Methods for Monitoring of Carbon Stock Changes and Greenhouse Gas Emissions and Removals in Tidal Wetland Restoration and Conservation Project Activities (M-TW)

Title	Methods for monitoring of carbon stock changes and greenhouse gas emissions in tidal wetland restoration and conservation project activities (M-TW)
Version	20170112
Date of Issue	13 January 2017
Type	Module
Sectoral Scope	Sectoral Scope 14
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1 SOURCES

This module is one of numerous modules that constitute the VCS approved methodology VM0007: REDD Methodology Modules whose framework document is coded REDD+ MF.

This module uses the latest version of the following methodology:

- *VM0033 Methodology for Tidal Wetland and Seagrass Restoration*

This module uses the latest version of the following modules:

- *Module BL-TW VMD00xx Estimation of baseline carbon stock changes and greenhouse gas emissions in tidal wetland restoration and conservation project activities (BL-TW)*
- *Module E-BPB VMD0013 Estimation of greenhouse gas emissions from biomass and peat burning*
- *Module X-STR VMD0016 Methods for stratification of the project area*
- *Module VMD0019 Methods to Project Future Conditions*
- *Module M-ARR VMD0045 Methods for monitoring greenhouse gas emissions and removals in ARR project activities on wetland and terrestrial soil*
- *Module E-FFC VMD0014 Estimation of emissions from fossil fuel combustion*
- *Module CP-AB VMD0001 Estimation of carbon stocks in the above- and belowground biomass in live tree and non-tree pools*

2 SUMMARY DESCRIPTION OF THE MODULE

This module is for the estimation of project emissions associated with WRC project activities implemented on tidal wetlands.

This module provides conservative procedures to estimate emission reductions and removals generated by Restoration of Wetland Ecosystems (RWE) and Conservation of Intact Wetlands (CIW) project activities.

3 DEFINITIONS

Allochthonous Soil Organic Carbon
Soil organic carbon originating outside the project area deposited within the project area (compare to *unreactive allochthonous soil organic carbon*, below).

Autochthonous Soil Organic Carbon
Soil organic carbon originating or forming in the project area (e.g., from vegetation)

Carbon Preservation Depositional Environment (CPDE)
Type of subaquatic sediment deposition environment that impacts the amount of deposited organic

carbon that is preserved. Carbon preservation is affected by mineral grain size, sediment accumulation and burial rates, O_2 availability in the overlying water column and sediment hydraulic conductivity.

Deltaic Fluidized Mud

A Carbon Preservation Depositional Environment (CPDE) type. This subaquatic depositional environment is characterized by sediment accumulation rates generally greater than 0.4 g per cm^2 per year in deltaic settings, consisting primarily of fluidized (unconsolidated) fine-grain materials. Surface sediments may be re-suspended by waves and tides, but deposited organic matter will be buried. Examples of these can be found in the Amazon and Mississippi deltas.

Extreme Accumulation Rate

A Carbon Preservation Depositional Environment (CPDE) type. This subaquatic depositional environment is characterized by accumulation rates generally greater than 1 g per cm^2 per year resulting in rapid and long-term burial of deposited sediments. Examples of these systems can be found in the Ganges-Brahmaputra and Rhone river deltas.

Impounded Water

A pool of water formed by a dam or pit

Mangrove

A subset of wetlands dominated by mangrove plant species, which are shrubs or trees that grow in coastal saline or brackish water

Marsh

A subset of wetlands characterized by emergent soft-stemmed vegetation and shrubs adapted to saturated soil conditions[1]

Mineral Soil

A soil that does not meet the definition of an organic soil

Mudflat

A subset of tidal wetlands consisting of soft substrate and a near absence of emergent vegetation

Normal marine

A Carbon Preservation Depositional Environment (CPDE) type. This is a depositional environment that does not meet the definition of the other four defined conditions (i.e., *deltaic fluidized mud*, *extreme accumulation rate*, *oxygen depletion zone*, or *small mountainous river*). Normal marine environments typically have low sedimentation rates and high O_2 availability in overlying sediments,

Open Water

An area in which water levels do not fall to an elevation that exposes the underlying substrate

Organic Soil

Soil with a surface layer of material that has a sufficient depth and percentage of organic carbon to meet

[1] There are many different kinds of marshes, ranging from the prairie potholes to the Everglades, coastal to inland, freshwater to saltwater, but the scope of this methodology is limited to tidal marshes. Salt marshes consist of salt-tolerant and dwarf brushwood vegetation overlying mineral or organic soils.

an internationally accepted threshold (e.g., host-country, FAO or IPCC) of organic soil. Where used in this methodology, the term *peat* is used to refer to organic soil.

Oxygen (O_2) Depletion Zone

A Carbon Preservation Depositional Environment (CPDE) type. This is a depositional environment with low O_2 levels in water overlying sediments due to restricted hydrologic circulation or impaired water quality that leads to hypoxic or anaerobic conditions (including euxinic and semi-euxinic).

Salinity Average

The average water salinity value of a wetland ecosystem used to represent variation in salinity during periods of peak CH_4 emissions (e.g., during the growing season in temperate ecosystems)

Salinity Low Point

The minimum water salinity value of a wetland ecosystem used to represent variation in salinity during periods of peak CH_4 emissions (e.g., during the growing season in temperate ecosystems)

Seagrass Meadow

An accumulation of seagrass plants over a mappable area. This definition includes both the biotic community and the geographic area where the biotic community occurs. Note that the vast majority of seagrass meadows are sub-tidal, but a percentage are intertidal.

