuals[9] and copies of the BioCondition assessment datasheet
- Access to the Internet in order to obtain information about the REs that occurs on the property or management area; RE maps (remnant, regrowth and pre-clear) and RE descriptions can also be obtained from the QSpatial website. With descriptions of REs available on the Queensland Government Website (http://www.qld.gov.au/).
- Benchmark documents for each of the REs that will be assessed. (Available on the Queensland Government Website (http://www.qld.gov.au/).
- Clinometer, hypsometer or ruler for measuring tree heights or slope
- Camera
- Clipboard, pencils and erasers
- Global Positioning System (GPS)
- Shovel, auger or percussive driver for sampling soil
- Steel ring for bulk density measure e.g. a tin approx. 10cm height x 7cm diameter
- Bucket
- Sample bags (zip lock bags are acceptable)
- Permanent marker - to label sample bags (that will not rub off)
- Kitchen scales or balance (grams)
- Field pH test meter (for level 2 assessment)

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[9] Eyre TJ, Kelly AL and Neldner VJ (2017). *Method for the Establishment and Survey of Reference Sites for BioCondition. Version 3.* Queensland Herbarium, Department of Science, Information Technology and Innovation, Brisbane.

Eyre, T.J., Kelly, A.L, Neldner, V.J., Wilson, B.A., Ferguson, D.J., Laidlaw, M.J. and Franks, A.J. (2015). *BioCondition: A Condition Assessment Framework for Terrestrial Biodiversity in Queensland. Assessment Manual. Version 2.2.* Queensland Herbarium, Department of Science, Information Technology, Innovation and Arts, Brisbane.

Appendix 3 Recommended guidelines for sampling and measurement of indicators

General methods for sampling soil are described in detail elsewhere (McKenzie et al., 2008), as are specific details for soil carbon sampling under the ERF methods[1]. Various issues can arise in the field that might inflate local variation of the soil condition indicators (for instance, the presence of gilgai, see http://www.dlgrma.qld.gov.au/resources/guideline/rpi-guideline-08-14-strategic-cropping-land-criteria.pdf), and steps to accommodate this local variation can lead to more accurate assessment of condition. For more information, we refer to McKenzie et al. (2008). For the soil condition indicators considered here, the following table gives brief sampling and measurement guidelines.

Indicator	Summary	Data Source and References
Soil organic carbon	Soil sample collection on site; laboratory measurement by combustion (possibly calibrated against infra-red spectroscopy approaches)	**Measurement**: ERF carbon methods[1] **Supporting datasets**: https://qldglobe.information.qld.gov.au/ https://www.asris.csiro.au/themes/NationalGrids.html
Soil pH	Soil sample collection; field or laboratory assessment using 1:5 soil water suspension (possibly calibrated against infra-red spectroscopy approaches)	**Measurement**: can be measured from soil carbon sample and determined in laboratory, e.g. Rayment and Lyons 2011 method 4A1, 4B1 or 4B5; field test kits can provide additional soil pH approximations on-site[2], e.g. Rayment and Lyons 2011 method 4G1 **Supporting datasets**: https://qldglobe.information.qld.gov.au/ https://www.asris.csiro.au/themes/NationalGrids.html
Ground Cover	Visual recording on site; photo evidence	**Measurement**: Biocondition guidelines; NRM Guide to estimating percentage groundcover[3] Supporting datasets:
Saline extent	photo evidence and visual recording on site	**Measurement**: Science notes Land series 137: measuring salinity[4] **Visual assessment**: https://www.qld.gov.au/environment/land/management/soil/salinity/identified **Supporting datasets**: Salinity site locations https://qldglobe.information.qld.gov.au/
Soil electrical conductivity (EC)	Soil sample collection; measurement of EC using 1:5 soil:water suspension or laboratory assessment using a soil saturation extract EC (ECse) or a 1:5 solution (possibly calibrated against infra-red spectroscopy approaches)	**Measurement**: can be measured from soil sample collected for carbon analysis and determined in laboratory, e.g. Rayment and Lyons 2011 method 3A1, 14B1 **Supporting datasets**: https://qldglobe.information.qld.gov.au/

