A Global Benchmark for Carbon

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Sectoral Scope 14

Methodology for Rewetting Drained Tropical Peatlands

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1 SOURCES

This methodology uses the latest versions of the following tools:

- VCS *Tool for the Demonstration and Assessment of Additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) Project Activities*
- CDM *Tool for testing significance of GHG emissions in A/R CDM project activities*

Stratification by peat depletion time is based on VCS methodology, *VM0004 Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests*.

2 SUMMARY DESCRIPTION OF THE METHODOLOGY

Additionality and Crediting Method	
Additionality	Project Method
Crediting Baseline	Project Method

This methodology applies to project activities in which drained tropical peatlands are rewet through the construction of permanent and/or temporary structures (eg, dams) which hold back water in drainage waterways. As such, this methodology is categorized as a Restoring Wetland Ecosystems (RWE) methodology.

This methodology quantifies the reduction in carbon dioxide (CO_2) emissions due to decreased oxidation of soil organic material that occurs as a result of project activities. Annex I provides a recommended approach for determining the number and location of dams that are included in the project. Emissions from nitrous oxide (N_2O) are conservatively excluded from this methodology since project activities increase the water table in comparison to the baseline, and thus such emissions will be equal or lower as a result of project activities.

The quantification of emission reductions is based primarily on outputs from the Simulation of Groundwater (SIMGRO) model which estimates the water table depth based on a range of input parameters such as terrain characteristics, peat thickness and climate variables.

This methodology is only applicable to projects in Southeast Asia; specifically, Malaysia, Indonesia, Brunei and Papua New Guinea.

The main methodological steps are provided below:

- **Definition of the project area**: Various geographic areas must be specified for the peat rewetting project. The project area is specified for all eligible discrete areas of peatland to be subjected to rewetting project activities. The area of the watershed(s) of interest that is modeled to estimate the impact of project activities on water levels in the area of hydrological influence is also specified. Under the applicability conditions of this methodology, the project area is not required to coincide with the area of the watershed(s) of interest. However, the watershed(s) of interest must constitute one or more complete hydrological units or watersheds and the entire project area must be contained within the watershed(s) of interest. A spatially explicit digital terrain model (DTM), which characterizes elevation and slope, is used to determine the spatial extent of the watershed(s) of interest for this study. Topographic conditions (elevation, slope) determine the direction of water flow in a region and thus the watershed area. If there are areas within the watershed(s) of interest, but outside the project area, this excluded area of the watershed(s) must also be delineated. Discrete land areas within the watershed(s) of interest and the project area are recorded in spatially explicit polygons.

- **Stratification**: Initial project conditions are established by modeling peat depth and water levels relative to the peat surface across the watershed(s) of interest using remote sensing and field data in combination with a hydrological model. The project area is stratified by drainage depth. The application of this methodology requires the ex-ante stratification of the project area by peat depth.
- **Identifying the baseline scenario**: The latest version of the VCS *Tool for the Demonstration and Assessment of Additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) Project Activities* must be used to identify the potential alternative baseline land use scenarios in the project area and in the modeled watershed area excluded from the project area. The methodology provides a stepwise approach to determine the most plausible baseline scenario(s) in the project area and in the excluded area of watershed(s).
- **Demonstration of additionality**: Additionality is demonstrated through application of the latest version of the VCS *Tool for the Demonstration and Assessment of Additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) Project Activities*.
- **Ex-ante calculation of baseline GHG emissions**: Drainage depth across the watershed(s) of interest is modeled in the baseline based on the current and historic layout of the relevant drainage system (considering any potential “natural damming” expected to occur in the watershed(s) of interest), current topographic data and historic climate data. Baseline CO_2 emissions from decomposition of peat are estimated by applying the relationship between water levels and CO_2 emissions specified in this methodology or other equations from appropriate literature as they may become available in the future. CO_2 emissions from oxidation in the baseline are only considered for project area lands with suitably thick peat depth (ie, areas where the peat has been completely depleted are not considered to emit CO_2 in the baseline). CH_4 and N_2O emissions in the baseline are conservatively not accounted for.
- **Calculation of ex-ante GHG project emissions**: CO_2 emissions in the project scenario are estimated following the same method used in the calculation of the baseline emissions considering the planned project intervention (ie, the establishment of dams in drainage waterways). It is conservatively assumed that emissions may occur over the entire project area over the entire project crediting period in the project scenario. Potential increases in CH_4 emissions are not accounted for because they are *de minimis* in comparison to the CO_2 emissions reduced by the project.

- **Leakage emissions**: The conditions under which this methodology may be applied are such that it is appropriate or conservative to not include leakage emissions in the quantification of net emission reductions and/or removals. Further details and rationale are provided in Section 8.3 below.
- **Baseline and project monitoring:** The project activity is monitored to verify the implementation of the technical intervention to rewet the previously drained tropical peatlands. Water levels relative to the peat surface are modeled at each monitoring event based on the current and historic layout of the relevant drainage system prior to project start, implementation of the technical intervention and climate data recorded during the monitoring period. Baseline and project emissions are estimated following the same method used in the calculation of ex-ante emissions. Actual water levels in the project area are measured and compared to modeled water levels. Methods are included to ensure conservative estimates of water levels are produced.

3 DEFINITIONS

Baseline Period
The time period between the project start date and the first monitoring event, or the time period between monitoring events

Excluded Area of Watershed(s)
The area within the watershed(s) of interest that is outside the project area

Ombrogenous Tropical Peatland
Peatland with a surface isolated from mineral soil-influenced groundwater, which only receives water through precipitation[1]

Peat
Organic soils with at least 65% organic matter and a minimum thickness of 30 cm[2,3]

Watershed
The entire area that is drained by one waterway, such that all flow that originates in the area is discharged through a single outlet

Watershed of Interest
The one or more complete watersheds modeled to estimate the impact of project activities on water levels in the area of hydrological influence

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[1] Rydin, H and Jeglum, JK. 2006. *The Biology of Peatlands*. Oxford University Press, UK. 360 p. ISBN13: 9780198528722.

[2] Rieley, JO. and Page, SE. 2005. *Wise Use of Tropical Peatland: Focus on Southeast Asia*. Alterra, Wageningen, The Netherlands. 237 p. ISBN 90327-0347-1.

[3] Joosten H, Clarke D (2002) Wise use of mires and peatlands – Background and principles including a framework for decision-making. International Mire Conservation Group / International Peat Society, 304 pp.

Waterway
A natural or manmade feature in a peatland, including rivers and canals, that conducts water towards a hydrological outlet

Acronyms used in this methodology are listed below:

ASCII	American Standard Code for Information Interchange
ASPRS	American Society for Photogrammetry and Remote Sensing
DSM	Digital Surface Model
DTM	Digital Terrain Model
LiDAR	Light Detection and Ranging
PDOP	Position Dilution of Precision
PRA	Participatory Rural Appraisal
SIMGRO	Simulation of Groundwater model
RMSE	Root Mean Square Error
SRTM	Shuttle Radar Topography Mission
SVAT	Soil-Vegetation-Water Transfer unit

4 APPLICABILITY CONDITIONS

This methodology applies to project activities which rewet drained tropical peatlands through the construction of permanent and temporary structures which hold back water in drainage waterways.

Projects must meet the conditions below. Note that applicability conditions 13 and 14 must be satisfied at each and every verification event.

1. The project area must meet the definition of ombrogenous tropical peatland.
2. The project area must exist at an elevation less than 100m above sea level.
3. The project area must exist within Malaysia, Indonesia, Brunei or Papua New Guinea (hereafter referred to as *Southeast Asia*).
4. Mean annual water level below the peat surface within the project area for the baseline and project scenarios cannot be greater than 1 meter in depth.

5. The watershed(s) of interest that includes the project area must comprise one or more complete watersheds.

6. The watershed(s) of interest cannot be hydrologically-connected to adjacent peatland and non-peatland areas outside the project area.

7. The watershed(s) of interest cannot include areas where N-based fertilizers have been, or are planned to be, applied.

8. The project must demonstrate a significant difference in the net GHG benefit between the baseline and project scenarios for at least 100 years.

9. This methodology is only applicable where the most plausible baseline scenario is the scenario where the project area has been drained due to human-induced drainage activities and would remain drained in the absence of the project.

10. At the project start date, it must be demonstrated that no agents intend to implement further drainage activities within the project area.

11. At the project start date, land use activities in the project area cannot include deforestation, planned forest degradation, land use conversion, crop production or grazing of animals.

12. The baseline scenario in the watershed(s) of interest must result in equal or lower aboveground tree biomass compared to the project scenario.

13. Current and/or potential future land use activities in the excluded area of watershed(s) must not have a significant negative hydrologic impact on the project area. Acceptable evidence includes land use plans, laws or resource concession rights. This applicability condition must be satisfied at validation and at each verification event. Failure to meet this applicability condition at verification will render the project ineligible for further crediting.

14. Current and/or potential future legal land use activities taking place within the excluded area of watershed(s) must not be displaced by project activities. This applicability condition must be satisfied at validation and at each verification event. Failure to meet this applicability condition at verification will render the project ineligible for further crediting.

15. Peatland rewetting must occur through permanent and temporary structures (eg, dams) which hold back water in drainage waterways, thereby increasing annual average water levels within the project area. It is not necessary for all drainage waterways within the project area to be dammed by the project.

16. The project activity cannot include the creation of additional drainage waterways or other types of infrastructure that causes drainage.

17. The project activity cannot include any agricultural activities.

18. Baseline and project scenario water levels must be modeled using the latest version of the SIMGRO[4] model. The parameters of the model must be adjusted for ombrogenous peatlands in Southeast Asia.

5 PROJECT BOUNDARY

This section provides the methods for determining the following boundaries that must be specified by the project proponent:

- The geographic area associated with the project activity.
- The temporal boundaries relevant to the project activity.
- The sources and associated types of greenhouse gas emissions that the project activities will impact.

5.1 Geographic Boundary

The following geographic boundaries must be specified:

Watershed(s) of Interest

As per the applicability conditions of this methodology, the modeled watershed(s) of interest area must encompass a complete watershed within a peat dome. Each modeled watershed covering the project area must be self-contained and thus the hydrology within the area of the watershed(s) of interest does not impact the hydrology of other land areas. Topographic conditions (eg, elevation, slope) determine the direction of water flow in a region and thus the watershed area.

A spatially explicit DTM, which characterizes elevation and slope, must be used to determine the spatial extent of all watersheds included in the project area. Section 8.1.1 provides steps for creating a DTM of the project area.

Project Area

The peatland rewetting project activity may contain more than one discrete parcel of land. The project area is the discrete parcel(s) of peatland where the rewetting activity will impact hydrology.

[4] Querner, EP, Povilaitis, A. 2009. Hydrological effects of water management measures in the Dovine River basin, Lithuania. *Hydrological Sciences Journal*. 54: 363-374.

In addition, as per the applicability conditions of this methodology, the project proponent must demonstrate that all land within the project area exists on ombrogenous tropical peat. This must be demonstrated using remote sensing imagery[5] or a DTM and peat thickness model (see Section 8.1.1 below).

Excluded Area of Watershed(s)

The boundaries of the excluded area of watershed(s) must be specified.

When describing physical areas, the following information must be provided for each discrete area:

- Name of the project area (eg, compartment number, local name, watershed name);
- Unique ID for each discrete parcel of land;
- Map(s) of the area in digital format;
- Geographic coordinates of each polygon vertex along with the documentation of their accuracy. Such data must be provided in the format required by the VCS rules;
- Total land area; and
- Details of land ownership and land user rights.

5.2 Temporal boundary

The following temporal boundaries must be specified:

Start Date and End Date of the Historic Period for Determining Climate Variables

Baseline emissions are estimated based on drainage depth as a function of long-term climate variables (among other parameters). The long-term average climate variables must be determined using data from weather stations that are representative of the project area and must include at least 20 years of historic data.

Start Date and End Date of the Project Crediting Period

The project crediting period for WRC projects must be between 20 and 100 years. Baseline and project scenario GHG emissions are estimated for the entire project crediting period. The project cannot claim GHG reductions for longer than the time it would have taken for all the peat in the

[5] Tropical peat swamp forests feature a unique signature in multispectral satellite imagery, when compared to other, adjacent forest types. This is related to several physiognomic parameters of the peat swamp forest, such as the hydrologic conditions, a homogenous canopy structure, small tree crown diameter, among others. This makes them identifiable in satellite images, in particular in images which have a band in the 1.55-1.75 micron range of Mid Infrared spectrum (eg, Landsat- 5 TM, Landsat-7 ETM+, SPOT-4 and SPOT-5). The spectral band responds to differences in moisture (Lillesand, T.M., Kiefer, R.W. Chipman, J.W. 2008. Remote sensing and image interpretation. 6th Edition. New York.) and makes these datasets particularly suitable. The delineation is carried out in the GIS by visual interpretation of the image in conjunction with elevation analysis based on the SRTM.

entire project area to be completely lost under the baseline scenario, as determined by estimation of the peat depletion time.

Monitoring Period

Given the monitoring procedures of this methodology, it is recommended, but not required, that the minimum duration of each monitoring period be at least one year, and that the maximum duration of each monitoring period be five years.

Baseline projections must be annual and must be available for each proposed future verification date.

Date at Which the Project Baseline Must be Revised

The estimation of baseline emissions must be revised prior to each verification event, based on monitored climate variables for the baseline period.

Where the baseline scenario is reassessed (in accordance with VCS rules for baseline reassessment), the project proponent must reassess regulatory surplus and the behavior of agents that cause changes in hydrology and/or land and water management practices.

5.3 Carbon Pools

Carbon pool	Included?	Justification/Explanation
Aboveground tree biomass	Yes	Required for inclusion by VCS rules.
Aboveground non-tree biomass	No	It is conservative to exclude this carbon pool.
Belowground biomass	No	It is conservative to exclude this carbon pool.
Litter	No	It is conservative to exclude this carbon pool.
Deadwood	No	It is conservative to exclude this carbon pool.
Soil	Yes	Main pool addressed by project activities.
Wood Products	No	It is conservative to exclude this carbon pool.