Small Mountainous River (SMR)

A Carbon Preservation Depositional Environment (CPDE) type. This is a depositional environment from which the sediment is supplied from small mountainous rivers, most commonly found in tectonically active margins and small steep gradients. Sediment accumulation rates are generally greater than 0.27 g per cm^2 per year. Examples of these systems can be found in the rivers flowing from the island of Taiwan and the Eel river of California.

Tidal Wetland

A subset of wetlands under the influence of the wetting and drying cycles of the tides (e.g., marshes, seagrass meadows, tidal forested wetlands and mangroves). Subtidal seagrass meadows are not subject to drying cycles, but are still included in this definition.

Tidal Wetland Restoration

Restoration of degraded tidal wetlands in which establishment of prior ecological conditions is not expected to occur in the absence of the project activity. For the purpose of this methodology, this definition also includes activities that create wetland ecological conditions on mudflats or within open or impounded water.

Unreactive Allochthonous Soil Organic Carbon

The portion of soil organic carbon originating outside the project area deposited within the project boundary that is stable over the project period regardless of depositional environment. In practice, it is the portion of allochthonous soil organic carbon associated with and stabilized by soil minerals.

Water Table Depth

Depth of sub-soil or above-soil surface of free water, relative to the soil surface.

Acronyms

ARR	Afforestation, Reforestation and Revegetation
REDD	Reducing Emissions from Deforestation and forest Degradation
RWE	Restoration of Wetlands Ecosystems
CIW	Conservation of Intact Wetlands
VCS	Verified Carbon Standard
WRC	Wetlands Restoration and Conservation
CPDE	Carbon Preservation Depositional Environment
GHG	Greenhouse Gas
SOC	Soil Organic Carbon

4 APPLICABILITY CONDITIONS

This module applies to tidal wetland restoration and conservation project activities, as defined in *REDD+ MF*. This module is applicable under the same applicability conditions outlined in *REDD+ MF* for WRC project activities.

5 PROCEDURES

5.1 General

5.1.1 General Procedures

Emissions in the project scenario are attributed to carbon stock changes in biomass carbon pools, soil processes, or a combination of these. In addition, where relevant, emissions from fossil fuel use may be quantified.

When referred to use procedures in Module *BL-TW*, for all equations in these sections, the subscript *BSL* must be substituted by *WPS* to make clear that the relevant values are being quantified for the project scenario.

Emissions in the project scenario are estimated as:

$$GHG_{WPS-TW} = GHG_{WPS-biomass} + GHG_{WPS-soil} + GHG_{WPS-fuel} + GHG_{WPS-burn} \quad \textbf{(1)}$$

$$GHG_{WPS-biomass} = -\sum_{t=1}^{t^*}\sum_{i=1}^{M_{WPS}}\left(\frac{44}{12}\times \Delta C_{WPS-biomass,i,t}\right) \quad \textbf{(2)}$$

$$GHG_{WPS-soil} = \sum_{t=1}^{t^*}\sum_{i=1}^{M_{WPS}} GHG_{WPS-soil,i,t} \quad \textbf{(3)}$$

$$GHG_{WPS-fuel} = \sum_{t=1}^{t^*} \sum_{i=1}^{M_{WPS}} GHG_{WPS-fuel,i,t} \quad (4)$$

$$GHG_{WPS-burn} = \sum_{t=1}^{t^*} \sum_{i=1}^{M_{WPS}} GHG_{WPS-burn,i,t} \quad (5)$$

Where:

GHG_{WPS-TW}	Net CO_2e emissions in the project scenario up to year *t**; t CO_2e
$GHG_{WPS-biomass}$	Net CO_2e emissions from biomass carbon pools in the project scenario up to year *t**; t CO_2e
$GHG_{WPS-soil}$	Net CO_2e emissions from the SOC pool in the project scenario up to year *t**; t CO_2e
$GHG_{WPS-fuel}$	Net CO_2e emissions from fossil fuel use in the project scenario up to year *t**; t CO_2e
$GHG_{WPS-burn}$	Net CO_2e emissions from prescribed burning in the project scenario up to year *t**; t CO_2e
$\Delta C_{WPS-biomass,i,t}$	Net carbon stock changes in biomass carbon pools in the project scenario in stratum *i* in year *t*; t C yr^{-1}
$GHG_{WPS-soil,i,t}$	GHG emissions from the SOC pool in the project scenario in stratum *i* in year *t*; t CO_2e yr^{-1}
$GHG_{WPS-fuel,i,t}$	GHG emissions from fossil fuel use the project scenario in stratum *i* in year *t*; t CO_2e yr^{-1}
$GHG_{WPS-burn,i,t}$	GHG emissions from prescribed burning in the project scenario in stratum *i* in year *t*; t CO_2e yr^{-1}
i	1, 2, 3 …M_{WPS} strata in the project scenario
t	1, 2, 3, … *t** years elapsed since the project start date

Estimation of GHG emissions and removals related to the biomass pool is based on carbon stock changes. For ARR project activities on tidal wetlands, procedures are provided in Module *M-ARR*. For REDD project activities on tidal wetlands, procedures are provided in Module *CP-AB*. When using Modules *M-ARR* and *CP-AB*, note must be taken of procedures provided in Section 5.2.

