CHAPTER 7

WETLANDS

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Section based on the IPCC Good Practice Guidance for LULUCF

Appendix 2 – Possible approach for estimating CO_2 emissions from lands converted to permanently Flooded Land: Basis for future methodological development

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Appendix 3 CH_4 Emissions from Flooded Land: Basis for future methodological development

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7.1 INTRODUCTION

This chapter provides guidance on estimating and reporting greenhouse gas (GHG) emissions from managed wetlands. Wetlands include any land that is covered or saturated by water for all or part of the year, and that does not fall into the Forest Land, Cropland, or Grassland categories. Managed wetlands will be restricted to wetlands where the water table is artificially changed (e.g., drained or raised) or those created through human activity (e.g., damming a river). Emissions from unmanaged wetlands are not estimated.

Methodologies are provided for:

- Peatlands cleared and drained for production of peat for energy, horticultural and other uses (Section 7.2). The estimation methodology, although essentially the same as in the IPCC report on Good Practice Guidance for Land use, Land-Use Change and Forestry (*GPG-LULUCF*), now includes emissions from the use of horticultural peat.

- Reservoirs or impoundments, for energy production, irrigation, navigation, or recreation (Section 7.3). The scope of the assessment now includes CO_2 emissions from all lands converted to permanently Flooded Lands. Flooded Lands exclude regulated lakes and rivers unless a substantial increase in water area has occurred.

For simplicity, the remainder of this section will refer to peatlands managed for peat extraction as peatlands, and lands flooded in reservoirs as Flooded Lands. Table 7.1 clarifies the scope of the assessment, and the corresponding sections of this chapter.

TABLE 7.1
SECTIONS ADDRESSING MAJOR GREENHOUSE GAS EMISSIONS FROM MANAGED WETLANDS

Land-use category/GHG	**Peatlands**	**Flooded Land**
Wetlands Remaining Wetlands		
CO_2	Section 7.2.1.1	No Guidance [1]
CH_4	No Guidance [2]	Appendix 3
N_2O	Section 7.2.1.2	No Guidance [3]
Lands Converted to Wetlands		
CO_2	Section 7.2.2.1	Section 7.3.2.1 and Appendix 2
CH_4	No Guidance [2]	Appendix 3
N_2O	Section 7.2.2.2	No Guidance [3]

NOTES:

[1] CO_2 emissions from *Flooded land Remaining Flooded land* are covered by carbon stock change estimates of land uses and land-use change (e.g., soils) upstream of the Flooded Land.

[2] Methane emission from peatlands is negligible after drainage during conversion and peat extraction.

[3] N_2O emissions from Flooded Land are included in the estimates of indirect N_2O from agricultural or other run-off, and waste water.

Wetlands are frequently managed for other uses, such as forest and grassland management, or croplands. Scientific level of knowledge on greenhouse gas balances of different kind of wetlands is still, in general, rather low and uncertain, but the area is continuously studied further (e.g., see papers in Boreal Env. Res. 11, 2006). Table 7.2 indicates where to find the guidance relative to these managed wetlands.

TABLE 7.2 GUIDANCE ON EMISSIONS FROM WETLANDS MANAGED FOR OTHER USES	
Land-use category	**Volume/Section in these Guidelines**
Wetlands already converted or being converted to:	
Cropland, including "bogs" for cranberry and other ericaceous fruits	Volume 4, Chapter 5 (Section 5.3)
Managed Grassland	Volume 4, Chapter 6 (Section 6.3)
Managed Forest Land, including drained or undrained forested wetlands according to national definitions	Volume 4, Chapter 4 (Section 4.3)
Rice cultivation	Volume 4, Chapter 5 (Section 5.5)

Some uses of wetlands are not covered, because adequate methodologies are not available. These include manure management ponds, industrial effluent ponds, aquaculture ponds, and rewetting of previously drained wetlands or wetland restoration (see Section 7.5, Future methodological development). Countries where these activities are significant should consider research to assess their contribution to greenhouse gas emissions or removals. N_2O emissions from wetlands managed for the filtration of non-point source agricultural effluents, such as fertilizers and pesticides, are included in indirect emissions from soil amendments (Volume 4, Chapter 11).

Most ecological classifications of wetlands, including those of the Ramsar Convention on Wetlands, consider many of these lands as Wetlands, even those disturbed by human activities or artificially built. The Wetlands classification adopted by the Ramsar Convention (Ramsar, 1996) is widely used to address management issues. Table 7.3 relates wetland classes in this report to selected definitions in the Ramsar Convention.

TABLE 7.3 RAMSAR CLASSES OF HUMAN-MADE WETLANDS		
RAMSAR class	**Corresponding wetlands sub-categories in the IPCC terminology**	**Methodological guidance**
Aquaculture	Flooded Land	No [1]
Ponds	Flooded Land	No [1]
Irrigated land (if cultivated)	Cropland	No [2]
Seasonally flooded agricultural land	Rice Cultivation	Yes (Vol. 4, Chapter 5)
Salt exploitation sites	---	No [1]
Water storage areas	Flooded Land	Yes (this chapter)
Excavations (partly)	Peatlands managed for peat extraction	Yes (this chapter)
Wastewater treatment areas	"Constructed wetlands" or Waste Sector	No [3]
Canals and drainage channels, ditches.	--	No [3]

NOTES:

[1] No suitable default methodologies are available for these sources.

[2] The Cropland Chapter includes this source.

[3] Emissions of CH_4 and N_2O from wastewater discharges to canals, rivers, lakes, seas, and drainage channels or ditches, as well as wastewater treatment areas, are covered in Volume 5, Chapter 3 though any additional emissions from new wetlands are not. Emissions of N_2O from leachate of nitrogenous fertilisers are covered in Volume 4, Chapter 11.

Source: Ramsar, 1996

Greenhouse gas emissions and removals from wetlands

Wetlands are ecosystems where the biological and geochemical processes, and resulting greenhouse gas emissions and removals, are controlled by the degree of water saturation as well as climate and nutrient availability.

As in other ecosystems, a net carbon flux to or from the atmosphere is a result from the balance between carbon uptake from the atmosphere by photosynthesis and its release as a result of decomposition. Both the rates of C uptake and decay losses are influenced by climate, nutrient availability, water saturation or oxygen availability. In aerobic conditions (abundant oxygen), which are prevalent in most upland ecosystems, decomposition releases CO_2; while CH_4 emissions prevail in anaerobic conditions (Moore and Knowles, 1989).

In most wetlands, some 90 percent of the carbon in gross primary production returns to the atmosphere by decay (Cicerone and Oremland, 1988). The undecayed material sinks to the bottom of the water body and accumulates on top of previously deposited material.

Under saturated conditions[1] or in flooded environments, the activity of aerobic bacteria and other decay organisms is limited by oxygen availability. Anoxic (oxygen-depleted) conditions commonly found at the bottom of water bodies prevent further organic matter decomposition by these organisms. Other bacteria, methanogens, sulfurgens and others, are able to decompose at least part of the organic matter, which results in emissions of CH_4 and other gases. If the methane diffuses up through the water column or top layer of aerated soil, still another group of bacteria, methanotrophs, partially oxidize the methane into CO_2, before it escapes. Generally, wetlands are a natural source of CH_4, with estimated emissions of 55-150 Tg CH_4 yr^{-1} (Watson *et al.*, 2000).

Generally, N_2O emissions from saturated ecosystems are very low, unless there is a sustained supply of exogenous nitrogen. When wetlands, especially peatlands, are drained, N_2O emission rates are largely controlled by the provision of nitrogen by mineralization, hence by soil fertility. In minerotrophic (nutrient-rich) conditions, other controls such as pH, temperature and water level will regulate the nitrification of mineral nitrogen, and its subsequent reduction into N_2O (Klemedtsson *et al.*, 2005; Martikainen *et al.*, 1995).

In summary, wetland drainage results in a reduction of CH_4 emissions, an increase in CO_2 emissions due to increased oxidation of soil organic material, and an increase in N_2O emissions in minerotrophic wetlands.