Soil total N	Soil sample collection; laboratory measurement by combustion (possibly calibrated against infra-red spectroscopy approaches)	**Measurement:** by high-temperature combustion, e.g. Rayment and Lyons 2011 method 7A5 **Supporting datasets**: https://qldglobe.information.qld.gov.au/ https://www.asris.csiro.au/themes/NationalGrids.html
Soil bulk density	Soil sample collection; measurement by weight of intact core of known dimensions	**Measurement:** ERF carbon methods[1] **Supporting datasets**: https://qldglobe.information.qld.gov.au/ https://www.asris.csiro.au/themes/NationalGrids.html

[1]<http://www.cleanenergyregulator.gov.au/ERF/Pages/Forms%20and%20resources/Methods/Resources%20for%20agricultural%20methods/A%20guide%20to%20the%20estimating%20sequestration%20of%20carbon%20in%20soil%20using%20default%20values%20method/Overview-of-a-soil-carbon-project.aspx>

[2]<https://www.qld.gov.au/environment/land/management/soil/soil-properties/ph-levels>

[3]<http://www.nrm.gov.au/system/files/resources/455ba44f-a18b-476b-8a05-a041ef8f05b2/files/guide-estimating-percentage-ground-cover.pdf>

[4]<https://www.publications.qld.gov.au/dataset/science-notes-soils/resource/6205ff5f-92b6-444b-95b7-f195fe4a64d6>

Appendix 4. Generalised Land Restoration Fund guide to land use change and potential impact of soil condition indicators

Current land use	Cropping[10]			Remnant native vegetation (with or without grazing)		Grazing modified pastures (including native pastures derived by clearing trees)		
New land use	Pasture	Trees (agriculture, orchard)	Trees (native regrowth, revegetation)	Improved grazing management (including HIR in remnant vegetation)	Savanna fire	Trees (agriculture, orchard)	Trees (native regrowth, revegetation)	Savanna fire
Soil organic carbon	Positive *Plenty of research in long term trials*	Positive *Not a lot of biomass removal.* *Application of organic amendments likely.*	Positive	Neutral/ Positive	Neutral	Neutral/ Positive *Very little data.*	Neutral/ Positive *Less biomass removal.* *However dependant on location/rainfall*	Neutral
Soil acidification (critical threshold: pH < 5.5, pH > 9)	Positive – at least in net terms *Rate of acidification would decrease (avoiding a negative).* *Only get a positive benefit (i.e. trend toward neutral) if ameliorants added, such as lime for acidifying soil).* *Dependant on district practice - which may include liming of pastures.*	Positive *Depends on management. Depends on of tree planted and whether it requires liming.*	Positive *Majority would be neutral (99% chance in a long time frame).* *Only get a positive over long periods of time (but low confidence in this)*	Neutral	Neutral	Neutral *Likely only neutral unless planted species requires liming of soils.*	Neutral	Neutral

[10] Includes dryland, irrigated and mixed systems). Irrigated systems likely starting from lower baseline. Average cultivation frequency must be at least 3 times in last 10 years

Water erosion	Positive *Increased cover*	Positive *Increased cover*	Positive *Increased cover* *In theory this is the maximum positive benefit that you could get.*	Neutral/ Positive *Dependant on how well the pasture is managed.* *Likely to be on the positive side of neutral however the difference may not be practically measurable.*	Neutral/Positive *Patchier burns are expected to leave more cover*	Negative/Neutral/ Positive *Dependant on how well the pasture is managed.* *Likely to be on the positive side of neutral however the difference may not be practically measurable.*	Neutral *Probably over all close to neutral*	Neutral/Positive *Patchier burns are expected to leave more cover*
Wind erosion	Positive *Increased cover*	Positive *Increased cover* *Windbreak effect*	Positive *Increased cover* *Windbreak effect*	Positive	Neutral/Positive *Patchier burns leave more cover*	Negative/ Neutral/Positive *Depends on state of pasture before change.* *Dependant on species planted.*	Neutral *Dependant on state of pasture before change.*	Neutral/Positive *Patchier burns leave more cover*
Salinity	Positive *Benefit depends on local landscape scenario.*	Positive *Increase in deep rooted vegetation and perennial systems.* *Benefit depends on local landscape scenario*	Positive *Increase in deep rooted vegetation.* *Benefit depends on local landscape scenario.* *In theory this is the maximum positive benefit that you could get.*	Positive *Deep rooted vegetation.*	Neutral	Positive *Deep rooted vegetation*	Positive *Deep rooted vegetation*	Neutral