5.4 Sources of Greenhouse Gases

Source		Gas	Included?	Justification/Explanation
Baseline	Peat oxidation	CO_2	Yes	Main source and gas to be addressed by project activities.
		N_2O	No	Considered negligible in peatlands. N_2O emissions are conservatively not accounted for in the baseline scenario by this methodology.
		CH_4	No	Considered negligible in drained peatlands. CH_4 emissions from tropical peatlands are considered *de minimis* because they amount to less than 5% of the CO_2 emissions.[6]
Project	Peat oxidation	CO_2	Yes	Main source and gas to be addressed by project activities.
		N_2O	No	Considered negligible in tropical Southeast Asia peatlands.[7] Project activities increase the water table in comparison to the baseline and thus N_2O emissions will be equal or lower as a result of project activities.
		CH_4	No	Considered negligible in drained peatlands. CH_4 emissions from tropical peatlands are considered *de minimis* because they amount to less than 5% of the CO_2 emissions.

Studies of GHG fluxes associated with land use change in tropical peatland indicate that CH_4 and N_2O fluxes are small and can be considered negligible compared to fluxes of CO_2[8]. A meta-analysis of changes in CH_4 fluxes from the conversion of tropical peat swamp forests indicate that CH_4 emissions from rewetting are very low and do not offset the corresponding increase in soil

[6] Riley, J.O., Wüst, R.A.J., Jauhiainen, J., Page, S.E., Wösten, H., Hooijer, A., Siegert, F., Limin, S.H., Stahlhut, M. 2008. Tropical Peatlands: Carbon stores, carbon gas emissions and contribution to climate change processes. In: Strack, M.(Ed.), Peatlands and Climate Change. International Peat Society. Stockholm.

[7] Estimated at 0.0054 t N_2O ha^{-1} in meta-analysis by Couwenberg, J, Dommain, R, Joosten, H. 2009., Greenhouse gas fluxes from tropical peatlands in south-east Asia. *Global Change Biology*, 16: 1715–1732. doi: 10.1111/j.1365-2486.2009.02016.x

[8] Couwenberg, J, Dommain, R, Joosten, H. 2009., Greenhouse gas fluxes from tropical peatlands in south-east Asia. *Global Change Biology*, 16: 1715–1732. doi: 10.1111/j.1365-2486.2009.02016.x; Hirano, T, Jauhiainen, J, Inoue, T, Takahashi, H. 2009. Controls on the carbon balance of tropical peatlands. *Ecosystems* 12: 873-887.; Murdiyarso, D, Hergoualc'h, K, Verchot, L. 2010. Opportunities for reducing greenhouse gas emissions in tropical peatlands. *Proceedings of the National Academy of Sciences of the United States of America* 107: 19,655-19,660; Strack, M (ed.). 2008. *Peatlands and Climate Change*. International Peat Society.

CO_2 emissions from peatland drainage[9].

Based on the applicability conditions of the methodology, the project activities will cause peatland rewetting and will not result in a lower water table levels than in the baseline and therefore, N_2O emissions are excluded. While peatland rewetting could potentially cause greater methane emissions than in the baseline, the relevance of CH_4 emissions in tropical peatlands is very low in comparison to the CO_2 emissions and are therefore deemed to be *de minimis*. Peer reviewed literature shows that CH_4 emissions are negligibly small in comparison to the CO_2 emissions in tropical peatlands.[10]

6 PROCEDURE FOR DETERMINING THE BASELINE SCENARIO

The latest version of the VCS *Tool for the Demonstration and Assessment of Additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) Project Activities* must be used to identify the potential alternative baseline land use scenarios in the project area.

The chart below, which reflects the applicability conditions of this methodology, must be used to determine the most plausible baseline scenario.

[9] Hergoualc'h K, Verchot, L. 2012. Changes in CH_4 fluxes from the conversion of tropical peat swamp forests: a meta-analysis. Journal of Integrative Environmental Sciences 9(2): 93-101

[10] Riley, J.O., Wüst, R.A.J., Jauhiainen, J., Page, S.E., Wösten, H., Hooijer, A., Siegert, F., Limin, S.H., Stahlhut, M. 2008. Tropical Peatlands: Carbon stores, carbon gas emissions and contribution to climate change processes. In: Strack, M.(Ed.), Peatlands and Climate Change. International Peat Society. Stockholm.

<table>
<tr><td colspan="8">Has the project area been drained by human-constructed waterways?</td></tr>
<tr><td>No
This methodology is not applicable</td><td colspan="7">Yes
Is land use conversion, deforestation, crop production, planned forest degradation and/or grazing of animals the existing land use?</td></tr>
<tr><td></td><td>Yes
This methodology is not applicable</td><td colspan="6">No
Is there evidence that demonstrates that land use conversion, deforestation, crop production, planned forest degradation and/or grazing of animals will not take place in the baseline scenario?</td></tr>
<tr><td colspan="2"></td><td colspan="2">No
This methodology is not applicable</td><td colspan="4">Yes[a]
Is there any evidence that demonstrates that no agents intend to implement further drainage activities within the project area at the project start date?</td></tr>
<tr><td colspan="3"></td><td colspan="2">No
This methodology is not applicable</td><td colspan="3">Yes[b]
Is there evidence that demonstrates that the existing or historical land use activities will continue to take place?</td></tr>
<tr><td colspan="4"></td><td colspan="2">No
This methodology is not applicable</td><td colspan="2">Yes[c]
Is there evidence that demonstrates that the hydrology of the watersheds of interest is drained by existing drainage waterways and will remain similarly drained in the absence of the project?</td></tr>
<tr><td colspan="6"></td><td>No
This methodology is not applicable</td><td>Yes[d]
The most plausible baseline scenario is that the project area has been drained due to human-induced drainage activities, and would remain drained in the absence of the project</td></tr>
</table>

a. The project proponent must provide evidence that the listed activities will not occur. This must include items such as legal permissibility, suitability of project area to land use and/or existing documented baseline management plans.

b. Acceptable evidence includes land use plans, results of the PRA, laws or resource concession rights.

c. This evidence must include items such as legal permissibility, common practice and/or existing management and budget plans.

d. Evidence must be presented to demonstrate that no plans exist for altering waterway drainage in the watersheds of interest. Long-term average climate variables (at least 20 years of data) that influence water table depths and the timing and quantity of water flow must be used to demonstrate that water inputs are expected to be similar to existing conditions in the absence of the project.

7 PROCEDURE FOR DEMONSTRATING ADDITIONALITY

The latest version of the VCS *Tool for the Demonstration and Assessment of Additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) Project Activities* must be used to demonstrate additionality.

8 QUANTIFICATION OF GHG EMISSION REDUCTIONS AND REMOVALS

8.1 Baseline Emissions

Net GHG emissions in the baseline scenario are determined as:

$$\Delta C_{BSL} = \sum_{t=1}^{t_{\max}} \Delta C_{BSL,t} \tag{1}$$

Where:

ΔC_{BSL}	Net greenhouse gas emissions in the baseline scenario from the continuation of peatlands in a drained state (t CO_2e)
$\Delta C_{BSL,,t}$	Net carbon stock change in all pools in the baseline scenario at time *t* (t CO_2e)
t	*1,2,3 …*t_{max} years elapsed since the project start date up to the maximum number of years for stratum *i*

Baseline emissions must be estimated for both the project crediting period and for 100 years.

8.1.1 Prepare Modeling Data

Baseline CO_2 emissions are based on the water level with respect to peat surface. These water levels are modeled based on the current and historic layout of relevant drainage systems (including any potential "natural damming" expected to occur in the project area) and the long-term average weather prior to the project start date.

The following steps must be followed to model water levels over time within the watershed(s) of interest:

1) Generate land cover map
2) Generate DTM
3) Generate peat thickness model
4) Collect climate variable data
5) Delineate waterways
6) Validate SIMGRO model for project area conditions

8.1.1.1 Generate Land Cover Map

A land cover map of the watershed(s) of interest is required in order to:

- Perform a detailed accuracy assessment of the DTM regardless of the option selected for generation of the DTM in Section 8.1.1.2
- Correct radar-derived digital surface models (DSM) for vegetation if Option 2 for generation of the DTM is selected in Section 8.1.1.2

Remote sensing images used must have a spatial resolution of 30m or higher.[11,12] Remote sensing data must be geo-referenced into a common geodetic system with the other used datasets (eg, using the UTM system). The target geometric accuracy of the image data is an RMS of 0.5 pixels. The land cover classes must be validated by reference data collected in the field or high resolution remote sensing imagery (resolution ≤5 m). Overall classification of forest-non-forest must have an accuracy of 90% or more.

[11] Guidance on the selection of data sources can be found in Chapter 3A.2.4 of the IPCC 2006 GL AFOLU and in GOFC-GOLD (2011), Reducing greenhouse gas emissions from deforestation and degradation in developing countries: a source book of methods and procedures for monitoring, measuring, and reporting.

[12] The following satellite sensors are suitable to assess the land cover:

Satellite	Sensor	Geometric resolution	Spectral resolution	MIR/SWIR
Landsat-5	TM	30m	7 bands	YES
Landsat-7	ETM+	30m	7 bands	YES
SPOT-4/5	XS	20/10m	4 bands	YES

The land cover classes must be grouped according to average vegetation height. The overall stratification must be based on internationally recognized vegetation classification systems, such as the International Geosphere-Biosphere Programme land use classification system, but the project proponent may further refine stratification if appropriate for the project area. The minimum land cover classes are:

- Forest (lands meeting the internationally recognized country's forest definition)
- Shrubs (lands with woody vegetation below the minimum height criteria in the country's forest definition and with canopy cover greater than 10%)
- Grassland (lands with herbaceous type of cover; tree and shrub cover must not exceed 10%)
- Water

In addition, in the case that a radar-derived DSM is used to generate the DTM (Option 2 in Section 8.1.1.2), the land cover classification must be used to correct the radar data for vegetation height. In this case the stratification must be created from remote sensing imagery which has been acquired in the same time range as the radar data used for creating the DTM (maximum difference in acquisition data +/- 6 months). This is necessary in order to assure that the satellite image shows the same land cover situation as elevation data.

8.1.1.2 Generate DTM

A DTM of the peat surface, generated by 3D modeling within a GIS environment by means of digital elevation data, must exist for the area within the watershed(s) of interest. The DTM is required to determine the area of the watershed(s) covering the project area and is a required input to create the peat thickness model as well as a required input to SIMGRO for modeling baseline and project scenario water levels in the project area. The DTM may have a larger spatial extent than the watershed(s) of interest and must meet the requirements below.

Two DTM creation options are presented below. The methods described under Option 2, Step 4 below must be used to assess the accuracy of the DTM, regardless of which option is used.

If the required data are available, the DTM must be derived using airborne LiDAR data. Otherwise, Option 2 presented below must be used to derive the DTM.

Option 1: Derivation of DTM with LiDAR Data

Step 1: Derive the DTM with LiDAR Data

If LiDAR data are used to generate a terrain model, the LiDAR point cloud must be filtered with a terrain adaptive filtering technique[13] in order to separate ground points from vegetation points.

The technical specifications of the LiDAR data must meet the following quality criteria:

- Minimum point density is 2 points per square meter, with higher point densities recommended in order to facilitate more laser returns from the terrain surface.
- LiDAR data must be either multiple return or full-waveform LiDAR data with 2-8 points per square meter (recommended in forested areas with dense vegetation cover) or first-last pulse data.
- The maximum permissible scan angle must be 10°.
- The vertical accuracy of the LiDAR data must be assessed by dGPS ground measurements and must have an RMSE of < 50 cm.

These specifications facilitate a high accuracy of the LiDAR derived DTM, and limits uncertainty in the terrain measurements. This is a precondition for a conservative estimate of emission reductions.

It is recommended that the DTM area be fully covered with LiDAR data. However, if full coverage LiDAR data is not available or cannot be acquired, it is allowable to use regularly spaced LiDAR transects that systematically cover the DTM area. This is justified due to the fact that the topography of tropical peat swamps is usually very even and smooth.

In order to facilitate the best possible representation of the terrain, ancillary information (eg, SRTM digital elevation model and available satellite images) must be consulted during planning. The placement of transects must fulfill the following requirements:

- A minimum of 4 transects must be uniformly distributed over the whole area of the DTM.
- Transects must be oriented parallel or in a regularly spaced grid.
- The transects must accurately represent terrain variations in the watershed(s) of interest.
- The transects must cover the full elevation range of the watershed(s) of interest.

These LiDAR transects must then be interpolated into a full coverage DTM by completing the following steps:

[13] Pfeifer, N., Stadler, P. & Briese, C. (2001). Derivation of digital terrain models in SCOP++ environment. OEEPE Workshop on Airborne Laserscanning and Interferometric SAR for Detailed Digital Elevation Models, Stockholm.

- Filtering of the LiDAR point clouds with a terrain adaptive filtering technique to separate ground points from vegetation points, such as the Hierarchic Robust Filtering (Pfeiffer et al. 2001).
- Mathematical modeling of the surface based on the LiDAR point cloud (eg, with the Kriging algorithm or a Bézier). The Bézier surface is obtained by applying a Cartesian product to the Bézier equations of a Bézier curve.[14]

Step 2: Assess the accuracy of the LiDAR derived DTM

LiDAR derived DTMs must be validated with topographic field measurements using dGPS devices by the methods described under Option 2, Step 4 below. A network of measurement points must be designed for the whole project area and terrain elevation must be measured. The accuracy of the validation data must be at least three times higher than the DTM dataset to be assessed.

Option 2: Derivation of DTM from a DSM

In cases where LiDAR data are not available, a DTM derived from radar data, including data from the Shuttle Radar Topography Mission (SRTM), must be used.

Step 1: Generation of surface model

Radar data (eg, SRTM data[15] or other superior radar datasets as they become available in the future) covering the entire DTM area must be used to create a DTM. The minimum horizontal resolution for the radar data is 90m while the minimum vertical resolution for radar data is 1m.

Step 2: Correction of surface model for vegetation height

The DSM derived from radar data must be corrected for the vegetation height in order to obtain a DTM showing the peat dome topography. The forest canopy height for different types of peat swamp forests may be derived by comparing vegetation height to terrain height on forested and non-vegetated areas or through representative field measurements of tree height.

