WR Methodological Module
Estimation of carbon stocks in the soil organic carbon pool (CP-S)

I. SCOPE, APPLICABILITY AND PARAMETERS

Scope

This module allows for estimation of soil carbon stocks for the baseline and project cases. Uncertainty of estimates is treated in module X-UNC. Identification of baseline land-uses is treated in modules BL-WR, BL-WR-WL, BL-WR-HM, and BL-WR-HM-WL.

Applicability

This module is applicable to wetland soils in the Mississippi Delta. This module is applicable if the soil organic carbon pool is included as part of the project boundary as per applicability criteria in the framework module WR-MF. Soil organic carbon shall be included if determined to be significant using module T-SIG.

Parameters

This module produces the following parameters:

Parameter	SI Unit	Description
ΔC_{SOC_BSL}	t CO_2-e	Cumulative total of carbon stock changes of soils for the baseline scenario
ΔC_{SOC}	t CO_2-e	Cumulative total of the carbon stock changes of soils due to project activities

II. PROCEDURES

The mean carbon stock in the wetland soils above specific known time horizons will be estimated based on field measurements at fixed locations. Cesium^{137} analysis of cores will be used to establish baseline soil carbon stock, while feldspar marker horizons will be used to monitor soil carbon stock through the project lifetime. The number of sampling plots should ensure that they adequately represent the area being measured by utilizing module T-PLOTS.

Soil Cores

Measurement of the carbon content of wetland soils requires collection of soil cores[1,2,3,4,5]. Any core with more than 5% compaction (compaction distance/total core length x 100) should be

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[1] DeLaune, R.D., Patrick, Jr., W.H., Buresh, R.J., 1978. Sedimentation Rates Determined by 137Cs. Nature 275, 532–533.

[2] Craft, C. B., and W. P. Casey, 2000. Sediment and Nutrient Accumulation in Floodplain and Depressional Freshwater Wetlands of Georgia, USA. Wetlands 20:323–332.

discarded and retaken. An alternative to coring tubes is the use of a McAuley coring device, which allows cores to be taken with virtually no compaction[6]. The number of replicates should be determined by sample variability and desired confidence (e.g., 90%).

Cesium^{137} dating

Long-term soil organic carbon accretion rate should be calculated by taking soil cores for Cesium^{137} analysis[7,8,9]. The accretion rate is calculated from the height of material above the peak Cesium^{137} activity, which correlates to circa 1964 when nuclear testing was banned. The core samples should also be analyzed for total carbon using elemental analysis. Soil carbon accumulation rates can then be calculated as a product of average surface accretion rates and average carbon density (i.e., equation 2).

Feldspar Marker Plots

Feldspar markers should be put in place at the start of the project activity. Feldspar marker horizons are prepared by spreading a thin (≈1cm) layer of white feldspar clay on the wetland surface[10] [11] [12] [13]. The rate of vertical accretion is calculated by dividing the mean thickness of material above the surface of the horizon by the amount of time the horizon had been in place. Material accumulated above the feldspar marker should be analyzed for carbon content. As with Cesium^{137} core analysis, the soil carbon accumulation rates can be calculated as a product of average surface accretion rates and average carbon density.

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3 Euliss, et al., 2006. North American Prairie Wetlands are Important Nonforested Land-Based Carbon Storage Sites. Science of the Total Environment 361: 179-188.

4 Gross, M. F., M. A. Hardisky, P. L. Wolf, and V. Klemas. 1991. Relationship Between Aboveground and Belowground Biomass of Spartina alterniflora (Smooth Cordgrass). Estuaries 14:180–191.

5 Delaune, R. D., & S. R. Pezeshki, 2003. The role of soil organic carbon in maintaining surface elevation in rapidly subsiding U.S. Gulf of Mexico coastal marshes. Water, Air, & Soil Pollution 3: 167-179. 20(1): 57-64.

6 Bricker-Urso, S., S. W. Nixon, J. K. Cochran, D. J. Hirschberg, and C. Hunt, 1989. Accretion Rates and Sediment Accumulation in Rhode Island Salt Marshes. Estuaries 12:300-317.

7 Bryant, J. C. and R. H. Chabreck, 1998. Effects of Impoundment on Vertical Accretion of Coastal Marsh. Estuaries 21(3): 416-422.