Appendix 5. Plotted functions for calculation of indicator condition scores

Soil pH

Rayment and Lyons (2011) give ratings for soil pH, defining moderately acid for pH range 5.6-6.0, strongly acid for pH 5.1-5.5, moderately alkaline for pH 7.9-8.4 and strongly alkaline for pH 8.5-9.0. Based on these thresholds, we define here a pH neutral range of 6.0–7.9, which allows for a buffer of around 0.5 pH units from the strongly acid and alkaline critical values. The ICS function for pH is designed so that:

- It takes the value of 100 whenever the account pH value is within half a unit of the reference value
- Changes from the reference pH towards the neutral pH range are not penalised
- Outside the neutral pH range and beyond the half-unit buffer of the reference value, the ICS decays as a linear function to reach 0 at the extreme pH values of 3.0 and 11.0

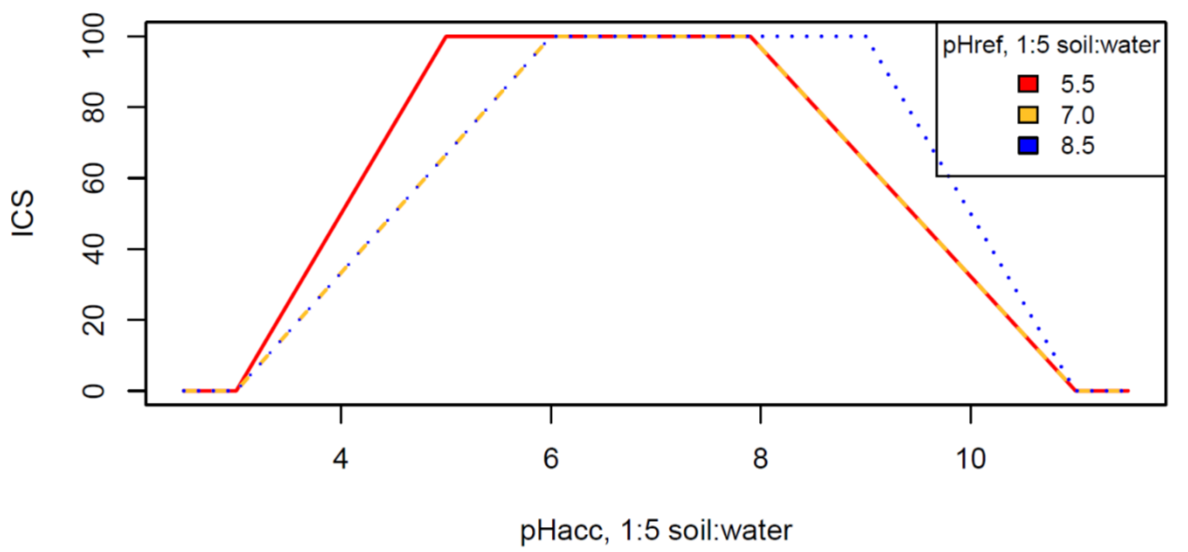


Figure 2. Model representing indicator condition scores (%, y-axis) for pH samples (pHacc, unitless, x-axis), derived from Caritat et al (2011). Note that the top of this function shifts with the reference value