To estimate canopy height for each land cover class in the land cover map generated in Section 8.1.1.1 in the absence of LiDAR, data field measurements within the DTM area must have occurred. Canopy height must be measured at locations for each land cover stratum determined using representative random sampling or systematic sampling with a random initiation point. At each location, the height of at least three representative individuals (eg, trees, shrubs) of the dominant canopy layer must be measured. Sufficient number of locations must be measured in

[14] Salomon, D. 2006. Curves and Surfaces for Computer graphics. 460 p. ISBN-13: 9780387284521

[15] The SRTM data set is a freely available DSM which has an almost global coverage (from 80° N to 80°S), which contains the elevation of the earth surface (ie, the elevation including the vegetation cover).

each land cover stratum to achieve a precision of equal or less than 15% of the mean at the 95% confidence interval in the estimate of vegetation height for each land cover class.

$$H_{LC} = \frac{\sum_{loc=1}^{Loc} \frac{\sum_{ind=1}^{Ind} H_{ind,loc,LC}}{Ind}}{Loc} \qquad (2)$$

Where:

H_{LC}	Mean height of vegetation land cover class LC (m)
$H_{ind,loc,LC}$	Height of individual *ind* at sampling location *loc* within land cover class *LC* (m)
Ind	1,2,3 …Ind individuals measured at sampling location *loc* within land cover class *LC*
Loc	1,2,3 …Loc locations of measurements within land cover class *LC*
LC	1,2,3 …LC land cover classes within project area

<u>Step 3: Derive DTM from DSM</u>

Radar-derived elevation profiles placed in a regular spacing over the coverage of the DTM must then be analyzed in conjunction with the land cover stratification in order to subtract the vegetation height of the different strata from the correspondent section of the elevation profiles.

The number of profiles depends on several factors, most importantly the area covered by the DTM and homogeneity of the terrain and vegetation cover in the study areas. In order to achieve good interpolation results the following criteria must be fulfilled:

- The profiles must be oriented to accurately represent terrain variations in the project area.
- The profiles must cover the full elevation range of the project area.
- The profiles must cover all vegetation strata.

The corrected elevation profiles must then be modeled with a polynomial trend function in order to compensate for small undulations in the profile caused by scatter in the elevation data. The modeled terrain elevation profiles must then be interpolated with the Kriging algorithm into a full coverage DTM.

The adequacy of the number, placement and spacing of the elevation profiles is evaluated by the accuracy assessment of the DTM. If the DTM meets the accuracy requirements of this methodology the number, placement and spacing of the elevation profiles are considered adequate.

Step 4: Accuracy assessment of the DTM

Radar-derived DTMs must be validated with topographic field measurements (eg, by dGPS, Tachymeter or total station) or LiDAR derived elevation measurements from a LiDAR dataset of known accuracy. The methods described below must be used to assess the accuracy of radar-derived DTMs. The accuracy of LiDAR datasets used to validate SRTM-derived DTMs must also be assessed as described below.

The minimum acceptable accuracy for the DTM is 1.75m.

Due to the flat topography of the peat dome, the data quality of the topographic field measurements of elevation must fulfill the following requirements:

- Elevation data (LiDAR or field measurements) used for the validation of the DTM must have a relative accuracy at least three times higher than the DTM dataset to be assessed.[16]
- Horizontal accuracy must be less than 1m.
- Vertical accuracy of the validation data must be at least three times higher than the DTM dataset to be assessed.
- The validation points must be representative of the area covered by the DTM.
- A minimum number of 20 points per vegetation class must be used.
- A minimum of 5 satellites must be available for GPS position measurements.
- A maximum PDOP of 5 or less must be achieved.

Where the minimum satellite visibility or maximum PDOP cannot be fulfilled at a given location, GPS measurement must be taken at a location where these requirements can be met (the “station”). Then, the X-, Y- and Z- offset from the station point must be measured by traverse or better controlled traverse measurements with a total station or tachymeter. The traverse method requires the exact determination of two points with GPS and the exact distance and angle between these two reference points (the “station”). Then, offset points which are referred to as the traverse must be measured from the station. The controlled traverse method is an improvement over the traverse method, and requires another station after the traverse to assess and correct the measurement errors in the offset points.

If field measurements are used to assess the accuracy of the DTM, the accuracy of the DTM must be calculated by comparison of the DTM elevation at the measurement points with the field measured elevation data according to the guidelines of the ASPRS Lidar Committee.[17] The accuracy assessment must assess the fundamental accuracy (accuracy of the DTM on open terrain), as well as supplemental accuracy for the present ground cover types.

[16] ASPRS Lidar Committee. 2004. Vertical Accuracy Reporting for Lidar Data V1
[17] ASPRS Lidar Committee. 2004. Vertical Accuracy Reporting for Lidar Data V1

Where no field measurements are available, the accuracy of radar-derived DTMs can alternatively be validated with LiDAR derived elevation measurements. Since the accuracy of LiDAR derived elevation data is dependent of the filtering of ground points, if LiDAR data is used to validate the radar-derived DTM, the LiDAR data must be validated as described below. When using LiDAR as validation data, it must be assured that only data from the actual LiDAR swath is taken, and not from interpolated areas between different LiDAR swaths.

First, the errors (difference between DTM and field measured or LiDAR elevation) must be tested for normal distribution with a suitable test such as the Kolmogorov-Smirnov (KSA) test, or by calculating the skewness.[18]

If the errors are normally distributed, the Root Mean Square Error (RMSE) must be used to determine the vertical accuracy ($Accuracy_z$) of the DTM.

RMSE is calculated with the equation:

$$RMSE_{DTM} = \sqrt{\frac{\sum_{q=1}^{Q}(Z_{val,q} - Z_{DTM,q})^2}{Q}} \quad (3)$$

Where:

$RMSE_{DTM}$	RMSE in DTM (m)
$Z_{val,q}$	Validation elevation value q (m)
$Z_{DTM,q}$	DTM elevation value q (m)
q	1,2,3…Q sample number

Then, vertical accuracy ($Accuracy_z$) of the DTM at the 95 percent confidence level must be calculated by the equation:

$$Accuracy_z = 1.96 * RMSE_{DTM} \quad (4)$$

Where:

$Accuracy_z$	Vertical accuracy of the DTM (m)
$RMSE_{DTM}$	Root Mean Square Error for DTM (m)

If the test for normal distribution fails (ie, the errors feature an asymmetric distribution), the use of RMSE is not appropriate for assessing the vertical accuracy. In this case, the 95th percentile of

[18] ASPRS Lidar Committee. 2004. Vertical Accuracy Reporting for Lidar Data V1

the errors must be calculated to determine $Accuracy_z$.[19] $Accuracy_z$ then directly equals the 95th percentile.

Where field measurements are used for assessing the accuracy of the DTM, the accuracy of the DTM directly equals the vertical accuracy.

$$Accuracy_{DTM} = Accuracy_z \tag{5}$$

Where:

$Accuracy_{DTM}$	Accuracy of the DTM (m)
$Accuracy_z$	Vertical accuracy of the DTM (m)

Where LiDAR derived elevation data are used for assessing the vertical accuracy of the radar-derived DTM, the uncertainty assessment must consider the accuracies of both datasets by error propagation. The accuracy of the LiDAR data ($Accuracy_{LiDAR}$) must be assessed with topographic field measurements of elevation applying the same methods and criteria described for assessment of the vertical accuracy of the DTM using topographic field measurements. Alternatively, if the dataset has been validated by the data provider and not the project, it must be assured that the accuracy of the data has been reported in accordance with the ASPRS guidelines[20] as “Tested (meters, feet) vertical accuracy at 95 percent confidence level” whenever possible. This requires:

- Availability of an independent validation data source (from a third party).
- Accuracy of the independent dataset must be at least three times higher than the dataset assessed.

If these requirements cannot be fulfilled, the accuracy of the LiDAR dataset must be reported as *Compiled to meet (meters, feet) vertical accuracy at 95 percent confidence level*. This may be used where:

- The validation dataset was measured by the data provider and not a third party.
- The accuracy of the validation dataset is not three times higher than the DTM being validated.
- The LiDAR dataset used for validation was validated, but outside the project area.

Accuracy in the radar-derived DTM validated with LiDAR data is calculated as:

$$\text{Accuracy}_{\text{DTM}} = \sqrt{\text{Accuracy}_{\text{z}}^{2} + \text{Accuracy}_{\text{LiDAR}}^{2}} \tag{6}$$

[19] ASPRS Lidar Committee. 2004. Vertical Accuracy Reporting for Lidar Data V1

[20] ASPRS Lidar Committee. 2004. Vertical Accuracy Reporting for Lidar Data V1

Where:

$Accuracy_{DTM}$	Accuracy of the radar-derived DTM (m)
$Accuracy_{z}$	Vertical accuracy of the radar-derived DTM as assessed with LiDAR data (m)
$Accuracy_{LiDAR}$	Accuracy of the LiDAR dataset (m)

8.1.1.3 Generate Peat Thickness Model

The terrain model must be combined with peat drilling data to generate a spatially explicit model of peat thickness within the watershed(s) of interest.

Step 1: Obtain peat thickness data

In order to determine peat thickness, the depth of peat at each sampling location must be determined through peat drilling using a peat auger such as an Eijkelkampp, until the mineral soil underneath the peat is reached.

Peat drilling locations in the watershed(s) of interest must be determined using representative random sampling or systematic sampling. It is acceptable to conduct drilling along transects that extend from one boundary of the peat dome to the opposite boundary and intersects the highest point of the peat dome. Sampling intervals must range from 500 to 1500 meters depending on the size of the peat dome and terrain accessibility. The highest point must be determined using the DTM. In highly inaccessible areas peat thickness can be interpolated using a correlation function between the peat surface and peat thickness data.[21] Uncertainty in peat drilling data must be addressed by assuming the lower bound of the peat thickness model as described below.

Step 2: Estimate peat thickness

If drilling measurements are systematically distributed across the watershed(s) of interest, direct spatial interpolation, such as Kriging, must be applied to estimate peat thickness. In highly inaccessible areas peat thickness may be estimated using a binominal correlation function between the peat surface elevation derived from the DTM and peat thickness data. The surface elevation of the peat dome must be normalized to the elevation of the boundary of the peat dome with the equation:

$$h(norm) = h - h(bound) \quad (7)$$

Where:

h(norm)	Normalized peat surface elevation relative to the peat boundary
h	Terrain elevation

[21] Jaenicke, J, Rieley, JO, Mott, C, Kimman,P, and Siegert ,F. 2008. Determination of the amount of carbon stored in Indonesian peatlands. *Geoderma* 147: 151-158

h(bound) Elevation at the peat dome boundary

For the establishment of the correlation function, the surface elevation is extracted from the DTM at the drilling locations. Then a binominal trend function between those variables must be calculated with the equation:

$$PTh = a * h(norm)^2 + b * h(norm) + c \quad (8)$$

Where:

PTh Peat thickness

h(norm) Normalized peat surface elevation

a, b, c Coefficients of the binominal correlation function, determined on reference data

The minimum acceptable model correlation between peat surface elevation and peat thickness is $R^2 > 0.7$. Otherwise, peat thickness cannot be derived using the correlation function.

The peat thickness model must then be obtained by applying the correlation function to each grid cell of the normalized DTM.

The accuracy of the peat thickness model must be assessed with validation peat thickness data not used for calibrating the model. As the peat thickness model is derived from peat drilling data and the DTM, first the calculated accuracy based on the peat thickness data must be combined with the accuracy of the DTM by error propagation to determine the overall vertical accuracy in the peat thickness model.

The errors (difference between measured peat thickness and the modeled peat thickness) must be tested for normal distribution distribution with a suitable test such as the Kolmogorov-Smirnov (KSA) test, or by calculating the skewness.[22]

If the errors are normally distributed, the Root Mean Square Error (RMSE) must be used to determine the accuracy of the peat thickness model. RMSE is calculated with the formula:

$$RMSE_{PTh} = \sqrt{\frac{\sum_{q=1}^{Q} (PTh_{val,q} - PTh_{MOD,q})^2}{Q}} \quad (9)$$

Where:

$RMSE_{PTh}$ RMSE in peat thickness model (m)

$PTh_{val,q}$ Validation peat thickness value q (m)

[22] ASPRS Lidar Committee. 2004. Vertical Accuracy Reporting for Lidar Data V1

$PTh_{MOD,q}$ Modeled peat thickness value q (m)

q 1,2,3…Q sample number

Then, accuracy ($Accuracy_{PTh}$) of the peat thickness model at the 95 percent confidence level must be calculated by the equation:

$$Accuracy_{PTh} = 1.96 * RMSE_{PTh} \quad (10)$$

Where:

$Accuracy_{PTh}$ Accuracy of the peat thickness model (m)

$RMSE_{PTh}$ RMSE for peat thickness model (m)

If the test for normal distribution fails (ie, the errors feature an asymmetric distribution), the use of RMSE is not appropriate for assessing the accuracy of the peat thickness model. In this case, the 95th percentile of the errors must be calculated to determine $Accuracy_{Pth}$.[23] $Accuracy_{PTh}$ then directly equals the 95th percentile.

Peat thickness is conservatively estimated by assuming the lower bound of the estimated peat thickness is the actual peat thickness at the project start date.

$$PTh_{Adjusted,x,t0} = PTh_{x,t0} - Accuracy_{PTh} \quad (11)$$

$PTh_{Adjusted,x,t0}$ Peat thickness in grid cell *x* at start of the project activity adjusted for uncertainty in the peat thickness estimate (m)

$PTh_{x,t0}$ Peat thickness in grid cell *x* at start of the project activity as calculated from peat thickness model (m)

$Accuracy_{PTh}$ Accuracy of the peat thickness model (m)

At each verification event, peat thickness must be updated for the associated baseline period to update the estimate of baseline emissions by conservatively assuming a reduction in peat depth due to subsidence.

$$PTh_{x,t} = PTh_{Adjusted,x,t0} - (S_p * 0.01 * t) \quad (12)$$

Where:

$PTh_{x,t}$ Peat thickness in grid cell *x* at start of baseline period (m)

[23] ASPRS Lidar Committee. 2004. Vertical Accuracy Reporting for Lidar Data V1

$PTh_{Adjustedx,t0}$ Peat thickness in grid cell x at the start of the project activity adjusted for uncertainty in the peat thickness estimate (m)

S_p Peat subsidence rate (see Section 8.1.2)

t 0,1,2,3…t number of years elapsed since the start of the project (years)

During first baseline period $PTh_{x,t} = PTh_{Adjusted,x,t0}$

8.1.1.4 Collect Climate Variable Data

Long-term climate variables are determined using data from weather station(s) representative of the watershed(s) of interest. Precipitation data must be available on the daily time step for a climate station within 100 km and within ±100 m elevation of the project area for 20 years prior to the project start date, thus capturing the range of precipitation conditions in the area. Additionally, evapotranspiration rates of the dominant vegetation cover(s) must be available as an input to the SIMGRO model.

