Supplement to the Carbon Credits (Carbon Farming Initiative – Estimation of Soil Organic Carbon Sequestration using Measurement and Models) Methodology Determination 2021

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Contents

Preface

The purpose of this document is to outline specific requirements for the *Carbon Credits (Carbon Farming Initiative—Estimation of Soil Organic Carbon Sequestration using Measurement and Models) Methodology Determination 2021 (the Determination)*. This document also provides some guidance for carrying out projects under the Determination.

Part A: Mapping Carbon Estimation Areas, exclusion areas and emissions accounting areas

Requirements of Part A are used primarily to guide the operation of a project at start-up under section 4 of Schedule 1 and section 5 of Schedule 2 of the Determination. Section 5 of Schedule 1 and section 6 of Schedule 2 of the Determination requires that the mapping of each Carbon Estimation Area (CEA), exclusion area or emissions accounting area must be done in accordance with this Supplement.

Requirements:

1. It is a requirement that geospatial maps are provided to the Regulator with the following features (in the following circumstances) clearly identified, for the purposes of subparagraphs 32(1)(e) and 32(1)(g) of the Determination:

   a) Each CEA in the project (provided with every offsets report and sampling plan)

   b) Each exclusion area in the project (provided with every offsets report and sampling plan)

   c) Each emissions accounting area in the project (provided with every offsets report and sampling plan)

   d) Provided to the Regulator with every offsets report, for each sampling round or estimation event in the reporting period:

      i) Strata boundaries

      ii) Intended sampling locations (which were included with the sampling plan) with the sequence of samples to be taken, composite sample identifiers (e.g. which samples feed into which composite), and reserve locations (excess sampling locations).

      iii) If a sampling round occurred, actual sampling locations (with the sequence of samples taken, composite sample identifiers (e.g which samples feed into which composite), and reserve locations (excess sampling locations)

      iv) Actual composite sample identifiers.

2. It is a requirement that project proponents use one or more of the following sources of data to delineate the boundaries of CEAs, exclusion areas and emissions accounting areas:

   a) Differential Global Navigation Satellite System (GNSS)

   b) Field surveys and sampling

   c) Orthorectified aerial photographs

   d) Orthorectified satellite imagery

e) Cadastral databases.

3. It is a requirement to provide spatial data that has a horizontal accuracy of at least 10 meters at 95 per cent threshold in accordance with the Intergovernmental Committee on Surveying and Mapping (ICSM) - Australian Map and Spatial Data Horizontal Accuracy Standard 2009.

4. It is a requirement that carbon estimation area boundaries are delineated with a maximum resolution of ± four meters. For clarity, a resolution as small as possible is preferable and must not exceed ± four meters.

5. CEA boundaries must not be changed in such a way as to result in the change in boundaries of any strata, in any sampling round or estimation event for which samples have been allocated under Part B Section 2.0.

    a. Where a CEA has used equal area strata and across strata compositing for a sampling round or estimation event, such strata may be merged, and considered a single stratum within the merged CEA. The composite samples previously collected across the original equal area strata must be considered within-strata composites for the purposes of this Supplement.

    Note: This does not limit new strata boundaries being formed for subsequent sampling rounds or estimation events.

6. It is a requirement that if CEA boundaries are changed, they are not changed in such a way as to result in CEAs with less than three sampling strata for any sampling round or estimation event for which samples have been allocated under Part B Section 2.0.

7. It is a requirement that if CEA boundaries are changed when spectroscopy has been used in the first or last sampling round or estimation event in a reporting period, they are not changed in such a way as to result in the requirements of Part D Section 2.2 or Section 3.2 not being met for that sampling round or estimation event.

Recommendations:

1. It is recommended that project proponents assess the appropriateness of the dataset(s) (used for Requirement 3 of this Part) against the following criteria:

    a) Age of spatial information

    b) Scale

    c) Resolution

    d) Accuracy

    e) Classification, aggregation, generalisation systems

    f) Integrity of dataset

Part B: Developing Sampling Design

Requirements of Part B are used primarily to guide the setup and operation of sampling design under sections 6 and 7 of Schedules 1 and 2 of the Determination, respectively, which require sampling design to meet any requirements in this Supplement.

Requirements:

1. It is a requirement that a sampling plan is developed and documented for the baseline sampling round or, as it is referred to in Schedule 2 of the Determination, the first estimation event.

2. It is a requirement that a new sampling plan is documented prior to each of the subsequent sampling rounds or estimation events to incorporate changes to the sampling plan compared to the previous sampling round or estimation event.

3. It is a requirement to document all changes to the sampling plan (e.g. if a CEA is selected for sampling under Requirement 3 of Part E Section 2.0).

4. It is a requirement that a sampling plan includes:

    a) a geospatial map prepared in accordance with Part A, which includes details of carbon estimation areas, exclusion areas, emissions accounting areas (in accordance with Section 1.0 of this Part) and strata for each sampling round or estimation event.

    b) the process and plan for randomly assigning sampling locations (see Section 2.0 of this Part) and compositing samples.

    c) if a reserve list of locations is to be used when obstacles are encountered – the process and plan for the random selection of locations on that list (see Section 2.0 of this Part).

5. It is a requirement that if Requirement 4(a) of Section 2.0 of this Part applies, random numbers are generated and applied after a sampling plan has been submitted to the Regulator.

Recommendations:

1. It is recommended that proponents develop a sampling plan in consultation with information that is well documented in the peer reviewed literature. Some examples of useful resources include:

    a) Sampling protocols published in the peer reviewed literature (e.g. de Gruijter et al., 2016; Viscarra Rossel et al., 2016b).

    b) Generating spatially and statistically representative maps of environmental variables to test the efficiency of alternative sampling protocols (Cunningham et. al, 2017)

    c) Soil carbon stock in the tropical rangelands of Australia: Effects of soil type and grazing pressure, and determination of sampling requirement (Pringle et. al, 2011)

    d) A geostatistical method to account for the number of aliquots in composite samples for normal and lognormal random variables (Orton et. al, 2015)

    e) CFI Equal area stratification soil sampling design guidelines (https://publications.industry.gov.au/publications/climate-change/system/files/pages/b341ae7a-5ddf-4725-a3fe-1b17ead2fa8a/files/cfi-soil-sampling-design-method-and-guidelines.pdf)

2. It is recommended to consider the following when deciding on your sampling design:

    a) Number of samples you can afford per CEA, noting the minimum sampling requirements outlined in Part B 2.0.

b) How much you know about the soil carbon variability across the project area, noting that the collection of additional samples may improve the accuracy and precision of soil carbon stock change estimates and reduce the impact of the probability of exceedance approach outlined in Schedules 1 and 2 of the Determination.

1.0 Stratification

Requirements:

1. It is a requirement that each CEA is divided into three or more strata for each sampling round or estimation event.

   a) Strata may be non-contiguous, noting that this may limit flexibility under Part A (Requirements 6 and 7) where strata would need to be moved between CEAs without splitting or merging the strata.

2. It is a requirement that strata do not overlap.

3. It is a requirement to identify in the sampling plan if strata are equal (within 5%) or unequal in area across a given CEA.

4. It is a requirement that strata boundaries are delineated by generating a set of spatial coordinates that define the geographic limits of the land included within each stratum by using a geographic information system to generate spatial data files.

5. It is a requirement that spatial data files documenting the strata boundaries are created for each sampling round, or estimation event, even if the strata boundaries remain the same (as per Part A Requirement 1).

6. It is a requirement, if samples are composited across strata, that strata have an equal area. For the purpose of this requirement, strata will be considered to have an equal area if there is no more than 5% difference in area (based on the average strata size) between the smallest and largest strata in a CEA.

7. It is a requirement to identify in the sampling plan if strata are equal (i.e. there is no more than 5% difference in area between the smallest and largest strata in the CEA) or unequal in area across a given CEA.

Quick Guide to stratification

Equal-area stratification is where all of the strata in a CEA are of equal area and was required in the 2014 method. **Unequal-area stratification** allows for strata of varying sizes and this may be beneficial for stratifying CEAs into areas with similar soil organic carbon stocks (this may for example follow geological or topographical lines).
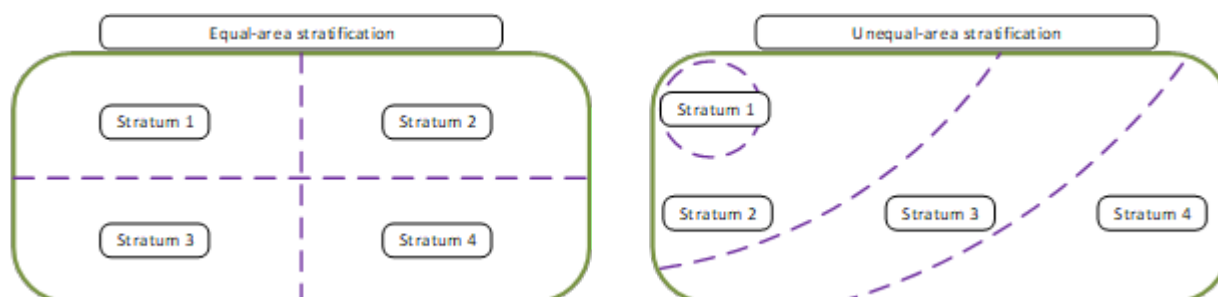
Compositing is the process of combining multiple soil cores together to form a single sample. This allows more cores to be used for each sample, with the aim of producing a more homogenous result across composite samples. Where equal-area stratification has been used, proponents may elect to use **across strata compositing**, where cores from different strata are combined to form a single composite sample. Proponents may also elect to use **within strata compositing** where cores from a single stratum are combined. It is not a requirement to composite samples. Samples may be kept separate.

Within strata compositing summary:

Stratum 1: ●●● A   ○○○ B   ○○○ C
Stratum 2: ●●● D   ○○○ E   ●●● F
Stratum 3: ○○○ G   ●●● H   ●●● I
Stratum 4: ●●● J   ●●● K   ●●● L

Across strata compositing summary:

Stratum 1: ●A ●B ○C ●D ○E ●F ○G ●H ●I
Stratum 2: ●A ●B ○C ●D ○E ●F ○G ●H ●I
Stratum 3: ●A ●B ○C ●D ○E ●F ○G ●H ●I
Stratum 4: ●A ●B ○C ●D ○E ●F ○G ●H ●I
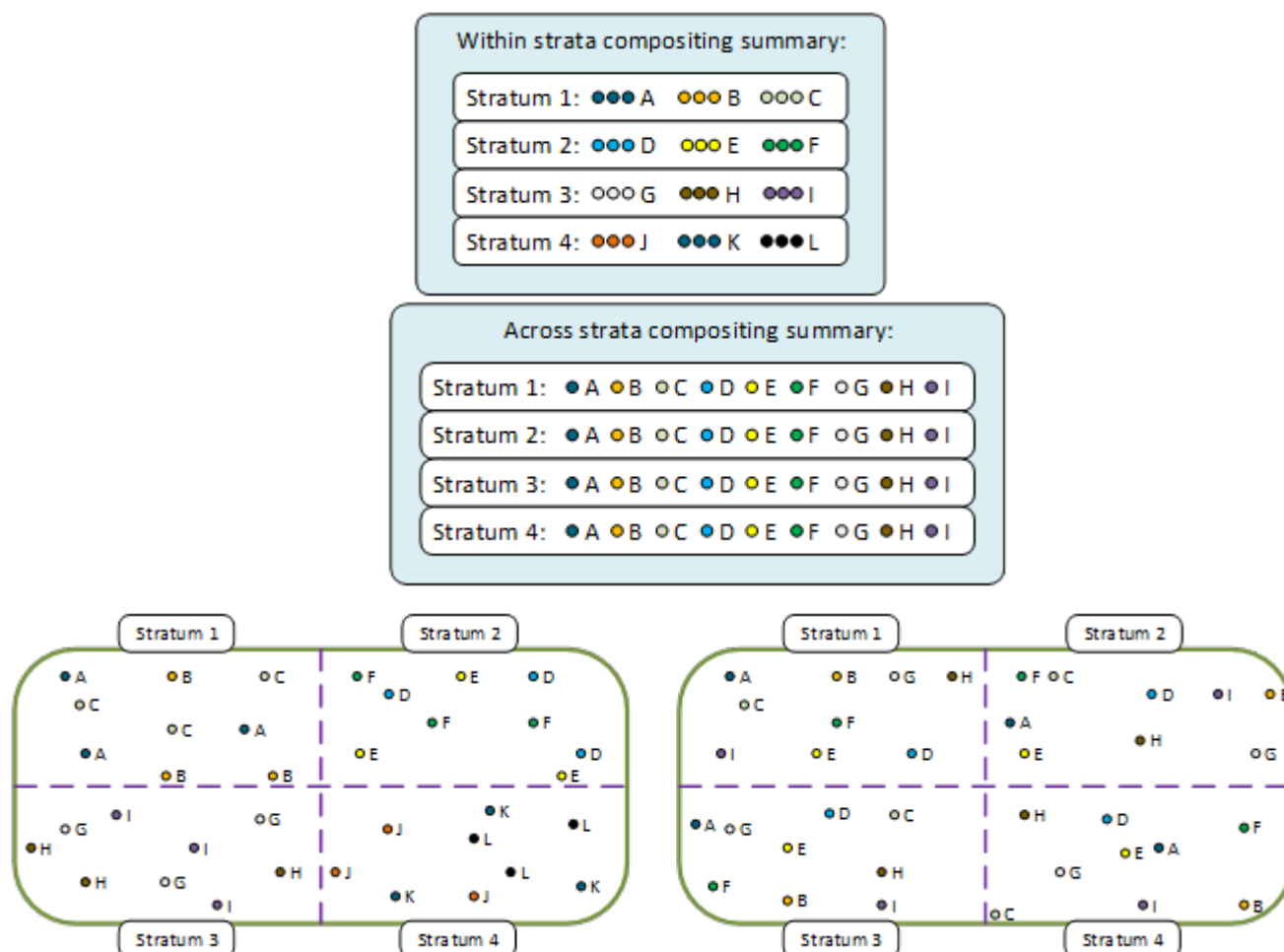
Note: Each coloured circle represents one soil core and each letter represents a composite sample consisting of multiple cores.

Recommendations:

1. It is recommended that if strata are unequal in size that:

    a) stratification is undertaken to minimise the variation in soil carbon stock within each stratum.

    b) the soil within strata is homogenous with respect to land management (e.g. inter-row vs. intra-row in cropping systems), soil type, land form or other variables.

    c) variables highly correlated to carbon content or stock are used to inform stratification of each carbon estimation area into individual strata.

d) each carbon estimation area is restratified for each sampling round as better information (with respect to Recommendation 1a) of this Section) becomes available.

> **Note**: This may limit flexibility to move strata between CEAs in accordance with Part A of this Supplement as the movement between strata cannot result in the division or merger of any previous strata boundaries.

2. It is recommended that if nothing is known about the spatial variability of soil carbon within a CEA, the variation in soil carbon within the CEA is minimized by:

a) compositing samples across strata within a given carbon estimation area.

b) using individual core analysis before mathematically compositing under Part D Section 5.0 to provide data on which to base stratification in subsequent sampling rounds.

2.0 Assigning sampling locations

Requirements:

1. It is a requirement that sampling locations are determined prior to any core extraction in a given stratum for a given sampling round or estimation event, with the following exception:

a) Allocation of new sample points for the purposes of collecting model-validation samples if the CEA is selected for sampling under Part E 2.0 (Requirement 3). However, the model-validation samples' locations must be determined before the collection of those samples and a revised sampling plan submitted to the Regulator.

2. It is a requirement that the geographic point location of assigned sampling points are digitally recorded along with the units used to define the location.

3. It is a requirement that the precision of each sampling location (or alternative sampling location) is:

a) if longitude and latitude are used – a minimum of five decimal places using the Geocentric Datum of Australia (GDA94 or GDA2020); or

b) if eastings and northings are used – a minimum of three decimal places using the Geocentric Datum of Australia (GDA94 or GDA2020).

4. It is a requirement that within each stratum, sampling locations are assigned using a pseudo-random number generator with a defined seed number where either:

a) all of the following apply:

    i) the process and plan to link the numbers generated by the pseudo-random number generator to sampling locations, and determine which samples are combined into composites, is prepared and documented;

    ii) the prepared process and plan (from 1 above) is provided to, and receipt acknowledged by, the Clean Energy Regulator before random numbers are generated and applied;

> **Note**: As at 3 December 2021, an email inbox has been provided by the Clean Energy Regulator for this purpose. Receipt is acknowledged with a reply email. The address of this inbox is available on the Regulator's website.

iii) the outputs of the pseudo-random number generator used are verifiable and suitable evidence of this is maintained;

iv) the process and plan uses a defined unpredictable seed number which is not known at the time the process and plan is developed (such as the ASX 200 index reported by asx.com.au at a specified future date/time);

v) if a reserve list of locations is used when obstacles are encountered—the circumstances when they will be used and the process and plan for the selection of those locations.

vi) after the plan is provided to the Clean Energy Regulator, the boundaries of CEAs and strata must not be varied for the sampling rounds or estimation events covered by the plan (this does not preclude subsequent plans from have revised CEAs or strata);

vii) the approach is transparent, reproducible and auditable;

viii) the approach achieves a genuinely random allocation of sampling locations; or

b) the process applies an approach pre-approved by the Clean Energy Regulator for generating and using random sampling locations. Such approaches may be approved for individual projects or generally in guidance published by the Clean Energy Regulator for the purposes of this subparagraph. Applications for individual approvals must be made by the project proponent for the project to the Clean Energy Regulator.

5. It is a requirement that, unless exceptional circumstances apply, sampling in accordance with a proposed process and plan should not be abandoned and started again. Exceptional circumstances would include unforeseen circumstances that make carrying out the process and plan impossible or hazardous, and other circumstances agreed in writing by the Regulator to be exceptional.

Note: Resubmission of a process and plan under Requirement 4 above would be inconsistent with a genuinely random allocation of sampling locations in all but exceptional circumstances (as the first plan's random locations are discarded).

6. It is a requirement that there are at least three sampling locations within each stratum.

7. It is a requirement that if compositing samples across equal-area strata, that an equal number of sampling locations (at least three) are assigned to each stratum.

8. It is a requirement that a soil core is taken at each sampling location (or alternative sampling location) assigned in this Part, and is prepared, analysed and the results reported as per Part D.

Recommendations:

1. It is recommended that project proponents take into account guidance from the Clean Energy Regulator as to how best to implement these requirements and provide the necessary evidence to demonstrate they have been complied with.

Transitional:

1. Sampling undertaken or commenced by 1 September 2020 need not comply with Requirement 4 of this Part.

Part C: Sampling

Requirements of Part C are used primarily to guide the operation of sampling under sections 7 and 8 of Schedules 1 and 2 of the Determination, respectively, which require sampling to meet any requirements in this Supplement.

1.0 Locating sampling locations

Requirements:

1. It is a requirement that a GNSS device with a minimum accuracy of ± four meters is to be used to locate the intended sampling location in the field.

