2013 SUPPLEMENT TO THE 2006 IPCC GUIDELINES FOR NATIONAL GREENHOUSE GAS INVENTORIES: WETLANDS

Methodological Guidance on Lands with Wet and Drained Soils, and Constructed Wetlands for Wastewater Treatment

Subject to Final Copyedit

OVERVIEW

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[1] Until February, 2013.

1 INTRODUCTION

The *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (*Wetlands Supplement*) provides methods for estimating anthropogenic emissions and removals of greenhouse gases from wetlands and drained soils. The scope of the *Wetlands Supplement* is broader than the coverage of Wetlands in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*[2] (*2006 IPCC Guidelines*), where managed wetlands are defined as lands where the water table is artificially changed (e.g. drained or raised) or those created through human activity (e.g. damming a river) and that do not fall into Forest Land, Cropland, or Grassland categories. The emissions and removals from wetlands and drained soils addressed in the *Wetlands Supplement* can occur under any land-use category or other relevant category of the *2006 IPCC Guidelines*. The guidance in the *Wetlands Supplement* is not intended to change the allocation of wetlands for reporting purposes.

The guidance provided is supplementary to that contained in the *2006 IPCC Guidelines,* which provide methodologies for estimating national anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol[3]. The content of the *2006 IPCC Guidelines* on wetlands is restricted to peatlands drained and managed for peat extraction, conversion to flooded lands, and some guidance for drained organic soils. It is therefore incomplete; it does not cover all wetland types and does not characterize all of the significant activities occurring on wetlands that are covered (e.g., rewetting of peatlands is not included).

This *Wetlands Supplement* supplements the *2006 IPCC Guidelines* by filling in gaps in the coverage and providing updated information reflecting scientific advances. This includes updating of emission factors. It covers inland organic soils and wetlands on mineral soils, coastal wetlands including mangrove forests, tidal marshes and seagrass meadows, and constructed wetlands for wastewater treatment. For the reasons described subsequently, the *Wetlands Supplement* does not provide guidance on permanently flooded lands such as reservoirs.

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[2] Intergovernmental Panel on Climate Change (IPCC 2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

[3] Greenhouse gases addressed in the *Wetlands Supplement* are: CO_2, CH_4 and N_2O.

2 BACKGROUND

The *IPCC Expert Meeting on HWP, Wetlands and Soil N_2O* held on 19-21 October, 2010 in Geneva[4], concluded that:

> *Since the 2006 IPCC Guidelines were completed much new scientific information is now available about various wetlands that enable emissions and removals to be estimated from wetland restoration and rewetting especially for peat lands. The meeting recommended that the IPCC provide additional methodological guidelines for the rewetting and restoration of peat land; emissions from fires, ditches and waterborne carbon; and constructed wetlands for waste water disposal, to fill gaps in the existing guidelines.*

The *Wetlands Supplement* has been produced in response to the conclusions of this expert meeting, and in response to an invitation from the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the United Nations Framework Convention on Climate Change (UNFCCC) at its 33rd session, held in December, 2010 in Cancun, which invited the IPCC to prepare additional guidance on wetlands, focusing on the rewetting and restoration of peatlands. Document FCCC/SBSTA/2010/13, paragraph 72 states:

> *...the SBSTA invited the IPCC to undertake further methodological work on wetlands, focusing on the rewetting and restoration of peatland, with a view to filling in the gaps in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (hereinafter referred to as the 2006 IPCC Guidelines) in these areas and to complete this work for the thirty-ninth session of the SBSTA.*

In response to this invitation, the IPCC held a scoping meeting in Genevafrom 30 March to 1 April, 2011. This meeting produced a draft Terms of Reference (ToR), including annotated chapter outline, which was approved by the IPCC at its 33rd Session in Abu Dhabi (10-13 May 2011).

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[4] IPCC 2011, *IPCC Expert Meeting on HWP, Wetlands and Soil N_2O*. Eggleston H.S., Srivastava N., Tanabe K., Baasansuren J., and Fukuda M. (eds). Meeting Report of the IPCC Expert Meeting on HWP, Wetlands and Soil N_2O, Geneva, Switzerland, 19-21 October, 2010, Published: IGES, Japan 2011.

3 COVERAGE OF THE WETLANDS SUPPLEMENT

The *2006 IPCC Guidelines* classify all land area into six broad land-use categories: Forest Land, Cropland, Grassland, Wetlands, Settlements, and Other Land (see Chapter 3, Volume 4 of the *2006 IPCC Guidelines*). The lands covered in the *Wetlands Supplement* may occur in any of the IPCC land-use categories. The land-use category that land is reported under depends on national land-use category definitions, data collection systems and tracking of land transitions. For example, forested peatland can be classified as Forest Land, plantations on peatland may be classified as Forest Land or Cropland depending on national forest definitions, and mangrove forests may be classified as Forest Land or Wetlands. Due to its function, constructed wetlands are not considered as a land-use category. The coverage of the *Wetlands Supplement* is briefly summarized in Table 1.

TABLE 1
COVERAGE OF THE *WETLANDS SUPPLEMENT*

Chapter	Coverage
1. Introduction	Guidance on the use of this report and generic information on the linkages between the *2006 IPCC Guidelines* and the supplementary guidance presented in this document.
2. Drained Inland Organic Soils	Guidance for managed inland organic soils including land drained for forestry, croplands, grazing, and settlements across climate zones.
3. Rewetted Organic Soils	Guidance on rewetted organic soils including boreal, temperate, and tropical wetlands occurring in any land-use category.
4. Coastal Wetlands	Guidance for specified management activities in coastal areas of mangroves, tidal marshes and seagrass meadows.
5. Inland Wetland Mineral Soils	Guidance for managed inland wetland mineral soils, including lands used for forestry, cropland, grazing, and settlements, and rewetted mineral soils.
6. Constructed Wetlands for Wastewater Treatment	Guidance on wetlands constructed for wastewater treatment.
7. Cross-cutting Issues and Reporting	Overall guidance on how to report anthropogenic emissions and removals from wetlands in the framework of the *2006 IPCC Guidelines*. Also gives general good practice guidance on cross-cutting issues (key category and uncertainty analysis, times series consistency and quality assurance/quality control) to supplement that given in Volume 1 of the *2006 IPCC Guidelines*.

A summary of the main methodological updates to the *2006 IPCC Guidelines* is provided below. Chapter 1 provides a decision tree to help inventory compilers determine which chapters of this supplement to apply and describes the coverage and definitions of the wetland types.

Peatlands and organic soils. The *2006 IPCC Guidelines* included some guidance on drainage (Chapter 4, Volume 4) and peat extraction (Chapter 7, Volume 4), but not on rewetting. In this supplement, peatlands are included along with organic soils and both drainage and rewetting are covered. Updated emission factors and methods are provided for both drained and rewetted organic soils including for off-site carbon dioxide (CO_2) emissions via waterborne carbon losses. Guidance on methane (CH_4) emissions from rewetting of organic soils (Chapter 3 of the *Wetlands Supplement*), ditches on drained inland organic soils and CO_2, CH_4 and carbon monoxide (CO) emissions from peat fires are also provided (Chapter 2 of the *Wetlands Supplement*).

Peatland managed for peat production. Peat production is covered in the *2006 IPCC Guidelines* (Chapter 7, Volume 4) and no additional guidance is given here except some updated emission factors in Chapter 2.

Rice cultivation. Rice cultivation is covered in the *2006 IPCC Guidelines* (Chapter 5, Volume 4) and additional emission factors for lowland rice production are given in Chapter 2.

Coastal wetlands. The *2006 IPCC Guidelines* provided no specific guidance for coastal wetlands and new guidance is given in Chapter 4 on how to treat anthropogenic emissions and removals associated with specified human activities that affect them. Coastal wetlands in this supplement include mangrove forests, tidal marshes and seagrass meadows. Emissions factors and methodologies are provided for management of mangrove forests (i.e. harvesting), rewetting, revegetation and creation, aquaculture and drainage.

Inland wetland mineral soils (IWMS). The *2006 IPCC Guidelines* provided limited data on soil carbon in wetland mineral soils. Chapter 5 provides updated default soil carbon factors and covers methodologies for quantifying emissions and removals of CO_2 and emissions of CH_4 from (i) artificial drainage of IWMS (ii) subsequently rewetting of artificially drained IWMS and (iii) the artificial flooding of mineral soils for the purposes of wetland creation. Mineral soil wetlands[5] include riparian wetlands, forested swamps and marshes and can occur in all climate zones.

Saline inland wetlands. Saline wetlands are important parts of otherwise arid landscapes across the globe but little information is available in the literature to assess potential greenhouse gas emissions or removals from these lands. Thus emission or removal factors cannot be given and no guidance is provided for these wetland types. These are also known as playas, pans, salt lakes, brackish wetlands, salinas, and sabkhas.

Constructed wetlands for wastewater treatment. The guidance supplements Volume 5 of the *2006 IPCC Guidelines* on Waste (Chapter 6). These are wetlands that have been designed and constructed to use natural processes involving vegetation, soils, and associated microbial assemblages to treat wastewater. New guidance is also provided on semi-natural treatment wetlands.

Permanently flooded lands. No new guidance on permanently flooded lands is provided. The *Expert Meeting on HWP, Wetlands and Soil* N_2O[6] did not agree that there was sufficient new information available to produce new and additional guidance based on the latest literature[7]. The *IPCC Special Report on Renewable Energy Sources and Mitigation of Climate Change*[8] also noted that it was not possible to make global estimates of the size of emissions from reservoirs.

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[5] Wetlands do not all have organic soils. Wetland Mineral Soils are classified as Aquic soil (USDA) or Gleysols (World Reference Base), and are described as having restricted drainage leading to periodic flooding and anaerobic conditions (Table 2.3, Chapter 2 of the *2006 IPCC Guidelines*).

[6] IPCC 2011, *IPCC Expert Meeting on HWP, Wetlands and Soil* N_2O. Eggleston H.S., Srivastava N., Tanabe K., Baasansuren J., and Fukuda M. (eds). Meeting Report of the IPCC Expert Meeting on HWP, Wetlands and Soil N_2O, Geneva, Switzerland, 19-21 October, 2010, Published: IGES, Japan 2011.

[7] The attendees of the *Expert Meeting on HWP, Wetlands and Soil* N_2O agreed on the need to discuss a range of issues such as the impact of reservoirs on total emissions from watersheds, allocation of emissions to specific drivers, and how emissions may be related to specific reservoir typologies.

[8] IPCC, 2011, *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. Prepared by Working Group III of the Intergovernmental Panel on Climate Change. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds). Published: Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1075 pp.

4 MANAGED LAND AND ANTHROPOGENIC EMISSIONS

Parties to the UNFCCC have committed to report anthropogenic emissions and removals of greenhouse gases not covered by the Montreal Protocol[9]. In practice, it is difficult to separate anthropogenic and natural emissions in Agriculture, Forestry and Other Land Use (AFOLU). Thus, the *2006 IPCC Guidelines* provides that it is *good practice* to report emissions and removals from managed land as a proxy for anthropogenic emissions and removals (Pages 1.4-1.5, Chapter 1, Volume 4 of the *2006 IPCC Guidelines*). An expert meeting[10] held in May 2009 in Brazil, reconsidered the issue and concluded that, although suitable methods for a better quantification of anthropogenic emissions and removals had been demonstrated in specific circumstances, there was no suitable, globally applicable alternative to the use of managed land as a proxy for anthropogenic emissions and removals.

The *Wetlands Supplement* continues to usemanaged land as a proxy for estimation of anthropogenic emissions and removals. The *Wetlands Supplement* notes that many wetlands on managed land have significant non-anthropogenic fluxes of greenhouse gases. The *2006 IPCC Guidelines* restricted managed wetlands to those lands where the water table is artificially changed (e.g., drained or raised). This *Wetlands Supplement* extends this coverage also to include wetlands created (e.g., constructed), or where emissions and removals from coastal wetlands are attributed to specified human activities. The focus on human activities such as drainage or construction of aquaculture ponds maintains the justification for the managed land proxy. In the case of seagrass meadows the guidance estimates emissions and removals associated with changes linked to a specific human activity, rather than estimating emissions and removals from that coastal wetland type as a whole. Application of the supplement will maintain consistency with previous estimates so long as these activities can be recognised as subsets within the broader definition of managed land. The application of new emission factors will not introduce inconsistency so long as the historical time series is updated, consistent with long-standing IPCC guidance.

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[9] UNFCCC Article 4.1 (a). http://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/conveng.pdf

[10] IPCC 2010, *Revisiting the Use of Managed Land as a Proxy for Estimating National Anthropogenic Emissions and Removals*, Eggleston H.S., Srivastava N., Tanabe K., Baasansuren J. (eds). Meeting Report, 5-7 May, 2009, INPE, São José dos Campos, Brazil, Published: IGES, Japan 2010.

5 THE WETLANDS SUPPLEMENT AND THE 2006 IPCC GUIDELINES

The *Wetlands Supplement* follows the same approach to estimating emissions and removals as the *2006 IPCC Guidelines.* The *2006 IPCC Guidelines* themselves are an evolutionary development starting from the *1996 IPCC Guidelines*, *2000 IPCC Good Practice Guidance (GPG2000)* and *Good Practice Guidance – Land Use, Land-use Change and Forestry (GPG-LULUCF).* This evolutionary approach helps ensure continuity, and allows for the incorporation of experiences with the existing guidelines, new scientific information, and the results of the UNFCCC inventory review process. An important structural change occurred in Volume 4, which consolidated the guidance for *LULUCF* in *GPG-LULUCF* and the Agriculture sector in *GPG2000* into a single Agriculture, Forestry and Other Land Use (AFOLU) Volume. This *Wetlands Supplement* adds to the guidance given in Volume 4 of the *2006 IPCC Guidelines*, and provides updates where science has advanced, but does not replace it. This *Wetlands Supplement* also adds to the guidance given in Volume 5 (Waste). Where the *Wetlands Supplement* provides guidance that updates emission factors for land areas, categories, gases, and pools covered directly by Volumes 4 and 5, the guidance in the *Wetlands Supplement* should take precedence.

The *2006 IPCC Guidelines* retained the definition of *good practice* that was introduced with *GPG2000*. This definition has gained general acceptance amongst countries as the basis for inventory development. According to this definition, national inventories of anthropogenic greenhouse gas emissions and removals consistent with *good practice* are those, which contain neither over- nor under-estimates so far as can be judged, and in which uncertainties are reduced as far as practicable. These requirements are intended to ensure that estimates of emissions by sources and removals by sinks, even if uncertain, are *bona fide* estimates, in the sense of not containing any biases that could have been identified and eliminated.

The *Wetlands Supplement,* like the *2006 IPCC Guidelines*, generally provides guidance, usually with decision trees, on estimation methods at three levels of detail, from Tier 1 (the default method) to Tier 3 (the most detailed method; Chapter 1, Volume 1). The Tier 1 guidance generally consists of mathematical specification of the methods and equations for estimating emissions/removals, information on emission factors or other parameters to use in generating the estimates, and sources of activity data to estimate the overall level of net emissions (emission by sources minus removals by sinks). Properly implemented, all tiers are intended to provide unbiased estimates, and accuracy and precision are expected to improve from Tier 1 to Tier 3. The provision of different tiers enables inventory compilers to use methods consistent with their resources and to focus their efforts on those categories of emissions and removals that contribute most significantly to national emission totals and trends.

National circumstances include the availability of data and knowledge, and contribution made by the category to total national emissions and removals and to their trend over time. The most important categories, in terms of total national emissions and the trend, are called *key categories*[11]. The decision trees generally require Tier 2 or Tier 3 methods for *key categories*. This approach to the use of different tiers allows limited resources to be focused on those areas of the inventory that contribute significantly to the overall total or trend in emissions.

Within Chapter 7 of the *Wetlands Supplement* advice is also provided on:

(i) ensuring time series are consistent,

(ii) estimation of uncertainties,

(iii) guidance on quality assurance and quality control procedures to provide cross-checks during inventory compilation,

(iv) information to be documented to achieve transparent reporting, avoiding double-counting and omissions, to facilitate review and assessment of inventory estimates, and

(v) reporting tables and worksheets for Tier 1 methods are provided as well as mapping between the categories and guidance in the *2006 IPCC Guidelines* and the changes to those introduced by the *Wetlands Supplement.*

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[11] In the *GPG2000* and *GPG-LULUCF* these were called *key sources* or *key categories* where there could be removals.

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GLOSSARY

Aerenchymous species

Plant species with a tissue consisting of thin-walled cells and large intercellular spaces that allows for plant internal circulation of air, enhancing gas exchange between the root layer and the atmosphere. Aerenchymous plants are widespread in wetlands.

Aquic

Condition pertaining to soil layers that are virtually free of dissolved oxygen and have a reducing environment because of saturation with ground water or capillary water (adapted from Table 2.3, Chapter 2, Volume 4 of the *2006 IPCC Guidelines*).

Aquaculture

The organised production of aquatic animals and plants (e.g. fish, crustaceans, and seaweeds) in marine or freshwater environments. The most important aquacultural practices in coastal wetlands are fish farming and shrimp ponds.

Autotrophic respiration

Release of carbon dioxide by living plants from internal metabolism (growth and maintenance).

Blanket bog

A bog type (see *bog*) that covers the underlying undulating landscape like a blanket.

Bog

Peatland only fed by precipitation and consequently generally nutrient-poor and acidic (see also *fen*).

Brackish/saline water

Water that generally contains 0.5 or more parts per thousand (ppt) of dissolved salts.

Brackish/saline wetland

A wetland inundated or saturated by brackish/saline water for all or part of the year.

CO_2 or CH_4 or N_2O Flux

Rate of flow of dissolved or gaseous CO_2 or CH_4 or N_2O across a given surface or area and over a certain amount of time.

Chamber

Gas-tight enclosure used for measuring greenhouse gas fluxes.

Coastal wetland

Wetland at or near the coast that is influenced by *brackish/saline water* and/or astronomical tides.

Constructed wetland for wastewater treatment

Wetland designed and constructed to use natural processes to help treat wastewater.

Created wetland

Previously dry land converted to a *wetland* by raising the water table in inland wetlands or removing obstructions to hydrologic flow and/or raising or lowering the soil elevation to appropriate tidal elevation in coastal wetlands.

Dam

A barrier constructed to obstruct the flow of water.

Denitrification

Reduction of nitrate or nitrite to molecular nitrogen.

Dissolved Inorganic Carbon (DIC)

Sum of all inorganic carbon species in solution (e.g. carbonate, bicarbonate, carbonic acid, carbon dioxide).

Dissolved Organic Carbon (DOC)

Organic carbon remaining in solution after filtering the sample, typically using a 0.45 micrometer filter.

Ditch

A long, narrow excavation made in the ground by digging, as for draining or irrigating land.

Drainage/drained

Artificial lowering of the soil water table. In this supplement, ‘drainage’ is used to describe the act of changing a *wet soil* into a *dry soil*. A *drained* soil is a soil that formerly has been a *wet soil* but as a result of human intervention is tending to become a *dry soil*, to which the *2006 IPCC Guidelines* would apply.

Drainage class

A collection of water table depths sharing a common characteristic. (e.g. the class ‘shallow-drained’ is characterized by having a mean annual water table depth of less than 30 cm below the surface, whereas the class ‘deep-drained’ has a mean annual water table depth of 30 cm and deeper below the surface;Chapter 2). The mean annual water table is the water table averaged over a period of several years.

Eddy covariance

Micrometeorological method that uses differences in concentration associated with turbulence in the air to quantify net vertical gas exchange.

Eutrophic

Nutrient-rich (see also *oligotrophic*).

Extraction

In this supplement, to remove soil (and associated biomass,dead wood and litter).

Fen

Peatland that in addition to precipitation water also receives water that has been in contact with mineral soil or bedrock (see also *bog*).

Fish cages or pens

Types of enclosures at the water surface or fixed to the seabed that maintain a free exchange of water and fine particles and used to cultivate aquatic organisms for human consumption.

Fish pond

In this supplement, a general term covering ponds constructed in brackish or saline water, designed to retain and culture fish for commercial production (aquaculture).

Flooded Land

In this supplement, *Flooded Land* is 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) of the Guidelines* (Chapter 7.3, Volume 4 of the *2006 IPCC Guidelines*).

Flooding

Overflowing of water on land normally dry.

Floodplain

Land adjacent to a stream or river that experiences flooding during periods of high discharge.

Freshwater

Water that contains < 0.5 parts per thousand (ppt) of various dissolved salts.

Freshwater wetland

A *wetland* inundated or saturated by *freshwater* for all or part of the year.

Heterotrophic respiration

The total of physical and chemical processes in an organism by which oxygen is conveyed to tissues and cells, and the oxidation products CO_2 and water, are given off.

Horizontal subsurface flow (HSSF)

A type of constructed wetland with horizontal subsurface flow.

Hydroperiod

Inundation frequency, differentiated into permanent and intermittent.

Immobilization

With respect to nitrogen, the process by which inorganic N, as ammonium (NH_4) and nitrate (NO_3) is assimilated by microorganisms.

Impoundment

Body of water formed by containment.

Inundated/inundation

Covered by water; see also *Flooded Land.*

Mangrove

A *coastal wetland* that has trees able to live in areas that are tidally flooded by brackish/saline water.

Marsh

A *wetland*, typically treeless, periodically inundated and characterized by grasses, sedges, cattails, and rushes.

Methanogen

Microorganism that produces methane during the decomposition of organic matter.

Methanotroph

Microorganism that utilizes methane for metabolism.

Mineral soil

Every soil that does not meet the definition of *organic soil* (see Annex 3A.5, Chapter 3, Volume 4 of the *2006 IPCC Guidelines*).

Mineralization

The process of converting organic compounds to inorganic compounds.

Minerotrophic

(Of peatland): supplied with nutrients from other sources (groundwater, flood water) than the atmosphere (see also *ombrotrophic*).

Nitrification

The microbial oxidation of NH_x to NO_3.

Ombrotrophic

Only supplied with nutrients by the atmosphere (see also *minerotrophic*) and consequently often acidic and low in nutrients.

Oligotrophic

Poor to extremely poor in nutrients (see also *eutrophic*).

Organic soil

In line with the *2006 IPCC Guidelines* (Annex 3A.5, Chapter 3, Volume 4), soil that satisfies the requirements 1 and 2, or 1 and 3 below:

1) Thickness of organic horizon greater than or equal to 10 cm. A horizon of less than 20 cm must have 12 percent or more organic carbon when mixed to a depth of 20 cm;
2) Soils that are never saturated with water for more than a few days must contain more than 20 percent organic carbon by weight (i.e., about 35 percent organic matter); and
3) Soils are subject to water saturation episodes and have either:
    a) At least 12 percent organic carbon by weight (i.e., about 20 percent organic matter) if the soil has no clay; or
    b) At least 18 percent organic carbon by weight (i.e., about 30 percent organic matter) if the soil has 60% or more clay; or
    c) An intermediate proportional amount of organic carbon for intermediate amounts of clay.

Except for the 10 cm criterion mentioned under 1), the *2006 IPCC Guidelines* do not define a minimum thickness for the organic horizon to allow for country-specific definitions of organic soil.

Paludiculture

Agriculture and forestry on wet (undrained, rewetted) organic soil.

Particulate Organic Carbon (POC)

Organic carbon that is larger than 0.45 micrometer in size (see also *Dissolved Organic Carbon*).

Peat[1]

Soft, porous or compressed, sedentary deposit of which a substantial portion is partly decomposed plant material with high water content in the natural state (up to about 90 percent). Countries may define *peat* according to their national circumstances.

Peat compaction

Volume reduction of peat in the aerated zone above the water table, resulting in increased bulk density.

Peat consolidation

Volume reduction of peat in the saturated zone below the water table owing to increased loading (downward pressure) from the drained top peat (by loss of buoyancy) on the peat below. See also *peat compaction*.

Peat decomposition

The process by which peat is broken down into simpler forms of matter. In mineralisation, decomposition proceeds to the mineral components, including CO_2 and H_2O.

Peat subsidence

The loss in peat elevation resulting from *peat compaction, peat comsolidation* and *peat oxidation*.

Prairie

An extensive area of flat or rolling, predominantly treeless grassland; often considered to be part of the temperate grasslands, savannas, and shrublands biome.

Refractory carbon

Soil carbon that does not get broken down and released as dissolved or gaseous CO_2 (predominantly by microorganisms) within the time scale of the inventory.

Rehabilitation

The re-establishment, on formerly drained sites, of some but not necessarily all the hydrological, biogeochemical and ecological processes and functions that characterized pre-drainage conditions.

Restoration

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[1] Consistent with the definition of peat found in the Energy sector of the *2006 IPCC Guidelines* (Volume 2, Chapter 1, Table 1.1)

The process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed. In case of drained former wetlands, restoration always has to include ‘rewetting’.

Rewetted soil

A soil that formerly has been *drained* but as a result of human intervention has once more become a *wet soil*.

Rewetting

The deliberate action of changing a *drained soil* into a *wet soil*, e.g. by blocking drainage ditches, disabling pumping facilities or breaching obstructions.

Riparian

Of, inhabiting, or situated on the bank of a river.

Saline inland wetland

Wetland that accumulates salts in its soil typically as a result of semi-arid to arid conditions.

Salt production

The production of salt by evaporating brackish or saline tidal water.

Seagrass meadow

Coastal wetland vegetated by seagrass species (rooted, flowering plants), permanently or tidally covered by brackish/saline water.

Sediment

Deposit of inorganic or organic material that has been carried and deposited by wind, water, or ice.

Semi-natural treatment wetland

Natural *wetland* that has been modified for wastewater treatment, e.g. by increasing the volume reserved (i.e. dams) and constructing channels for targeting the influent and effluent.

Surface flow (SF)

A type of constructed wetland with surface flow.

Swamp

Wetlands dominated by trees or woody species.

Tidal freshwater wetland

Wetland inundated or saturated for all or part of the year by tidal freshwater. The upper boundary is recognized as the landward extent of tidal inundation.

Tidal marsh

Marsh inundated or saturated for all or part of the year by tidal freshwater or brackish/saline water. The upper boundary is recognized as the landward extent of tidal inundation.

Total organic carbon (TOC)

All carbon in organic matter.

Vertical subsurface flow (VSSF)

A type of constructed wetland with vertical subsurface flow.

Wastewater treatment plant

A facility designed to receive wastewater and to remove materials that damage water quality and threaten public health and safety when discharged into receiving streams or bodies of water.

Waterborne carbon

DIC, DOC or *POC* contained in or conveyed by water.

Wetland

In this supplement, the term ‘wetland’ is used to refer to land with a *wet soil*. For the IPCC land-use category Wetlands, see below.

Wetlands

This guidance uses the term ‘Wetlands’ (with capital ‘W’ and plural) when referring to the IPCC land-use category Wetlands. The terms ‘wetland’ or ‘wetlands’ (except in titles with lowercase ‘w’ and singular or plural) are used to refer to land with wet soil (see above).

Wetland mineral soil

A mineral soil that is classified as an ‘aquic soil’ or a ‘gleysol’ according to the default mineral soil classification in Annex 3A.5, Figures 3A.5.3 and 3A.5.4, Chapter 3, Volume 4 of the *2006 IPCC Guidelines*.

Wet soil

A soil that is inundated or saturated by water for all or part of the year to the extent that biota, adapted to anaerobic conditions, particularly soil microbes and rooted plants, control the quality and quantity of the net annual greenhouse gas emissions and removals.