Evapotranspiration may be assumed to be a constant daily value of 3.5 mm per day, [24] or another location-specific factor may be used if the project proponent demonstrates that it meets the VCS requirements with respect to the selection of appropriate default factors, since evapotranspiration is fairly constant in the humid tropical areas and yearly variations in evapotranspiration show low variance. Evapotranspiration is mainly driven by wind speed, temperature and air humidity. These climatic factors are fairly similar for the tropical Southeast Asia region and therefore evapotranspiration is considered to be fairly uniform across the region.

Half day to daily time steps are required for modeling water flow in the unsaturated zone and groundwater; the selected time steps for each must match but may vary within this range.

Data for the watershed(s) of interest may be supplied from more than one weather station falling within 100 km of the watershed(s) of interest boundary. In this case the relevant station must be specified for each of the SVAT-units in the model. Where more than one weather station data exists, data on climate variables may be interpolated for the watershed(s) of interest. If more than one weather station meets the location requirements for a given SVAT-unit, for time periods where data from the selected weather station is not available, data from an alternate weather station that meets the location requirements of the SVAT-unit may be substituted.

[24] Takahashi, H., Usup, A., Hayasaka, H., Kamiya, M., Limin, S.H., 2004. The importance of ground water level and soil moisture of subsurface layer on peat/forest fire in a tropical peat swamp forest. In: Päivänen, J. (Eds.), Wise Use of Peatlands. Volume 1. Proceedings of the 12th International Peat Congress, Tampere, Finland, 6-11 June 2004. International Peat Society, Jyväskylä, Finland, p. 760.

Using the historic daily climate data, an average precipitation per day within a month must be calculated. This historic climate data will be used to run the SIMGRO model for ex-ante estimations for the baseline and project scenarios.

For each baseline period, the historical climate data used must be updated to update the estimate of baseline emissions.

8.1.1.5 Delineate Waterways

Waterways in the watershed(s) of interest must be delineated and information on water characteristics such as width and depth is measured in the field and recorded as average values for each waterway type.

Delineation and characterization of waterways is completed by the following steps:

Step 1: Remote Sensing delineation of waterways

Waterways may be delineated by combining high resolution satellite images with field surveys.[25] High spatial resolution satellite imagery (10-m or better such as ALOS or SPOT) may be used to delineate the location, length, and outflow of waterways using visual interpretation and measurement tools in a Geographic Information System (GIS) or similar software. Where waterways cannot be delineated with high resolution satellite images, the waterways may be delineated in the field.

Step 2: Field delineation of waterways and creation of waterway classes

All identified waterways delineated with high resolution satellite images must be confirmed by field checks. Field data must also be used to delineate waterways that cannot be delineated with high resolution satellite images.

At all identified waterways, GPS measurements must be taken verifying the location of the waterway. The total length of waterways may be estimated based on interviews with local communities, or alternatively GPS measurements may be taken along identified waterways delineating the waterway. All measurements must be incorporated into a geodatabase of waterway locations.

Waterways must be stratified into waterway classes (eg, major river, minor river, major canal, medium canal, hand-dug canal) based on their physical parameters.

It is conservative to assume a waterway does not exist while modeling baseline emissions, therefore, it is *not* necessary to ensure *all* waterways have been identified. If an identified waterway cannot be field verified, then it must be assumed to not exist in the model.

[25] Jaenicke, J, Wösten, H, Budiman, A and Siegert, F. 2010. Planning hydrological restoration of peatlands in Indonesia to mitigate carbon dioxide emissions. *Mitigation and Adaptation Strategies for Global Change* 15: 223-239.

Step 3: Characterization of waterway classes

Waterways must be divided into size classes for sampling according to their physical characteristics. A representative subset of waterways must be selected to characterize each waterway class. Selection of waterways for sampling must be random or systematic with random start. A minimum of 10 waterways or 10% of total identified waterways must be sampled, whichever is higher, unless fewer than 10 waterways are identified, in which case all waterways must be sampled.

For each sampled waterway in a waterway class, field teams must travel the length of the waterway and record information at regular intervals (eg, 100 m) allowing for at least 5 measurements per selected waterway measured:

- Physical characteristics:
  - Waterway Width (m)
  - Waterway Depth (distance from bottom of waterway to surface of peat next to waterway) (m)
- Natural Damming evidence:
  - Water flow[26] (slow, medium, fast)
  - Mud sedimentation within waterflow (presence/absence)
  - Weed growth within flow of waterway (presence/absence)
  - Natural damming (presence/absence)

All data collected must be geo-referenced and included in the geodatabase.

Some natural damming of waterways may take place. The expected rate of such blocking must be estimated within the SIMGRO model. The field data collected must be used to estimate the percentage of waterways likely to experience natural damming before the end of the project crediting period as follows. Any sampled waterway where at more than 50% of the measurement points slow water flow, presence of mud sedimentation within waterflow, presence of weed growth within flow of waterway, and presence of natural damming is observed is considered to undergo natural damming within the project crediting period. The expected rate of natural damming estimated within the SIMGRO model is the proportion of sampled waterways identified as undergoing natural damming within the project crediting period.

[26] Slow, medium, and fast water flow is specified relative to project field measurements. “Slow” water flow is measured surface discharge in the bottom third of all surface discharge measurements for the project area, “medium” water flow is measured surface discharge in the middle third of all surface discharge measurements for the project area, and “fast” water flow is measured surface discharge in the top third of all surface discharge measurements for the project area.

Field measurements of physical characteristics must be averaged to create an average characteristic per waterway class. The following equation must be repeated for all waterway physical characteristics measured (width and waterway depth):

$$Ch_{A,w} = \frac{\sum_{m=1}^{M} \frac{\sum_{p=1}^{P} Ch_{A,m,p,w}}{P}}{M} \tag{13}$$

Where:

$Ch_{A,w}$	Mean value of waterway characteristic *A* for waterclass *w* (variable)
$Ch_{A,m,p,w}$	Value of waterway characteristic *A* for waterway measured *m* at measurement point p for waterclass *w* (variable)
A	1,2,3 ….A waterway characteristic for waterclass *w* (width and waterway depth)
1, 2, 3, …	W water class within project area
m	1,2,3 ,…M waterways measured
p	1,2,3, …P points where measurements taken in waterway *m* of waterway class *w*

8.1.1.6 Validate SIMGRO Model for Watershed(s) of Interest Conditions

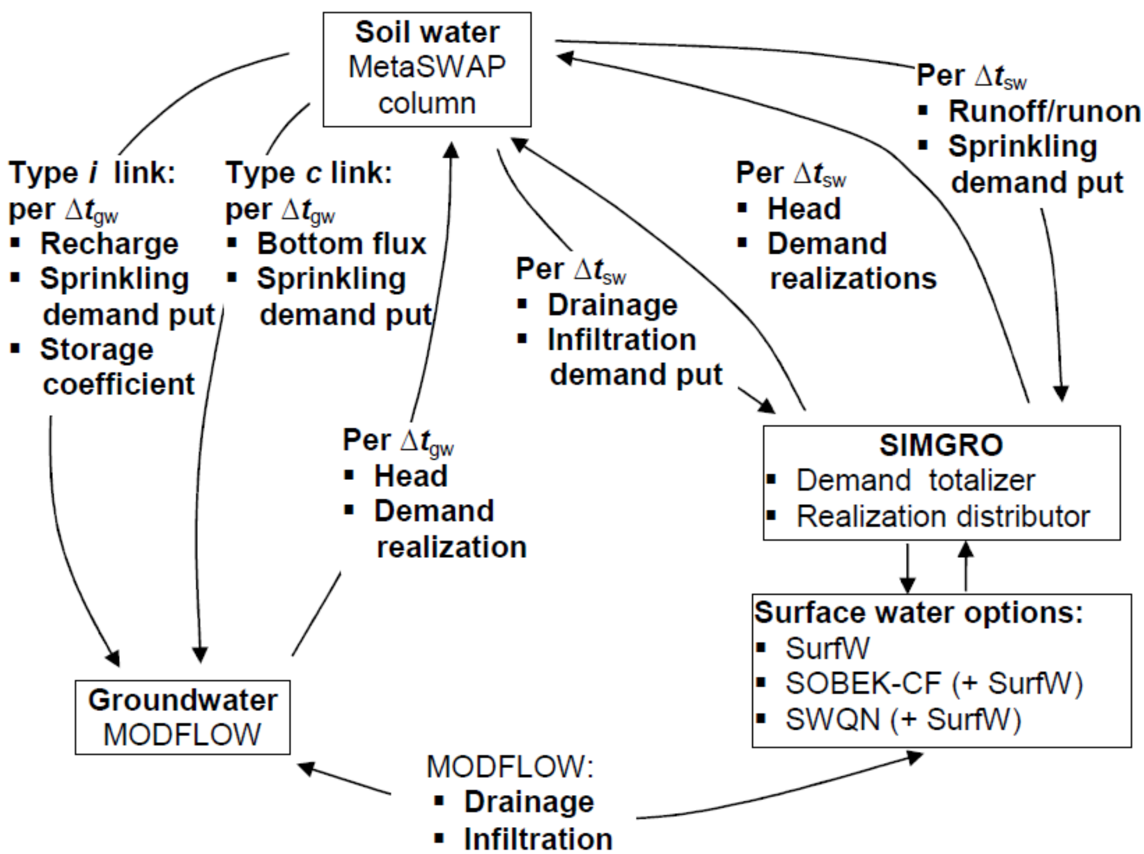
To model water levels in the watershed(s) of interest and stratify the project area by drainage depth, the project proponent must use the SIMGRO model.[27] The parameters of the model must be adjusted for ombrogenous tropical peatlands in Southeast Asia. The project proponent must determine whether this model calibration adequately models water table level in the watershed(s) of interest.

The SIMGRO model is a dynamic integrated model which simulates soil-water-atmosphere interaction within Soil-Vegetation-Atmosphere Transfer (SVAT) units to calculate water levels in the project area. The Soil Vegetation Atmosphere Transfer (SVAT) model simulates the exchange of energy between the land surface and the free atmosphere. The SVAT model incorporates a biological component, which simulates the rate of plant-atmosphere and plant-soil interactions (photosynthesis and transpiration) and a physical component, which simulates radiative transfer, surface energy balance, and groundwater and surface water flow. The biological and physical components are based on the characteristics of soil, vegetation and climate of the region being modeled. Commonly, the Penman-Monteith equation or variants of this equation are used to simulate the biological component. Within SIMGRO, the groundwater

[27] van Walsum, PEV., Veldhuizen, AA, , van Bakel, PJT, van der Bolt, FJE, Dik, PE, Groenendijk, P, Querner, EP, Smit, MFR. 2007. SIMGRO 6.0.2, Theory and model implementation. Wageningen, Alterra. http://www.alterra.wur.nl/UK/research/Specialisation+water+and+climate/Integrated+Water+Management/SIMGRO

and surface water flow models are spatially explicit and incorporate regional climate data (precipitation, soil evaporation, evapotranspiration) and water management (groundwater abstraction, irrigation). Various modules within SIMGRO may be used for simulating surface water and drainage flow and module selection depends on ease of use. Use of ASCII output files are recommended for ease in analysis of results. The following diagram provides an overview of SIMGRO modules with relationships and options.

Figure 1: SIMGRO Modules with Relationships and Options[28]



Within the SIMGRO model, saturated groundwater flow is modeled using the finite element method with the top of the mineral layer set as aquifer bottom. A two-layer peat profile is schematized consisting of a fibric to hemic peat top layer (defined as less than 1m depth) and a sapric deeper layer (defined as all peat greater than 1m) with a characteristic hydraulic conductivity specified for each of these layers. The hydraulic conductivity defines the rate at which water moves through a porous media, in this case the soil. Measurements of hydraulic conductivity were obtained from standard pump test methods which indicate how the aquifer

[28] Walsum, P.E.V. 2010. SIMGRO, User's guide V7.1.0. Wageningen, Alterra. Alterra-Report 913.2 82 pp.

responds to a withdrawal in groundwater such as those described in Ong and Yogeswaran[29] and Takahashi and Yonetani.[30]

The SIMGRO model also provides a default value for the water storage coefficient, defined as the difference between the peat water content at saturation (when the groundwater level is at land surface) and the peat water content at a pressure head corresponding with a groundwater level typical for the drained situation (for example 1 or 1.5m below land surface).

Table 1: Default Coefficient Values Used in SIMGRO Model[31]

	Hydraulic conductivity	Water storage coefficient
Surface layer (≤1 m from peat surface)	30 m day^{-1}	0.5
Deep layer (>1 m from peat surface)	0.5 m day^{-1}	0.5

Although saturated hydraulic conductivity and water storage coefficients can vary, a conservative value has been used in comparison to other values reported for peatlands.[32]

Although the parameters of the SIMGRO model are adjusted for ombrogenous tropical peatlands in Southeast Asia in accordance with the requirements above, limited field sampling must still take place to validate the results produced by the model for the peatland found within the watershed(s) of interest.

Modeled water levels must be compared with actual field measurements of water levels to assess the accuracy of the model. Field measurements must take place within the project area. It is allowable for sampling locations to be chosen based on accessibility. The following conditions must be met at the sampling locations:

- All data required for SIMGRO modeling must have been collected using criteria within the methodology.

[29] Ong BY, Yogeswaran M 1992. Peatland as a resource for water supply in Sarawak. In: Aminuddin BY, Tan SL, Aziz B, Samy J, Salmah Z, Siti Petimah, Choo ST eds. Proceedings of the International Symposium on Tropical Peatland, Kuching, Sarawak, May 1991. Ministry of Agriculture, MARDI, pp 255–268.

[30] Takahashi, H and Yonetani, Y. 1997. Studies on microclimate and hydrology of peat swamp forest in Central Kalimantan, Indonesia. In: Rieley, JO, Page, SE eds. *Biodiversity and sustainability of tropical peatlands*. Samara, Cardigan, pp 179–187

[31] Jaenicke, J, Wösten, H, Budiman, A and Siegert, F. 2010. Planning hydrological restoration of peatlands in Indonesia to mitigate carbon dioxide emissions. *Mitigation and Adaptation Strategies for Global Change* 15: 223-239.