2. It is a requirement that, if a large immovable obstruction (such as a tree or boulder) prevents sampling at the intended sampling location, the actual sampling location is to be determined by one of the following processes:

    a) A reserve list

        i)   Determine a reserve list of alternative sampling locations at the same time that sampling locations are assigned in Part B Section 2.0, for that sampling round.

    b) Offsetting:

        i)   move north until the obstacle is cleared;

        ii) if the stratum boundary is hit before the obstacle is cleared, continue changing the direction of movement in 15 degree increments in the same direction and away from the intended sampling location until the obstacle is cleared and the actual sampling location is within the stratum boundary (Figure 1).

    Note: In order to comply with this requirement, sampling technicians need to be provided with stratum boundaries and instructions for sampling where obstacles are encountered.

Key:
⭐ = intended sampling location
- - - = stratum boundary
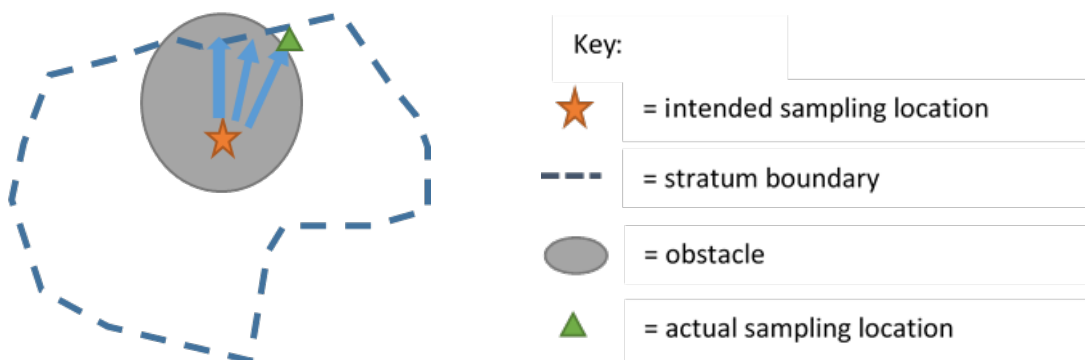⬭ = obstacle
▲ = actual sampling location

Figure 1: Example of determining an alternative sampling location within a stratum in the presence of an obstacle using the offsetting approach.

3. It is a requirement that both the intended and the actual sampling locations are reported (even if they are the same).

4. It is a requirement to include the following information in each offsets report—geographic coordinates, time and location stamped photographic or video evidence of obstacles that changed the intended sampling location of a sample.

Transitional:

1. If the information required by Requirement 4 of this Part was not collected for sampling undertaken or commenced by 1 September 2020, other information can be provided in the offsets report of how obstacles were addressed in the sampling.

2.0 Extracting cores

Requirements:

1. It is a requirement that the sampling location is cleared of living plants, plant litter and surface rocks, prior to core extraction using a consistent protocol between sampling rounds.

2. It is a requirement that the nominated soil depth (d_n) is a minimum of 30cm. However, sampling can occur to a depth of xcm where x > 30cm with x meeting the requirement of paragraph 7(2)(a) of Schedule 1 and paragraph 8(2)(a) of Schedule 2 of the Determination.

3. It is a requirement that soil samples are collected to the minimum depth of 30cm and all samples from the 0-30cm soil layer are extracted from a single core. The core can be split into any number of individual soil depth layers and sub-layers after removal.

4. It is a requirement that, if sampling occurs beyond the minimum depth of 30cm, soil from the 0-30cm layer and the 30-xcm layer are separated prior to the sample preparation step (unless Part D, Section 2.2 – Intact core applies).

5. It is a requirement that the baseline nominated soil depth is the same at all sampling locations in a given carbon estimation area. It is acceptable to have an actual sampling depth less than the nominated depth for a sample where the nominated soil depth cannot be reached due to bedrock or impenetrable layers. The actual sampling depth must be recorded.

   a) Depths in subsequent sampling rounds or estimation events may be adjusted to best match the equivalent soil mass calculated under section 12 of Schedule 1 and section 13 of Schedule 2 of the Determination, subject to any requirements to sample more deeply (e.g. where soil disturbance has occurred).

6. It is a requirement that, if the soil profile is disturbed (incorporating substances external to the profile, or vertically altering the profile – e.g. tilling, clay delving, water ponding), the minimum nominated soil depth must be at least 10cm below the depth of profile disturbance.

   a) For example, if the management practice applied to a soil mixes the soil to a depth of 30cm, it will be a requirement to sample to a depth of 40cm (30cm plus the additional 10cm) and divide the sampled soil core into 0-30cm and 30-40cm layers for analysis.

7. It is a requirement that the sampling depth attempts to attain the equivalent soil mass set by the baseline sampling round or first estimation event under paragraph 7(2)(a) of Schedule 1 and paragraph 8(2)(a) of Schedule 2 of the Determination.

8. It is a requirement that the inner cutting edge of the coring device has a minimum diameter of 38mm.

9. It is a requirement to have a clean coring device. Coring devices must only be cleaned with water.

10. It is a requirement to use only water to assist with insertion and extraction of the coring device.

11. It is a requirement that there is a minimum of one year between the median day of sampling for a sampling round or an estimation event and the median day of the next sampling round or estimation event that occurs in that CEA.

12. To comply with paragraph 4(1)(c) under Schedule 1 of the Determination, it is a requirement that there is a maximum of five years between the median day of sampling for a sampling round and the median day of sampling for the next sampling round that occurs in that CEA.

    a) To comply with paragraph 5(2)(b) under Schedule 2 of the Determination, it is a requirement that there is a maximum of ten years between the median day of sampling for a sampling round in a CEA and the median day of sampling for the next sampling round that occurs in that CEA.

    Note: The median day of sampling is calculated from the period within which all calibration and model-validation samples for that sampling round were collected.

13. It is a requirement that all cores are extracted from a given CEA for a given:

    a) sampling round for the purposes of Schedule 1 of the Determination, or estimation event for the purposes of subsection 14(3) of Schedule 2 of the Determination, over no more than 60 calendar days.

    b) estimation event for the purposes of section 14(5) of Schedule 2 of the Determination, over no more than 120 calendar days.

    Note: In exceptional circumstances preventing sampling within these timeframes, a project proponent may apply to the Regulator to seek an extension of time to carry out the sampling round.

14. It is a requirement to report the day, month and year that a given sampling round (for the purposes of Schedule 1 of the Determination) or sampling for an estimation event (for the purposes of Schedule 2 of the Determination) for a given CEA starts and finishes.

15. It is a requirement to report the median day of sampling for a sampling round (for the purposes of Schedule 1 of the Determination) or estimation event (for the purposes of Schedule 2 of the Determination).

16. If calibration or model-validation samples have been collected for Schedule 2 of the Determination, it is a requirement to report the start and end date for samples collected for that purpose.

17. It is a requirement that soil extracted is analysed for all soil properties separately for the 0-30cm layer and the 30-xcm layer (unless Part D, Section 2.2 applies).

Part D: Sample Preparation and Analysis

Requirements of Part D are used primarily for the calculation of carbon stocks under Divisions 3-5 of Schedules 1 and 2 of the Determination.

1.0 Samples: Single Cores, Composites, Layers and Sub-layers

1.1 Separating and combining cores for analysis

Requirements:

1. It is a requirement to decide and record whether the soil organic carbon stock change will be determined, in accordance with section 9 of Schedule 1 and section 10 of Schedule 2 of the Determination, on either:

   a) 0-30cm layers; or

   b) 0-xcm layers.

2. It is a requirement to report the baseline nominated depth, and subsequent nominated depths to which samples will be collected as d_n in centimetres.

   a) While subsequent nominated depths can vary from the baseline nominated depth (in order to ensure sufficient soil mass is collected to match the equivalent soil mass defined in the baseline sampling round or first estimation event), it is a requirement to nominate and report the subsequent nominated depth for each sampling round (for Schedule 1) or estimation event (for Schedule 2) to ensure compliance with section 9 of Schedule 1 and section 10 of Schedule 2.

3. It is a requirement, if Requirement 1 Option b. of this Section is chosen, that the soil core is divided into layers to produce at a minimum a soil sample for the 0-30cm depth and one soil sample for the 30-xcm. However, each layer can be divided into any number of sub-layers.

4. It is a requirement, if a soil core is divided into multiple sub-layers, that the sub-layers do not extend across the 30cm depth boundary.

5. It is a requirement to report the actual soil sampling depth achieved for the 0-30cm or 0- xcm soil layers at each sampling location in accordance with Equation S1 (unless Equations S2 or S21 apply).

$$d_a = \sum_{sl=1}^{n} t_{a_{sl}}$$

Equation S1

Where:

d_a is the actual depth of the soil collected for the 0-30cm or 0-xcm layer at an individual sampling location (centimetres).

$t_{a_{sl}}$ is the thickness of each soil sub-layer within the sampled 0-30cm or 0-xcm layer at an individual sampling location (in centimetres).

sl is the designator of each individual soil sub-layer within the sampled 0-30cm or 0-xcm layer at an individual sampling location.

n is the total number of soil sub-layers into which the 0-30cm or 0-xcm soil core collected at an individual sampling location was divided.

6. If a soil layer (0-30cm or 0-xcm) is divided into sub-layers it is a requirement to record the actual thickness of each sub-layer as $t_{a_{sl}}$ in centimetres.

7. It is a requirement that soil sample preparation is undertaken separately for each sub-layer in accordance with Part D, Section 2 of this Supplement.

8. It is a requirement to decide and record whether the samples will be collected and analysed as either:

   a) individual soil samples (derived from a single soil core); or

   b) composite soil samples (soil samples collected from multiple cores are combined and mixed to form a single soil sample).

9. If Requirement 8 Option b. of this Section is chosen, it is a requirement to report the type of compositing:

   a) across strata compositing (which must not be used if strata are unequal in size, or if the samples are model-validation samples for the purposes of subsection 14(5) of Schedule 2 of the Determination); or

   b) within strata compositing (which must not be used if the samples are model-validation samples for the purposes of subsection 14(5) of Schedule 2 of the Determination).

10. It is a requirement, if across strata compositing is chosen, that each composite sample contains all soil collected from the appropriate depth for exactly one core from every stratum within the CEA from which the cores were collected.

11. If requirement 8 Option a. of this Section is chosen, it is a requirement to undertake analysis on a sample prepared in one of the following ways:

    a) homogenised sample (Section 2.1 of this Part); or

    b) in-tact core (Section 2.2 of this Part).

12. If Requirement 8 Option b. of this section is chosen, it is a requirement to undertake analysis on a homogenised sample (Section 2.1 of this Part).

13. If a sample is a composite sample, it is a requirement to calculate the actual depth of soil for the 0-30cm or 0-xcm layers of the composite sample in accordance with Equation S2 instead of Equation S1 (unless Equation S21 applies).

$$d_a = \frac{\sum_{i=1}^{n} d_{a_i}}{n}$$

Equation S2

Where:

d_a is the actual soil depth of the composite sample (centimetres).

d_{a_i} is the actual soil depth for an individual core (sampling location) that was combined to form the composite sample (centimetres) using Equation S1.

i is the designator of an individual soil core (sampling location) included in the composite sample.

n is the total number of individual soil cores (sampling locations) included in the composite sample.

14. If a sample is a composite sample, it is a requirement to calculate the thickness of each composited sub-layer of the composite sample in accordance with Equation S3.

$$t_{a_{sl}} = \frac{\sum_{i=1}^{n} t_{a_{sl_i}}}{n}$$

Equation S3

Where:

$t_{a_{sl}}$ is the thickness of the composite sub-layer (centimetres)

$t_{a_{sl_i}}$ is the thickness of the sub-layer from an individual soil core (sampling location) that was combined to form the composite sample (in centimetres).

i is the designator of an individual soil core (sampling location) included in the composite sample.

n is the total number of individual soil cores (sampling locations) included in the composite sample.

Note: The relationship between d_n, d_a and $t_{a_{sl}}$ is provided in Figure 2.

Figure showing four soil depth columns (a), (b), (c), (d) with nominated and actual sampling depths.

(a) 0-30 cm soil depth layer – no sublayers

(b) 0-30 cm soil depth layer - three sublayers

(c) 0-x cm soil depth layer with x = 80 cm - two sublayers

(d) 0-x cm soil depth layer with x = 80 cm - multiple sublayers

Soil Depth (cm)

(a): $d_n = 30$, $d_a = 29.8$; $t_{a_1} = 29.8$

(b): $d_n = 30$, $d_a = 29.8$; $t_{a_1} = 10$, $t_{a_2} = 10$, $t_{a_3} = 9.8$

(c): $t_{a_1} = 30$; $d_n = 80$, $d_a = 79.5$; $t_{a_2} = 49.5$

(d): $t_{a_1} = 10$, $t_{a_2} = 10$, $t_{a_3} = 10$; $d_n = 80$, $d_a = 79.5$; $t_{a_4} = 25$, $t_{a_5} = 24.5$

☐ Denotes the nominated soil depth to be sampled, d_n

■ Denotes the actual depth of soil sampled, d_a

1.2 Calculating appropriate 0-30cm and 0-*x*cm values for use in the equations in Schedule 1 and 2 of the Determination

Requirements:

1. It is a requirement that the number of sub-layers to be included in the mass estimate for each sampling round or estimation event in a layer (*nSl*) is determined by one of the following requirements:

   a) For the 0-30cm layer, the total number of sub-layers within the 0-30cm layer

   b) For the 0-xcm layer, either of the following nominated by the project proponent:

      i) the total number of sub-layers within the 0-xcm layer, or

      ii) a lesser number of sub-layers, where the conditions of paragraph c are met.

   c) The following conditions must apply before a lesser number of sub-layers can be used:

i) The sum of the thickness of the lessor number of sub-layers exceeds both 30cm and the depth required to be sampled under paragraph 7(2)(a) of Schedule 1 and paragraph 8(2)(a) of Schedules 2 of the Determination, and

ii) The equivalent soil mass for the baseline samples, calculated by applying section 12 of Schedule 1 and section 13 of Schedule 2 to the lesser number of sub-layers in the baseline samples or first estimation event (which is calculated from the M_a calculated under Equation S5), must equal or exceed the lowest mass of any sample in the last estimation event or sampling round (tx), in the reporting period.

Note 1: This means that baseline carbon stock and soil mass estimates can be lowered to match the mass achieved in subsequent rounds – but sub-layers cannot be removed to lower the mass below the highest comparable mass between sampling rounds.

Note 2: The default under sub-requirement b. is to use the total number of sub-layers analysed in the mass estimates under Equation S5. The option to remove sub-layers from mass estimates has been designed to allow the ESM to be adjusted down if subsequent samples fail to attain the same soil mass as the baseline sampling round or first estimation event. The option operates through Equation S5 by lowering the mass that informs the ESM calculation in section 12 of Schedule 1 and section 13 of Schedule 2 of the Determination. It is an option that can only be used under strict conditions to avoid selective exclusion of sub-layers. It is designed to only impact the baseline equivalent soil mass estimate as all other estimates must only consider equal or lesser soil masses under section 13 of Schedule 1 and sections 15, 21,27, 29 and 31 of Schedule 2 of the Determination

2. It is a requirement to use Equation S4 (unless Equation S20 applies) to derive the oven dry mass of whole soil in each soil depth sub-layer sampled (M_{sl}).

$$M_{sl} = t_{a_{sl}} \times BD_{sl} \times 100$$

Equation S4

Where:

M_{sl} is the mass of oven dry whole soil within a sub-layer (tonnes of oven dry whole soil/hectare).

$t_{a_{sl}}$ is the actual thickness of the sub-layer sampled (cm). For a composite soil sample, $t_{a_{sl}}$ is calculated as the average thickness across all soil samples that were composited to derive a single soil sample for the sub-layer in accordance with Equation S3 of this Supplement.

BD_{sl} is the bulk density of the sub-layer (g oven dry whole soil/cm³ whole soil) determined in accordance with Part D, Section 4.0 of this Supplement.

sl is the designator for the soil sub-layer.

Note: M_{sl} is the oven dry mass of whole soil in the sub-layer including the mass of gravel. If using the conventional method to determine bulk density (Part D, Section 4.0/4.1) the value for bulk density can be used directly. If the bulk density has been determined using gamma attenuation, the water content correction (Part D, Section 4.0/4.2) must be applied to derive the appropriate oven dry soil bulk density value.

3. It is a requirement to use Equation S5 to derive the oven dry mass of whole soil in the 0-30cm and 0-xcm soil layers (unless Equation S19 applies). The values derived for M_a are to be used in section 13 of Schedule 1 and sections 15 and 31 of Schedule 2 of the Determination for the 0-30cm and 0-xcm depth layers.

$$M_a = \sum_{sl=1}^{nSl} M_{sl}$$

<div align="right">*Equation S5*</div>

Where:

M_a is the mass of oven dry whole soil within the 0-30cm or the 0-xcm soil depth layer (tonnes of oven dry whole soil/hectare).

sl is the designator for the soil sub-layer.

nSl is the number of sub-layers within the 0-30cm or 0-xcm soil depth layer determined under Requirement 1 of this Section. The value of n increases with increasing depth such that sub-layer 1 denotes the soil surface sub-layer and sub-layer nSl denotes the deepest soil sub-layer that is considered under Requirement 1. If *x* is greater than 30cm, nSl must be at least 2.

M_{sl} is the mass of oven dry whole soil within a sub-layer determined in accordance with Equation S4 (tonnes of oven dry whole soil/hectare).

Note: M_a is the total oven dry mass of whole soil in the 0-30 or 0-xcm soil depth layers and includes the mass of gravel.

1.3 Derivation of soil organic carbon stocks

Requirements:

1. The stock of soil organic carbon contained within an individual or composite soil sample must be calculated for each sample collected in a sampling round in accordance with this Section.

2. The calculation process must always be applied to the 0-30cm soil layer. If the nominated depth is greater than 30cm, the calculation process must also be applied to the 0-xcm soil layer.

3. If samples are taken to a nominated depth greater than 30cm:

    a) the organic carbon content of the deeper layer of soil (from a depth of 30cm to the nominated sampling depth of x, i.e. the 30–xcm layer) must be analysed separately to that of the 0-30cm layer, and

    b) the stock of soil organic carbon must be reported separately for the 0–30cm and the 0–xcm soil layers.

4. The stock of soil organic carbon in all soil sub-layers collected and analysed separately within the 0-30cm and 0-xcm soil layers must be calculated in accordance with Equation S6 (unless Equation S22 applies).

$$SOC_{sl} = OC_{sl} \times BD_{sl} \times t_{a_{sl}}$$

Equation S6

Where:

SOC_{sl} is soil organic carbon stock within an individual soil sub-layer (tonnes of soil carbon/ha).

OC_{sl} is the gravimetric concentration of organic carbon determined for the sub-layer (%, g organic carbon/100 g oven dry whole soil) determined by Section 3.0 of Part D.

Note: Corrections for both the gravimetric water content of the air dried <2 mm sieved soil analysed and the gravimetric gravel content of whole soil must have been applied to derive the value of OC_{sl} in accordance with Part D, Section 3 of this Supplement. Both dry combustion and spectroscopic estimates of organic carbon may be available for samples used to build spectroscopic models. The dry combustion value is to be used in this equation for those samples.

BD_{sl} is the bulk density of the sub-layer determined in accordance with Part D, Section 4.0 of this Supplement (g oven dry whole soil/cm3 whole soil).