Ground cover

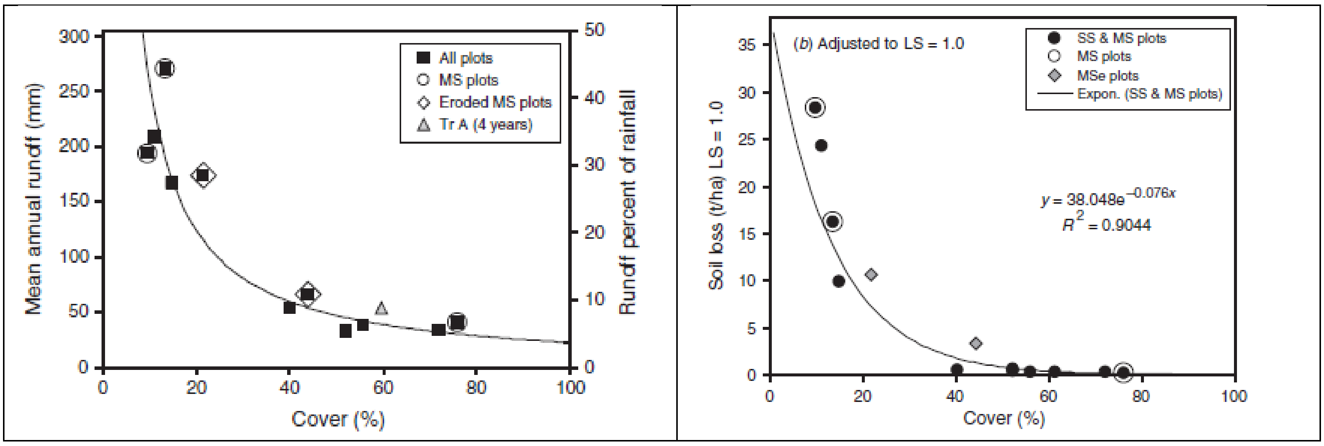
Relationships between ground cover and runoff and between ground cover and soil loss are shown in Figures 3a and 3b (Silburn et al., 2011). These relationships clearly demonstrate the importance of cover, particularly for changes between 10% and 40% cover. The ICS function for ground cover is made up of two relationships put together, the first between cover and runoff (based on Figure 3a), and the second between runoff and the ICS. The cover-runoff relationship describes how cover should be expected to affect runoff, as a percentage of annual rainfall. This equation was based on the fitted curve shown in Silburn et al. (2011; Figure 3a here), for which an original parametric equation was not given. Points on the original fitted line were extracted, and a powered exponential equation fitted, with a plateau imposed for cover values less than 10% to avoid undue extrapolation. The result of this was an equation which gave a plateau value of 41% runoff for cover less than 10%, a sharply decreasing runoff with increasing cover between around 10% and 40% cover, and a gradual decrease thereafter, eventually decreasing to a runoff of 2% at a cover of 100% (see Figure 3c).

$$runoff = \begin{cases} 41 & \text{if } cover < 10 \\ 2 + 39 * \exp\left\{-\dfrac{(cover - 10)^{0.68}}{6.2}\right\} & \text{if } cover \geq 10 \end{cases}$$

The second part of the ground cover ICS function is the relationship between runoff and the ICS. This was designed to have a maximum value of 100 whenever the account cover exceeded the reference cover (i.e. the account runoff was smaller than the reference runoff); the ICS then decreases as a linear function of runoff to reach an ICS of 0 when the runoff reaches 41% (the maximum value in the fitted cover-runoff relationship).

$$ICS = \begin{cases} 100 & \text{if } cover_{acc} \geq cover_{ref} \\ 100 * \dfrac{41 - runoff_{acc}}{41 - runoff_{ref}} & \text{if } cover_{acc} < cover_{ref} \end{cases}$$

When these two relationships are put together, the result is an ICS that decreases from a value of 100 at the reference cover to a value of 0 when the cover decreases to 10%, with the ICS changing most rapidly between covers of 10 and 40%. Figure 3d shows the cover ICS function for three potential reference cover values.



