Appendix 3a.3 Wetlands Remaining Wetlands: Basis for future methodological development

3a.3.1 Introduction

This section develops the coverage of Section 5.4.3 (Other Possible Categories of Activity) of the *IPCC Guidelines* by describing methodologies for estimating carbon stock changes, as well as CH_4 and N_2O emissions (which can be as significant as CO_2 emissions) from wetlands remaining wetlands. Land conversion to wetlands is described in Section 3.5 of this report.

The estimate of CO_2 emissions in wetland has two basic elements, as shown in Equation 3a.3.1.

EQUATION 3a.3.1
CO_2 EMISSIONS IN WETLAND REMAINING WETLAND

$$CO_2\ emissions_{WW} = CO_2\ emissions_{WW\ peat} + CO_2\ emissions_{WW\ flood}$$

Where:

$CO_2\ emissions_{WW}$ = CO_2 emissions in wetland remaining wetland, Gg CO_2 yr^{-1}

$CO_2\ emissions_{WW\ peat}$ = CO_2 emissions from organic soils managed for peat extraction (Section 3a.3.1), Gg CO_2 yr^{-1}

$CO_2\ emissions_{WW\ flood}$ = CO_2 emissions from flooded land (Section 3a.3.2), Gg CO_2 yr^{-1}

The estimate of N_2O emissions has the same two basic elements, as shown in Equation 3a.3.2.

EQUATION 3a.3.2
N_2O EMISSIONS FROM WETLAND REMAINING WETLAND

$$N_2O\ emissions_{WW} = N_2O\ emissions_{WW\ peat} + N_2O\ emissions_{WW\ flood}$$

Where:

$N_2O\ emissions_{WW}$ = N_2O emissions from wetland remaining wetland, Gg N_2O yr^{-1}

$N_2O\ emissions_{WW\ peat}$ = N_2O emissions from organic soils managed for peat extraction (Section 3a3.2), Gg N_2O yr^{-1}

$N_2O\ emissions_{WW\ flood}$ = N_2O emissions from flooded land (Section 3a.3.3), Gg N_2O yr^{-1}

At present, a default methodology for CH_4 can be provided only for flooded land (Equation 3a.3.3):

EQUATION 3a.3.3
METHANE EMISSIONS FROM WETLANDS REMAINING WETLANDS

$$CH_4\ emissions_{WW} = CH_4\ emissions_{WW\ flood}$$

Where:

$CH_4\ emissions_{WW}$ = CH_4 emissions from wetlands remaining wetlands, Gg CH_4 yr^{-1}

$CH_4\ emissions_{WW\ flood}$ = CH_4 emissions from flooded land (Section 3a.3.3), Gg CH_4 yr^{-1}

3a.3.2 Organic Soils Managed for Peat Extraction

As shown in Table 3a.3.1 and Equations 3a.3.1 and 3a.3.2, methods for estimating emissions from organic soils managed for peat extraction currently are provided only for CO_2 and N_2O.

TABLE 3a.3.1
SUMMARY OF TIERS FOR ORGANIC SOILS MANAGED FOR PEAT EXTRACTION

	Tier 1	Tier 2	Tier 3
Change in Living Biomass ($\Delta C_{WW\ peat\ LB}$)	Not estimated (or assumed zero).	Unlikely to be significant (see below), but may be estimated if country-specific data are available, following guidance in Section 3.4.1.1 (Grassland, Changes in Carbon Stock in Living Biomass).	Unlikely to be significant (see below), but may be estimated if detailed country-specific data or advanced methods are available, following guidance in Section 3.4.1.1 (Grassland, Changes in Carbon Stock in Living Biomass).
Change in Soil Organic Matter ($\Delta C_{WW\ peat\ SOM}$)	Emissions from peat extraction can be estimated using default emission factors and area data.	Estimated using more disaggregated, country-specific factors. If data are available, emissions from restoration of peatlands and stockpiles may be estimated.	May be estimated if detailed country-specific data or advanced methods are available.
N_2O	Emissions from peat extraction can be estimated using default emission factors and area data.	Estimated using more disaggregated, country-specific factors. If data are available, emissions from restoration of peatlands may be estimated.	May be estimated if detailed country-specific data or advanced methods are available.
CH_4	Not estimated at present.	Estimated using country-specific factors. If data are available, emissions from restoration of peatlands may be estimated.	May be estimated if detailed country-specific data or advanced methods are available.

3a.3.2.1 CO_2 EMISSIONS FROM ORGANIC SOILS MANAGED FOR PEAT EXTRACTION

The estimate of CO_2 emissions from lands managed for peat extraction has two basic elements, as shown in Equation 3a.3.4.

EQUATION 3a.3.4
CO_2 EMISSIONS IN LAND MANAGED FOR PEAT EXTRACTION

$$CO_2\ emissions_{WW\ peat} = (\Delta C_{WW\ peat_{LB}} + \Delta C_{WW\ peat_{Soils}}) \bullet 10^{-3} \bullet 44/12$$

Where:

$CO_2\ emission_{WWpeat}$ = CO_2 emissions from land managed for peat, Gg CO_2 yr^{-1}

$\Delta C_{WW\ peat\ LB}$ = change in carbon stock in living biomass, tonnes C yr^{-1}

$\Delta C_{WW\ peat\ Soils}$ = change in carbon stock in soils, tonnes C yr^{-1}

The carbon stock changes are converted to CO_2 emissions (Equation 3a.3.4 is expected to result in a loss of carbon). Emissions are reported as positive values and removals as negative values (for more details on reporting and the rule on the signs, see Section 3.1.7 and Annex 3A.2 Reporting Tables and Worksheets).

3a.3.2.1.1 CHANGE IN CARBON STOCKS LIVING BIOMASS

In general, the portion of emissions coming from the change in carbon stock in living biomass will be small compared to the carbon emissions associated with soil organic matter. This is because vegetation is typically removed on organic soils managed for peat extraction, although there may be some vegetation in drainage ditches or along boundaries. Nevertheless substantial amounts of vegetation may be removed when the peatland comes under management, which is addressed in Section 3.5 of this report. Due to scarcity of data and the likely small relevance of changes in biomass on lands managed for peat extraction, no default guidance is provided here, and it can be assumed in Tier 1 that the change in carbon stocks in living biomass on managed peatland is zero. However, countries in which wetlands are a key category may develop data to support the estimation of emissions from vegetation using higher tier methods based on national expertise.

3a.3.2.1.2 CHANGE IN CARBON STOCKS IN SOILS

3a.3.2.1.2.1 Methodological Issues

CO_2 emissions from soil occur at several stages in the peat process, as shown in Equation 3a.3.5.