CHAPTER 1

INTRODUCTION

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1 INTRODUCTION

1.1 BACKGROUND

The *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (*2006 IPCC Guidelines*) acknowledged that the methodological guidance for the land-use category Wetlands in Volume 4 (Agriculture, Forestry and Other Land Use—AFOLU), Chapter 7 (Wetlands) is incomplete and limited to estimating emissions of carbon dioxide (CO_2) and nitrous oxide (N_2O) from *peatlands cleared and drained for production of peat for energy, horticultural and other uses* (Section 7.2, Chapter 7 in Volume 4 of the *2006 IPCC Guidelines*), and CO_2 emissions from land converted to flooded land such as *reservoirs for production of hydroelectricity, irrigation and navigation* (Section 7.2, Chapter 7 in Volume 4 of the *2006 IPCC Guidelines*). In October 2010, an IPCC expert meeting on harvested wood products, wetlands, and N_2O emissions from soils concluded that there is sufficient new scientific information available to provide additional methodological guidance and fill gaps in the existing *2006 IPCC Guidelines* for the rewetting and restoration of peatlands; emissions from fires, ditches, and waterborne carbon; and constructed wetlands for waste water disposal (IPCC, 2011). In December 2010, the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the United Nations Framework Convention on Climate Change (UNFCCC) invited the IPCC *to undertake further methodological work on wetlands, focusing on the rewetting and restoration of peatland, with the objective of filling in the gaps in the 2006 IPCC Guidelines in these areas*.

In response to the invitation of SBSTA, this *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*: *Wetlands - Methodological Guidance on Lands with Wet and Drained Soils, and Constructed Wetlands for Wastewater Treatment* - (*Wetlands Supplement*) provides new and supplementary guidance on estimating and reporting greenhouse gas emissions and removals from lands with organic soils and with wet mineral soils in Wetlands and other land-use categories with these soil types that are subject to human activities (‘managed’). The *Wetlands Supplement* is organized into the following chapters:

- Chapter 2: Drained Inland Organic Soils
- Chapter 3: Rewetted Organic Soils
- Chapter 4: Coastal Wetlands
- Chapter 5: Inland Wetland Mineral Soils
- Chapter 6: Constructed Wetlands for Wastewater Treatment
- Chapter 7: Cross-Cutting Issues and Reporting

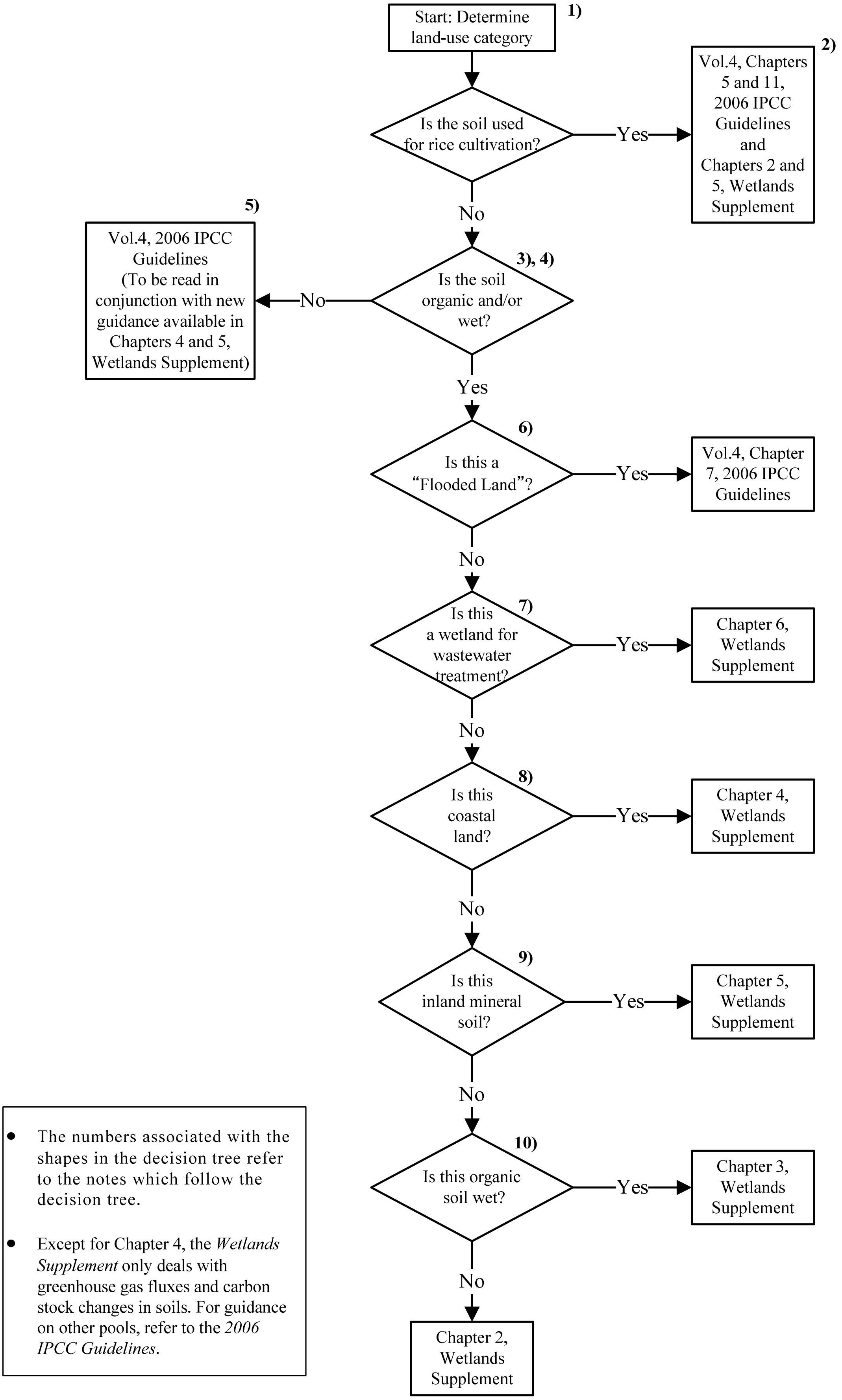
1.2 GUIDANCE FOR USING THIS SUPPLEMENT

This introductory chapter provides guidance on how to use this *Wetlands Supplement* in conjunction with the existing *2006 IPCC Guidelines* when preparing a greenhouse gas inventory that includes lands with organic , wet and drained mineral soils across all IPCC land-use categories.

The decision tree (Figure 1.1) can be used by inventory compilers as a guide to the relevant chapters within this *Wetlands Supplement* and/or the *2006 IPCC Guidelines*. The numbers located near the “start” box and the diamonds in the decision tree refer to the guidance notes below. The notes explain and illustrate the terms used in the decision tree and in this document (see also the glossary).

The terms are for the purpose of this document and their definitions are not intended to pre-empt other definitions of these terms in other contexts. For example: Except for in the name of this supplement, this guidance uses the term ‘Wetlands’ (with capital ‘W’ and always plural) solely when referring to the IPCC land-use category Wetlands. The terms ‘wetland’ or ‘wetlands’ (with lowercase ‘w’ and singular or plural) are used to refer to land with wet soil as defined in note 4 below. Other articulations of the ‘wetland’ concept are possible e.g. that used by the Ramsar Convention (www.ramsar.org/cda/en/ramsar-documents-texts-convention-on/main/ramsar/1-31-38%5E20671_4000_0__) but this does not affect the applicability of the methodological guidance.

Figure 1.1 **Decision tree for finding the appropriate guidance chapter within the *Wetlands Supplement* or the *2006 IPCC Guidelines***



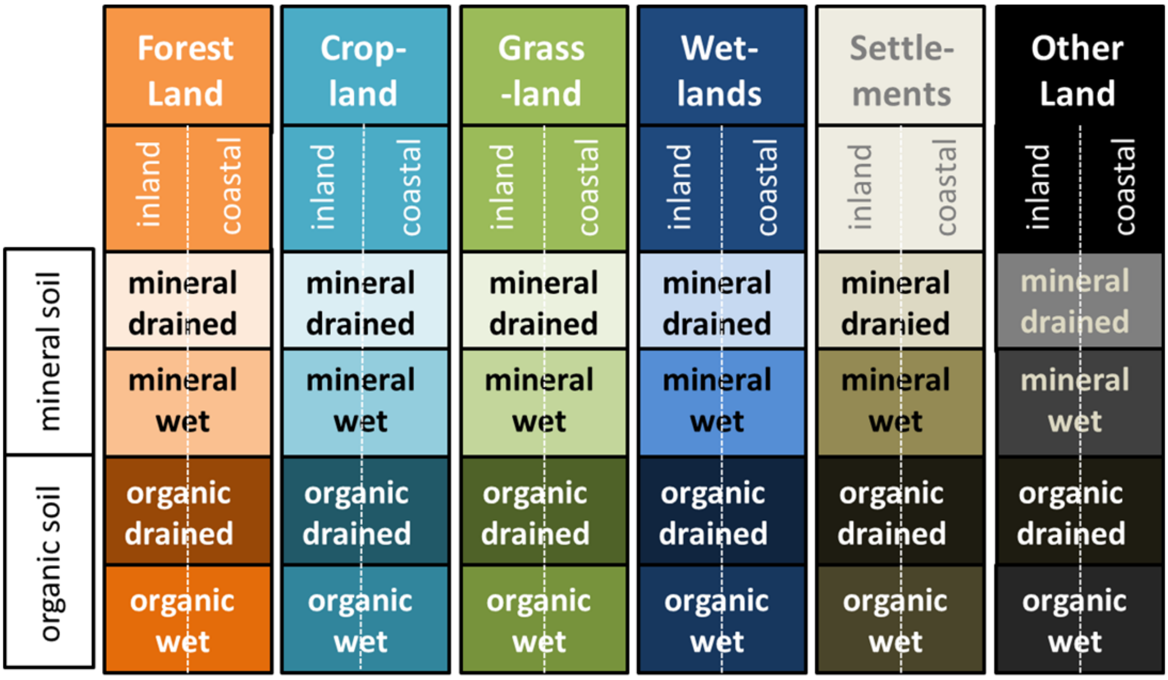
- The numbers associated with the shapes in the decision tree refer to the notes which follow the decision tree.
- Except for Chapter 4, the *Wetlands Supplement* only deals with greenhouse gas fluxes and carbon stock changes in soils. For guidance on other pools, refer to the *2006 IPCC Guidelines*.

Note 1: Determine land-use category

The *Wetlands Supplement* covers land with wet and drained organic soils, and wet and drained mineral soils (see notes 2, 3, and 4 for the definition of these terms) across all IPCC land-use categories (Forest Land, Cropland, Grassland, Wetlands, Settlements, and Other Land, see Figure 1.2). The *Wetlands Supplement* is consistent with Chapter 3 (Consistent Representation of Lands) in Volume 4 of the *2006 IPCC Guidelines* in that it does not change the assignment of land to a category. If using Approach two or three for the land representation[1], land-use conversions (e.g., Forest Land converted to Cropland, Cropland converted to Settlements) should also be identified.

Compared to the *2006 IPCC Guidelines* the *Wetlands Supplement* identifies relevant subcategories (see Figure 1.2 below) and specifies emission factors for all land-use categories with organic soils and wet and drained mineral soils (including drained 'wetland mineral soils' – see Note 4 below - subject to rewetting; inland wetland mineral soils subject to long-term cultivation; inland dry mineral soils that have been wetted; coastal drained mineral soils subject to rewetting and coastal mineral soils subject to other management practices[2]).. The *Wetlands Supplement* differentiates coastal land from inland land, because water salinity and dynamics (e.g., tides) may, for the same land-use category, modify emission factors compared to inland land. .

Figure 1.2 Soil based subcategories that are being addressed in the *Wetlands Supplement*



		Forest Land	Crop-land	Grass-land	Wet-lands	Settle-ments	Other Land
		inland ⋮ coastal	inland ⋮ coastal	inland ⋮ coastal	inland ⋮ coastal	inland ⋮ coastal	inland ⋮ coastal
mineral soil		mineral drained	mineral drained	mineral drained	mineral drained	mineral dranied	mineral drained
		mineral wet	mineral wet	mineral wet	mineral wet	mineral wet	mineral wet
organic soil		organic drained	organic drained	organic drained	organic drained	organic drained	organic drained
		organic wet	organic wet	organic wet	organic wet	organic wet	organic wet

Notes on Figure 1.2: Guidance for all the soils shown in this figure is included the *Wetlands Supplement*. Guidance for 'mineral dry' soils except for those drained for long-term cultivation and drained coastal wetlands (see note 5) is provided in the *2006 IPCC Guidelines*.

It is *good practice* to subdivide each land use/conversion category into subcategories with similar characteristics. The *Wetlands Supplement* proposes a division into four soil subcategories; all with a coastal and inland subdivision where appropriate (see Figure 1.2 above):

1) drained mineral soil

2) wet mineral soil

3) wet organic soil

4) drained organic soil.

In the case of dry mineral soil, the guidance in the *2006 IPCC Guidelines* in the Forest Land, Cropland or Grassland Chapters as appropriate has to be used. Chapter 4 of the *Wetlands Supplement* provides new guidance

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[1] Cf. Section 3.3.1, Chapter 3 in Volume 4 of the *2006 IPCC Guidelines*

[2] Other management activities on coastal wetland mineral soils covered in the Supplement include extraction, revegetation and aquaculture.

for drained coastal mineral soils whereas Chapter 5 presents new guidance for drained inland wetland mineral soils (see note 4 below) that have been continuously managed for > 20 years to cultivate predominantly annual crops. In all other cases, use the decision tree (see Figure 1.1 above) to identify the appropriate guidance chapter within this *Wetlands Supplement* or the *2006 IPCC Guidelines*

The *2006 IPCC Guidelines* are used for estimating and reporting anthropogenic greenhouse gas emissions and removals only. With respect to 'land' this requires inventory compilers to differentiate between 'managed' and 'unmanaged' land for all land-use categories besides Cropland and Settlements, which are inherently managed land. The *Wetlands Supplement* continues to apply the Managed Land Proxy (see Section 1.3 of this supplement) to estimate anthropogenic greenhouse gases. In case of coastal wetlands, guidance is provided to estimate and report anthropogenic emissions and removals from specific management activities.

Note 2: Is the soil used for rice cultivation?

Guidance on rice cultivation is provided in Chapters 2 and 5 of the *Wetlands Supplement* and Chapters 5 and 11, Volume 4 of the *2006 IPCC Guidelines*.

Note 3: Is the soil organic?

An organic soil is a soil with a high concentration of organic matter (see below). Every soil that is not an organic soil is classified as a mineral soil, following the *2006 IPCC Guidelines* (Annex 3A.5, Chapter 3 in Volume 4). The *Wetlands Supplement* follows the definition of organic soils in the *2006 IPCC Guidelines* (Annex 3A.5, Chapter 3 in Volume 4):

Organic soils are identified on the basis of criteria 1 and 2, or 1 and 3 listed below (FAO 1998):
1. Thickness of organic horizon greater than or equal to 10 cm. A horizon of less than 20 cm must have 12 percent or more organic carbon when mixed to a depth of 20 cm.
2. Soils that are never saturated with water for more than a few days must contain more than 20 percent organic carbon by weight (i.e., about 35 percent organic matter).
3. Soils are subject to water saturation episodes and has either:
  a. At least 12 percent organic carbon by weight (i.e., about 20 percent organic matter) if the soil has no clay; or
  b. At least 18 percent organic carbon by weight (i.e., about 30 percent organic matter) if the soil has 60% or more clay; or
  c. An intermediate proportional amount of organic carbon for intermediate amounts of clay.

The *2006 IPCC Guidelines* largely follow the definition of Histosols by the Food and Agriculture Organization (FAO), but have omitted the thickness criterion from the FAO definition to allow for often historically determined, country-specific definitions of organic soils.

For peat and peatland, no IPCC definitions exist. Definitions of peatland and peat soil differ between countries with respect to how thick the peat layer must be to call something a peatland or a peat soil. Also the definition of peat varies among countries and disciplines, especially with respect to the minimum percentage of organic matter the material has to contain (Joosten and Clarke, 2002). In the *Wetlands Supplement* the concept of peatland is considered to be included in '(land with) organic soil'.

It is *good practice* that, when a country uses another definition of organic soil in accordance with its national circumstances, the concept of organic soil (and its possible subdivisions) applied is clearly defined and that the definition is applied consistently both across the entire national land area and over time.

Note 4: Is the soil wet?

A wet soil is a soil that is inundated or saturated by water for all or part of the year to the extent that biota, adapted to anaerobic conditions, particularly soil microbes and rooted plants, controlled the quality and quantity of the net annual greenhouse gas emissions and removals**.**

Drainage is the process of changing a wet soil into a dry soil. A drained soil is a soil that formerly has been a wet soil but as a result of human intervention has become a dry soil. All organic soils are assumed to have originally been wet, so that a dry organic soil always is also a drained organic soil.

Rewetting is the process of changing a drained soil into a wet soil. A rewetted soil is a soil that formerly has been a drained soil but as a result of human intervention has become a wet soil. Similarly, wetting is the process of changing an originally dry soil into a wet soil as a result of human intervention, as in wetland creation. Restoration (adjective restored) is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed. In case of drained former wetlands, restoration always has to include rewetting.

With respect to inland wet mineral soils the *Wetlands Supplement* only provides Tier 1 guidance for 'wetland mineral soils' and mineral soils that have been wetted by human intervention for the purpose of wetland creation. 'Wetland mineral soils' include the 'wetland soils' as defined in footnote 6 of Volume 4, Table 2.3 of the *2006*

IPCC Guidelines as *Soils with restricted drainage leading to periodic flooding and anaerobic conditions (in WRB classification Gleysols; in USDA classification Aquic suborders).* Sandy soils (as defined by footnote 3 of Volume 4, Table 2.3 of the *2006 IPCC Guidelines*) that are wet are not included.

Chapter 3 of the *Wetlands Supplement* covers organic soils that are rewetted and wet organic soils that are subject to other management practices such as paludicultures. Chapter 4 covers coastal wetland soils that are subject to rewetting (after drainage) and to other management practices such as extraction, revegetation and aquaculture. Chapter 5 covers rewetting of drained inland wetland mineral soils and wetting of originally dry mineral soils.

Note 5: New guidance for drained coastal mineral soils and 'inland wetland mineral soils'

Dry mineral soils in inland lands subject to management activities other than rewetting or wetting respectively are covered in Volume 4, *2006 IPCC Guidelines*. Chapter 4 of the *Wetlands Supplement* provides new guidance for drained coastal mineral soils, whereas Chapter 5 presents new guidance on 'inland wetland mineral soils'(see note 4 above) that have been continuously managed (by default for > 20 years)with predominantly annual cultivation. Tier 1 methods for both mineral and organic soils do not differentiate between recently and long-time drained soils.'

Drained mineral soils may have a high organic matter content which makes their greenhouse gas emission characteristics different from those of mineral soils that have never been wet, or which were originally wet, but have been in a dry state for a long time. These differences fade with time after drainage, but so long as they persist, the soil is described in this supplement as being in a drained state.

Note 6: Is this a 'Flooded Land'?

Flooded Land is defined in the *2006 IPCC Guidelines* 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) of the Guidelines* (Section 7.3, Chapter 7 in Volume 4 of the *2006 IPCC Guidelines*).

This *Wetlands Supplement* does not include additional guidance for Flooded Land. Estimating emissions from this category of land use is discussed in Section 7.3, Chapter 7, Volume 4 of the *2006 IPCC Guidelines*. Reservoirs constructed as wetlands for wastewater treatment are covered in Chapter 6 of the *Wetlands Supplement*.

Note 7: Is this a wetland for wastewater treatment?

A wetland for wastewater treatment is a wetland that is used for or influenced by waste water treatment. Chapter 6 of the *Wetlands Supplement* provides guidance for wetlands for wastewater treatment, both for wetlands that are constructed for that purpose (constructed wetlands for wastewater treatment) and for natural wetlands that are used for or influenced by wastewater treatment. The emissions are reported under the Waste Sector. Other constructed (i.e., man-made, engineered or artificial wetland creation) wetlands are included in Chapter 5 of the *Wetlands Supplement.*

Note 8: Is this coastal land?

Coastal land is land at or near the coast. It is *good practice* that a country clearly defines the concept of 'coastal land' and its sea- and landward limits in accordance with its national circumstances and applies that definition consistently both across the entire national land area and over time. All land that is not coastal is inland.

A coastal wetland is a wetland (see note 4) at or near the coast that is influenced by brackish/saline water and/or astronomical tides. Coastal wetland may occur on both organic and mineral soils. Brackish/saline water is water that normally contains more than 0.5 or more parts per thousand (ppt) of dissolved salts. Every mineral soil wetland that is neither a coastal wetland, nor a Flooded Land (see note 6) nor a constructed wetland (see note 7) for waste water treatment is classified as inland wetland (cf. Chapter 5).

Note 9: Is this inland mineral soil?

Inland mineral soil is all mineral soil (see note 3) that is not on coastal land (see note 8).

Note 10: Is this organic soil wet?

Chapter 3 of the *Wetlands Supplement* focuses on rewetted organic soils and peatlands. While Chapter 3 of the *Wetlands Supplement* does not provide Tier 1 methods for management practices such as paludicultures, these are discussed in the general discussion and in the higher tier sections of that chapter. Chapter 2 of the *Wetlands Supplement* covers drained organic soils.

Box 1.1
GREENHOUSE GAS EMISSIONS AND REMOVALS OF MANAGED ORGANIC AND WET SOILS

Lands with organic and wet soils are crucial in maintaining the Earth's carbon balance as they contain soils with high organic carbon content (Mitra *et al.*, 2005; Joosten and Couwenberg, 2008; Donato *et al.*, 2011). Human activities on wetlands (e.g., drainage, agriculture, forestry, peat extraction, aquaculture) and their effects (e.g., oxidation of soil organic matter) may significantly affect the carbon and nitrogen balance and, thus, the greenhouse gas emissions and removals from these lands. The actual magnitude of human-induced emissions and removals from lands with organic or wet soils depends on numerous variables, including soil type, type of land use/conversion, wetland type, wetland size, management practice, vegetation composition, water table depth, growing season length, salinity, precipitation, and temperature and is discussed in greater detail in this *Wetlands Supplement*.

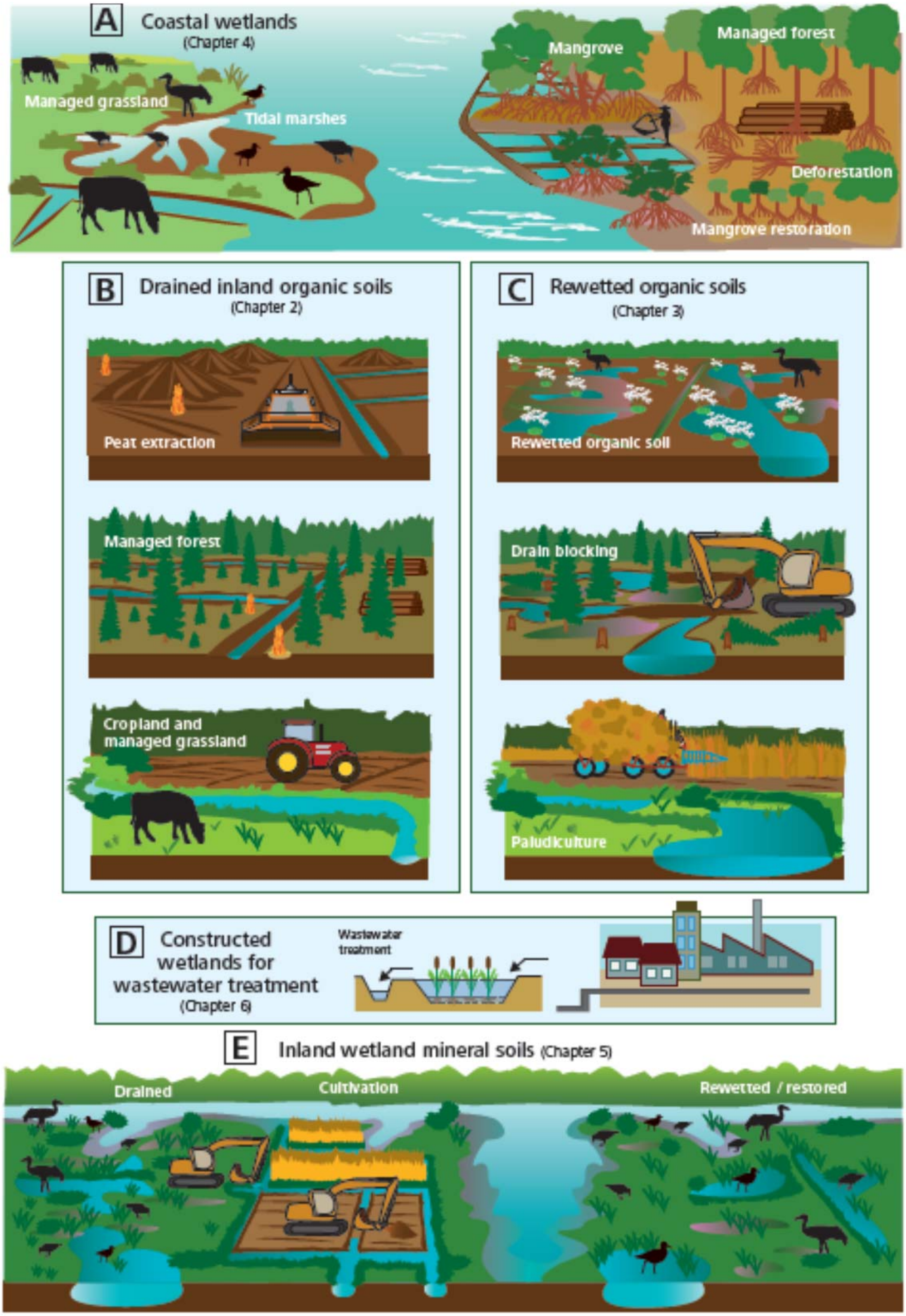
Draining inland organic soils lowers the water table and increases the oxygen content of the soil, thus increasing CO_2 emissions. CH_4 emissions from drained inland organic soils are generally negligible because the soil carbon is then preferentially oxidized to CO_2. However, methanogenesis may take place in drainage ditches with a higher water table causing significant sources of CH_4 to the atmosphere. Drained organic soils can also emit significant amounts of N_2O from nitrogen in the organic matter or nitrogen added by fertilization. Losses of particulate and dissolved organic carbon in drainage waters from organic soil are also included in this *Wetlands Supplement* (Chapter 2). Rewetting inland organic soils raises the water table again, decreases CO_2 emissions, rapidly decreases N_2O emissions to close to zero, and increases CH_4 emissions compared to the drained state as the oxygen level in the soil drops and methanogenesis starts again. Rewetting can also restore wetlands to a state where net CO_2 emissions are greatly reduced or even become negative and the wetlands function as a net remover of greenhouse gases from the atmosphere (Chapter 3 of this supplement). CO_2 emissions from coastal wetlands can be significant especially during the construction phase of aquaculture and salt production/extraction. CH_4 and N_2O emissions from coastal wetlands are not significant except when the wetlands are enriched with nutrients from agricultural run-off or sewage (Chapter 4 of this supplement). Restoring and creating wetlands on mineral soils, similar to rewetting organic soils, creates anoxic conditions and increases CH_4 emissions (Chapter 5 of this supplement). Constructed and semi-natural wetlands used for wastewater treatment emit CH_4 and N_2O (Chapter 6 of this supplement).

1.3 APPLICATION OF THE MANAGED LAND PROXY TO WETLANDS

The Managed Land Proxy is used in the *2006 IPCC Guidelines* and *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (*GPG-LULUCF*) as a pragmatic way to estimate anthropogenic emissions and removals because detailed factoring out of natural emissions or removals is impractical at the country level. According to the *2006 IPCC Guidelines* (Section 3.2, Chapter 3 in Volume 4), *managed land is land where human interventions and practices have been applied to perform production, ecological or social functions*, and all emissions and removals from managed land are to be reported regardless of whether they are anthropogenic or non-anthropogenic.

The Managed Land Proxy continues to be applied in the *Wetlands Supplement*. For coastal wetlands (Chapter 4 of this supplement), this *Wetlands Supplement* provides guidance to estimate and report countries' emissions and removals from specific management activities (e.g., aquaculture, salt production, dredging). See Figure 1.3 below for some typical management practices on wetlands.