Wösten, JHM, Clymans, E, Page, SE, Rieley, JO, Limin, SH. 2008. Peat – water interrelationships in a tropical peatland ecosystem in Southeast Asia. *Catena* 73, 212-224

[32] Department of Irrigation and Drainage. 2001. Water management guidelines for agricultural development in coastal lowlands of Sarawak, Department of Irrigation and Drainage, Sarawak. http://www.did.sarawak.gov.my/modules/web/page.php?id=381

- Yearly water table level range must be within ±50 cm of that within project area
- Minimum peat thickness in the area modeled must be greater than the minimum within the project area

Sampling points must be located randomly or systematically with a random starting location. For example, a first sampling point may be chosen at a fixed distance from a canal (eg, 10m), and additional sampling points may be positioned in a regular grid with a distance fixed distance (eg, 50m) between point location. Locations should be accessible without great difficulty to allow for repeated measurements.

Sample transects must be located at various positions along the canals, if possible. If only a single measurement transect can be installed along a canal, it must be assured that it is located close to the canal mouth, because the water tables at this location are considered to be closest to the peat surface during the dry season and resulting emissions are lowest. Therefore, an overestimation of emission reductions by the project measures is conservatively avoided. At each sampling point the level from the peat surface to the water table must be recorded.[33] Field data measurements must be taken for a minimum of 8 months, but must include measurements within the dry season and the wet season at a frequency of at least once per month. Sampling location, water table level, and date of measurement must be recorded in a geodatabase. A minimum of 10 sampling points is required to obtain 80 measurements for the required time period of 8 months for model validation.

The metric used to validate the model is the difference between calculated and measured water levels relative to the peat surface at a geographic location and on the date of field measurements.

First, the errors (difference between calculated and measured water levels) must be tested for normal distribution with a suitable test such as the Kolmogorov-Smirnov (KSA) test, or by calculating the skewness[34]. If the errors are normally distributed, the Root Mean Square Error (RMSE) must be used to compare calculated and measured water levels. RMSE provides information on the accuracy of the model. It is allowable to calculate separate RMSE for each season of a year (eg, wet season and dry season). RMSE is calculated with the formula:

$$RMSE_{WT} = \sqrt{\frac{\sum_{g=1}^{G}(Meas_g - Mod_g)^2}{G}} \quad (14)$$

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[33] Guidance on water level measurement can be found in:

Morgan P. and Stolt. M H. 2004. *A comparison of several approaches to monitor water-table fluctuations*. *Soil Science Society of America Journal*. 68:562–566

Vidon and Smith 2008. Assessing the Influence of Drainage Pipe Removal on Wetland Hydrology Restoration: A Case Study. *Ecological Restoration* V26, N1, 33-43.

[34] ASPRS Lidar Committee. 2004. Vertical Accuracy Reporting for Lidar Data V1

Where:

$RMSE_{WT}$	Root Mean Square Error for water levels (cm)
$Meas_g$	Measured water level relative to the peat surface value *g* (cm)
Mod_g	Model calculated water level relative to the peat surface value *g* (cm)
g	1,2,3…G sample number

An RMSE less than or equal to 40 cm is required. If this value is not met, the SIMGRO model cannot be considered applicable to the project area and this methodology cannot be used.

If the test for normal distribution fails, (ie, the errors feature an asymmetric distribution), the use of RMSE is not appropriate for assessing the accuracy in the modeled water levels. In this case, the 95th percentile of the errors must be calculated to determine the accuracy of modeled water levels. The accuracy of modeled water levels then directly equals the 95th percentile.

The uncertainty in water level estimate is calculated as:

$$U_{WT} = \frac{RMSE_{WT}}{j_{max}} * 100\% \quad (15)$$

U_{WT}	Percentage uncertainty in water table levels estimate (%)
$RMSE_{WT}$	RMSE calculated for validation of SIMGRO model (cm)
j_{max}	Maximum absolute modeled value of water table level relative to the peat surface (cm)

The metric used to test bias in the model is the mean error (ME).

$$ME = \frac{1}{G} * \sum_{g=1}^{G}(Meas_g - Mod_g) \quad (16)$$

Where:

ME	Mean error (cm)
$Meas_g$	Measured water level relative to the peat surface value *g* (cm)
Mod_g	Model calculated water level relative to the peat surface value *g* (cm)
g	1,2,3…G sample number

An ME less than or equal to ±20 cm is required, otherwise this methodology is not applicable.

8.1.2 Stratify Project Area by Peat Depletion Time

Emissions from peat can occur only as long as there is a peat supply available to undergo oxidation. In drained peat conditions, the peat surface has been found to subside resulting in the aerobic peat layer becoming thinner. Published information has indicated that during the first few years after drainage, subsidence is the result of both soil compaction and oxidation, but in subsequent years the cause of subsidence is oxidation.[35] This subsidence is greatest in the years directly after drainage, but stabilizes after several years following the initial drainage event. Under non-drained conditions, net subsidence does not occur in forested peatland areas.[36] Subsidence rates under drained conditions are differing and are dependent on conditions at the project site in regards to land-use history, water table, current land cover, fire history, microtopography and several other factors. As the subsidence rate under drained conditions is strictly dependent on the conditions at the project site, a value for subsidence rate must be used by the project proponent, which meets the VCS requirements with respect to the selection of appropriate default factors.

The number of years until all peat is depleted must be calculated across the project area and within the excluded area of watershed(s) boundary for each SIMGRO grid cell based on the peat thickness model at the project start date adjusted for uncertainty in the estimate of peat thickness. Based on this conservative calculation, for locations within where peat will remain at the end of the project crediting period, it is assumed that emissions from peat can take place for all years within the project crediting period. However, for locations where the depth of peat is smaller and therefore the peat is depleted prior to the end of the project crediting period, the project area and excluded area of watershed(s) must be stratified by the maximum number of years where emissions can be assumed to take place:

$$t_{PDT,x} = \frac{PTh_x}{S_p * 0.01} \tag{17}$$

if $t_{PDT,x} + t > t_{crediting\_period}$ then for grid cell x $t_{max} = t_{crediting\_period}$ (18)

if $t_{PDT,x} + t < t_{crediting\_period}$ then for grid cell x $t_{max} = t_{PDT,x} + t$ (19)

Where:

$t_{PDT,x}$	Assumed number of years until all peat is depleted within grid cell x (years)
PTh_x	Peat thickness in grid cell x at the start of the baseline period (meters)
S_p	Peat subsidence rate
$t_{crediting\_period}$	Length of the project crediting period (years)
t_{max}	Maximum number of years emissions can take place in grid cell x in project crediting period (years)

[35] Jauhiainen, J. H Takahashi, JEP Heikkinen, PJ Martikainen, and H Vasander. 2005 Carbon fluxes from a tropical peat swamp forest floor. Global Change Biology: 11, 1788–1797) and carbon density of 21.6 t CO_2 ha^{-1} cm^{-1} (listed in units: 60 kg C cm^{-3} in: Hooijer, A., S. Page, J. G. Canadell, M. Silvius, J. Kwadijk, H. Wosten, and J. Jauhiainen. 2010. Current and future CO2 emissions from drained peatlands in Southeast Asia. Biogeosciences, 7, 1505–1514

[36] Hooijer, A, Page, S, Jauianinen, J, Lee, WA, Lu, XX, Idris, A, Anshari, G. 2012. Subsidence and carbon loss in drained tropical peatlands. *Biogeosciences* 9: 1053 – 1071

t	1, 2, 3 …$t_{crediting\_period}$ years elapsed since the start of the project

The maximum number of years emissions can take place for a given grid cell must be reassessed at each verification event using updated peat thickness estimates calculated in Section 8.1.1.3. The peat depletion time strata must be updated during baseline reassessment using updated peat thickness estimates calculated in Section 8.1.1.3.

8.1.3 Estimate Ex-ante Modeled Water Levels within Project Area Over Project Crediting Period and for 100 Years

The SIMGRO model must be run across the watershed(s) of interest area for the project crediting period and for 100 years using the above spatial data sets and the historic mean daily precipitation data, updated for each baseline period.

The output of the SIMGRO model for the baseline scenario in the watershed(s) of interest area over the project crediting period must be used to stratify the project area by drainage depth per day for each year of the project crediting period. Each grid cell in the model will have a known daily drainage depth for each year of the project crediting period.

Subsidence of the peat layer due to drainage is assumed to cause a reduction in the distance from the water level and the peat surface. To account for reduced CO_2 emission rates resulting from progressive subsidence, an annual correction is made to the water table levels based on an average annual subsidence rate.

$$j_{corr,x,d,t} = j_{x,d,t} - (t * S_p) \quad (20)$$

$j_{corr,x,d,t}$	*0, 1, 2, 3*…$J_{corr,t}$ Water table level relative to the peat surface, corrected for subsidence, in grid *x,* on day *d,* in year *t* (cm) (maximum 100 cm) (if $j_{x,d,t} \leq 0$ then assume $j_{x,d,t}=0$ on day *d*)
j	*0, 1, 2, 3*…J SIMGRO modeled water table level relative to the peat surface in grid *x,* on day *d, in year t* (cm) (maximum 100 cm)
S_p	Peat subsidence rate
x	1, 2, 3 …X grid cells in project area
d	1, 2, 3 … 365 days of year *t*
t	1, 2, 3, … t_{max} years elapsed since the start of the project crediting period

8.1.4 Calculate Ex-ante GHG Emissions in the Baseline

The baseline emissions are calculated by adding emissions from net changes in the carbon pools and the non-CO_2 emissions. Therefore, baseline net GHG emissions are calculated as:

$$\Delta C_{BSL,t} = \sum_{x=1}^{X} \Delta C_{BSL,x,t} * A_x \quad (21)$$

$$\Delta C_{BSL,x,t} = \Delta C_{BSL,CO2,x,t} + GHG_{BSL,x,t} \quad (22)$$

$$GHG_{BSL,x,t} = 0 \quad (23)$$

Where:

$\Delta C_{BSL,t}$	Net baseline GHG emissions, in year *t* (t CO_2e)
$\Delta C_{BSL,x,t}$	Net baseline GHG emissions in grid *x*, in year *t* (t CO_2e ha^{-1})
$\Delta C_{BSL,CO2,x,t}$	Net carbon stock change in all pools in the baseline in grid *x*, in year *t* (t CO_2e ha^{-1})
$GHG_{BSL,x,t}$	Non-CO_2 emissions taking place in the baseline in grid *x*, in year *t* (t CO_2e ha^{-1})
A_x	Area of grid cell x
x	*1,2,3,… X* grid cells in project area
t	1, 2, 3, … t_{max} years elapsed since the project start date

The only carbon pools that are accounted for in the baseline and project scenarios are aboveground tree biomass and soil carbon. Under the baseline scenario, the carbon stocks in aboveground tree biomass will be decreasing or stable due to increased chance of burning or tree death due to low water table levels. Therefore, it is conservative to assume that the change in aboveground tree biomass in the baseline scenario is equal to zero. Any loss of sediment within drainage canals in the baseline scenario is conservatively not accounted for.

$$\Delta C_{BSL,CO2,x,t} = \Delta C_{AB\_tree,x,t} + \Delta C_{B-SOC,x,t} \quad (24)$$

$$\Delta C_{AB\_tree,x,t} = 0 \quad (25)$$

Where:

$\Delta C_{BSL,CO2,xt}$	Net carbon stock change in all pools in the baseline in grid cell *x*, in year *t* (t CO_2e ha^{-1})
$\Delta C_{AB\_tree,xt}$	Net carbon stock change in the aboveground tree biomass pool in the baseline in grid cell *x*,in year *t* (t CO_2e ha^{-1})
$\Delta C_{B-SOC,xt}$	Net emissions from soil carbon pool in the baseline in grid cell *x*,in year *t* (t CO_2e ha^{-1})
x	1,2,3,… X grid cells in project area

t 1, 2, 3, … t_{max} years elapsed since the project start date

Emissions in the baseline scenario must be estimated for the entire project crediting period and for 100 years.

CO_2 emissions from peat oxidation in the baseline scenario are estimated considering the daily water levels relative to the peat surface in the project area and a CO_2 emission factor linking water levels to CO_2 emissions from oxidation. For days where the water table level is less than zero (eg, the peat is flooded), the emissions are assumed to be zero at that location.

The procedure to calculate CO_2 emissions from peat oxidation in the baseline scenario is as follows. For each grid cell, emissions must only be estimated to take place up to the year of peat depletion.

$$\Delta C_{B-SOC,x,t} = \sum_{d=1}^{D} j_{corr,BSL,x,d,t} * 0.01 * \frac{EF_{CO2}}{356} \quad (26)$$

Where:

$\Delta C_{B-SOC,xt}$ Emissions from soil carbon pool resulting from peat oxidation in the baseline in grid cell x, year t (t CO_2e ha^{-1in})

EF_{CO2} Emission Factor; t CO_2 ha^{-1} yr^{-1} m^{-1} of water level relative to peat surface; 98[37]

$j_{corr,BSL,x,d,t}$ *0, 1, 2, 3* …$J_{corr,d,t}$ Water table level relative to the peat surface, corrected for subsidence, in baseline, in grid x, on day d, in year t (cm) (if $j_{corr,x,d,t} \leq 0$ then assume $j_{corr,x,d,t}=0$ on day d)

x 1, 2, 3 …X grid cells in project area

d 1, 2, 3 … 365 days of year t

t 1, 2, 3, … t_{max} years elapsed since the project start date

The above emission factor is based on a review of GHG fluxes from tropical peatlands in Southeast Asia.[38] An alternative emission factor may be used if the project proponent demonstrates that it meets the VCS requirements with respect to the selection of appropriate default factors.

8.2 Project Emissions

Project emissions are estimated based on modeled water levels relative to the peat surface. Project emissions include only CO_2 emissions from peat oxidation.

[37] Hooijer, A., S. Page, J. Jauhiainen, W. A. Lee, X. X. Lu, A. Idris, and G. Anshari. 2012. Subsidence and carbon loss in drained tropical peatlands. Biogeosciences, 9, 1053–1071.
[38] Ibid.

The proposed project activity will raise water levels relative to the peat surface within the watershed(s) of interest through permanent and temporary structures which hold back water in drainage waterways such as dams. As a consequence, compared to the baseline CO_2 would decrease. CO_2 emissions from peat oxidation within the project area are determined based on drainage level.