EQUATION 3a.3.5
CHANGE IN SOIL CARBON ON LANDS MANAGED FOR PEAT EXTRACTION

$$\Delta C_{WW\ peat_{Soils}} = (\Delta C_{WW\ peat_{Soils,\ drainage}} + \Delta C_{WW\ peat_{Soils,\ extraction}} + \Delta C_{WW\ peat_{Soils,\ stockpiling}} + \Delta C_{WW\ peat_{Soils,\ restoration}})$$

Where:

$\Delta C_{WW\ peat\ Soils}$ = change in carbon stock in soils, tonnes C yr^{-1}

$\Delta C_{WW\ peat_{Soils,\ drainage}}$ = change in soil carbon during drainage, tonnes C yr^{-1}

$\Delta C_{WW\ peat_{Soils,\ extraction}}$ = change in soil carbon during peat extraction, tonnes C yr^{-1}

$\Delta C_{WW\ peat_{Soils,\ stockpiling}}$ = change in soil carbon during stockpiling of peat prior to removal for combustion, tonnes C yr^{-1}

$\Delta C_{WW\ peat_{Soils,\ restoration}}$ = change in soils carbon due to practices undertaken to restore previously cultivated lands, tonnes C yr^{-1}

Currently a default method can only be provided for estimating the changes in carbon stock associated with peat extraction ($\Delta C_{WW_{Soils,\ extraction}}$), that are essentially emissions caused by enhanced oxidation of soil organic matter at the production fields. Emissions from peat stockpiles and restoration operations are much less well understood. Higher temperatures may cause stockpiles to release more CO_2 than the excavation field, but data are not at present sufficient to provide guidance. Countries may develop national methods for estimating the other terms in equation 3a.3.5 at higher tiers, which could also account for the effect of peatlands restoration and the dynamics which lead to higher emissions immediately after drainage compared with the period during which peat is being removed.

Choice of method

The Tier 1 method relies on basic area identification and default emission factors, while the Tier 2 method is disaggregated to smaller spatial scales and uses country-specific emission factors where available. Given the current state of the science, few countries will use Tier 3 methods, and so only the main elements for a Tier 3 method are described.

Tier 1: Tier 1 estimates only emissions directly associated with the change in soil carbon during peat extraction (fugitive emissions from the production fields). The emissions from the peat extracted are covered by the emissions from peat combustion which are reported in the Energy Sector. In Tier 1, Equation 3a.3.6 is applied at an aggregate level to a country's area of organic soils managed for peat extraction, using default emission factors.

EQUATION 3a.3.6
CO_2 EMISSIONS FROM ORGANIC SOILS MANAGED FOR PEAT EXTRACTION

$$\Delta C_{WW\ peat_{Soils,\ extraction}} = A_{peat\ Nrich} \bullet EF_{peat\ Nrich} + A_{peat\ Npoor} \bullet EF_{peat\ Npoor}$$

Where:

$\Delta C_{WW\ peat\ Soils,\ extraction}$ = CO_2 emission from organic soils managed for peat extraction expressed as carbon, tonnes C yr^{-1}

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

$A_{peat\ Npoor}$ = area of nutrient poor organic soils managed for peat extraction, including abandoned areas in which drainage is still present, ha

$EF_{peat\ Nrich}$ = emission factors for CO_2 from nutrient rich organic soils managed for peat extraction, tonnes C ha^{-1} yr^{-1}

$EF_{peat_{Npoor}}$ = emission factors for CO_2 from nutrient poor organic soils managed for peat extraction, tonnes C ha^{-1} yr^{-1}

Tier 2: The Tier 2 method can be applied if area data and country-specific emission factors are available. It may be possible to subdivide activity data and emission factors according to soil fertility, site type and drainage level, and previous land use such as forest or cropland. Emission factors for sub-categories such as peat stockpiles, drained and restored peatlands could also be included. In addition, it may be possible to develop emission factors that reflect differences in emission levels between the period directly after drainage and the period of ongoing peat extraction.

Tier 3: Tier 3 methods would require statistics on the area of organic soils managed for peat extraction according to site type, fertility, time since drainage, time since restoration, which could be combined with appropriate emission factors, and or/process based models. Studies utilising information on changes in soil bulk density and carbon content could also be used to detect changes in soil carbon stocks provided the sampling was of sufficient intensity. Such data could also be used to develop appropriate emission factors for CO_2, correcting for carbon losses as dissolved organic carbon leaching, losses of dead organic matter through runoff or as CH_4 emissions.

Choice of emission factors

Tier 1: Implementation of the Tier 1 method requires default emission factors for EF_{peat}. Default emission factors for Tier 1 are presented in Table 3a.3.2. These factors are identical to those provided in Table 3.5.2 (Emission factors and associated uncertainty for organic soils after drainage) to estimate CO_2 emissions associated with the drainage of land for peat extraction (a land conversion described in Section 3.5). Although it is recognised that emissions in the period immediately following drainage will be higher than those during ongoing peat extraction, there are currently no sufficient data to develop specific default emission factors for those activities. As noted above, under Tier 2, countries may be able to develop more disaggregated country-specific emission factors and differentiate between emission rates during land conversion to peat land and the ongoing fugitive emissions during peat extraction.

TABLE 3A.3.2
EMISSION FACTORS FOR CO_2-C AND ASSOCIATED UNCERTAINTY FOR ORGANIC SOILS AFTER DRAINAGE

Region/Peat Type	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_{Npoor}	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_{Nrich}	1.1	0.03 to 2.9	Laine *et al.*, 1996; LUSTRA, 2002; Minkkinen *et al.*, 2002; Sundh *et al.*, 2000
Tropical			
EF	2.0	0.06 to 6.0	Calculated from the relative difference between temperate (nutrient poor) and tropical in Table 3.3.5.

[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 Europe.

Nutrient-poor bogs predominate in boreal regions, whilst in temperate regions, nutrient-rich fens and mires are more common. 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. The uncertainty values come from a lognormal distribution and represent a 95% confidence interval.

Tiers 2 and Tier 3: Tiers 2 and 3 require country-specific data that accounts for management practices such as drainage of different peat types. The literature is sparse and results sometimes contrasting. Countries are encouraged to derive country-specific emission factors by measurements against appropriate reference virgin sites. Data should be shared between countries with similar environmental conditions.

Choice of activity data

Tier 1: The activity data required for all tiers is the area of organic soil managed for peat extraction. Ideally, under Tier 1 countries will obtain national data on the area of peat extraction. In boreal and temperate regions, these area data need to be disaggregated by soil fertility to correspond to the default emission factors presented in Table 3a.3.2. Possible sources of such data are national statistics, peat mining companies and government ministries responsible for land use. Peat extraction area can also be estimated using statistics on peat production for fuel and horticultural use if the national average extraction rate is known. If this rate is unavailable it can be roughly assumed that the extraction rate is 0.04 million m^3/km^2 or 0.016 million t/km^2.