Figure 1.3 Typical management practices on organic and wet soils



(Figure by Riikka Turunen, Statistics Finland)

1.4 COHERENCE AND COMPATIBILITY WITH 2006 IPCC GUIDELINES

This section provides an overview of the linkages between the *2006 IPCC Guidelines* and the information presented in this *Wetlands Supplement*. Section 1.4.1 presents an outline of the activities in the *2006 IPCC Guidelines* that are the topic of additional guidance in this supplement. Section 1.4.2, highlights the guidance in this supplement that was not previously included in the *2006 IPCC Guidelines* and may need to be considered by inventory compilers.

1.4.1 Guidance on activities in the 2006 IPCC Guidelines that are also covered in the Wetlands Supplement

CARBON STOCK CHANGES AND CO_2 EMISSIONS AND REMOVALS IN MINERAL AND ORGANIC SOILS

The *2006 IPCC Guidelines* provide guidance for estimating carbon stock changes in mineral soils and drained organic soils within the land use categories Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land. In Section 2.3.3, Chapter 2 in Volume 4 of the *2006 IPCC Guidelines*, complete guidance is provided at the Tier 1 level, with additional guidance for Tiers 2 and 3. For mineral soils, the default method is based on changes in soil carbon stocks over a finite period of time. The change is computed based on the carbon stock after the management change relative to the carbon stock in a reference condition. To estimate CO_2 emissions from drained organic soils an area-based annual emission factor is applied that is differentiated by climate region and land use. The *Wetlands Supplement* provides additional guidance for both organic and mineral soils (subdivided into wet and drained) and the information with respect to organic soils is expanded to include activities on wet (undrained, rewetted) organic soils. The information in Table 4.6 in Chapter 4 (Forest Land), Table 5.6 in Chapter 5 (Cropland), and Table 6.3 in Chapter 6 (Grassland) in Volume 4 of the *2006 IPCC Guidelines*, which provide CO_2 emission factors for drained organic soils, is updated in Table 2.1 in the *Wetlands Supplement*.

CH_4 EMISSIONS FROM MANAGED SOILS

Section 2.3.3.1, Chapter 2 in Volume 4 of the *2006 IPCC Guidelines* assumes CH_4 emissions due to the drainage of organic soils are negligible. The *Wetlands Supplement* provides guidance on estimating CH_4 emission from drained organic soils and drainage ditches, including default emission factors in Table 2.3 and 2.4 in Chapter 2, respectively.

The *2006 IPCC Guidelines* do not provide guidance on estimating CH_4 emissions from mineral soils except for rice cultivation. The *Wetlands Supplement* provides guidance on this potential source in Table 5.4 in Chapter 5, based upon a review of the available scientific literature.

BIOMASS AND DEAD ORGANIC MATTER CARBON STOCK CHANGES

The generic methodologies for estimating above-ground and below-ground biomass carbon stock changes for all land-use categories are available in Section 2.3.1, Chapter 2 in Volume 4 of the *2006 IPCC Guidelines*. Guidance to estimate the dead organic matter pool is provided in Section 2.3.2, Chapter 2 in Volume 4 of the *2006 IPCC Guidelines*. More specific guidance by land-use categories can be found in Volume 4 of the *2006 IPCC Guidelines* under the specific land-use category Chapters: 4 (Forest Land), 5 (Cropland), 6 (Grassland), 7 (Wetlands), 8 (Settlements), and 9 (Other Land). The *Wetlands Supplement* provides additional guidance for these carbon pools with respect to coastal wetlands in Section 4.2, Chapter 4.

The *Wetlands Supplement* does not provide additional guidance for these pools in Chapters 2, 3 and 5.

DIRECT AND INDIRECT N_2O EMISSIONS FROM MANAGED SOILS

In Section 11.2, Chapter 11 in Volume 4 of the *2006 IPCC Guidelines*, methodologies are provided to estimate both direct and indirect N_2O emissions from managed soils. Generic equations are presented that can be applied to all land areas in aggregate or to specific land-use categories if activity data are available. N_2O emissions from drained organic soils are estimated using an area-based annual emission factor differentiated by climate region.

The *2006 IPCC Guidelines* cautions of the risk of double counting of indirect N_2O emissions that are reported elsewhere, e.g. under Agriculture (Chapter 11, Volume 4). This caution is reiterated here with regard to the use of the additional information about N_2O emissions,

Certain Tier 1 N_2O emission factors provided in Tables 11.1 (direct emissions), Chapter 11 in Volume 4 of the *2006 IPCC Guidelines* are updated Table 2.5, Chapter 2 in the *Wetlands Supplement*.

NON-CO_2 EMISSIONS FROM BIOMASS BURNING

Generic guidance for non-CO_2 emissions due to burning of live and dead biomass on managed lands (Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land) is provided under Section 2.4, Chapter 2, Volume 4 of the *2006 IPCC Guidelines*. The existing guidance does not include burning of peat and other organic soils, which is a large emission source for some countries. The *Wetlands Supplement* addresses CO_2, CH_4 and carbon monoxide (CO) emissions associated with burning of organic soils.

RICE CULTIVATION

CH_4 emissions from rice cultivation are included in Section 5.5, Chapter 5 in Volume 4 of the *2006 IPCC Guidelines*. Soil carbon stock changes are accounted for using guidance as described above in Section 2.3.3, Chapter 2 in Volume 4 of the *2006 IPCC Guidelines*. Chapter 2 of the *Wetlands Supplement* provides emission factors for CO_2, CH_4 and N_2O for rice cultivation on tropical drained organic soils.

WETLANDS

In the Wetlands chapter of the *2006 IPCC Guidelines* (Chapter 7 in Volume 4), methodologies are provided to estimate greenhouse gas emissions and removals from peatlands cleared and drained for extracting peat for energy, horticulture and other uses (Section 7.2, Chapter 7 in Volume 4 of the *2006 IPCC Guidelines*). Emissions from the use of horticultural peat are accounted for in Chapter 7 in Volume 4 of the *2006 IPCC Guidelines*, while emissions from peat used for energy generation are estimated under the Energy Sector (Volume 2 of the *2006 IPCC Guidelines*). In the *2006 IPCC Guidelines*, guidance for peat extraction that does not include drainage is not provided; this remains the case in this *Wetlands Supplement*.

WASTEWATER TREATMENT

Chapter 6 in Volume 5 of the *2006 IPCC Guidelines* (wastewater treatment and discharge) provides a methodology to estimate CH_4 and N_2O emissions from domestic and industrial wastewater treatment. CO_2 emissions from wastewater are not considered in the *IPCC Guidelines* and should not be included in national total emissions because of their biogenic origin. The *Wetlands Supplement* provides guidance on CH_4 and N_2O emissions associated with constructed and natural wetlands used for wastewater treatment.

1.4.2 Supplementary guidance in this report

Figure 1.3 shows schematic representations of typical generic management practices that are covered in each of the chapters of the *Wetlands Supplement*. The illustrations are not intended to be comprehensive; rather they are a visual guide to the landscapes and ecosystem types that are to be considered when using this supplement.

CHAPTER 2—DRAINED INLAND ORGANIC SOILS

Chapter 2 in the *Wetlands Supplement* provides an updated summary of emission factors and supplementary guidance to Volume 4 of the *2006 IPCC Guidelines* on estimating greenhouse gas emissions and removals from drained inland organic soils for all land-use categories: Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land, (see Figure 1.3, Frame B in this chapter).

Additional Tier 1 guidance is provided to include the impact of drainage depth (water-table level) on the emission of CO_2, CH_4 and N_2O. New emission factors to estimate the release of CH_4 from drainage ditches are also provided.

Chapter 2 in the *Wetlands Supplement* also identifies additional pathways by which carbon is lost from the soil: namely carbon loss as Dissolved Organic Carbon (DOC), as Particulate Organic Carbon (POC), and as Dissolved Inorganic Carbon (DIC). Guidance is provided to estimate these carbon losses separately from the direct emissions. The loss of carbon from managed organic soils via DOC can be estimated using the Tier 1 methodology and the emission factors provided. Chapter 2 does not provide Tier 1 methodologies for emissions associated with POC or DIC. However, Annex 2A.1, Chapter 2 in the *Wetlands Supplement* sets out the basis for future methodological development for estimating CO_2 emissions associated with waterborne carbon loss from POC. Fire on drained organic soils causes not only on-site CO_2, CH_4, and N_2O emissions directly from the burning, but also has a high potential to increase off-site carbon loss from waterborne organic matter. Chapter 2 in the *Wetlands Supplement* provides supplementary methodological guidance to estimate CO_2, CH_4 and CO emissions.

CHAPTER 3—REWETTED ORGANIC SOILS

Chapter 3 in the *Wetlands Supplement* provides new guidance and emission factors for organic soils that had been drained for forestry, crop production, grazing, peat extraction or other purposes, and subsequently have been rewetted to re-establish water saturation (see Figure 1.3, Frame C in this chapter). Rewetting may have several objectives such as emission reduction, restoration for nature conservation or enabling other management practices on saturated organic soils (paludicultures). While restoration may take place on undrained sites (e.g., restoration of damaged vegetation cover), in the majority of cases restoration will include rewetting.

Chapter 3 provides Tier 1 guidance for assessing the greenhouse gas (CO_2, CH_4 and N_2O) emissions and removals from rewetted organic soils by climate region and general guidance for utilizing higher tier methodologies.

CHAPTER 4—COASTAL WETLANDS

Chapter 4 in the *Wetlands Supplement* provides guidance on estimating emission and removals of greenhouse gases (CO_2, CH_4 and N_2O) associated with specific activities on managed coastal wetlands, which may or may not result in a land use change. Coastal wetlands are wetlands near the coast that are influenced by tidal and/or saline or brackish water. They may consist of mangrove, tidal marsh and seagrass vegetation and can have organic and mineral soils (see Figure 1.3, Frame A in this chapter). Management practices included in the guidance are aquaculture, salt production, extraction, drainage, rewetting, revegetation and creation, and forest management practice in mangroves.

CHAPTER 5—INLAND WETLAND MINERAL SOILS

Chapter 5 in the *Wetlands Supplement* provides guidance for managed inland mineral soils, including drained wetland mineral soils subject to rewetting; those under long term cultivation; and any other mineral soils that have been wetted by human intervention (e.g., inundation for the purpose of wetland creation) not included in Chapter 4 (coastal wetlands) or Chapter 6 (constructed wetlands for wastewater treatment) in the *Wetlands Supplement*. The chapter provides methodologies for estimating greenhouse gas emissions and removals, gives updated default reference values for soil organic carbon stocks and offers a default stock change factor for land-use for long term cultivation of croplands on inland wetland mineral soils. It also gives guidance not contained in the *2006 IPCC Guidelines*, including a default stock change factor for land use for rewetted croplands, and methodologies and emission factors for CH_4 emissions for mineral soils in any land-use category that have been rewetted or have been inundated for the purpose of wetland creation.

Chapter 5 in the *Wetlands Supplement* does not provide guidance on the application of the methodology from Chapter 11 in Volume 4 of the *2006 IPCC Guidelines*, for estimating N_2O emissions associated with loss of soil carbon as a result of changes in land use and/or management on inland wetland mineral soils based on estimates of the loss of soil carbon in relation to the updated and new defaults for SOC_{REF} and SOC stock change factors. However the chapter suggests a future development on the issue.

CHAPTER 6—CONSTRUCTED WETLANDS FOR WASTEWATER TREATMENT

Chapter 6 in the *Wetlands Supplement* provides guidance on estimating CH_4 and N_2O emissions from constructed wetlands and semi-natural treatment wetlands used for wastewater treatment (see Figure 1.3, Frame D in this Chapter). The guidance supplements Chapter 6 in Volume 5 of the *2006 IPCC Guidelines* on wastewater treatment. Default emission factors for different types of constructed wetlands, e.g., those with surface, subsurface vertical or subsurface horizontal flows, are provided for the Tier 1 method. The types of wastewater include domestic, industrial wastewater, collected runoff from agricultural land and leachate from landfill. To avoid double-counting, N_2O emissions from wetlands managed for the filtration of non-point source agricultural effluents such as fertilizers are included in indirect N_2O emissions from managed soils (Chapter 11 in Volume 4 of the *2006 IPCC Guidelines*) as part of the leaching/runoff and volatilization components of indirect emissions, and are not considered within this Supplement. No specific guidance for estimating potential changes in carbon pools associated with constructed wetlands for wastewater treatment is presented in Chapter 6 in the *Wetlands Supplement*. The inventory compiler is encouraged to consider guidance in the *2006 IPCC Guidelines* and in the *Wetlands Supplement* for possible approaches to reporting these carbon pools.

CHAPTER 7—CROSS-CUTTING ISSUES AND REPORTING

Chapter 7 in the *Wetlands Supplement* provides guidance on reporting and cross-cutting issues, including uncertainties, key category analysis, completeness, time series consistency, quality control, and quality assurance. The chapter summarizes the *good practice* guidance on these cross-cutting issues found in Volume 1 of the *2006 IPCC Guidelines* and addresses the cross-cutting issues specific to Chapters 2 to 6 of this *Wetlands Supplement*. Worksheets that can be used for estimating the emissions and removals for each category using the Tier 1 guidance, and revised background tables are included in the annex of the chapter.

OVERVIEW OF GENERAL CONSIDERATIONS IN USING THE WETLANDS SUPPLEMENT AND THE 2006 IPCC GUIDELINES

It is *good practice* for countries to avoid double-counting emissions that have already been estimated elsewhere in the greenhouse gas inventory. This is especially relevant because lands with organic soils or with wet soils can be included under various land categories.

In particular, there is a risk that using the guidance provided in Chapters 4 and 6 of the *Wetlands Supplement* could result in double-accounting of N_2O emissions from wetlands that result from non-point source agricultural effluents that are already addressed as indirect emissions from soil amendments (e.g., nitrogen fertilizers) within Chapter 11 in Volume 4 of the *2006 IPCC Guidelines*. Double-accounting can be avoided by considering only those management practices that result in direct N_2O emissions.

Chapter 2 of this supplement provides guidance on waterborne carbon (DOC, DIC and PIC), However, waterborne carbon may already have been included in a country’s emission estimates if the country uses a methodology in which soil carbon stock changes are measured in situ (e.g., soil sampling associated with forest inventories).

Table 1.1 below provides guidance on which chapters of this *Wetlands Supplement* are relevant when the inventory compiler is considering methods for particular combinations of land use, soil type and soil condition. Where no guidance is provided in this *Wetlands Supplement* the table is blank. To estimate total greenhouse gas emissions from organic and wet soils correctly, this *Wetlands Supplement* should be used together with the *2006 IPCC Guidelines*.

TABLE 1.1
LOOK-UP TABLE FOR *WETLANDS SUPPLEMENT* BY LAND-USE CATEGORIES, SOIL TYPE AND CONDITION AND INLAND OR COASTAL LOCATION

Soil Type		Gas	Forest land		Cropland		Grassland		Wetlands		Settlements		Other Land	
			Inland	Coastal	Inland	Coastal	Inland	Coastal	Inland	Coastal	Inland	Coastal	Inland	Coastal
Mineral	Mineral Dry	CO_2	Refer to the 2006 IPCC Guidelines											
		CH_4												
		N_2O												
	Mineral Drained[3],	CO_2	5	4	5	4	5	4	5	4	5	4	5	4
		CH_4	5	4	5	4	5	4	5	4	5	4	5	4
		N_2O		4		4		4		4		4		4
	Mineral Wet	CO_2	5	4	5	4	5	4	5	4	5	4	5	4
		CH_4	5	4	5	4	5	4	5	4	5	4	5	4
		N_2O	5	4	5	4	5	4	5	4	5	4	5	4
Organic	Organic wet	CO_2	3	4	3	4	3	4	3	4	3	4	3	4
		CH_4	3	4	3	4	3	4	3	4	3	4	3	4
		N_2O	3	4	3	4	3	4	3	4	3	4	3	4
	Organic Drained	CO_2	2	4	2	4	2	4	2	4	2	4	2	4
		CH_4	2		2		2		2		2		2	
		N_2O	2		2		2		2		2		2	
	Constructed and Natural Wetlands for Wastewater treatment	The emission sources discussed in the *Wetlands Supplement* Chapter 6 provide guidance for the Waste Sector and do not impact on estimates of emissions and removals within AFOLU. However, the area of constructed wetlands should be reported as Wetlands, Settlements, or other land-use categories as appropriate and the impact on biomass, soil carbon and other pools may be considered. Care is required to avoid double-counting of emissions.												
	Emissions due to burning of organic soils	Chapter 2 in the *Wetlands Supplement* provides guidance for estimation of greenhouse gas emissions due to burning of organic soils. This guidance can be applied across all land use categories as appropriate where burning is reported as occurring.												
	DOC, DIC, PIC, POC	Chapter 2 in the *Wetlands Supplement* provides a discussion and some guidance on carbon loss from organic soils through water pathways. The information is relevant to all land use categories.												

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[3] Here “Mineral Drained” comprises drained inland wetland mineral soils subject to rewetting and drained coastal wetland mineral soils.

1.5 RELEVANT DATABASES FOR WETLANDS AND ORGANIC SOILS

To generate estimates of emissions and removals from wetlands and organic soils, inventory compilers will need to gather activity data and secondary data, such as soil type (organic or mineral), climate zone, wetland type, size, water table level, vegetation composition, and management practices. Guidance on data collection is provided in Chapter 2 in Volume 1 of the *2006 IPCC Guidelines*. It is *good practice* to focus these efforts on collecting data needed to improve estimates of *key categories*, which will vary by country depending on which emission sources are the largest, have the largest potential to change or have the greatest uncertainty. Chapters 2-6 of the *Wetlands Supplement* provide specific guidance on assembling the necessary activity data for implementation of the Tier 1 methodology as well as general guidance on activity data that may be necessary for implementation of higher tiers. Chapter 7 in the *Wetlands Supplement* provides general guidance for producing consistent times series when activity data are not available for all years.

Inventory compilers may be able to collect activity data from in-country natural resource agencies or national experts. To supplement in-country data, or if in-country data are not readily available, inventory compilers may use internationally available data. Table 1.2 below presents a list of online resources that may prove useful to inventory compilers in obtaining activity data for estimating greenhouse gas emissions and removals from the wetlands and organic soils included in this *Wetlands Supplement*. The most notable wetlands dataset is the Ramsar database of the Ramsar Convention. For most 'wetlands of international importance,' the Ramsar database provides relevant characteristics, including wetland type, area, elevation, persistence of water, salinity, soil type, land use inside and adjacent to the wetland, and vegetation types. In addition, the FAO provides a variety of metadata sets, including forestry, agriculture, and carbon emissions at a country scale. The United Nations Environment Programme (UNEP) in collaboration with the World Conservation Monitoring Centre (WCMC) has a collection of wetland atlases and offer open source geospatial data. Wetlands International is the only global NGO that focuses on wetland best practices, restoration and conservation. This organization has regional offices in all continents and has compiled a variety of data on wetlands and organic soils.

TABLE 1.2
GLOBAL AND REGIONAL ON-LINE RESOURCES THAT PROVIDE METADATA SETS FOR DEVELOPING AN INVENTORY OF GREENHOUSE GAS EMISSIONS AND REMOVALS FROM WETLANDS AND ORGANIC SOILS

Online Resources	**Description**
The Ramsar Convention on Wetlands http://www.ramsar.org	The Convention on Wetlands of International Importance, called the Ramsar Convention, is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. In 2013, this convention consists of 167 Contracting Parties, 2,122 wetlands of International Importance, and 205,366,160 hectares of wetlands designated as Ramsar sites.
FAOSTAT http://faostat3.fao.org/home/index.html	A large time series and cross section of data relating to hunger, commodity prices, foods, forestry, agriculture, and emissions for 245 countries and territories and 35 regional areas, from 1961 to the most recent year
United Nations Environment Programme and Word Conservation Monitoring Centre (UNEP-WCMC) http://www.unep-wcmc.org/datasets-tools--reports_15.html	This site provides a set of metadata on conservation in general. It also contains several atlases of wetlands, e.g. World Mangrove Atlas, and World Atlas of Seagrass.
GeoNetwork Open Source Geographic data sharing for everyone http://geonetwork.grid.unep.ch/geonetwork/srv/en/main.home	This site is managed by UNEP. It contains geographic metadata that can be freely requested.
Wetlands International http://www.wetlands.org/	Wetlands International is the only global not-for-profit organisation dedicated to the conservation and restoration of wetlands. This NGO also has several regional metadatasets, e.g. South Asia Wetlands, Australia Wetlands, etc.

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CHAPTER 2

DRAINED INLAND ORGANIC SOILS

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2.1 INTRODUCTION

Organic soils are defined in Chapter 3 Annex 3A.5 of Volume 4 of the *2006 IPCC Guidelines* and Section 5, Chapter 1, section 5 of this *Wetlands Supplement*. The guidance in this Chapter applies to all inland organic soils that have been drained, i.e., drainage of lands that started in the past and that still persists, or newly drained lands within the reporting period. This means that the water table level is at least temporarily below natural levels. Natural levels mean that the mean annual water table is near the soil surface but can experience seasonal fluctuations. Within each land-use category water table level is manipulated to varying degrees depending on land-use purpose, e.g., for cultivating cereals, rice, or for aquaculture, which can be reflected by different drainage classes.

This Chapter deals with inland organic soils, which do not meet the definition of "coastal" defined in Chapter 4 of this *Wetlands Supplement*.The term "organic soils" refers to "inland organic soils" in this Chapter.

This Chapter provides supplementary guidance on estimating greenhouse gas emissions and removals from drained inland organic soils in the following land-use categories as defined in the *2006 IPCC Guidelines* Volume 4: Chapter 4 (Forest Land), Chapter 5 (Cropland), Chapter 6 (Grassland), Chapter 7 (Wetlands), Chapter 8 (Settlements) and Chapter 9 (Other Land). Managed coastal organic soils are covered in Chapter 4 of this Supplement. Rewetted organic soils are considered in Chapter 3 of the *Wetlands Supplement*.

This Chapter clarifies Volume 4 of the *2006 IPCC Guidelines* by summarizing all emission factors and harmonizing the methods for organic soils in all land-use types. On the basis of recent advances in scientific information, this Chapter also updates, improves, and completes methodologies and emission factors for greenhouse gas emissions and removals of the *2006 IPCC Guidelines* and fills gaps where new scientific knowledge allows implementation of robust methodologies and use of better emission factors at the Tier 1 level.

This Chapter updates the *2006 IPCC Guidelines* for:

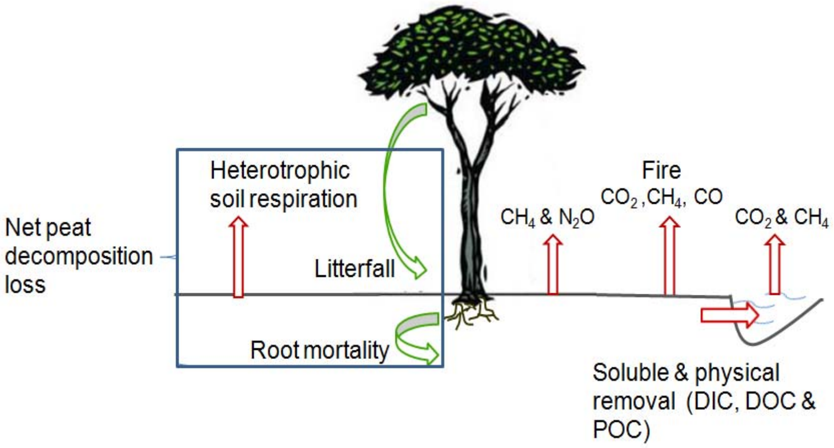
- CO_2 emissions and removals from drained organic soils (referring to Chapters 4 to 9, Volume 4, *2006 IPCC Guidelines*);
- CH_4 emissions from drained organic soils (referring to Chapter 7, Volume 4, *2006 IPCC Guidelines*);
- N_2O emissions from drained organic soils (referring to Chapter 11, Volume 4, *2006 IPCC Guidelines*).

This Chapter gives new guidance not contained in the *2006 IPCC Guidelines* by:

- providing methodologies and emission factors for CH_4 emissions from drainage ditches (referring to Chapters 4 to 9, Volume 4, *2006 IPCC Guidelines*);
- providing methodologies and emission factors for off-site CO_2 emissions associated with dissolved organic carbon (DOC) release from organic soils to drainage waters (referring to Chapters 4 to 9, Volume 4, *2006 IPCC Guidelines*);
- providing methodologies and emission factors for CO_2, CH_4 and CO emissions from peat fires

The chapter also contains an appendix that provides the basis for future methodological development for estimating CO_2 emissions associated with other forms of waterborne carbon loss, specifically particulate organic carbon (POC) and dissolved inorganic carbon (referring to Chapters 4 to 9)., Volume 4, *2006 IPCC Guidelines*). All fluxes are summarized in Figure 2.1.

Figure 2.1 Summary of fluxes from drained organic soils



2.2 LAND REMAINING IN A LAND-USE CATEGORY

The *2006 IPCC Guidelines* provide guidance for carbon stock changes in the carbon pools in above-ground and below-ground biomass, dead wood and litter as well as soil for managed land on organic soils. This Chapter updates the *2006 IPCC Guidelines* for the soil organic carbon pool in organic soils.

2.2.1 CO_2 emissions and removals from drained inland organic soils

This section deals with the impacts of drainage and management on CO_2 emissions and removals from organic soils due to organic matter decomposition and loss of dissolved organic carbon (DOC) in drainage waters. DOC losses lead to off-site CO_2 emissions. There are also erosion losses of particulate organic carbon (POC) and waterborne transport of dissolved inorganic carbon (primarily dissolved CO_2) derived from autotrophic and heterotrophic respiration within the organic soil. At present the science and available data are not sufficient to provide guidance on CO_2 emissions or removals associated with these waterborne carbon fluxes; Appendix 2a.1 provides a basis for future methodological development in this area. General information and guidance for estimating changes in soil carbon stocks are provided in Section 2.3.3, Chapter 2, Volume 4 in the *2006 IPCC Guidelines* which needs to be read before proceeding with the guidance provided here. This guidance is based on the observation that in drained organic soils, emissions persist as long as the soil remains drained or as long as organic matter remains (Wösten *et al.*, 1997; Deverel and Leighton, 2010).

Equation 2.3 in Chapter 2, Volume 4, *2006 IPCC Guidelines* refers to annual carbon stock changes for a stratum of a land-use category as a sum of changes in all pools. This section addresses the stratum of a land-use category on drained organic soils. The Equation is repeated here as Equation 2.1 to demonstrate how the guidance in this *Wetlands Supplement* links to the *2006 IPCC Guidelines*.

EQUATION 2.1
ANNUAL CARBON STOCK CHANGES FOR A STRATUM OF A LAND-USE CATEGORY AS A SUM OF CHANGES IN ALL POOLS
(EQUATION 2.3 IN THE CHAPTER 2, VOLUME 4, *2006 IPCC GUIDELINES*)

$$\Delta C_{LU_i} = \Delta C_{AB} + \Delta C_{BB} + \Delta C_{DW} + \Delta C_{LI} + \Delta C_{SO} + \Delta C_{HWP}$$

Where:

ΔC_{LU_i} = carbon stock changes for a stratum of a land-use category

Subscripts denote the following carbon pools:

AB = above-ground biomass

BB = below-ground biomass

DW = dead wood

LI = litter

SO = soils

HWP = harvested wood products

The guidance for the carbon pools above-ground biomass, below-ground biomass, deadwood, litter and harvested wood products in the *2006 IPCC Guidelines* is not further dealt with in these guidelines.

This section of the *Wetlands Supplement* updates and complements the guidance on drained organic soils component of ΔC_{SO}, which was called $L_{organic}$ in Equation 2.24, Chapter 2, Volume 4 of the *2006 IPCC Guidelines*. For transparent distinction between drained and rewetted organic soils, the term is further specified as $CO_2\text{-}C_{organic,\ drained}$ in Equation 2.2. $CO_2\text{-}C_{organic,\ drained}$ consists of on-site CO_2 emissions/removals of the organic soil from mineralization and sequestration processes ($CO_2\text{-}C_{\text{-}on\text{-}site}$), off-site CO_2 emissions from leached carbon from the organic soil ($CO_2\text{-}C_{DOC}$) and anthropogenic peat fires (L_{fire}). Countries are encouraged to consider particulate organic carbon (POC) when using higher tier methodologies (see Appendix 2a.1). CO_2 emissions from peat fires have not been explicitly addressed in Equation 2.3, Chapter 2, Volume 4 of the *2006 IPCC Guidelines*, but can be important on drained organic soils. Therefore, CO_2 emissions from peat fires are included in Equation 2.2 as L_{fire} (Section 2.2.2.3).