Therefore, project net GHG emissions are calculated as:

$$\Delta C_P = \sum_{t=1}^{t_{crediting\_period}} \Delta C_{\mathrm{Pr},t} \qquad (27)$$

Where:

ΔC_P	Net greenhouse gas emissions in the project scenario (t CO_2e)
$\Delta C_{Pr,t}$	Net greenhouse gas emissions in the project scenario at time *t* (t CO_2e)
t	*1,2,3 …t* years elapsed since the project start date

Emissions in the project scenario must be estimated for the entire project crediting period and for 100 years.

8.2.1 Modeling of Water Levels

Ex-ante and ex-post project CO_2 emissions are estimated following the same approach as used for determining the baseline emissions. In this case, water levels relative to the peat surface in the project scenario must be projected by modeling the effects of the measures implemented by the project on the hydrology of the watershed(s) of interest.

8.2.1.1 Modification of Model for Project Scenario

For the ex-ante estimation of project emissions, dam location must be based on dam location plans. For ex-post, the actual date and location of dam construction must be stored in a geodatabase and input into the SIMGRO model.

The ex-ante estimated water levels relative to the peat surface in the watershed(s) of interest considering the project intervention is determined by the SIMGRO model using the historic precipitation data.

The model must be updated ex-post with actual precipitation data and information on implementation of the project intervention to simulate water levels relative to the peat surface in the project area ex-post.

8.2.2 Calculate Ex-ante GHG Emissions in the Project Scenario

The project net GHG emissions are calculated as:

$$\Delta C_{\mathrm{Pr},t} = \sum_{x=1}^{X} \Delta C_{\mathrm{Pr},x,t} * A_x \qquad (28)$$

$$\Delta C_{\mathrm{Pr},x,t} = \Delta C_{\mathrm{Pr},CO2,x,t} \qquad (29)$$

Where:

$\Delta C_{Pr,t}$	Net project GHG emissions, in year t (t CO_2e)
$\Delta C_{Pr,x,t}$	Net project GHG emissions in grid x, in year t (t CO_2e ha^{-1})
$\Delta C_{Pr,CO2,x,t}$	Net carbon stock change in all carbon pools in the project scenario in grid x, in year t (t CO_2e ha^{-1})
A_x	Area of grid cell x
x	*1,2,3,… X* grid cells in project area
t	1, 2, 3, … t_{max} years elapsed since the project start date

8.2.2.1 Project Net Carbon Stock Change in Pools

The only carbon pools that are included in the project scenario are aboveground tree biomass and soil carbon. However, it is conservatively assumed that no changes occur in the aboveground tree biomass as a result of project activities, since, in the baseline scenario carbon stocks in aboveground tree biomass will be decreasing or stable due to increased chance of burning or tree death due to low water table levels.

$$\Delta C_{\mathrm{Pr},CO2,x,t} = \Delta C_{AB\_tree,x,t} + \Delta C_{P-SOC,x,t} \qquad (30)$$

$$\Delta C_{AB\_tree,x,t} = 0 \qquad (31)$$

Where:

$\Delta C_{Pr,CO2,x,t}$	Net carbon stock change in all carbon pools in the project scenario in grid x in year t (t CO_2e ha^{-1})
$\Delta C_{AB\_tree,x,t}$	Net carbon stock change in aboveground tree biomass pool in grid x in year t (t CO_2e ha^{-1})
$\Delta C_{P-SOC,x,t}$	Net emissions from soil carbon pool in the project scenario in grid x in year t (t CO_2e ha^{-1})
x	*1,2,3,… X* grid cells in project area
t	1, 2, 3, … $t_{crediting\_period}$ years elapsed since the project start date

The SIMGRO model must be run across the watershed(s) of interest for the project crediting period and for 100 years using the above spatial data sets and the historic mean daily precipitation data. CO_2 emissions from peat oxidation in the project scenario are estimated considering the daily water levels relative to the peat surface in the project area and a CO_2 emission factor linking water levels to CO_2 emissions from oxidation.

The procedure to calculate CO_2 emissions from peat oxidation in the project scenario is implemented as follows. For each stratum, emissions can only be estimated to take place up to the year of peat depletion.

Any sedimentation occurring within dammed canals is conservatively excluded.

$$\Delta C_{P-SOC,x,t} = \sum_{d=1}^{D} j_{\text{Pr},corr,x,d,t} * 0.01 * \frac{EF_{CO2}}{356} \qquad (32)$$

Where:

$\Delta C_{P\text{-}SOC,x,t}$	Emissions from soil carbon pool resulting from peat oxidation in the project scenario in grid x in year t (t CO_2e ha^{-1})
EF_{CO2}	Emission Factor; t CO_2 ha^{-1} yr^{-1} of water level relative to the peat surface; 98[39]
$j_{Pr,corr,xd,t}$	*0, 1, 2, 3* …$J_{\text{Pr,corr,x,d,t}}$ Water table level relative to the peat surface in the project scenario, corrected for subsidence in grid x, in day d, in year t (cm) (if $j_{Pr,x,d,t} \leq 0$ then assume $j_{Pr,x,d,t}=0$ on day d)
x	1, 2, 3 …X grid cells in project area
d	1,2,3 …D days in year t
t	1, 2, 3, … $t_{crediting\_period}$ years elapsed since the project start date

The above emission factor is based on a review of GHG fluxes from tropical peatlands in Southeast Asia.[40] An alternative emission factor may be used if the project proponent demonstrates that it meets the VCS requirements with respect to the selection of appropriate default factors.

Ex-post project emissions must be calculated using the methods described above in this Section 8.2.

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[39] Hooijer, A, S Page, J Jauhiainen, WA. Lee, XX. Lu, A Idris, and G Anshari. 2012. Subsidence and carbon loss in drained tropical peatlands. Biogeosciences, 9, 1053–1071

[40] Hooijer, A., S. Page, J. Jauhiainen, W. A. Lee, X. X. Lu, A. Idris, and G. Anshari. 2012. Subsidence and carbon loss in drained tropical peatlands. Biogeosciences, 9, 1053–1071; Hooijer, A, Page, S, Canadell, JG, Silvius, M, Kwadijk, J, Woster, H, Jauhiainen, J. 2010. Current and future CO2 emissions from drained peatlands in Southeast Asia. Biogeosciences, 7: 1505-1514; and Couwenberg, J, Dommain, R, Joosten, H. 2010. Greenhouse gas fluxes from tropical peatlands in south-east Asia. Global Change Biology 16: 1715-1732.

8.3 Leakage

Leakage represents the increase in GHG emissions which occur outside the project area that are measurable and attributable to the project activity. The forms of leakage relevant to the project activity are market leakage, activity-shifting leakage and ecological leakage.

With respect to market leakage and activity-shifting leakage, since emissions from deforestation and degradation are not included in the quantification of baseline emissions, reductions in GHG emissions from preventing these activities are not included in the project scenario, and no agents of deforestation or drainage remain in the project area at the project start date (please refer to the applicability conditions), it is not relevant for this methodology to account for these forms of leakage.

With respect to ecological leakage, although rewetting activities in the project scenario may result in an increase of CH_4 emissions outside the project area, these are considered *de minimis* because they amount to less than 5 percent of the CO_2 emissions.[41] As such, it is conservative to not account for emissions due to ecological leakage.

8.4 Summary of GHG Emission Reduction and/or Removals

Net greenhouse gas emission reductions associated with the project activity are calculated as follows:

$$C_{PRC,t} = \Delta C_{BSL,t} - \Delta C_{P,t} \quad (33)$$

Where:

$C_{WRC,t}$	Total net greenhouse emission reductions at time *t* (t CO_2e)
$\Delta C_{BSL,t}$	Net greenhouse gas emissions in the baseline scenario at time *t* (t CO_2e)
$\Delta C_{P,t}$	Net greenhouse gas emissions in the project scenario at time *t* (t CO_2e)
t	$1,2,3\ldots t_{crediting\_period}$ years elapsed since the project start date

Net GHG emission reductions must be estimated for each year in the project crediting period and for a period of 100 years.The total net changes in only the carbon stocks is calculated as:

$$\Delta C_{Carbont} = \sum_{i=1}^{I} \Delta C_{BSL,i,t} + \sum_{i=1}^{I} \Delta C_{\mathrm{Pr},i,t} \quad (34)$$

[41] Riley, J.O., Wüst, R.A.J., Jauhiainen, J., Page, S.E., Wösten, H., Hooijer, A., Siegert, F., Limin, S.H., Stahlhut, M. 2008. Tropical Peatlands: Carbon stores, carbon gas emissions and contribution to climate change processes. In: Strack, M.(Ed.), Peatlands and Climate Change. International Peat Society. Stockholm.

Where:

$\Delta C_{Carbon,t}$	Total carbon stock change in all pools at time *t* (t CO_2e)
$\Delta C_{BSL,i,t}$	Net carbon stock change in all pools in the baseline scenario in stratum *i* at time *t* (t CO_2e)
$\Delta C_{Pr,i,t}$	Net carbon stock change in all pools in the project scenario in stratum *i* at time *t* (t CO_2e)
i	1, 2, 3 …I peat depletion time strata in the baseline
t	$1,2,3\ldots t_{crediting\_period}$ years elapsed since the project start date

8.5 Uncertainty Analysis

Assessment of uncertainty must follow guidance provided by IPCC 2000, IPCC GPG-LULUCF and IPCC AFOLU. This methodology allows for the estimation of uncertainty in GHG emissions and removals associated with project activities. Use of this methodology while planning the project can help assure that measurements are of sufficient intensity to minimize uncertainty deductions. Procedures including stratification and the allocation of sufficient measurement plots can help the project proponent to ensure that low uncertainty in carbon stocks results and ultimately full crediting can result. It is good practice to apply this methodology at an early stage to identify the data sources with the highest uncertainty to allow the opportunity to conduct further work to diminish uncertainty.

Uncertainty in emissions from change in carbon pools due to uncertainty in modeled water table levels must be assessed and quantified as follows. The uncertainty in water table levels calculated in Section 8.1.1.6 is used to calculate the uncertainty in the change in carbon pools due to uncertainty in modeled water table levels.

$$\mathrm{Uncertainty}_{\mathrm{Total}} = U_{WT} \quad (35)$$

Where:

$Uncertainty_{Total}$	Total uncertainty for entire project (%)
U_{WT}	Percent uncertainty in water table levels (%)

The allowable uncertainty is +/- 30% of C_{WRC} at the 95% confidence level. Where this precision level is met, then no deduction must result for uncertainty. Where uncertainty exceeds 30% of $C_{WRC,t}$ at the 95% confidence level, then the deduction must be equal to the amount that the uncertainty exceeds the allowable level. Adjusted value for $C_{WRC,t}$ to account for uncertainty must be calculated as:

$$Adjusted\_C_{WRC,t} = C_{WRC,t} * (100\% - Uncertainty_{Total} + 30\%) \quad (36)$$

Where:

*Adjusted_* $C_{WRC,t}$	Cumulative total net GHG emission reductions at time *t* adjusted to account for uncertainty (t CO_2e)
$C_{WRC,t}$	Cumulative total net GHG emission reductions at time *t* (t CO_2e)
$Uncertainty_{Total}$	Total uncertainty for WRC project activity (%)

8.6 Calculation of VCS Buffer

The number of credits to be deposited in the AFOLU pooled buffer account is determined as a percentage of the change in carbon stocks. The buffer withholding is calculated as:

$$Buffer_{WRC} = \Delta C_{carbon} * Buffer\% \quad (37)$$

$$\Delta C_{carbon} = \sum_{t=1}^{t*} \Delta C_{carbon,t} \quad (38)$$

Where:

$Buffer_{WRC,}$	Buffer withholding for the WRC activity (t CO_2e)
ΔC_{carbon}	Total net change in carbon stocks (t CO_2e)
$\Delta C_{carbon,t}$	Net change in carbon stocks at time *t* (t CO_2e)
Buffer%	Buffer withholding percentage (%)
t	*1,2,3 …t** years elapsed since the project start date

Buffer withholding percentage must be calculated using the latest version of the VCS *AFOLU Non-Permanence Risk Tool*.

8.7 Calculation of Verified Carbon Units

The number of Verified Carbon Units (VCUs) for the monitoring period T = t2-t1 is calculated as follows:

$$VCU_t = (Adjusted_{C_{WRC,t2}} - Adjusted\_C_{WRC,t1}) - Buffer_{WRC} \quad (39)$$

Where:

VCU_t	Number of Verified Carbon Units at time t = t2-t1 (VCU)
*Adjusted_* $C_{WRC,t1}$	Cumulative total net GHG emission reductions at time *t1* adjusted to account for uncertainty (t CO_2e)

$Adjusted\_C_{WRC,t2}$	Cumulative total net GHG emission reductions at time *t2* adjusted to account for uncertainty (t CO_2e)
$Buffer_{WRC}$	Total permanence risk buffer withholding for the WRC activity; t CO_2-e

9 MONITORING

9.1 Data and Parameters Available at Validation

Data / Parameter	$H_{ind,loc,LC}$
Data unit	Meters
Description	Height of individual *Ind* at sampling location *loc* within land cover class *LC*
Equations	2
Source of data	Field measurements of tree height
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	Height measured from ground level to top of individual either through direct measurements or by using an instrument such as a clinometer, relascope or laser inventory instrument
Purpose of data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	$Z_{val,q}$
Data unit	Meters
Description	Elevation value q from the validation dataset
Equations	3
Source of data	Elevation measurements from field or LiDAR data
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	Radar-derived DTMs must be validated with topographic field measurements (eg, by dGPS, Tachymeter or Total station) or LiDAR derived elevation measurements from a LiDAR dataset of known accuracy
Purpose of data	Calculation of baseline emissions
Comment	N/A

Data / Parameter	$Z_{DTM,q}$

Data unit	Meters
Description	DTM elevation value q
Equations	3
Source of data	DTM
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	Elevation values are extracted from the DTM
Purpose of data	Calculation of baseline emissions
Comment	N/A

Data / Parameter	$PTh_{val,q}$
Data unit	Meters
Description	Peat thickness value q as determined from the validation dataset
Equations	9
Source of data	Field measurements of peat thickness
Value applied	
Justification of choice of data or description of measurement methods and procedures applied:	The depth of peat at each sampling location must be determined through peat drilling (using a peat auger such as an Eijkelkampp) until the mineral soil underneath the peat is reached.
Purpose of data	Calculation of baseline emissions
Comment	N/A

Data / Parameter	$PTh_{MOD,q}$
Data unit	Meters
Description	Modeled peat thickness value q
Equations	9
Source of data	Peat thickness model
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	Peat thickness values are extracted from the peat thickness model.