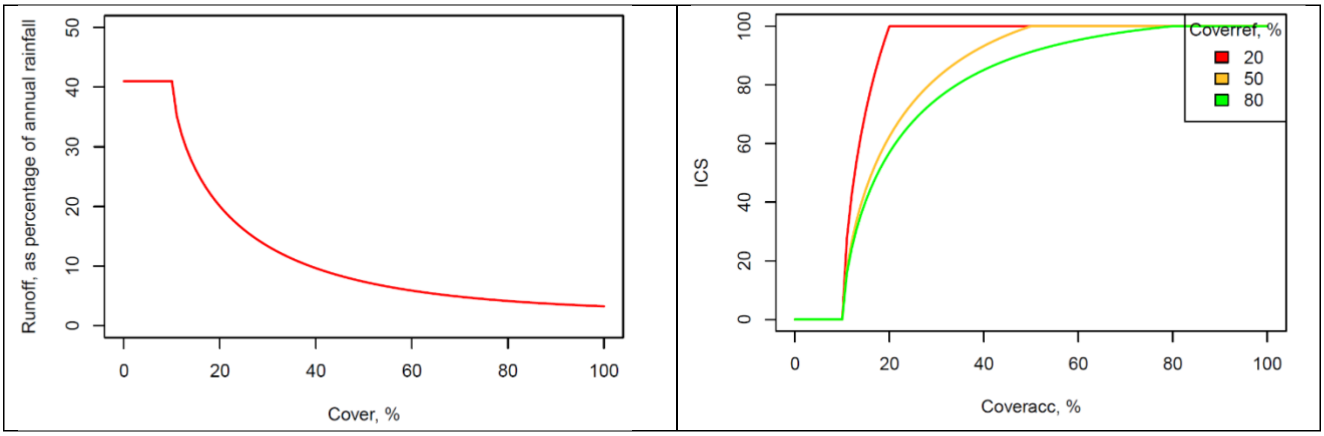


Figure 3. Relationships between groundcover and runoff (3a, top left panel) and groundcover and soil loss (3b, top right panel), as shown in Silburn et al. 2011. Figure 3c (bottom left panel) shows the same cover-runoff relationship as Figure 3a with a plateau imposed for cover <10%, and Figure 3d (bottom right panel) expresses the indicator condition score (ICS, %) as a function of groundcover (Coveracc, %) for three different reference values of cover.

Soil Electrical conductivity (EC)

O'Brien and Thomas (2018) classed saline soils (in terms of their impact on cropping) based on ECse (measured in saturated extract), with no salinity constraint for ECse < 2 dS/m, a mild constraint for 2 < ECse < 4 dS/m, and a moderate-severe constraint for ECse > 4 dS/m. An approximate conversion of ECse to EC1:5 depends on texture, with conversions of ECse = 12.5 * EC1:5 for sand through to ECse = 6 * EC1:5 for heavy clay. Based on this, a reasonably conservative estimate of the value of topsoil EC1:5 at which a mild salinity constraint might be expected would be 0.2 dS/m, while moderate-severe constraints might be expected at around 0.4 dS/m. Therefore, any EC reference values below 0.2 dS/m should be put equal to 0.2 dS/m. The function for calculating the EC ICS gives a value of 100 when the measured *ECacc* value (the EC for the time of the account) is less than the reference value and decreases to a value of 0 when is three times the reference value; between these values it is a quadratic function. This means that when a reference value of EC is large, there can still be benefits if at the start of the project the EC was larger than this reference. The function for calculating the soil EC indicator condition score is shown in Figure 4. Three reference values 0.2, 0.4 and 0.7 dS/m are considered in this example; the function decreases to an ICS value of 0 when the measured EC condition is $3 * EC_{ref}$ dS/m.