EQUATION 2.2
CO_2-C EMISSIONS/REMOVALS BY DRAINED ORGANIC SOILS

$$CO_2 - C_{organic,drained} = CO_2 - C_{on-site} + CO_2 - C_{DOC} + L_{fire} - CO_2 - C$$

Where:

$CO_2\text{-}C_{organic,\ drained}$ = CO_2-C emissions/removals by drained organic soils, tonnes C yr^{-1}

$CO_2\text{-}C_{on\text{-}site}$ = on-site CO_2-C emissions/removals by drained organic soils, tonnes C yr^{-1}

$CO_2\text{-}C_{DOC}$ = CO_2-C emissions from dissolved organic carbon exported from drained organic soils, tonnes C yr^{-1}

L_{fire}-CO_2-C = CO_2-C emissions from burning of drained organic soils, tonnes C yr^{-1}

2.2.1.1 ON-SITE CO_2 EMISSIONS/REMOVALS FROM DRAINED INLAND ORGANIC SOILS (CO_2-$C_{ON\text{-}SITE}$)

This section gives supplementary guidance for CO_2 emissions and removals from drained organic soils in all land-use categories as defined in Section 2.3.3, Chapter 2, Volume 4, of the *2006 IPCC Guidelines*. The IPCC land-use categories are discussed in Chapter 4 (Forest Land), Chapter 5 (Cropland), Chapter 6 (Grassland), Chapter 7 (Wetlands), Chapter 8 (Settlements) and Chapter 9 (Other Land). Flooded Lands (Chapter 7) are not included in this *Wetlands Supplement*.

Guidance is given for CO_2 emissions from the soil carbon pool in drained organic soils in line with the Section 3.3., Chapter 2, Volume 4 in the *2006 IPCC Guidelines*. Guidance for changes in the carbon pools in above-ground and below-ground biomass, dead wood, and litter on these lands is provided in the *2006 IPCC Guidelines* and remains unchanged.

CHOICE OF METHOD

The most important factors considered for estimating on-site CO_2 emissions and removals from drained organic soils are land-use and climate. Other factors such as nutrient status (or fertility) of the soil and drainage level affect emissions and can be considered where appropriate and with higher Tier methods. It is *good practice* to stratify land-use categories by climate domain (Table 4.1 , Chapter 4, Volume 4 of the *2006 IPCC Guidelines*), nutrient status (*GPG-LULUCF* and Section 7.2.1.1, Chapter 7, Volume 4 of the *2006 IPCC Guidelines*) and drainage class (shallow or deep) according to the stratification in Table 2.1.

Nutrient status is defined in *GPG-LULUCF* and *2006 IPCC Guidelines* (Section 7.2.1.1, Chapter 7, Volume 4). Generally, ombrogenic organic soils are characterized as nutrient poor, while minerogenic organic soils are characterized as nutrient rich. This broad characterization may vary by peatland type or national circumstances.

Drainage class is defined as the mean annual water table averaged over a period of several years; the shallow-drained class is defined as the mean annual water table depth of less than 30 cm below the surface; the deep-drained class is defined as the mean annual water table depth of 30 cm and deeper below the surface.

For Tier 1 methods, if the typical range of mean annual water table levels of drained organic soils for each land-use category is unknown, the default is that the organic soil is deep-drained (water-table depth is specific for land-use categories and climate domains) because deep-drained conditions are the most widespread and suitable for a wide range of management intensities. Higher Tier methods could further differentiate the drainage intensity within land-use categories if there are significant areas which differ from the default deep-drained conditions.

Figure 2.5 in, Section 2.3.3, Chapter 2, Volume 4 of the *2006 IPCC Guidelines* provides the decision tree for identification of the appropriate tier to estimate CO_2 emissions from drained organic soils by land-use category.

Tier 1

The basic methodology for estimating annual carbon loss from drained organic soils was presented in Section 2.3.3 and Equation 2.26 in Volume 4 of the *2006 IPCC Guidelines* as further specified in Equation 2.2. Equation 2.3 refers to $CO_2\text{-}C_{on\text{-}site}$ in Equation 2.2 with stratification of land-use categories by climate domain and nutrient status. Nutrient status and drainage classes only need to be differentiated for those land-use categories and climate domains for which emission factors are differentiated in Table 2.1.

At Tier 1, there is no differentiation between CO_2 emissions from long-term drained organic soils and organic soils after initial drainage or where drainage is deepened. High carbon loss from drained organic soils can occur immediately after initial drainage of organic soils (Hooijer *et al.*, 2012; Wösten *et al.*, 1997 Stephens *et al.*, 1984) even if land-use does not change. These $CO_2\text{-}C_{on\text{-}site}$ emissions in the transition phase are not captured by the Tier 1 default emission factors shown in Table 2.1, which were derived from data representing long-term land-uses present for decades in the boreal and temperate climate zones, and land-uses drained for more than 6 years in the tropical climate zone. A transitional phase is not captured by the Tier 1 methodology due to lack of data for deriving default emission factors. After initial drainage of organic soils and if a transitional phase occurs, it should be addressed by higher tier methods.

EQUATION 2.3

ANNUAL ON-SITE CO_2-C EMISSIONS/REMOVALS FROM DRAINED ORGANIC SOILS EXCLUDING EMISSIONS FROM FIRES

$$CO_2\text{-}C_{on-site} = \sum_{c,n,d} \left(A \bullet EF \right)_{c,n,d}$$

Where:

$CO_2\text{-}C_{on\text{-}site}$ = Annual on-site CO_2-C emissions/removals from drained organic soils in a land-use category, tonnes C yr^{-1}

A = Land area of drained organic soils in a land-use category in climate domain c, nutrient status n, and drainage class d, ha

EF = Emission factors for drained organic soils, by climate domain c, nutrient status n, and drainage class d, tonnes C ha^{-1} yr^{-1}

Tier 2

The Tier 2 approach for CO_2 emissions/removals from drained organic soils incorporates country-specific information in Equations 2.2 and 2.3 to estimate the CO_2 emissions/removals. Tier 2 uses the same procedural steps for calculations as provided for Tier 1. Improvements to the Tier 1 approach may include: 1) a derivation of country-specific emission factors; 2) specification of climate sub-domains considered suitable for refinement of emission factors; 3) a finer, more detailed classification of management systems with a differentiation of land-use intensity classes; 4) a differentiation by drainage classes; 5) differentiation of emission factors by time since drainage or the time since changes in drainage class, e.g. between emission factors reflecting additional emissions after deepening of drainage or new drainage and long-term stable water tables, or 6) a finer, more detailed classification of nutrient status, e.g., by nitrogen, phosphorus or pH.

It is *good practice* to derive country-specific emission factors if measurements representing the national circumstances are available. Countries need to document that methodologies and measurement techniques are compatible with the scientific background for the Tier 1 emission factors in Annex 2A.1. Moreover, it is *good practice* for countries to use a finer classification for climate and management systems, in particular drainage classes, if there are significant differences in measured carbon loss rates among these classes. Note that any country-specific emission factor must be accompanied by sufficient national or regional land-use/management activity and environmental data to represent the appropriate climate sub-domains and management systems for the spatial domain for which the country-specific emission factor is applied.

The general guidance of the *2006 IPCC Guidelines,* Section 2.3.3, Chapter 2, Volume 4 also applies here.

Tier 3

CO_2 emissions/removals from drained organic soils can be estimated with model and/or measurement approaches. Dynamic, mechanistic models will typically be used to simulate underlying processes while capturing the influence of land-use and management, particularly the effect of seasonally variable levels of drainage on decomposition (van Huissteden *et al.,* 2006). The general considerations for organic soils in the Section 2.3.3, Chapter 2, Volume 4 of the *2006 IPCC Guidelines* also apply here. It is *good practice* to describe the methodologies and models transparently, document the considerations for choosing and applying the model in the inventory and provide evidence that it represents the national circumstances according to the guidance in Section 5, Chapter 2, Volume 4 of the *2006 IPCC Guidelines*.

CHOICE OF EMISSION/REMOVAL FACTORS

Tier 1

All Tier 1 emission factors have been updated from the *2006 IPCC Guidelines* based on a large number of new measurement data in all land-use categories and climate zones. The new evidence allows for stratification of more land-use categories and climate domains by nutrient status than in the *2006 IPCC Guidelines*. In addition, temperate, nutrient-rich Grassland is further stratified into shallow-drained (less than approximately 30 cm below surface) and deep-drained. Within each land-use category, drained organic soils can experience a wide range of mean annual water table levels that depend upon regional climatic characteristics and specific land-use activity or intensity. For temperate Grassland EFs are given for shallow-drained and deep-drained soils. The shallow-drained and deep-drained Grassland emission factors differ significantly. Without additional national information about mean annual water table and/or land-use intensity as proxy, countries should choose deep-drained as default.

The *GPG-LULUCF* and *2006 IPCC Guidelines* (Section 7.2.1.1, Chapter 7, Volume 4) distinguish between nutrient-rich and nutrient-poor organic soils in some land-use categories and climate zones. This approach is maintained here, in line with guidance in the *2006 IPCC Guidelines*. For boreal nutrient-poor Forest Land two alternative emission/removal factors are given in Table 2.1 and countries need to choose the one that matches their national land-use definition.

Default Tier 1 emission/removal factors for drained organic soils (Table 2.1) were generated using a combination of subsidence and flux data found in the literature as described in Annex 2A.1. CO_2-C losses occur predominantly in the drained, oxic soil layer and thus reflect human-induced CO_2-C fluxes. The part of the soil profile affected by drainage can be deeper or shallower than the default 0 to 30 cm layer considered in the Tier 1 default methodology for SOC pools in mineral soils.

TABLE 2.1
TIER 1 CO_2 EMISSION/REMOVAL FACTORS FOR DRAINED ORGANIC SOILS IN ALL LAND-USE CATEGORIES*

Land-use category		**Climate / vegetation zone**	**Emission Factor[a] (tonnes CO_2-C ha^{-1} yr^{-1})**	**95% Confidence Interval[b]**		**No. of sites**	**Citations/comments**
Forest Land, drained, including shrubland and drained land that may not classify as forest[c]	Nutrient-poor	Boreal	0.37	-0.11	0.84	63	Lohila *et al.*, 2011; Minkkinen & Laine, 1998; Minkkinen *et al.*, 1999; Ojanen *et al*,. 2010, 2013; Simola *et al.*, 2012
Forest Land, drained[d]	Nutrient-poor	Boreal	0.25	-0.23	073	59	Lohila *et al.*, 2011; Minkkinen & Laine, 1998; Minkkinen *et al.*, 1999; Ojanen *et al*,. 2010, 2013; Simola *et al.*, 2012
	Nutrient-rich	Boreal	0.93	0.54	1.3	62	Laurila *et al.*, 2007 ; Lohila *et al.*, 2007; Minkkinen & Laine, 1998; Minkkinen *et al.*, 1999, 2007b; Ojanen *et al.*, 2010, 2013; Simola *et al.*, 2012
Forest Land, drained		Temperate	2.6	2.0	3.3	8	Glenn *et al.*, 1993; Minkkinen *et al.*, 2007b; Von Arnold *et al.*, 2005a,b, Yamulki *et al.*, 2013
Forest Land and cleared Forest Land (shrubland[e]), drained		Tropical	5.3	-0.7	9.5	21	Ali *et al.*, 2006; Brady, 1997; Chimner & Ewel, 2005; Comeau *et al.*,2013; Dariah *et al.*, 2013; Darung *et al.*, 2005; Furukawa *et al.*, 2005; Hadi *et al.*, 2005; Harisson *et al.*, 2007; Hergoualc'h & Verchot, 2011; Hertel *et al.*, 2009; Hirano *et al.*, 2009, 2012; Inubushi *et al.*, 2003; Ishida *et al.*, 2001; Jauhiainen *et al.*, 2008, 2012a; Melling *et al.*, 2005a, 2007a; Rahaoje *et al.*, 2000; Shimamura & Momose, 2005; Sulistiyanto, 2004; Sundari *et al.*, 2012
Plantations, drained, unknown or long rotations[f]		Tropical	15	10	21	n/a.	Average of emission factors for *Acacia* and oil palm
Plantations, drained, short rotations, e.g. *Acacia*[f, g],		Tropical	20	16	24	13	Basuki *et al.*, 2012; Hooijer *et al.*, 2012; Jauhiainen *et al.*, 2012a; Nouvellon *et al.*, 2012; Warren *et al.*, 2012
Plantations, drained,.oil palm[f]		Tropical	11	5.6	17	10	Comeau *et al.*, 2013; Dariah *et al.*, 2013; DID and LAWOO, 1996; Henson and Dolmat, 2003; Hooijer et al., 2012; Couwenberg, and Hooijer 2013; Lamade and Bouillet, 2005; Marwanto and Agus,

						2013; Melling *et al.,* 2005a, 2007a, 2013; Warren *et al.,* 2012
Plantations, shallow drained (typically less than 0.3 m), typically used for agriculture, e.g. sago palm[f]	Tropical	1.5	-2.3	5.4	5	Dariah *et al.*, 2013; Hairiah *et al.*, 1999; Ishida *et al.*, 2001; Lamade and Bouillet, 2005; Matthews *et al.*, 2000; Melling *et al.,* 2005a, 2007a; Watanabe *et al.,* 2009
Cropland, drained	Boreal & Temperate	7.9	6.5	9.4	39	Drösler *et al.,* 2013; Elsgaard *et al.,* 2012, Grønlund *et al.,* 2008, Kasimir-Klemedtsson *et al.,* 1997; Leifeld *et al.,* 2011; Maljanen *et al.,* 2001a, 2003a, 2004, 2007a; Morrison *et al.,* 2013b, Petersen *et al*. 2012
Cropland and fallow, drained	Tropical	14	6.6	26	10	Ali *et al.,* 2006; Chimner, 2004; Chimner & Ewel, 2004; Dariah *et al.*, 2013; Darung *et al.,* 2005; Furukawa *et al.*, 2005; Gill and Jackson, 2000; Hairiah *et al.,* 2000; Hirano *et al.,* 2009; Ishida *et al.*, 2001; Jauhiainen *et al.*, 2012; Melling *et al.*, 2007a;
Cropland, drained – paddy rice	Tropical	9.4	-0.2	20	6	Dariah *et al.*, 2013; Furukawa et *al.*, 2005; Hadi *et al.*, 2005; Hairiah *et al.*, 1999; Inubushi *et al.*, 2003; Ishida *et al.*, 2001; Matthews *et al.*, 2000; Melling *et al.*, 2007a
Grassland, drained	Boreal	5.7	2.9	8.6	8	Grønlund *et al.,* 2006; Kreshtapova & Maslov, 2004; Lohila *et al.,* 2004; Maljanen *et al.,* 2001a, 2004; Nykänen *et al.,* 1995; Shurpali *et al.,* 2009
Grassland, drained, nutrient-poor	Temperate	5.3	3.7	6.9	7	Kuntze, 1992; Drösler *et al.,* 2013
Grassland, deep-drained, nutrient- rich	Temperate	6.1	5.0	7.3	39	Augustin, 2003; Augustin *et al*., 1996; Czaplak & Dembek, 2000; Drösler *et al*., 2013; Elsgaard *et al.,* 2012; Höper, 2002; Jacobs *et al.,* 2003; Kasimir-Klemedtsson *et al.,* 1997; Langeveld *et al.,* 1997; Leifeld *et al.,* 2011; Lorenz *et al.,* 1992; Meyer *et al.,* 2001; Nieveen *et al.,* 2005; Okruszko 1989 ; Schothorst, 1977 , Schrier-Uijl, 2010a, c; Veenendaal *et al.,*2007; Weinzierl, 1997
Grassland, shallow drained, nutrient-rich	Temperate	3.6	1.8	5.4	13	Drösler *et al.,* 2013; Jacobs *et al.,* 2003 ; Lloyd, 2006

Grassland, drained	Tropical	9.6	4.5	17	n/a.	Updated from Table 6.3, Chapter 6, Volume 4, *2006 IPCC Guidelines* [h]
Peatland Managed for Extraction[i]	Boreal & Temperate	2.8	1.1	4.2	20	Ahlholm and Silvola 1990; Glatzel *et al.,* 2003,; McNeil and Waddington 2003; Shurpali *et al.,* 2008; Strack and Zuback 2013; Sundh *et al.*, 2000; Tuittila and Komulainen, 1995; Tuittila *et al.,* 2000; 2004, Waddington *et al.*, 2010
Peatland Managed for Extraction[i]	Tropical	2.0	0.06	7.0	n/a.	Table 7.4, Chapter 7, Volume 4, *2006 IPCC Guidelines*
Settlements	All climate zones	There is no fixed default emission/removal factor for Settlement. It is *good practice* to take the default emission/removal factor in Table 2.1 of the land-use category that is closest to the national conditions of drained organic soils under Settlements. Information about national conditions could include drainage level, vegetation cover, or other management activities. For example, drained organic soils in urban green areas, parks or gardens could use the default Tier 1 emission/removal factor for Grassland, deep-drained in Table 2.1.				
Other Land	All climate zones	*Other Land Remaining Other Land*: 0 *Land Converted to Other Land*: Maintain emission factor of previous land-use category				

[a] Mean

[b] Some confidence intervals contain negative values.These were mathematically calculated based on error propagation of uncertainties. All underlying CO_2 fluxes, however, were positive.

[c] Forest broader than FAO definition

[d] Forest according to FAO definition

[e] Shrubland refers to any type of land sparsely or fully covered with shrubs or trees, which may fulfil the national forest definition. It extends to degraded lands, which cannot be clearly classified as forest or non-forest.

[f] Plantations are reported under land-use categories acccording to national land use definitions.

[g] Number derived solely from Acacia plantation data.

[h] The emission factor for Cropland in the tropical zone was multiplied with the ratio between the emission factors for Grassland, drained, nutrient-poor and Cropland for the temperate zone; same for confidence interval. This new ratio updates the ratio applied to derive the emission factor for Grassland in the tropical zone in Table 6.3, Chapter 6, Volume 4, *2006 IPCC Guidelines.*

[i] On-site CO_2–C emissions from drained peat deposits only. For off-site CO_2–C emissions from peat extracted for horticultural or energy use see Chapter 7, Volume 4, *2006 IPCC Guidelines.*

Common tropical plantations include oil palm, sago and *Acacia crassicarpa*. In Table 2.1, plantations are not allocated to a specific land-use category. It is *good practice* to report plantations in the appropriate national land-use category according to national land use definitions. Commonly, national land-use definitions classify timber and fibre plantations as Forest Land and oil palm or sago palm plantations as Cropland.

Tier 2

The Tier 2 approach for carbon loss from drained organic soils incorporates country-specific information in Equation 2.2 to estimate the emissions. Also, Tier 2 uses the same procedural steps for calculations as provided for Tier 1. Tier 2 emission factors by land-use category can, in general, be developed depending on a) climate, b) drainage layout and intensity, c) nutrient status and d) land-use intensity and practices.

Tier 2 emission factors could include the following refinements:

- Use of country specific emission factors measured or calculated locally taking into account climatic factors that provide for wetter or drier drainage classes than those defined here;
- Use of country specific emission factors measured or calculated locally taking into account slope factors (e.g., blanket bogs) that may promote wetter or drier drainage classes than those defined here;
- Derivation of emission factors for boreal Forest Land by nutrient status (rich/poor) if the two EFs are significantly different (See Table 2.1);
- Development of boreal and temperate Grassland emission factors according to land-use intensity, for example to distinguish high-intensity (fertilized, ploughed and reseeded) Grassland from low-intensity permanent Grassland, or moorland rough grazing (grazing by hardier breeds of sheep) on drained blanket bogs.
- Integration of temporal dynamics associated with changes in decomposition rates that may be related to, drainage, management or the physical and chemical changes to peat over time, including a possible transition period of high emissions associated with drainage or deepening of drainage in lands remaining in a landuse category.

CO_2 measurements by methods described in Annex 2A.1, disaggregated by management practices, should be used to develop more precise, locally appropriate emission factors. CO_2 flux measurements do not take account of waterborne carbon losses, which must therefore be considered separately. In contrast, subsidence based measurements effectively incorporate waterborne carbon losses in the estimated stock change. This methodological difference has to be considered when developing higher tier methods to avoid double counting.Tier 3

A Tier 3 approach allows for a variety of methods and might use measurements or process-based models or other more elaborate approaches, adequately validated using observation data that take into account temporal and spatial variations. Tier 3 should involve a comprehensive understanding and representation of the dynamics of CO_2 emissions and removals on drained organic soils, including the effect of management practices, site characteristics, peat type and depth, drainage depth, etc. Tier 3 approaches could start by developing relationships between drainage or nutrient status and heterotrophic CO_2 emissions, which can be further refined by land-use category and fertilization. Furthermore, organic soils in Forest Land undergo a cycle related to rotation of the tree cohorts and carbon losses associated with harvesting and site preparation should be accounted. Models could describe the rotational variation in water tables.

When peat is extracted, the peatland surface is disturbed by machinery and may be fertilized afterwards or otherwise amended for regeneration. Moreover, drainage systems may be renewed and dredging of ditches may cause disturbances that alter the greenhouse gas emissions and removals. These measures result in emission/removal rates that vary predictably over time, which may in Tier 3 methods be captured by models used. Emissions from stockpiles of drying peat 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. Methods for estimating this emission may be developed at Tier 3.

CHOICE OF ACTIVITY DATA

All management practices for land remaining in a land-use category are assumed to result in persistent emissions from soils as long as the management system remains in place or as long as the land falls under the definition of organic soils. Activity data consist of areas of land remaining in a land-use category on organic soils stratified by climate domains, soil nutrient status, drainage class or additional criteria such as management practices. Total areas should be determined according to approaches laid out in Chapter 3, Volume 4 of the *2006 IPCC Guidelines* and should be consistent with those reported under other sections of the inventory. The estimation of CO_2 emissions/removals from drained organic soils will be greatly facilitated if this information can be used in conjunction with national soils and climate data, vegetation inventories, and other biophysical data. Stratification of land-use categories according to climate domains, based on default or country-specific classifications can be accomplished with overlays of land-use on suitable climate and soil maps.

Under most circumstances, the area of organic soils will remain constant over time. However, the area of organic soils may change as organic soil disappears following drainage.

Tier 1

The Tier 1 approach requires area data of drained organic soils for each land-use category, disaggregated by appropriate climate domains, nutrient status and drainage class as applicable. Classification systems for activity data that form the basis for a Tier 1 inventory are provided in the respective land-use chapters of the *2006 IPCC Guidelines*.

Several institutions, including ISRIC and FAO have country-specific and global maps that include organic soils (http://www.fao.org/geonetwork/srv/en/main.home or http://www.isric.org/). A global consortium has been formed to make a new digital soil map of the world at fine resolution (http://www.globalsoilmap.net/).

The *GPG-LULUCF* and *2006 IPCC Guidelines* (Section 7.2.1.1, Chapter 7, Volume 4) distinguish between nutrient-rich and nutrient-poor organic soils in some land-use categories and climate zones. This approach is maintained here, in line with guidance in the *2006 IPCC Guidelines*. Nutrient-poor organic soils predominate in boreal regions, while in temperate regions nutrient-rich organic soils are more common. It is *good practice* that boreal countries that do not have information on areas of nutrient-rich and nutrient-poor organic soils should use the emission factor for nutrient-poor organic soils. It is *good practice* that temperate countries that do not have such data use the emission factor for nutrient-rich organic soils. Only one default factor is provided for tropical regions, so disaggregating by soil fertility is not necessary in the tropical climate zone using the Tier 1 method. Due to lack of data, rice fields on tropical organic soils are not disaggregated by water management regimes.

The areas of shallow-drained and deep-drained organic soils with Grasslands need to be derived from national data. Data from water management plans, such as target water table levels can serve as a source of information. Land-use intensity, e.g., the time of the first cut of Grassland, grazing intensity or animal production levels can serve as a proxy as well as restrictions imposed by water management or biodiversity management (e.g. riparian zones, buffer zones, nature conservation for species or habitats with typical water regime).

Without additional national information about mean annual water table and/or land-use intensity as proxy, countries should choose deep-drained as the default.

Tier 2 and 3

Activity data for higher Tier estimates are generally derived following the methods presented in Chapter 3 of Volume 4 of the *2006 IPCC Guidelines* Activity data may be spatially explicit and could be disaggregated by type of management, drainage depth, and/or nutrient status to improve the accuracy of the inventory if different land management systems use different drainage depths and/or nutrient levels, and if appropriate emissions factors are available. In general, practices that increase carbon stocks in mineral soils by increased organic material input (fertilization, liming, etc.) do not have a sequestration effect in drained organic soils.

The combination of land-use databases and soil maps or spatially explicit data allow delineation of combinations of land-use categories, climate domains, drainage classes and management systems and their changes over time on organic soils. Data and their documentation could combine information from a land-use transition matrix specifically made for organic soils. Stratification needs to be consistently applied across the entire time series.

Information sources about drainage with adequate disaggregation may include:

- National land-use statistics, land-use maps and soil maps, maps of water and nature conservation zones with restrictions for water management, wetlands.
- National water management statistics: in most countries, the agricultural land base including Cropland is usually surveyed regularly, providing data on distribution of different land-uses, crops, tillage practices and other aspects of management, often at sub-national regional level. These statistics may originate, in part, from remote sensing methods, from which additional information about wetness or periods with seasonal flooding could be extracted.
- Inventory data from a statistically-based, plot-sampling system of water table wells, ditches and surface waters on organic soils: water table is monitored at specific permanent sample plots either continuously or on plots that are revisited on a regular basis. It has to be documented that the water data represent the water table in the organic soil and for what land-use and drainage stratum and that the data cover a representative period, which represents a multi-year mean annual water table.
- Water management plans and documentation from water management installations.
- Drainage maps.

- Maps of drainage or (partial) rewetting projects including remote sensing.

CALCULATION STEPS FOR TIER 1

The steps for estimating the direct loss of soil carbon from drained organic soils are as follows:

Step 1: Determine areas with drained organic soils under each land-use category, disaggregated by climate domain and other appropriate factors as outlined above. Where needed for Tier 1 emission factors, land areas are further stratified by nutrient-rich and nutrient-poor organic soils. Temperate nutrient-rich Grassland is further stratified into shallow-drained and deep-drained classes.

Step 2: Assign the appropriate emission factor (EF) from Table 2.1 for annual losses of CO_2 to each land-use category, climate domain, nutrient status and drainage class stratum.

Step 3: Multiply each area with the appropriate emission factor using Equations 2.3.

UNCERTAINTY ASSESSMENT

Three broad sources of uncertainty exist in estimating emissions and removals in organic soils: 1) uncertainties in land-use and management activity and environmental data; 2) uncertainties in the emission/removal factors for Tier 1 or 2 approaches; and 3) model structure/parameter error for Tier 3 model-based approaches, or measurement error/sampling variability associated with Tier 3 measurement-based inventories. In general, precision of an inventory is increased and confidence ranges are smaller with more sampling to estimate values for land-use categories, while accuracy is more likely to be increased through implementation of higher Tier methods that incorporate country-specific information.

For Tier 1, the default uncertainty level of emissions/removal factors is the 95% confidence interval in Table 2.1. Countries developing specific emission factors for their inventories at higher tiers should assess the uncertainty of these factors.