If neither of these approaches is possible, default data on areas in peat can be obtained from estimates in the literature. Data on organic soils areas for other countries and an estimate of the proportion of tropical versus temperate and boreal peatlands are available from Table 1 in Andriesse (1988). Table 3a.3.3 provides rough estimates of the drainage of wetlands at the continental scale. These data do not necessarily apply to organic soils and do not distinguish site type. However they can be regarded as a first crude estimate of land use on peatlands where more detailed data are unavailable. Additional data on peatland areas can be obtained from the following: Andriesse (1988), Lappalainen (1996), OECD/IUCN (1996), Tarnocai, *et al.*. (2000), Umeda and Inoue (1996), Xuehui and Yan (1996). Other sources of data are http://www.worldenergy.org/wec-geis/publications/reports /ser/peat/peat.asp and http://www.wetlands.org.

Tiers 2 and 3: Countries should assess the total area of organic soils managed for peat extraction including abandoned areas on which drainage or the effects of former peat extraction are still present to the level of disaggregation required by the tier calculation or the modelling approach being used. If possible, countries are encouraged to collect data on the areas of fens versus bogs and drainage level to enable the use of more disaggregated default emission factors or country-specific factors. If restoration is underway, countries are encouraged to report separately the areas of restored organic soils formerly managed for peat extraction and estimate emissions from peat extraction lands.

TABLE 3a.3.3
ESTIMATES OF PEATLAND AREAS AND USE FOR TIER 1 IN 1000 HECTARES

Country or region	Peatland area total (Unmanaged + managed) 1000 ha	Agriculture, drained (Cropland + grassland) 1000 ha	Managed forest, drained1000 ha	Peat extraction (Industrial peatlands) 1000 ha [a]	% in tropics[b]	Reference
Europe	**95695**	**(56-65% of wetlands drained for agriculture and forestry)**			**0**	**1, 9**
Belarus	2939	900	(small)	109	0	1, 2
Denmark	142	140	(small)	1.2	0	1, 2
Estonia	1009	130	320	258	0	1, 2
Finland	8920	350	3540	53	0	1, 2, 3
France	100	55	(small)	(small)	0	1, 2
Germany	1420	210	(small)	32	0	1, 2
Great Britain	1754	500	500	5.4	0	1, 2
Hungary	100	80	0	0.2	0	1, 2
Iceland	1000	120	(small)		0	1, 2
Ireland	1176	90	45	82	0	1, 2
Italy	120	30		(small)	0	1, 2
Latvia	669	160	50	27	0	1, 2
Lithuania	352	25	190	36	0	1, 2
Netherlands	279	250	(small)	3.6	0	1, 2
Norway	2370	190	280	2.5	0	1, 2
Poland	1255	760	370	2.5	0	1, 2
Slovenia	100	30	0	(small)	0	1, 2
Sweden	10379	300	524	12	0	1, 2
Ukraine	1008			19	0	1, 2

TABLE 3A.3.3 (CONTINUED)
ESTIMATES OF PEATLAND AREAS AND USE FOR TIER 1 IN 1000 HECTARES

Country or region	Peatland area total (Unmanaged + managed) 1000 ha	Agriculture, drained (Cropland + grassland) 1000 ha	Managed forest, drained 1000 ha	Peat extraction (Industrial peatlands) 1000 ha [a]	% in tropics[b]	Reference
Asia	**24446**	**(27% of wetlands drained for agriculture and forestry, increasing)**				**4b, 9**
Burma	965				100	4
China	1044-3480	135		104	30	4b, 5
Indonesia	17000-27000	400		3.6 (fuel only)	100	4
Iraq	1790				100	4
Japan	201				0	4b, 6
Malaysia	2250-2730	500			100	4b
Papua New Guinea	685				100	4b
Phillipines	104-240				100	4b
Russia	39000-76000	700	2500	9120	0	1, 2
South Korea	630				0	4b
New Zealand	165				30	8
Africa	**5840**	**(2% of wetlands drained for agriculture and forestry)**				**4a, 11**
Guinea	525				100	4a
Nigeria	700				100	4a
South Africa	950				100	4a
Uganda	1420				100	4a
Zambia	1106				100	4a
North America	**173500**	**(56-65% of wetlands drained for agriculture and forestry)**				**4c, 9**
Canada[c]	111328	25	100	16	0	7
USA Alaska: S of 49°N:	 49400 10240				 0 2.5	8
Central and South America	**11222**	**(6% of wetlands drained for agriculture and forestry)**				**4c, 9**
Brazil	1500-3500				100	4c
Chile	1047				10	4c
Cuba	658				100	4c
Guyana	814				100	4c
Honduras	453				100	4c
Mexico	1000				100	4c
Nicaragua	371				100	4c
Venezuela	1000				100	4c

References: 1 Lappalainen (1996), 2 European wetlands inventory review, draft national reports (http://www.wetlands.org), 3 national inventory, 4a-c Lappalainen and Zurek (1996), 5 Xuehui and Yan (1996), 6 Umeda and Inoue (1996), 7 Tarnocai, *et al.* (2000), 8 Andriesse (1988), 9 OECD/IUCN (1996)

[a] Peat extraction for fuel: http://www.worldenergy.org/wec-geis/publications/reports/ser/peat/peat.asp

[b] Andriesse (1988); The definition for tropics used by Andriesse (1988) is broader than the commonly used area between the between the Tropic of Cancer (25° N) and the Tropic of Capricorn (25° S). Using this definition, e.g. land areas of New Zealand and Iraq would not be classified as tropical.

[c] Total area affected by hydroelectric reservoir construction estimated to exceed 9000km^2.

3A.3.2.1.2.2 Uncertainty Assessment

Tier 1: The key uncertainties in Tier 1 are the default emission factors and area estimates. Emission factors and parameters have been developed from only a few (less than 10) data points, 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. Countries are encouraged to use the range rather than the standard deviation.

The area of drained peatlands may have an uncertainty of 50% in Europe and North America, but may be a factor of 2 in the rest of the world. Uncertainty in Southeast Asia is extremely high and the peatlands are under particular pressure, mainly because of urbanisation and intensification of agriculture and forestry, and possibly also for peat extraction.

Tier 2: Countries with significant areas of organic soils managed for peat extraction that use a Tier 2 method are encouraged to provide an assessment of total uncertainty (see Chapter 5, Section 5.2, Identifying and Quantifying Uncertainties of this report) for all significant contributions to the emissions (drainage / rewetting, area, country-specific parameters).

Tier 3: Process-based models will in principle provide more realistic estimates but need to be calibrated and validated against measurements. Generic guidance on uncertainty assessment for advanced methods is given in Chapter 5 (Section 5.2 Identifying and Quantifying Uncertainties) of this report. Since drainage of peatlands leads to peat compaction and oxidation the stock change approach to monitor CO_2 fluxes can be imprecise. If used, it should be calibrated with appropriate flux measurements.