$t_{a_{sl}}$ is the actual thickness of the sub-layer sampled (cm). For a composite sample, $t_{a_{sl}}$ is calculated as the average actual sub-layer thickness across all soil samples that were composited in accordance with Equation S3.

5. It is a requirement, that for each sub-layer on which carbon content is determined, that a value of bulk density is also determined (in accordance with Part D, Section 4.0).

2.0 Sample Preparation

2.1 Homogenised sample

Requirements:

1. It is a requirement to adhere to the process in Figure 3 for sample preparation of homogenised samples.

2. It is a requirement that the process in Figure 3 is followed separately for each sub-layer that is sampled.

3. It is a requirement if mid-IR is used to analyse the sample for carbon content, samples are ground to pass at least a 0.5mm mesh sieve or finer as per 3.2.2 (1)(b) of this Part.

4. If using mathematical compositing (compositing after analysis), it is a requirement that the mathematical compositing follows the requirements in Section 5 of Part D of this Supplement.

5. If mathematical compositing is not used, and composite samples are used, it is a requirement:

   a) that composite samples are formed before step 4 in Figure 3 (thoroughly mix the sample).

   b) to report between which steps the composite sample was formed. For example, the cores might be dried and crushed as individual cores, then form a composite sample between step 2 and step 3; or composites might be mathematically combined.

6. It is a requirement that each soil sample (individual core or composite) is dried separately.

7. It is a requirement to report the mass (air-dry) of the sub-sample (note that this is not the same as a sub-layer – see Figure 3 Item 5) used for laboratory analysis.
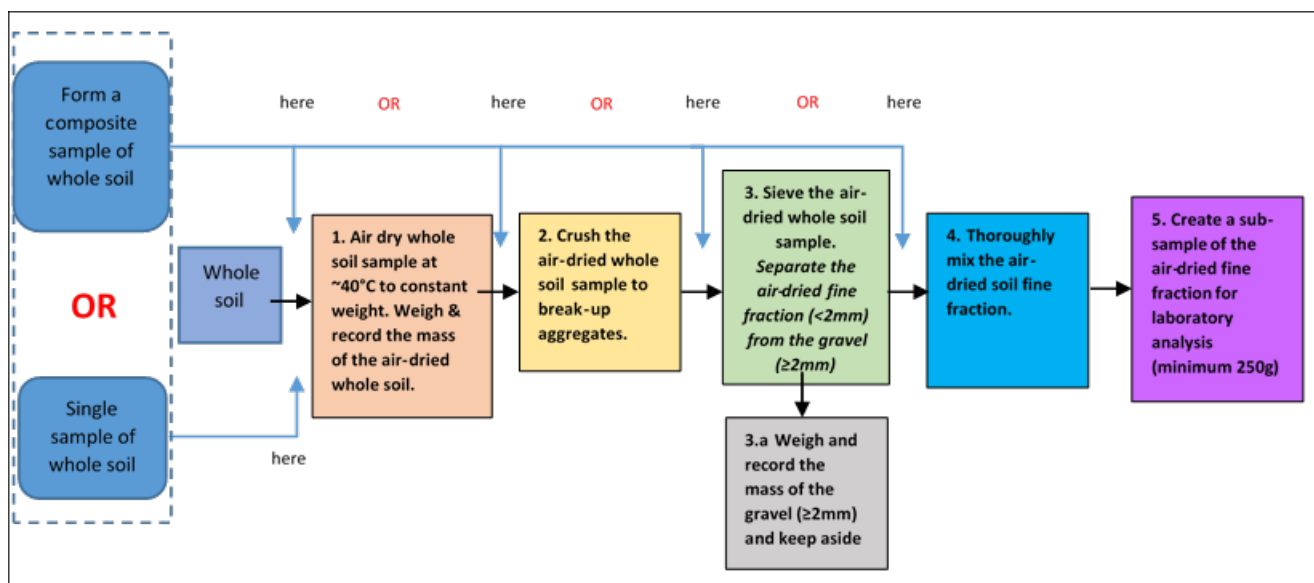
Recommendations:

1. It is strongly recommended that samples are laid out to be air dried on the same day they are extracted.

2. If Recommendation 1 of this Section is not possible, it is strongly recommended that samples are stored at low temperatures (e.g. refrigerator or ice box) until air-drying of the sample is possible.

2.2 Intact core

Where soil carbon stocks will be determined using an intact core (e.g. using visible near infra-red spectroscopy), the sample preparation described in Section 2.1 for the cores on which the spectral measurement is taken, is not applicable. However, the sample preparation described in Section 2.1 must be applied to all soil samples sent for soil organic carbon analysis that are used to derive the spectroscopic model that will be used to predict the gravimetric soil organic carbon concentration from the acquired visible/near infra-red spectra.

3.0 Measuring gravimetric soil organic carbon content

Requirements:

1. It is a requirement that the gravimetric organic carbon content of each collected soil sample is determined by following the requirements in either Section 3.1 or Section 3.2 of this Part. All sublayers in a soil core must be treated identically in this respect.

2. It is a requirement that if Section 3.2 of this Part is chosen, that Section 2.1 and Section 3.1 of this Part are followed for the preparation and analysis of gravimetric soil organic carbon used for the spectroscopic model training and validation with the following differences:

    a) It is a requirement that preparation and analysis is undertaken on individual samples (not composite samples).

    b) It is a requirement that the soil sample corresponding to each spectrum (refer to Section 3.2.2 Requirement 1 of this Part) in the training and validation sets are prepared and analysed separately.

        Note: independent validation sets are only required during subsequent rounds of sampling.

3. If both Section 3.1 and 3.2 could apply to a sample, it is a requirement that Section 3.1 is applied for the purposes of Equation S6.

    a) Note this applies in particular to training and validation sets of soil samples used for spectroscopy but may also apply to samples for which confidence in the spectroscopic measurement is low.

3.1 Dry Combustion analysis

The following requirements and recommendations apply for the dry combustion analysis technique for measuring gravimetric soil organic carbon content, including the analysis of soil samples used to derive the spectroscopic model.

> Note: The calculations included in this Section apply to any sample of soil where dry combustion analyses are being performed (e.g. individual or composite soil samples).

Requirements:

1. It is a requirement that dry combustion analysis is undertaken on a soil sample prepared as per Section 2.1 of this Part.

2. It is a requirement that analysis of organic carbon content is undertaken by a laboratory that is certified for organic carbon analysis by the Australasian Soil and Plant Analysis Council (ASPAC).

3. It is a requirement that the method used to analyse organic carbon content is a dry combustion approach which has been certified by ASPAC (such as ASPAC code 6B2b (Total organic carbon by Dumas high-temperature combustion with no soil pretreatment) for soils that do not contain carbonate and a modified version of 6B3 (Total organic carbon by Dumas high-temperature combustion carbon with prior chemical removal of carbonates) for soils that do contain carbonate. The modification required to the 6B3 method is to not physically remove charcoal.

4. It is a requirement that the method used to analyse organic carbon content is a dry combustion approach and has been accredited, for that laboratory, by the National Association of Testing Authorities (NATA) under ISO-IEC 17025 (chemical testing).

2. Sub-sample A

Weigh and record mass of air dried soil fine fraction (less container)

3. Sub-sample A

Oven dry air dried soil fine fraction at 105°C to

4. Sub-sample A

Place oven dried soil fine fraction into a desiccator to

5. Sub-sample A

Weigh and record oven dry mass of soil fine fraction (less

6. Calculate & report gravimetric water content to 2 decimal places

(Equation S7)

1. Air dried sub-sample of the soil fine fraction (Box 5 Figure 3)

Split portions of the fine fraction for subsequent analyses (sub-sample A & sub-sample B)

7. Sub-sample B

Grind air dried soil fine fraction to ≤0.5mm

8. Sub-sample B

Carry out gravimetric organic carbon analysis of the air dried soil fine fraction as per NATA accredited dry combustion organic carbon method

9. Calculate & report gravimetric organic carbon content on the basis of an oven dry weight of soil fine fraction (Equation S8)

15. Calculate & report gravimetric soil organic carbon content on the basis of an oven dry weight of whole soil

(Equation S12)

10. Mass of air dried whole soil (Box 1. Figure

11. Mass of gravel in whole soil (Box 3a, Figure 4)

12. Calculate the oven dry mass of the soil fine fraction

13. Calculate the oven dry mass of the whole soil (Equation S10)

14. Calculate the gravimetric gravel content (Equation S11)

5. It is a requirement to adhere to the process depicted in Figure 4 to produce a value for the gravimetric soil organic carbon content expressed on the basis of a percentage of oven dry whole soil mass (i.e. g soil organic carbon/100 grams oven dry whole soil). All steps and calculations required to derive the gravimetric soil organic carbon content of a soil sample include the following:

a) Calculate the gravimetric water content of the air-dried soil fine fraction according to Equation S7.

$$GWC_{ad\_ff} = \frac{M_{ad} - M_{od}}{M_{od}}$$

Equation S7

Where:

GWC_{ad_ff} is the gravimetric water content of the air dried soil fine fraction as per Box 6 in Figure 4 (grams water/grams oven dry soil fine fraction).

M_{ad} is the mass of the air dried soil fine fraction weighed and recorded as per Box 2 in Figure 4 (grams air dry soil fine fraction).

M_{od} is the mass of the oven dried soil fine fraction weighed and recorded as per Box 5 in Figure 4 (grams oven dry soil fine fraction).

b) Calculate the gravimetric organic carbon content of the soil fine fraction expressed on an oven dry basis according to Equation S8.

$$OC_{od\_ff} = OC_{ad\_ff} \times \left(1 + GWC_{ad\_ff}\right)$$

<div align="right">

Equation S8

</div>

Where:

OC_{od_ff} is the gravimetric organic carbon content of the soil fine fraction expressed on an oven dry basis (grams organic carbon/100 grams oven dry soil fine fraction).

OC_{ad_ff} is the gravimetric organic carbon content of the air-dried fine fraction as determined by the dry combustion analysis in Box 9 of Figure 4 (grams organic carbon/100 grams of air dry soil fine fraction).

GWC_{ad_ff} is the gravimetric water content of the air-dried soil fine fraction calculated from Equation S7 (grams water/grams oven dry soil fine fraction).

c) Calculate the mass of oven dry soil fine fraction contained in the collected soil sample according to Equation S9.

$$M_{od\_ff} = \frac{M_{ws} - M_{gravel}}{\left(1 + GWC_{ad\_ff}\right)}$$

<div align="right">

Equation S9

</div>

Where:

M_{od_ff} is the oven dry mass of the soil fine fraction in the collected soil sample (grams oven dry fine fraction).

M_{ws} is the air dry mass of the whole soil measured and recorded as per Box 1, Figure 3 (grams whole soil).

M_{gravel} is the air dry mass of the gravel (>2 mm material) sieved out, weighed and recorded as per Box 3a in Figure 3 (grams gravel).

GWC_{ad_ff} is the gravimetric water content of the air dried soil fine fraction calculated from Equation S7 (grams water/grams oven dry soil fine fraction).

Note: The numerator of Equation S9 is equivalent to the total mass of air-dried fine fraction in the collected soil sample.

d) Calculate the oven dry mass of whole soil in the collected soil sample according to Equation S10.

$$M_{od\_ws} = M_{od\_ff} + M_{gravel}$$

Where:

M_{od_ws} is the oven dry mass of the whole soil in the collected soil sample as per Box 13 in Figure 4 (grams oven dry whole soil).

M_{od_ff} is the oven dry mass of the soil fine fraction calculated according to Equation S9 (grams oven dry soil fine fraction).

M_{gravel} is the air dry mass of the gravel (>2 mm material) sieved out, weighed and recorded as per Box 3a in Figure 3 (grams gravel).

e) Calculate the gravimetric gravel content in the whole soil according to Equation S11.

$$GGC_{od\_ws} = \frac{M_{gravel}}{M_{od\_ws}}$$

Where:

GGC_{od_ws} is the gravimetric gravel content in the oven dry whole soil as per Box 14 in Figure 4 (grams gravel/grams oven dry whole soil)

M_{gravel} is the air dry mass of the gravel (>2 mm material) sieved out, weighed and recorded as per Box 3a in Figure 3 (grams gravel).

M_{od_ws} is the oven dry mass of the whole soil in the collected soil sample calculated according to Equation S10 (grams oven dry whole soil).

f) Calculate the gravimetric soil carbon content of the oven dry whole soil according to Equation S12.

$$OC_{sl} = OC_{od\_ff} \times \left(1 - GGC_{od\_ws}\right)$$

Where:

OC_{sl} is the gravimetric soil organic carbon content of the oven dry whole soil as per Box 15 in Figure 4 (grams organic carbon/100 grams oven dry whole soil).

OC_{od_ff} is the organic carbon content of the soil fine fraction expressed on an oven dry basis according to Equation S8 (grams organic carbon/100 grams oven dry soil fine fraction).

GGC_{od_ws} is the gravimetric gravel content in the whole soil according to Equation S11 (grams gravel/grams oven dry whole soil).

6. If the laboratory undertaking the dry combustion analyses reports a value of organic carbon content in either of the following units, rather than the mass of air dried fine fraction (OC_{ad_ff}), the following applies:

    a) oven dried fine fraction OC_{od_ff} , substitutes for the result of Equation S8 and results of Equation S7 need not be applied for the purpose of Equation S8.

    b) oven dried whole soil (OC_{sl}), substitutes for the result of Equation S12 and results of Equation S7 need not be applied for the purpose of Equations S7-S12. Equations S9 and S10 may still need to be calculated for the purposes of Section 4.0 of this Part.

3.2 Spectroscopic modelling

The practices described below provide standardised methods and guidance for recording of visible and infrared spectra of soil samples with spectrometers, multivariate modelling, validation and spectroscopic estimation of the gravimetric soil organic carbon content in a sublayer (OC_{sl}).

The practices apply to analyses conducted within the visible (vis: 400–700 nm), near-infrared (NIR: 700–2500 nm) and mid-infrared (MIR: 2500–25,000 nm) regions of the electromagnetic spectrum, with wavelengths ranging from 400 to 25,000 nm (equivalent to 25,000–400cm^{-1}).

The practices describe the spectrometers and procedures for recording soil spectra, the measurement of the reference soil organic carbon content data, the development of multivariate spectroscopic models, the validation of the spectroscopic models, the assessment of model performance and the estimation of OC_{sl}. The instructions cover techniques that are routinely applied in quantitative soil spectroscopy using coarsely ground or finely ground soil and intact soil cores.

Note that the gravimetric concentration of organic carbon determined for the sub-layer (%, g organic carbon/100 g oven dry whole soil) for the purposes of equation S6, for samples collected prior to 3 December 2021 are deemed to satisfy this section if they also satisfied s3.2 of the *Supplement to the Carbon Credits (Carbon Farming Initiative— Measurement of Soil Carbon Sequestration in Agricultural Systems) Methodology Determination 2018*.

3.2.1 The spectrometer

Requirements:

1. It is a requirement that the spectrometer used, is able to measure spectra from within the following wavelength range:

    a) 400–25,000 nm, which encompasses the visible, near-infrared and mid-infrared regions of the electromagnetic spectrum

2. It is a requirement that spectrometers be operated in accordance with manufacturers' instructions (notwithstanding any requirements in this Supplement).

3. It is a requirement that the spectral resolution of the spectrometer(s) is recorded and reported.

4. It is a requirement that, as well as the spectrometer's resolution (as in Requirement 1 of this Part), the wavelength/wavenumber interval in the spectra (i.e. the spacing between wavelengths/wavenumbers of the spectra) used for the spectroscopic modelling be at least:

a) 10 nm for the vis–NIR or NIR

b) 16cm^{-1} for the mid-IR

5. It is a requirement that the spectrometer calibration is performed following instructions and practices recommended by the spectrometer manufacturer or using peer-reviewed published protocols and standard materials, for example:

a) For vis–NIR, Spectralon Diffuse Reflectance Standards (https://www.labsphere.com/)

b) For mid-IR, gold, silicon carbide (SiC) standards

6. It is a requirement that the spectrometer control parameters be maintained for the collection of all spectra of soil samples in the project within and between sampling rounds.

7. It is a requirement that if the calibration configuration uses an external standard (as per Requirement 5 of this Section) that the same configuration is used for the soil sample measurements within and between sampling rounds.

8. It is a requirement to ensure that the spectrum of the reference background represents 100% reflection at all wavelengths across the particular spectral range, with no more than 5% noise. Often noise is present towards the edges of the sensor's response and towards the extreme of the wavelength range. If the reference spectrum shows noise that exceeds this threshold, check the setup, clean the reference standard material (following manufacturer's instructions) and repeat the calibration. If it persists, check with the instrument manufacturer for repair.

9. It is a requirement that the spectrometer be calibrated

a) For vis–NIR every 10 minutes or once every 30 sub-samples if sequentially measuring many samples in blocks of time.

b) For mid-IR once per hour or once per measurement plate, depending on the setup

Recommendations:

1. Most instruments include the necessary accessories to perform the spectroscopic measurements. It is recommended that proponents use these accessories following manufacturers' guidelines, or with reference to the guidelines provided by the peer reviewed scientific literature (e.g. for vis–NIR spectra, those provided by the global spectral library project (Appendix B in Viscarra Rossel et al., 2016a)).

2. It is recommended that the spectrometer control parameters be set to:

a) For vis–NIR and NIR: record and average ≥30 readings, or a sufficient acquisition time recommended by the spectrometer's manufacturer, per soil sample, and ≥50 readings, or a sufficient acquisition time recommended by the spectrometer's manufacturer, per calibration with the standard reference material (Requirement 5 of this Section).

b) For mid-IR: record and average ≥64 readings per soil sample and ≥64 readings per calibration with the standard reference material (Requirement 5 of this Section).

3. It is recommended that instrument performance is tested as per manufacturers' recommendations and instructions at the time of instrument calibration.

4. It is recommended that the instruments are monitored on a periodic (6 monthly basis) following either:

a) the instrument manufacturer's recommendations and instructions or

b) a relevant approach published in scientific peer reviewed literature.

5. It is recommended that the same spectrometer be used for the baseline and subsequent rounds of sampling (projects using schedule 1) and for first and subsequent estimation events (projects using schedule 2). If a different spectrometer is used in subsequent rounds of sampling or estimation events, it is recommended that the spectra be measured by following strictly the same protocols and that spectral pre-processing algorithms (e.g. first derivatives) or calibration transfer methods (Fearn, 2001), such as direct standardisation or piecewise direct standardisation be used to address the differences in the spectra.

3.2.2 Spectroscopic measurements

Requirements:

1. It is a requirement that the spectra are recorded from soil samples prepared in one of the following ways:

   a) any surface (external or internal) of intact soil cores (air-dry or at field condition), for the sublayer (see Requirement 3 of this Section) prepared as per Section 2.2 of this Part; or

   b) homogenised soil (from the sub-layer) that was dried, crushed, ground and sieved (as per Section 2.1 of this Part). For vis–NIR the samples are ground to pass a ≤2mm sieve and for mid-IR the samples are ground to pass at least a ≤0.5 mm mesh sieve, or finer.

2. It is a requirement that the soil samples used in the spectroscopic analysis are prepared in the same manner (as in Requirement 1 of this Section) for the baseline and all subsequent sampling rounds or the first and subsequent estimation events.