If using aggregate land-use area statistics for activity data (e.g., FAO data), the inventory agency may have to apply a default level of uncertainty for the land area estimates on organic soils (±20%; twice the uncertainty estimate in Table 3.7 for mineral soils in the 2006 Guidelines). It is *good practice* for the inventory compiler to derive uncertainties from country-specific activity data instead of using a default level of uncertainty. Uncertainties in activity data may be reduced through a better monitoring system, such as developing or extending a ground-based survey with additional sample locations and/or incorporating remote sensing to provide additional coverage. Uncertainties in activity data and emission/removal factors need to be combined using an appropriate method, such as simple error propagation equations. Details are given in Chapter 3, Volume 1 of the *2006 IPCC Guidelines* and Chapter 5 of *GPG-LULUCF.*

Accuracy can be increased by deriving country-specific factors using a Tier 2 method or by developing a Tier 3 country-specific estimation system. The underlying basis for higher tier approaches will be measurements in the country or neighbouring regions that address the effect of land-use and management on CO_2 emissions/removals from drained organic soils. In addition, uncertainties can be reduced through stratification by significant factors responsible for within-country differences in land-use and management impacts, such as variation among climate domains and/or organic soil types.

2.2.1.2 OFF-SITE CO_2 EMISSIONS VIA WATERBORNE CARBON LOSSES FROM DRAINED INLAND ORGANIC SOILS

Waterborne carbon comprises dissolved organic carbon (DOC), particulate organic carbon (POC), the dissolved gases CO_2 and CH_4, and the dissolved carbonate species HCO_3^- and CO_3^{2-}. Particulate inorganic carbon (PIC) losses are negligible from organic soils. Collectively, waterborne carbon export can represent a major part of the overall carbon budget of an organic soil, and in some cases can exceed the net land-atmosphere CO_2 exchange (e.g., Billett *et al.,* 2004; Rowson *et al.,* 2010). It is therefore important that waterborne carbon is included in flux-based (i.e., gain-loss) approaches for soil carbon estimation, to avoid systematic under-estimation of soil carbon losses. Airborne (erosional) POC loss may also be significant where land-use leads to bare soil exposure, but few data exist to quantify this (see Appendix 2a.1).

Different forms of waterborne carbon have different sources, behaviour and fate, and different approaches are therefore required to quantify the off-site CO_2 emissions associated with each form. In most peatlands and organic soils, DOC forms the largest component of waterborne carbon export (e.g., Urban *et al.,* 1989; Dawson *et al.,* 2004; Jonsson *et al.,* 2007; Dinsmore *et al.,* 2010). DOC export can be affected by land-use, in particular drainage (Wallage *et al.*, 2006; Strack *et al.*, 2008; Urbanová *et al.*, 2011; Moore *et al.*, 2013). It is reactive within aquatic ecosystems and most DOC is thought to be ultimately converted to CO_2 and emitted to the atmosphere (see Annex 2A.2 for supporting discussion). Therefore, it is *good practice* to include DOC export in CO_2 reporting, and a Tier 1 methodology is described below.

Of the other forms of waterborne carbon, POC fluxes are typically very low from vegetated peatlands and organic soils, but can become very large where bare organic soil becomes exposed, e.g., due to erosion, peat extraction, burning and conversion to Cropland. Although it may be possible to estimate POC loss fluxes as a function of bare soil exposure, high uncertainty remains regarding the reactivity and fate of POC exported from organic soils. Some POC is likely to be converted to CO_2, but POC that is simply translocated from the soil profile to other stable carbon stores, such as freshwater or marine sediments, may not lead to CO_2 emissions. Due to the uncertain fate of POC export, an estimation method is not presented at this time; current knowledge and data needs to support POC estimation in future are described in Appendix 2a.1.

Gaseous CO_2 and CH_4 dissolved in water transported laterally from the organic soil matrix represent indirectly emitted components of the total emission of these gases from the land surface. Dissolved CO_2 in excess of atmospheric pressure will also be degassed from drainage waters, whilst some dissolved inorganic carbon (DIC) may be transported downstream. At present, available data are insufficient (particularly from drained organic soils) to permit default emission factors to be derived. Additional information and future methodological requirements to support full accounting of emissions associated with waterborne inorganic carbon are included in Appendix 2a.1.

CHOICE OF METHOD

The basic methodology for estimating annual off-site CO_2 emissions associated with waterborne carbon loss from drained organic soils is presented in Equation 2.4:

EQUATION 2.4
ANNUAL OFF-SITE CO_2 EMISSIONS DUE TO DOC LOSS FROM DRAINED ORGANIC SOILS (CO_2)

$$CO_2\text{–}C_{DOC} = \sum_{c,n} \left(A \bullet EF_{DOC} \right)_{c,n}$$

Where:

CO_2-C_{DOC} = Annual off-site CO_2-C emissions due to DOC loss from drained organic soils, tonnes C yr^{-1}

$A_{c,\,n}$ = Land area of drained organic soils in a land-use category in climate zone c and nutrient status n, ha

$EF_{DOCc,n}$ = Emission factors for annual CO_2 emissions due to DOC loss from drained organic soils, by climate zone c and nutrient status n, tonnes C ha^{-1} yr^{-1}

EF_{DOC} can be calculated from Equation 2.5:

EQUATION 2.5
EMISSION FACTOR FOR ANNUAL CO_2 EMISSIONS DUE TO DOC EXPORT FROM DRAINED ORGANIC SOILS

$$EF_{DOC} = DOC_{FLUX\_NATURAL} \bullet \left(1 + \Delta DOC_{DRAINAGE}\right) \bullet Frac_{DOC-CO_2}$$

Where:

EF_{DOC} = Emission factor for DOC from a drained site, tonnes C ha^{-1} yr^{-1}

$DOC_{FLUX\_NATURAL}$ = Flux of DOC from natural (undrained) organic soil, tonnes C ha^{-1} yr^{-1}

$\Delta DOC_{DRAINAGE}$ = Proportional increase in DOC flux from drained sites relative to un-drained sites

$Frac_{DOC\text{-}CO_2}$ = Conversion factor for proportion of DOC converted to CO_2 following export from site

Because of the lack of data for other components of waterborne carbon fluxes and uncertainty about their sources and/or fate, off-site CO_2 emissions associated with waterborne carbon are only represented by DOC losses at this stage. However, if in the future adequate data become available or if adequate data are available for higher tiers, inventory compilers can expand Equation 2.4 to include POC and/or DIC (See section on methodological requirements in Appendix 2a.1).

CHOICE OF EMISSION FACTOR

Tier 1

A detailed description of the derivation of default values for Tier 1 is provided in Annex 2A.2. In summary, measurements show clear differentiation of natural DOC fluxes between boreal, temperate and tropical organic soils, and Tier 1 emission factors therefore follow a broad classification based on climate zones. Annex 2A.2 provides details and data sources for the derivation of parameter values. Note that a single default value for $\Delta DOC_{DRAINAGE}$ is currently proposed for all organic soil/land-use types, based on data from a range of studies undertaken in different climate zones. A substantial body of scientific evidence indicates a high conversion of organic soil-derived DOC to CO_2 in aquatic systems, on which basis a default $Frac_{DOC\text{-}CO_2}$ value of 0.9 (± 0.1) is proposed (see Annex 2A.2).

TABLE 2.2
DEFAULT DOC EMISSION FACTORS FOR DRAINED ORGANIC SOILS

Climate zone	$DOC_{FLUX\_NATURAL}$ (t C ha^{-1} yr^{-1})	$\Delta DOC_{DRAINAGE}$ [a]	$Frac_{DOC\text{-}CO_2}$	$EF_{DOC\_DRAINED}$ (t C ha^{-1}yr^{-1})
Boreal	0.08 (0.06-0.11)	0.60 (0.43-0.78)	0.9 (± 0.1)	0.12 (0.07-0.19)
Temperate	0.21 (0.17-0.26)			0.31 (0.19-0.46)
Tropical	0.57 (0.49-0.64)			0.82 (0.56-1.14)

Values shown in parentheses represent 95% confidence intervals. For data sources and supporting references see Tables 2A.2 and 2A.3.

[a] Due to the limited number of available studies, a single Tier 1 value for $\Delta DOC_{DRAINAGE}$ has been assigned to all soil types based on all available comparisons of drained and undrained sites. For fens, there is more uncertainty associated with the estimation of DOC flux changes after drainage, therefore countries may choose to apply values of $DOC_{FLUX\_NATURAL}$ given above (multiplied by $Frac_{DOC\text{-}CO_2}$ but assuming $\Delta DOC_{DRAINAGE} = 0$) or to obtain direct measurements of the DOC flux from drained sites.

Tier 2

A Tier 2 approach for estimation of DOC may follow the Tier 1 methodology provided above, but should use country–specific information where possible to refine the emission factors used. Possible refinements where supporting data are available could include:

- Use of country-level measurements from natural (undrained) organic soils to obtain accurate values of $DOC_{FLUX\text{-}NATURAL}$ for that country, for example by developing specific values for raised bogs versus fens, or for blanket bogs;
- Use of country-level data on the impacts of organic soil drainage on DOC flux to derive specific values of $\Delta DOC_{DRAINAGE}$ that reflect local organic soil types, and the nature of drainage practices and subsequent land-use. If sufficient, robust, direct measurements are available from representative drained sites, these may be used to estimate DOC fluxes from drained sites, replacing $DOC_{FLUX\_NATURAL}$ in Equation 2.5. Specific DOC flux estimates from drained organic soils in different land-use categories could also be considered where data support this level of stratification;
- Use of alternative values for $Frac_{DOC\text{-}CO2}$ where evidence is available to estimate the proportion of DOC exported from drained organic soils that is transferred to stable long-term carbon stores, such as lake or marine sediments.

Tier 3

A Tier 3 approach might include the use of more detailed data to develop and apply process models that describe DOC release as a function of vegetation composition, nutrient levels, land-use category, water table level and hydrology, as well as temporal variability in DOC release in the years following land-use change (e.g. initial drainage) and on-going management activity (e.g., drain maintenance, forest management) (see Annex 3A.2, Chapter 3 of the *Wetlands Supplement*).

Guidance is not currently presented for the effects of land-use other than drainage on DOC loss from peatlands and organic soils, for example the effects of managed burning or intensity of agricultural use. However, these may be included in higher tier methods if sufficient evidence can be obtained to develop the associated emission factors.

CHOICE OF ACTIVITY DATA

Tier 1

Activity data consist of areas of land remaining in a land-use category on drained organic soils summarised by organic soil type, climate zones and land-use type (specifically occurrence of drainage). Total areas should be determined according to Approaches laid out in Chapter 3 of Volume 4 of the *2006 IPCC Guidelines* and should be consistent with those reported under other sections of the inventory. They also need to be consistent with activity data for on-site CO_2 emissions. For boreal and temperate raised bogs and fens, additional data on annual mean precipitation may be used to refine emission estimates, as shown in Table 2.2.

Tier 2 and 3

For higher Tier approaches, additional activity data requirements may include specific information on the land-use type associated with drained organic soils, and intensity of drainage. Use of a variable $Frac_{DOC\text{-}CO_2}$ value at a country level, or within a country, would require information on the characteristics of downstream river networks (e.g., water residence time, extent of lakes and reservoirs, lake sedimentation rates). A Tier 3 modelling approach could include additional information on the timing of drainage, drain maintenance and land-management (e.g., forest management, influence of fertiliser application rates on DOC production).

CALCULATION STEPS FOR TIER 1

The steps for estimating the off-site emissions from soil carbonon drained organic soils are as follows:

Step 1: Determine areas with drained organic soils under each land-use category for land remaining in a land-use category, disaggregated by climate domain and other appropriate factors as outlined above.

Step 2: Assign the appropriate values for $DOC_{FLUX\_NATURAL}$, $\Delta DOC_{DRAINAGE}$ $Frac_{DOC\text{-}CO_2}$ from Table 2.2 for each land-use category and climate domain.

Step 3: Calculate EF_{DOC} for each land-use category using Equation 2.5

Step4: Multiply activity data by the emission factor for each land-use category and sum across land-use categories.

UNCERTAINTY ASSESSMENT

Three broad sources of uncertainty exist in estimating off-site emissions and removals: 1) uncertainties in land-use and management activity and environmental data; 2) uncertainties in the emission/removal factors for Tier 1 or 2 approaches; and 3) uncertainties in the fraction of DOC that is emitted as CO_2. In general, precision of an inventory is increased and confidence ranges are smaller with more sampling to estimate values for these categories, while accuracy is more likely to be increased through implementation of higher tier methods that incorporate country-specific information.

Uncertainties for land use and management activities are the same as for on-site emissions and will not be repeated here. Uncertainty ranges (95% confidence intervals) are provided for DOC emission factors in Table 2.2. These ranges are calculated from literature data in Annex 2A.2 based on observations from natural peatlands used to derive values of $DOC_{FLUX\text{-}NATURAL}$ in each of the peat classes used (Table 2A.2); observations of $\Delta DOC_{DRAINAGE}$ from published studies (Table 2A.3); and an uncertainty range for $Frac_{DOC\text{-}CO_2}$ value of 0.8 to 1.0 as described above. These uncertainty ranges may be adapted or refined under Tier 2 if further sub-classification according to land-use type or intensity is undertaken, based on additional measurement data.

2.2.2 Non-CO_2 emissions and removals from drained inland organic soils

In the *2006 IPCC Guidelines*, CH_4 emissions were assumed to be negligible from all drained organic soils. Here new methodologies and emission factors are provided for soil CH_4 emissions from drained organic soils and drainage ditches (Section 2.2.2.1).

2.2.2.1 CH_4 emissions and removals from drained inland organic soils

In the *2006 IPCC Guidelines*, CH_4 emissions were assumed to be negligible from all drained organic soils. However, recent evidence suggests that some CH_4 emissions can occur from the drained land surface, and also from the ditch networks constructed during drainage. Each of these emission pathways is considered here (Best and Jacobs, 1997; Minkkinen and Laine 2006; Schrier-Uijl *et al.,* 2011; Hyvönen *et al.,* 2012).

Drainage lowers the water table and exposes formerly saturated organic soil layers to oxidation and, as described above, increases CO_2 emissions from the land surface. Drainage alters environmental factors such as temperature, reduction–oxidation potential, and the amount of easily decomposable organic matter. Drainage also affects the activity of methanogens and methanotrophs (Blodau, 2002; Treat *et al.,* 2007). Drainage increases plant root respiration and mitigates CH_4 emission dramatically (Martikainen *et al.,* 1995a; Strack *et al.*, 2004; Hergoualc'h and Verchot, 2012) as the methanogenic bacteria thrive only in anoxic conditions. Shifts in vegetation with dominant aerenchymous species to other vegetation types will also reduce the transfer of methane from the soil profile to the atmosphere (e.g., Tuittila *et al*., 2000). In general, when the organic soil is drained the natural production of CH_4 is reduced and organic soils may even become a CH_4 sink, once methanotrophs dominate the CH_4 cycle.

Ditch networks provide a further source of CH_4 emissions from drained organic soils. This occurs due to a combination of lateral CH_4 transfer from the organic soil matrix, and in-situ CH_4 production within the ditches themselves (e.g., Roulet and Moore, 1995; Van den Pol 1999c; Van Dasselaar *et al.,* 1999a; Sundh *et al.,* 2000; Minkkinen and Laine, 2006; Teh *et al.,* 2011; Vermaat *et al.,* 2011). These emissions may approach, or even exceed, the CH_4 flux from an undrained organic soil when averaged over the land surface (Roulet and Moore, 1995; Schrier-Uijl *et al.,* 2011). Emission/removal factors for ditch CH_4 emissions were compiled from available published literature (See Annex 2A.1). We present only general factors for ditches because of limited data. Effects of ditch maintenance, deepening etc. may be addressed at higher Tiers.

CHOICE OF METHOD

Tier 1

CH_4 emissions from the land surface are estimated using a simple emission factor approach (See Equation 2.6), depending on climate and type of land-use. The default methodology considers boreal, temperate and tropical climate zones and nutrient-rich and nutrient-poor organic soils. Different land-uses imply drainage to different depths. The CH_4 emission factors depend on gas flux measurements, either from closed chambers or (for land-surface emissions) from eddy covariance.

Ditch CH_4 emissions should be quantified for any area of drained organic soil where there are ditches or drainage canals (note that CH_4 may also be emitted from ditches within re-wetted organic soils, where ditches remain present, although at Tier 1 it is assumed that this flux equates to that from the remainder of the re-wetted site; see Chapter 3 of the *Wetlands Supplement*). Estimation of ditch CH_4 emissions requires information on the land-use class and on the area of the landscape occupied by the drainage ditch network, $Frac_{ditch}$.

EQUATION 2.6

ANNUAL CH_4 EMISSION FROM DRAINED ORGANIC SOILS

$$CH_{4\_organic} = \sum_{c,n,p} \left(A_{c,n,p} \bullet \left(\left(1 - Frac_{ditch}\right) \bullet EF_{CH_4\_land_{c,n}} + Frac_{ditch} \bullet EF_{CH_4\_ditch_{c,p}} \right) \right)$$

Where:

$CH_{4\_organic}$ = Annual CH_4 loss from drained organic soils, kg CH_4 yr^{-1}

$A_{c,n,p}$ = Land area of drained organic soils in a land-use category in climate zone c, nutrient status n and soil type p, ha

$EF_{CH4\_landc,n}$ = Emission factors for direct CH_4 emissions from drained organic soils, by climate zone c and nutrient status n, kg CH_4 ha^{-1} yr^{-1}

$EF_{CH4\_ditchc,p}$ = Emission factors for CH_4 emissions from drainage ditches, by climate zone c and soil type p, kg CH_4 ha^{-1} yr^{-1}

$Frac_{ditch}$ = Fraction of the total area of drained organic soil which is occupied by ditches (where 'ditches' are considered to be any area of man-made channel cut into the peatland). The ditch area may be calculated as the width of the ditches multiplied by their total length. Where ditches are cut vertically, ditch width can be calculated as the average distance from bank to bank. Where ditch banks are sloping, ditch width should be calculated as the average width of open water plus any saturated fringing vegetation.

Tier 2

The Tier 2 approach for CH_4 emissions from drained organic soils incorporates country-specific information in Equation 2.6 to estimate the emissions. Tier 2 uses the same procedural steps for calculations as provided for Tier 1. Under Tier 2, the emission factors for CH_4 from the surface of drained organic soils can be further differentiated by drainage depth, land-use subcategories or vegetation type (such as presence or absence of plant species that act as transporters of CH_4 from the soil to the atmosphere). Guidance for further stratification follows the principles given in Section 2.2.1.1 of this chapter.

Tier 2 approaches for CH_4 emissions from drainage ditches generally follow the Tier 1 approach described above, with country-specific measurements or estimates of annual mean ditch CH_4 emissions, and national or regional estimates of fractional ditch area that reflect local drainage practices. The land-use sub-categories in Table 2.4 may be expanded or sub-divided where appropriate to reflect the range of observed land-use on drained organic soils.

Tier 3

Tier 3 methods for estimating CH_4 emissions from drained organic soils involve a comprehensive understanding and representation of the dynamics of CH_4 emissions and removals on managed peatlands and organic soils, including the effect of site characteristics, peat/soil type, peat degradation and depth, land-use intensity, drainage depth, management systems, and the level and kinds of fresh organic matter inputs. Also emission spikes may occur, for example during spring thaw or strong rains or when debris from ditch dredging is deposited on adjacent land.

For CH_4 emissions from drainage ditches, development of a Tier 3 approach could take account of the influence of land-management activities (e.g., organic matter additions to agricultural land) on substrate supply for methane production in ditches, of possible short-term pulses of ditch CH_4 emissions associated with land-use change, and of the legacy effects of past land-use (e.g. nutrient-enriched soils). Information on drainage ditch characteristics and maintenance may be used to refine ditch CH_4 emissions estimates, for example taking account of the potential effects of plant or algal growth within ditches; presence of subsurface drainage in Croplands and Grasslands; water flow rates, transport length of water and oxygen status; ditch maintenance activities, and the deposition of organic material removed from ditches onto adjacent land areas.

CHOICE OF EMISSION FACTORS

Tier 1

Default emission factors for the Tier 1 method are provided in Table 2.3 for EF_{CH4_land} and Table 2.4 for EF_{CH4_ditch}. EF_{CH4_land} were derived from the mean of all data within each land-use class, typically from chamber measurements, and uncertainty ranges were calculated as 95% confidence intervals. References are given in Table 2.3.

At present, literature data are sufficient to provide Tier 1 default values of EF_{CH4_ditch} for each of the four major land-use classes on drained organic soils (Forest Land, Grassland, Cropland and Wetlands used for peat extraction) in boreal and temperate regions (Table 2.4). For Cropland, because no data are currently available, Tier 1 default values for deep-drained Grassland may be applied. For tropical organic soils, few data on ditch CH_4 emissions are currently available, and a single Tier 1 EF is therefore provided for all drained land-use classes. Scientific background for EF_{CH4_ditch} and $Frac_{ditch}$ is given in Annex 2A.2.

Tier 2

Tier 2 emission factors EF_{CH4_land} may be based on country- or region-specific emission factors for CH_4 emissions from the surface of drained organic soils. These allow a further stratification of land-use categories by drainage class, nutrient status or vegetation characteristics.

Methane emissions from drainage ditches will vary according to peat/soil type, land-use type, drainage intensity, and (for agriculturally managed areas) land-use intensity. For example labile organic matter and nutrient inputs from terrestrial areas are likely to increase CH_4 production in ditches (Schrier-Uijl *et al.,* 2011). The Tier 1 emission factors EF_{CH4_ditch} provided are based on measurements from ditches located within the organic layer. Subsurface drainage systems may represent additional sources of CH_4 emissions in Cropland and Grassland, and could be incorporated in the approach provided that appropriate measurement data are available. Countries are encouraged to obtain new measurement data for significant land-use classes to enhance the current dataset, and to develop country-specific Tier 2 emission factors. Sharing of data between countries may be appropriate where environmental conditions and practices are similar.

Tier 3

A Tier 3 approach for CH_4 emissions from drained organic soils might include further details and processes or capture the seasonal dynamics of CH_4 emissions as additional element of stratification or by dynamic modelling.

A Tier 3 approach for CH_4 emissions from drainage ditches might include the use of more detailed data to develop and apply process models that describe CH_4 emissions as a function of drainage ditch characteristics and maintenance, for example taking account of the potential effects of plant or algal growth within ditches; water flow rates, transport length of water and oxygen status; ditch maintenance activities, and the deposition of organic material removed from ditches onto adjacent land areas.

A Tier 3 approach to estimating ditch CH_4 emissions could take account of the temporal variability of hydrological conditions, labile substrate and nutrient supply, and controls on the composition of in-ditch-vegetation that might enhance or reduce emission rates.

Emissions from stockpiles of drying peat are uncertain and stockpiles may release or consume CH_4 at different rates than the excavation field, but data are not at present sufficient to provide guidance. Methods for estimating this flux may be developed for Tier 3 approaches.

Table 2.3
Tier 1 CH_4 emission/removal factors for drained organic soils ($EF_{CH_4\_LAND}$) in all land-use categories

Land-use category		Climate / vegetation zones	Emission Factor* (kg CH_4 ha^{-1} yr^{-1})	95% Confidence Interval** (centred on mean)		No. of Sites	Citations/Comment
Forest Land, drained	Nutrient-poor	Boreal	7.0	2.9	11	47	Komulainen *et al.* 1998 ; Lohila *et al.,* 2011; Maljanen *et al.*, 2006a ; Martikainen *et al.,* 1992 1993, 1995b; Minkkinen and Laine, 2006 ; Minkkinen *et al.*, 2006a, 2007a; Nykänen *et al.,* 1998 ; Ojanen *et al.*, 2010, 2013
	Nutrient-rich	Boreal	2.0	-1.6	5.5	83	Komulainen *et al.,* 1998; Laine, *et al.,* 1996; Mäkiranta *et al.,* 2007; Maljanen *et al.,* 2001, 2003b, 2006a ; Martikainen *et al*., 1992, 1995b; Minkkinen and Laine, 2006; Minkkinen *et al*., 2007a; Nykänen *et al.,* 1998; Ojanen *et al.*, 2010, 2013
Forest Land, drained		Temperate	2.5	-0.60	5.7	13	Glenn *et al.,* 1993; Moore and Knowles, 1990; Sikström *et al.*, 2009; Von Arnold *et al.,* 2005a, b; Weslien *et al.,* 2009; Yamulki *et al*., 2013
Forest Land and cleared Forest Land (shrubland***), drained		Tropical/ Subtropical	4.9	2.3	7.5	7	Jauhiainen *et al.,* 2008; Hirano *et al.,* 2009; Furukawa *et al.,* 2005
Forest plantations, drained ****		Tropical/ Subtropical	2.7	-0.9	6.3	5	Basuki *et al.*, 2012 Jauhiainen *et al*, 2012c
Plantation: oil palm		Tropical/ Subtropical	0	0	0	1	Melling *et al.,* 2005b
Plantation: sago palm		Tropical/ Subtropical	26.2	7.2	45.3	6	Watanabe *et al.,* 2009; Melling *et al.,* 2005b; Inubushi *et al.*, 1998
Cropland, drained		Boreal & Temperate	0	-2.8	2.8	38	Augustin, 2003; Augustin *et al.*, 1998; Drösler *et al.,* 2013; Elsgaard *et al.,* 2012; Flessa *et al.*, 1998; Kasimir-Klemedtsson *et al*., 2009;Maljanen *et al.,* 2003a,b, 2004, 2007a; Petersen *et al.,* 2012; Regina *et al*., 2007; Taft *et al*., 2013
Cropland		Tropical/ Subtropical	7.0	0.3	13.7	5	Furukawa *et al.,* 2005; Hirano *et al.,* 2009
Rice*****		Tropical/	143.5	63.2	223.7	6	Furukawa *et al.,* 2005; Hadi *et al.,* 2001; Inubushi *et al.,*

	Subtropical					2003
Grassland, drained	Boreal	1.4	-1.6	4.5	12	Grønlund *et al.,* 2006; Guðmundsson and Óskarsson 2008; Hyvönen *et al.,* 2009; Maljanen *et al.,* 2001, 2003b, 2004; Nykänen *et al.*, 1995; Regina *et al*., 2007
Grassland, drained, nutrient-poor	Temperate	1.8	0.72	2.9	9	Drösler *et al*., 2013; Kasimir-Klemedtsson *et al*., 2009; Van Den Bos, 2003
Grassland, deep drained, nutrient- rich	Temperate	16	2.4	29	44	Augustin *et al.,* 1996; Best & Jacobs, 1997; Drösler *et al.,* 2013; Flessa *et al.* 1997, 1998 ; Jacobs *et al.* 2003; Kroon *et al.* 2010; Langeveld *et al.,* 1997; Meyer *et al.,* 2001; Nykanen *et al.*, 1995; Petersen *et al.*, 2012; Schrier-Uijl, 2010a,b; Teh *et al.,* 2011; Van Den Bos, 2003; Van den Pol-Van Dasselaar *et al.*, 1997; Wild *et al.,* 2001
Grassland, shallow drained, nutrient-rich	Temperate	39	-2.9	81	16	Augustin, 2003; Drösler *et al*., 2013; Jacobs *et al.,* 2003, Van den Pol-Van Dasselaar *et al.,* 1997
Grassland	Tropical/ Subtropical	7.0	0.3	13.7	5	Same emission factor as tropical Cropland
Peat Extraction	Boreal & Temperate	6.1	1.6	11	15	Hyvönen *et al*., 2009; Nykänen *et al*., 1996; Strack and Zuback, 2013; Sundh *et al*., 2000; Tuittila *et al*., 2000; Waddington and Day, 2007
Settlements	All climate zones	There is no fixed default emission/removal factor for Settlements. It is *good practice* to take the default emission/removal factor in Table 2.3 of the land-use category that is closest to the national conditions of drained organic soils under Settlements. Information about national conditions could include drainage level, vegetation cover, or other management activities. For example, drained organic soils in urban green areas, parks or gardens could use the default Tier 1 emission/removal factor for Grassland, deep-drained in Table 2.3.				
Other Land	All climate zones	*Other Land Remaining Other Land*: 0 *Land Converted to Other Land*: Maintain emission factor of previous land-use category				

* Mean

** Some confidence intervals contain negative values.This indicates that, while the mean emission factor is zero or a net CH_4 emission, a net CH_4 uptake has been observed in some studies.