3a.3.2.2 N_2O EMISSIONS FROM DRAINED PEATLAND

3a.3.2.2.1 Methodological Issues

The method for estimating N_2O emissions from drained peatlands is shown in the equation below.

EQUATION 3a.3.7
N_2O EMISSIONS FROM DRAINED WETLANDS

$$\text{Direct } N_2O \text{ emissions}_{WW\,peat} = (A_{peat_{Nrich}} \bullet EF_{peat\,Nrich} + A_{peat\,Npoor} \bullet EF_{peat\,Npoor}) \bullet 44/28 \bullet 10^{-6}$$

Where:

N_2O emissions$_{WW\,peat}$ = emissions of N_2O, Gg N_2O yr^{-1}

$A_{peat_{Nrich}}$ = area of drained nutrient rich organic soils, ha

$A_{peat_{Npoor}}$ = area of drained nutrient poor organic soils, ha

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

$EF_{peat\,Npoor}$ = emission factor for drained nutrient poor organic soils, kg N_2O-N ha^{-1} yr^{-1}

Choice of method

Tier 1: The Tier 1 method for estimating N_2O emissions from drained wetlands is similar to that described for drained agricultural soils in the *IPCC Guidelines*, and for drained forest soils (Appendix 3a.2 Non-CO_2 emissions from drainage and rewetting of forest soils: Basis for future methodological development) and is shown in Equation 3a.3.7. The area of drainage (disaggregated as appropriate) is multiplied by a corresponding emission factor. As with drained forest lands, under the Tier 1 method, the default factors for temperate and boreal lands are provided for nutrient poor and nutrient rich soils. As only a single emission factor is provided for tropical regions, it is not necessary to disaggregate by soil fertility in this case.

Tier 2: Under Tier 2, land area is disaggregated by additional factors such as fertility, site type and drainage level and disaggregated country-specific emission factors are used.

Tier 3: Process-based models will in principle provide a more realistic estimate but need to be calibrated and validated against measurements. Sufficient representative measurements are needed for validation purposes. Generic guidance on uncertainty assessment for advanced methods is given in Section 5.2, Identifying and Quantifying Uncertainties.

Choice of emission/removal factors

Tier 1: Default emission factors for the Tier 1 method are provided in Table 3a.3.4.

TABLE 3a.3.4
DEFAULT EMISSION FACTORS FOR N_2O EMISSIONS FROM WETLANDS

Climate Zone and Soil Type	Emission Factor $EF_{2\ peat}$ 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	0.1	0 to 0.3	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	18	2 to 25	The value for tropical areas is calculated from the relative difference between temperate and tropical in Chapter 4 of the *IPCC Guidelines* and GPG2000. The same approach was used in Table 3.2.2 and the orders of magnitude are similar.

* The uncertainty values come from a lognormal distribution and represent a 95% confidence interval.

Tier 2: Tier 2 integrates country-specific data, if available, especially data that accounts for management practices such as drainage of different peat types. Since literature is sparse and results sometimes contrasting, countries are encouraged to derive country-specific emission factors by measurements against appropriate reference virgin sites. Specific guidance on how to derive country-specific emission factors for N_2O is given in Box 4.1.of *GPG2000* (page 4.62).

Tier 3: Tier 3 incorporates models that should be validated against measurements. The suitability to country-specific conditions should be proven.

Choice of activity data

The same activity data should be used for estimating CO_2 and N_2O emissions from organic soils managed for peat extraction, and information on obtaining these data is provided in Section 3a.3.3.3.1 above. For countries in boreal and temperate regions using the Tier 1 method, area data should be stratified by soil fertility, since the default values are provided for nutrient rich and nutrient poor soils. National data should be available from soil services and from wetland surveys, e.g., for international conventions. If it is not possible to stratify by peat fertility, countries may rely on expert judgement. Boreal climates tend to promote nutrient-poor raised bogs, while temperate and oceanic climates tend to promote the formation of nutrient-richer peatlands.

Further stratification may be possible under Tier 2. For example, area could also be distinguished by management practices such as drainage of different peat types, fertility (e.g., bog versus fen, nitrogen status), and tree type. Chapter 2 provides guidance on the approaches available to classify land area.

Tier 3 may require additional, possibly geo-referenced, information about soil properties, management and climate conditions depending on the input to models or other sophisticated methodologies.

3a.3.2.2.2 Uncertainty assessment

Tier 1: The default emission factors of Tier 1 are based on fewer than 20 paired data sets from a limited number of studies with geographical focus on Europe. For these reasons, they should be considered highly uncertain. The standard deviation of the emission factors easily exceeds 100% of the mean, but underlying probability functions are likely to be non-normal. Therefore, both the standard deviation of the mean and the range of the underlying data are given below. Given the preliminary nature of the underlying data, countries are encouraged to use the range rather than the standard deviation. Uncertainties for the default emission factors for $EF2_{WW}$ in Tier 1 are given in Table 3a.3.4.

The uncertainty in the area of peatlands and its division between nutrient-poor (ombrotrophic, bogs) and nutrient-rich (minerotrophic, fens) peat types is best calculated by a country-specific assessment of uncertainties. Present estimates of areas of drained and rewetted forest peatlands within a country vary in a wide range between different data sources and may have an uncertainty of 50% or more.

Tier 2: Where country-specific emission factors are used, the uncertainty should be calculated as part of the process of developing the factors. Guidance in derivation of country-specific emission factors is described in Box 4.1, *Good Practice* in Derivation of Country-Specific Emission Factors, *GPG2000*.

The area of peatlands and its division between nutrient-poor and nutrient-rich peat types needs a country-specific assessment of uncertainties, which can be conducted by comparing various sources of data and applying different area statistics, e.g., in sensitivity or Monte Carlo analyses (Section 5.2, Identifying and Quantifying Uncertainties).

Tier 3: Process-based models will probably provide a more accurate estimate of emissions but they need to be calibrated and validated against measurements. Sufficiently representative measurements are needed for validation purposes. Generic guidance on uncertainty assessment is given in Section 5.2, Identifying and Quantifying Uncertainties.

3a.3.2.3 COMPLETENESS

A complete inventory should estimate emissions from all industrial peatlands including abandoned peat mining areas in which drainage is still active, and areas drained for future peat extraction.

3a.3.2.4 DEVELOPING A CONSISTENT TIME SERIES

General guidance on consistency in time series can be found in Section 5.6 (Time Series Consistency and Recalculations). The emission estimation method should be applied consistently to every year in the time series, at the same level of disaggregation. Moreover, when country-specific data are used, national inventories agency should use same measurements protocol (sampling strategy, method, etc.). If it is not possible to use the same method or measurement protocol throughout the time series, the guidance on recalculation in Chapter 5 should be followed. The area of organic soils managed for peat extraction may need to be interpolated for longer time series or trends. Consistency checks should be made (i.e., by contacting peat-mining companies), to gather temporal information about areas affected by former or future peat extraction, and differences in emissions between inventory years should be explained, e.g., by demonstrating changes in areas of industrial peatlands or by updated emission factors. Differences in emissions between inventory years should be explained, e.g., by demonstrating changes in areas of peatlands or by updated emission factors.