3. If Requirement 1 Option a of this Section is chosen, it is a requirement that spectra are recorded at intervals of:

   a) no more than 5cm intervals between spectral measurement within the sublayer; and

   b) no less than 1cm intervals between spectra from the soil surface to the desired depth.

4. It is a requirement to use Requirement 1 Option b of this Section if the instrument is a mid-IR spectrometer.

5. It is a requirement that the spectra of all of the soil samples in a project or CEA are recorded with the same spectrometer within a sampling round or estimation event.

6. It is a requirement that the spectra of soil samples between sampling rounds or estimation events are measured with either the same spectrometer, or one that has at least the same spectral range.

7. It is a requirement that if after identification and verification of spectral outliers, they are removed, their sample numbers are recorded and saved for reporting.

Recommendations:

1. It is recommended that if Requirement 1 Option a. of this Section is chosen, the (internal or external) surface of the soil core is inspected prior to measurements to check for smearing of the soil surface, in which case, the soil surface should be 'brushed' with a bristle brush only to remove the smearing and to expose the true soil.

2. It is recommended that if Requirement 1 Option a. of this Section is chosen, the (internal or external) surface of the soil core is inspected prior to measurements to check the presence of plant roots, rocks, cracks and voids, in which case, measurements should be made only on the true soil.

3. It is recommended that spectral outliers are identified from the full set of CEA or project spectra, using published algorithms in the scientific literature (Martens H & Næs T, 1989).

4. It is recommended that if spectral outliers are identified, the soil samples are remeasured with the spectrometer for verification.

5. If after verification spectral outliers are present, it is recommended that they be removed from the acquired set of project or CEA spectra before selection of training sets in Section 3.2.3.1 of this part.

3.2.3 Data for the spectroscopic modelling and validation

Once the soil is sampled, all of the soil samples must be measured with the spectrometer as in Section 3.2.2 of this Part. From all of the project or CEA spectra, a training set of soil samples need to be identified independently of each other. Once the training set is selected, the remaining CEA spectra are called the prediction set. The soil samples of the training set need to be analysed to determine their gravimetric soil organic carbon content using the dry combustion analytical method described Section 3.1 of this Part.

The *training set* is used to develop the spectroscopic model by applying multivariate mathematics to calibrate the measured gravimetric soil organic carbon concentration derived from the combustion analysis of the same samples, with the spectra. After the optimal model parameters are selected, usually by optimisation, the model must be validated using k-fold cross-validation to estimate how the model might perform in general when used to make predictions on data not used during the training of the model, i.e. on the prediction set.

The *prediction set* refers to the spectra of the remaining soil samples (after selection of the training set) in the project or CEA. The trained model is used to estimate the total organic carbon concentration of *the prediction set.*

3.2.3.1 Selection of the training set

The number of spectra that are required to develop the spectroscopic model depends on the complexity and variability of the soil in the project or CEA.

Requirements:

1. It is a requirement that, once all of the spectra have been recorded from all of the soil samples collected from the project or CEA in a single sampling round (as in requirement 5 of Section 3.2.2 of this Part), a training set consisting of a minimum of 50 spectra (from at least 50 sub-layers across multiple cores) is selected using a peer-reviewed method that selects a representative subset of spectra useful for

deriving a spectroscopic calibration. Some of these methods might include algorithms such as the Kennard-Stone (Kennard & Stone, 1969), Select (Shenk & Westerhaus 1991), conditioned Latin Hypercube sampling (Ramirez-Lopez et al., 2014).

2. It is a requirement that the published method chosen in Requirement 1 of this Section ensures that the training set contains a subset of representative spectra that characterise the entire range of all of the project or CEA spectra that are to be used in the spectroscopic modelling.

3. It is a requirement that the training set is clearly identified in the sampling plan and reported.

4. It is a requirement that the soil samples that correspond to the selected training set spectra are sent to the laboratory for gravimetric soil organic carbon content analysis as per the requirements in Section 3.2.4 of this Part.

Recommendations:

1. It is recommended that as the complexity and variability of the soil in the project or CEA increases, the number of soil samples in the training set should also increase.

2. It is recommended that proponents should opt for using more (rather than less) soil samples in the training set for the spectroscopic modelling.

3.2.3.2 The prediction set

Requirements:

1. It is a requirement that after the training set has been taken for the spectroscopic modelling, the remaining spectra are identified and reported as the *prediction* set.

3.2.4 Determining the total organic carbon content of the soil samples with the reference analytical method used in the spectroscopic modelling

Requirements:

1. It is a requirement that for each spectrum in the training set, the corresponding soil sample be analysed to determine the gravimetric soil organic carbon content using the reference analytical method.

2. It is a requirement that the soil samples in the training set are prepared and analysed following Sections 2.1 and 3.1 of this part.

3. It is a requirement, if Requirement 1 Option a of Section 3.2.2 of this Part is chosen, that for a given spectrum, the corresponding soil sample from the different sublayers of the soil cores analysed using the reference analytical approach is:

   a) at least the width of the spectrometer measurement spot size (width of orange band in Figure 5); and

   b) at most the distance of halfway between the locations where two adjacent spectra were recorded, to halfway between the locations where the next two spectra were recorded (distance between two dotted lines in Figure 5).
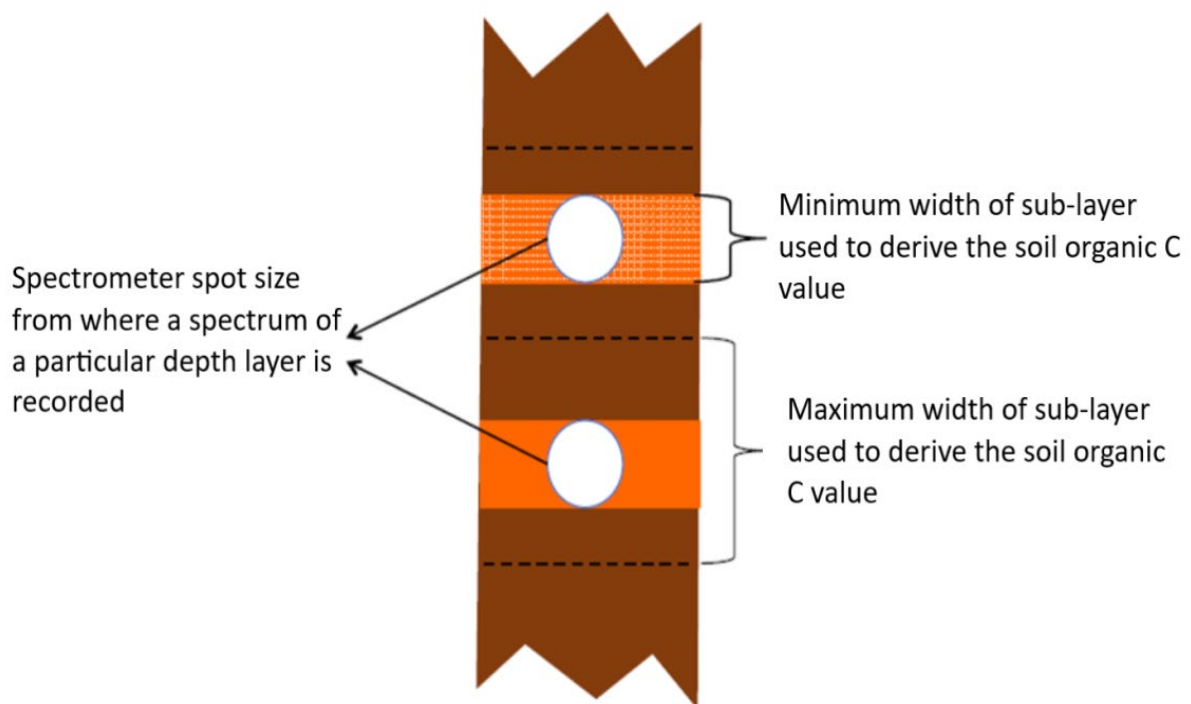
Figure 5. A soil core showing the spot size from where a spectrum of a particular depth layer is recorded, and the minimum and maximum width of the soil core sub-layers that are cut, crushed, sieved and sent to the analytical laboratory to measure the soil organic carbon content.

4. It is a requirement, if Requirement 1 Option b of Section 3.2.2 is chosen, that for a given spectrum, the soil sample analysed using the reference analytical approach is prepared and analysed following Sections 2.1 and 3.1.

5. It is a requirement that if Requirement 1 Option b of Section 3.2.2 is chosen, both the spectroscopic and the reference analytical measurements be made on the same prepared (air-dry, crushed, sieved, ground) soil sample.

6. It is a requirement that the composition of the soil samples taken for spectroscopic measurements and for reference laboratory analyses be representative of the soil at the time the samples are taken, and that the composition is maintained during transport for preparation and analysis in the laboratory.

3.2.4.1 Accuracy of reference analytical approach

The accuracy of the spectroscopic estimate of organic carbon content is dependent on the accuracy of the reference analysis values used for training and validating the spectroscopic model.

Requirements:

1. It is a requirement that all total soil organic carbon concentrations are expressed on the basis of the mass of oven dry whole soil (Part D, Section 1.3).

Recommendations:

1. It is recommended that a minimum of five sub-samples (from the training set) are selected at random and sent to the laboratory as 'blind duplicates' for assessment of accuracy of the reference analysis values, using a measure of the standard error of laboratory measurements (SEL). The accuracy of the spectroscopic method will be limited by that of the reference analytical method, as such, the accuracy of the spectroscopic estimate can never exceed the accuracy of the reference method.

2. It is recommended that if the SEL of the blind duplicates is larger than the analytical error reported by the laboratory that proponents contact the laboratory and ask for the samples to be re-analysed.

3.2.5 Developing the spectroscopic model

The procedures described are for site-specific (or local) multivariate spectroscopic modelling performed with the spectra of soil samples from only the particular project area or CEA. However, if proponents have access to a larger spectral library with a wider range of soil types and from different areas (e.g. other projects), and through experimentation they find that they can improve their modelling, they may combine their site-specific data with data from the larger spectral library.

The inaccuracy of the models can be assessed using k-fold cross validation and by calculating the root means squared error (RMSE) and Lin's concordance correlation (ρ_{Lin}). Inaccuracy, as measured by the RMSE, encompasses both bias, measured by the mean error (ME) and imprecision, measured by the standard deviation of the error (SDE)---see Part J: Glossary for the equations.

3.2.5.1 Preparing the data for modelling

Requirements:

1. It is a requirement that once the gravimetric soil organic carbon concentrations of the training set are returned from the laboratory, the results are reported in 3.2.3.1 and matched with their corresponding spectra to develop the spectroscopic model.

Recommendations:

1. If proponents have a larger spectral library with a wider range of soil types and from different environments, they may use it to augment their project- or CEA-specific training data set (see Section 3.2.3.1 of this Part) to develop a spectroscopic model with the combined data. It is recommended that they only do this if the additional data complements the local set and improves the accuracy of the models when assessed by k-fold cross-validation.

3.2.5.2 Spectral transformations, pre-processing and pre-treatments

Various algorithms can be applied to the spectra prior to the development of the multivariate spectroscopic model to remove random noise, remove undesired spectral variations due to light scatter effects and variations in effective path length during measurements.

Requirements:

1. It is a requirement that any implemented spectral transformations, pre-processing and/or pre-treatments, are applied consistently to all the training set spectra and prediction set spectra from within the project or CEA, and that these are reported.

Recommendations:

1. It is recommended that the effects of random noise, undesired spectral variations due to light scatter effects and variations in effective path length during measurement are corrected by testing different spectral transformations, pre-processing and pre-treatments that are reported in peer-reviewed scientific literature. This might result in an improvement of the signal-to-noise ratio.

2. It is recommended that different spectral transformations, pre-processing and pre-treatment algorithms reported in peer-reviewed scientific literature are tested and applied to the spectra prior to development of the multivariate spectroscopic model to test which, if any, will most effectively achieve Recommendation 1 of this Section.

3. Most spectroscopic software packages (see Section 3.2.7 of this Part) will enable the implementation of these techniques. These could include but are not limited to:

    a) Transformation of reflectance (R) spectra to apparent absorbance (A), where A = Log(1/R);

    b) Spectral pre-processing to test can include the multiplicative scatter correction (MSC) (Geladi, McDougel & Martens 1985), standard normal variate (SNV) (Barnes, Dhanoa & Lister, 1989), digital filters to smooth the spectra such as mean or median filters, moving average, the Savitsky-Golay filter (Savitzky & Golay, 1964), first and second derivatives, or other methods that are published in the peer-reviewed scientific literature;

    c) Pre-treatment includes mean centering the spectra, which involves calculating the arithmetic mean spectrum of the data set and subtract that mean from each spectrum. The result is that the mean centred spectra will have a mean of zero.

3.2.5.3 Corrections for the effects of field conditions on spectra

This Section only contains recommendations.

Recommendations:

1. It is recommended that if the spectroscopic model was derived with spectra measured in the laboratory, but the estimation is to be done using soil spectra that are recorded under field condition, the latter are corrected for water using a method that has been tested and verified by publication in scientific peer-reviewed literature (e.g. External Parameter Orthogonalisation (EPO) (Minasny et al., 2011), or direct standardization (DS) or piecewise direct standardisation (PDS) (Ji, et al., 2015a, b) if:

    a) the spectroscopic measurements are made on soil cores or homogenised and ground soil from soils that are wetter than their air-dry condition; or

    b) a larger spectral library was used to augment the site-specific data for the modelling.

2. It is recommended that the transformation matrix, or transfer set, to make the corrections for water using either EPO or DS are made on a site-specific basis.

3.2.5.4 Statistical transformation of the reference analytical data

Requirements:

1. It is a requirement that any transformation to the statistical distribution of the measured gravimetric soil organic carbon data for the training set is also applied to the prediction set and reported.

2. If the modelling is performed on transformed data, it is a requirement that the predictions of the gravimetric soil organic carbon are back transformed to the original units for subsequent calculations and reporting.

Recommendations:

1. It is recommended that the organic carbon concentration data be transformed to approximate normal distribution before modelling, if its statistical distribution is (positively) skewed and the algorithm used for modelling assumes normally distributed data and residuals. For example, the data may be transformed (e.g. using square root or logarithmic transformations), depending on the data and the degree of transformation required.

3.2.5.5 Calculating the multivariate spectroscopic model

The spectroscopic modelling relates the gravimetric soil organic carbon concentration values to the spectra measured on the training set and optimises (see Section 3.2.5.8 of this Part) and validates the model using k-fold cross validation (see Section 3.2.5.9 of this part). Development of the optimised and validated spectroscopic model allows estimation of the gravimetric soil organic carbon concentrations in the prediction set.

Requirements:

1. It is a requirement that the spectroscopic model is derived using methods and algorithms that have been tested and verified for soil spectroscopic modelling by publication in scientific peer-reviewed literature.

2. It is a requirement that the peer-reviewed technique used:

    a) follows best practice as indicated in the publication(s) that describe the algorithm and its implementation, and the software being used; and

    b) ensures the data used in the model does not violate the statistical assumptions of the model; and

    c) is capable of producing a model that can be validated as described in Section 3.2.5.9 of this Part, below.

3. It is a requirement that the methods and algorithms used (in Requirements 1 and 2 of this Section) are reported.

Recommendations:

1. It is recommended that partial least squares regression (PLSR) (Martens & Næs, 1989) is tested for the spectroscopic modelling before testing other methods reported in the peer-reviewed literature for example, support vector machines (SVM), regression trees (RT), Cubist, random forest (RF), neural networks (e.g. Viscarra Rossel & Behrens, 2010).

3.2.5.6 Model diagnosis

Requirements:

1. It is a requirement to diagnose the spectroscopic model and departures from the statistical assumptions of the model being used by calculating the residuals of each specimen in the training set (model residuals = observed – estimated) and deriving a plot of these residuals on the y-axis and the estimated soil organic carbon on the x-axis.

2. It is a requirement to report the plot of residuals vs soil organic carbon. If all assumptions about the model are correct, then the model has a good diagnosis and a plot of residuals against the estimated values should show a horizontal band as illustrated in Figure 6(a). Deviations from this, for example as illustrated in Figure 6(b), indicate dependence on the predicted value, suggesting incorrect numerical calculations or that an intercept term has been omitted from the model. If the pattern of residuals is like those in Figure 6(c), it indicates that the variance is non-constant (or heteroscedastic) and increases with each increment of the predicted value. The pattern of residuals in Figure 6(d) indicates non-linear trends in the data, indicating the need for transformation or curvilinear modelling methods.
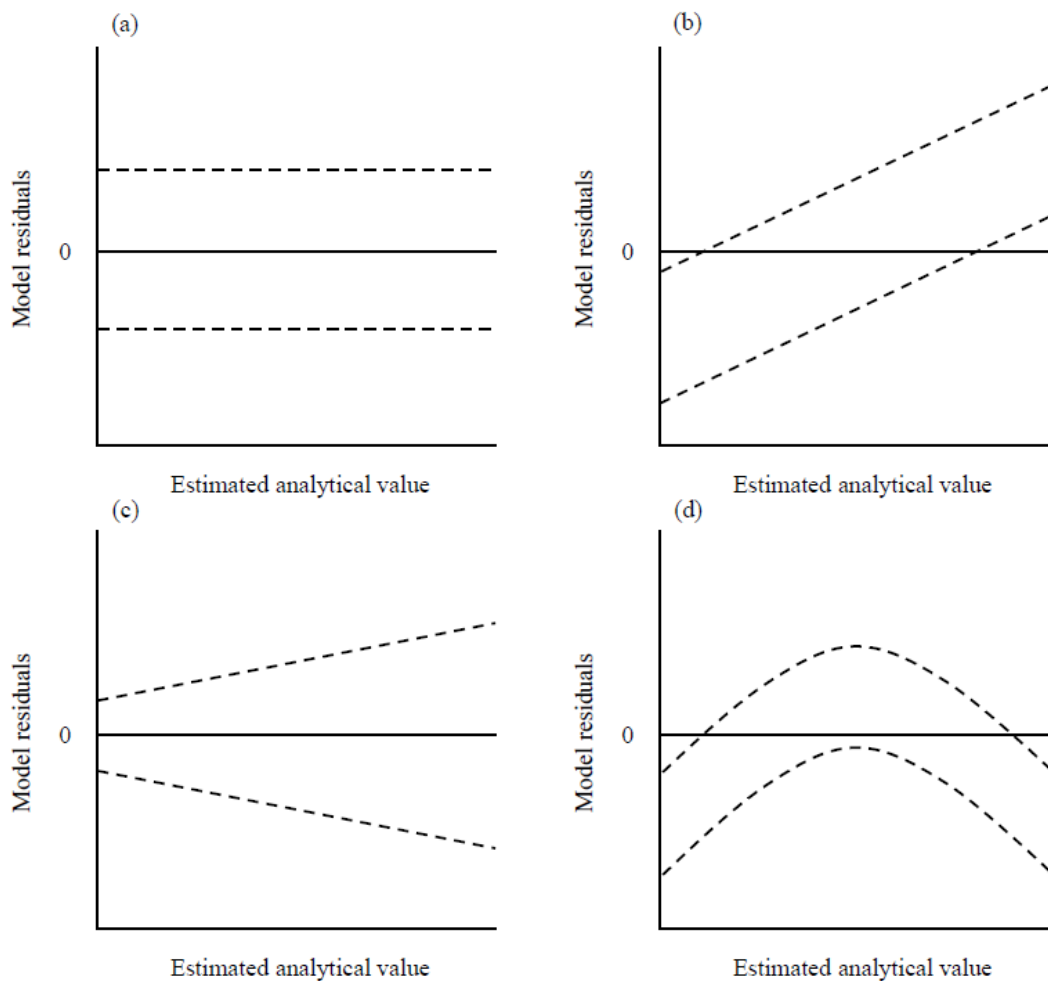
Figure 6: Possible residual plots for model diagnosis. Residuals can be located anywhere between the dashed lines. Adapted from Kalivas & Gemperline (2006)

Recommendations:

1. If the pattern of residuals is like those in Figure 6(c), which indicates that the variance is non-constant (or heteroscedastic) and increases with each increment of the predicted value, it is recommended that the statistical distribution of the soil organic carbon data be transformed as in Section 3.2.5.4 of this Part.