Conversely, the creation of wetlands through flooding alters the pattern of greenhouse gas emissions towards greater CH_4 emissions and less CO_2 emissions. Depending on climate and reservoir characteristics, both CO_2 and CH_4 can be emitted from the decay of submerged biomass, and the decomposition of inundated soil organic matter and other dissolved organic matter particles.

Methodological issues more specific to the two types of managed wetlands are discussed in the corresponding sections of this chapter.

Summary of what to report

Total CO_2 emissions from wetlands are estimated as the sum of emissions from the two types of managed wetlands (Equation 7.1).

EQUATION 7.1
CO_2 EMISSIONS FROM WETLANDS

$$CO_{2\_W} = CO_{2\_Wpeat} + CO_{2\_Wflood}$$

Where:

CO_{2_W} = CO_2 emissions from wetlands, Gg CO_2 yr^{-1}

CO_{2_Wpeat} = CO_2 emissions from peatlands managed for peat production, Gg CO_2 yr^{-1}

CO_{2_Wflood} = CO_2 emissions from (lands converted to) Flooded Land, Gg CO_2 yr^{-1}

Because of the nature of organic soils, saturated soils, and water-covered surfaces, the CO_2 estimation methodology generally relies on the development of emission factors and information on biomass stocks on land prior to flooding. Some activities, e.g., vegetation removal and its subsequent burning on *Land Being Converted for Peat Extraction*, result in emissions that can be estimated as carbon stock changes, in which case reference is provided to the generic methods of Chapter 2.

A default methodology for N_2O emissions is provided only for peatlands managed for peat extraction.

[1] The soil is saturated when all the air space between soil particles is filled with water, resulting in anaerobic conditions.

7.2 MANAGED PEATLANDS

Peat accumulates in wetlands when the annual generation of dead organic matter exceeds the amount that decays. The pattern of peat deposit development varies with climate and hydrology and the succession of peatland types on any area may be complex (Mitsch and Gosselink, 2000). Carbon sequestration may be only 20 to 50 kg/ha per year (Watson *et al*., 2000), which is rather small as compared with crop harvest yields. Most peat deposits have been accumulating for several thousand years, and many have been accumulating since the last ice-age glacial retreat more than 8000 years ago.

The production cycle on a peatland area has three phases (Canadian Sphagnum Peat Moss Association, 2004; Nilsson and Nilsson, 2004):

(i) Land conversion in preparation for peat extraction: Conversion begins by constructing main and secondary draining ditches that allow the water to drain out of the area. Once the water table starts dropping, the surface biomass, including any trees or shrubs and the living layer of peat-producing vegetation, is removed and destroyed. This phase may take several years. Peat extraction areas are also established on areas drained previously for other purposes. In general, this needs only some improvement or refining of the drainage pattern. The major greenhouse gas flux in this process is CO_2 emission from the removal of biomass and the decay of the drained peat. This phase correspond to land conversion to peatlands, and is covered in Section 7.2.2.

(ii) Extraction: One type of extraction annually "mills" or breaks up the surface of the peat into particles, which then dry during the summer months. The air-dried peat particles are then collected and transported from the area to stockpiles. An older type of extraction cuts the surface of the peat deposit into small blocks that are allowed to dry. Regardless of the extraction technology, the rate of drying and annual peat production increase with the frequency of dry weather conditions. Extraction may continue 20 to 50 years before the economic depth of the peat deposit is reached. The major greenhouse gas emissions in this phase are those from the decay of peat, both on-site (drained, exposed peat) and off-site (peat extracted and used elsewhere). This phase correspond to *Peatlands Remaining Peatlands*, and is treated in Section 7.2.1.

Since emissions from peatlands undergoing extraction differ substantially in scale and type from emissions from *Land Being Converted for Peat Extraction*, countries with an active peat industry should separate their managed peatlands accordingly.

(iii) Abandonment, restoration or conversion to other use: Peat extraction stops when it is no longer profitable to extract peat from the deposit. Generally, greenhouse gas emissions from these lands continue and should be reported following the guidance of Section 7.2.1 as long as the land is not converted to another use. Since no methodology is provided to estimate greenhouse gas emissions or removals from restored peatlands, countries with extensive restored peatlands may consider developing or gathering the scientific information to support the development of greenhouse gas estimation methodologies (see Section 7.5 Future Methodological Development). Cut-over peatlands that are afforested or cultivated should be reported under *Land Converted to Forest Land* (Chapter 4, Section 4.3) and *Land Converted to Cropland* (Chapters 5, Section 5.3).

Peatlands undergoing extraction (i.e., *Peatlands Remaining Peatlands*) will be considered first, similar to other chapters but contrary to the usual sequence of peat production as mentioned above.

7.2.1 Peatlands Remaining Peatlands

This section covers emissions from peatlands undergoing active peat extraction. Use of peat is widely distributed: about half is used for energy; the remainder for horticultural, landscape, industrial waster water treatment, and other purposes (International Peat Society, 2004). Techniques for extracting the peat from deposits are similar, and all on-site sources of greenhouse gas emissions should be reported under this category regardless of the end-use of peat. Emissions from the off-site energy use of peat should be reported in the Energy Sector, and are not considered in this chapter.

7.2.1.1 CO_2 EMISSIONS FROM PEATLANDS REMAINING PEATLANDS

Estimating CO_2 emissions from lands undergoing peat extraction has two basic elements: on-site emissions from peat deposits during the extraction phase, and off-site emissions from the horticultural (non-energy) use of peat

(Equation 7.2). Peat extraction starts with vegetation clearing (Section7.1), which prevents further carbon sequestration, so only CO_2 emissions are considered.

EQUATION 7.2
CO_2 EMISSIONS IN PEATLANDS DURING PEAT EXTRACTION

$$CO_{2_{WW_{peat}}} = \left(CO_2\text{–}C_{WW_{peat_{off-site}}} + CO_2\text{–}C_{WW_{peat_{on-site}}} \right) \bullet \left(\frac{44}{12} \right)$$

Where:

$CO_{2\ WWpeat}$ = CO_2 emissions from land undergoing peat extraction, Gg CO_2 yr^{-1}

$CO_2\text{–}C_{WW\ peat_{off\text{-}site}}$ = off-site CO_2–C emissions from peat removed for horticultural use, Gg C yr^{-1}

$CO_2\text{–}C_{WWpeat\ on\text{-}site}$ = on-site CO_2–C emissions from drained peat deposits, Gg C yr^{-1}

Off-site CO_2–C emissions are associated to the horticultural (non-energy) use of peat extracted and removed. Off-site emissions from peat used for energy should be reported in the Energy Sector, and is therefore not included here.

Regardless of the end-use of peat, the choice of method, emission factors, and activity data for estimating the on-site emissions can be the same, so long as the data are disaggregated for type of peat, which is closely associated with nutrient level (rich and poor), and if appropriate climate zone.

CHOICE OF METHOD

Figure 7.1 presents the decision tree to estimate greenhouse gas emissions from peatlands.

Tier 1

A default methodology is provided that covers on-site CO_2 emissions (without distinction between the phases of peat production), and the horticultural use of peat (Equations 7.3 to 7.5).