Estimation of GHG emissions and removals from the SOC pool is based on either various proxies (e.g., carbon stock change, water table depth) or through the use of literature, data, default factors or models. Procedures are provided in Module *BL-TW*. When referred to use procedures in Module *BL-TW*, for all equations in these sections, the subscript *BSL* must be substituted by *WPS* to make clear that the relevant values are being quantified for the project scenario.

Procedures for the estimation of emissions from fossil fuel use are provided in Module *E-FFC*.

Procedures for the estimation of emissions from biomass burning use are provided in Module *E-BPB*.

Ex-ante estimates of GHG_{WPS} must be based on a project scenario that is defined *ex ante*, and must be projected using the latest version of VCS module *VMD0019 Methods to Project Future Conditions*.

Ex-post estimates of GHG_{WPS} must be based on monitoring results.

5.2 Accounting for Submergence and Erosion

See Section 5.2 in Module *BL-TW* for procedures for accounting for submergence and erosion. For all equations, the subscript *BSL* must be substituted by *WPS* to make clear that the relevant values are being quantified for the project scenario.

In areas with wave action, there may be a net loss of soil material in cases where erosion exceeds deposition, which would lead to carbon removal. In the project scenario, assuming that all carbon is oxidized and returned to the atmosphere is conservative. However, in most cases a portion of this carbon will not return to the atmosphere. Procedures are provided in Section 5.3.3 in Module *BL-TW* to estimate this quantity.

5.3 Assessing Soil GHG Emissions in the Project Scenario

5.3.1 General

Net GHG emissions from soil in the project scenario are estimated as:

$$GHG_{WPS\text{-}soil,i,t} = A_{i,t} \times (GHG_{WPS\text{-}soil\text{-}CO2,i,t} - Deduction_{alloch} + GHG_{WPS\text{-}soil\text{-}CH4,i,t} + GHG_{WPS\text{-}soil\text{-}N2O,i,t}) \quad \textbf{(6)}$$

CO_2 emissions from the SOC pool in the project scenario may occur in situ or indirectly following soil erosion (see Equation 7). For strata with *in-situ* emissions, follow the procedures set out in Section 5.3.2 below. For strata where soil erosion occurs, the procedures in Section 5.3.3 must be used. For strata with *in-situ* emissions, CH_4 and N_2O emissions must be estimated using the procedures in Sections 5.3.4 and 5.3.5, respectively.

$$GHG_{WPS\text{-}soil\text{-}CO2,i,t} = GHG_{WPS\text{-}insitu\text{-}CO2,i,t} + GHG_{WPS\text{-}eroded\text{-}CO2,i,t} \quad \textbf{(7)}$$

Where:

$GHG_{WPS\text{-}soil,i,t}$	GHG emissions from the SOC pool in the project scenario in stratum *i* in year *t*; t CO_2e yr^{-1}
$GHG_{WPS\text{-}soil\text{-}CO2,i,t}$	CO_2 emissions from the SOC pool in the project scenario in stratum *i* in year *t*; t CO_2e ha^{-1} yr^{-1}
$Deduction_{alloch}$	Deduction from CO_2 emissions from the SOC pool to account for the percentage of the carbon stock that is derived from allochthonous soil organic carbon; t CO_2e ha^{-1} yr^{-1}
$GHG_{WPS\text{-}soil\text{-}CH4,i,t}$	CH_4 emissions from the SOC pool in the project scenario in stratum *i* in year *t*; t CO_2e ha^{-1} yr^{-1}
$GHG_{WPS\text{-}soil\text{-}N2O,i,t}$	N_2O emissions from the SOC pool in the project scenario in stratum *i* in year *t*; t

	$t\ CO_2e\ ha^{-1}\ yr^{-1}$
$GHG_{BSL\text{-}insitu\text{-}CO2,i,t}$	CO_2 emissions from the SOC pool of *in-situ* soils in the baseline scenario in stratum *i* in year *t*; t CO_2e ha^{-1} yr^{-1}
$GHG_{BSL\text{-}eroded\text{-}CO2,i,t}$	CO_2 emissions from the eroded SOC pool environment in the baseline scenario in stratum *i* in year *t* ; t CO_2e ha^{-1} yr^{-1}
$A_{i,t}$	Area of stratum *i* in year *t*; ha
i	1, 2, 3 …M_{WPS} strata in the project scenario
t	1, 2, 3, … *t** years elapsed since the project start date

5.3.2 CO_2 Emissions from Soil – *in situ*

CO_2 emissions from soils may be estimated using:

1) Proxies
2) Published values
3) Default factors and emission factors
4) Models
5) Field-collected data, or
6) Historical or chronosequence-derived data

In certain cases, allochthonous soil organic carbon may accumulate in the project area, and such carbon must be accounted for in the project scenario. Procedures for the estimation of a compensation factor for allochthonous soil organic carbon are specified in Section 5.3.2.2.

5.3.2.1 Approaches for estimating $GHG_{WPS\text{-}insitu\text{-}CO2,i,t}$

$GHG_{WPS\text{-}insitu\text{-}CO2,i,t}$ must be calculated using the same procedures set out in Sections 5.3.2.1 – 5.3.2.5 in Module *BL-TW.* For all equations in these sections, the subscript *BSL* must be substituted by *WPS* to make clear that the relevant values are being quantified for the project scenario.