2. It is recommended that the residuals plot in Figure 6(a) be used to help with the identification of outliers. For instance, outliers might fall outside two standard deviations from the mean of the residuals. However, omission of outliers must be performed following the requirements in Section 3.2.5.7 of this Part.

3.2.5.7 Identification and omission of reference analytical (dry combustion) outliers

Requirements:

1. It is a requirement to identify analytical reference data (dry combustion as per Section 3.1 of this Part) outliers in the training set using methods that have been tested and verified by publication in the

scientific literature (Martens & Næs, 1989), for example using studentized residuals (Cook & Weisberg, 1982), and to report on the method used.

2. If analytical outliers are identified, it is a requirement to report the total number of identified and omitted outliers with their sample identification numbers. The reference analytical value will be used as per section 3.1 of this method but the data need not contribute to the training set (noting minimum spectra numbers must be maintained).

Recommendations:

1. It is recommended to look for outliers where:

   a) analytical values represent an extreme concentration (i.e. either very large or very small carbon concentration) relative to the remainder of the training set (these data will have a very large leverage on the model); and

   b) samples' estimated values are significantly different to the reference analytical values. This indicates either an error in the reference analytical value, a sample mislabelling issue, or failure of the model.

3.2.5.8 Optimising and assessing the model

Optimisation of the algorithm used for the spectroscopic modelling is important to prevent the model from under fitting or over fitting. Different methods will have different hyperparameters to optimise. For example, PLSR requires optimising the number of latent variables to use, or using other machine learning methods. It could be the number of trees, committees, nodes, basis functions, or another method-specific parameter. There are various methods used for hyperparameter optimisation, e.g. grid search and random search, however other more complex methods such as Bayesian or evolutionary optimisation methods do exist.

Requirements:

1. It is a requirement that the optimization of the spectroscopic model is performed using a method reported in the peer-reviewed scientific literature and that this method is reported. The most common methods are grid search and random search. Grid search refers to an exhaustive search through a user defined set of hyperparameters, while random search selects, at random, combinations of hyperparameters to test.

2. It is a requirement to report the values of the optimized model parameters.

3. It is a requirement that the skill of the optimised model is assessed using the root mean squared error (RMSE) and following the requirements in Sections 3.2.5.10 of this Part.

3.2.5.9 Validation of the spectroscopic model

Validation of the optimised spectroscopic model by k-fold cross-validation enables assessment of the skill of the model. The k-fold cross validation method results in a less biased and less 'optimistic' estimates of the model skill than other methods, such as a simple train/test split. A value of k = 5 or k= 10 is commonly chosen, but there is no formal rule. Larger values of k will produce less biased estimates at the expense of having higher variance. A value of k = 10 has been found to generally result in a model skill estimate with relatively low bias a modest variance.

Requirements:

1. It is a requirement that the spectroscopic model derived using the training data set is validated using k-fold cross validation and that the k value used is reported.

2. It is a requirement that leave-one-out cross validation (i.e., k = n, where n is the number of samples in the dataset) is not used.

3.2.5.10 Assessing the accuracy of the model.

Requirements:

1. It is a requirement that the cross-validation estimates are compared statistically to the values obtained by the reference analytical method.

2. It is a requirement to assess and report the accuracy, precision and bias of the model, which can be measured by the root mean squared error (RMSE), the standard deviation of the error (SDE), and the mean error (ME) respectively.

3. It is a requirement to also assess and report Lin's concordance correlation (ρ_{Lin}) and the coefficient of determination (R^2).

4. There is support for a general rule that overall soil variation influences the accuracy of the predictions (Stenberg et al., 2010). Thus, it is a requirement that the RMSE value be reported together with the mean and standard deviation of the gravimetric soil organic carbon content data of the training data set.

5. If Lin's concordance correlation, is below 0.60 ($\rho_{Lin} < 0.60$), then it is a requirement that estimation of gravimetric soil organic carbon content is not conducted using spectroscopy and that proponents revert back to the process outlined in Part D Section 3.1 without the use of Part D Section 3.2.

6. It is a requirement that the bias of the model, measured by the ME, is zero (the spectroscopic models may need to be adjusted for bias to achieve this).

Recommendations:

1. It is recommended that the model cross-validation assessment statistics values (as in Section 3.2.5.9) be compared to those reported in the peer reviewed-scientific literature for data that has a similar statistical distribution: similar mean and standard deviation. For example, Viscarra Rossel et. al, (2016a) reports that the RMSE of field- and farm-scale estimates of the gravimetric soil organic carbon content, using vis–NIR spectra, range from 0.1–0.6%, with the median being 0.3% gravimetric soil organic carbon content.

2. It is recommended that the following graphs are used to understand the relationships between the RMSE, ρ_{Lin} and the R^2.
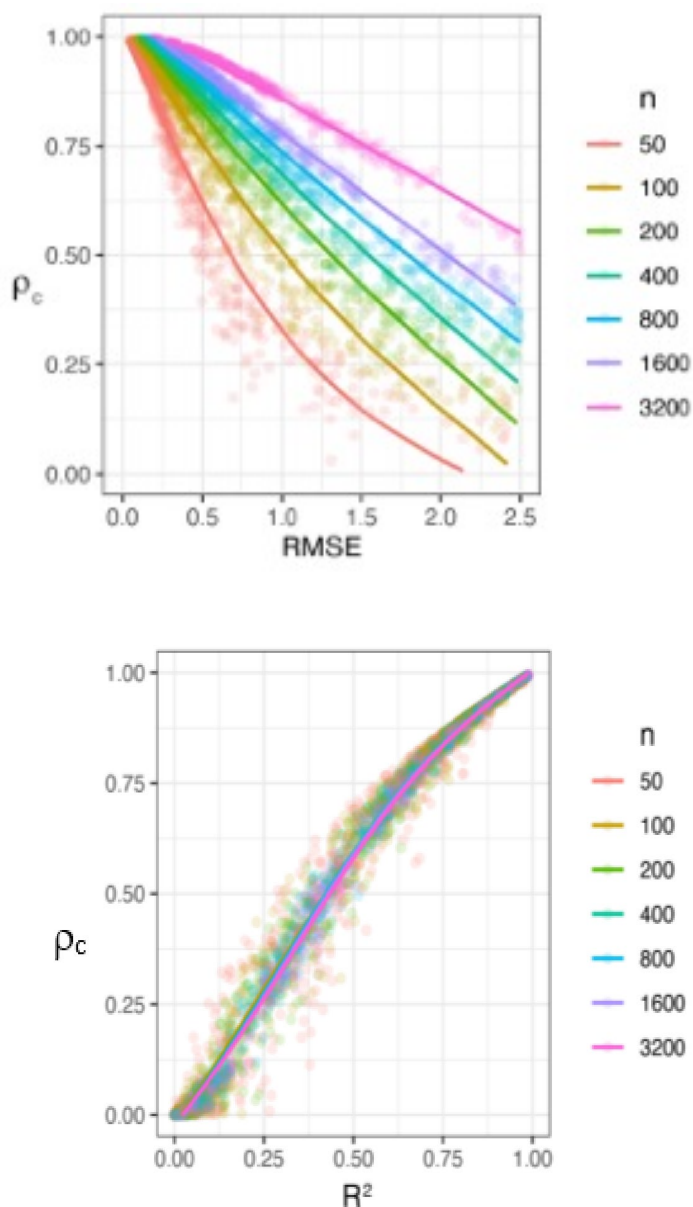
Figure 7: Relationship between Lin's concordance correlation (ρ_{Lin} / ρ_c), the RMSE and the coefficient of determination (R2), where n represents the number of samples from layers across multiple cores. As n increases so does the mean soil organic carbon content.

3.2.5.11 Using the spectroscopic model to estimate the soil organic carbon content of the prediction set

Requirements:

1. It is a requirement that if the spectra of the training set were transformed, pre-processed and/or pre-treated, as in Section 3.2.5.2, all of the remaining spectra in the prediction set be transformed, pre-processed and/or pre-treated in exactly the same manner.

2. It is a requirement that the spectroscopic model that was optimised (see Section 3.2.5.8) and cross-validated (see Section 3.2.5.9) is applied to all of the spectra in the prediction set, to estimate the soil organic carbon concentration of those samples.

3. It is a requirement that if the model was developed on the logarithmic scale, that the estimates of the prediction set be back-transformed, provided Requirement 1 is complied with, to the original scale using:

$$\hat{y} = e^{\left(\hat{\psi} + \frac{\frac{1}{N}\sum_{i=1}^{N}(\hat{\psi}_i - \psi_i)^2}{2}\right)}$$

Equation S13

Where:

$\hat{y}$ = the back-transformed data

$\hat{\psi}$ = the estimates of the soil organic C

ψ = the observed values, for each sample

$_i$ = both on the logarithmic scale, and the numerator in the exponent represents the mean squared error (MSE) of the model, or the MSE of the independent validation set.

4. It is a requirement that the spectroscopic model be used to estimate the gravimetric soil organic carbon content of all of the project or CEA spectra, which includes the training set and the prediction set. This will ensure that all observations in the training prediction sets have the same measurement error.

3.2.6 Estimation of soil organic carbon in subsequent sampling rounds after the baseline

The requirements and recommendations in Sections 3.2.1 to 3.2.5 pertain to the measurement and modelling of soil carbon with spectroscopy and generally apply to the baseline sampling round or first estimation event and to subsequent sampling rounds. Additional requirements and recommendations for spectroscopic measurements and modelling in subsequent sampling rounds are given in this Part.

Requirements:

1. It is a requirement that, once soil sampling has been performed in a sampling round (after the baseline sampling round), all of the spectra from the project or CEA are recorded as in Section 3.2.2 of this Part.

2. It is a requirement that a subset of the soils with corresponding spectra are selected by random sampling for validating the spectroscopic model estimates of soil organic carbon as follows:

    a) If the modelling is performed on a CEA basis, it is a requirement that the validation set consists of a minimum of 20 soil samples with spectra, from the different sublayers of the soil cores.

    b) If the modelling is performed on a project basis, it is a requirement that the validation set consists of a minimum number of soil samples with spectra from each CEA being:

        i)   A minimum of 1, if the project has 20 or more CEAs

        ii) A minimum of 2, if the project has less than 20 but more than 5 CEAs; and

iii) A minimum of 5, if the project has between 2 and 5 CEAs.

This subset represents an independent validation set.

3. It is a requirement that the validation set is clearly identified in the offsets reports, and the process for sample selection is outlined in the sampling plan (noting that sampling locations may not be allocated at this time).

4. It is a requirement that for each spectrum in this validation set, the corresponding soil sample be analysed to determine the gravimetric soil organic carbon content using the reference analytical method, as in Section 3.2.4 of this Part and that these values are reported.

5. It is a requirement that any implemented spectral transformations, pre-processing and pre-treatments as in Sections 3.2.5.2–3.2.5.3 of this Part, are applied consistently to all of the spectra in Requirement 1 of this Section.

6. It is a requirement that the spectroscopic model to estimate the gravimetric soil organic carbon content of the samples in Requirement 1 of this Section which include the validation set is either:

   a) A spectroscopic model derived (following Section 3.2.5) that uses the same training set as in the baseline or first estimation event, or previous sampling round but with a minimum of 10 additional soil samples with spectra from the different sublayers of the soil cores collected in the current sampling round to account for any possible change in the range and composition of the soil organic carbon in the project or CEA. The selection of these samples should be as per Section 3.2.3.1; or

   b) A spectroscopic model as in (a) of this Requirement, but with a different (newer) algorithm.

7. It is a requirement that the spectroscopic model in Requirement 6 of this Section is developed as per Section 3.2.5.

8. It is a requirement that the accuracy of the estimates on the validation set be assessed as described in Sections 3.2.5.9 and 3.2.5.10 of this Part. If the validation statistics are less accurate than required under Section 3.2.5.10 it is a requirement to return to section 3.2.3.1 of this Part and select an additional set of training samples to augment the training set and proceed the development of the spectroscopic model for the new round as described in Section 3.2.5 of this Part.

3.2.7 Workflow and Software

Requirements:

1. It is a requirement that, using this document and the procedures outlined in Sections 3.2.1 to 3.2.6 of this Part, proponents develop a workflow to perform the spectroscopic measurements, modelling and estimation and that this workflow is reported.

Recommendations:

1. It is recommended that proponents use one of the software platforms that were specifically developed for spectroscopic data analysis, modelling and estimation. There are several stand-alone commercial and shareware software with point-and-click graphical user interfaces:

   a) Unscrambler - https://www.aspentech.com/en/acquisition/camo-analytics

b) GramsAI - https://www.thermofisher.com/order/catalog/product/INF-15000

c) ParLeS - http://www.sciencedirect.com/science/article/pii/S0169743907001347

As well as these, there are more general statistical software, some of which are programmable and with specific modules for spectroscopic data analysis and modelling:

d) JMP - https://www.jmp.com/

e) Matlab - https://au.mathworks.com

f) R - https://www.r-project.org

3.2.8 Troubleshooting – sources of error

This section contains only recommendations.

Recommendations:

1. It is recommended that proponents use Table 1 as a source of information and possible solutions for general sources of error in the spectroscopic measurements and multivariate modelling.

Table 1: General sources of error

Source of error	Possible solution
Poor spectrometer performance	Conduct instrument performance tests as per manufacturer's instructions and section 3.2.1 of this Part.
Spectroscopic calibration standard is dirty	Clean the calibration standard following the manufacturer's instructions.
Chemical and physical variation of soil sample with time	Perform measurements soon after sample collection and ensure appropriate storage of the air-dry soil sample.
Spectroscopy insensitive to property being modelled	Try different spectral range (e.g. mid-IR) or defer back to reference analytical technique.
Inadequate population in training set	Review criteria and method for selection of training set. Test an alternative method for the selection.
Outliers degrade the training model	Employ robust outlier detection methods and omit outlying data, or alternatively remeasure the soil sample for verification.
Reference analytical data errors	Analyse additional blind duplicate samples to test the 'true' error of the laboratory.
Poor model	Check model cross validation statistics and compare with independent validation statistics – they should be similar. Check that independent validation set is representative of the population.

Errors in the multivariate analysis	Prepare a logical workflow that is checked by someone with experience in the use of the methods and software.

4.0 Soil bulk density

Requirements:

1. It is a requirement that bulk density is determined following either Section 4.1 or 4.2 of this Part.

2. It is a requirement that all sublayers in a soil core (or composite sample) must be treated identically in this respect.

4.1 Soil bulk density using conventional laboratory approach

Requirements:

1. It is a requirement to use Equation S14 to calculate the volume of soil collected for each soil depth sub-layer on which gravimetric soil carbon analysis was completed.

$$V_{sl} = \Sigma_i^n \left(t_{a_i} \times A_{CS_i} \right)$$

Equation S14

Where:

V_{sl} is the volume of soil collected for the sub-layer (cm3).

t_{a_i} is the actual thickness of the soil sub-layer collected from soil sampling location i (cm).

A_{CS_i} is the area of the cutting surface of the core tube used to collect the soil sub-layer from soil sampling location i (cm^2).

i is the identifier for each soil sampling location used to derive the collected soil sub-layer (unit less).

n is the number of soil sampling locations from which soil was combined to produce the soil sub-layer sample. Where soil was collected from a single location, n=1. Where soil from multiple locations are combined to produce a composite sample, n≥2.

2. It is a requirement to calculate the bulk density of the soil in the sampled soil sub-layer in accordance with Equation S15.

$$BD_{sl} = \frac{M_{od\_ws}}{V_{sl}}$$

Equation S15

Where:

BD_{sl} is the bulk density of the soil in the sampled soil sub-layer (g oven dry whole soil/cm3 whole soil).

M_{od_ws} is the oven dry mass of the whole soil collected for the sampled sub-layer as per Equation S10 and its dependencies as well as Box 13 in Figure 4 (g oven dry whole soil).

V_{sl} is the volume of soil collected for the sampled soil sub-layer (cm3 whole soil) calculated using Equation S14.

4.2 Soil bulk density using Gamma-ray attenuation sensing

The practices below provide a guide for the standardised methods of measuring soil bulk density using gamma-ray attenuation axially through a cylindrical soil core sample. The practices describe the instrumentation and procedures for measuring and collecting data. The theory and principle of the measurements can be found elsewhere (Lobsey & Viscarra Rossel, 2016).

4.2.1 The densitometer

Requirements:

1. It is a requirement that the gamma-ray attenuation instrument consists of a radioactive source, a scintillation detector, and a data logger.

2. It is a requirement that the activity of the radioactive source be selected to measure soil core samples with densities ranging from 0.5–2.65 g/cm^3.

3. It is a requirement that the purchase and operation of the radioactive source follow guidelines and requirements set by the relevant State and Territory regulatory bodies or the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA).

4. It is a requirement that the instrument is operated in accordance with the instructions of the instrument manufacturer.

Recommendations:

1. It is recommended that the radioactive energy source is a 137Cs with an activity of 185MBq and a peak gamma energy of 0.662MeV.

2. It is recommended that the scintillation detector be a NaI scintillation crystal of 25-mm diameter and 25-mm length.

3. It is recommended that instrument performance and decay of the radioactive source be tested regularly or as per manufacturer's instructions.

4.2.2 Setting up the densitometer

Requirements:

1. It is a requirement that the gamma ray source and detector are mounted and aligned with the centre of the core (with diameters ranging from 40–85 mm) so that the gamma source emits a narrow beam of collimated gamma-rays at a particular energy (e.g. [137]Cs at 0.662 MeV), and that these photons pass axially through the soil core and are recorded by the detector on the other side (Figure 8).

Source   Soil core   Detector
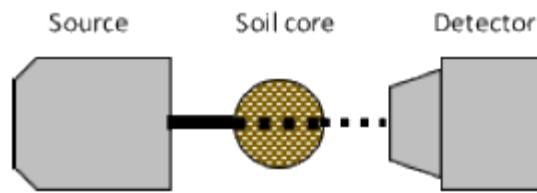
4.2.3 Measurements of soil bulk density using gamma-ray attenuation

Requirements:

1. It is a requirement that on the setup of the instrument, a once-off experiment be performed to determine the mass attenuation coefficient of soil, μ_s, and water, μ_w, using the particular instrument and setup and using Equation S16:

$$\mu_s = \frac{1}{x\rho_b} ln\left(\frac{I_0}{I}\right)$$

Equation S16

Where:

I is the measured counts s^{-1} and is taken as the average of four measurements.

x is the measured longitudinal thickness of the core in cm.