EQUATION 7.3
CO_2–C[2] EMISSIONS FROM MANAGED PEATLANDS (TIER 1)

$$CO_2\text{–}C_{WW_{peat}} = CO_2\text{–}C_{WW_{peat_{off-site}}} + CO_2\text{–}C_{WW_{peat_{on-site}}}$$

Where:

$CO_2\text{–}C_{WWpeat}$ = CO_2 –C emissions from managed peatlands, Gg C yr^{-1}

$CO_2\text{–}C_{WW\ peat\ on\text{-}site}$ = on-site emissions from peat deposits (all production phases), Gg C yr^{-1}

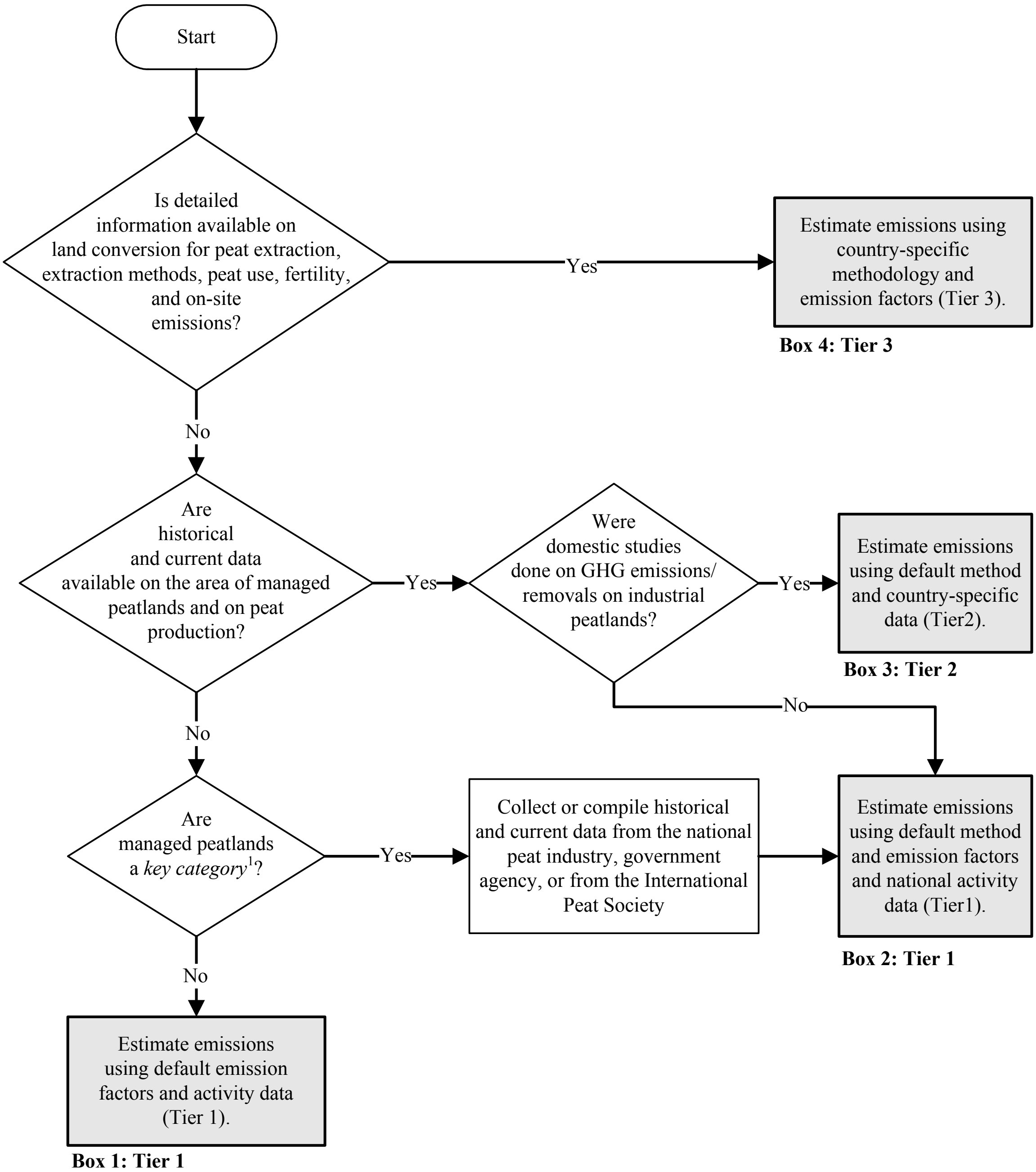
$CO_2\text{–}C_{WW\ peat\ off\text{-}site}$ = off-site emissions from peat removed for horticultural use, Gg C yr^{-1}

Equation 7.4 is applied to the total area of managed peatlands, including land being converted to peatlands and abandoned peatlands, unless abandoned peatlands were converted to another use, in which case emissions should be attributed to the new land use, e.g., Cropland or Forest Land.

The Tier 1 methodology considers only emissions from biomass clearing. When the total area of managed peatlands increases, conversion to peatland is occurring. The conversion of peatlands for peat extraction involves clearing and removal of vegetation. The term $\Delta C_{WW\ peat\ B}$ of Equation 7.4 is estimated as $\Delta C_{conversion}$, using Equation 2.16 (Chapter 2 of this Volume). Other changes in C stocks in living biomass on managed peat lands are assumed to be zero.

[2] CO_2–C refers to carbon emitted as CO_2

Figure 7.1 Decision tree to estimate CO_2–C and N_2O emissions from *Peatlands Remaining Peatlands*



Note:
1: See Volume 1 Chapter 4, "Methodological Choice and Identification of Key Categories" (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.

EQUATION 7.4
ON-SITE SOIL CO_2–C EMISSIONS FROM MANAGED PEATLANDS (TIER 1)

$$CO_2\text{–}C_{WW_{peat_{on-site}}} = \left[\frac{(A_{peatRich} \bullet EF_{CO_{2\,peatRich}}) + (A_{peatPoor} \bullet EF_{CO_{2\,peatPoor}})}{1000} \right] + \Delta C_{WW_{peat_B}}$$

Where:

CO_2–C $_{WW\ peat\ on\text{-}site}$ = on-site CO_2–C emissions from peat deposits (all production phases), Gg C yr^{-1}

$A_{peatRich}$ = area of nutrient-rich peat soils managed for peat extraction (all production phases), ha

$A_{peatPoor}$ = area of nutrient-poor peat soils managed for peat extraction (all production phases), ha

$EF_{CO_2 peatRich}$ = CO_2 emission factors for nutrient-rich peat soils managed for peat extraction or abandoned after peat extraction, tonnes C ha^{-1} yr^{-1}

$EF_{CO_2 peatPoor}$ = CO_2 emission factors for nutrient-poor peat soils managed for peat extraction or abandoned after peat extraction, tonnes C ha^{-1} yr^{-1}

$\Delta C_{WW\ peat\ B}$ = CO_2–C emissions from change in carbon stocks in biomass due to vegetation clearing, Gg C yr^{-1}

Off-site emission estimates are derived by converting the annual peat production data (either volume or air-dry weight) to the weight of carbon (Equation 7.5). All carbon in horticultural peat is assumed to be emitted during the extraction year. Countries may modify this assumption at higher tiers.

EQUATION 7.5
OFF-SITE CO_2–C EMISSIONS FROM MANAGED PEATLANDS (TIER 1)

$$CO_2\text{–}C_{WW_{peat_{off-site}}} = \frac{(Wt_{dry\_peat} \bullet Cfraction_{wt\_peat})}{1000}$$

or

$$CO_2\text{–}C_{WW_{peat_{off-site}}} = \frac{(Vol_{dry\_peat} \bullet Cfraction_{vol\_peat})}{1000}$$

Where:

CO_2–C $_{WW\ peat\ off\text{-}site}$ = off-site CO_2–C emissions from peat removed for horticultural use, Gg C yr^{-1}

Wt_{dry_peat} = air-dry weight of extracted peat, tonnes yr^{-1}

Vol_{dry_peat} = volume of air-dry peat extracted, m^3 yr^{-1}

$Cfraction_{wt\_peat}$ = carbon fraction of air-dry peat by weight, tonnes C (tonne of air-dry peat)$^{-1}$

$Cfraction_{vol\_peat}$ = carbon fraction of air-dry peat by volume, tonnes C (m^3 of air-dry peat)$^{-1}$

Tier 2

Tier 2 calculations use country-specific emission factors and parameters, spatially disaggregated to reflect regionally important practices and dominant ecological dynamics. It may be appropriate to subdivide activity data and emission factors according to extraction practices (e.g., the technology used to dry and extract peat), peat fertility and composition as influenced by previous vegetation cover, and the carbon fraction of air-dry peat under local climates. Generally, peatland drainage leads to peat compaction and subsidence as well as oxidation and carbon losses other than as CO_2. The acrotelm (upper, oxic zone of the peat) is susceptible to seasonal variations in volumetric moisture content especially if the peat structure has been altered (Waddington & Price, 2000). Hence, measurements of carbon stock changes in peat soils are difficult to make and are unlikely to estimate correctly CO_2 fluxes from these soils, and are therefore not recommended unless data are carefully calibrated.