Note that linear interpolation of the default factor may not be used for areas with a crown cover between 15% and 50%.

5.3.2.2 Deduction for allochthonous carbon

A deduction must be applied to account for allochthonous carbon using the procedures set out in Section 5.3.2.6 of Module *BL-TW*. The project proponent must also follow the additional guidance below.

The determination of the deduction for allochthonous carbon is mandatory for the project scenario unless the project proponent is able to demonstrate that the allochthonous carbon would have been returned to the atmosphere in the form of carbon dioxide in the absence of the project.

The deduction for allochthonous carbon must only be applied to soil layers deposited or accumulated after the project start date (such as materials formed above a feldspar marker horizon).

If the organic surface layer exceeds 10 cm, the soil is deemed organic and no deduction is required. If an organic surface layer of up to 10 cm is present, *deduction_alloch* must be determined only in such cases where the project experiences mineral sedimentation events sufficient to create mineral soil layers. In practice, the project area may show mineral sedimentation in places. If this is observed it is assumed that at some point during the project crediting period mineral sediment can be deposited on top of organic surface layers, unless the project proponent can justify that strata with an organic surface layer of less than 10 cm will not experience mineral sedimentation during the project crediting period.

5.3.3 CO_2 Emissions from Eroded Soil

For each stratum *i* at time *t* the project proponent must determine if soil erosion occurs.

CO_2 emissions from eroded soil material ($GHG_{WPS\text{-}eroded\text{-}CO2,i,t}$) may be calculated directly or may be calculated from estimates of the amount of carbon that is eroded ($C_{WPS\text{-}eroded,i,t}$) and the percentage of the eroded carbon that is returned to the atmosphere ($C\%_{WPS\text{-}emitted\text{-}CO2,i,t}$) as defined in Equation 8.

$$GHG_{WPS\text{-}eroded\text{-}CO2,i,t} = 44/12 \times C_{WPS\text{-}eroded,i,t} \times C\%_{WPS\text{-}emitted,i,t} / 100 \quad \textbf{(8)}$$

Where:

$GHG_{WPS\text{-}eroded\text{-}CO2,i,t}$	CO_2 emissions from the eroded SOC pool in the project scenario; t CO_2e ha^{-1} yr^{-1}
$C_{WPS\text{-}eroded,i,t}$	C mass present in eroded soil material in the project scenario; t C ha^{-1} yr^{-1}
$C\%_{WPS\text{-}emitted,i,t}$	C emissions as a percentage of C mass present in eroded soil material in the project scenario[2]; %

$$C_{WPS\text{-}eroded,i,t} = C\%_{WPS\text{-}eroded,i,t} \times BD \times Depth \quad \textbf{(9)}$$

Where:

$C\%_{WPS\text{-}eroded,i,t}$	% Carbon of soil material eroded; %
BD	Soil bulk density; kg m^{-3}
Depth	Depth of the eroded area from the surface to the surface prior to erosion; m

Project proponents can use any combination of the following methods to calculate these terms:

1) Proxies

2 To ensure a conservative outcome, emissions must be estimated for a 1-year time period following the initial year of erosion.

2) Published values

3) Default factors

4) Models

5) Field-collected data, or

6) Historical or chronosequence-derived data

5.3.3.1 Approaches for estimating $GHG_{WPS\text{-}eroded\text{-}CO2,i,t}$

$GHG_{WPS\text{-}eroded\text{-}CO2,i,t}$ must be calculated using the same procedures set out in Sections 5.3.3.1 – 5.3.3.6 in Module *BL-TW.* For all equations in these sections, the subscript *BSL* must be substituted by *WPS* to make clear that the relevant values are being quantified for the project scenario.

5.3.4 CH_4 Emissions from Soil – *in situ*

The estimation of CH_4 emissions in the project scenario must follow one of the approaches provided in Section 5.3.5 in Module *BL-TW*. For all equations in these sections, the subscript *BSL* must be substituted by *WPS* to make clear that the relevant values are being quantified for the project scenario.

5.3.5 N_2O Emissions from Soil – *in situ*

Where the project proponent is able to demonstrate (e.g., by referring to peer-reviewed literature based on similar project circumstances[3]) that N_2O emissions do not increase in the project scenario compared to the baseline scenario, N_2O emissions may be excluded.

N_2O emissions must be accounted for in the project scenario in strata where water levels were lowered as a result of project activities[4]. Seagrass restoration projects do not require N_2O emission accounting. The estimation of N_2O emissions in the project scenario may follow one of the approaches provided in Section 5.3.6 in Module *BL-TW*. For all equations in these sections, the subscript *BSL* must be substituted by *WPS* to make clear that the relevant values are being quantified for the project scenario.

In addition, where the project proponent is able to demonstrate (e.g., by referring to peer-reviewed literature) that N_2O emissions in the project scenario are *de minimis*, N_2O emissions may be excluded. To demonstrate that N_2O emissions are *de minimis* in the project scenario, the project proponent must use CDM tool *Tool for testing significance of GHG emissions in A/R CDM project activities*, or refer to peer-reviewed literature.