8 Callaway, J.C., J.A. Nyman, and R.D. DeLaune, 1996. Sediment Accretion in Coastal Wetlands: A Review and a Simulation Model of Processes. Current Topics in Wetland Biogeochemistry 2: 2-23.

9 Pennington, W., R.S. Cambray, and E.M. Fisher, 1973. Observations of Lake Sediment Using Fallout ^{137}Cs as a Tracer. Nature 242:324-326.

10 DeLaune, R. D., R. H. Bauman, & J. G. Gosselink, 1983. Relationships among Vertical Accretion, Coastal Submergence and Erosion in a Louisiana Gulf Coast Marsh. Journal of Sedimentary Petrology 53: 147-157.

11 Cahoon, D. R. and R. E. Turner, 1989. Accretion and Canal Impacts in a Rapidly Subsiding Wetland. Feldspar marker horizon technique. Estuaries 12:260-268.

12 Conner, W. H., and Day, J. W., 1991. Variations in Vertical Accretion in a Louisiana Swamp. Journal of Coastal Research. 7: 617-622

13 Cahoon, D. R., J. C. Lynch, and R. M. Knaus, 1996. Improved Cryogenic Coring Device for Sampling Wetland Soils. Journal of Sedimentary Research 66:1025-1027.

Baseline Calculations

Cumulative soil carbon stock changes for the baseline scenario (ΔC_{SOC_BSL})

The soil carbon stock changes over a given period of time in the baseline scenario (ΔC_{SOC_BSL}) should be carried out using the following equation:

(1)

$$\Delta C_{SOC\_BSL} = f\, C_{SOC\_BSL} * T$$

where:

ΔC_{SOC_BSL} Cumulative soil carbon stock changes for the baseline scenario; t CO_2-e

$f\, C_{SOC\_BSL}$ Rate of increase in soil carbon stock for the baseline scenario; t CO_2-e yr^{-1}

T Period of time; yr

Baseline soil carbon stock rate of change ($f\, C_{SOC\_BSL}$)

The change in carbon stock in the soil pool in the baseline scenario ($f\, C_{SOC\_BSL}$) will be estimated by determining the carbon accumulated since 1964 and then dividing by the years since 1964. The material located above the peak $Cesium^{137}$ activity should be analyzed for total carbon using CHN elemental analysis as well as for bulk density[14].

(2)

$$f\, C_{SOC\_BSL} = \frac{44}{12} \sum_{i=1}^{n} (CF_{SOC\_BSL_{sample\ i}} * BD_{BSLi} * Depth_{BSLi} * Area_{BSLi} * 0.01) / T_{Cs}$$

where:

$f\, C_{SOC\_BSL}$ Rate of change in soil carbon stock for the baseline scenario; t CO_2-e yr^{-1}

44/12 Ratio of molecular weight of CO_2 to carbon; dimensionless

$CF_{SOC\_BSL\ sample\ i}$ Carbon fraction of the sample in stratum *i* of the baseline scenario, *as* determined in laboratory; g C g^{-1} d.m.

BD_{BSLi} Bulk density in stratum *i* of the baseline scenario as determined in laboratory*;* g cm^{-3}

$Depth_{BSLi}$ Depth to peak $Cesium^{137}$ isotopic marker activity in stratum *i* of the baseline scenario; cm

$Area_{BSLi}$ Area of in stratum *i* of the baseline scenario, m^2

0.01 Multiplier to convert units into ton C

T_{Cs} Time since 1964 and the year of sample collection; yr

i *1, 2, 3, … n* strata in the project scenario

[14] Brady, N.C., R.R. Weil. 2001. The Nature and Properties of Soils (13th Edition). Prentice Hall, Upper Saddle River, NJ.

Project Calculations

2.0 Soil carbon stock generated since the start of project activities (C_{SOC})

The carbon stock in the soil pool during project activities (C_{SOC}) will be estimated by determining the carbon accumulated above the feldspar marker and then dividing by the years since the marker was put in place (i.e., since the start of project activities). The material located above the feldspar marker should be analyzed for total carbon using CHN elemental analysis as well as for bulk density.

Step 1. Measure the soil organic carbon to the depth of the feldspar marker horizon by using a soil corer.

Step 2. Soil samples collected should be aggregated to reduce the variability and analyzed in the laboratory.

Step 3. For bulk density analysis, a single core shall be taken next to one for carbon analysis. The samples are then oven dried and weighed for bulk density and soil organic carbon determination.