Tier 2 methodologies involve separating peatlands being converted for peat extraction from those already producing commercial peat. Section 7.2.2 describes estimation methodologies for *Land Being Converted for Peat Extraction*. Care should be taken not to double-count CO_2 emissions from biomass clearing.

Tier 3

A Tier 3 approach involves a comprehensive understanding and representation of the dynamics of CO_2 emissions and removals on managed peatlands, including the effect of site characteristics, peat type and depth, extraction technology, and the phases of peat extraction described at the beginning of Section 7.2. The methodology will include all the known on-site sources of CO_2 (Equation 7.6). The term $CO_2\text{–}C_{WW\ peat_{conversion}}$ of Equation 7.6 refers to emissions from the land conversion, including changes in biomass carbon stock and soil emissions. The term $CO_2\text{–}C_{WW\ peat_{extraction}}$ corresponds to on-site emissions to be reported under Tier 1 (less the biomass term, now included in $CO_2\text{–}C_{WW\ peat_{conversion}}$). Emissions from stockpiles of drying peat (variable $CO_2\text{–}C_{WW\ peat_{stockpiling}}$) are much more uncertain. Higher temperatures may cause stockpiles to release more CO_2 than the excavation field, but data are not at present sufficient to provide guidance. CO_2 emission patterns from abandoned peatlands ($CO_2\text{–}C_{WW\ peat_{post}}$) vary with restoration techniques and the rates of soil respiration and vegetation regrowth (Petrone *et al*., 2003; Waddington & McNeil, 2002; Komulainen *et al*., 1999); these patterns are therefore quite site-specific. As in Tier 2, direct measurements of soil C stock changes are not recommended. Countries with a significant peat extraction industry and restoration activities should undertake to document separately the three on-site sources of CO_2 of Equation 7.6.

EQUATION 7.6
ON-SITE CO_2–C EMISSIONS FROM MANAGED PEATLANDS (TIERS 2 AND 3)

$$CO_2\text{–}C_{WW_{peat_{on-site}}} = \begin{pmatrix} CO_2\text{–}C_{WW_{peat_{conversion}}} + CO_2\text{–}C_{WW_{peat_{extraction}}} + \\ CO_2\text{–}C_{WW_{peat_{stockpiling}}} + CO_2\text{–}C_{WW_{peat_{post}}} \end{pmatrix}$$

Where:

$CO_2\text{–}C_{WW\ peat_{on\text{-}site}}$ = on-site CO_2–C emissions from peat deposits, Gg C yr^{-1}

$CO_2\text{–}C_{WW\ peat_{conversion}}$ = on-site CO_2–C emissions from lands conversion for peat extraction, Gg C yr^{-1}

$CO_2\text{–}C_{WW\ peat_{extraction}}$ = CO_2–C emissions from the surface of peat extraction area, Gg C yr^{-1}

$CO_2\text{–}C_{WW\ peat_{stockpiling}}$ = CO_2–C emissions from peat stockpiles prior to off-site removal, Gg C yr^{-1}

$CO_2\text{–}C_{WW\ peat_{post}}$ = CO_2–C emissions from soils of abandoned, cut-over peatlands, Gg C yr^{-1}

CHOICE OF EMISSION FACTORS

Tier 1

Implementation of Tier 1 method requires the application of default on-site emission factors $EF_{CO_2peatRich}$ and $EF_{CO_2peatPoor}$, and default carbon fractions of peat by weight ($Cfraction_{wt\_peat}$) or by volume ($Cfraction_{vol\_peat}$,) to estimate off-site emissions from production data in weight or volume, respectively. Default values of $EF_{CO_2peatRich}$ and $EF_{CO_2peatPoor}$ are provided in Table 7.4. Default carbon fractions of peat are provided in Table 7.5. Nutrient-poor bogs predominate in boreal regions, while in temperate regions, nutrient-rich fens and mires are more common. Types of peatlands can be inferred from the end-use of peat: sphagnum peat, dominant in oligotrophic (nutrient-poor) bogs, is preferred for horticultural uses, while sedge peat, more common in minerotrophic (nutrient rich) fens, is more suitable for energy generation. Boreal countries that do not have information on areas of nutrient-rich and nutrient-poor peatlands should use the emission factor for nutrient-poor peatlands. Temperate countries that do not have such data should use the emission factor for nutrient-rich peatlands. Only one default factor is provided for tropical regions, so disaggregating peatland area by soil fertility is not necessary for tropical countries using the Tier 1 method.

TABLE 7.4 EMISSION FACTORS FOR CO_2–C AND ASSOCIATED UNCERTAINTY FOR LANDS MANAGED FOR PEAT EXTRACTION, BY CLIMATE ZONE			
Climate zone	**Emission factor (tonnes C ha^{-1} yr^{-1})**	**Uncertainty [a] (tonnes C ha^{-1} yr^{-1})**	**Reference/Comment [b]**
Boreal and Temperate			
Nutrient – Poor $EF_{CO_2peatPoor}$	0.2	0 to 0.63	Laine and Minkkinen, 1996; Alm *et al.*, 1999; Laine *et al.*, 1996; Minkkinen *et al.*, 2002
Nutrient – Rich $EF_{CO_2peatRich}$	1.1	0.03 to 2.9	Laine *et al.*, 1996; LUSTRA, 2002; Minkkinen *et al.*, 2002; Sundh *et al.*, 2000
Tropical			
EF_{CO_2peat}	2.0	0.06 to 7.0	Calculated from the relative difference between temperate (nutrient-poor) and tropical

[a] Range of underlying data

[b] The boreal and temperate values have been developed as the mean from a review of paired plot measurements, assuming that conditions on organic soils converted to peat extraction are lightly drained only. Most of the data are from European peatlands not necessarily under production.

TABLE 7.5 CONVERSION FACTORS FOR CO_2–C FOR VOLUME AND WEIGHT PRODUCTION DATA		
Climate zone	**$Cfraction_{wt\_peat}$ [tonnes C (tonne air-dry peat)$^{-1}$]**	**$Cfraction_{vol\_peat}$ (tonnes C m^{-3} air-dry peat)**
Boreal and Temperate		
Nutrient –Poor	0.45	0.07
Nutrient –Rich	0.40	0.24
Tropical		
Tropical humus	0.34	0.26

Computed from US Geological Survey (2004): survey average bulk density, and typical moisture content and carbon contents. Based on a 35-55% moisture content of air-dry peat.

Tiers 2 and 3

The uncertainty of emission factors can be reduced by measuring the moisture content and carbon fraction of extracted peat under local climates and extraction practices, taking into account interannual climate variability. Spatially disaggregated CO_2 flux measurements should be used to develop more precise on-site emission factors, correcting for carbon losses through leaching of dissolved organic carbon or runoff. In boreal zones, winter emissions can account for 10-30% of net annual emissions (Alm *et al.*, 1999); and should be estimated. Disaggregated CO_2 flux measurements from peat stockpiles, abandoned and restored peat excavation sites would assist in reducing further estimate of uncertainties. The literature is sparse and countries are encouraged to share data, when peat quality, environmental conditions and extraction practices are similar.

CHOICE OF ACTIVITY DATA

All Tiers require data on areas of peatlands managed for peat extraction ($A_{peatRich}$ and/or $A_{peatPoor}$) and peat production data by weight or volume of air-dry peat (Wt_{dry_peat} or Vol_{dry_peat}).

Tier 1

The default methodology assumes that a country has estimates of the total area on which peat is currently and was extracted, including former commercial peatlands that have not been converted to other uses. In temperate and boreal regions, this area should, where possible, be separated into nutrient-rich and nutrient-poor with the default assumption consistent with the advice above on selection of emission factors. In addition, the quantity (by dry weight or volume) or peat extracted annually must be known to estimate off-site CO_2 emissions.