Purpose of data	Calculation of baseline emissions
Comment	N/A

Data / Parameter	$Ch_{A,m,p,w}$
Data unit	Variable
Description	Value of waterway characteristic *A* for waterway measured *m* at measurement point *p* for waterclass *w*
Equations	13
Source of data	Field measurements
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	A sample of waterways in each waterway class is selected for measurement to characterize each waterway class.
Purpose of data	Calculation of baseline emissions
Comment	N/A

Data / Parameter	$Meas_g$
Data unit	Centimeters
Description	Measured water level relative to the peat surface value *g*
Equations	14, 16, 41, 42
Source of data	Field measurements
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	Measurement of water depth must be done through direct measurement or with an automatic water logger.
Purpose of data	Calculation of baseline emissions
Comment	Guidance on water level measurement can be found in: Morgan P. and Stolt. M H. 2004. A comparison of several approaches to monitor water-table fluctuations. *Soil Science Society of America Journal*. 68:562–566. Vidon and Smith 2008. Assessing the Influence of Drainage Pipe Removal on Wetland Hydrology Restoration: A Case Study. *Ecological Restoration* V26, N1, 33-43.

Data / Parameter	Mod_g
Data unit	Centimeters
Description	Model calculated water level relative to the peat surface *g*
Equations	14, 16, 41, 42
Source of data	SIMGRO model
Value applied	
Justification of choice of data or description of measurement methods and procedures applied:	The metric used to validate the SIMGRO model for the project area is the difference between calculated and measured water levels relative to the peat surface at a geographic location and on the date of field measurements. The model calculated water level at the location and on the date of corresponding field measurements is extracted from the SIMGRO model outputs. Value is an output of the SIMGRO model.
Purpose of data	Calculation of baseline emissions
Comment	N/A

Data / Parameter	j_{max}
Data unit	Centimeters
Description	Maximum absolute modeled value of water table level relative to the peat surface; cm
Equations	15
Source of data	SIMGRO model
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	Water table level is modeled with SIMGRO for the baseline and project scenario ex-ante based on historic climate data.
Purpose of data	Calculation of baseline emissions
Comment	N/A

Data / Parameter	$PThx_{,t0}$
Data unit	Meters
Description	Peat thickness in grid cell *x* at the project start date
Equations	11, 12, 19
Source of data	Peat thickness model, based on field measurements of peat depth

Value applied	
Justification of choice of data or description of measurement methods and procedures applied	The peat thickness model is a gridded spatial explicit model where each grid cell is a uniform size ($_{Agrid\_x}$) and the sum of the area of all grid cells equates to the project area.
Purpose of data	Calculation of baseline emissions
Comment	N/A

Data / Parameter	S_p
Data unit	Centimeters per year
Description	Peat subsidence rate
Equations	12, 19, 20
Source of data	Most appropriate default value from published applicable literature must be selected by project proponent
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	As subsidence rate varies as a result of the conditions at the project site, no default value is suggested. Variables influencing the subsidence rate are water table, land-use historic, drainage, current land cover, peat bulk density, carbon content and others.
Purpose of data	Calculation of baseline emissions
Comment	N/A

Data / Parameter	$t_{crediting\_period}$
Data unit	Years
Description	Length of project crediting period
Equations	18, 19
Source of data	Determined ex-ante
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	Per VCS *AFOLU Requirements*, the minimum length of the project crediting period is 20 years and the maximum length is 100 years.
Purpose of data	Calculation of baseline emissions
Comment	N/A

Data / Parameter	A_{grid_x}
Data unit	Hectares
Description	Area of peat thickness model grid cell *x*
Equations	N/A
Source of data	Calculated from peat thickness model
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	The peat thickness model is a gridded spatial explicit model where each grid cell is a uniform size (A_{grid_x}) and the sum of the area of all x grid cells equates to the project area.
Purpose of data	Calculation of baseline and project emissions
Comment	Maximum size threshold is 90m x 90m

Data / Parameter	*J*
Data unit	Centimeters
Description	SIMGRO modeled water table level relative to the peat surface, (maximum 100 cm)
Equations	N/A
Source of data	SIMGRO model
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	Water table level is modeled for the baseline and project scenario ex-post based on actual precipitation data.
Purpose of data	Calculation of baseline and project emissions
Comment	N/A

Data / Parameter	$A_{Excluded}$
Data unit	Hectares
Description	Total area of the excluded area of watershed(s).
Equations	N/A
Source of data	SIMGRO model
Value applied	
Justification of choice of data or description of	Outputs from SIMGRO Model are used to determine total area of the excluded area of watershed(s) in a spatial environment.

measurement methods and procedures applied	
Purpose of data	Calculation of baseline and project emissions
Comment	N/A

Data / Parameter	EF_{CO2}
Data unit	t CO_2 ha^{-1} yr^{-1} m^{-1} of water level relative to the peat surface
Description	Emission factor
Equations	26, 32,
Source of data:	Hooijer, A, Page, S, Jauianinen, J, Lee, WA, Lu, XX, Idris, A, Anshari, G. 2012. Subsidence and carbon loss in drained tropical peatlands. *Biogeosciences* 9: 1053 – 1071
Value applied	98
Justification of choice of data or description of measurement methods and procedures applied	The above emission factor is based on a review of GHG fluxes from tropical peatlands in Southeast Asia. An alternative emission factor may be used if the project proponent demonstrates that it meets the VCS requirements with respect to the selection of appropriate default factors.
Purpose of data	Calculation of baseline and project emissions
Comment	N/A

Data / Parameter	*Δhead*
Data unit	Centimeters
Description	Desired head difference
Equations	46
Source of data	Determined based on expert opinion, considering the permeability and low bearing capacity of peat soils, as published in the scientific literature.
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	This is the preferred difference between upstream and downstream waterway water level across a dam. Recent research showed that due to the low bearing capacity and high permeability of peat soils the head difference should be less than 0.5 m: Ritzema, H., Limin, S., Kusin, K., Jauhiainen, J., Wösten, H. 2014. Canal blocking strategies for hydrological restoration of degraded

	tropical peatlands in Central Kalimantan, Indonesia. Catena 114: 11-20.
Purpose of data	Calculation of project emissions
Comment	N/A

Data / Parameter	*cascade_slope*
Data unit	Meters/centimeters
Description	Average slope of cascade of dams
Equations	46
Source of data	DTM
Value applied	
Justification of choice of data or description of measurement methods and procedures applied	The average slope of cascade of dams must be determined with elevation measurements in the field or determined directly from the DTM.
Purpose of data	Calculation of project emissions
Comment	N/A

9.2 Data and Parameters Monitored

Data / Parameter	*J*
Data unit	Centimeters
Description	SIMGRO modeled water table level relative to the peat surface(maximum 100 cm)
Equations	N/A
Source of data	SIMGRO output
Description of measurement methods and procedures to be applied	Water table level is modeled for the baseline and project scenario ex-post based on actual precipitation data
Frequency of monitoring/recording	Prior to each verification event
QA/QC procedures to be applied	To ensure that the SIMGRO model is conservatively modeling water levels relative to the peat surface, the results of the SIMGRO model must be compared with monitored field measurements of water level relative to the peat surface
Purpose of data	Calculation of baseline and project emissions

Comment	N/A

Data / Parameter	$Meas_g$
Data unit	Meters
Description	Measured water level value relative to the peat surface *g*
Equations	14, 16, 41, 42
Source of data	Field measurements
Description of measurement methods and procedures to be applied	Measurement of water depth must be done through direct measurement or with an automatic water logger. Guidance on water level measurement can be found in: Morgan P. and Stolt. M H. 2004. *A comparison of several approaches to monitor water-table fluctuations*. *Soil Science Society of America Journal*. 68:562–566 Vidon and Smith 2008. Assessing the Influence of Drainage Pipe Removal on Wetland Hydrology Restoration: A Case Study. *Ecological Restoration* V26, N1, 33-43.
Frequency of monitoring/recording	Direct measurement must be done at least every month, with an automatic water logger daily measurements must be recorded.
QA/QC procedures to be applied	Water level measurements data must be archived in electronic and paper format
Purpose of data	Calculation of baseline emissions
Comment	N/A

Data / Parameter	Mod_g
Data unit	Centimeters
Description	Model calculated water level relative to the peat surface *g*
Equations	41, 42
Source of data	SIMGRO model
Description of measurement methods and procedures to be applied	The model calculated water level at the location and on the date of corresponding field measurements is extracted from the SIMGRO model outputs.
Frequency of monitoring/recording	Prior to each verification event

QA/QC procedures to be applied	Model calculated water levels at the location and on the date of corresponding field measurements must be stored in electronic and paper format
Purpose of data	Calculation of baseline emissions
Comment	N/A

Data / Parameter	S_p
Data unit	Centimeters per year
Description	Peat subsidence rate
Equations	12, 17, 20,
Source of data	Most appropriate default value from published applicable literature must be selected by project proponent
Description of measurement methods and procedures to be applied	As subsidence rate varies as a result of the conditions at the project site, no default value is suggested. Variables influencing the subsidence rate are water table, land-use historic, drainage, current land cover, peat bulk density, carbon content and others.
Frequency of monitoring/recording	Prior to each verification event
QA/QC procedures to be applied	
Purpose of data	Calculation of baseline emissions
Comment	N/A

Data / Parameter	EF_{CO2}
Data unit	t CO_2 ha^{-1} yr^{-1} m^{-1} of water level relative to the peat surface
Description	Emission factor; EF_{CO2} = 98
Equations	26, 32
Source of data	Hooijer, A, Page, S, Jauianinen, J, Lee, WA, Lu, XX, Idris, A, Anshari, G. 2012. Subsidence and carbon loss in drained tropical peatlands. *Biogeosciences* 9: 1053 – 1071
Description of measurement methods and procedures to be applied	The above emission factor is based on a review of GHG fluxes from tropical peatlands in souteast Asia. An alternative emission factor may be used if the project proponent demonstrates that it meets the VCS requirements with respect to the selection of appropriate default factors.
Frequency of	Prior to each verification event

monitoring/recording	
QA/QC procedures to be applied	
Purpose of data	Calculation of baseline and project emissions
Comment	N/A

Data / Parameter	Daily precipitation
Data unit	Millimeters/day
Description	Input into SIMGRO model
Equations	N/A
Source of data	Precipitation data must be available on the daily time step for a climate station within 100 km and within ±100 m elevation of the project area for 20 years prior to the project start date
Description of measurement methods and procedures to be applied	Precipitation data is collected from a precipitation gauge on a daily basis
Frequency of monitoring/recording	Daily
QA/QC procedures to be applied	Precipitation data must be archived in electronic and paper format
Purpose of data	Calculation of baseline and project emissions
Comment	N/A

Data / Parameter	Evapotranspiration
Data unit	Millimeters per day
Description	Input into SIMGRO model
Equations	N/A
Source of data	Takahashi, H., Usup, A., Hayasaka, H., Kamiya, M., Limin, S.H., 2004. The importance of ground water level and soil moisture of subsurface layer on peat/forest fire in a tropical peat swamp forest. In: Päivänen, J. (Eds.), Wise Use of Peatlands. Volume 1. Proceedings of the 12th International Peat Congress, Tampere, Finland, 6-11 June 2004. International Peat Society, Jyväskylä, Finland, p. 760. An alternative value may be used if the project proponent demonstrates that it meets VCS rules with respect to the selection of appropriate default factors.

Description of measurement methods and procedures to be applied	Evapotranspiration may be assumed to be a constant daily value of 3.5 mm day^{-1}. Alternatively, evapotranspiration may be determined by the closest meteorological station or by field measurements. If evapotranspiration is determined by field measurements an evapotranspiration pan may be used.
Frequency of monitoring/recording	If evapotranspiration is determined by field measurements then measurements must be recorded daily
QA/QC procedures to be applied	Precipitation data must be archived in electronic and paper format
Purpose of data	Calculation of baseline and project emissions
Comment	N/A

Data / Parameter	Location and construction date of new and maintained dams
Data unit	Latitude/longitude, date
Description	Location and date of dams constructed and maintained. Input into SIMGRO model.
Equations	N/A
Source of data	GPS field measurements
Description of measurement methods and procedures to be applied	The dam identification number, geographic coordinates, and date of construction are recorded for the actual location of each large and small dam established. This information must be stored in a geodatabase as inputs for the SIMGRO model. Dams that have been destroyed or damaged may be rebuilt. If a dam is damaged/destroyed, the date of monitoring and identification number of dam must be recorded into the geodatabase. Within the SIMGRO model the damaged/destroyed dam must be recorded as having been removed in the year following the last dam monitoring event. If a dam is repaired or rebuilt or if additional dams are built, the dam identification number, dam construction date, and geospatial location must be recorded in the geodatabase. The updated geodatabase will then be used in subsequent ex-post simulations of the project scenario.
Frequency of monitoring/recording	At a minimum every 5 years
QA/QC procedures to be applied	If dams are not monitored yearly, it must be assumed that the dams were destroyed in the year following the previous monitoring event

Purpose of data	Calculation of project emissions
Comment	N/A

Data / Parameter	Area burned
Data unit	Hectares
Description	Area burned, and grid cells *x* burned at time *t* in the project area.
Equations	N/A
Source of data	Fire area delineated through direct field measurements or using remote sensing imagery
Description of measurement methods and procedures to be applied	The presence or absence of any potential fires within the project area may first be determined using local and/or global remote sensing products such as NASA's Fire Information for Resource Management System (FIRMS). Where remote sensing products indicate a significant fire (greater than 1 ha) has occurred the area burned must be mapped either through the use of a GPS in the field or by hand delineating remote sensing imagery with a resolution higher than 30 m. http://earthdata.nasa.gov/data/near-real-time-data/firms
Frequency of monitoring/recording	Annually
QA/QC procedures to be applied	A GIS database must be developed and updated to map and archive the date and spatial extent of all fires within the project area
Purpose of data	Calculation of project emissions
Comment	N/A

Data / Parameter	Land use in excluded area of watershed(s)
Data unit	Unitless
Description	Land use activities in area of watershed(s) of interest not included in the project area
Equations	N/A
Source of data	Documented evidence of land use (eg, concession rights, land use zoning, etc.)
Description of	The project proponent must monitor land use activities in the

measurement methods and procedures to be applied	excluded area of watershed(s) to verify that land use activities within the excluded area of watershed(s) do not include the creation of additional drainage waterways deforestation, land use conversion, crop production or grazing of animals. At each monitoring event the project proponent must provide documented evidence demonstrating that current a land use activities in the excluded area of watershed(s) meet these requirements. If the creation of additional drainage waterways deforestation, land use conversion, crop production, or grazing of animals occur in the excluded area of watershed(s) during the project crediting period, this methodology is no longer applicable to the project activity.
Frequency of monitoring/recording	Every 5 years
QA/QC procedures to be applied	Documented evidence of land use activities in the excluded area of watershed(s) must be archived in paper and electronic format
Purpose of data	Applicability of the methodology to the project activity
Comment	N/A

9.3 Description of the Monitoring Plan

The project area, climate variables, dam construction and water level relative to the peat surface values must be monitored during project implementation.