ρ_b is the bulk density of the core determined by conventional analytical methods (Part D, Section 4.1 of this Supplement), in g/cm^3.

I_0 is the counts/second measured with no soil in the core over the longitudinal thickness of x.

For the calculation of μ_w use Equation S16, replacing μ_s with μ_w, replacing the soil core with a cylindrical container with pure water that has the same shape and diameter of the soil core, and replacing ρ_b with ρ_w (density of water taken as 1 g/cm^3).

2. It is a requirement that the instrument be monitored daily at the start of the measurements using standards of known density. Standards to use must have the same shape and diameter as the soil core and must span the density range between 0.5–1.8 g/cm^3, e.g. standard materials with known densities of 1.0, 1.5 and 1.7 g/cm^3.

3. It is a requirement that the measurement be recorded only when the counts per second measured by the detector have stabilised.

4. It is a requirement that, if using soil spectroscopy to measure the total soil organic carbon content of an intact core, both the gamma and spectroscopic measurement be taken at exactly the soil same depth interval (Figure 9).

Spectrometer with fibre optic — SIDE VIEW

Gamma ray
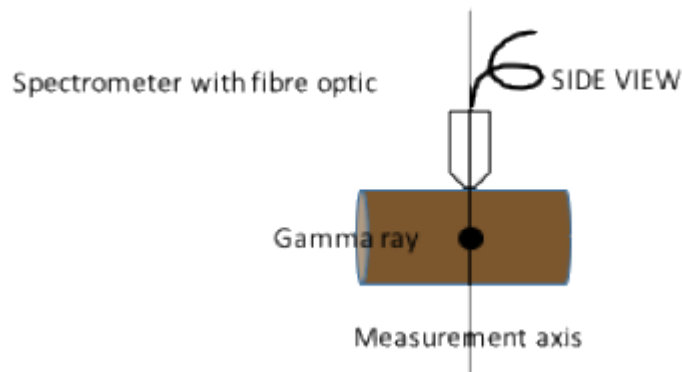
Measurement axis

5. It is a requirement that at least one measurement be taken at intervals of a maximum of 5cm and a minimum of 1cm, or the width of the spectrometer spot size (see Section 3.2.2 between gamma readings from the soil surface to the desired depth, to ensure that the measurements are representative of the soil depth sub-layer of interest (e.g. for measurements taken at 5cm intervals there are 6 measurements within the 0–30cm layer).

6. It is a requirement that Equation S17 be used to determine the bulk density of the soil being measured. If the measurements are made on oven-dry soil core samples then Θ is zero, the portion of Equation S17 located to the right of the minus sign becomes zero and the measurements are of the soil bulk density. However, if the measurements are made on soil cores that are wet or at field condition, then independent measures of Θ are required to solve Equation S17. The bulk density of the soil, ρ_b, can be derived using:

$$\rho_b = \frac{1}{x\mu_s} \ln\left(\frac{I_0}{I}\right) - \frac{\mu_w}{\mu_s} \rho_w \theta$$

Equation S17

Where:

I = the incident radiation at the detector.

I_0 = the un-attenuated radiation emitted from the source.

x is the sample thickness in cm.

μ_s = the mass attenuation coefficient of dry soil in cm^2/g.

μ_w = the mass attenuation coefficient of soil water at 0.662 MeV (reported values for the μ_w in the literature, for similar configurations have a mean of 0.0832cm^2/g and standard deviation 0.0006cm^2/g).

ρ_w = the density of water (taken as 1 g water/cm^3).

θ is the volumetric water content of the soil in cm^3 water/cm^3 core and can be calculated using Equation S18.

$$\theta = \frac{M_w/\rho_w}{V_b}$$

Where:

θ is the volumetric water content of the soil in cm³ water/cm³ core.

M_w is the mass of water present in the core (g water) which can be determined by measuring the mass loss on drying the core at 105°C to constant mass.

ρ_w is the density of water (taken as 1 g water/cm³ water).

V_b is the volume of the core (cm³ core).

Recommendations:

1. It is recommended that the independent estimate of θ be acquired using spectroscopic modelling, following the procedures described the 'Total soil organic carbon' section above and following the method described by Lobsey & Viscarra Rossel (2016).

2. It is recommended that using the gamma-ray sensors, as well as bulk density, cumulative soil mass (CSM) is calculated as described by Viscarra Rossel & Behrens (2010).

4.3 Equivalent Soil Mass Percentile

The equivalent soil mass is set at the 10th percentile of the masses of the samples collected for the baseline sampling round in the CEA. It is an estimate of the soil mass to the depth that is expected to be exceeded in at least 90% of samples across all sampling rounds in the CEA. This avoids one shallow sample reducing the mass for which changes in soil carbon concentrations are monitored and credited thereafter over the entire project crediting period.

Requirements:

1. It is a requirement to use the 10th percentile for P_{Supp} in Section 12 of Schedule 1 and Section 13 of Schedule 2 of the Determination.

5.0 Mathematical composite samples

Mathematical composites allow for individual core analysis before compositing (mathematically rather than physically) results to form a single composite sample. This allows for individual core analyses of soil carbon to inform future stratification approaches as well as other analyses of cores that may be more useful agronomically if done at an individual core scale level than in composite cores (e.g. soil nutrient analyses).

Requirements:

1. It is a requirement that the sampling plan required under "Part B – Section 2.0 Assigning sampling locations" include how composites will be combined prior to undertaking sampling

2. It is a requirement that each individual core be analysed individually as in "Part D - Section 2.1 Homogenised sample".

    a) If mathematical compositing of soil samples is to be used and organic carbon content is determined by dry combustion analysis, homogenised soil must be used.

3. If mathematical compositing of soil samples is to be used and organic carbon content is determined by spectroscopy, it is a requirement that all spectroscopic analyses must be performed on intact soil; however, all soil samples identified as calibration and model-validation samples for analysis by dry combustion, must be homogenised after spectroscopic analysis and before dry combustion analysis. Making mathematical compositing from individual soil samples must follow the following process:

    a) The mass of oven dry whole soil of the mathematical composite soil sample for the 0-30cm and 0-xcm soil depth layers must be calculated according to Equation S19 instead of Equation S5.

$$M\_mc_a = \frac{\sum_{i=1}^{n} M_{a_i}}{n}$$

Equation S19

Where:

M_mc_a is the mass of oven dry whole soil associated with the mathematical composite soil sample for the 0-30cm or 0-xcm soil depth layer (tonnes of oven dry whole soil/hectare).

M_{a_i} is the mass of oven dry whole soil within the 0-30cm or the 0-xcm soil depth layer (tonnes of oven dry whole soil/hectare) calculated according to Equation S5 in this Supplement for an individual soil core (sampling location) that is to be included in the mathematical composite (tonnes of oven dry whole soil/hectare).

i is the designator of the individual soil core to be included in the mathematical composite.

n is the total number of individual soil cores to be included in the mathematical composite soil sample.

b) The mass of oven dry whole soil of the mathematical composite soil sample for a given sub-layer within the 0-30cm or 0-xcm soil depth layer must be calculated according to Equation S20 instead of Equation S4:

$$M\_mc_{sl} = \frac{\sum_{i=1}^{n} M_{sl_i}}{n}$$

Equation S20

Where:

M_mc_{sl} is the mass of oven dry whole soil associated with the mathematical composite soil sample for a sub-layer (tonnes of oven dry whole soil/hectare).

M_{sl_i} is the mass of oven dry whole soil for a sub-layer (tonnes of oven dry whole soil/hectare) calculated according to Equation S4 in this Supplement for an individual soil core (sampling location) that is to be included in the mathematical composite (tonnes of oven dry whole soil/hectare).

i is the designator of the individual soil core to be included in the mathematical composite.

n is the total number of individual soil cores to be included in the mathematical composite soil sample.

c) The actual depth of soil associated with the mathematical composite for the 0-30cm and 0- xcm soil depth layers must be calculated according to Equation S21 instead of using Equations S1 or S2.

$$d\_mc_a = \frac{\sum_{i=1}^{n} d_{a_i}}{n}$$

Equation S21

Where:

d_mc_a is the actual depth of soil for the mathematical composite for the 0-30cm or 0-xcm soil layer (centimetres).

d_{a_i} is the actual depth of the 0-30cm or 0-xcm soil layer of an individual soil core (sampling location) to be included in the mathematical composite calculated according to Equation S1 in this Supplement (centimetres).

i is the designator of the individual soil core (sampling location) to be included in the mathematical composite.

n is the total number of individual soil cores (sampling locations) to be included in the mathematical composite soil sample.

d) The stock of soil organic carbon within each soil sub-layer of the mathematical composite soil sample must be calculated according to Equation s22 instead of using Equation S6.

$$SOC\_mc_{sl} = \frac{\sum_{i=1}^{n} SOC_{sl_i}}{n}$$

Equation S22

Where:

SOC_mc_{sl} is the stock of soil organic carbon in a soil sub-layer of the mathematical composite soil sample (tonnes of soil organic carbon/hectare).

SOC_{sl_i} is the stock of soil organic carbon in a soil sub-layer calculated according to Equation S6 in this Supplement for an individual soil core to be included in the mathematical composite (tonnes of soil organic carbon/hectare).

i is the designator of the individual soil core to be included in the mathematical composite.

n is the total number of individual soil cores to be included in the mathematical composite soil sample.

e) Calculate the stock of soil organic carbon of the mathematical composite sample associated with the 0-30cm and 0-xcm soil layers. The conditional approach defined in Equations 52 or 53 of Schedule 1 or Equations 75 or 76 of Schedule 2 the Determination must be used. However, the values of M_a, M_{sl}, d_a and SOC_i must be respectively replaced with those calculated for $M\_mc_a, M\_mc_{sl}, d\_mc_a$ and SOC_mc_{sl} and (Equation S19, S20, S22 and S23).

f) The value for M_a used in in Section 12 of Schedule 1 and Section 13 of Schedule 2 of the Determination must be calculated using the data derived for the mass of individual sampling locations as defined in Section 1.3, Part D of this Supplement.

Part E: The hybrid approach to estimating soil organic carbon sequestration

1.0 Modelled carbon stock estimates

This Part sets out the relevant requirements for modelled carbon stock estimates provided for the purposes of subsection 14(4) of Schedule 2 of the Determination.

Requirements:

1. For the estimation event, it is a requirement that a geospatial model estimation map must be produced of the model estimates that meets the requirements in Part A of this Supplement (with the exception of Requirement 1(d)(ii, iii and iv) – as sampling locations must be determined in accordance with Part E 2.0 of this Supplement).

2. It is a requirement that each CEA must have sampling strata outlined in the model estimation map which will correspond with those used in Part B 1.0 of this Supplement for the purposes of any sampling that occurs for the estimation event.

3. It is a requirement that modelled carbon stock estimates are provided either in raster format or polygons – both of which must align as closely as feasible with, and completely encompass the boundaries of the CEA and strata.

4. It is a requirement that the variables in Table 2 must be provided for each stratum, in every CEA for which subsection 14(4) or 14(5) of Schedule 2 is applied. Additionally:

   a) At least three unique (i.e. for three spatially discrete locations) estimations (raster cell or polygons) must be provided per stratum as per subsection 5(5) of Schedule 2 of the Determination.

   b) The variables must be allocated into layers (0-30cm, and 30-xcm where 0-xcm layer accounting is permitted, or required, by section 10 of Schedule 2 of the Determination). Modelled carbon stock estimates can be divided into sub-layers within each of those layers.

Table 2: Variables for modelled carbon stock estimates

Variable (Units)	Description	Scale	Required metadata	Used in
$ModSOC_{i,sl}$ (Tonnes of soil organic carbon per hectare)	The modelled soil organic carbon stock in a soil sub-layer, for the estimation event, for raster or polygon unit i	Each raster or polygon unit in the CEA (at least 3 unique values per strata), for all units in the strata	Layer identifier* (0-30cm, 30-$x$cm**) Sub-layer identifier *** (1 -x)	Section 29 of Schedule 2 of the Determination
$ModM_{a,i,sl}$ (Tonnes of oven dry soil per hectare)	The modelled oven dry mass of whole soil in a sub-layer, for the estimation event, for raster or polygon unit I, corresponding with the above value of $ModSOC_{i}$,sl	Raster or polygon (at least 3 unique values per strata), for all units in the strata	Layer identifier* (0-30cm, 30-$x$cm**) Sub-layer identifier *** (1 -x)	Section 29 of Schedule 2 of the Determination
$ModM_{a,i}$ (Tonnes of oven dry soil per hectare)	The modelled oven dry mass of whole soil in the layer (0-30cm or 0-$x$cm), for the estimation event, for raster or polygon unit i, which is the sum of the above $ModM_{i,sl}$ values for unit i. It is calculated as follows $$ModM_{a,i} = \sum_{sl=1}^{n} ModM_{i,sl}$$ Where n is the number of sub-layers in the relevant layer for which section 21, 27, 29 or 31 of Schedule 2 in the Determination is being applied (0-30cm or 0-$x$cm). The 0-$x$cm layer includes the 0-30cm and 30-$x$cm sub-layers.	Raster or polygon (at least 3 unique values per strata), for all units in the strata	Layer identifier* (0-30cm, 30-$x$cm**)	Section 29 of Schedule 2 of the Determination
$Mod\overline{SOC}_{h,sl}$	The mean modelled soil organic carbon stock in a sub-layer, for stratum h. It must be	Strata (single estimate)	Layer identifier* (0-30cm, 30-$x$cm**)	Sections 21 and 27 of Schedule 2

Variable (Units)	Description	Scale	Required metadata	Used in
(**Tonnes of soil organic carbon per hectare**)	the area weighted average of the above $ModSOC_i$,sl values for all raster or polygon units in strata h calculated as follows $$Mod\overline{SOC}_{h,sl} = \sum_{i=1}^{n} a_i ModSOC_i, \text{sl}$$ Where a_i is the relative area of the strata covered by raster or polygon unit *i*, in the stratum *h*, expressed as a proportion of the total stratum area.		Sub-layer identifier *** (1 -*x*)	of the Determination
$Mod\overline{M_{h,sl}}$ (**Tonnes of oven dry soil per hectare**)	The modelled oven dry mass of whole soil in a sub-layer, for the estimation event, for stratum *h*. It must be the area weighted average of the above $ModSOC_i$,sl values for all raster or polygon units in strata h calculated as follows: $$ModM_{h,sl} = \sum_{i=1}^{n} a_i ModM_{i,sl}$$ Where a_i is the relative area of the strata covered by raster or polygon unit *i*, in the stratum *h*, expressed as a proportion of the total stratum area.	Strata (single estimate)	Layer identifier* (0-30cm, 30-*x*cm**) Sub=layer identifier *** (1 -*x*)	Sections 21 and 27 of Schedule 2 of the Determination
$Mod\overline{M_{a,h}}$ (**Tonnes of oven dry soil per hectare**)	The mean modelled oven dry mass of whole soil in the layer (0-30cm or 0-*x*cm) for the estimation event, for stratum *h*. It is the sum of the above $ModM_{a,i}$ values for all relevant sub-layers for the	Strata (single estimate)	Layer identifier* (0-30cm, 30-*x*cm**) Sub-layer identifier *** (1 -*x*)	Sections 21 and 27 of Schedule 2 of the Determination

Variable (Units)	Description	Scale	Required metadata	Used in
	layer (0-30cm,0-$x$cm) in stratum h calculated as follows $$ModM_{a,h} = \sum_{sl=1}^{n} Mod\overline{M_{h,sl}}$$ Where n is the number of sub-layers in the relevant layer for which section 21, 27, 29 or 31 of Schedule 2 in the Determination is being applied (0-30cm or 0-$x$cm). The 0-$x$cm layer includes the 0-30cm and 30-$x$cm sub-layers.			

*Note: Layer identifiers are used if sub-layers need to be removed to align soil carbon stocks with the ESM. Where 0-$x$cm accounting occurs, participants should ensure sufficient sub-layers are estimated in the 0-30cm layer to allow for mass to equal or exceed the 0-30cm layer.

**Only required in accordance with section 10 of Schedule 2 of the Determination

***Sub-layer 1 denotes the soil surface sub-layer and sub-layer n denotes the deepest sub-layer. The number of sub-layers must be consistent across all raster or polygon units in the strata.

5. The modelled carbon stock estimates for the CEA must be provided to, and receipt acknowledged by, the Clean Energy Regulator with project and CEA identifiers that are maintained for the purposes of Part E 2.0 of this Supplement.

> **Note**: As at 3 December 2021, an email inbox has been provided by the Clean Energy Regulator for this purpose. Receipt is acknowledged with a reply email. The address of this inbox is available on its website.

Recommendations:

1. It is recommended that project proponents consider the recommendations in Part A and Part B 1.0 of this document.

2. It is recommended that project proponents provide carbon stocks for as many discrete sub-layers as possible which sum to equal or exceed Equivalent Soil Mass. While sections 21, 27 , 29 and 31 of Schedule 2 allows for linear interpolation of results to the Equivalent Soil Mass – this may be a conservative interpolation as soil carbon concentration is assumed to decline at depth.

3. It is recommended that more than three unique estimations be provided under Requirement 4 of this section for each stratum, as enough sampling locations and sampling must occur to meet Requirement 6 of Part E Section 2.0 (having fewer estimates per stratum makes it more likely that sample sites will be randomly allocated to the same estimation point – requiring more samples to be collected).

2.0 Model-validation sampling for modelled carbon stock estimates

This Section sets out the relevant requirements for model-validation sampling for the purposes of validating modelled carbon stock estimates provided for the purposes of subsection 14(5) of Schedule 2 of the determination.

Requirements:

1. It is a requirement that model-validation sampling must meet all the requirements for sampling in the Determination.

2. It is a requirement that model-validation sampling must occur using the sampling strata outlined in Part E 1.0 (Requirement 2).

3. It is a requirement that the model-validation sampling locations must be allocated (under Part B Section 2.0 of this Supplement) after the modelled carbon stock estimates have been provided to the Regulator under Part E 1.0 (Requirement 5).

4. If calibration sampling has occurred in a CEA, it is a requirement that the model-validation samples must be collected within a period where the first calibration sample and the last model-validation sample collected meets the timing requirements of Requirement 13b) of Part C Section 2.0 for which both sample collections are considered a single estimation event).

    Note: The two-part sampling round is divided by the provision of model estimates to the Regulator consistent with Requirement 5 of Section 1.0 of this Part. If calibration sampling has occurred in a CEA, sample allocation must reoccur for the model-validation samples (under Part B Section 2.0 of this Supplement).

5. It is a requirement that enough sampling locations must be allocated to enable model-validation sampling locations to overlay at least 18 unique estimations in at least 6 sampling strata (see Requirement 3.3(3) of this Part).

6. It is a requirement that enough samples must be collected from each stratum to compare three unique estimations to three unique sample sites where each sample site corresponds to one of the modelled areas (polygon or raster units within each stratum – see Requirement 4(a) of Section 1.0 of this Part.