International data sets on peat extraction sites and production vary in quality and consistency. The sources of production and area data may not be the same and different definitions and years between sources and countries will likely introduce inconsistencies. Because peat extraction methods rely on dry and sunny days for drying peat, the annual production varies depending on suitable summer weather. For the purpose of estimating off-site emissions, peat production data should be separated according to end-use, i.e., horticultural peat and combustion peat, since the estimation methods of this Chapter only require the production of horticultural peat. If it is impossible to separate the quantity of peat produced by end-use, emissions from peat consumption should be accounted under the inventory sector corresponding to the predominant end-use of domestically produced peat. Useful area data can be found in Joosten (2004); Joosten & Clarke (2002); Sirin & Minayeva (2001); Lappalainen (1996); and inventories published by Wetlands International (http://www.wetlands.org/). Data on peat production are available from World Energy Council (2004) (for combustion peat) and the United States Geological Survey (http://minerals.usgs.gov/minerals/pubs/commodity/peat/). Additional information may be obtained from the International Peat Society (http://www.peatsociety.org/) or the International Mire Conservation Group (http://www.imcg.net/).

When either areas or production data are missing, it may be possible to derive one from the other by using a default conversion factor equal to an average production rate provided by the local industry. In a mature, industrialized peat industry, block-cut methods can yield up to 1750 tonnes of air-dry peat per hectare annually, while the vacuum method can extract up to 100 tonnes per hectare per year (Cleary *et al.*, 2005). Air-dry peat contains between 35% and 55% moisture (World Energy Council, 2004).

Tiers 2 and 3

Countries using higher Tiers should obtain national peat production data and the corresponding peatland areas. In boreal and temperate regions, these area data need to be disaggregated by soil fertility to correspond to appropriate emission factors. Possible sources of such data are national energy statistics, peat extraction firms, peat industry associations, landscaping industry associations, and government ministries responsible for land use or geological surveys. If it is not possible to stratify by peat fertility, countries may rely on expert judgment. Boreal climates tend to promote nutrient-poor raised bogs, while temperate and oceanic climates tend to promote the formation of nutrient-rich peatlands. Priorities for the development of country-specific activity data include: i) areas of organic soils currently and formerly managed for peat extraction and disaggregated based on nutrient status if relevant; ii) peat production data; iii) local moisture content that will reflect ambient conditions at the time of peat extraction; and iv) country-specific carbon content, preferably by peat type.

More sophisticated estimation methodologies will require the determination of areas in each of the three phases of the peat extraction cycle, including abandoned areas on which drainage or the effects of former peat extraction are still present; and if warranted, areas characterized by different peat extraction technology, peat types and extraction depths. If site restoration is underway, countries are encouraged to report separately the areas of restored organic soils formerly managed for peat extraction and estimate emissions and removals from these lands. In addition, countries with a significant production of horticultural peat may develop data to monitor the off-site fate of extracted peat in order to develop time-sensitive decay curves.

7.2.1.2 NON-CO_2 EMISSIONS FROM PEATLANDS REMAINING PEATLANDS

METHANE

When peatlands are drained in preparation for peat extraction, the natural production of CH_4 is largely reduced, but not entirely shut down (Strack *et al.*, 2004), as the methanogen bacteria thrive only in anaerobic conditions. Under Tier 1, methane emissions are assumed to be insignificant in these drained peatlands. At higher tiers, countries are encouraged to examine the pattern of CH_4 emissions from topographic lows and drainage ditches, which can contribute a significant proportion of the total greenhouse gas emissions from these managed peatlands (Sundh *et al.*, 2000).

NITROUS OXIDE

Depending on site fertility, peat deposits may contain significant amounts of organic nitrogen in inactive form. Drainage allows bacteria to convert the nitrogen into nitrates, which then leach into the surface where they are reduced to N_2O. In drained peatlands, the potential quantity of N_2O emitted depends on the nitrogen content of the peat. At C:N ratios exceeding 25, the N_2O emissions may be considered insignificant (Klemedtsson *et al.*, 2005).

Currently, there are no estimation methods that would allow separation of N_2O emissions from organic matter decay during the off-site use of horticultural peat. Nitrogen fertilizers are commonly added to horticultural peat before use, and this source would likely dominate N_2O emission patterns. In order to avoid double-counting N_2O emitted from the use of fertilizers, the default approach for estimating N_2O emissions from lands managed for peat extraction excludes emissions from the decay of organic nitrogen in horticultural peat.

Choice of method

Use the decision tree of Figure 7.1 to determine the appropriate methodological tier for N_2O emissions.

Tier 1

The Tier 1 method for estimating N_2O emissions from drained wetlands is similar to that described for drained organic soils for agriculture or forestry, but emission factors are generally lower. The default methodology only considers nutrient-rich peatlands.

EQUATION 7.7
N_2O EMISSIONS FROM PEATLANDS DURING PEAT EXTRACTION

$$N_2O_{WW_{peatExtraction}} = \left(A_{peatRich} \bullet EF_{N_2O-N_{peatRich}}\right) \bullet \frac{44}{28} \bullet 10^{-6}$$

Where:

$N_2O_{WWpeat\ Extraction}$ = direct N_2O emissions from peatlands managed for peat extraction, Gg N_2O yr^{-1}

$A_{peatRich}$ = area of nutrient-rich peat soils managed for peat extraction, including abandoned areas in which drainage is still present, ha

$EF_{N_2O-N_{peat\ Rich}}$ = emission factor for drained nutrient-rich wetlands organic soils, kg N_2O–N ha^{-1} yr^{-1}

Tier 2

Under Tier 2, the activity data are disaggregated by additional factors such as peat type and fertility, phase of peat extraction, and time since the onset of drainage activities. The corresponding emission factors are country-specific and take into account conditions and practices of peat extraction, drainage depth, and changes in the C:N ratio down the peat profile.

Tier 3

Tier 3 methods involve a comprehensive understanding and representation of the dynamics of N_2O emissions and removals on managed peatlands, including the effect of site characteristics, peat type and depth, extraction technology, and the phases of peat extraction as described at the beginning of Section 7.2. The methodology will include all the relevant sources of N_2O. Both on-site and off-site emissions will be considered, and take into account the rate of peat decay under common extraction and utilization conditions. Methods should be consistent with the estimation procedures for CO_2 emissions, e.g., the same off-site decay rates should be used. If process-based models are used, they should be calibrated and validated against independent measurements which are representative of the national conditions.

Choice of emission/removal factors

Tier 1

Default emission factors for the Tier 1 method are provided in Table 7.6.

Tiers 2 and 3

Countries applying Tier 2 methods develop country-specific emission factors, which may be able to differentiate emission rates during land conversion to peat land and the ongoing emissions during peat extraction. Tiers 2 and 3 require country-specific emission data that account for site characteristics, peat type and depth, extraction technology, the phases of peat extraction or other relevant factor. Peat type is especially relevant to its decomposability and the ensuing N_2O emissions. Emissions from the off-site use of horticultural peat should be included in Tier 3 methods. Currently, the literature is sparse and results are sometimes contrasting. Countries are encouraged to share comparable data, when environmental conditions and extraction practices are similar.

TABLE 7.6 DEFAULT EMISSION FACTORS FOR N_2O EMISSIONS FROM MANAGED PEATLANDS			
Climate zone	**Emission factor EF_{N_2O} (kg N_2O-N ha^{-1} yr^{-1})**	**Uncertainty range (kg N_2O-N ha^{-1} yr^{-1})**	**Reference/ Comments**
Boreal and Temperate Climate			
Nutrient-poor organic Soil	negligible	negligible	Alm *et al*., 1999; Laine *et al*., 1996; Martikainen *et al*., 1995; Minkkinen *et al*., 2002; Regina *et al*., 1996
Nutrient-rich organic Soil	1.8	0.2 to 2.5	
Tropical Climate	3.6	0.2 to 5.0	The value for tropical areas is twice that for northern climates, based on the relative difference between temperate and tropical N_2O EF in Table 11.1, Chapter 11.
Most of the data are from European peatlands not necessarily under production. Climate zones are as described in Chapter 3.			