3a.3.2.5 REPORTING AND DOCUMENTATION

It is appropriate to document and archive all information required to produce the national emissions/removals inventory estimates as outlined in Chapter 5 of this report subject to the following specific considerations. Emissions from land managed for peat extraction are not explicitly mentioned in the *IPCC Guidelines* but correspond in aggregate to the IPCC category 5E “Other”.

Emission factors: Since the literature data are so sparse, 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 companies dealing with peat extraction. 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.

Emission results: 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.

3a.3.2.6 INVENTORY QA/QC

Quality assurance/quality control (QA/QC) checks should be implemented as outlined in Chapter 5 (Section 5.5) of this report. Additional quality control checks as outlined in Tier 2 procedures in Chapter 8, QA/QC, of *GPG2000*, and quality assurance procedures may also be applicable, 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 cross-check 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 data from other countries;
- Checking the plausibility of estimates by cross-referencing areas of organic soils managed for peat extraction with data of peat industries and peat production.

3a.3.3 Flooded Land Remaining Flooded Land

Flooded lands are defined as water bodies regulated by human activities for energy production, irrigation, navigation, recreation, etc., and where substantial changes in water area due to water level regulation occur. Regulated lakes and rivers, where the main pre-flooded ecosystem was a natural lake or river, are not considered as flooded lands. Rice paddies are addressed in the Agriculture chapter of the *IPCC Guidelines* and *GPG 2000.*

There is little statistical evidence to suggest that greenhouse gas emissions from flooded lands vary with time (Duchemin *et al.*, 1999; Duchemin, 2000; Duchemin *et al.*, 2000 and 2002a; Keller and Stallard, 1994), although recent studies suggest that CO_2 emissions for the first ten years after flooding are as a result of decay of organic matter on the land prior to flooding, whereas subsequent CO_2 emissions are from material transferred into the flooded area (S. Houel, 2002; Hélie, 2003). If this is true, then the CO_2 emissions attributed to flooding alone would be limited to approximately 10 years.

This section provides preliminary information on how to estimate emissions of CO_2, CH_4 and N_2O from flooded lands. This information is drawn from available literature and may be useful to countries that want to begin estimating emissions from this source. Due to the close linkage between CO_2, CH_4 and N_2O emissions and methodologies, all three gas species are addressed in this section and no distinction for emissions from flooded land is made based on the age of the reservoir. The emissions from changes in living aboveground biomass due the conversion to flooded land are addressed in Section 3.5.2.2.

3a.3.3.1 METHODOLOGICAL ISSUES

Greenhouse gas emissions from flooded lands can occur via the following pathways after flooding has occurred:

- Molecular diffusion across the air-water interface for CO_2, CH_4 and N_2O (diffusive emissions);
- Bubbles of CH_4 from the sediment through the water column (bubble emissions);
- Emissions resulting from the water passing through a turbine and/or through the spillway and turbulence downstream (degassing emissions); and
- Emissions from decay of above-water biomass[1].

The first two pathways – diffusive emissions and bubble emissions – are estimated in the Tier 1 method. For hydroelectric reservoirs, degassing emissions, which are caused by an increase in dissolved CO_2 and CH_4 in the water due to flooding and are released to the atmosphere when water is passing through the turbine or over the spillway (Galy-Lacaux and al., 1997), can be included in Tier 2 if data are available.. In tropical regions, emissions from the decay of above-water biomass can be an important pathway (Fearnside, 2002) and related emissions can be estimated at Tier 3. CO_2 and CH_4 emissions from reservoirs are affected by season. In boreal and temperate regions CO_2 and CH_4 will be accumulated under ice and release at break-up (Duchemin, 2000).

CHOICE OF METHOD

The following discussion describes how to estimate emissions from reservoirs under various tiers, with increasing level of accuracy associated with higher tier methods. Within the discussion of particular tiers, specific issues related to estimating emissions of CO_2, CH_4 and N_2O are covered.

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[1] Above-water biomass is the biomass in trees not submerged by the flooding, especially located in shallow flooded zones (Fearnside, 2002)

Tier 1

The Tier 1 approach provides a simplified approach to estimating greenhouse gas emissions from reservoirs using default emission data and highly aggregated area data. Unless otherwise indicated the area used in Tier 1 calculations is the flooded total surface area, which includes any areas covered with water before the flooding, because area data *minus* these previously flooded areas are generally not available.

CO_2 emissions

The method in Section 3.5.2.2 to estimate the carbon stock change in aboveground living biomass due to land conversion to flooded land assumes that all aboveground biomass is converted into CO_2 in the first year following the conversion. In actuality, the part of the above-ground biomass that is left on site before flooding will decompose more slowly. Decay of soil carbon will also contribute to the emissions and a Tier 1 method for these CO_2 emissions is shown in Equation 3a.3.8:

EQUATION 3a.3.8
CO_2 EMISSIONS FROM FLOODED LANDS (TIER 1)

$$CO_2\ emissions_{WW\ flood} = P \bullet E(CO_2)_{diff} \bullet A_{flood,\ total\ surface}$$

Where:

$CO_2\ emissions_{WW\ flood}$ = total CO_2 emissions from flooded lands, Gg CO_2 yr^{-1}

P = period, days (usually 365 for annual inventory estimates)

$E(CO_2)_{diff}$ = averaged daily diffusive emissions, Gg CO_2 ha^{-1} day^{-1}

$A_{flood,\ total\ surface}$ = total flooded surface area, including flooded land, flooded lake and flooded river surface area, ha

The CO_2 estimation method is simple – the only emission pathway that is estimated under Tier 1 is diffusion emission during ice-free and ice-cover periods. CO_2 bubble emissions are not significant. The default assumption is that the CO_2 emissions would be limited to approximately 10 years after the flooding took place.

The CO_2 emissions estimated with the equation 3a.3.8 are highly uncertain and will depend on the site-specific conditions (soil type in particular). The use of the Equation 3a.3.8 may also lead to overestimation of the emissions when used together with the Equation 3.5.6 in Section 3.5.2.2. If countries use a Tier 2 method they can more accurately represent the proper time profile of the CO_2 emissions following flooding. Guidance on Tier 2 methods is given below.