Recommendations:

1. When determining how many samples to collect from each stratum, it is recommended project proponents consider:

    a) the needs of model calibration for future estimation events; and

    b) the effect of sample numbers on the degrees of freedom in Equation 115 of the Determination.

3.0 Validated model-only estimates

This section sets out the relevant requirements for validated modelled carbon stock estimates provided for the purposes of section 14(4) of Schedule 2 of the Determination. It does not apply to the first (baseline) estimation event in the CEA consistent with paragraph 5(2)(a) of Schedule 2 of the Determination.

3.1 Operation of this Part

Requirements:

1. Modelled carbon stock estimates under Part E 1.0 of this Supplement, must be considered validated modelled carbon stock estimates for the estimation event if they meet the requirements set out in Section 3.2- 3.5 of the Supplement.

3.2 Validation groups

Requirements:

1. It is a requirement that project proponents intending to use model-only estimates under subsection 14(4) of Schedule 2 of the Determination must include those CEAs in a validation group.

    a) Validation groups are specific to each estimation event. This means that for subsequent estimation events, CEAs can be added to or removed from the validation group.

2. It is a requirement that a validation group must consist of one or more CEAs from a project or projects registered under the Determination. Validation groups are not restricted to being within a single project or with a single project proponent.

3. It is a requirement that CEAs must not be included in a validation group for an estimation event, if:

    a) the CEA has been selected for model-validation sampling in the last year (this aligns with the minimum sampling intervals for CEAs as outlined in Requirement 11 of Part C Section 2.0); or

    b) there is insufficient time to sample the CEA and align with the timing requirements as per Requirement 13(b) of Part C Section 2.0 (such as if calibration sampling has occurred in a CEA).

4. It is a requirement that all CEAs in the validation group must provide modelled carbon stock estimates to the Regulator under Part E 1.0 (Requirement 5) at the same time (consisting of one or several geospatial files).

5. It is a requirement that each CEA must be assigned to a sampling sub-group in accordance with Section 3.3 of this Part, and this allocation must be included with the provision of data under the above requirement.

6. It is a requirement that the process used to randomly select a sub-group for sampling under Section 3.4 of this Part must accompany the modelled carbon stock estimates.

7. It is a requirement that the provision of the data must be accompanied by signed consent from every participant that has included a CEA in the validation group.

8. It is a requirement that at least 50% of CEAs in a validation group must have had an estimation event under subsections 14(3) or 14(5) of Schedule 2 of the Determination in the last 5 years.

Note: This is a sampling requirement intended to operate in parallel with the maximum sampling interval of 10 years for each CEA in the Determination (Schedule 2 paragraph 5(2)(b) of the Determination).

Recommendations:

1. It is recommended that project proponents should consider appropriate risk management or contractual arrangements if validation groups include multiple project proponents.

2. It is recommended that project proponents should acknowledge the following before including their CEA in a validation group:

   a) The inclusion of the CEA in a validation group may mean that the CEA is selected for model-validation sampling in a sampling round.

   b) All CEAs selected for model-validation sampling must undertake model-validation sampling and include the results in an offsets report (with any auditing required) before, or concurrently to, providing validated modelled carbon stock estimates under subsection 14(4) of Schedule 2 of the Determination for the other CEAs in the validation in an offsets report.

   c) The failure of any of the CEAs to undertake model-validation sampling and report results as required will mean that results under subsection 14(4) of Schedule 2 of the Determination cannot be reported for the other CEAs in the validation group.

   d) The inclusion of CEAs in the model-validation group may mean that the modelled carbon stock estimates may supersede any sampling results in accordance with subsection 14(2) of Schedule 2 of the Determination.

3.3 Validation sub-groups

Requirements:

1. It is a requirement that a validation group must consist of one to ten sub-groups of CEAs, with each sub-group containing as close as possible to a minimum of 10% of the area of the CEAs in the validation group. To the extent possible, each subgroup must contain a consistent proportion of total CEA area (noting that project clustering may cause necessary differences in proportions).

   a) To avoid having to split or merge CEAs, subgroups can contain a minimum of 7% of the total area of the CEAs in the validation group.

2. It is a requirement that if a sub-group is randomly selected, then all CEAs in the sub-group are selected at the same time for sampling.

   a) Including all CEAs in the validation group in one sub-group will result in all CEAs being selected for sampling for every estimation time.

   b) Using more sub-groups will result in a smaller proportion of CEAs being sampled for every estimation event.

3. It is a requirement that each sub-group must include sufficient CEAs and sampling strata to enable model-validation sampling locations to overlay at least 18 unique estimations in at least 6 sampling strata (across one or multiple CEAs).

4. It is a requirement that all CEAs in a validation group must be allocated into at least two consistent clusters which contain:

    a) at least one CEA, and

    b) as close as possible, the same proportion of total CEA area from each consistent cluster must be included in each validation sub-group.

5. When allocating CEAs into consistent clusters, it is a requirement that the following non-exclusive factors must be taken into account, using consistent data across CEAs wherever possible:

    a) soil factors such as baseline soil carbon stock and soil texture,

    b) environmental factors such as temperature and rainfall (over the last five years), and

    c) management activities of individual CEAs (over the last five years) which may include cropping and pasture use, productivity (crop yield), fertilizer use, tillage practices.

    Note: CEAs can also be clustered by project (so they are not split into different sub-groups) to ensure reporting and sampling are aligned.

Recommendations:

1. It is recommended that participants only use one sub-group where there are:

    a) CEAs that have not yet been randomly selected for sampling that are approaching the 10-year maximum sampling interval, or

    b) where the number of CEAs that have been sampled in the last five years makes it hard to form validation groups that comply with Part E Section 3.2 Requirement 8.

2. It is recommended that clustering occurs into as many groups as is feasible to ensure representativeness when sub-groups are formed from at least one CEA from each cluster.

3.4 Allocating sub-groups for validating a model

In order to validate modelled carbon stock estimates for an estimation event, a sub-group must be randomly selected for sampling.

Requirements:

1. It is a requirement that the subgroups must be selected for sampling using a pseudo-random number generator with a defined seed number where either:

    a) all of the following apply:

        i) the process and plan to link the numbers generated by the pseudo-random number generator to validation sub-groups is prepared and documented;

ii) the prepared process and plan (from i. above) are provided to, and receipt acknowledged by, the Clean Energy Regulator before random numbers are generated and applied;

Note: As at 3 December 2021, an email inbox has been provided by the Clean Energy Regulator for this purpose. Receipt is acknowledged with a reply email. The address of this inbox is available on its website.

iii) the outputs of the pseudo-random number generator used are verifiable and suitable evidence of this is maintained;

iv) the process and plan use a defined unpredictable seed number which is not known at the time the process and plan is developed (such as the ASX 200 index reported by asx.com.au at a future specified date/time);

v) the approach is transparent, reproducible and auditable;

vi) the approach achieves a genuinely random selection of the validation sub-group to be sampled; or

b) the process applies an approach pre-approved by the Clean Energy Regulator for selecting a validation sub-group for sampling. Such approaches may be approved for particular validation groups or generally in guidance published by the Clean Energy Regulator for the purposes of this subparagraph.

Recommendations:

1. It is recommended that proponents take into account guidance from the Clean Energy Regulator as to how best to implement these requirements and provide the necessary evidence to demonstrate they have been complied with.

3.5 Validation results

In order to ascertain the uncertainty of modelled carbon stock estimates for an estimation event, the results of model-validation sampling in the validation sub-group must be provided to the Regulator (in the relevant offsets report(s) for all the CEAs in the validation group) to allow the uncertainty of modelled carbon stock estimates in sampled CEAs to be applied to unsampled CEAs.

Requirements:

1. It is a requirement that the value of (df_{CEA}) for the purposes of section 25 of Schedule 2 must be worked out using the following equation:

$$df_{CEA} = \sum_c \frac{A_{CEA}^2 \times \text{Reg}\overline{SOC}_{CEA}}{\sum_c \left(A_{CEA}^2 \times \text{Reg}\overline{SOC}_{CEA}\right)} df_{CEA_c}$$

Equation s23

Where:

c is an identifier for each validation-sampled CEA in the subgroup.

A_{CEA} is the area of the CEA, in hectares.

$\text{Reg}\overline{SOC}_{CEA}$ is the regression carbon stock estimate for the CEA, given by section 40 of Schedule 2 of the Determination, reported in the relevant offsets report for the validation-sampled CEA.

df_{CEA_c} is the degrees of freedom for the sampling variance of the mean soil organic carbon stock within a CEA, given by section 45 of Schedule 2 of the Determination, and reported in the relevant offsets report for the validation-sampled CEA.

2. The values of $Bias_{Supp}$ r_{Supp}, fv_{Supp} and d_{Supp} as required by equations 86 and 87 of the Determination, for CEAs in the validation group that are not model-validation sampled, are given by the following requirements in this Section.

3. It is a requirement that the extrapolated bias of the model for the unsampled CEAs ($Bias_{Supp}$), in tonnes of soil organic carbon per hectare, for the purposes of equation 86 of the Determination, must be worked out using the following equation:

$$Bias_{Supp} = \sum_c \frac{A_{CEA}^2 \times \text{Reg}\overline{SOC}_{CEA}}{\sum_c \left(A_{CEA}^2 \times \text{Reg}\overline{SOC}_{CEA} \right)} ModBias_{CEA}$$

Equation S24

Where:

c is an identifier for each validation-sampled CEA in the subgroup.

A_{CEA} is the area of the CEA, in hectares.

$\text{Reg}\overline{SOC}_{CEA}$ is the regression carbon stock estimate for the CEA, given by section 40 of Schedule 2 of the Determination, reported in the relevant offsets report for the validation-sampled CEA.

$ModBias_{CEA}$ is the bias of modelled values in the validation-sampled CEA given by equation 110 of the Determination and reported in the relevant offsets report for the validation-sampled CEA. A relevant offsets report may be the same offsets report for which the $Bias_{Supp}$ is calculated or an offsets report that been previously provided for another project, or project area, which contains the model-validation sampling results. Unreported results will mean that this statistic cannot be calculated and the model will not be considered valid.

4. It is a requirement that the correlation of the modelled and measured carbon stocks for the validation group (r_{Supp}), for the purposes of equation 87 of the Determination, must be worked out using the following equation:

$$r_{Supp} = \sum_c \frac{A_{CEA}^2 \times \text{Reg}\overline{SOC}_{CEA}}{\sum_c \left(A_{CEA}^2 \times \text{Reg}\overline{SOC}_{CEA} \right)} r_{CEA}$$

Equation S25

Where:

c is an identifier for each validation-sampled CEA in the subgroup.

A_{CEA} is the area of the CEA, in hectares.

$\text{Reg}\overline{SOC}_{CEA}$ is the regression carbon stock estimate for the CEA, given by section 40 of Schedule 2 of the Determination, reported in the relevant offsets report for the validation-sampled CEA.

r_{CEA} is the correlation of the modelled and measured carbon stocks for the validation-sampled CEA, given by equation 111 of the Determination and reported in the relevant offsets report for the CEA. A relevant offsets report may be the same offsets report for which the r_{Supp} is calculated or an offsets report that been previously provided for another project, or project area, which contains the model-validation sampling results. Unreported results will mean that this statistic cannot be calculated and the model will not be considered valid.

5. It is a requirement that the fraction of sampling variance in the selected sub-group (fv_{Supp}), in tonnes of soil organic carbon per hectare, for the purposes of equation 87 of the Determination, must be worked out using the following equation:

$$fsv_{Supp} = \sum_{c} \frac{A_{CEA}^2 \times \text{Reg}\overline{SOC}_{CEA}}{\sum_c \left(A_{CEA}^2 \times \text{Reg}\overline{SOC}_{CEA}\right)} fsv$$

Equation S26

Where:

c is an identifier for each validation-sampled CEA in the subgroup(s).

A_{CEA} is the area of the CEA, in hectares.

$\text{Reg}\overline{SOC}_{CEA}$ is the regression carbon stock estimate for the CEA, given by section 40 of Schedule 2 of the Determination, reported in the relevant offsets report for the validation-sampled CEA.

fsv is the fraction of sampling variance for the validation-sampled CEA given by equation 112 of the Determination and included in the relevant offsets report for the CEA. A relevant offsets report may be the same offsets report for which the fsv_{Supp} is calculated or an offsets report that been previously provided for another project, or project area, which contains the model-validation sampling results. Unreported results will mean that this statistic cannot be calculated and the model will not be considered valid.

6. The d_{Supp}, a discount factor for the purposes of equation 87 of the Determination, is equal to 4.

Note: This discount factor applies as the sampling variance of the model in unsampled projects is unknown and must be conservatively estimated based on the sampling variance in the validation-sampled CEAs. The discount has an effect ranging from:

   i. 1, which assumes equal sampling variance to the model-validation sampled CEA where a correlation of 1 is observed under Requirement 3.5(4) of this Part, to

   ii. 5, which assumes 5 times the sampling variance of the model-validation sampled CEA where a correlation of 0 is observed under Requirement 3.5(4) of this Part (such a high variance would indicate the model results are unlikely to be robust and make crediting improbable).

Part F: Emissions Factors

This Part sets out the Standard Parameters and Emissions Factors for the Determination. They align with the values used in the National Greenhouse Gas Inventory.

Table 3: Sheep (g) Emission Factors (kg CO_2-e/head/day)

This table has been updated from the Supplement to the Carbon Credits (Carbon Farming Initiative – Measurement of Soil Carbon Sequestration in Agricultural Systems) Methodology Determination 2018 Version 1.2 – July 2020 to align with the values used in the National Greenhouse Gas Inventory.

State (i)	Season (k)	Class (j)					
		Rams	Wethers	Maiden Ewes (intended for breeding)	Breeding Ewes	Other Ewes	Lambs & Hoggets
NSW/ACT	Spring	1.03	0.85	0.61	0.81	0.77	0.32
	Summer	0.88	0.64	0.49	0.58	0.59	0.34
	Autumn	0.83	0.66	0.52	0.63	0.60	0.40
	Winter	0.91	0.73	0.60	0.71	0.68	0.47
Queensland	Spring	0.58	0.50	0.35	0.43	0.45	0.22
	Summer	0.65	0.59	0.43	0.48	0.53	0.29
	Autumn	0.71	0.62	0.46	0.55	0.57	0.26
	Winter	0.67	0.56	0.40	0.47	0.53	0.30
South Australia	Spring	1.04	0.91	0.68	0.74	0.71	0.53
	Summer	0.76	0.70	0.55	0.59	0.59	0.48
	Autumn	0.49	0.42	0.36	0.41	0.38	0.17
	Winter	0.78	0.67	0.58	0.69	0.61	0.36
Tasmania	Spring	1.24	0.75	0.63	0.81	0.69	0.25
	Summer	1.01	0.59	0.48	0.53	0.53	0.28
	Autumn	0.91	0.61	0.55	0.63	0.61	0.45

	Winter	0.72	0.44	0.48	0.57	0.48	0.41
Victoria	Spring	0.91	0.78	0.65	0.77	0.65	0.32
	Summer	0.70	0.59	0.48	0.55	0.53	0.31
	Autumn	0.79	0.64	0.53	0.63	0.61	0.42
	Winter	0.60	0.50	0.41	0.49	0.50	0.36
Western Australia	Spring	1.01	0.80	0.67	0.76	0.74	0.43
	Summer	0.69	0.58	0.48	0.54	0.53	0.33
	Autumn	0.42	0.31	0.35	0.40	0.29	0.13
	Winter	0.85	0.64	0.60	0.75	0.66	0.31

Table 4: Beef Cattle (g) Emission Factors (kg CO_2-e/head/day)

This table has been updated from the Supplement to the Carbon Credits (Carbon Farming Initiative – Measurement of Soil Carbon Sequestration in Agricultural Systems) Methodology Determination 2018 Version 1.2 – July 2020 to align with the values used in the National Greenhouse Gas Inventory.

State/Region (i)	Season (k)	Class (j)						
		Bulls <1	Bulls >1	Steers <1	Steers >1	Cows <1	Cows 1 to 2	Cows >2
Northern Territory	Spring	3.152	5.762	3.136	3.885	2.793	3.830	4.645
	Summer	2.358	6.587	2.402	3.572	2.390	3.302	4.852
	Autumn	2.866	6.563	3.014	3.982	2.986	3.668	4.785
	Winter	3.008	6.095	3.111	3.994	2.993	3.832	4.722
NSW/ACT	Spring	1.766	4.952	1.723	4.383	1.723	3.683	5.962
	Summer	2.945	5.379	2.765	4.646	2.765	4.459	5.332
	Autumn	3.473	5.496	3.191	4.806	3.191	4.332	4.987

State/Region (i)	Season (k)	Class (j)						
		Bulls <1	Bulls >1	Steers <1	Steers >1	Cows <1	Cows 1 to 2	Cows >2
	Winter	3.527	5.402	3.343	4.731	3.343	4.453	5.016
Queensland	Spring	2.946	5.811	2.940	5.020	2.825	3.719	4.400
	Summer	2.118	6.120	2.360	4.461	2.189	3.494	5.467
	Autumn	2.515	6.135	2.847	4.466	2.562	3.655	4.800
	Winter	2.967	6.006	2.774	4.655	2.619	3.734	4.332
South Australia	Spring	3.695	7.421	3.400	4.425	3.304	4.610	5.375
	Summer	4.231	6.155	3.841	4.293	3.747	4.521	4.871
	Autumn	2.040	4.656	1.924	3.918	1.811	3.514	4.975
	Winter	2.709	5.740	2.567	4.020	2.436	4.157	4.766
Tasmania	Spring	2.283	6.340	2.143	5.138	2.097	4.154	6.665
	Summer	5.619	6.697	2.678	5.101	2.536	4.248	6.045
	Autumn	3.490	6.469	3.013	5.058	2.833	3.839	4.421
	Winter	2.976	5.428	2.760	4.305	2.549	4.079	4.019
Victoria	Spring	3.744	7.340	3.647	5.616	3.647	5.096	6.206
	Summer	3.437	6.618	3.347	5.126	3.159	4.796	5.078
	Autumn	1.927	6.107	1.917	4.390	1.917	3.695	5.989
	Winter	2.357	6.056	2.223	4.653	2.223	3.579	5.191

State/Region (i)		Season (k)	Class (j)						
			Bulls <1	Bulls >1	Steers <1	Steers >1	Cows <1	Cows 1 to 2	Cows >2
Western Australia	South West	Spring	5.178	7.313	4.550	5.782	3.947	5.179	5.751
		Summer	4.406	5.829	4.061	4.527	3.705	4.852	4.804
		Autumn	2.025	5.876	2.025	3.676	1.846	3.715	5.137
		Winter	3.088	6.000	2.714	4.132	2.528	3.566	5.145
	Pilbara	Spring	2.403	5.003	2.403	4.658	2.290	3.994	5.341
		Summer	2.934	6.192	2.934	5.047	2.826	4.541	5.295
		Autumn	4.107	6.893	4.107	5.346	3.991	4.463	4.963
		Winter	3.797	5.304	3.797	4.620	3.687	4.644	4.459
	Kimberley	Spring	3.542	5.421	3.429	3.858	3.200	4.442	4.025
		Summer	2.533	6.574	2.428	5.216	2.244	3.368	6.440
		Autumn	3.196	7.245	3.084	5.718	2.763	4.197	5.300
		Winter	3.354	5.675	3.242	4.714	2.599	4.005	4.111

Table 5: Dairy Cattle (g) Emission Factors (kg CO_2-e/head/day)

This table has been updated from the Supplement to the Carbon Credits (Carbon Farming Initiative – Measurement of Soil Carbon Sequestration in Agricultural Systems) Methodology Determination 2018 Version 1.2 – July 2020 to align with the values used in the National Greenhouse Gas Inventory.