Choice of activity data

Tier 1

The same activity data should be used for estimating CO_2 and N_2O emissions from managed peatlands. Information on obtaining these data is provided in Section 7.2.1 above. For countries in boreal and temperate regions using the Tier 1 method, area data should be stratified by soil fertility, since only nutrient-rich peat soils are considered. If the available information does not allow stratification by peat fertility, countries may rely on expert judgment. Boreal climates tend to promote nutrient-poor raised bogs or fens, while temperate and oceanic climates tend to promote the formation of nutrient-rich peatlands. Low fertility peatlands are generally acidic (with low pH). Under Tier 1, additional uncertainty arises from the use of unique default CO_2 and N_2O emission factors, applied to both *Land Being Converted for Peat Extraction* and *Peatlands Remaining Peatlands*, as the nitrogen content and bioavailability of organic C and N may change with depth.

Tiers 2 and 3

Priorities for the development of country-specific activity data include areas of organic soils managed for peat extraction, disaggregated based on nutrient status if relevant, and annual peat production data. More sophisticated estimation methodologies will require the determination of areas in each of the three phases of the peat extraction cycle, including abandoned areas on which drainage or the effects of former peat extraction are still present; and if warranted, areas characterized by different peat extraction technology, peat types and extraction depths. If site restoration is underway, countries should report separately the areas of restored organic soils formerly managed for peat extraction and estimate emissions and removals from these lands. In addition, countries with a significant production of horticultural peat may develop data to monitor the off-site fate of extracted peat in order to develop time-sensitive decay curves (see also Section 7.2.1).

7.2.1.3 UNCERTAINTY ASSESSMENT

Emission factors

For both CO_2 and N_2O, the key uncertainties in Tier 1 estimation procedures are the default emission factors (Tables 7.4 and 7.6), and other parameters such as moisture content of air-dry peat. Emission factors and parameters have been developed from only a few (less than 10) data points, mostly in temperate and boreal regions, and may not be representative for large areas or climate zones. The standard deviation of the emission factors easily exceeds 100% of the mean, but underlying probability functions are likely to be non-normal. The variability in peat specific gravity and its moisture holding capacity accounts for a significant component of this uncertainty. Depending on peat characteristics, the interannual variability in precipitation can alter the rate of organic matter decay by 25% to 100% (Waddington *et al*., 2002). Variability in peat moisture content and peat quality accounts for a 20% uncertainty on the carbon content of air-dry peat. In general, countries are encouraged to use the range rather than the standard deviation.

Many organic soils have been drained and converted to other uses, e.g., agricultural or forestry production. These soils are frequently on more fertile sites, and thus emission factors are higher. In addition to drainage, management activities will alter the distribution of organic matter along the soil profile, and consequently the greenhouse gas emission patterns. Hence, greenhouse gas emission patterns from organic soils under different land management practices are expected to differ. When country-specific factors are developed, countries should use sufficient sample sizes and techniques to minimize standard errors. Ideally, probability density functions (i.e., providing mean and variance estimates) should be derived for all country-defined parameters. At a minimum, Tier 2 approaches should provide error ranges for each country-defined parameter. Such data can be used in advanced uncertainty analyses such as Monte Carlo simulations.

Under Tier 3, emission factors and their associated probability density functions are used to develop means and confidence intervals for the entire category, with advanced procedures (e.g., Monte-Carlo). Process-based models will in principle provide more realistic estimates but need to be calibrated and validated against measurements. Uncertainties arising from the use of models need to be quantified with similar procedures. Refer to Volume 1, Chapter 3 of these *Guidelines* for guidance on developing such analyses.

Activity data

Countries that used aggregated activity data for managed peatlands should factor in an uncertainty of 50% in Europe and North America, but a factor of 2 in the rest of the world. Uncertainty can be higher if managed peatland areas are based on total (managed and unmanaged) peatlands, or on production data, since peat production strongly depends on good weather conditions. Under Tiers 2 and 3, the spatial disaggregation of peatland areas by relevant eco-climatic parameters and/or management practices, information on the end-use of peat, and the distinction between recently converted peatlands and those under ongoing production and restoration, will enable more accurate estimation procedures.

7.2.2 Land Being Converted for Peat Extraction

Under a Tier 1 approach, the activity data do not distinguish between peatlands under peat extraction (*Peatlands Remaining Peatlands*), and those being converted for peat extraction (see the beginning of Section 7.2 for a description of the three phases of peat extraction). Countries using such an approach should refer to Section 7.2.1 for methodological guidance. Countries using a Tier 2 methodology should make the separation. This section provides guidance specific to peatlands being drained and converted for peat extraction.

7.2.2.1 CO_2 EMISSIONS ON LANDS BEING CONVERTED FOR PEAT EXTRACTION

As described in the introduction of Section 7.2, the peat extraction cycle has three phases, the first one of which being the development or conversion for peat extraction, characterized by extensive drainage work (if the area was not already drained for other purposes), but little peat extraction. This conversion phase typically lasts for 2 to 5 years. In contrast with other land-use conversions in these *Guidelines*, the recommended default transition period for *Land Being Converted for Peat Extraction* is five years.

Greenhouse gas emissions from lands being cleared and drained for peat extraction are significantly different from the emissions of lands currently undergoing peat extraction or have been exhausted and abandoned. The major emissions during the conversion process arise from the removal and destruction of the living biomass of the peatland ecosystem, and from soils during drainage. Since these lands are not yet into production, there is no peat extraction and therefore no off-site emissions from extracted peat.

Equation 7.8 represents the main sources of CO_2–C emissions during land conversion for peat extraction.

EQUATION 7.8
CO_2 –C EMISSIONS IN PEATLAND BEING DRAINED FOR PEAT EXTRACTION

$$CO_2\text{–}C_{LW_{peat\_on-site}} = \left(-\Delta C_{WW_{peat_B}}\right) + \left(-\Delta C_{WW_{peat_{DOM}}}\right) + CO_2\text{–}C_{LW_{peat\_drainage}}$$

Where:

$CO_2\text{–}C_{LWpeat\_on\text{-}site}$ = CO_2–C emissions from land being converted for peat extraction, Gg C yr^{-1}

$\Delta C_{WWpeat\ B}$ = CO_2–C emissions from change in carbon stocks in living biomass, Gg C yr^{-1}

$\Delta C_{WWpeat_{DOM}}$ = CO_2–C emissions from change in carbon stocks in dead organic matter pool, Gg C yr^{-1}

$CO_2\text{–}C_{LWpeat\ drainage}$ = CO_2–C emissions from soils during drainage, Gg C yr^{-1}

CHOICE OF METHOD

Tier 2

None of the procedures for estimating these quantities is unique to this category, except for emissions from soils during drainage. If pre-clearing standing vegetation is Forest Land or Grassland, the estimation procedures for emissions from the living biomass from the conversion of Forest Land or Grassland to Cropland is discussed in Chapter 5, Section 5.3. Where fires are used to clear vegetation, emissions of non-CO_2 gases, i.e., CH_4 and N_2O will also occur. These emissions can be estimated following guidance also provided in Chapter 2. Biomass burning and decay of unburned biomass and dead organic matter can be estimated, if country-specific emission factors are available. The areas of land being drained can be broken down according to peat fertility, peat type, and previous land-use or land cover. Countries may be able to refine emission factors accordingly.

Equation 7.9 provides the general approach to estimate emissions from soil during drainage. Conceptually, it is the same as Equation 7.6 used to determined $CO_2–C_{WW\ peat_{on-site}}$ for managed peatlands.

