Appendix 3a.2 Non-CO_2 Emissions from Drainage and Rewetting of Forest Soils: Basis for Future Methodological Development

3a.2.1 Introduction

The drainage and rewetting of organic soils and wet mineral soils with high contents of soil organic carbon affect emissions and removals of greenhouse gases. CO_2 is significantly affected, and methods for estimating changes in emissions/removals of CO_2 from these lands are discussed in the sections dealing with organic soils in Sections 3.2 to 3.5.

In addition, intensively drained soils have large N_2O emissions because drainage increases the aerated layer and enhances the mineralisation of soil organic matter. In contrast, unmanaged organic soils are very small natural sources or sinks of N_2O (Regina et al., 1996). The effect of drainage on N_2O emissions depends upon soil characteristics; higher emissions are associated with minerotrophic (nutrient rich) and lower emissions with ombrotrophic (nutrient poor) peat types (Regina et al., 1996). Data on N_2O emissions from drained organic soils and wet mineral soils are relatively sparse and variable, so the uncertainty in the methods presented here is high.

In the following, the methodologies for N_2O emissions focus on forest land not addressed in the *IPCC Guidelines*. N_2O emission from drained cropland and grassland soils are covered in the Agriculture Chapter of the *IPCC Guidelines* and *GPG2000*. Given data availability and the current state of understanding, the same method can be used for forest land remaining forest land and lands converted to forest land.

Rewetting organic soils will reduce the N_2O emissions down to the original level around zero.

The CH_4 emitted from undrained organic soils is a natural process and the emissions are highly variable. Drainage of organic soils reduces these emissions and may even turn the area into a small CH_4 sink (see *IPCC Guidelines*, Reference Manual, Section 5.4.3, Wetland drainage). Methods for estimating the effect of drainage or rewetting of forests and wetlands on CH_4 emissions are not provided in the *IPCC Guidelines* nor in this report due to paucity of data although the magnitude of the effect, in terms of CO_2-equivalent, may be large in cases in which high CH_4 emitting areas are intensively drained. However, the effect of drainage on CH_4 may be small in cases a) with low natural CH_4 emissions, b) in which still a shallow water table is maintained, or c) in which the CH_4 sink in drained areas is compensated by CH_4 emissions from drainage ditches. A default value of zero emissions of CH_4 after drainage is used in this appendix (Laine et al., 1996; Roulet and Moore, 1995).

CH_4 emissions can increase in rewetted organic soils. “Rewetting” means the return of the water table to pre-drainage levels. If a country is rewetting organic soils, these soils are considered as managed. In this case, it is these drainage/rewetting effects that can be reported based on country-specific data. According to literature, the CH_4 source by rewetting organic soil covered by forest is estimated in a first approximation in a range of 0 to 60 kg CH_4 ha^{-1} yr^{-1} in temperate and boreal climate, and 280 to 1260 kg CH_4 ha^{-1} yr^{-1} in tropical conditions (Bartlett and Harriss 1993). There is some evidence that CH_4 emissions may still be smaller in rewetted peatlands than in the virgin state (Komulainen *et al*. 1998, Tuittila *et al*. 2000). At present, no good practice guidance can be given for CH_4 emissions from rewetting of organic soils.

3a.2.2 Methodological Issues

3a.2.2.1 Choice of method

The same method is applied for forest land remaining forest land (FF) and lands converted to forest land (LF). The decision trees presented in Section 3.1 (Figure 3.1.1 Decision tree for identification of appropriate tier-level for land remaining in the same land-use category and Figure 3.1.2 (Decision tree for identification of appropriate tier-level for land converted to another land-use category) can be used to identify the appropriate tier for the N_2O estimate, by considering the availability data. N_2O emissions from drainage and rewetting of forest soils contribute to the subcategory “soils” in the decision trees.

The basic method for estimating direct N_2O emissions from drained forest organic soils is shown in Equation 3a.2.1. N_2O emissions from rewetted forest organic soils are estimated to be at natural level, and the default is set as zero. The equation can be applied at various levels of disaggregation depending upon data availability, particularly with respect to the availability of country-specific emission factors.

EQUATION 3a.2.1
DIRECT N_2O EMISSIONS FROM DRAINED FOREST SOILS (TIER 1)

$$N_2O\ emissions_{FF} = \sum(A_{FF_{organic\ IJK}} \bullet EF_{FF_{drainage,\ organic\ IJK}}) + A_{FF_{mineral}} \bullet EF_{FF_{drainage,\ mineral}} \bullet 44/28 \bullet 10^{-6}$$

Where:

$N_2O\ emissions_{FF}$ = emission of N_2O in units of nitrogen, kg N

$A_{FF_{organic}}$ = area of drained forest organic soils, ha

$A_{FF_{mineral}}$ = area of drained forest mineral soils, ha

$EF_{FF_{drainage,\ organic}}$ = emission factor for drained forest organic soils, kg N_2O-N ha^{-1} yr^{-1}

$EF_{FF_{drainage,\ mineral}}$ = emission factor for drained forest mineral soils, kg N_2O-N ha^{-1} yr^{-1}

ijk = soil type, climate zone, intensity of drainage, etc. (depends on level of disaggregation)

The same method is applied to calculate N_2O emissions from drained organic soils of lands converted to forest.

Tier 1: In Tier 1 Equation 3a.2.1 is applied with a simple disaggregation of drained forest soils into “nutrient rich” and “nutrient poor” areas and default emission factors are used. Default data are presented in Section 3a.2.2.2 and guidance for obtaining activity data is described in Section 3a.2.2.3.