5.4 Monitoring Procedures

5.4.1 Soil coring approach for estimating soil organic carbon

Soil organic carbon stock ($C_{WPS\text{-}soil\ i,t}$) may be estimated by determining the organic carbon present above a consistent reference plane. The reference plane must be established using a marker horizon (most

3 Project circumstances are defined by pre-project land use (e.g., forestry, agriculture, abandonment after such activities) and its intensity (especially related to N-fertilization), climatic zone, water table depths, and soil type.

4 See applicability conditions.

commonly using feldspar)[5], a strongly contrasting soil layer (such as the boundary between organic and mineral soil materials), an installed reference plane (such as the shallow marker in a surface elevation table)[6], a layer identified biogeochemically (such as through radionuclide, heavy metal, or biological tracers)[7], a layer with soil organic carbon indistinguishable from the baseline SOC concentration (as determined in Module *BL-TW* Section 5.3.2.5)[8] or other accepted technologies. Note that feldspar marker horizons may not be used in systems where they are unstable, such as some sandy soils and systems with significant bioturbation. The material below the reference plane may be conservatively assumed to have zero change due to project activities.

The material located above the reference plane must be analyzed for total carbon and bulk density. Sediment samples may be collected for the estimation of $\%C_{depsed}$ (see Section 5.3.2.6 of Module *BL-TW*) using sediment tiles,[9] through collection of suspended sediments in tidal channels during a period of high suspended sediment concentration or by collecting cores of sediment deposits in tidal flats. Total organic carbon must be analyzed directly using CHN elemental analysis or the Walkley-Black chromic acid wet oxidation method or determined from loss-on-ignition (LOI) data using the following equation:

$\%C_{soil} = 0.04 \times \%OM_{soil} + 0.0025 \times \%OM_{soil}^2$ (only for marsh soils)[10] **(10)**

$\%C_{soil} = \%OM_{soil} / 1.724$ (only for mangrove soils)[11] **(11)**

$\%C_{soil} = -0.21 + 0.40\ (\%OM_{soil})$ (only for seagrass soils with $\%OM_{soil} < 20$ percent)[12] **(12)**

$\%C_{soil} = -0.33 + 0.43\ (\%OM_{soil})$ (only for seagrass soils with $\%OM_{soil} > 20$ percent)[13] **(13)**

Alternatively, an equation developed using site-specific data may be used or an equation from peer-reviewed literature may be used if the equation represents soils from the same or similar systems as those in the project area.

Inorganic carbon must be removed from samples if present in significant quantities, usually through acid treatment (such as sulfurous or hydrochloric acid). Live coarse below-ground tree biomass must be removed from soil samples prior to analysis. Additional live below-ground biomass may be removed or included. Soil samples collected may be aggregated to reduce the variability.

The mass of carbon per unit area is calculated as follows:

$$C_{WPS-soili,t} = \sum_{i=1}^{Ndepth} \left(CF_{SOC,sample} \times BD \times Thickness \times 100 \right) \quad \textbf{(14)}$$

Where:

$C_{WPS\text{-}soil\ i,t}$	Carbon stock in the project scenario in stratum *i* in year *t* (t C ha^{-1})
Ndepth	Number for soil horizons, based on subdivisions of soil cores

5 Cahoon and Turner 1989
6 Cahoon *et al.* 2002
7 DeLaune *et al.* 1978
8 Greinier *et al.* 2013
9 Pasternack and Brush 1998
10 Craft *et al.* 1991
11 Allen 1974
12 Fourqurean *et al*. 2012 as summarized in Howard *et al*. 2014
13 Fourqurean *et al*. 2012 as summarized in Howard *et al*. 2014

CF_{SOC_sample}	Carbon fraction of the sample, as determined in laboratory (%)
BD	Bulk density, as determined in laboratory (kg cm^{-3})
Thickness	Thickness of soil horizon (cm)
100	Conversion factor of g cm^{-3} to Mg ha^{-1}

5.4.2 Monitoring CH_4 and N_2O emissions

Direct measurement of CH_4 and/or N_2O emissions may be made with either a closed chamber technique or a chamber-less technique such as eddy covariance flux. For eddy covariance methods, the guidelines presented in VCS methodology *VM0024 Methodology for Coastal Wetland Creation* must be followed, taking into account the additional guidance below.

Flux measurements are expected to conform to standard best practices used in the scientific community[14]. The basic design of the closed chamber for wetlands requires a base that extends into the soil (5 cm minimum), and a chamber that is placed over the plants and sealed to the base. To prevent the measurement from disturbing CH_4 emissions, the base must be placed at least one day in advance, and the plot must be approached on an elevated ramp or boardwalk when taking samples, although failure to do so is conservative because it will cause higher fluxes. CH_4 flux is calculated as the difference in initial and final headspace CH_4 concentration, without removing non-linear increases caused by bubble (ebullition) fluxes that may have occurred. Initial and final concentrations will be determined as the average of duplicate determinations. Because CH_4 and N_2O emissions can be low from tidal wetlands, it may be necessary to enclose large areas ($\geq$ 0.25 m^2) or lengthen the measurement period to improve sensitivity.

Methane emissions from strata lacking vegetation (<25 percent cover), such as open water, hollows or ponds, can be dominated by episodic bubble emissions (i.e., ebullition). Chambers for open water emissions are typically a single piece that floats such that the bottom extends under the water surface (5 cm minimum). Floating chambers must be deployed for a minimum of 4 days.

Eddy covariance techniques sense total CH_4 and N_2O emissions (diffusive and ebullition) at high temporal resolution; such systems must be deployed for a minimum of 48 hours of useable data.