EQUATION 7.9
CO_2–C EMISSIONS FROM SOILS IN PEATLAND BEING DRAINED FOR PEAT EXTRACTION

$$CO_2\text{–}C_{LW_{peat\_drainage}} = \left[\frac{\left(A_{drained\_peat_{Rich}} \bullet EF_{CO_2 drained\_peat_{Rich}}\right) + \left(A_{drained\_peat_{Poor}} \bullet EF_{CO_2 drained\_peat_{Poor}}\right)}{1000} \right]$$

Where:

$CO_2–C_{LW\ peat\_drainage}$ = CO_2–C emissions from soils on lands converted for peat extraction, Gg C yr^{-1}

$A_{drained\ peat_{Rich}}$ = area of nutrient-rich peat soils being drained, ha

$A_{drained\ peat_{Poor}}$ = area of nutrient-poor peat soils being drained, ha

$EF_{CO_2 drained\ peat_{Rich}}$ = emission factors for CO_2–C from nutrient-rich peat soils being drained, tonnes C ha^{-1} yr^{-1}

$EF_{CO_2\ drained\ peat_{Poor}}$ = emission factors for CO_2–C from nutrient-poor peat soils being drained, tonnes C ha^{-1} yr^{-1}

Tier 3

Tier 3 methods involve a comprehensive understanding and representation of the dynamics of CO_2 emissions and removals on *Land Being Converted for Peat Extraction*, including the effect of peat type and fertility, site characteristics such as blanket or raised bogs, and previous land-use or land cover if relevant, which could be combined with appropriate emission factors and/or process-based models. The methodology includes the fate of C in all pools, C transfers between pools upon conversion (e.g., biomass to dead organic matter), and distinguishes immediate and delayed emissions. Estimates based on changes in stocks should be corrected for carbon losses due to the leaching of dissolved organic carbon, losses of dead organic matter through runoff, or as CH_4 emissions.

CHOICE OF EMISSION/REMOVAL FACTORS

Tier 2

Countries applying Tier 2 methods will develop country-specific emission factors $EF_{CO_2 drained\ peat_{Rich}}$ and $EF_{CO_2\ drained\ peat_{Poor}}$ to differentiate emission rates during land conversion, from the ongoing emissions during the peat extraction phase. It may be possible to differentiate emission factors further by type of peat, its fertility, and drainage depth, previous land use or land cover, and climatic zones.

Tier 3

Under Tier 3, all parameters should be country-specific. The literature is sparse and it is *good practice* to derive country-specific emission factors and data should be shared between countries with similar environmental conditions.

CHOICE OF ACTIVITY DATA

Tier 2

The basic activity data required are the area of organic soils converted for peat extraction and disaggregated by nutrient status (or fertility). Possible sources of area data are peat extraction firms, peat industry associations, and government ministries responsible for land information. Under Tier 2, countries can also incorporate information based on the original land use, peat type and peat fertility of the lands being converted. This information could be gathered from regular updates of the national peatland inventory.

Tier 3

Under Tier 3, detailed information on the original land use, peat type, and peat fertility of areas converted for peat extraction, is needed. More specific data needs may be defined depending on the estimation procedures.

7.2.2.2 NON-CO_2 EMISSIONS FROM LANDS BEING CONVERTED TO MANAGED PEATLANDS

The discussion of methodological issues in Section 7.2.1.2 "Non-CO_2 Emissions from *Peatlands Remaining Peatlands*" will also apply here with the exception of non-CO_2 emissions from the off-site decay of horticultural peat; since there is no peat extraction during the phase of land conversion and preparation. Under higher tiers, methane emissions may no longer be assumed negligible on lands being drained. Equation 7.7 of Section 7.2.1 also describes the default approach to estimate N_2O emissions.

7.2.2.3 UNCERTAINTY ASSESSMENT

Emission factors

Refer to the discussion on emission factor uncertainties in Section 7.2.1.3

Uncertainty attached to the carbon content of pre-conversion vegetation cover, as affected by the previous land use, should be included in the uncertainty assessment of CO_2 estimates. The uncertainty probability distribution of the emissions is likely to be non-normal, so the 95% interval of a log-normal distribution is assumed here as default uncertainty (see Tables 7.4 and 7.6). It is recommended to use this range rather than a symmetrical standard deviation.

Activity data

Agencies providing area data should have information on area uncertainties; otherwise default uncertainty data associated with the advice on area estimation in Chapter 3 can be used.

7.3 FLOODED LAND

Flooded Lands are defined as water bodies where human activities have caused changes in the amount of surface area covered by water, typically through water level regulation. Examples of Flooded Land include reservoirs for the production of hydroelectricity, irrigation, and navigation. Regulated lakes and rivers that do not have substantial changes in water area in comparison with the pre-flooded ecosystem are not considered as Flooded Lands. Some rice paddies are cultivated through flooding of land, but because of the unique characteristics of rice cultivation, rice paddies are addressed in Chapter 5 (Cropland) chapter of the *Guidelines.*

Flooded Lands may emit CO_2, CH_4 and N_2O in significant quantities, depending on a variety of characteristic such as age, land-use prior to flooding, climate, and management practices. Emissions vary spatially and over time.

While there is evidence, especially in tropical areas, of increased CH_4 emissions due to flooding, the high temporal and spatial variability of CH_4 emissions has so far precluded the development of default emission factors for all climatic regions. The available information regarding CH_4 emissions is provided in Appendix 3.

Nitrous oxide emissions from Flooded Lands are typically very low, unless there is a significant input of organic or inorganic nitrogen from the watershed. It is likely that such inputs would result from anthropogenic activities such as land-use change, wastewater treatment or fertilizer application in the watershed. In order to avoid double-counting N_2O emissions already captured in the greenhouse gas budget of these anthropogenic sources, and in light of the very limited contribution of N_2O emissions from Flooded Lands reported in the literature, the current section will not consider these emissions.

7.3.1 Flooded Land Remaining Flooded Land

No methodologies are provided for *Flooded Land Remaining Flooded Land*. As explained above, it is assumed that CO_2 and N_2O emissions occurring on flooded lands are already covered by methodologies described in other sectors. The default methodology for *Land Converted to Flooded Land* provides guidance for estimation of CO_2 emission due to flooding. Available information on CH_4 emissions is provided in Appendix 3 but it is not possible, at present, to recommend a default methodology. Countries seeking to report CH_4 emissions from flooded lands should, where feasible, develop domestic emission factors. Guidance on the development of such factors is provided in Appendix 2, Box 2a.1.

7.3.2 Land Converted to Flooded Land

For reasons already explained, this section provides guidance only on estimation of CO_2 emissions from *Land Converted to Flooded Land*.

7.3.2.1 CO_2 EMISSIONS FROM LAND CONVERTED TO FLOODED LAND

CHOICE OF METHOD AND EMISSION FACTOR

The method for estimating carbon stock change due to land conversion to permanently flooded land is shown in Equation 7.10. The carbon stock of the land prior to conversion can be estimated following the method for living biomass described for various land-use categories in other sections of this volume. Here, it is assumed that the carbon stock after conversion is zero.

EQUATION 7.10
ANNUAL CHANGE IN CARBON STOCKS IN LIVING BIOMASS ON LAND CONVERTED TO PERMANENTLY FLOODED LAND

$$\Delta C_{LWflood_{LB}} = \left[\sum_i A_i \bullet (B_{After_i} - B_{Before_i}) \right] \bullet CF$$

$$CO_{2\_LWflood} = \Delta C_{LWflood_{LB}} \bullet \frac{-44}{12}$$

Where:

$\Delta C_{LWflood_{LB}}$ = annual change in carbon stocks in biomass on *Land Converted to Flooded Land*, tonnes C yr^{-1}

A_i = area of land converted annually to Flooded Land from original land use *i*, ha yr^{-1}

B_{After_i} = biomass immediately following conversion to Flooded Land, tonnes d.m. ha^{-1} (default = 0)

B_{Before_i} = biomass in land immediately before conversion to Flooded Land, tonnes d.m. ha^{-1}

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonne d.m.)$^{-1}$

$CO_{2\_LWflood}$ = annual CO_2 emissions on *Land Converted to Flooded Land*, tonnes CO_2 yr^{-1}

It is possible that the carbon remaining on the converted land prior to flooding may be emitted over several years after flooding.

No guidance is provided on carbon stock changes from soils due to land conversion to Flooded Land at this time.

The stock change method assumes that all the carbon in biomass that existed prior to flooding is emitted and this may lead to overestimates. Countries are encouraged to develop higher tier country-specific methods based on models, measurements and associated parameters. A possible approach is given in Appendix 2. Generic guidance on the development of country-specific methods based on models and measurements is available in Chapter 2, Section 2.5.