*** Shrubland refers to any type of land sparsely or fully covered with shrubs or trees, which may fulfil the national forest definition. It extends to degraded lands, which cannot be clearly classified as forest or non-forest.

**** Number derived solely from Acacia plantation data.

***** The default value applies to countries without data about flooding regime for rice on organic soils. Countries with data about flooding regime for rice on organic soil may continue to use the methodologies and emission factors provided in the *2006 IPCC Guidelines.*

Plantations can be defined as Forest Land or Cropland or any other land-use category, according to national definitions. It is *good practice* to report plantations in the appropriate national land-use category according to the national land use definitions.

CHOICE OF ACTIVITY DATA

Tier 1

It is *good practice* to use the same activity data for estimating CO_2, N_2O and CH_4 emissions from drained organic soils. Information on obtaining these data is provided in Section 2.2.1 above. For countries in boreal and temperate regions using the Tier 1 method, if the available information does not allow stratification by nutrient status of organic soils, countries may rely on guidance given in Section 2.2.1.1.

Activity data required to estimate CH_4 emissions from drainage ditches at Tier 1 consist of areas of drained organic soils disaggregated by land-use category (Forest Land, Grassland, Cropland, Wetlands used for peat extraction) as shown in Table 2.4. Fractional ditch areas recorded in published studies are given for individual sites in Table A2.1, and these data have been used to provide indicative $Frac_{ditch}$ values by land-use class in Table 2.4. However it should be noted that these proportions are likely to vary between countries and it is therefore *good practice* to derive country-specific activity data on fractional ditch areas wherever possible, to reflect local land-use practices. This fractional ditch area may depend on the topographic situation and organic soil properties rather than on land-use alone. Fractional ditch area can be calculated from spatially explicit information about ditch and canal networks. From these the length and width of ditches can be derived, or alternatively, ditch spacing and ditch width on organic soils, which gives the ditch area on organic soils. This geometrical information is converted to fractional ditch area by dividing the ditch area on organic soils through the area of drained organic soils.

Tier 2 and 3

Activity data required for higher Tier methods are likely to include more detailed information on land-use, in particular land-use intensity within Grassland and Cropland classes. Further stratification may be necessary for other classes if sufficient data become available to estimate emission factors, e.g., for cleared peat swamp forest, oil palm or pulpwood plantation in tropical peat areas.

Activity data for higher Tier methods may be spatially explicit and consist of areas of drained organic soils managed for different forest types, peat extraction, production systems, horticulture and plantations, disaggregated according to nutrient status of the organic soil if relevant. More sophisticated estimation methodologies will require the determination of areas in different phases of land-uses with longer term rhythms such as age-classes in Forest Land or in a peat extraction operation, where on abandoned areas drainage or the effects of former peat extraction are still present. Land-use intensity, particularly fertilizer and organic matter addition, may be used to refine CH_4 emission estimates for Grassland and Cropland, as emissions are likely to change under more intensive management systems.

To estimate CH_4 emissions from drainage ditches, additional activity data are required on fractional ditch area within each land use category. Country-specific values of fractional ditch areas are used to reflect drainage methodologies such as typical ditch spacing, depth, width and length, maintenance (such as vegetation clearance) and land-use practices. Fractional ditch area can be stratified by type of organic soil or topographic situation, peat/soil properties and land-use.

Activity data for CH_4 emissions from drainage ditches could incorporate additional information on water table level and variability (such as seasonal water management regime), flow rates, in-ditch vegetation and land-use factors affecting substrate supply for methanogenesis, such as livestock density and fertilizer application in intensive Grasslands and Croplands. Incorporating seasonal and short-term controls on emissions would require additional activity data on the nature and timing of agricultural activities (such as organic matter additions) and on hydrological parameters.

CALCULATION STEPS FOR TIER 1

The steps for estimating the CH_4 emissions from drained organic soils are as follows:

Step 1: Determine areas with drained organic soils under each land-use category for lands remaining in a land-use category, disaggregated by climate domain and other appropriate factors as outlined above and consistently with on-site CO_2 emissions estimates from drained organic soils. Where needed for Tier 1 emission factors, land areas are further stratified by nutrient-rich and nutrient-poor organic soils. Temperate nutrient-rich Grasslands are further stratified into shallow-drained and deep-drained classes.

Step 2: Assign the appropriate value for the fraction of areas covered by ditches using national statistics. If statistics are not available, values given in Table 2.4 provide appropriate defaults.

Step 3: Assign the appropriate emission factor values (EF_{CH4_land} and EF_{CH4_ditch}) from Tables 2.3 and 2.4, respectively.

Step 4: Multiply each area with the appropriate emission factor by using Equation 2.6 and sum across land use categories.

TABLE 2.4
DEFAULT CH_4 EMISSION FACTORS FOR DRAINAGE DITCHES

Climate zone	**Land-use**	**EF_{CH4_ditch} (kg CH_4 ha^{-1} yr^{-1})**	**Uncertainty range [a] (kg CH_4 ha^{-1} yr^{-1})**	**No. of sites**	**$Frac_{ditch}$ (indicative values[e])**	**References**
Boreal /temperate	Drained forest, Drained wetland[b]	217	41 – 393	11	0.025	Cooper & Evans, 2013; Glagolev *et al.,* 2008; Minkkinnen & Laine, 2006 (two study areas); Roulet & Moore, 1995 (three study areas); Sirin *et al.,* 2012 (3 study areas); von Arnold *et al.,* 2005b.
	Shallow-drained Grassland	527	285 – 769	5	0.05	Best & Jacobs, 1997; Hendriks *et al.,* 2007, 2010; Van den Pol-Van Dasselaar *et al.,*1999a; Vermaat *et al.,* 2011; McNamara, 2013
	Deep-drained Grassland Cropland[c]	1165	335 – 1995	6	0.05	Best & Jacobs, 1997; Chistotin *et al.,* 2006 ;; Schrier-Uijl *et al.,* 2010, 2011; Sirin *et al.,* 2012; Teh *et al.,* 2011; Vermaat *et al.,* 2011.
	Peat Extraction	542	102 – 981	6	0.05	Chistotin *et al.,* 2006; Nykänen *et al.,* 1996; Sirin *et al.,* 2012; Sundh *et al.,* 2000; Waddington & Day, 2007; Hyvönen *et al.,* 2013
Tropical	All land-use involving drainage	2259	599 – 3919[d]	2	0.02	Jauhianen & Silvennoinen, 2012 (drained and abandoned, and pulpwood plantation)

[a] Values represent 95% confidence intervals unless otherwise stated

[b] Ditch CH_4 emissions from wetlands subject to drainage but no other land-use modification are assumed to be equivalent to those from organic soils drained for forestry.

[c] Ditch CH_4 emissions from Cropland are assumed to be the same as those from high-intensity Grassland, for which more data exist.

[d] Due to limited data for CH_4 emissions from tropical drainage channels, the range of measurements is shown, rather than 95% confidence intervals.

[e] Indicative values for $Frac_{ditch}$ within each class are derived from the mean of studies reporting CH_4 emission values for this class. Note that studies from the Netherlands were not included in this calculation, because they are characterised by much higher fractional ditch areas (0.1 to 0.25) that are not typical of drained organic soils in other countries.

UNCERTAINTY ASSESSMENT

The principal sources of uncertainty for CH_4 emissions from drained organic soils are activity data, including associated information on the fraction of drained areas covered by ditches, and emission factors. Uncertainty ranges are provided in Tables 2.3 for values of EF_{CH4_land} and Table 2.4 for values of EF_{CH4_ditch} for each organic soil/land-use category. Uncertainty ranges in Table 2.3 are expressed as 95% confidence intervals or as standard errors, depending on the number of studies available. The major source of uncertainty in these values is simply the small number of studies on which many Tier 1 estimates are based, and the high degree of heterogeneity in measured fluxes between different studies undertaken within some classes. Confidence intervals (95%) have been calculated for all classes other than the drained tropical organic soil class, for which only one study (Jauhiainen and Silvennoinen, 2012) is available, which provides estimates of ditch CH_4 emissions from areas of drained, deforested and abandoned organic soils, and pulpwood plantation. For the drained tropical organic soils category, the uncertainty range is provided by the lower (abandoned) and higher (pulpwood plantation) emission values recorded.

The final calculation of $CH_{4\_organic}$ is also sensitive to uncertainties in the activity data, and in particular to data used to estimate the proportion of the land area which is occupied by drainage ditches, $Frac_{ditch}$. Many countries lack such data and although activity data should be country-specific, even for Tier 1, indicative values from Table 2A.1 can be used at the discretion of the inventory compiler. Uncertainty assessments should therefore also take account of this source of uncertainty in calculating total CH_4 emissions from drained organic soils.

2.2.2.2 N_2O EMISSIONS FROM DRAINED INLAND ORGANIC SOILS

N_2O emissions from soils are produced by the microbiological processes of nitrification and denitrification (to N_2O or N_2) (Davidson 1991; Firestone and Davidson, 1989). These processes are controlled by several factors, including water-filled pore space (Aulakh and Sigh, 1997; Davidson 1991; Dobbie *et al.* 1999; Ruser *et al., 2001*), temperature (Keeney *et al.,* 1979; Kroon *et al.*, 2010), and concentration of mineral nitrogen (Bremner 1997; Firestone and Davidson, 1989; Ryden and Lund, 1980).

Drained organic soils emit significant amounts of N_2O, whereas emissions from wet organic soils are close to zero (Kasimir-Klemedtsson *et al.,* 1997; Flessa *et al.,* 1998; Couwenberg *et al.*, 2011). A main reason for increased N_2O emissions is nitrogen mineralization associated with organic matter decomposition in drained organic soils (Höper, 2002). Emissions from this N mineralization will be dealt with here. Other sources of anthropogenic N in organic soils include nitrogen fertilizer, application of crop residues, and organic amendments. These emissions from other N sources are dealt with in Chapter 11 of Volume 4 of the *2006 IPCC Guidelines* and in all earlier guidance.

Most of the published data on N_2O fluxes from drained organic soils refer to boreal and temperate ecosystems and these data served as the basis for the emission factors in the *2006 IPCC Guidelines*. With new studies published since 2005, there are enough data to derive separate N_2O emission factors for Forest Land, Cropland, Grassland, and peatlands under peat extraction in boreal and temperate zones and these new values replace the values Table 7.6 in Volume 4, Chapter 7 of the *2006 IPCC Guidelines*.

There are still limited data available for drained tropical organic soils. However, the studies that have been published over the past decade provide enough data to develop Tier 1 emissions factors for the first time.

CHOICE OF METHOD

Tier 1

This section presents the equation for estimating direct emissions of N_2O due to drainage of organic soils. The revisions presented here, as shown in Equation 2.7, are applicable to Equation 11.1 presented in Chapter 11, Volume 4 of the *2006 IPCC Guidelines*. This Equation is used to estimate N_2O for specific land-use categories, but there are not enough data available for developing coefficients to modify EFs by condition-specific variables (e.g., variations of drainage depths). The Equations 11.1 and 11.2 have been modified to include variables for the boreal climate zone as well by adding terms $F_{OS,\ CG\ Bor\ NR}$, $F_{OS,\ CG,\ Bor\ NP}$, $F_{OS,\ F,\ Bor,\ NR}$, and $F_{OS,\ F\ Bor\ NP}$ (the subscripts CG, F, Bor, NR and NP refer to Cropland and Grassland, Forest Land, Boreal, Nutrient-Rich, and Nutrient-Poor, respectively) and their respective emissions factors.

Direct N_2O emissions from managed soils are estimated using Equation 11.1 in Chapter 11, Volume 4 of the *2006 IPCC Guidelines*. This Equation has three segments: one for emissions associated with N inputs, one for organic soils, and one for urine and dung inputs during grazing. In this section, updates are provided for the second segment focusing on organic soils as follows:

EQUATION 2.7

DIRECT N_2O EMISSIONS FROM MANAGED/DRAINED ORGANIC SOILS

$$N2O-N_{OS}=\begin{bmatrix}\left(F_{OS,CG,Bor}\bullet EF_{2CG,Bor}\right)+\left(F_{OS,CG,Temp}\bullet EF_{2CG,Temp}\right)+\left(F_{OS,CG,Trop}\bullet EF_{2CG,Trop}\right)+\\ \left(F_{OS,F,Bor,NR}\bullet EF_{2F,Bor,NR}\right)+\left(F_{OS,F,Temp,NR}\bullet EF_{2F,Temp,NR}\right)+\\ \left(F_{OS,F,Bor,NP}\bullet EF_{2F,Bor,NP}\right)+\left(F_{OS,F,Temp,NP}\bullet EF_{2F,Temp,NP}\right)+\left(F_{OS,F,Trop}\bullet EF_{2F,Trop}\right)\end{bmatrix}$$

Where:

$N_2O–N_{OS}$ = Annual direct N_2O–N emissions from managed/drained organic soils, kg N_2O–N yr^{-1}

F_{OS} = Annual area of managed/drained organic soils, ha (Note: the subscripts CG, F, Temp, Trop, NR and NP refer to Cropland and Grassland, Forest Land, Temperate, Tropical, Nutrient Rich, and Nutrient Poor, respectively)

EF_2 = Emission factor for N_2O emissions from drained/managed organic soils, kg N_2O–N ha^{-1} yr^{-1}; (equivalent to Table 11.1, Chapter 11, Volume 4, of the *2006 IPCC Guidelines* but using updated emission factor values provided in Table 2.5 below; note: the subscripts CG, F, Temp, Trop, NR and NP refer to Cropland and Grassland, Forest Land, Temperate, Tropical, Nutrient Rich, and Nutrient Poor, respectively.).

Tier 2

Tier 2 estimates are to be based on the Tier 1 Equation 2.7, but use country or region–specific emission factors. These can be further stratified by drainage class, nutrient status of organic soils or other criteria used for stratifying organic soils for direct N_2O emissions. The corresponding emission factors are country or region-specific and take into account the land management systems. Tier 2 emission factors can follow the Tier 1 assumption that N mineralization from the degrading organic matter exceeds the amount of N input so that the measured N_2O emissions are entirely attributed to the drained organic soil.

Tier 3

Tier 3 approaches can attribute N_2O emissions from drained organic soils separately to the mineralization of peat or organic matter versus N input by fertilizer, crop residues and organic amendments. Attribution could rely on the fraction of N_2O released by N_2O emission peaks after N fertilization, or by subtracting a fertilizer EF from total N_2O emissions. Nitrogen mineralization from the drained organic soil can be estimated by the CO_2-C emission from the drained organic soil and the C/N ratio of the topsoil and this value could be used to predict N_2O emissions.

Tier 3 methods are based on modelling or measurement approaches. Models can simulate the relationship between the soil and environmental variables that control the variation in N_2O emissions and the size of those emissions (Stehfest & Bouwman, 2006; Kroon *et al.*, 2010; Dechow & Freibauer, 2011). These models can be used at larger scales where measurements are impractical. Models should only be used after validation against representative measurements that capture the variability of land-use, management practices and climate present in the inventory (IPCC, 2010).

CHOICE OF EMISSION FACTORS

Tier 1

Emission factors for drained organic soils

The *2006 IPCC Guidelines* provided emission factors that were partly disaggregated for land-use types or climatic zones (Table 11.1), Chapter 11, Volume 4). An increased availability of scientific data allows for an improved choice of default emission factors (Table 2.5). Nutrient poor and rich organic soils drained for forestry have different N_2O emissions. Croplands and Grasslands are established on nutrient-rich organic soil or are amended for better nutrient availability, and are considered here as rich. Peat extraction occurs both on nutrient-poor (bogs) and nutrient-rich (fens) peatlands. Peat extraction occurs both on nutrient poor (bogs) and nutrient-rich (fens) peatlands. It is common for the residual bottom peat layers of peat extraction sites to consist of minerogenous but recalcitrant nutrient-rich peat.There is not enough data available to disaggregate for the peat types in peat extraction areas.

Default emission factors were derived from the mean of all data within each land-use class, typically from chamber measurements, and uncertainty ranges were calculated as 95% confidence intervals. References are given in Table 2.5.

TABLE 2.5
TIER 1 DIRECT N_2O EMISSION/REMOVAL FACTORS FOR DRAINED ORGANIC SOILS IN ALL LAND-USE CATEGORIES*

Land-use Category		**Climate / vegetation zone**	**Emission Factor (kg N_2O-N ha^{-1} yr^{-1})**	**95 % confidence interval**		**No. of Sites**	**Citations/Comment**
Forest Land, drained	Nutrient-poor	Boreal	0.22	0.15	0.28	43	Lohila *et al*., 2011; Maljanen *et al.,* 2006a; Martikainen *et al.*, 1993, 1995a; Ojanen *et al*., 2010, 2013; Regina *et al.,* 1996
	Nutrient-rich	Boreal	3.2	1.9	4.5	75	Ernfors *et al*., 2011; Mäkiranta *et al.,* 2007; Maljanen *et al.,* 2001, 2003a, 2006a, 2010a; Martikainen *et al.,* 1993, 1995a; Ojanen *et al.,* 2010, 2013 ; Pihlatie *et al*., 2004; Regina *et al.,*1998; Saari, *et al.,* 2009
Forest Land, drained		Temperate	2.8	-0.57	6.1	13	Sikström *et al*., 2009; Von Arnold *et al*., 2005a, b; Weslien *et al.,* 2009; Yamulki *et al*., 2013
Forest Land and cleared Forest Land (shrubland**), drained		Tropical/ Subtropical	2.4	1.3	3.5	10	Furukawa *et al.,* 2005; Jauhiainen *et al.,* 2012b; Takakai *et al.,* 2006
Plantation: oil palm		Tropical/ Subtropical	1.2	n.a.	n.a.	1	Melling *et al.,* 2007b
Plantation: sago palm		Tropical/ Subtropical	3.3	n.a.	n.a.	1	Melling *et al.,* 2007b
Cropland, drained		Boreal & Temperate	13	8.2	18	36	Augustin *et al.,* 1998; Drösler *et al.,* 2013; Elsgaard *et al*., 2012; Flessa *et al.,* 1998; Kasimir-Klemedtsson *et al*., 2009; Maljanen *et al.,* 2003a,b, 2004, 2007a; Petersen *et al.,* 2012; Regina *et al.,* 2004; Taft *et al*., 2013
Cropland except rice		Tropical/ Subtropical	5.0	2.3	7.7	8	Furukawa *et al.,* 2005; Jauhiainen *et al*.., 2012b; Takakai *et al*.., 2006
Rice		Tropical/ Subtropical	0.4	-0.1	0.8	6	Furukawa *et al,* 2005; Hadi *et al.,* 2005; Inubushi *et al,* 2003
Grassland, drained		Boreal	9.5	4.6	14	16	Grønlund *et al*., 2006; Hyvönen *et al.,* 2009; Jaakkola, 1985; Maljanen *et al*. , 2001, 2003a, 2004, 2009; Nykänen *et al.,* 1995; Regina *et al.,* 1996, 2004
Grassland, drained, nutrient-poor		Temperate	4.3	1.9	6.8	7	Drösler *et al.,* 2013; Kasimir-Klemedtsson *et al.,* 2009
Grassland, deep drained, nutrient-rich		Temperate	8.2	4.9	11	47	Augustin and Merbach, 1998; Augustin *et al*., 1996, 1998; Drösler *et al*., 2013; Flessa *et al.,* 1997, 1998; Jacobs *et al.,* 2003; Kroon *et al.,* 2010; Langeveld *et al.,* 1997; Meyer *et al.,* 2001; Nykänen *et al.,* 1995; Petersen *et al*., 2012; Teh

						et al., 2011; van Beek *et al.,* 2010; Velthof *et al* ,1996; Wild *et al*., 2001
Grassland, shallow drained, nutrient-rich	Temperate	1.6	0.56	2.7	13	Drösler *et al.,* 2013; Jacobs *et al*., 2003
Grassland	Tropical/ Subtropical	5.0	2.3	7.7	8	Emission factor for tropical Cropland can be used
Peatland Managed for Extraction	Boreal & Temperate	0.30	-0.03	0.64	4	Hyvönen *et al*., 2009 ; Nykänen *et al.,* 1996 ; Regina *et al.,* 1996
Peatlands Managed for Extraction	Tropical/ Subtropical	3.6	0.2 to 5.0			Emission factor from Table 7.6 of Chapter 7, vol. 4 of the *2006 IPCC Guidelines* can be used.
Settlements	All climate zones	There is no fixed default emission/removal factor for Settlements. It is *good practice* to take the default emission/removal factor in Table 2.5 of the land-use category that is closest to the national conditions of drained organic soils under Settlements. Information about national conditions could include drainage level, vegetation cover, or other management activities. For example, drained organic soils in urban green areas, parks or gardens could use the default Tier 1 emission/removal factor for Grassland, deep-drained in Table 2.5.				
Other Lands	All climate zones	*Other Land Remaining Other Land*: 0 *Land Converted to Other Land*: Maintain emission factor of previous land-use category				

* Mean

** Shrubland refers to any type of land sparsely or fully covered with shrubs or trees, which may fulfil the national forest definition. It extends to degraded lands, which cannot be clearly classified as forest or non-forest.

Plantations can be defined as Forest Land or Cropland. The attribution to Cropland made in this table is not binding. It is *good practice* to report plantations in the appropriate national land-use category according to the national land use definitions.

In the *2006 IPCC Guidelines*, emission factors were provided for $EF_{2CG,\ Trop}$ and $EF_{2F,\ Trop}$, based on the expectation that net mineralization was twice as high in tropical soils compared to temperate soils. Research in tropical soils suggests that net mineralization is not a useful predictor of N_2O flux and that net nitrification or the nitrate portion of the inorganic-N pool are better predictors (Verchot *et al.,* 1999, 2006; Ishizuka *et al.,* 2005). It also needs to be highlighted that all measurements of N_2O emissions on tropical organic soils to date are from Southeast Asia and from a very limited number of studies. Nonetheless these EFs are to be used for all tropical ecosystems until better data become available.

Tier 2

Tier 2 emission factors may be based on country- or region-specific emission factors for N_2O emissions from the surface of drained organic soils. These allow a further stratification of land-use categories by drainage class, nutrient status or vegetation characteristics. Countries are encouraged to obtain new measurement data for significant land-use classes to enhance the current dataset, and to develop country-specific Tier 2 emission factors. Sharing of data between countries may be appropriate where environmental conditions and practices are similar.

Tier 3

Tier 3 emission factors or relations are based on country-specific emission data and models calibrated for management practices such as drainage intensity; crop, livestock or forest type; fertiliser or organic matter additions; peat extraction technology and the phases of peat extraction or other relevant factors for N_2O emissions.

CHOICE OF ACTIVITY DATA

Activity data consist of areas of land remaining in a land-use category on drained organic soils stratified by major land-use types, management practices, and disturbance regimes. Total areas should be determined according to approaches laid out in Chapter 3 of Volume 4 of the *2006 IPCC Guidelines* and should be consistent with those reported under other sections of the inventory. Stratification of land-use categories according to climate regions, based on default or country-specific classifications, can be accomplished with overlays of land-use on suitable climate and soil maps.

Tier 1

It is *good practice* to use activity data for N_2O emissions consistent with activity data for CO_2 and CH_4 emissions from soils. Guidance for activity data is given in the respective sections in this Chapter.

Tier 2 and 3

Activity data required for higher Tier methods are likely to include more detailed information on land-use, in particular land-use intensity within Grassland and Cropland classes. Further stratification may be necessary for other classes if sufficient data become available to estimate emission factors, e.g., for cleared peat swamp forest, oil palm or pulpwood plantations in tropical peat areas.

Activity data for higher Tier methods may be spatially explicit and consist of areas of drained organic soils under different forest types, peat extraction, cultivation systems, horticulture and plantations, disaggregated according to nutrient status of the organic soil if relevant, and annual peat production data. More sophisticated estimation methodologies will require the determination of areas in different phases of land-uses with longer term rhythms such as age-classes in Forest Land or in a peat extraction cycle, where on abandoned areas drainage or the effects of former peat extraction are still present.

CALCULATION STEPS FOR TIER 1

The steps for estimating N_2O emissions on drained organic soils are as follows:

Step 1: Determine areas with drained organic soils under each land-use category for lands remaining in a land-use category, disaggregated by climate domain and other appropriate factors as outlined above. Where needed for Tier 1 emission factors, land areas are further stratified by nutrient-rich and nutrient-poor organic soils. Temperate nutrient-rich Grassland is further stratified into shallow-drained and deep-drained classes.

Step 2: Assign the appropriate values for EF_2 from Table 2.5 for each land-use category, climate domain, nutrient status and drainage class stratum.

Step 3: Multiply activity data by the emission factor for each land use category according to Equation 2.7.

UNCERTAINTY ASSESSMENT

Uncertainties in estimates of direct N_2O emissions from drained organic soils are caused by uncertainties related to the emission factors (see Table 2.5 for uncertainty ranges), inter-annual variability associated with temperature and precipitation, activity data, lack of coverage of measurements, spatial aggregation, and lack of information on specific on-farm practices.

Additional uncertainty will be introduced in an inventory when emission factors are derived from measurements that are not representative of the variation of conditions in a country. Because of very high spatial variability of N_2O emissions from soils, most estimates have large standard errors relative to the mean flux. In general, the uncertainty of activity data will be lower than that of the emission factors. Additionally, uncertainties may be caused by missing information on variation in drainage levels, and changing management practices in farming. Generally, it is difficult to obtain information on the actual drainage levels and possible emission reductions achieved as well as information on farming practices. For more detailed guidance on uncertainty assessment refer to Chapter 3, Volume 1 of the *2006 IPCC Guidelines*.

2.2.2.3 CO_2 AND NON-CO_2 EMISSIONS FROM FIRES ON DRAINED INLAND ORGANIC SOILS

Fires can be a large and variable source of greenhouse gases and significantly affect other feedbacks within the climate system. When compared to combustion of above-ground vegetation, the emissions from both uncontrolled wildfires and managed (prescribed) fires in organic (peat) soils are high. On organic soils, fires comprise both surface fires that consume vegetation, litter and duff, and ground fires which burn into and below the surface. Ground fires consume soil organic matter and deadwood mass as a fuel source. The latter are smouldering fires that may persist for long periods of time, burn repeatedly in response to changing soil moisture and surface hydrology, and penetrate to different depths. This section addresses the emissions arising from combustion of soil organic material. Although the focus of guidance in this chapter is for drained organic soils, the guidance in Section 2.2.2.3 could also be used to calculate emissions from fires on managed land with undrained and rewetted organic soils (Chapter 3 of the *Wetlands Supplement*).

In any ecosystem, fire activity is strongly influenced by several factors, namely weather/climate, fuel availability, drainage and ignition agents, including human activities (Johnson, 1992; Swetnam, 1993). In ecosystems with organic soils, conditions such as organic soil depth and density, soil moisture, vegetation composition and soil surface micro-topography (e.g., Benscoter and Wieder., 2003) along with fire characteristics, such as intensity, frequency and duration (Kasischke *et al.,* 1995), which are affected by fire management practices, influence the quantity of organic matter consumed and hence the emissions of greenhouse gases (Kuhry 1994; Kasischke *et al.,* 1995; Kasischke and Bruhwiler, 2003).

2006 IPCC Guidelines covered emissions from burning of above-ground carbon stocks (biomass and dead organic matter) but did not cover the often substantial release of emissions from combustion of organic soils. It is *good practice* to report greenhouse gas emissions from fires on all managed lands with organic soils. Including all fire related emissions both from natural fires as well as those that have a human-induced cause (e.g., soil drainage) even if the initiation of the fire is non-anthropogenic (e.g., lightening strike).