CH_4 and N_2O emission estimates must be either accurate or conservative. Accurate estimates must account for variation in time caused by changes in plant activity, temperature, water table depth, salinity and other sources of variation, and in space caused by factors such as topography (e.g., hummocks versus hollows) or plant cover. A conservative estimate may be based on direct measurements taken at times and places in which CH_4 or N_2O emissions are expected to be the highest based on expert judgment, datasets or literature.

Fluxes must be measured in the stratum with the highest emissions. For CH_4, these are likely to be strata in the wettest strata that support emergent vegetation, but may include stagnant pools of water. Eddy flux towers must be placed so that the footprint lies in the stratum with the highest CH_4 or N_2O emissions for 50 percent of the time. CH_4 fluxes must be measured when the water table is <10 cm from the soil surface, during times of year when emissions are highest, such as the warmest month and/or wettest month. When CH_4 emission rates incorporate measurements from periods of time outside the peak, they must be made at approximately monthly intervals.

[14] Oremland 1975

In addition to the conservative principles above, the project proponent must consider other factors that are specific to the method applied. In particular, closed chambers must be transparent and deployed in daylight unless it is can be shown that CH_4 emissions are not sensitive to light.

Regardless of method, emissions must be averaged and expressed as daily (24 hour) rates and converted to annual estimates using the following equations:

$$GHG_{WPS\text{-}soil\text{-}CH4,i,t} = GHG_{CH4\text{-}daily,i,t} \times 365 \times CH4\text{-}GWP \quad \textbf{(15)}$$

Where:

$GHG_{WPS\text{-}soil\text{-}CH4,i,t}$	CH_4 emissions from the SOC pool in the project scenario in stratum *i* in year *t* (t CO_2e ha^{-1} yr^{-1})
$GHG_{CH4\text{-}daily,i,t}$	Average daily CH_4 emissions in the project scenario based on direct measurements of stratum *i* in year *t* (mg CH_4 m^{-2} d^{-1})
CH4-GWP	Global warming potential of CH_4 (dimensionless)
i	1, 2, 3 …M_{WPS} strata in the project scenario
t	1, 2, 3, … *t** years elapsed since the project start date

$$GHG_{WPS\text{-}soil\text{-}N2O,i,t} = GHG_{N2O\text{-}daily,i,t} \times 365 \times N2O\text{-}GWP \quad \textbf{(16)}$$

Where:

$GHG_{WPS\text{-}soil\text{-}N2O,i,t}$	N_2O emissions from the SOC pool in the project scenario in stratum *i* in year *t* (t CO_2e ha^{-1} yr^{-1})
$GHG_{N2O\text{-}daily,i,t}$	Average daily N_2O emissions in the project scenario based on direct measurements of stratum *i* in year *t* (mg N_2O m^{-2} d^{-1})
N2O-GWP	Global warming potential of N_2O (dimensionless)
i	1, 2, 3 …M_{WPS} strata in the project scenario
t	1, 2, 3, … *t** years elapsed since the project start date

Where the default factor approach is used for CH_4 emissions (see Section 5.3.4), the salinity average or salinity low point will be measured on shallow pore water (within 30 cm from soil surface) using a handheld salinity refractometer or other accepted technology. The salinity average must be calculated from observations that represent variation in salinity during periods of peak CH_4 emissions (e.g., during the growing season in temperate ecosystems or the wet season in tropical ecosystems). When the number of observations during this period is small (fewer than one per month for one year), the salinity low point from these data must be used. The salinity of the floodwater source (e.g., an adjacent tidal creek) during this period may be used as a proxy for salinity in pore water provided there is regular hydrologic exchange between the source and the wetland (i.e., the source floods the wetland at least on 20 percent of high tides).

5.4.3 Estimation of Eroded Soil Depth and Depth of Soil Exposed to Aerobic Conditions

Soil carbon loss may occur through three mechanisms: 1) vertical edge erosion at a wetland edge or channel bank, generally occuring at the seaward margin of wetlands exposed to wave energy, 2) horizontal surface soil erosion; and/or 3) soil exposure to aerobic conditions.

1) Vertical edge erosion at a wetland edge or channel bank: The depth of eroded soil may be measured in the field directly from the difference in elevation between the emergent wetland surface at the wetland edge to the surface of an adjacent mudflat, or sediments below adjacent waters. The adjacent point must be chosen conservatively, and must represent the shallowest point of the transition from the wetland to mudflat or adjacent subaquatic sediment surface. Determination of the surface elevation of mudflat slope must be based upon the projected amount of emergent wetland retreat. Internal loss of sediment through channel enlargement and or channel network expansion occurs in wetlands with insufficient sediment supply to build at a pace matching sea level rise in settings with a tidal range greater than 1 m. Change in channel volume can be calculated using hydraulic geometry equations and approaches.[15]

2) Horizontal surface soil erosion: Soil depth may be calculated by direct measurement at a reference site with reference to a datum that can be justified as not having shifted vertically relative to the original soil surface. This datum may be depth to a mineral soil horizon that has not shifted due to compaction or a bedrock soil horizon, a point on mangrove stumps held in place vertically (generally due to soils composed of coarse silt or sand), or through radiometric analysis to identify the age of exposed soil surfaces.