Tier 2: Tier 2 can be used if country-specific emission factors and corresponding area data are available. Typically, these data will enable the estimate to be disaggregated to account for management practices such as drainage of different peatland types, fertility (e.g., bog versus fen, nitrogen status), and tree type (broadleaved versus coniferous), with specific emission factors developed for each sub-class. Adequately disaggregated area data could be obtained from soil information in the national forest inventory.

Tier 3: If more complex models or detailed surveys are available, a national Tier 3 approach can be used to estimate N_2O emissions. Given the spatial and temporal variability and uncertainty in N_2O emissions, this type of approach is most warranted in a country in which direct N_2O emissions from managed forest are a key category because applying advanced methods could more accurately represent the management practices and the most relevant driving variables.

3a.2.2.2 CHOICE OF EMISSION/REMOVAL FACTORS

Where Tiers 1 and 2 are used, emission factors for N_2O emissions per unit area per year are needed.

Tier 1: Default emission factors derived from the literature are used in Tier 1, and these values are shown in Table 3a.2.1.

Due to the paucity of data, the default emission factors for the respective nutrient levels and climatic zones can be taken as indicative only and may not properly reflect the real magnitude of emissions in a given country.

Emissions from drained forest mineral soils should be calculated by using separate and lower emission factors than for drained forest organic soils. Emissions from drained forest mineral soils can be assumed as about a tenth of $EF_{drainage}$ for organic soils (Klemedtsson *et al*., 2002). More measurements, especially in tropical climate, are needed to improve the indicative emission factors of Table 3a.2.1. If drained forest is rewetted (i.e., the water table returns to pre-drainage levels) it is assumed that N_2O emissions return to the natural level close to zero.

Climate Zone and Soil Type	Emission Factor $EF_{FF_{drainage}}$ kg N_2O-N ha^{-1} yr^{-1}	Uncertainty range* kg N_2O-N ha^{-1} yr^{-1}	Reference/ Comments
Temperate and Boreal Climate			
Nutrient Poor Organic Soil	0.1	0.02 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	0.6	0.16 to 2.4	Klemedtsson *et al.*, 2002; Laine *et al.*, 1996; Martikainen *et al.*, 1995; Minkkinen et al., 2002: Regina *et al.*, 1996
Mineral Soil	0.06	0.02 to 0.24	Klemedtsson *et al.,* 2002
Tropical Climate	8	0 to 24	Estimated as half the factor of drained organic croplands

TABLE 3a.2.1
DEFAULT EMISSION FACTORS N_2O EMISSIONS FROM DRAINAGE OF FOREST SOILS

* 95% confidence interval of log-normal distribution

Tier 2: When country-specific data are available, in particular for different management regimes, specific emission factors can be defined in Tier 2. These country-specific emissions should be derived from surveys performed in the country or in comparable neighbouring countries and, if possible, disaggregated by drainage level, vegetation (broadleaved versus coniferous) and fertility of peat. Since literature is sparse and results sometimes contrasting, country-specific emission factors should be derived through a rigorous measurement programme. Good practice guidance on how to derive country-specific emission factors for N_2O emissions from soils is given in Box 4.1, Good Practice in Derivation of Country-Specific Emission Factors, Page 4.62, of *GPG2000*.

Tier 3: Under Tier 3, all parameters should be country-defined using more accurate values rather than the defaults. The literature is scarce and results sometimes contradictory and countries are therefore encouraged to derive country-specific emission factors by measurements against appropriate undrained forest sites as a reference. Data should be shared between countries with similar environmental conditions.

3a.2.2.3 CHOICE OF ACTIVITY DATA

The activity data needed to estimate this source is the area of drained and rewetted forest lands. In Tier 1, the national estimate of drained forest soils is stratified by soil fertility, since the default values are provided for nutrient rich and nutrient poor soils. National data will be available at soil services and from wetland surveys, e.g., for international conventions. In case no stratification by peat fertility is possible, 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, and tree types. Chapter 2 provides guidance on the approaches available to classify land area.

3a.2.2.4 UNCERTAINTY ASSESSMENT

Estimates of anthropogenic emissions of N_2O emissions from forests are highly uncertain because of: a) high spatial and temporal variability of the emissions, b) scarcity of long-term measurements and their likely non-representativeness over larger regions, and c) uncertainty in spatial aggregation and uncertainty inherent to the emission factors and activity data.

Tier 1: The uncertainty associated with the Tier 1 default emission factors are shown in Table 3a.2.1.

The uncertainty in the area of forest 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: Good practice in derivation of country-specific emission factors is described in Box 4.1, Good Practice in Derivation of Country-Specific Emission Factors, Page 4.62, of *GPG2000*.

The area of forest peatlands and its division between nutrient-poor and nutrient-rich peat types needs a country-specific assessment of uncertainties, preferably 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 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.

3a.2.3 Completeness

In order to ensure consistency with reporting on CO_2 emissions from drained forest soils, please refer to Section 3.2.3 on completeness in the main text.

3a.2.3.1 Developing a consistent time series

In order to ensure consistency with reporting on CO_2 emissions from drained forest soils, please refer to Section 3.2.4 on developing a consistent time series in the main text.

3a.2.4 Reporting and Documentation

In order to ensure consistency with reporting on CO_2 emissions from drained forest soils, please refer to Section 3.2.5 on reporting and documentation in the main text.

3a.2.5 Quality Assurance/ Quality Control (QA/QC)

In order to ensure consistency with reporting on CO_2 emissions from drained forest soils, please refer to Section 3.2.6 on inventory quality assurance/quality control (QA/QC) in the main text.