This Chapter updates the *2006 IPCC Guidelines* by:

- Providing default methodologies and emission factors for CO_2, CH_4 and CO emissions from fires on organic soils
- Providing generic guidance for higher Tier methods to estimate these fluxes

Change in soil organic carbon following fire is the result of both CO_2 as well as non-CO_2 emissions (principally of CH_4 and CO). Emissions of both CO_2 and non-CO_2 greenhouse gases are addressed in the following sections. These deal specifically with below-ground biomass as opposed to vegetation and litter losses (the latter are included in the estimation of carbon stock changes in the *2006 IPCC Guidelines*).

CHOICE OF METHOD

CO_2 and non-CO_2 emissions from burning of drained organic soils can either be directly measured or estimated using data on area burnt along with the default values for mass of fuel consumed and emission factors provided in this chapter. Previous IPCC Guidelines have noted that emissions from wildfires on managed (and unmanaged) land can exhibit large inter-annual variations that may be driven by either natural causes (e.g., climate cycles, random variation in lightning ignitions), or indirect and direct human causes (e.g., prescribed burning, historical fire suppression and past forest harvest activities) or a combination of all three causes, the effects of which cannot be readily separated. This variability is also true for emissions from fires on organic soils which critically depend on the extent and depth of the organic soil, the fuel moisture, the water table depth, and hence the thickness of the drained layer and the resulting depth of the consumed organics, all of which are affected by site characteristics, weather, land management, fire type, and climate. At Tier 1, differentiation by land management category and fire type is possible, but reporting at higher Tiers will enable a greater level of differentiation between land-use, site characteristics and fire types.

The parameters required to calculate the CO_2 and non-CO_2 emissions from burning organic soils are: area burned, mass of fuel available for consumption, combustion factor (this is also known as burning efficiency and can be used to characterize smouldering vs. flaming fires) and emission factor. Compared with vegetation fires, the uncertainties involved in estimating emissions from fires on organic soils are much higher because organic soils can burn repeatedly and to different depths. Furthermore, the type and density of the soil organic material combined with the combustion efficiency will determine the nature of the gases and other compounds emitted.

The mass of fuel that can potentially burn in a fire event on organic soils will be determined by measuring the depth of burn, along with soil bulk density and carbon content; the former is strongly controlled by soil water content (influenced by position of the water table or permafrost depth) while the latter variables are ideally measured in the field. While default values can be used for Tier 1 reporting, for higher Tiers data on the depth of burn and soil carbon density need to be determined. The combustion factor describes how much of the fuel mass available is actually consumed during a fire event, i.e., converted into CO_2 or non-CO_2 gases. The emission factor (G_{ef}) determines the mass of CO_2 or non-CO_2 gas emitted per mass of fuel consumed by the fire (e.g., g CO_2/kg dry fuel). The total emissions of CO_2 or non-CO_2 gases are calculated from the product of area burnt and the corresponding biomass loading, combustion factor, and emission factor.

EQUATION 2.8

ANNUAL CO_2-C AND NON-CO_2 EMISSIONS FROM ORGANIC SOIL FIRE

$$L_{fire} = A \bullet M_B \bullet C_f \bullet G_{ef} \bullet 10^{-3}$$

Where:

L_{fire} = amount of CO_2 or non-CO_2 emissions, e.g., CH_4 from fire, tonnes

A = total area burned annually, ha

M_B = mass of fuel available for combustion, tonnes ha^{-1} (i.e. mass of dry organic soil fuel) (default values in Table 2.6; units differ by gas species)

C_f = combustion factor, dimensionless

G_{ef} = emission factor for each gas, g kg^{-1} dry matter burnt (default values in Table 2.7)

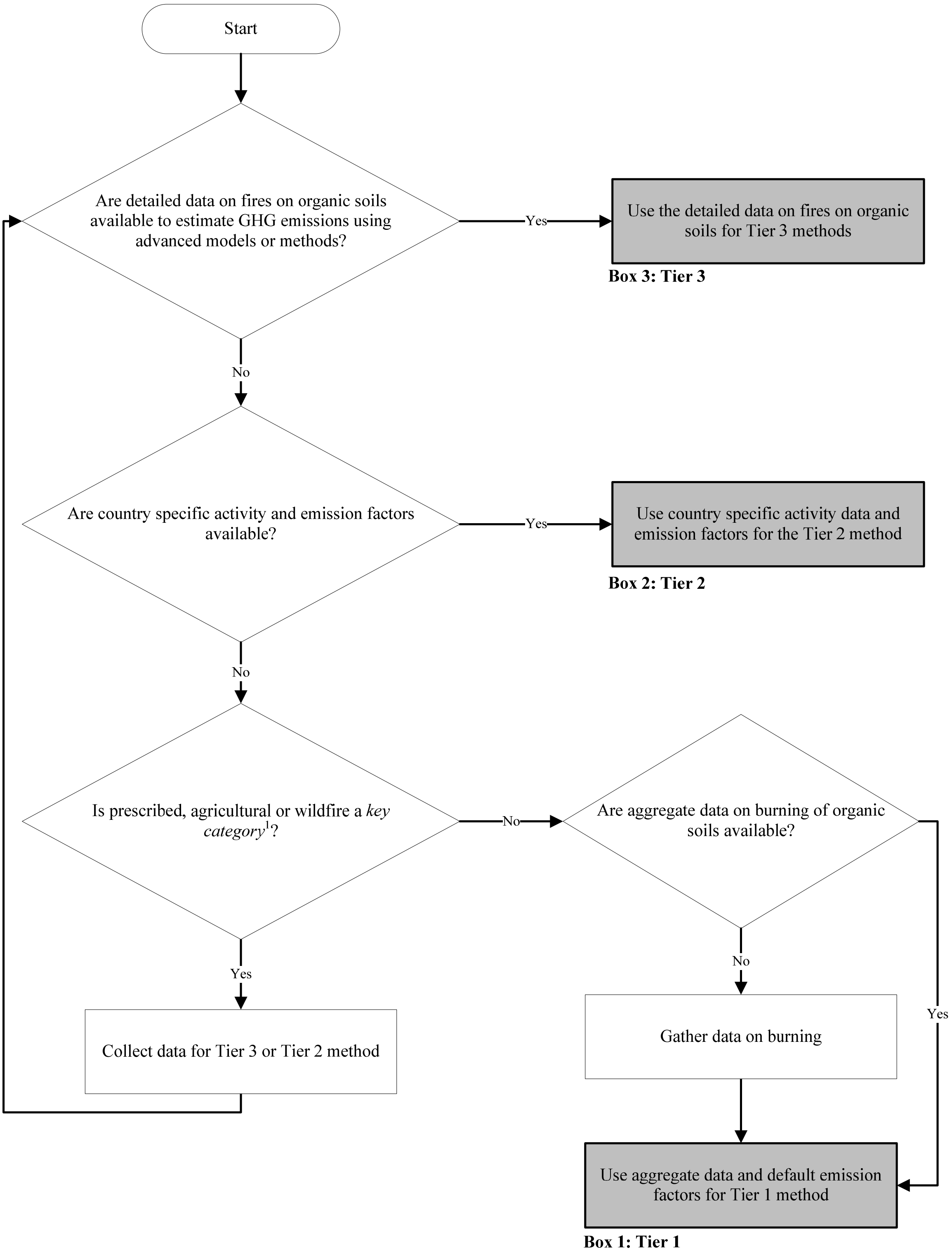
Where data for M_B and C_f are not available, a default value for the amount of fuel actually burnt (the product of M_B and C_f) can be used under Tier 1 methodology (Table 2.6). The value 10^{-3} converts L_{fire} to tonnes.

The amount of fuel that can be burned is given by the area burned annually and the mass of fuel available in that area.

Default values for the Tier 1 method or components of a Tier 2 method are provided in Tables 2.6 and 2.7. For higher Tiers, data on the variation in the mass of fuel available (based on site or region-specific data, including area of organic soil burnt, depth of organic soil, depth of burn and/or depth of water table/soil moisture content values and soil bulk density) are incorporated.

Figure 2.1 presents a decision tree that guides the selection of the appropriate Tier level to report CO_2 and non-CO_2 emissions from the burning of organic soils.

Figure 2.2 Generic decision tree for identification of the appropriate tier to estimate greenhouse gas emissions from fires on organic soils



Note:

1: See Chapter 4, "Methodological Choice and Identification of Key Categories" (noting Section 4.1.2 on limited resources), Volume 1 of the *2006 IPCC Guidelines* for discussion of *key categories* and use of decision trees.

Tier 1

Countries may choose to report CO_2 emissions using the Tier 1 method if fires on organic soils are not a *key category*. This approach is based on highly aggregated data and default factors. It does, however, require primary data on area burned.

If burning in ecosystems with organic soils is a *key category*, countries are encouraged to report emissions by applying the highest tier possible, given national circumstances. For prescribed fires, country-specific data will be required to generate reliable estimates of emissions.

At Tier 1, it is assumed that there is either no or very little combustive loss of soil organic matter during prescribed fires on organic soils.

Tiers 2 and 3

The Tier 1 method is refined by incorporating more disaggregated area estimates (per organic soil and fire type sub-categories) and country-specific estimates of combustion and emission factors into Equation 2.8. Tier 2 uses the same procedural steps for calculations as provided for Tier 1. Potential improvements to the Tier 1 approach may include:

- Knowledge of the amount of soil organic matter consumed;
- The position of the soil water table relative to the surface;
- Improved information on land-use/management and their effects on organic soil condition, in particular hydrological status; and
- Improved data on area burnt, estimated using remotely sensed data of adequate spatial and temporal resolutions and verified according to a robust sampling design at suitable periodicity to take account of the monthly variations of area burnt. Estimates of the depth of burn in a representative number of locations.

Countries may further stratify the data on area burnt by depth of burn, organic soil condition (e.g., drained vs. undrained, with further detail possible through characterisation of the intensity of drainage) and fire types (wildfire vs. prescribed).

It may also be possible to develop models with algorithms to generate regional scale maps of area burnt using satellite data of multiple sources and of moderate spatial resolution. Model results should be validated, for example, by using high spatial resolution data augmented by field observations, and refined based on the validation results whenever possible. A sampling approach can be designed to generate estimates of area burnt. This reporting method should provide estimates (fluxes) of the impact of burning on below-ground biomass, particularly including the depth of burn, and if feasible the variation of depth within the area burned. Reporting at higher Tiers should differentiate fires burning at different intensities (critical for Tier 3) and with different proportions of smouldering vs. flaming combustion (i.e. different Modified Combustion Efficiency (MCE) defined as $\Delta CO_2/(\Delta CO_2 + \Delta CO)$ which is an index of the relative proportion of smouldering vs. flaming combustion). The development of robust methodologies to assess burn severity in organic soils would enable more accurate quantification of greenhouse gas emissions from below-ground fires.

CHOICE OF EMISSION FACTORS

Tier 1

The Tier 1 method uses default values for M_B, C_f and G_{ef} along with default emissions factors provided in Tables 2.6 & 2.7 respectively. Gas species in Table 2.7 are given as CO_2-C, CO and CH_4, respectively.

Due to the limited data available in the scientific literature, organic soils have been very broadly stratified according to climate domain (boreal/temperate and tropical) and fire type (wild vs. prescribed). Values are derived from the literature for all categories with the exception of prescribed fires.

For all organic soil fires, the default combustion factor is 1.0, since the assumption is that all the fuel is combusted (Yokelson *et al.,* 1997).

TABLE 2.6
ORGANIC SOIL FUEL CONSUMPTION VALUES (MASS OF DRY MATTER FOR A RANGE OF ORGANIC SOIL AND FIRE TYPES, TO BE USED IN CONJUNCTION WITH EQUATION 2.8, TO ESTIMATE THE PRODUCT OF QUANTITIES M_B AND C_F)

Climate/vegetation zone	Sub-category	Mean (t d.m. ha^{-1})	95% CI (t d.m. ha^{-1})		References
Boreal/temperate	Wildfire (undrained peat)	66	46	86	Zoltai *et al.,* 1998; Turetsky & Wieder, 2001; Benscoter & Wieder, 2003; Kasischke & Bruhwiler, 2003; Amiro *et al.,* 2001; Kajii *et al.,* 2002; Kasischke *et al.,* 1995; Pitkänen *et al.*, 1999; Cahoon *et al.,* 1994; Turetsky *et al.,* 2011a; Turetsky *et al.,* 2011b; Poulter *et al.,* 2006; de Groot & Alexander, 1986; Kuhry, 1994
	Wildfire (drained peat)	336	4***		Turetsky *et al.,* 2011b
	Prescribed fire (land management)	-	-		No literature found
Tropical	Wildfire (undrained peat)	-	-		No literature found.
	Wildfire (drained peat)	353	170	536	Page *et al.,* 2002; Usop *et al.*, 2004; Ballhorn *et al.,* 2009
	Prescribed fire (agricultural land management)†	155	82	228	Saharjo & Munoz, 2005; Saharjo & Nurhayati, 2005

Note: Where fuel consumption values have been reported as t C ha^{-1}, default values for organic soil bulk density (0.1 g cm^{-3})* and carbon density (50% mass dry weight)** have been applied to derive a value for mass of fuel (t ha^{-1}) (following Akagi *et al.* 2011). At higher Tier levels, country or ecosystem specific values for both these variables are used.

*The value for surface organic soil bulk density is an average derived from Gorham (1991) who provides a default value of 0.112 g cm^{-3} for all northern peatlands and Page *et al.* (2011) who provide a default value of 0.09 g cm^{-3} for all tropical peats.

**The value for surface organic soil carbon content is an average derived from the typical average for eutrophic peat of 48% and the typical average for oligotrophic peat of 52% (after Lucas (1982), Immirzi *et al.* (1992) as reported in Charman (2002)).

***Standard error.

† The consumption value excludes crop residues.

TABLE 2.7
EMISSION FACTORS (G KG^{-1} DRY MATTER BURNED) FOR ORGANIC SOIL FIRES. VALUES ARE MEANS ± 95% CI (TO BE USED AS QUANTITY G_{EF} IN EQUATION 2.8)

Climate/vegetation zone	CO_2-C	CO	CH_4	References
Boreal/temperate	362 ± 41	207 ± 70	9 ± 4	Ward & Hardy, 1984; Yokelson *et al.,*1997; Yokelson *et al.,* 2013
Tropical	464	210	21	Christian *et al.,* 2003

1. These values have been derived from a very limited number of studies. The EF values for boreal/temperate fires are arithmetic means of the two values reported by Yokelson *et al.* (1997) for Alaska and Minnesota organic soils (carbon content 49% for Minnesota; n.d. for Alaska); of the minimum and maximum values reported by Ward and Hardy (1984) (no carbon contents reported) and the single value reported by Yokelson *et al.* (2013) for Alaskan organic soil (carbon content 42%). Surface (flaming) and deep (smouldering) organic soil fires produce a complex mixture of gases and fine particles, the nature of which will reflect vegetation type, fire behaviour, soil physical and chemical characteristics as well as the combustion conditions (in particular combustion efficiency) (Itkonen and Jantunen, 1986; NCDENR, 1998). The combustion of organic material leads to a loss of carbon; most of this is in the form of CO_2, but quantities of CO, CH_4, long-chain hydrocarbons, and carbon particulate matter are also emitted. Other greenhouse gases along with ozone precursors (NOx), volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons are also released (Ramadan *et al.,* 2000; Gebhart *et al.,* 2001; Honrath *et al.,* 2004; Val Martin *et al.,* 2006; Lapina *et al.,* 2008; Akagi *et al,.* 2011). Emission factors for N_2O and NO_x are not provided at Tier 1. There are very limited data for N_2O and NO_x emissions from organic soil fires and it should be noted that N_2O can be produced in canisters during sample storage (e.g. Cofer *et al*., 1990).). At higher Tiers, N_2O and NO_x can either be measured directly or could be calculated using published emission ratios for organic soil fires (e.g. Christian *et al.,* 2003; Hamada *et al*., 2013).
2. The composition of organic soil fire emissions differs substantially from forest fires on mineral soils; in part this is a function of the fact that organic soil fires are dominated by smouldering rather than flaming combustion owing to the moist and often oxygen-limiting substrate conditions. Fire temperatures also differ: the typical peak temperature of smouldering organic soil fires is in the range 500-700°C, while for flaming fires it can be 1000-1500°C (Usup *et al.,* 2004; Rein, 2008). The lower temperatures and smouldering combustion associated with organic soil fires makes them harder to detect by satellites and leads to the emission of high amounts of CO relative to CO_2 as well as large amounts of fine particulate matter (PM2.5); fires on tropical organic soils, for example, emit as much as 3 to 6 times more particulate matter per amount of biomass consumed than other types of biomass fires (grassland, forest, plantation fires) (Heil *et al.,* 2006). The emission ratio of CO to CO_2 ($ER_{CO/CO2}$) can be used as an indicator of the relative amount of flaming versus smouldering combustion during biomass burning with higher $ER_{CO/CO2}$ observed in smouldering fires (Cofer *et al.,* 1989, 1990; Christian *et al.,* 2007; Yokelson *et al.,* 2007).

Tier 2 and Tier 3

At higher Tiers the approach for estimating greenhouse gas emissions from fires on organic soils incorporates country-specific information in Equation 2.8. When deriving higher Tier emission factors, country-specific combustion factors need to be developed. Regional factors for stratification could include:

- Stratification by drainage class. Position of the soil water table is a proxy for soil moisture which determines depth of burn.
- Stratification by depth of burn. This can be measured in the field post-fire (e.g., Page *et al.,* 2002; Turetsky & Wieder, 2003; Turetsky *et al.,* 2011a, b) or using remote sensing approaches (e.g. LiDAR) (Ballhorn *et al.,* 2009).
- Stratification by different fire types (wild vs. prescribed fires). GIS techniques of interpolation may be helpful in this analysis. Under Tier 3, one might consider annual sampling of a number of control sites.
- Stratification by organic soil type taking into account general hydrology (e.g., bog vs. fen); vegetation structure (open, shrubby, forested) whenever possible.
- Use of regionally-specific values for organic soil bulk density and carbon concentration.
- Stratification by different land-use and management types, including differences in drainage lay-out and intensity, land-use intensity and practices, all of which will influence the mass of fuel available for combustion.

Emission factors can be derived from measurements (field or laboratory based) or calculations validated against country-specific measurements. The literature on emissions from fires on organic soils is very sparse and countries are encouraged to share data when organic soil quality, environmental conditions and land-use practices are similar.

A higher tier approach might also use process-based models, adequately validated using observation data that take into account temporal and spatial variations in the differences between fires on different types of organic soils and conditions and fuel combustion efficiencies. This approach will involve a comprehensive mechanistic understanding of combustion of organic soils, including the effects of site characteristics, drainage intensity, vegetation cover, soil type and depth, management practices, depth of water table and soil moisture among others. Higher Tier approaches could start by developing robust relationships between drainage and depth of burn which could then be further refined by land management category. Models ideally also take into account fire return interval. Fire changes organic soil chemical and physical characteristics (Yefremova & Yefremov, 1996; Zoltai *et al.,* 1998; Milner *et al.,* 2013) as well as the rate and nature of post-fire vegetation recovery, and thus can alter total net ecosystem productivity.

CHOICE OF ACTIVITY DATA

Activity data consist of areas of land remaining in a land-use category with organic soils stratified by climate zone and fire type. Total areas should be determined according to approaches laid out in Chapter 3 of Volume 4 of the *2006 IPCC Guidelines* and be consistent with those reported under other sections of the inventory. The assessment of fire-driven changes in soil carbon will be greatly facilitated if this information can be used in conjunction with national soils and climate data, vegetation inventories, maps of burned area and other biophysical data. Stratification of land-use categories according to climate zones, based on default or country-specific classifications can be accomplished with overlays of land-use on suitable climate and soil maps.

Tier 1

Tier 1 methods require data on burned area of organic soils stratified by climate domain and fire type (wild vs. prescribed). Data on burned area can be obtained from ground-based inventories, which can be very valuable in areas of small fire. Some countries/regions may have an established fire inventory method in place which they are encouraged to maintain rather than go with less comprehensive satellite methods. For larger and/or less accessible locations, burned area data are often obtained from a time series of images from remote sensors. In country burned area maps should ideally be mapped at Landsat TM scale (30-50 m resolution). If not available, this could be degraded to 250 m and even 1 km data. Box 2.3 provides more details on the remote-sensing platforms currently used for obtaining burnt area data. Other methods, such as national statistics and forest inventory fire data can also produce suitable information in some cases, but may not be as reliable or as comprehensive as remotely sensed data. Caution is advised regarding the use of detecting thermal anomalies using data sets derived from satellite data. Whilst providing a reasonable indicator of the presence of a fire, one cannot proceed to easily derive the burned area parameters required in the emission estimate equations.

BOX 2.1
RECENT ADVANCES IN SATELLITE-DERIVED FIRE PRODUCTS

Recent advances in satellite-derived fire products using MODerate resolution Imaging Spectroradiometer (MODIS) data from the Terra and Aqua satellites (Roy *et al.,* 2008; Giglio *et al.,* 2009); the Advanced Very High Resolution Radiometer (AVHRR) sensor on the National Oceanic and Atmospheric Administration (NOAA); Polar Operation Environmental Satellite (POES); the European AATSR and VEGETATION/PROBA satellites, and the Geostationary Operational Environmental Satellite (GOES) have all enabled the derivation of burned area data in near real-time and thereby enhanced the ability to estimate the areal extent of regional and global wildland fires and hence the scale of emissions (e.g. Gregoire *et al.,* 2003; Simon *et al.,* 2004; Tansey *et al.,* 2008; Giglio *et al.,* 2009; Kasischke *et al.,* 2011). Products derived from the satellite data sets either provide an indication of the area burned or an indication that a possible active fire is burning within the grid cell, which is based on a high surface temperature signal at thermal wavelengths. At the global scale, these data sets are coarse resolution (a pixel size larger than 500 m). The resulting uncertainties and particular challenges associated with commission and omission errors in remote sensing approaches to peat fire detection and characterization, however, need to be recognized and acknowledged. In normal years, for example, fires on tropical organic soils are relatively small (several hectares would be towards the upper end), and it is therefore necessary to consider using satellite data sets acquiring imagery at an appropriate resolution. During extended smouldering, fires in organic soils may be particularly difficult to pick up by sensors sensitive to thermal wavelengths. There are on-going issues with cloud cover, which are being addressed with increasing use of radar imagery. Furthermore, there are very few operational systems that can be used to develop robust and temporally stable products. The Landsat-8 mission and the forthcoming European Space Agency/European Commission Sentinel programme will help address this issue. The size of the study area is also very important as there may be existing data sets available from which a long term time series of fire disturbance can be reconstructed (e.g. 40 years of Landsat data with gap filling with radar imagery). There are useful materials on fire assessment and standards produced by the UN World Meteorological Organisation (e.g. GTOS 68, 2010).

Data on the location of organic soils can be obtained from several institutions, including ISRIC and FAO who have country-specific and global maps that include organic soils (FAO, 2012) (http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/; http://www.fao.org/geonetwork/srv/en/main.home; or http://www.isric.org/;). A global consortium has been formed to make a new digital soil map of the world at fine resolution (http://www.globalsoilmap.net/).

Tiers 2 and 3

Higher Tier methods require more disaggregated and spatially explicit activity data than lower Tiers. This includes disaggregation according to drainage classes, vegetation type and condition (the latter refers to moisture, leaf on/off, and other factors); drainage depth, and land management status to improve Tier 1 estimates and may also take into account such variables as seasonal norms and modifications in water table level due to seasonal weather patterns etc. Data on depth of burn (obtained from in situ field measurements), along with country-specific data on organic soil bulk density and carbon content will also greatly improve knowledge of the mass of fuel consumed and the scale of carbon emissions. Seasonal variations in fire-driven emissions are then aggregated to annual emissions.

The accuracy of emission estimates will be further improved if information is available on land-use and its effect on organic soil condition, since fire extent and severity and hence quantity of emissions increase according to the scale of disturbance (e.g., disturbance of vegetation cover, and the presence of drainage structures associated with agriculture, forestry, peat extraction, oil and gas extraction, roads etc. (e.g., Turetsky *et al.,* 2011a, b)). Remote sensing techniques (e.g., Kasischke *et al.,* 2009) can also be used to provide an indication of the likely fire risk by estimating soil water conditions and providing an accurate proxy measure of organic soil surface water content levels and hence likely depth of burn at a landscape scale.

CALCULATION STEPS FOR TIER 1

The steps for estimating the CO_2 and non-CO_2 emissions from fires on drained organic soils for land remaining in a land-use category are as follows:

Step 1: Using guidance in Chapter 3 of Volume 4 of the *2006 IPCC Guidelines*, stratify areas with drained organic soils of land remaining in a land-use category for each land-use category according to climate domain and fire type. Obtain estimates of A (area burnt) from national sources or, if those are not available, from global databases.

Step 2: Assign the appropriate fuel consumption value from Table 2.6 (Mb*Cf with Cf=1) and emission factor (Gef) from Table 2.6 and 2.7 respectively for the gas.

Step 3: Estimate the CO_2 or non-CO_2 emissions by multiplying burnt area with the appropriate fuel load (M_B) and emission factor (G_{ef}) from Tables 2.6 and 2.7 using Equation 2.8.

Step 4: Repeat step 3 for each greenhouse gas using emission factors (G_{ef}) in Table 2.7.

UNCERTAINTY ASSESSMENT

There are several sources of uncertainty related to estimates of CO_2 and non-CO_2 emissions from fires on organic soils. Fire behaviour varies greatly among wetland types and hence, disaggregation of vegetative formations will lead to greater precision. The fraction of fuel that is actually combusted during burning (the combustion factor) varies, not only between ecosystems, but also between fires, between years, and as a function of land management practices. Measurements from a given fire, year, and/or region cannot be extrapolated with confidence to other locations or years, or to the biome scale. An important cause of uncertainty is the choice of emission factor that partitions the smoke into CO_2, CO and other trace gasses, since this is strongly driven by the amount of flaming versus smouldering combustion that occurs, and this can vary widely in organic soils, and is not well characterized from field data. In addition, the accuracy of the estimates of area burnt, proportion of the available fuel oxidized, and the biomass fuel available also contribute to the emissions uncertainty. Uncertainties of estimates of areas burnt can vary markedly depending on the methodology employed – for example, where very high resolution remote-sensing is used it may be of the order of ±20%, whereas the use of global fire maps may result in uncertainties of up to two-fold. Uncertainties in estimates of greenhouse gas emissions over large regions from fire are likely to be at least ±50%, even with good country-specific data, and at least two-fold where only default data are used. The calculation of emission errors is addressed by French *et al.* (2004). The study looked at the possible ranges of error in the input variables, since robust data are not available for the range of fire conditions and vegetation types that can burn. The sensitivity analysis revealed that ground-layer fraction consumed is the most important parameter in terms of output uncertainty, indicating that burning in sites with deep organic soils can be the most problematic in terms of uncertainty. The results of this work showed that input data sets are incomplete in describing the possible variability in conditions for both pre-burn and during the fire, and attention to improving measurements and obtaining a range of measurements is a priority for modelling emissions from fire in organic soils.

2.3 LAND CONVERTED TO A NEW LAND-USE CATEGORY

2.3.1 CO_2 emissions and removals from drained inland organic soils

CO_2 emissions/removals from land converted to another land-use category on drained organic soils are calculated in the same way as CO_2 emissions/removals from land remaining in a land-use category. [1] CO_2 emissions/removals for the lands in the conversion category are calculated using Equations 2.1 and 2.2.

On-site CO_2 emissions after land-use change on drained organic soils can occur from all five carbon pools. Land-use change can result in direct losses/gains because of biomass clearance/ (re)planting. This is addressed by guidance for changes in the carbon pools in above-ground and below-ground biomass and dead organic matter on lands converted to another land-use category provided in the *2006 IPCC Guidelines.*

Land-use change can indirectly affect carbon gains and losses because of altered growth of woody biomass and altered respiration and organic matter oxidation through altered soil temperature. These effects are included in

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[1] For example if Forest Land is converted to Cropland, methodology and emission factors for Cropland are to be used.

the guidance for lands remaining in a land-use category provided in the *2006 IPCC Guidelines* for above-ground and below-ground biomass and dead organic matter and updated emission factors in Table 2.1 of section 2.2.1.1.