9.3.1 Monitoring of Water Courses

Over time additional information on the location and characteristics of waterways may be obtained. Project proponents may update the SIMGRO model with new watercourse maps and characteristics for both ex-ante and ex-post baseline and project emission calculations, but this is not required.

The methods delineated within Section 8.1.1.5 must be followed for any waterways to be added to the database and SIMGRO model. This would include location identification and characterization of waterway.

9.3.2 Monitoring of Climate Variables

Actual climate variables must be monitored and cataloged through the collection of data from weather station(s) representative of the watershed(s) of interest. Precipitation data must be available on the daily time step for a climate station within 100km and within ±100m elevation of the watershed(s) of interest boundary over the monitoring period. Additionally, evapotranspiration rates of the dominant vegetation cover(s) must be available as input to the SIMGRO model.

Evapotranspiration may be assumed to be a constant daily value of 3.5mm per day[42] or the most recently published applicable factor.

Data for the watershed(s) of interest area may be supplied from more than one weather station falling within 100km of the watershed(s) of interest boundary. In this case the relevant station must be specified for each of the SVAT-units in the model. Where more than one weather station data exists, data on climate variables may be interpolated for the watershed(s) of interest area. If more than one weather station meets the location requirements for a given SVAT-unit, for time periods where data from the selected weather station is not available, data from an alternate weather station that meets the location requirements of the SVAT-unit may be substituted.

Measured daily climate data must be monitored and used as an input into the SIMGRO model for ex-post analysis of the baseline and project scenarios.

9.3.3 Monitoring of Project Activities

9.3.3.1 Monitoring of Project Area

The project area is monitored to demonstrate that the actual project area conforms with the area outlined in the project description. The project proponent must monitor the project area to confirm that the project proponent maintains control over the entire area included within the project area. The project proponent must monitor the geographic location of dams constructed to confirm that all dams constructed are located within the project area.

9.3.3.2 Monitoring of Waterways

The waterway map and characteristics may be updated at each verification event. New information on waterway location and characteristics may be added using the methods in Section 8.1.1.5, though it is not required. If new waterways are added to the waterway map, estimations of both ex-ante baseline emissions and ex-post project emissions must consider the updated waterway map.

9.3.3.3 Monitoring of Dam Establishment

The optimal location of dams is determined ex-ante in the procedure for design of project measures described in Section 8.2.1.1.

Dam establishment and repair must be monitored. The geographic coordinates and date of construction are recorded for the actual location of each large and small dam established. Geographic coordinates of each dam are stored in a geodatabase as inputs for the SIMGRO

[42] Takahashi, H., Usup, A., Hayasaka, H., Kamiya, M., Limin, S.H., 2004. The importance of ground water level and soil moisture of subsurface layer on peat/forest fire in a tropical peat swamp forest. In: Päivänen, J. (Eds.), Wise Use of Peatlands. Volume 1. Proceedings of the 12th International Peat Congress, Tampere, Finland, 6-11 June 2004. International Peat Society, Jyväskylä, Finland, p. 760.

model to simulate water levels relative to the peat surface in the project area and estimate project emissions.

9.3.3.4 Monitoring of Dam Maintenance

The condition and maintenance of dams must be monitored to ensure that the project intervention functions to impact water levels relative to the peat surface in the project area. Each established dam must be monitored in the field at least every 5 years to determine dam condition. Dams that have been destroyed or damaged may be rebuilt. If a dam is damaged or destroyed, the date of monitoring and identification number of dam must be recorded into the geodatabase. Within the SIMGRO model the dam must be recorded as having been removed in the year following the last dam monitoring event. If a dam is repaired or rebuilt or if additional dams are built, the dam identification number, dam construction date, and geospatial location must be recorded in the geodatabase. The updated geodatabase must then be used in subsequent simulations of the project scenario.

9.3.3.5 Monitoring of the Excluded Area of Watershed(s)

The project proponent must monitor land use activities in the excluded area of watershed(s) to verify that land use activities within the excluded area of watershed(s) do not include the creation of additional drainage waterways, deforestation, land use conversion, crop production or grazing of animals. At each monitoring event, the project proponent must provide documented evidence demonstrating that current land use activities in the excluded area of watershed(s) meet these requirements. Activities may include planned forest degradation.

The results of monitoring of land use activities must be reported at each verification event. If the creation of additional drainage waterways deforestation, land use conversion, crop production or grazing of animals occur in the excluded area of watershed(s) during the project crediting period, this methodology is no longer applicable.

The project proponent must also monitor land use activities in the excluded areas of watershed(s) to determine if land use activities include the creation of dams within existing waterways. If there is evidence that dams have been created, the type, location and year of dam construction must be recorded in a geodatabase as inputs for the SIMGRO model to simulate water levels relative to the peat surface in the project area and estimate baseline and project emissions.

9.3.3.6 Monitoring of Sampled Water Levels

To validate the modeled results of the SIMGRO simulation of water table levels relative to the peat surface as a result of project construction of dams, field measurements of water table levels relative to the peat surface must be taken at sampling points.

A discrete area may be selected for sampling points based on ease of access, and sampling points may be selected within the discrete area using systematic sampling. An alternative approach to sampling may be used if it can be justified that the sampling method does not create bias. All sampling points must be within the project area.

At each sampling point, the location, water table level relative to the peat surface, and date of measurement must be recorded in a geodatabase. It is recommended, but not required, that permanent sampling points are established through the installation of groundwater tubes. Water levels relative to the peat surface must be measured by either installing automatic water loggers or manually.[43] Measurements must be taken on at least four separate days for each sampling point for each year after the project start date. Over the monitoring period, water table level relative to the peat surface sampling must include measurements taken within the dry season and the wet season. It is recommended but not required for field sampling to take place regularly throughout each year after the project start date.

9.3.4 Monitoring of Baseline Emissions

Information required to periodically reassess emissions in the baseline must be collected during the entire project crediting period. The key variables to be measured are weather station data and updated watercourse information.

Ex-post baseline emissions are estimated following the same approach as used for determining the ex-ante baseline emissions. The SIMGRO model is updated ex-post with actual precipitation data and updated watercourse information (not required) to simulate water levels in the project area ex-post.

The output of the SIMGRO model for the baseline scenario in the watershed(s) of interest over the project crediting period must be used to stratify the project area by drainage depth per day for each year of the project crediting period. Each grid cell in the model will have a known daily drainage depth for each year of the project crediting period.

The maximum number of years emissions can take place for a given grid cell must be reassessed at each verification event using updated peat thickness estimates calculated in Section 8.1.13. The peat depletion time strata must be updated during baseline reassessment using updated peat thickness. Changes in peat thickness are a function of annual subsidence.[44]

The ex-post modeled water levels relative to the peat surface must be determined using the same methods as implemented ex-ante. The ex-post GHG emissions in the baseline must be calculated using the methods described in Section 8.1.4

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[43] Guidance on water level measurement can be found in:

Morgan P. and Stolt. M H. 2004. *A comparison of several approaches to monitor water-table fluctuations*. *Soil Science Society of America Journal*. 68:562–566.

Vidon and Smith 2008. Assessing the Influence of Drainage Pipe Removal on Wetland Hydrology Restoration: A Case Study. *Ecological Restoration* V26, N1, 33-43.

[44] Wosten, JHM, Ismail, AB, van Wijk, ALM. 1997. Peat subsidence and its practical implications: a case study in Malaysia. *Geoderma*, 78: 25-36.

9.3.5 Monitoring of Project Emissions

Ex-post project emissions are estimated following the same approach as used for determining the baseline and ex-ante project emissions with the addition of accounting for the potential reversal of emission reductions resulting from peat fires within areas rewetted:

$$\Delta C_{\mathrm{Pr},x,t} = \Delta C_{\mathrm{Pr},CO2,x,t} + GHG_{\mathrm{Pr},x,t} + C_{PR,\mathrm{Rev},x} \quad (40)$$

Where:

$\Delta C_{Pr,t}$	Net project GHG emissions, in year t (t CO_2e)
$\Delta C_{Pr,x,t}$	Net project GHG emissions in grid x, in year t (t CO_2e ha^{-1})
$\Delta C_{Pr,CO2,x,t}$	Net carbon stock change in all carbon pools in the project scenario in grid x, in year t (t CO_2e ha^{-1})
$GHG_{Pr,x,t}$	Non-CO_2 emissions taking place in the project grid x in year t (t CO_2e ha^{-1})
$C_{Pr,Rev,x}$	Project emissions reversal due to from fire in grid x (t CO_2e ha^{-1})
A_x	Area of grid cell x
x	*1,2,3,… X* grid cells in project area
t	1, 2, 3, … t_{max} years elapsed since the project start date

The output of the SIMGRO model for the project scenario in the watershed(s) of interest over the project crediting period must be used to stratify the project area by water level relative to the peat surface per day for each year of the project crediting period. Each grid cell in the model will have a known daily drainage depth for each year of the project crediting period.

9.3.5.1 Modeling of Water Levels

The SIMGRO model is updated ex-post with actual precipitation data, updated watercourse information, and location of dams to simulate water levels relative to the peat surface in the project area. The ex-post modeled water levels relative to the peat surface must be determined using the same methods as implemented ex-ante.

To ensure that the SIMGRO model is conservatively modeling water levels relative to the peat surface, the results of the SIMGRO model must be compared with monitored field measurements of water level relative to the peat surface.

The metric used to validate the model is the difference between calculated and measured water levels relative to the peat surface at a geographic location and on the date of field measurements. Calculated and measured groundwater levels are compared by looking at the root mean square error (RMSE). RMSE provides information on the accuracy of the model. It is allowable to calculate separate RMSE for each season of a year (eg, wet season and dry season).

Root Mean Square Error (RMSE)

$$RMSE = \sqrt{\frac{\sum_{g=1}^{G}(Meas_g - Mod_g)^2}{G}} \quad (41)$$

Where:

$Meas_g$	Measured water level relative to the peat surface value *g* (cm)
Mod_g	Model calculated water level relative to the peat surface value *g* (cm)
g	1,2,3…G sample number

An RMSE less than or equal to 40 cm is required, otherwise this methodology is not applicable.

The metric used to test bias in the model is the mean error (ME).

$$ME = \frac{1}{G} * \sum_{g=1}^{G}(Meas_g - Mod_g) \quad (42)$$

Where:

ME	*Mean Error; cm*
$Meas_g$	Measured water level relative to the peat surface value *g* (cm)
Mod_g	Model calculated water level relative to the peat surface value *g* (cm)
g	1,2,3…G sample number

An ME less than or equal to 20 cm is required, otherwise this methodology is not applicable.

9.3.5.2 Monitoring of Fires in Project Area

Even though rewetting of the peatland areas will likely reduce incidence of fire, fires still may occur. Fires must be monitored within the project area and the area of fire delineated spatially. If fires take place within grid cells where emission reductions had previously occurred, all previous emission reductions in that grid cell must be accounted as project emissions in the year the fire takes place.

For all grid cells where fires occur:

$$C_{WRC,x,t} = \Delta C_{BSL,x,t} - \Delta C_{\mathrm{Pr},x,t} \quad (43)$$

$$C_{WRC,x} = \sum_{t=1}^{t\max} C_{WRC,x,t} \quad (44)$$

If $C_{WRC,x} < 0$ then $C_{Pr,Rev} = 0$ else: $C_{Pr,Rev,x} = C_{WRC,x}$ (45)

Where:

$C_{Pr,Rev,x}$	Project emissions reversal due to fire in grid x (t CO_2e ha^{-1})
$C_{WRC,x}$	Total net greenhouse emission reductions in grid x, since project start date (t CO_2e ha^{-1})
$C_{WRC,x,t}$	Total net greenhouse emission reductions in grid x, in year *t* (t CO_2e ha^{-1})
$\Delta C_{BSL,x,t}$	Net baseline GHG emissions in grid *x*, in year *t* (t CO_2e ha^{-1})
$\Delta C_{Pr,x,t}$	Net project GHG emissions in grid *x*, in year *t* (t CO_2e ha^{-1})
A_x	Area of grid cell *x*
x	*1,2,3,… X* grid cells in project area
t	1, 2, 3, … t_{max} years elapsed since the project start date

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ANNEX I: DESIGN OF PROJECT MEASURES

The project intervention may include the establishment of permanent and temporary structures which hold back water in drainage waterways, such as dams.

The below provides a recommended approach, though the method used to determine where dams are placed may be determined by the project proponent based on project-specific circumstances. The number and location of dams for blocking can be determined based on an analysis of the surface slope along each waterway chosen for closure together with an average hydraulic head difference (ie, difference between upstream and downstream waterway water level across a dam).

It is recommended that larger waterway classes be assigned a higher priority for blocking than smaller waterway classes. The optimal location of large permanent dams is determined by the practical use of the waterway. After building permanent dams, cascades of simple small dams may be installed. Simple small dams are installed according to optimal dam locations. For small dams the measured or DTM-derived slopes for each identified waterway may be used to calculate optimal spacing of dams within a cascade.

To achieve a given head difference the spacing of dams along the waterway is calculated according to the formula:

$$SpDist = \frac{\Delta head}{cascade\_slope} \tag{46}$$

Where:

SpDist	Recommended spacing between dams (m)
Δhead	Desired head difference (cm)
cascade_slope	Average slope of cascade (cm/m)

DOCUMENT HISTORY

Version	Date	Comment
v1.0	10 July 2014	Initial version