Step 4. The mass of carbon per unit volume is calculated by multiplying the carbon concentration (percent mass) and bulk density (g/cm^3).

(3)

$$\Delta C_{SOC} = \frac{44}{12} \sum_{i=1}^{n} (CF_{SOC\_sample\ i,t} * BD_{i,t} * Depth_{i,t} * Area_{i,t} * 0.01)$$

where:

ΔC_{SOC}	Cumulative soil carbon stock changes since start of project activities; t CO_2-e
44/12	Ratio of molecular weight of CO_2 to carbon; dimensionless
$CF_{SOC\_sample,i}$	Carbon fraction of the sample in stratum *i, as* determined in laboratory; g C g^{-1} d.m.
BD_i	Bulk density in stratum *i*, as determined in laboratory*;* g cm^{-3}
$Depth_i$	Depth to feldspar marker in stratum *i*; cm
$Area_i$	Area of stratum *i*; m^2
0.01	Multiplier to convert units into ton C
i	*1, 2, 3, … n* strata in the project scenario

EX-ANTE ESTIMATION METHODS

The Project proponent must make an *ex-ante* calculation of all net anthropogenic GHG removals and emissions for all included sinks and sources for the entire crediting period. Project proponent shall provide estimates of the values of those parameters that are not available before the start of monitoring activities. Project proponent must retain a conservative approach in making these estimates.

Ex-ante net GHG removals by sinks can be estimated using empirical methods or modeling based on peer-reviewed literature or field monitoring, reference sample plots or field monitoring of similar sites, and approved local or national parameters that confirm to the applicability conditions of this methodology in order to assess the verifiable changes in carbon pools. The

methodology ensures that the net anthropogenic GHG removals by sinks are estimated under the project in a conservative manner taking into account the uncertainties associated with the secondary data.

This methodology provides for the use of empirical methods as stand alone or as complements to modeling based on peer-reviewed literature for the purpose of *ex-ante* estimation of carbon stock changes. The empirical methods are the methods used in forest/wetland inventory and wetland management studies for estimating biomass, productivity etc. The data from research and published literature that use scientifically accepted empirical methods can be used for *ex-ante* estimation purposes provided such data are based on valid sampling and statistical procedures and are in agreement with the methods, steps and procedures outlined for the estimation of carbon pools under this methodology. For example, species data based on yield tables, peer-reviewed literature, national inventory data or default data, allometric equations, growth models, mortality studies, biomass estimation and nutrient cycling studies and local research such as land records, field surveys, archives, maps or satellite images of the land use/cover before the start of the proposed project activity, field surveys, and expert opinion that confirms to the methods outlined for estimation of carbon stock changes under this methodology can be utilized.

DATA AND PARAMETERS MONITORED

Data /parameter:	$Area_{BSLi}$
Data unit:	m^2
Used in equations:	2
Description:	Area of stratum *i* of the baseline scenario
Source of data:	Aerial map (e.g. orthorectified aerial photography or georeferenced remote sensing images)
Measurement procedures (if any):	Monitoring of strata shall be done preferably using a Geographical Information System (GIS), which allows for integrating data from different sources (including GPS coordinates and Remote Sensing data)
Monitoring frequency:	Monitoring must occur for baseline renewal. Where carbon stock enhancement is included, the monitoring frequency can range from 5 to 20 years. In situations where the project adopts a 40-year renewable crediting period, the monitoring frequency can be fixed to coincide with the crediting period.
QA/QC procedures:	
Any comment:	

Data /parameter:	$Area_i$
Data unit:	m^2
Used in equations:	3
Description:	Area of stratum *i*
Source of data:	Aerial map (e.g. orthorectified aerial photography or georeferenced remote sensing images)
Measurement procedures (if any):	Monitoring of strata shall be done preferably using a Geographical Information System (GIS), which allows for integrating data from different sources (including GPS coordinates and Remote Sensing data)
Monitoring frequency:	Monitoring must occur for baseline renewal. Where carbon stock enhancement is included, the monitoring frequency can range from 5 to 20 years. In situations where the project adopts a 40-year renewable crediting period, the monitoring frequency can be fixed to coincide with the crediting period.
QA/QC procedures:	
Any comment:	