CH_4 emissions

The Tier 1 method for estimating CH_4 emissions from flooded lands includes the diffusion and bubble pathways (Equation 3a.3.9):

EQUATION 3a.3.9
CH_4 EMISSIONS FROM FLOODED LANDS (TIER 1)

$$CH_4\ emissions_{WW\ flood} = P \bullet E(CH_4)_{diff} \bullet A_{flood,\ total\ surface} + P \bullet E(CH_4)_{bubble} \bullet A_{flood,\ total\ surface}$$

Where:

$CH_4\ emissions_{WW\ flood}$ = total CH_4 emissions from flooded land, Gg CH_4 yr^{-1}

P = period, days (usually 365 for annual inventory estimates)

$E(CH_4)_{diff}$ = averaged daily diffusive emissions, Gg CH_4 ha^{-1} day^{-1}

$E(CH_4)_{bubble}$ = averaged bubbles emissions, Gg CH_4 ha^{-1} day^{-1}

$A_{flood,\ total\ surface}$ = total flooded surface area, including flooded land, flooded lake and flooded river surface area, ha

N_2O emissions

The Tier 1 method for estimating N_2O emissions from flooded lands includes the diffusion pathway only. N_2O emissions via the bubble pathway are not significant (Equation 3a.3.10):

EQUATION 3a.3.10
N_2O EMISSIONS FROM FLOODED LANDS (TIER 1)

$$N_2O\ emissions_{ww\ flood} = P \bullet E(N_2O)_{diff} \bullet A_{flood,\ total\ surface}$$

Where:

$N_2O\ emissions_{WW\ flood}$ = total N_2O emissions from flooded land, Gg N_2O yr^{-1}

P = period, days (usually 365 for annual inventory estimates)

$E_f(N_2O)_{diff}$ = averaged daily diffusive emissions, Gg N_2O ha^{-1} day^{-1}

$A_{flood,\ surface}$ = total flooded surface area, including flooded land, flooded lake and flooded river surface area, ha

Tier 2

CO_2 emissions

In Tier 2, CO_2 emissions can be estimated from reservoirs following the approach shown in Equation 3a.3.11. The CO_2 emissions from flooded lands should be estimated only for ten years after flooding when using Tier 2 or 3 methods unless country-specific research indicates otherwise.

Depending on the amount of data available, both diffusive and degassing emissions can be estimated when using a Tier 2 approach. For the estimation of diffusive emissions, default emission factors can be used or country-specific factors can be developed. For estimation of degassing emissions, country-specific factors are necessary. The estimation of diffusion emissions can also be extended to distinguish between periods in which the reservoirs are ice-free and those in which they are ice-covered. This may be a significant improvement in accuracy for countries in colder climates. Flooded land surface area rather than total flooded area data can be used, depending on data availability. The flooded land area may be further disaggregated by climatic zone.

EQUATION 3a.3.11
CO_2 EMISSIONS FROM FLOODED LANDS (TIER 2)

$$CO_2\ emissions_{WW\ flood} = (P_f \bullet E_f(CO_2)_{diff} \bullet A_{flood,land}) + (P_i \bullet E_i(CO_2)_{diff} \bullet A_{flood,\ land}) + (([CO_2]_{diss} - [CO_2]_{equ}) \bullet Outflow \bullet 10^{-6}) + (([CO_2]_{spillway} - [CO_2]_{equ}) \bullet Spillway \bullet 10^{-6})$$

Where:

$CO_2\ emissions_{WW\ flood}$ = total CO_2 emissions from flooded land, Gg CO_2 yr^{-1}

P_f = ice-free period, days

P_i = period with ice cover, days

$E_f(CO_2)_{diff}$ = averaged daily diffusive emissions from air water-interface during the ice-free period, Gg CO_2 ha^{-1} day^{-1}

$E_i(CO_2)_i$ = diffusive emissions related to the ice-cover period, Gg CO_2 ha^{-1} day^{-1}

$A_{flood,\ land}$ = flooded land area, ha

$[CO_2]_{diss}$ = averaged concentrations of CO_2 before the turbines (water intake depth), kg l^{-1}

$[CO_2]_{equ}$ = averaged concentrations of CO_2 dissolved gases downstream of the dam or at equilibrium with the atmosphere, kg l^{-1}

$[CO_2]_{spillway}$ = averaged concentrations of CO_2 before the spillway (water intake depth), kg l^{-1}

Outflow = the averaged annual outflow rate in litres at the turbines, per hydroelectric reservoir, l yr^{-1}

Spillway = the averaged annual outflow rate in litres at the spillway, per hydroelectric reservoir, l yr^{-1}

CH_4 emissions

Tier 2 can extend the Tier 1 method by replacing default values with country-specific emission factors, by accounting for differences in diffusion and bubble emissions during periods when reservoirs are ice-free or ice-covered (for countries in the "boreal, wet" climate zone), by including (if data are available) degassing emissions from outflows and spillways (mostly hydroelectric reservoirs), and by correcting area estimates to flooded land area. Flooded land area may also be disaggregated by climatic zone. Tier 2 is described in Equation 3a.3.12:

EQUATION 3a.3.12
CH_4 EMISSIONS FROM FLOODED LANDS (TIER 2)

$$CH_4\ emissions_{WW\ flood} = (P_f \bullet E(CH_4)_{diff} \bullet A_{flood,\ land}) + (P_f \bullet E(CH_4)_b \bullet A_{flood,\ land}) + P_i \bullet (Ei(CH_4)_{diff} + Ei(CH_4)_{bubble}) \bullet A_{flood,\ land} + (([CH_4]_{diss} - [CH_4]_{equ.}) \bullet Outflow \bullet 10^{-6}) + (([CH_4]_{spillway} - [CH_4]_{equ}) \bullet Spillway \bullet 10^{-6})$$

Where:

$CH_4\ emissions_{WW\ flood}$ = total CH_4 emissions from flooded lands per year, Gg CH_4 yr^{-1}

P_f = ice-free period, days

P_i = period with ice cover, days

$E(CH_4)_{diff}$ = averaged daily diffusive emissions from air water-interface, Gg CH_4 ha^{-1} day^{-1}

$E(CH_4)_{bubble}$ = averaged bubbles emissions from air water-interface, Gg CH_4 ha^{-1} day^{-1}

$A_{flood,\ land}$ = flooded land area, ha

$[CH_4]_{diss}$ = averaged concentrations of CH_4 before the turbines (water intake depth), kg l^{-1}

$[CH_4]_{equ.}$ = averaged concentrations of CH_4 dissolved gases downstream of the dam or at equilibrium with the atmosphere, kg l^{-1}

$[CH_4]_{spillway}$ = averaged concentrations of CH_4 before the spillway (water intake depth), kg l^{-1}

Outflow = the averaged annual outflow rate in litre at the turbines, per hydroelectric reservoir, l yr^{-1}

Spillway = the averaged annual outflow rate in litre at the spillway, per hydroelectric reservoir, l yr^{-1}

N_2O emissions

The Tier 2 method for estimating N_2O emissions from flooded lands is the same as shown in Equation 3a.3.10, except that country-specific emission factors can be used, and (where data are available) flooded land surface area should be used rather than total flooded surface area.