State (i)	Class (j)				
	Milking Cows	Heifers >1	Heifers <1	Dairy Bulls >1	Dairy Bulls <1
NSW/ACT	12.724	4.307	2.113	5.342	2.601
Northern Territory	10.709	4.396	2.157	5.452	2.655
Queensland	10.354	4.307	2.113	5.342	2.601
South Australia	12.690	4.307	2.113	5.342	2.601
Tasmania	10.644	4.307	2.113	5.342	2.601
Victoria	11.598	4.307	2.113	5.342	2.601
Western Australia	12.437	4.307	2.113	5.342	2.601

Table 6: Other Livestock Emission Factors (kg CO_2-e/head/day)

This table has been updated from the Supplement to the Carbon Credits (Carbon Farming Initiative – Measurement of Soil Carbon Sequestration in Agricultural Systems) Methodology Determination 2018 Version 1.2 – July 2020 to align with the values used in the National Greenhouse Gas Inventory.

State (i)	Species (g)							
	Goats	Horses	Deer	Buffalo	Donkeys /Mules	Emus/ Ostriches	Alpacas	Camels
NSW/ACT	0.411	1.611	1.611	6.060	0.844	0.411	0.641	3.759
Northern Territory	0.489	2.268	1.830	6.718	1.063	0.489	0.719	4.416
Queensland	0.411	1.611	1.611	6.060	0.844	0.411	0.641	3.759
South Australia	0.411	1.611	1.611	6.060	0.844	0.411	0.641	3.759

Tasmania	0.411	1.611	1.611	6.060	0.844	0.411	0.641	3.759
Victoria	0.411	1.611	1.611	6.060	0.844	0.411	0.641	3.759
Western Australia	0.411	1.611	1.611	6.060	0.844	0.411	0.641	3.759

It is a requirement that for other livestock grazed on soil carbon projects not listed in this Part, the appropriate emissions factors that are to be applied are agreed with the Regulator.

Table 7: Synthetic Fertiliser (f) Emission Factors (t CO_2-e/t nitrogen in fertiliser)

This table has been updated from the Supplement to the Carbon Credits (Carbon Farming Initiative – Measurement of Soil Carbon Sequestration in Agricultural Systems) Methodology Determination 2018 Version 1.2 – July 2020 to align with the values used in the National Greenhouse Gas Inventory.

State (i)	Production System (j)						
	Irrigated pasture	Irrigated crop	Non-irrigated pasture	Non-irrigated crop	Sugar cane	Cotton	Horticulture /Vegetables
NSW/ACT	2.902	5.028	1.338	1.135	10.286	3.567	4.587
Northern Territory	2.902	5.028	1.862	1.779	–	–	4.871
Queensland	2.902	5.028	1.111	0.972	9.920	3.326	4.251
South Australia	2.902	5.028	1.749	1.232	–	–	4.662
Tasmania	2.902	5.028	2.060	2.007	–	–	5.024
Victoria	2.902	5.028	1.911	1.406	–	–	4.701
Western Australia	2.902	5.028	1.529	1.169	–	3.642	4.931

Table 8: Carbon dioxide emissions from urea applied as synthetic fertiliser

Production System (j)	Total emissions from synthetic fertiliser (t CO_2-e/t urea)
	EF_U
Urea	0.7333

Table 9: Crop Residue Parameters

This table has been updated from the Supplement to the Carbon Credits (Carbon Farming Initiative – Measurement of Soil Carbon Sequestration in Agricultural Systems) Methodology Determination 2018 Version 1.2 – July 2020 to align with the values used in the National Greenhouse Gas Inventory.

Crop type (v)	N content of residues		Dry Matter fraction of residue	Above ground residue: harvested crop ratio	Below ground to above ground residue ratio	fraction of residue remaining at burning	Fraction of above ground crop residue that is removed after harvest but before residue burning,	Emissions factor for residue burning
	$NC_{v,AB}$	$NC_{v,BG}$	DM_v	RC_v	$BGABRR$	$FRRB_v$	$RF_{v,B,PA}$ $RF_{v,RP,PA}$	$EF_{RB,v}$
Wheat[#0]	0.006	0.01	0.88	1.5	0.29	0.5	0/AVWE*	.071
Barley[#0]	0.007	0.01	0.88	1.24	0.32	0.5	0/AVWE*	.074
Maize[#0]	0.005	0.007	0.85	0.81	0.39	1.0	0/AVWE*	.071
Oats[#0]	0.006	0.01	0.88	1.42	0.43	0.5	0/AVWE*	.071
Rice[#0]	0.007	0.01	0.80	1.31	0.16	1.0	0/AVWE*	.077
Sorghum[#0]	0.008	0.007	0.80	1.50	0.22	0.5	0/AVWE*	.078
Triticale[#0]	0.006	0.01	0.88	1.50	0.42	0.5	0/AVWE*	0.071
Other Cereals[#0]	0.006	0.01	0.88	1.46	0.36	0.5	0/AVWE*	0.071
Pulses[#0]	0.009	0.01	0.87	1.37	0.51	0.5	0/AVWE*	0.081

Tuber and Roots[#1]	0.02	0.01	0.25	0.34	0.43	NA	0/AVWE*	NA
Sugar cane[#2]	0.005	0.007	0.20	0.25	0.45	1.0	0/AVWE*	0.068
Peanuts[#3]	0.016	0.014	0.80	1.07	0.20	0.5	0/AVWE*	0.106
Cotton[#4]	0.01	0.01	0.90	1.90	0.30	NA	0/AVWE*	NA
Hops[#5]	0.006	0.01	0.88	1.50	0.29	NA	0/AVWE*	NA
Oilseeds[#0]	0.009	0.01	0.96	2.08	0.33	0.5	0/AVWE*	0.081
Forage Crops (harvested)[#6]	0.006	0.01	0.88-	1.34	0.37	NA	0/AVWE*	NA

[#0] quantity of harvested crop is in tonnes of grain

[#1] quantity of harvested crop is in tonnes of tubers or roots

[#2] quantity of harvested crop is in tonnes of cut cane

[#3] quantity of harvested crop is in tonnes of peanuts (in shell)

[#4] quantity of harvested crop is in tonnes of baled cotton

[#5] quantity of harvested crop is in tonnes of hops (dry weight)

[#6] quantity of harvested crop is in tonnes of hay (if silage is used, convert yield to a moisture content to that istypical of hay).

*AVWE: Alternative Values with Evidence may be used in place of the default. Evidence may include industry standard practices, such as cover rating assessments (as per section 38). Consistent approaches should be used across baseline and reporting periods.

Table 10: Pasture Renewal and cover crop Parameters

Pasture type (v) / cover crop type (v)	Annual above ground dry Matter Yield (t /ha)	Below ground to above ground residue ratio	Fraction above-ground residue removed	Nitrogen content of Residues	
	DM_P & DM_{CC}	$BGABRR_{v,P}$ & $BGABRR_{v,CC}$	$RFv_{,P,B,PA}$ & $RFv_{,CC,B,PA}$	$NC_{P,AB}$ & $NC_{CC,AB}$	$NC_{P,BG}$ & $NC_{CC,BG}$
Annual grass	4.41	0.4	0.8	0.015	0.012
Grass clover mixture	8.34	0.8	0.8	0.025	0.016
Lucerne	8.62	0.4	0.8	0.027	0.019
Other legume	5.62	0.4	0.8	0.027	0.022
Perennial pasture	8.35	0.8	0.8	0.015	0.012
foraged crops*	7.1	0.56	0.8	0.0218	0.00872
cover crops**	7.1	0.56	0	0.0218	0.00872

*Foraged crops are rops that are not harvested but rather grazed directly by livestock. Yield estimates are based on the average of pasture attributes in the national inventory. If the crop is more similar to a particular pasture class than the others – the attributes for that class should be used.

** Cover crops are not harvested or grazed. Yield estimates are based on the average of pasture attributes in the national inventory. If the crop is more similar to a particular pasture class than the others – the attributes for that class should be used (except that fraction of above ground residue removed must remain 0).

Table 11: Agriculture lime application parameters

	Emission factor	Default carbonate content of lime type
	(t CO_2-e/t pure carbonate material)	tonnes of pure carbonate/tonne of lime type l.
Dolomite	0.48	0.95
Limestone	0.44	0.90

Table 12: Default carbon content values

Product	Default carbon content value
Restricted non-synthetic fertiliser	50%
Biochar	See table 15
Soil amendments containing coal	100%

Table 13: Parameter for the estimated quantity of fuel ($EQ_F\ T$)

Event	Diesel fuel use in kilolitres per hectare
Tillage	0.012

Table 14: Emissions factors for residue emissions per tonne of nitrogen

	Total emissions for residue decomposition (t CO_2-e/tN))
	$EF_{RD,N}$
All residues	4.16

Table 15: Applicable default biochar carbon content factors for the purposes of Equation 6 of the Determination.

Feedstock	Pyrolysis production process	Default carbon content value
Animal manure	Pyrolysis	87%
	Gasification	62%
Wood	Pyrolysis	100%
	Gasification	100%
	Pyrolysis	100%

Herbaceous (grasses, forbs, leaves; excluding rice husks and rice straw)	Gasification	78%
Rice husks and rice straw	Pyrolysis	90%
	Gasification	63%
Nut shells, pits and stones	Pyrolysis	100%
	Gasification	92%
Biosolids (paper sludge, sewage sludge)	Pyrolysis	75%
	Gasification	57%
Other/unknown feedstock/mixed feedstocks	Pyrolysis	100%
	Gasification	100%

Part G: Determining carrying capacity during the baseline

If a project proponent is unable to access complete records to apply section 39 of the Determination to the baseline period, this Section must be used for determining the assessed annual carrying capacity for the project for the baseline period.

1. An assessment of carrying capacity for the relevant project area must be obtained from the relevant government body.

2. The carrying capacity must:

    a) be expressed as a total number of animal units; and

    b) have regard to any available property-specific data; and

    c) be based on:

        i) the recommended pasture utilisation rate for the relevant district; and

        ii) an assessment that the carrying capacity is sustainable over a minimum of 5 years; and

        iii) the assumption that annual rainfall will be at the 5 year average for that district.

3. An auditable description of the process that was used to calculate the carrying capacity of the relevant carbon estimation area must be obtained from the relevant government body.

Part H: Additional Reporting Requirements when spectroscopy is used

Paragraph 32(1)(i) of the Determination requires offsets reports to include information this Supplement requires to be documented.

Requirements:

1. It is a requirement to include the following information in each offsets report that spectroscopy is used to analyse carbon content.

    a) Spectrometer

        - Manufacturer and model number

        - Spectral range

        - Instrument calibration material

    b) Soil condition

        - Measurement on intact cores – Y/N

        - Measurement on homogenised soil (air dry/crushed / ground/ sieved) – Y/N

    c) Selection of training and validation data

        - Total number of spectra measured in the CEA

        - Number of pairs of spectra and reference analytical values selected in training set

        - Method used for selection of training set

        - Number of pairs of spectra and reference analytical values selected for validation set

        - Method used for selection of validation set

        - Summary statistics for the training and validation sets showing the mean, standard deviation, minimum, first quartile, median, third quartile, maximum, and skewness coefficient

    d) Reference analytical approach

        - Reference analytical approach used

        - Value for the SEL calculated on the 'blind duplicate' samples (if conducted)

    e) Spectroscopic modelling

        - If used, the methods used for spectral transformations, pre-processing and pre-treatment

        - If used, the method for correcting for the effects of water on the spectra

        - If used, the statistical transformation of the reference analytical data

        - The method used for the multivariate spectroscopic modelling

- If any, the number of outliers removed, their analytical values and the outlier detection method used

- The optimised settings for the spectroscopic model

- The model residuals plot

- The cross validation R^2 and RMSE for the optimised model, indicating whether the organic C data was transformed and which transformation was used

f) Validation of the spectroscopic model

- Independent validation statistics R^2, RMSE, SDE, ME

- Plot of the observed vs predicted values

g) Estimates of unknowns – summary statistics for the estimates showing

- Mean

- Standard deviation

- Minimum

- First quartile

- Median

- Third quartile

- Maximum

- Skewness coefficient

h) Software(s) used and version(s) number

i) Datasets

- Total set of spectra collected along with the sample identification numbers, date and time of sampling, spatial location from which it was sourced (or locations, if it is a homogenised sample), depth layer (in cm)

- Training set with sample identification numbers, soil organic C data and corresponding spectra

- Validation set with sample identification numbers, soil organic C data and corresponding spectra

- Prediction set with sample identification numbers, spectra and corresponding predictions of soil organic C

2. It is a requirement to include the following information in each offsets report that gamma attenuation is used to determine bulk density:

a) Gamma-ray attenuation instrument used

- Manufacturer and model number

- Radiation source, activity (in MBq) and peak gamma energy (in MeV)

- Type of scintillation detector and size

b) Soil condition and set up

- Whether measurements on soil cores are at field condition or oven-dried

- A photograph of the instrument setup

c) Measurements

- Experimental values for μs, and μw.

- Values for parameters used to compute soil bulk density in Equation S17

- Method used for the independent measure of θ in Equation S17 if spectroscopy, follow instructions in 'The spectroscopic modelling procedure' and the reporting requirements as above

- Number of measurements within the 0–30cm, as well as where applicable, number of measurements within the 30–60cm layer and the 60–100+cm layer

d) Datasets

- The instrument monitoring data recorded daily at the start of the measurements, showing the counts per second attained for each of the standard materials with known densities as well as the densities of the known standards used

- All of the gamma and derived bulk density data collected along with the spatial location from which it was sourced

Part I: Specified Probability of Exceedance

The **Specified Probability of Exceedance** is set at 60%. This is intended to ensure estimates of net abatement are conservative, without precluding reasonable rates of soil organic carbon stock change being recognised.

Requirements:

1. For the relevant equations in the Determination, the "specified probability of exceedance" shall be calculated with an alpha value of:

$$\alpha \; = \; 0.4$$

2. The alpha value specified in Requirement 1 of this Part is to be used in the following sections:

    a) Schedule 1 Section 9 – Equation 49

    b) Schedule 1 Section 32 – Equation 69

    c) Schedule 2 Section 10 – Equation 70

    d) Schedule 2 Section 53 – Equation 116

Part J: Glossary

Accuracy, precision and bias - accuracy (measured by the root mean squared error, RMSE) refers to how close a measured value is to the actual 'true' value; precision (measured by the standard deviation of the error, SDE) is how close the measured values are to each other; and bias (measured by the mean error, ME) is a systematic error which makes all measurements wrong by a certain amount. $RMSE^2 = SDE^2 + ME^2$. Equations for these statistic are:

$$RMSE = \sqrt{\sum_{i=1}^{N} \frac{(\hat{y_i} - y_i)^2}{N}},$$

$$SDE = \sqrt{\sum_{i=1}^{N} \frac{(\hat{y_i} - \bar{y})^2}{(N-1)}},$$

$$ME = \sum_{i=1}^{N} \frac{(\hat{y_i} - y_i)}{N},$$

Equation S27

Where:

$\hat{y_i}$ is the predicted value for sample i, y_i is the observed value for sample i, $\bar{y}$ is the mean of the observed values, and N is the number of data.

Calibration - Operation that, under specified conditions, establishes a relation between the quantity values provided by measurement standards and corresponding spectrometer and uses this information to establish a relation for obtaining a measurement result from the spectrometer.

Confidence limits – represent Confidence limits for the mean are an interval estimate for the mean. The interval estimate gives an indication of how much uncertainty there is in our estimate of the true mean. The narrower the interval, the more precise is our estimate. Confidence limits are defined as:

$$\hat{y} \pm t_{1-\frac{\alpha}{2},N-1} \frac{s}{\sqrt{N}}$$

Equation S28

Where:

$\bar{y}$ is the sample mean value of the organic C predictions, s is the samples standard deviation, N is the sample size, $t1-\frac{\alpha}{2},N-1$ is the value of the t-distribution with N−1 degrees of freedom for the desired for the desired probability level α. For a 95% confidence interval, α=0.05.

Determination is the *Carbon Credits (Carbon Farming Initiative—Estimation of Soil Organic Carbon Sequestration using Measurement and Models) Methodology Determination 2021.*

Estimate - the value of the component concentration or soil property obtained by applying the multivariate (spectroscopic) model.

Estimation event - has the meaning given in section 2 of Schedule 2 of the Determination.

Model validation - the process of testing a multivariate (spectroscopic) model to determine accuracy between the estimates from the model and the reference analytical method.

Multivariate (spectroscopic) modelling - a process for creating a model that relates component concentrations of soil properties to the absorbance of a set of known reference samples at more than one wavelength.

Multivariate statistics - Multivariate statistics encompasses the simultaneous observation and analysis of more than one outcome variable.

Prediction set – the set of soil samples with spectra but no other analytical data onto which the spectroscopic model is to be generalised for predictions of the analyte.

Reference analytical approach - the analytical approach that is used to estimate the component concentration of the soil property value that is used in the modelling and validation procedures.

Reference analytical values - the carbon concentrations for the training or validation sets that are measured using the reference analytical approach.

Standard error of laboratory measurements (SEL) – represents the precision of a laboratory method. It can be determined by using one or more samples properly aliquoted and analysed in replicate by a laboratory. The average analytical value for the replicates on a single sample, $\bar{x}_i$, is determined by:

$$\bar{x}_i = \sum_{j=1}^{r} x_{ij}$$

and the SEL is given by:

$$SEL = \sqrt{\frac{\sum_{i=1}^{N} \sum_{j=1}^{M} \left(x_{ij} - \bar{x}_i\right)^2}{N(r-1)}},$$

Equation S29

Where:

x are the measurements on different samples, i, and different measurements, j, on the same sample, N are the total number of samples, M are the total number of measurements on the same sample, r, is the number of replicate analyses for each sample.

Standardised RMS, sRMSE – The sRMSE, shows the improvement that might be gained compared to using simply the mean of the training data as the prediction. Smaller values indicate less residual variance and better model validation. The sRMSE is calculated by:

$$sRMSE = \frac{RMSE}{\bar{y}}$$

<div align="right">*Equation S30*</div>

Where:

$\bar{y}$ is the mean of the observed values in the training set.

Sub-layer is the term used for layers within a layer. For example, there could be three sub-layers of 10cm each in the 0-30cm layer.

Training set - the set of reference soil samples used for developing a multivariate (spectroscopic) model. These soil samples are analysed using a spectrometer and the reference analytical method.

Validation set - the set of soil samples used in validating the multivariate (spectroscopic) model. The validation set are independent of the training set, but also analysed using a spectrometer as well as the reference analytical method.

Wavelength - defined as the distance between adjacent peaks (or troughs) in a wave of the electromagnetic radiation. Typically designated in units of meters, centimetres, micrometres (10^{-6} m) or nanometres (10^{-9} m).

Part K: References

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