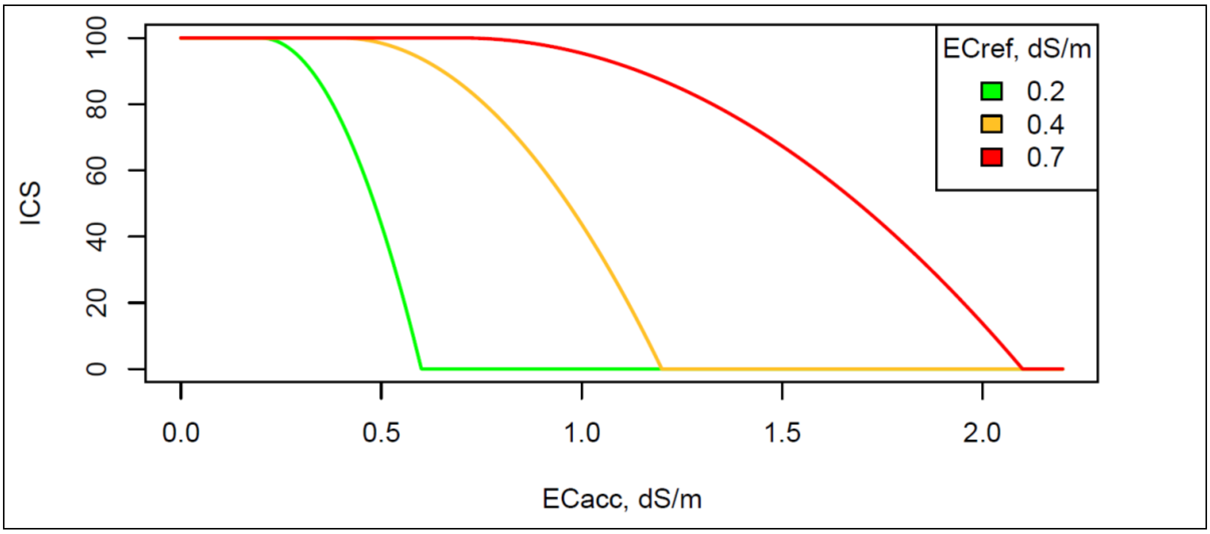


Figure 4. The function for calculating the indicator condition score (ICS, %, y-axis) for electrical conductivity (ECacc, dS/m, x-axis). The subscript acc indicates measurement of an indicator for the time of the account, while the subscript ref indicates the associated reference value.

Soil total N

The ICS function for soil total N (TN) takes the value of 100 whenever the account TN is within 10% of the reference TN. Outside of this range, the function decreases linearly to zeros at TN contents of 0 and $2 * TN_{ref}$ (see Figure 5).