3) Soil exposure to aerobic conditions: The depth of soil exposed to aerobic conditions through drainage is intended to identify the depth at which anaerobic conditions no longer suppress organic matter decomposition as they do in wetland soils. In wetland science, these anaerobic conditions are generally understood to correspond to the conditions in which iron is reduced. The depth to which the soil is reducing with respect to iron may be identified using platinum electrodes, IRIS (Indicator of Reduction in Soils) Tubes,[16] the presence of reduced iron in pore water or on soil ped surfaces (indicated with Alpha-alpha-Dipyridyl or other laboratory analysis), or other accepted technologies. These methods must be used during the time of year with the peak height of anaerobic condtions (ie, peak sustained water table and sufficient temperature for microbial activity[17]).

5.4.4 Monitoring Water Table

If water table is used as a proxy for carbon loss and GHG emissions, monitoring of water tables in the project or proxy area must be based on measurements in appropriate strata (see module *X-STR*). Water table depth measurements can be continuous with data loggers and using min-max devices (eg, Bragg et al., 1994) or simple water level gauges (dipwells consisting of e.g., perforated PVC tubes), Applied techniques must follow international standards of application or local standards as laid out in pertinent scientific literature or handbooks.

Water table depth measurements must be carried out at least every two months. At least 10 replicate dipwells must be evenly distributed per stratum, to ensure data consistency also when dipwells are lost. In peat swamp forest, dipwells must be placed in surface depressions between tree mounds. Visual

15 e.g., Allen 2000; Williams and Orr 2002
16 Rabenhorst *et.al*. 2013
17 Vaughan *et.al*. 2009

inspection of the multiple records within a single stratum allows for identification of outlier values at single locations, indicating measurement errors that should be excluded from analysis. For remote and inaccessible areas, project proponents may rely on vegetation cover as an indicator for water table depth as supported by data or literature references in a conservative way.

6 DATA AND PARAMETERS

6.1 Data and Parameters Available at Validation

Data / Parameter	*CH4-GWP*
Data unit	Dimensionless
Description	Global Warming Potential of CH_4
Equations	14
Source of data	IPCC
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	N/A
Purpose of Data	Calculation of project emissions
Comments	N/A

Data / Parameter	*N2O-GWP*
Data unit	dimensionless
Description	Global warming potential for N_2O
Equations	15
Source of data	IPCC
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	N/A
Purpose of Data	Calculation of project emissions
Comments	N/A

6.2 Data and Parameters Monitored

Estimation of GHG emissions and removals related to the biomass pool is based on carbon stock changes. For ARR project activities on tidal wetlands, data and parameters are provided in Module *M-ARR*. For REDD project activities on tidal wetlands, data and parameters are provided in Module *CP-AB*.

Data / Parameter	$GHG_{WPS\text{-}biomass}$
Data unit	t CO_2e
Description	Net CO_2e emissions from biomass carbon pools in the project scenario up to year *t**
Equations	1
Source of data	For ARR project activities on tidal wetlands, procedures are provided in Module *M-ARR*. For REDD project activities on tidal wetlands, procedures are provided in Module *CP-AB*. When using Modules *M-ARR* and *CP-AB*, note must be taken of procedures provided in Section 5.2.
Description of measurement methods and procedures to be applied	See Modules *M-ARR* and *CP-AB*
Frequency of monitoring/recording	See Modules *M-ARR* and *CP-AB*
QA/QC procedures to be applied	See Modules *M-ARR* and *CP-AB*
Purpose of Data	Calculation of project emissions
Calculation method	N/A
Comments	N/A

Data / Parameter	$GHG_{WPS\text{-}fuel}$
Data unit	t CO_2e
Description	Net CO_2e emissions from fossil fuel use in the project scenario up to year *t**
Equations	1
Source of data	Parameter E_{FC} in Module *E-FFC*
Description of	See Module *E-FFC*

measurement methods and procedures to be applied	
Frequency of monitoring/recording	See Module *E-FFC*
QA/QC procedures to be applied	See Module *E-FFC*
Purpose of Data	Calculation of project emissions
Calculation method	N/A
Comments	N/A

Data / Parameter	$GHG_{WPS\text{-}burn}$
Data unit	t CO_2e
Description	Net CO_2e emissions from prescribed burning in the project scenario up to year *t**; t CO_2e
Equations	1
Source of data	Parameter $E_{biomassburn}$ in Module *E-BPB*
Description of measurement methods and procedures to be applied	See Module *E-FFC*
Frequency of monitoring/recording	See Module *E-FFC*
QA/QC procedures to be applied	See Module *E-FFC*
Purpose of Data	Calculation of project emissions
Calculation method	N/A
Comments	N/A

Data / Parameter	$A_{i,t}$
Data unit	ha
Description	Area of stratum *i* in year *t*
Equations	6
Source of data	Module *X-STR*

Description of measurement methods and procedures to be applied	See Module *X-STR*
Frequency of monitoring/recording	See Module *X-STR*
QA/QC procedures to be applied	See Section 9.3 of REDD+ MF or other VCS methodology that uses this module.
Purpose of Data	Calculation of project emissions
Calculation method	N/A
Comments	N/A