Tier 3

The Tier 3 methods for estimating emissions of all gases are more comprehensive and can include additional country-specific data, such as emissions from above-water biomass. Tier 3 requires partitioning between emissions from the degradation of flooded organic matter and from the decay of organic matter that comes from the watershed.

CHOICE OF EMISSION FACTORS

The key default values needed to implement Tier 1 method are emission factors for CO_2, CH_4 and N_2O via the diffusion pathways, and an emission factor for CH_4 via the bubbles pathways. Table 3a.3.5 provides default emission factors for various climate zones that can be used under Tier 1. These default emission factors integrate some spatial and temporal variations in the emissions from reservoirs, as well as fluxes at the water-air interface of reservoirs. All default data have been obtained from measurements in hydroelectric or flood control reservoirs. The emissions factors for the ice-free period should be used in Tier 1 for the entire year.

For Tier 2, in addition to the above factors, data on CH_4 concentrations at various points upstream and downstream of the dam are needed to estimates degassing emissions. Country-specific emissions should be used instead of default factors to the extent possible. It is anticipated that a mix of default values and country-specific emission factors will be used when the latter do not cover the full range of environmental and management conditions. The development of country-specific emission factors is discussed in Box 3a.3.1. The derivation of country-specific factors should be clearly documented, and ideally published in peer reviewed literature. Guidance in Box 3a.3.1 is applicable also for derivation of emission factors for Tier 3.

TABLE 3A.3.5
DEFAULT EMISSIONS FACTORS FOR RESERVOIRS

Climate	Diffusive emissions (ice-free period) $E_f(GHG)_{diff}$ (kg ha^{-1} d^{-1})			References
	CH_4	CO_2	N_2O	
Boreal, wet	0.11 ± 88%	15.5 ±56%	0.008 ±300%	Duchemin, 2000; Huttunen *et al.*, 2002; Schlellhase, 1994, Duchemin *et al.*, 1999
Cold temperate, wet	0.2 ±55%	9.3 ±55%	nm	Duchemin, 2000; Duchemin 2002a, St-Louis *et al.*, 2000; Smith and Lewis, 1992
Warm temperate, dry	0.063 ± 0.032	-3.1 ±3.6	nm	Duchemin 2002b
Warm Temperate, wet	0.096 ±0.074	13.2 ±6.9	nm	Duchemin 2002b
Tropical, wet	0.64 ±330%	60.4 ±145%	0.05 ±100%	Keller et Stallard, 1994; Galy-Lacaux *et al.*, 1997; Duchemin *et al.*, 2000; Pinguelli Rosa *et al.*, 2002
Tropical, moist-long dry season	0.31 ±190%	11.65 ±260%	nm	Pinguelli Rosa *et al.*, 2002; Dos Santos, 2000
Tropical, moist-short dry season	0.44 ±465%	35.1 ±290%	nm	Pinguelli Rosa *et al.*, 2002; Dos Santos, 2000
Tropical, dry	0.3 ±115%	58.7 ±270%	nm	Pinguelli Rosa *et al.*, 2002; Dos Santos, 2000
	Bubbles emissions (ice-free period) $E_f(GHG)_{bubble}$ (kg ha^{-1} d^{-1})			
Boreal, wet	0.29 ±160%	ns	ns	Duchemin, 2000, Huttunen *et al.*, 2002; Schlellhase, 1994
Cold temperate, wet	0.14 ±70%	ns	ns	Duchemin, 2002a; St-Louis *et al.*, 2000; Smith and Lewis, 1992
Tropical, wet	2.83 ±45%	ns	ns	Galy-Lacaux *et al.*, 1997; Duchemin *et al.*, 2000; Pinguelli Rosa *et al.*, 2002
Tropical, moist-long dry season	1.9 ±155%	ns	ns	Pinguelli Rosa *et al.*, 2002
Tropical, moist-short dry season	0.13 ±135%	ns	ns	Pinguelli Rosa *et al.*, 2002
Tropical, dry	0.3 ±324%	ns	ns	Pinguelli Rosa *et al.*, 2002
	Emissions associated with the ice cover period $E_i(GHG)_{diff} + E_i(GHG)_{bubble}$ (kg ha^{-1} d^{-1})			
Boreal, wet	0.05 ±60%	0.45 ±55%	nm	Duchemin, 2000; Duchemin *et al.*, 2002a
ns : not significant, nm: not measured				

CHOICE OF ACTIVITY DATA

Several different types of activity data may be needed to estimate flooded land emissions, depending on the tier being implemented and the climatic zone. For Tier 1, total flooded area is required in all cases. For Tier 2, additional activity data includes the period during which reservoirs are ice-covered or ice-free in boreal wet regions as well as flow rates through hydroelectric outflow and spillways and flooded land area.

Flooded land area

Ideally, data on flooded area should be collected from national agencies. If such data are unavailable, however, Table 3a.3.6 contains information on total flooded surface area that can be used to estimate the emissions under Tier 1. This table only includes surface area of flooded land that existed before 1990.

For Tier 2, flooded land area is required to estimate diffusive and bubble emissions. These data can frequently be obtained from hydro utility companies. Alternatively, countries can obtain the flooded land area by a drainage basin cover analysis or by national dams database.

TABLE 3a.3.6 **DEFAULT RESERVOIR SURFACE AREA DATA**		
	ICOLD	**Specific-country data**
Country	**Surface area (Mha)**	**Surface area (Mha)**
Russia	7.32	7.96
USA	---	6.98
Canada	0	6.5
China	---	5.8
India	4.57	---
Brazil	0.69	3.98
Finland	0.73	---
Thailand	0.71	---
Egypt	0.70	---
Australia	0.66	---
Mexico	0.60	---
Zimbabwe	0.59	---
Venezuela	0.58	---
Turkey	0.56	---
Argentina	0.50	---
Ivory coast	0.29	---
New-Zealand	0.21	---
Malik *et al.*, 2000; US Army Corps Dams Database 1996; WCD, 2001; ICOLD 1998. Environment Canada Reservoir Database (Duchemin, 2002a); Dos Santos, 2000.		

Period of ice-free cover/Period of ice-cover

Under Tiers 2, and 3, the periods during which the reservoirs are ice-free or ice-covered are required to estimate diffusive and bubbles emissions of CH_4. These data can be obtained from national meteorological services or hydro utilitity companies.

Outflow/Spillway Volume

Under Tier 2, flooded land outflow and spillway volume are required to estimate degassing emissions of CH_4. These data can be obtained from hydro utility companies. Degassing fluxes are, mainly, a particularity of hydroelectric reservoirs.

Tier 3 has much more extensive data requirements which can support more complex modelling of emissions over time. Generally, this data can be compiled in a national reservoir inventory. The national reservoir inventory should cover all types of reservoirs and include data and/or information on reservoir names, types, surface area, depth, outflow rates, gas concentration before and after the turbines, climate conditions, water pH, geological basement, eco-region type, and geographical coordinates (Duchemin, 2000; Duchemin *et al.*, 1995; Tavares de lima, 2002; Duchemin *et al.*, 1999; Duchemin, 2002a).