Data /parameter:	BD_{BSLi}
Data unit:	$g\ cm^{-3}$
Used in equations:	2
Description:	Bulk density in stratum *i* of the baseline scenario as determined in laboratory
Source of data:	Field sampling and laboratory determination.
Measurement procedures (if any):	For bulk density determination, samples (cores) of known volume are collected in the field and oven dried to a constant weight at $105^{\circ}F$ (approximately 5d). The total sample is then weighed. The bulk density equals the oven dry weight of the soil core divided by the core volume.
Monitoring frequency:	Monitoring must occur for baseline renewal. Where carbon stock enhancement is included, the monitoring frequency can range from 5 to 20 years. In situations where the project adopts a 40-year renewable crediting period, the monitoring frequency can be fixed to coincide with the crediting period.

QA/QC procedures:	Standard quality control / quality assurance (QA/QC) procedures for forest inventory including field data collection and data management shall be applied. Use or adaptation of QA/QCs already applied in national forest monitoring, or available from published handbooks, or form the IPCC GPG LULUCF 2003, is recommended.
Any comment:	

Data /parameter:	BD_i
Data unit:	g cm^{-3}
Used in equations:	3
Description:	Bulk density in stratum *i*, as determined in laboratory
Source of data:	Field sampling and laboratory determination. The bulk density equals the oven dry weight of the soil core divided by the core volume.
Measurement procedures (if any):	For bulk density determination, samples (cores) of known volume are collected in the field and oven dried to a constant weight at 105°F (approximately 5d). The total sample is then weighed. The bulk density equals the oven dry weight of the soil core divided by the core volume.
Monitoring frequency:	Monitoring must occur for baseline renewal. Where carbon stock enhancement is included, the monitoring frequency can range from 5 to 20 years. In situations where the project adopts a 40-year renewable crediting period, the monitoring frequency can be fixed to coincide with the crediting period.
QA/QC procedures:	Standard quality control / quality assurance (QA/QC) procedures for forest inventory including field data collection and data management shall be applied. Use or adaptation of QA/QCs already applied in national forest monitoring, or available from published handbooks, or form the IPCC GPG LULUCF 2003, is recommended.
Any comment:	

Data /parameter:	$CF_{SOC\_BSL\ sample\ i}$
Data unit:	g C g^{-1} d.m.
Used in equations:	2
Description:	Carbon fraction of the sample in stratum *i* of the baseline scenario,

	as determined in laboratory
Source of data:	Field sampling and laboratory determination
Measurement procedures (if any):	For soil carbon determination, an aggregate sample (e.g. from 4 systematically-distributed cores) is collected from within a sample plot in the field. The sample should be thoroughly dried, ground, and mixed. The prepared sample is analyzed for percent organic carbon using either dry combustion using a controlled-temperature furnace (e.g. LECO CHN- 2000, LECO RC-412 multi-carbon analyzer, or equivalent), dichromate oxidation with heating, or Walkley-Black method. Further guidance is provided in the IPCC 2003 GPG-LULUCF and in Nelson, D.W., and L.E. Sommers. 1982. Total carbon, organic carbon, and organic matter. p. 539–580. In A.L. Page et al. (ed.) Methods of soil Analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI. Pearson, T., Walker, S. and Brown, S. 2005. Sourcebook for Land Use, Land-Use Change and Forestry Projects. Winrock International and the World Bank Biocarbon Fund. 57pp. Available at: http://www.winrock.org/Ecosystems/files/Winrock-BioCarbon_Fund_Sourcebook-compressed.pdf
Monitoring frequency:	Monitoring must occur for baseline renewal. Where carbon stock enhancement is included, the monitoring frequency can range from 5 to 20 years. In situations where the project adopts a 40-year renewable crediting period, the monitoring frequency can be fixed to coincide with the crediting period.
QA/QC procedures:	Standard quality control / quality assurance (QA/QC) procedures for forest inventory including field data collection and data management shall be applied. Use or adaptation of QA/QCs already applied in national forest monitoring, or available from published handbooks, or form the IPCC GPG LULUCF 2003, is recommended.
Any comment:	

Data /parameter:	$CF_{SOC\_sample,i}$
Data unit:	g C g^{-1} d.m.
Used in equations:	3
Description:	Carbon fraction of the sample in stratum *i, as* determined in laboratory