Data / Parameter	$Rate_{subs\text{-}WPS,i}$
Data unit	m yr^{-1}
Description	Rate of organic soil loss due to subsidence in the project scenario in stratum *i*
Equations	Similar to 10 in Module *BL-TW*
Source of data	The rate of organic soil loss due to subsidence must be based on verifiable information and may be derived from: 1) Data must be based on surface height measurements relative to a fixed reference point in m asl, following methods described in Ballhorn *et al*. 2009 (eg, using poles fixed in the underlying mineral soil or rock, or by remote sensing) or similar. Or 2) CO_2 emissions derived from GHG emission proxies, see Module *BL-TW*, in combination with data on volumetric carbon content of the organic soil. Divide the annual CO_2 emission (t CO_2 ha^{-1}) by 44/12, then divide by volumetric carbon content (g C cm^{-3}) to obtain height loss in m. The average depth of burn scars may be derived from expert judgment, datasets and/or literature of historic burn depths involving the project or similar areas. Data must be based on surface height measurements, using field measurements or remote sensing (eg, following methods described in Ballhorn *et al*. 2009). The areal extent of burn scars may be obtained from statistics and/or maps in official reports and/or field measurements or remote sensing data.
Description of measurement methods and procedures to be applied	See *Source of data* above and Couwenberg & Hooijer (2013).
Frequency of	At each monitoring period

monitoring/recording	
QA/QC procedures to be applied	See Section 9.3 of *REDD+ MF* or other VCS methodology that uses this module
Purpose of Data	Calculation of project emissions
Calculation method	See *Source of data* above
Comments	Refer to procedures set out in Module *BL-TW.* The subscript *BSL* must be substituted by *WPS*.

Data / Parameter	$C_{WPS\text{-}soil,i,t}$
Data unit	t C ha^{-1}
Description	Carbon stock in the project scenario in stratum *i* in year *t*
Equations	Similar to 11 in Module BL-TW
Source of data	Own measurements
Description of measurement methods and procedures to be applied	See Section 5.4.1
Frequency of monitoring/recording	At each monitoring period
QA/QC procedures to be applied	See Section 9.3 of *REDD+ MF* or other VCS methodology that uses this module
Purpose of Data	Calculation of project emissions
Calculation method	N/A
Comments	Refer to procedures set out in Module *BL-TW.* The subscript *BSL* must be substituted by *WPS*.

Data / Parameter	$\%OM_{soil}$
Data unit	%
Description	Percentage of soil organic matter
Equations	10, 11, 12, 13
Source of data	Direct measurements or may be derived from direct measurements of soil organic matter. These measurements may be made using samples collected in Section 5.4.1 or indirectly from the soil organic matter percentage determined through loss- on-ignition as described in Section 5.4.1.

Description of measurement methods and procedures to be applied	The equations provided were developed for tidal marsh soils by Craft *et al*. 1991 and for mangrove soils by Allen 1974
Frequency of monitoring/recording	At each monitoring period
QA/QC procedures to be applied	See Section 9.3 of *REDD+ MF* or other VCS methodology that uses this module
Purpose of Data	Calculation of project emissions
Calculation method	N/A
Comments	N/A

Data / Parameter	$C\%_{WPS\text{-}eroded,i,t}$
Data unit	%
Description	% Carbon of soil material eroded
Equations	9
Source of data	See Module *BL-TW*
Description of measurement methods and procedures to be applied	See Module *BL-TW*
Frequency of monitoring/recording	At each monitoring period
QA/QC procedures to be applied	See Section 9.3 of *REDD+ MF* or other VCS methodology that uses this module
Purpose of Data	Calculation of project emissions
Calculation method	N/A
Comments	Refer to procedures set out in Module *BL-TW*. The subscript *BSL* must be substituted by *WPS*.

Data / Parameter	$C\%_{WPS\text{-}emitted,i,t}$
Data unit	%
Description	C emissions as a percentage of C mass present in eroded soil material in the project scenario

Equations	8
Source of data	See Module *BL-TW*
Description of measurement methods and procedures to be applied	See Module *BL-TW*
Frequency of monitoring/recording	At each monitoring period
QA/QC procedures to be applied	See Section 9.3 of *REDD+ MF* or other VCS methodology that uses this module
Purpose of Data	Calculation of project emissions
Calculation method	N/A
Comments	Refer to procedures set out in Module *BL-TW*. The subscript *BSL* must be substituted by *WPS*.

Data / Parameter	*Depth*
Data unit	m
Description	Depth of the eroded area from the surface to the surface prior to erosion
Equations	9
Source of data	Own measurements
Description of measurement methods and procedures to be applied	See Module *BL-TW*
Frequency of monitoring/recording	At each monitoring period
QA/QC procedures to be applied	See Section 9.3 of *REDD+ MF* or other VCS methodology that uses this module
Purpose of Data	Calculation of project emissions
Calculation method	N/A
Comments	Refer to procedures set out in Module *BL-TW*. The subscript *BSL* must be substituted by *WPS*.

Data / Parameter	*BD*
Data unit	kg m^{-3}

Description	Dry bulk density
Equations	9, 14
Source of data	See Module *BL-TW*
Description of measurement methods and procedures to be applied	See Module *BL-TW*
Frequency of monitoring/recording	At each monitoring period
QA/QC procedures to be applied	See Section 9.3 of *REDD+ MF* or other VCS methodology that uses this module
Purpose of Data	Calculation of project emissions
Calculation method	N/A
Comments	Refer to procedures set out in Module *BL-TW*. The subscript *BSL* must be substituted by *WPS*.

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