Emissions of non-CO_2 gases from *Land Converted to Flooded Land* are covered in Appendix 3.

CHOICE OF ACTIVITY DATA

Countries can obtain their flooded land area from a drainage basin cover analysis, from a national dam database, from the International Commission on Large Dams (ICOLD, 1998) or from the World Commission on Dams report (WCD, 2000).

7.3.2.2 NON-CO_2 EMISSIONS FROM LAND CONVERTED TO FLOODED LAND

Available information on CH_4 emissions for *Land Converted to Flooded Land* can be found in Appendix 3.

7.3.2.3 UNCERTAINTY ASSESSMENT

National statistical information on the flooded area retained behind large dams (> $100km^2$) should be available and will probably be accurate to within 10 percent. Where national database on dams are not available, and other information is used, the flooded land areas retained behind dams will probably have an uncertainty of more than 50 percent, especially for countries with large flooded land areas. Detailed information on the location, type and function of smaller dams may be also difficult to obtain, though statistical inference may be possible based on the size distribution of reservoirs for which data are available. Reservoirs are created for a variety of reasons that influence the availability of data, and, consequently, the uncertainty on surface area is dependent on country specific conditions.

Uncertainty in biomass stocks is discussed in Chapters 4, 5 and 6.

7.4 COMPLETENESS, TIME SERIES CONSISTENCY, AND QA/QC

7.4.1 Completeness

Complete greenhouse gas inventories will include estimates of emissions from the two types of managed wetlands as described in Sections 7.2 and 7.3 above, unless these wetland types do not occur on the national territory.

As in other land categories, countries are encouraged to monitor the fate of managed wetlands, and avoid double-counting with lands in other categories. It is *good practice* to document the extent of reservoir areas. Once peatlands are brought under peat extraction, they remain managed peatlands even after peat extraction activities have ceased, until they are converted to another use. Rewetting of soils, or the return of the water table to pre-drainage levels, do not change the status of peatlands. See Section 7.5 “Future Methodological Development” for additional discussion of restored peatlands.

Countries using advanced methods and data should take care not to report greenhouse gas emissions already accounted for in other AFOLU chapters, or in other Volumes of these guidelines. In particular, wetlands may receive non-point source effluents and sediments with high nutrient contents; organic or inorganic N, and organic C emitted from these wetlands may have already been included in the estimation methodologies for Forest Land or Cropland, or the Waste Sector. When there is evidence of such non-point source of carbon or nitrogen to wetlands, it is *good practice* to ensure that the associated greenhouse gas emissions are reported under the proper inventory sectors and categories; countries are encouraged to develop, compile or use the available information in order to avoid biased estimates.

7.4.2 Developing a consistent time series

General guidance on consistency in time series can be found in Volume 1, Chapter 5 (Time Series Consistency). The emission estimation method should be applied consistently to every year in the time series, at the same level of spatial disaggregation. Moreover, when country-specific data are used, national inventories agency should use the same measurement protocol (sampling strategy, method, etc.) throughout the time series. If this is not possible, the guidance on interpolation techniques and recalculation in Volume 1, Chapter 5 should be followed. Differences in emissions between inventory years should be explained, e.g., by demonstrating changes in areas of peatlands or flooded lands, by updated emission factors.

7.4.3 Quality Assurance and Quality Control (QA/QC)

Quality assurance/quality control (QA/QC) procedures should be developed and implemented as outlined in Volume 1, Chapter 6 of this report. The development of additional, category-specific quality control and quality assurance activities may also be applicable (Volume 1, Chapter 6), particularly if higher tier methods are used to quantify emissions from this source category. Where country-specific emission factors are being used, they should be based on high quality experimental data, developed using a rigorous measurement programme, and be adequately documented.

It is, at present, not possible to crosscheck emissions estimates from organic soils managed for peat extraction with other measurement methods. However, the inventory agency should ensure that emission estimates undergo quality control by:

- cross-referencing reported country-specific emissions factors with default values, and values published in the scientific literature or reported by other countries;
- checking the accuracy of activity data with data of peat industries and peat production; and
- assessing the plausibility of estimates against those of other countries with comparable circumstances.

7.4.4 Reporting and Documentation

It is appropriate to document and archive all information required to produce the national emission/removal inventory estimates as outlined in Volume 1, Chapter 8 of these *Guidelines*.

EMISSION FACTORS

The scientific basis of new country-specific emission factors, parameters and models should be fully described and documented. This includes defining the input parameters and describing the process by which the emission factors, parameters and models were derived, as well as describing sources of uncertainties.

ACTIVITY DATA

Sources of all activity data used in the calculations (data sources, databases and soil map references) should be recorded, plus (subject to any confidentiality considerations) communication with industry. This documentation should cover the frequency of data collection and estimation, and estimates of accuracy and precision, and reasons for significant changes in emission levels.

TREND ANALYSIS

Significant fluctuations in emissions between years should be explained. A distinction should be made between changes in activity levels and changes in emission factors, parameters and methods from year to year, and the reasons for these changes documented. If different emission factors, parameters and methods are used for different years, the reasons for this should be explained and documented.

7.5 FUTURE METHODOLOGICAL DEVELOPMENT

Other types of managed wetlands may emit or sequester significant amounts of greenhouse gases, notably restored or constructed wetlands. Restored wetlands are wetlands which have been drained and perhaps converted to other uses in the past, but have recently been restored back to functioning wetland ecosystems by raising the water table to pre-drainage levels. In recent decades, public, non-profit and other programs in numerous countries have begun to restore former wetlands and construct others from uplands. A primary purpose is to reduce the runoff from agricultural fields and settlements which causes eutrophication, algal blooms, and hypoxic dead zones in lakes, estuaries, and enclosed bays and seas. Other important benefits include reducing flood damage, stabilizing shorelines and river deltas, retarding saltwater seepage, recharging aquifers, and improving wildlife, waterfowl, and fish habitat.

Most operational wetland restorations have occurred since 1990. The technical literature describes programs or projects in some 15 countries in North America, Europe, Asia, and Australia and New Zealand, in particular the river deltas. This literature suggests that wetland ecosystems can be restored, but over variable periods of time and with variable resemblance to natural wetland ecosystems. Currently, there is no available compilation of the global area of wetland restoration and construction. The IPCC Special Report on Land Use, Land-Use Change and Forestry estimates that maximum areas available for restoration are in the range of 30 to 250 Mha (Watson *et al*., 2000).

At the time of preparation of these *Guidelines*, published studies based on observational data are too recent and limited to develop default emission factors for any of the major greenhouse gases--- CO_2, CH_4 or N_2O. Better understanding of the biogeochemical fluxes within drainage basins will be needed to prevent double-counting emissions due to fertilizer application and waste treatment. Hence, the estimation of greenhouse gas emissions and removals from restored or constructed wetlands remains an area for further development.

An increase in CH_4 emissions is expected to occur upon the rewetting of organic soils. A first approximation of CH_4 emissions on rewetted organic soils with a forest cover is from 0 to 60 kg CH_4 ha^{-1} yr^{-1} in temperate and boreal climates, and from 280 to 1260 kg CH_4 ha^{-1} yr^{-1} in tropical climates (Bartlett and Harriss, 1993). However, in the short term these emissions may not return to their pre-drainage levels (Tuittila et al., 2000; Komulainen et al, 1998).

The effect of non-point nutrient sources to flooded lands (reservoirs) also remains poorly documented. Countries using advanced, domestic approaches should implement cross-sectoral checks, ideally using mass-balance, to ensure that the fate of all carbon and nitrogen released in a watershed is properly accounted for. The lack of observational data from reservoirs in Asia is a notable gap in the data samples used to develop CO_2 emission factors for flooded land. It may be possible, in future editions of these guidelines, to incorporate more information from this region.

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SECTION 7.1: INTRODUCTION & SECTION 7.2: PEATLANDS MANAGED OR BEING CONVERTED FOR PEAT EXTRACTION

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