Source of data:	Field sampling and laboratory determination
Measurement procedures (if any):	For soil carbon determination, an aggregate sample (e.g. from 4 systematically-distributed cores) is collected from within a sample plot in the field. The sample should be thoroughly dried, ground, and mixed. The prepared sample is analyzed for percent organic carbon using either dry combustion using a controlled-temperature furnace (e.g. LECO CHN- 2000, LECO RC-412 multi-carbon analyzer, or equivalent), dichromate oxidation with heating, or Walkley-Black method. Further guidance is provided in the IPCC 2003 GPG-LULUCF and in Nelson, D.W., and L.E. Sommers. 1982. Total carbon, organic carbon, and organic matter. p. 539–580. In A.L. Page et al. (ed.) Methods of soil Analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI. Pearson, T., Walker, S. and Brown, S. 2005. Sourcebook for Land Use, Land-Use Change and Forestry Projects. Winrock International and the World Bank Biocarbon Fund. 57pp. Available at: http://www.winrock.org/Ecosystems/files/Winrock-BioCarbon_Fund_Sourcebook-compressed.pdf
Monitoring frequency:	Monitoring must occur for baseline renewal. Where carbon stock enhancement is included, the monitoring frequency can range from 5 to 20 years. In situations where the project adopts a 40-year renewable crediting period, the monitoring frequency can be fixed to coincide with the crediting period.
QA/QC procedures:	Standard quality control / quality assurance (QA/QC) procedures for forest inventory including field data collection and data management shall be applied. Use or adaptation of QA/QCs already applied in national forest monitoring, or available from published handbooks, or form the IPCC GPG LULUCF 2003, is recommended.
Any comment:	

Data /parameter:	$Depth_{BSLi}$
Data unit:	cm
Used in equations:	2
Description:	Depth to peak Cesium^{137} isotopic marker activity in stratum *i* of the baseline scenario
Source of data:	Field sampling and laboratory determination
Measurement	Soil cores for Cesium^{137} analysis should be sectioned in the field

procedures (if any):	into 2-cm increments, separated in labeled bags, and brought to the laboratory to be analyzed for Cesium^{137} activity. The increment with peak Cesium^{137} activity correlates to circa 1964 when nuclear testing was banned.
Monitoring frequency:	Once for each Cesium^{137} core collected for *ex-ante* estimation of the baseline
QA/QC procedures:	Cesium^{137} analysis must be carried out by an accredited laboratory with previous isotopic analysis experience
Any comment:	The rate of vertical accretion is calculated by dividing the mean thickness of material above the Cesium^{137} marker by the amount of time since 1964.

Data /parameter:	$Depth_i$
Data unit:	cm
Used in equations:	3
Description:	Depth to feldspar marker in stratum *i*;
Source of data:	Recorded in the field at feldspar plots.
Measurement procedures (if any):	This should be done *in situ* by cryogenic coring or by measuring the depth to the feldspar layer with a hand ruler when cores are taken for bulk density and %carbon.
Monitoring frequency:	Monitoring must occur for baseline renewal. Where carbon stock enhancement is included, the monitoring frequency can range from 5 to 20 years. In situations where the project adopts a 40-year renewable crediting period, the monitoring frequency can be fixed to coincide with the crediting period.
QA/QC procedures:	
Any comment:	The rate of vertical accretion is calculated by dividing the mean thickness of material above the surface of the horizon by the amount of time the horizon had been in place.

Data /parameter:	*T*
Data unit:	yr
Used in equations:	1
Description:	Period of time

Source of data:	This is the period of time of *ex-ante* estimation of baseline soil carbon stocks (e.g., 5, 10 years).
Measurement procedures (if any):	Since monitoring must occur for baseline renewal, and can range from 5 to 20 years if carbon stock enhancement is included, time periods shall occur at these intervals.
Monitoring frequency:	Values should be given to one decimal place (e.g., 5.2 yrs).
QA/QC procedures:	
Any comment:	

Data /parameter:	T_{Cs}
Data unit:	yr
Used in equations:	2
Description:	Time since 1964 and the year of sample collection
Source of data:	Time elapsed from 1964, the year when nuclear testing was banned, to the year of sample collection.
Measurement procedures (if any):	
Monitoring frequency:	Once for each $Cesium^{137}$ core collected
QA/QC procedures:	$Cesium^{137}$ analysis must be carried out by an accredited laboratory with previous isotopic analysis experience
Any comment:	