CO_2 and CH_4 concentrations upstream and downstream of dams

Under Tiers 2 and 3, CH_4 concentrations upstream and downstream of dams would be needed for estimation of the degassing emissions. These data can be obtained as described by Fearnside (2002), Galy-Lacaux *et al.* (1997) and Duchemin (2002b).

BOX 3a.3.1
DERIVATION OF COUNTRY-SPECIFIC EMISSION FACTORS

In general, derivation of country-specific emission factors requires the measurement of emissions by individual sub-source category (i.e., flooded land surface area, flooded land age, management types, such as hydroelectric, agriculture, and water regulation). Emission levels vary widely between reservoirs depending upon factors such as: area, type of ecosystems flooded, reservoir depth and shape, local climate, geological basement the way in which the dam is operated, and ecological and physical characteristics of the dammed river basin. Emissions can also vary widely between different parts of the same reservoir (largely due to changes in depth, exposure to wind and sun, and growth of water plants), and from year to year, season to season, and even between night and day (Duchemin, 2000; Duchemin *et al.*, 1995; Tavares de lima, 2002; Duchemin *et al.*, 1999; Duchemin, 2002a).

For emission factors to be representative of environmental and management conditions within the country, measurements should be made in different flooded lands regions within a country, in all seasons, and if relevant, in different geographic regions and under different management regimes (Duchemin *et al.*, 1999, Duchemin *et al.*, 2002a). Appropriate selection of regions or regimes may enable a reduction in the number of sites that must be sampled to derive a reliable flux estimate. Maps, remote sensing data, or a dams database can provide a useful basis for delineation by utilising the variability of a system or landscape. Aggregation errors may occur if available measurements do not cover the actual range of environmental and flooded lands management conditions, and inter-annual climatic variability. Validated, calibrated, and well-documented simulation models may be a useful tool to develop area-average emission factors on the basis of measurement data (Duchemin, 2000).

Regarding measurement period and frequency, emission measurements should be taken over an entire year, and preferably over a series of years, in order to reflect differences in weather conditions, inter-annual climatic variability and flooded land evolution (Scott *et al.*, 1999; Duchemin, 2000; Tavares de Lima, 2002). A good description of the measurement techniques that are available can be found in Duchemin *et al.* (1995), Galy-Lacaux *et al.* (1997), Duchemin (2000), Fearnside (2002) and Duchemin et al (2002b).

To ensure accurate emission factors of diffusive and bubble emissions, representative sites for factors that may influence annual and inter-annual variability of the emissions, would need to be monitored. Such factors include depth and water level variation, water temperature, wind speed. Degassing emission factors may vary with water temperature, which should be measured upstream of turbines and downstream of dams so that the correlation can be established for higher tier methods.

The frequency of measurement should be consistent with the frequency of the factors that influence annual and inter-annual variability. Emissions are likely to be variable among geographic regions, especially among different eco-regions, climatic zones and geological basements.

In general, emission factors are determined by taking the mean of the emissions of representative sites. This averaging needs to consider the importance of each geographic zone and seasonal period for the country.

3a.3.3.2 UNCERTAINTY ASSESSMENT

The two largest sources of uncertainty in the estimation of greenhouse gas emissions from reservoirs are associated with the emission factors from the various pathways (diffusive, bubble and degassing) and to the reservoir surface area estimates.

Emission factors: Daily average diffusive emissions, derived from field measurements, vary by an order of magnitude for CH_4 and by a factor of 5 for CO_2 and N_2O (Table 3a.3.4). Furthermore, daily average bubble emissions of CH_4 vary by more than an order of magnitude. Use of default measurements for different reservoir types and in other regions will also result in uncertainty. Furthermore, most of the greenhouse gas flux measurements have been undertaken on hydroelectric reservoirs, so that other types of reservoirs are not included in the default emissions estimates.

Flooded land surface area: Information on the flooded area retained behind larger dams should be available and will probably be uncertain by no more than a few percent. However, information on the flooded land surface area may be more difficult to obtain and will probably be uncertain to more than a few percent, especially in countries without large dams or with only a few hydroelectric reservoirs. 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. In addition, reservoirs are created for variety of reasons that influence the availability of data.

3a.3.3.3 COMPLETENESS

A complete inventory should include all flooded lands. Maintaining a full area accounting, stratified by major climate and ecosystem zones and by purposes is encouraged.

3a.3.3.4 DEVELOPING A CONSISTENT TIME SERIES

General guidance on consistency in time series can be found in Section 5.6 (Time Series Consistency and Recalculation). The emission estimation method should be applied consistently to every year in the time series, at the same level of disaggregation. Moreover, when country-specific data are used, national inventories agency should use same measurements protocol (sampling strategy, method, etc.). If it is not possible to use the same method or measurement protocol throughout the time series, the guidance on recalculation presented in Chapter 5 should be followed. Differences in greenhouse gas emissions between inventory years should be explained, e.g., by demonstrating changes in areas of flooded lands or by updated emission factors. Consistency checks should be made (i.e., by contacting hydro utility companies) to gather temporal information about areas affected by former or future flooding.

3a.3.3.5 REPORTING AND DOCUMENTATION

It is appropriate to document and archive all information required to produce the national inventory estimates. It is suggested that the following additional information is particularly important to document for this source category:

Emission factors: The sources of the emission factors and parameters that were used (i.e., specific IPCC default values or otherwise) should be given. If country- or region-specific emission factors and parameters were used, and if new methods (other than IPCC default methods) were used, the scientific basis of these emission factors, parameters and models should be well- 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 and magnitudes of uncertainties.

Activity data: Sources of all activity data used in the calculations should be documented (i.e. complete citations for the statistical databases from which the data were collected, communication with companies dealing with reservoirs). In cases where activity data were not available directly from databases or multiple data sets were combined, the information, assumptions and procedures that were used to derive the activity data should be described. This documentation should include the frequency of data collection and estimation, and estimates of accuracy and precision.

Emission results: 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.

3a.3.3.6 INVENTORY QA/QC

It is appropriate to implement quality assurance/quality control (QA/QC) checks as outlined in Chapter 5 (Section 5.5) of this report, and to conduct expert review of the emission estimates. Given the shortage of data these reviews should be conducted regularly to take account of new research findings. Additional quality control checks as outlined in Tier 2 procedures in Chapter 8, QA/QC, of *GPG2000*, and quality assurance procedures may also be applicable, 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 cross-check emissions estimates from flooded lands through external measurements. However, the inventory agency should ensure that emission estimates undergo quality control by:

- Cross-referencing reported country-specific emissions factors with default values and data from other countries;

- Cross-referencing areas of flooded land with data of hydro utility companies, with the database of the International Commission on Large Dams, and with data submitted to national dams safety inventories.