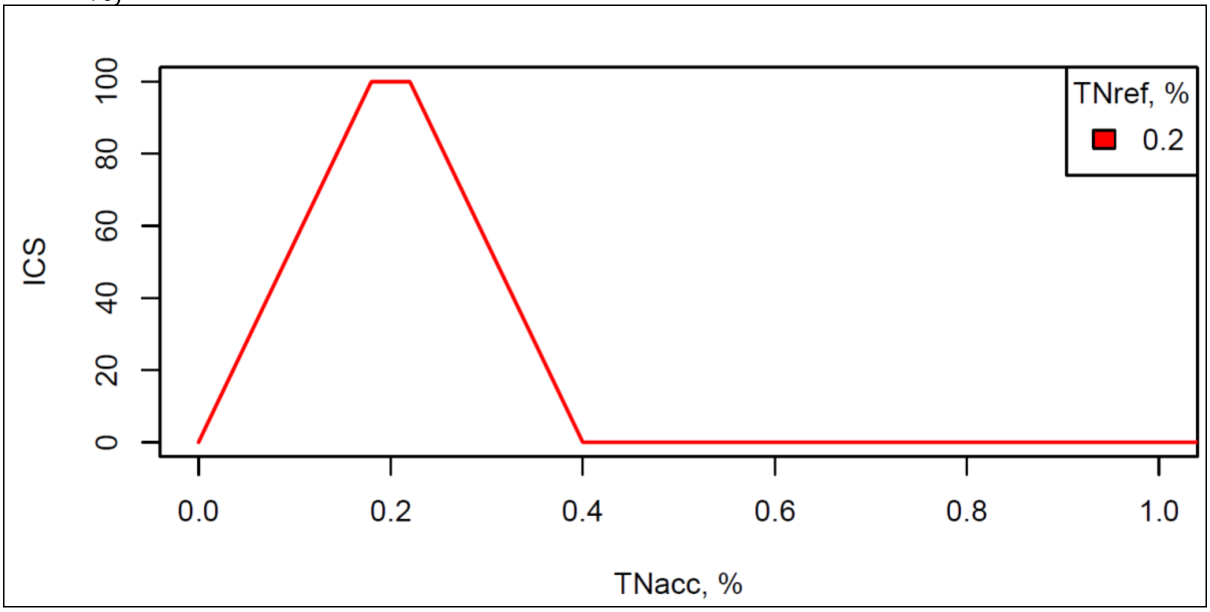


Figure 5. The function for calculating the indicator condition score (ICS, %, y-axis) for soil total N (TNacc, %, x-axis). The subscript acc indicates measurement of an indicator for the time of the account, while the subscript ref indicates the associated reference value.

Soil bulk density

Bulk density provides an indication of soil compaction, with root growth tending to be restricted when the bulk density is greater than 1.6 g/cm^3 (http://soilquality.org.au/factsheets/bulk-density-measurement). Therefore, any reference values of bulk density less than 1.6 g/cm^3 should be set to be equal to 1.6 g/cm^3, so that any changes below this value will not be considered as either detrimental or beneficial. The function for the ICS for bulk density is linear between the reference value, BD_{ref}, and a value of 2.0 g/cm^3, representing a severely compacted soil, is shown in Figure 6.

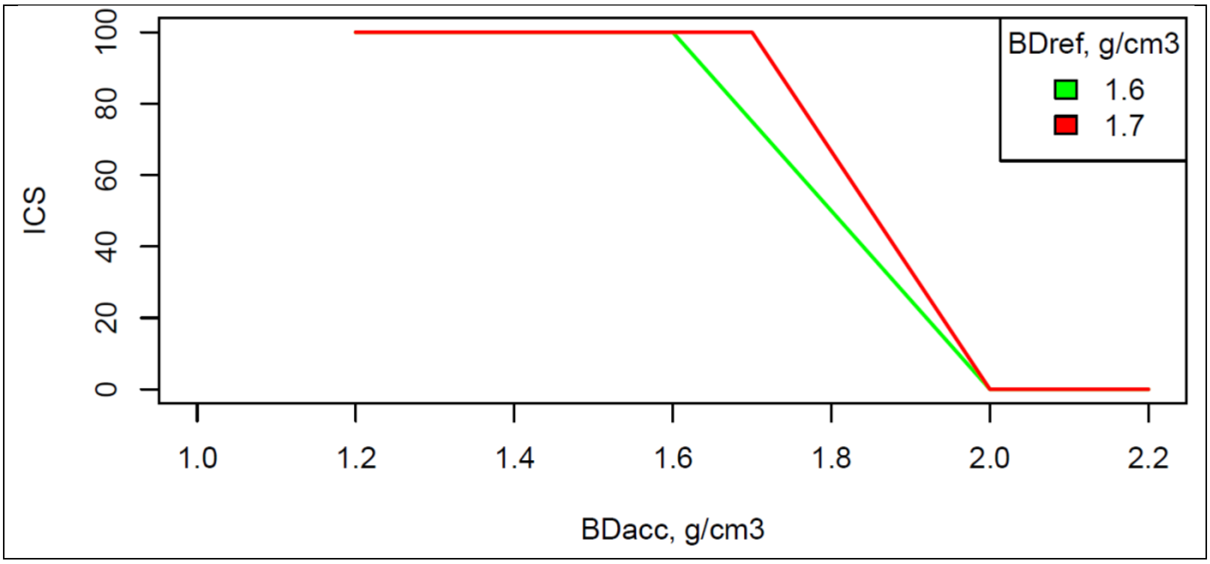


Figure 6. The function for calculating the indicator condition score (ICS, %, y-axis) for soil bulk density (BDacc, g/cm^3, x-axis). The subscript acc indicates measurement of an indicator for the time of the account, while the subscript ref indicates the associated reference value.