Additional carbon losses from biomass and soil can occur through altered fire frequency after drainage and land-use change. These CO_2 emissions from fire are addressed in section 2.3.2.3.

2.3.1.1 ON-SITE CO_2 EMISSIONS/REMOVALS FROM DRAINED INLAND ORGANIC SOILS (CO_2-$C_{ON-SITE}$)

CHOICE OF METHOD

Tier 1

CO_2 emissions/removals from land converted to another land-use category on drained organic soils within the inventory time period are calculated in the same way as CO_2 emissions/removals from land remaining in a land-use category. CO_2 emissions/removals for the lands in the conversion category are calculated using Equation 2.3 if the soils are drained. Specific guidance by other land-use categories is given in the *2006 IPCC Guidelines*, Chapters 5, 6, 8 and 9.

At Tier 1, there is no transition period for CO_2 emissions from drained organic soils because the land immediately switches to the methods for the new land-use category. High carbon loss from drained organic soils can occur after converting natural vegetation to another land use, e.g. after converting tropical forest land to palm plantations, or converting grassland to cropland, and in particular, immediately after initial drainage of organic soils (Hooijer *et al.*, 2012; Wösten *et al.*, 1997 Stephens *et al.*,1984). These CO_2-$C_{on-site}$ emissions in the transition phase are not captured by the Tier 1 default emission factors shown in Table 2.1, which were derived from data representing long-term land-uses present for decades in the boreal and temperate climate zones, and land-uses drained for more than 6 years in the tropical climate zone. A transitional phase is not captured by the Tier 1 methodology due to lack of scientific data for deriving default emission factors. After initial drainage of organic soils and if a transitional phase occurs, it should be addressed by higher tier methods.

Tier 2

Country specific Tier 2 emissions factors may include the CO_2 emissions in the transition phase after land conversions; in particular, after initial drainage of organic soils and when land conversion is associated with deeper drainage.

Tier 3

Tier 3 methodologies could further consider the dynamic nature of the additional CO_2-$C_{-on-site}$ emissions in the transition phase, which may be highest in the first years after the transition.

Additional guidance on the Tiers 1, 2 and 3 approaches is given in Section 2.2.1.1.

CHOICE OF EMISSION/REMOVAL FACTORS

Tier 1

At Tier 1, CO_2 emissions/removal factors for lands in the conversion category are the same as for land remaining in a land-use category. For Tier 1 these are given in Table 2.1. Additional guidance on the Tiers 1, 2 and 3 emission/removal factors is given in Section 2.2.1.1.

Tier 2

If land conversions on drained organic soils contribute significantly to CO_2 emissions from soils and if CO_2 emissions from soils are a key category, it is *good practice* to develop country specific Tier 2 emission factors that include the additional CO_2-$C_{on-site}$ emissions in the transition phase. Tier 2 emission factors could be stratified by type of land conversions and by the magnitude of change in water table through drainage. Unless other country specific evidence is available the default length of 20 years can be used for the transition phase.

Tier 3

Tier 3 methodologies could develop response functions or models that capture the dynamic nature of the additional CO_2-$C_{soil-onsite}$ emissions in the transition phase.

CHOICE OF ACTIVITY DATA

Guidance is the same as for land remaining in a land-use category in Section 2.2.1.1.

UNCERTAINTY ASSESSMENT

Guidance is the same as for land remaining in a land-use category in Section 2.2.1.1.

2.3.1.2 OFF-SITE CO_2 EMISSIONS VIA WATERBORNE CARBON LOSSES FROM DRAINED INLAND ORGANIC SOILS ($CO_2\text{-}C_{SOIL\text{-}ONSITE}$)

CHOICE OF METHOD

Tier 1

At Tier 1, CO_2 emissions/removals from land converted to another land-use category on drained organic soils within the inventory time period are calculated in the same way as CO_2 emissions/removals from land remaining in a land-use category. Guidance is given in Section 2.2.1.2 for DOC. CO_2 emissions/removals for the lands in the conversion category are calculated using Equations 2.4 and 2.5.

Tier 2

The Tier 2 approach for waterborne carbon losses from drained organic soils incorporates country-specific information to estimate the emissions. Tier 2 uses the same procedural steps for calculations as provided for Tier 1. Tier 2 emission factors can be developed following the same principles as for land remaining in a land-use category. Guidance is found in Section 2.2.1.2. Generally, the same stratification should be used for land converted to another land-use category as is used for land remaining in a land-use category. Tier 2 approaches for land-use changes can be further stratified according to the time since land-use change. Specific transition periods can be considered depending on the type of land-use change and the persistence of emissions or removals which differ from those on lands that have been in the new land-use category for a long time. Alternatively, the default transition period applicable to the new land-use category in the *2006 IPCC Guidelines* can be applied.

Tier 3

The development of Tier 3 approaches follows the guidance given in section 2.2.1.2 including the guidance for transparent documentation of Tier 3 approaches given in Section 2.2.1.1. Generally, the same approach should be used for land converted to another land-use category as is used for land remaining in a land-use category. Tier 3 methods should further differentiate transition effects of increased or reduced waterborne carbon losses after land-use change and the time since land-use change.

Additional guidance on the Tiers 1, 2 and 3 approaches is given in Section 2.2.1.2.

CHOICE OF EMISSION/REMOVAL FACTORS

CO_2 emissions/removal factors for the lands in the conversion category are the same as for land remaining in a land-use category. For Tier 1 these are given in Table 2.2. Additional guidance on the Tiers 1, 2 and 3 emission/removal factors is given in Section 2.2.1.2.

CHOICE OF ACTIVITY DATA

Guidance is the same as for land remaining in a land-use category in Section 2.2.1.2.

UNCERTAINTY ASSESSMENT

Guidance is the same as for land remaining in a land-use category in Section 2.2.1.2.

2.3.2 Non-CO_2 emissions and removals from drained inland organic soils

2.3.2.1 CH_4 EMISSIONS/REMOVALS FROM DRAINED INLAND ORGANIC SOILS

CHOICE OF METHOD

CH_4 emissions/removals from land converted to another land-use category on drained organic soils within the inventory time period are calculated in the same way as CH_4 emissions/removals from land remaining in a land-use category[2]. CH_4 emissions/removals for the lands in the conversion category are calculated using Equation 2.5. Additional guidance on the Tiers 1, 2 and 3 approaches is given in Section 2.2.2.1.

CHOICE OF EMISSION/REMOVAL FACTORS

CH_4 emissions/removal factors for the lands in the conversion category are the same as for land remaining in a land-use category. For Tier 1 these are given in Tables 2.3 and 2.4. Additional guidance on the Tiers 1, 2 and 3 emission/removal factors is given in Section 2.2.2.1.

CHOICE OF ACTIVITY DATA

Guidance is the same as for land remaining in a land-use category in Section 2.2.2.1.

UNCERTAINTY ASSESSMENT

Guidance is the same as for land remaining in a land-use category in Section 2.2.2.1.

2.3.2.2 N_2O EMISSIONS FROM DRAINED INLAND ORGANIC SOILS

CHOICE OF METHOD

N_2O emissions from land converted to another land-use category on drained organic soils within the inventory time period are calculated in the same way as N_2O emissions from land remaining in a land-use category. N_2O emissions for lands in the conversion category are calculated using Equation 2.7. Additional guidance on the Tiers 1, 2 and 3 approaches is given in Section 2.2.2.2.

CHOICE OF EMISSION/REMOVAL FACTORS

N_2O emission factors for the lands in the conversion category are the same as for land remaining in a land-use category. For Tier 1 these are given in Table 2.5. Additional guidance on the Tiers 1, 2 and 3 emission/removal factors is given in Section 2.2.2.2.

CHOICE OF ACTIVITY DATA

Guidance is the same as for land remaining in a land-use category in Section 2.2.2.2.

UNCERTAINTY ASSESSMENT

Guidance is the same as for land remaining in a land-use category in Section 2.2.2.2.

2.3.2.3 NON-CO_2 EMISSIONS FROM BURNING ON DRAINED ORGANIC SOILS

CHOICE OF EMISSION/REMOVAL FACTORS

Non-CO_2 emission factors for the lands in the conversion category are the same as for land remaining in a land-use category. For Tier 1 these are given in Tables 2.6 and 2.7. Additional guidance on the Tiers 1, 2 and 3 emission/removal factors is given in Section 2.2.2.3.

CHOICE OF ACTIVITY DATA

Guidance is the same as for land remaining in a land-use category in Section 2.2.2.3.

UNCERTAINTY ASSESSMENT

Guidance is the same as for land remaining in a land-use category in Section 2.2.2.3.

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[2] For example if a Forest Land is converted to Cropland, methodology and emission factors for Cropland are to be used.

2.4 COMPLETENESS, TIME SERIES CONSISTENCY, QA/QC, AND REPORTING AND DOCUMENTATION

2.4.1 Completeness

Complete greenhouse gas inventories will include estimates of all greenhouse gas emissions and removals on drained inland organic soils for which Tier 1 guidance is provided in this Chapter, for all types of organic soils and land-use categories that occur on the national territory. Further guidance on completeness is provided in Chapter 7.5 of the *Wetlands Supplement.*

2.4.2 Time series consistency

It is *good practice* that countries clearly define organic soils and use this definition consistently over time.

Consistent time series require that the same methodology is used for the entire time series. Whenever new methodologies are used previous estimates should be recalculated using the new methods for all years in the time series. It is also *good practice* to report why the new estimates are regarded as more accurate or less uncertain.

One potential problem in recalculating previous estimates is that certain data sets may not be available for the earlier years. There are several ways of overcoming this limitation and they are explained in detail in Chapter 5, Volume 1, of the *2006 IPCC Guidelines*. Time series consistency is discussed further in Chapter 7.6 of the *Wetlands Supplement* and Chapter 5, Volume 1, (Time series consistency and recalculations) of the *2006 IPCC Guidelines*.

2.4.3 Quality Assurance and Quality Control

It is *good practice* to develop and implement quality assurance/quality control (QA/QC) procedures as outlined in Chapter 7.7 of the *Wetlands Supplement*. Countries using Tier 1 methods are encouraged to critically assess the applicability of the default assumptions to their national circumstances. These default assumptions presented in the main text and Annexes of this Chapter. Water table or drainage classes and time after water table drawdown likely have the strongest impact on greenhouse gas emissions and removals. Water table information should be factored into the assessment of applicability of or development of emission factors. Countries are encouraged to focus efforts of QA/QC procedures on the accuracy of water table information.

Higher tier methods should be carefully designed to ensure that resulting estimates are compatible across different pools. In particular, potential double-counting or omission of emissions or removals could occur if measurements underlying national emission factors comprise several carbon pools, e.g. the organic soil pool and dead organic matter, soil repiration with components of autotrophic and heterotrophic respiration that are not attributable to the organic soil, or combined on-site and off-site CO_2 emissions. Annex A2.1 of this Chapter describes the underlying assumptions and methodologies used in deriving the Tier 1 emission factors that avoid double counting or omission of carbon pools.

Where country-specific emission factors are being used, they should be based on high quality field data, developed using a rigorous measurement programme, and be adequately documented, preferably in the peer-reviewed, scientific literature.

It is *good practice* to develop additional, category-specific quality control and quality assurance procedures for Greenhouse gas emissions and removals from drained organic soils. Examples of such procedures include, but are not limited to, examining the time series of the total area of managed land on organic soils and the fraction of these soils that is drained, across all land-use categories to ensure there are no unexplained gains or losses of land; conducting a comparative analysis of emission factors with scientific literature or neighbouring countries with similar environmental and management conditions.

2.4.4 Reporting and documentation

Chapter 7.2.1.1 provides specific guidance where to report greenhouse gas emissions and removals from drained organic soils.

It is *good practice* that countries report and document how they define organic soils, how they ensure consistency with the IPCC definition, and how drained organic soils are identified.

Countries using Tier 1 methods are encouraged to document their assessment whether the default assumptions are applicable to their national circumstances and of actions taken in case the default assumptions are considered not or only partially applicable. It is *good practice* to document how national data compare to the default assumptions and why they may differ. Whenever national methodologies are used it is *good practice* to document transparently and completely the data sources, underlying assumptions, compatibility with the assumptions in the Tier 1 methodology or reasons for deviations, data used, and models or calculation algorithms used in the national methodology. It is *good practice* to document, and countries are encouraged to publish, the data, methodology and the result of their assessment how and why they represent the national circumstances and to document the QA/QC procedures, e.g. peer-review of methodologies before application in the inventory.

Annex 2A.1 Scientific background for developing CO_2-C emission/removal factors for drained inland organic soil from the scientific literature in Table 2.1

The Tier 1 CO_2 emission factors presented in Table 2.1 were calculated as annual net change of the soil organic carbon (SOC) plus the belowground portion of the litter carbon in the different land-uses. CO_2 emissions were obtained by two well established methodologies: **(1) Flux method:** flux measurements are commonly used on all types of organic soils to determine gas exchange at frequencies from minutes to weeks over monitoring periods of up to a few years; or **(2) Subsidence method:** determining subsidence rates of drained organic soils at frequencies of months to years, over periods representing one to many years of subsidence.

Flux methods

The flux method uses chamber based techniques or eddy covariance in combination with auxiliary carbon pool data from the study sites.

Dark chamber measurements

Chamber flux measurements are made with varying frequency over short periods with dark chambers to determine total respiration (Rt) which includes autotrophic (Ra) plus heterotrophic (Rh) respiration from the soil and heterotrophic respiration from litter. To obtain organic soil CO_2 emissions the observed flux (Rt) must be adjusted for the contributions from other carbon pools (*e.g.,* litter) and autotrophic (plant root) respiration needs to be subtracted. For these calculations, the proportion of Rh to Rt was estimated from a limited number of studies.

As with any mass balance approach, outputs must be balanced against inputs to calculate a net flux to the atmosphere. Thus, inputs in the form of root mortality and aboveground litter fall are important in calculating net carbon loss or gain. Tier 1 assumes that the litter pool remains constant in a land use remaining in a land use, so litter inputs to the SOC are equal to litterfall plus root mortality. While litterfall is relatively easy to measure, belowground litter inputs are hard to measure directly (Finér *et al.,* 2011; Gaudinski *et al.,* 2010; Sah *et al.,* 2010). Estimates of litter inputs were made from a limited number of studies and were subtracted from Rh to estimate the net flux of carbon to the atmosphere. On Peatlands Managed for Extraction no vegetation is present so that the net change in soil carbon was assumed to be Rh.

Transparent chambers

CO_2 emission measurements using transparent chambers determine net ecosystem exchange (NEE) i.e., the balance between Rt and the gross primary productivity (GPP). To obtain SOC emissions the observed flux, NEE must be corrected for the contributions from other carbon pools (*e.g.,* litter, above-ground biomass, etc.). Design and use of transparent chambers is described in detail by Drösler (2005)

Eddy Covariance flux measurements

The Eddy Covariance (EC) method finds its greatest utility over larger site or landscape scales. Sophisticated instrumentation and data processing software calculate fluxes of gases by the covariance of gas concentrations with the upward and downward movements of air parcels. In its simplest interpretation for CO_2 fluxes the EC method measures NEE (the balance of ecosystem respiration and GPP). Whenever photosynthetically active radiation (PAR) is zero (such as at night) GPP is zero and NEE is equivalent to ecosystem respiration or Rt. In essence the strategy for obtaining Rh from EC results are the same as for transparent chambers - correction is required for Ra (above and below ground), removals of biomass carbon, inputs of carbon from fertilizers, etc.

Subsidence Method

Drainage of an organic soil leads to subsidence or loss of elevation (Armentano and Menges, 1986; Grønlund *et al.*, 2008; Leifeld *et al.*, 2011). Oxidative loss of carbon can be related to volume loss of the organic soil using bulk density and soil carbon content obtained from soil cores or pits. Total subsidence of the drained organic soil surface is tracked over time using elevation markers. Other markers, such as pollen have been used to correlate horizons among cores (Minkkinen *et al.,* 1999) as an aid to determining subsidence rates.

The parameters used for calculating emission in each study varied slightly. We applied a standardized approach to calculating the emissions from each study so that assumptions across sites would be consistent. CO_2 emission estimates are obtained by converting the volume loss to carbon via bulk density, carbon content and estimates of the oxidized fraction of the volume lost as compared to compaction. Bulk density was considered to remain constant over short periods of time and oxidation fractions were calculated from data in each paper, when available, or data from similar sites were used when data were not available. In all papers in tropical climate, carbon content was measured by loss on ignition, which may lead to an underestimate of the carbon content. For these studies carbon content was estimated using the relationship of Warren *et al.* (2012). Subsidence emissions were corrected for dissolved organic carbon losses using Tier 1 default factors from Section 2.2.1.2.

Tropical emission/removal factors

Two types of data were available for the tropical climate zone: flux studies and studies based on subsidence. Integrating the two approaches was problematic because the data for each approach were different and because many studies had not measured all parameters required to fully assess C losses. The approach that was finally adopted was to calculate one estimate using a gain-loss approach based on flux data for each of the gain and loss terms of the mass balance for each land use. A second estimate was calculated using the subsidence approach, aggregated by site. The average of the two approaches was used to determine the EF, when there were appropriate data available for a particular land use. This was only the case for *Acacia* and oil palm plantations.

There was a divergence of opinion on several points in each of the calculations described above; the general approach adopted by the authors was to calculate independent estimates using different best judgments about the application of subsidence and gain-loss calculations to the dataset and then average the two calculations when they came to different values. One point of divergence was over the importance of consolidation of peat layers below the water table. Another was over the ability of surface flux measurements to adequately capture respiration of belowground litter. Two calculations were made, one excluding one recently cleared subsidence site and including the belowground carbon inputs to the measured surface fluxes. A second calculation was made including the site previously excluded and excluding below-ground inputs. The final EF was derived from the average of these two calculations.

Errors were propagated by the quadrature of absolute errors method (Malhi *et al.*, 2009) for each calculation. Most estimates converged, but several estimates differed by more than 4 tonnes C ha^{-1} y^{-1}. These differences were not statistically significant and means from each approach were within the 95% CI of each other. To resolve the discrepancy between the two approaches, the final EF was determined to be the mean of the two approaches. The uncertainty interval was taken from the highest and lowest value of the 95% CI for either approach.

Selection of studies

A dramatic increase in published studies of CO_2 fluxes occurred recently but not all studies reported results that could be used to develop Table 2.1. Studies included in the derivation of emission factors were assessed by a set of quality criteria.

- Study site characteristics (site location, land-use, soil type, peat depth, land-use history prior to current land-use described, water table). Sites on drained organic soils were included. All sites in the boreal and temperate zone had a decadal history of the reported land-use. Sites in tropical climate had at least six years of drainage and current land-use.
- Experimental study design: need for unrealistic data exclusion, e.g. extreme fertilization, extreme water table level. Only "control" and common practice sites were included. Many experimental studies involved manipulations other than drainage so often their results could not be used; exceptions are results from a "control" drained site. Survey studies, particularly on Cropland and Grassland, often involved fertilization or annual cropping where corrections were often possible to determine Rh. Most studies in the boreal climate region and many in the temperate were conducted seasonally – typically from April/May through September/October (in the N. Hemisphere). Annualization of seasonal results were guided by several studies that specifically targeted winter fluxes (*e.g.,* Alm et al., 1999; Heikkinen et al., 2002; Saarnio et al., 2007). Tropical sites were assessed as representative of the annual flux (1) if data adequately covered dry and wet season: in practice 7 months or more, (2) if there were at least monthly flux observations (typically more in short studies)
- Monitoring and flux quality (study design and position of chambers and subsidence poles, temporal coverage, spatial coverage, monitoring frequency, total number of samples, number of replicates, measurement methodology, methodology used for annual flux estimates, data quality control, uncertainty estimate for fluxes provided). Studies were accepted if there were at least three spatial replicates. Studies in tropical climate were additionally ranked from "A" = "very good and robust" to "E" = "highly uncertain, inadequate for deriving annual emission factors". Studies classified from A to D were included in the derivation of emission factors to use the broadest possible data base despite sometimes considerable uncertainty.
- Every site entered as one entry into the emission factor data. Multi-year observations were averaged to a single value to avoid over-representation of sites with long time series of observations.

- Transparency & traceability of reported values and calculations: in case of studies with incomplete methodology description or inconsistent reported numbers the authors of the assessed studies were contacted. This allowed reducing the uncertainty in a few studies. Unclear studies were excluded.

- No double counting: some studies were performed close to each other. Authors who knew the exact positions of the observations points were contacted to check whether the observations were independent of each other. Sites located within few metres from each other were treated as one. Some of the subsidence studies had large numbers of replicates, which may be partially independent of each other. There was no agreement among the authors how to objectively split these studies into sub-sites so that each subsidence study was treated as a single site.

- Criteria for gain and loss terms of the mass balance for the flux method: Some studies using the flux method, including most studies in tropical climate, have reported total soil respiration only. In these cases the reported CO_2 flux had to be corrected by gain and loss terms of the mass balance to derive the CO_2 flux from the organic soil pool in Table 2.1 and to avoid double counting with biomass and litter carbon pools. These terms are the ratio of heterotrophic to total respiration, aboveground litter input, and fine root mortality (Hergoualc'h and Verchot, 2013). Whenever available, the terms were taken directly from the flux studies. Otherwise, generic land-use specific values were developed based on studies of these terms that passed the quality criteria of study site characteristics, monitoring quality, transparency and traceability. The ratio of heterotrophic to total respiration data was purely derived from studies on organic soils. When no data was available, e.g. for sago palm plantations and rice, the ratio was transferred from the most similar land-use type. Above-ground litter and root input were available from studies on organic soils for all land-use types except for plantations and rice. Instead of *Acacia crassicarpa*, which is grown on organic soils, data from *Acacia mangium* chronosequences on mineral soils (Nouvellon et al. 2012) were used, which best reflected the age-dependent litter production. For oil palm, data from mineral and organic soils were used (Lamade and Bouillet 2005; Henson and Dolmat, 2003). Due to the high root biomass and spatial heterogeneity (Dariah *et al.*, 2013), root input by oil palm is particularly uncertain. For sago palm, the oil palm values were used due to lack of land-use specific data.

Annex 2A.2 Derivation of ditch CH_4 emission factors

The Tier 1 default EFs presented in Table 2A.1 were derived from the published studies listed. The number of studies available remains relatively small, although some include a substantial number of individual measurement sites. Measured fluxes are generally quite variable within each soil/land-use type, and are not evenly distributed across different organic soil types (for example, most of the data for deep-drained and shallow-drained Grassland on organic soils are obtained from studies in The Netherlands). Tier 1 defaults for $EF_{CH4\text{-}ditch}$ were derived from the mean of all data within each land-use class, and uncertainty ranges were calculated as 95% confidence intervals. Indicative Tier 1 default values for the fractional area of ditches within drained organic soils were calculated in the same way, except that data from the Netherlands were omitted from the Grassland classes, on the basis that fractional ditch areas are considered to be higher here than elsewhere, and that their inclusion would therefore lead to atypically high default values. Note that here are currently few data on CH_4 emissions from ditches in tropical organic soils or from blanket bogs. Further published data on ditch CH_4 emissions may be used to refine the default values presented in Table 2.4, or to derive country-specific Tier 2 emission factors.

TABLE 2A.1
COLLATED DATA ON DITCH CH_4 EMISSIONS FROM DRAINED AND RE-WETTED ORGANIC SOILS

Organic soil/land-use type	**Country**	**Reference**	**EF_{CH4_ditch} (t CH_4-C ha^{-1} yr^{-1})**	**$Frac_{ditch}$**
Deep-drained Grassland	The Netherlands	Schrier-Uijl *et al.,* 2010, 2011	0.435	0.21
Deep-drained Grassland	The Netherlands	Vermaat *et al.,* 2011	0.592	0.25
Deep-drained Grassland	The Netherlands	Best & Jacobs, 1997	0.072	0.06
Deep-drained Grassland	UK	McNamara, 2013	0.580	0.04
Dee-drained Grassland	Russia	Sirin *et al., 2*012	0.450	0.04
Deep-drained Grassland	Russia	Chistotin *et al.,* 2006	1.989	0.04
Deep-drained Grassland	USA	Teh *et al.,* 2011	1.704	0.05
Shallow-drained Grassland	The Netherlands	Vermaat *et al.,* 2011	0.592	0.25
Shallow-drained Grassland	The Netherlands	Best & Jacobs, 1997	0.345	0.06
Shallow-drained Grassland	The Netherlands	Van den Pol-Van Dasselaar *et al.,* 1999a,b,c	0.085	0.25
Shallow-drained Grassland	The Netherlands	Hendriks *et al.* (2007, 2010)	0.375	0.10
Drained treed bog	Canada	Roulet & Moore, 1995	0.114	0.03
Drained treed fen	Finland	Minkkinen & Laine, 2006	0.783	0.03
Drained afforested fen	Russia	Sirin *et al.,* 2012	0.139	0.02
Drained afforested fen	Russia	Glagolev *et al.,* 2008	0.088	0.04
Drained treed bog	Canada	Roulet & Moore, 1995	0.028	0.03
Drained afforested bog	Russia	Sirin *et al.,* 2012	0.301	0.01
Drained afforested bog	Russia	Sirin *et al.,* 2012	0.011	0.01
Drained afforested bog	Canada	Roulet & Moore, 1995	0.192	0.03
Drained afforested bog	Sweden	Von Arnold *et al.,* 2005b	0.013	0.02

Drained afforested bog	Finland	Minkkinen & Laine, 2006	0.053	0.03
Peat extraction site	Finland	Nykänen *et al.,* 1995	0.133	0.02
Peat extraction site	Sweden	Sundh *et al.,* 2000	0.356	0.03
Peat extraction site	Russia	Sirin *et al.,* 2012	1.022	0.04
Peat extraction site	Russia	Chistotin *et al.,* 2006	0.797	0.04
Peat extraction site (inactive)	Finland	Hyvönen *et al*., 2013	0.011	0.06
Peat extraction (inactive)	Canada	Waddington & Day, 2007	0.110	0.05
Drained blanket bog	UK	Cooper & Evans, 2013	0.070	0.03
Drained tropical peat (abandoned)	Indonesia	Jauhiainen & Silvennoinen, 2012	0.449	0.02
Drained tropical peat (pulpwood plantation)	Indonesia	Jauhiainen & Silvennoinen, 2012	2.939	0.02

Annex 2A.3 Derivation of DOC emission factors

Dissolved organic carbon (DOC) is commonly the largest component of waterborne carbon loss from peatlands and organic soils, with measured fluxes from natural peatlands ranging from 0.04 to 0.63 t C ha^{-1} yr^{-1}. In many peatlands, this flux is of comparable magnitude to the rate of long-term carbon accumulation (e.g., Gorham, 1991; Turunen *et al.,* 2004), and the size of waterborne carbon flux can therefore determine whether the site is a carbon sink or carbon source (e.g., Billett *et al.,* 2004; Rowson *et al.,* 2010). If this DOC is subsequently converted to CO_2 via photochemical or biological breakdown processes, this flux will also contribute to overall CO_2 emissions from the organic soil (as an 'off-site' emission). This section describes the methodology that has been used to derive emission factors for DOC losses from drained peatlands and organic soils. At present, it is not considered possible to set reliable emission factor estimates for other forms of waterborne carbon loss, or for the effects of specific land-use and land-use changes (other than drainage) on DOC loss. Methodological requirements to develop these emission factors in future are described in Appendix 2a.1. The approach is based on Equation 2.5.

Estimation of $DOC_{FLUX-NATURAL}$

Most of the available published studies of drainage impacts on DOC loss report concentration changes relative to undrained comparison sites, rather than direct (robust) flux measurements. On the other hand, a larger number of studies provide reliable DOC flux estimates from natural, or near-natural, peatland systems. These two data sources (DOC fluxes from natural sites, and DOC changes from drained-natural comparisons) were therefore combined to derive best estimates of the DOC flux from drained sites, following Equation 2.5.

Default values for $DOC_{FLUX-NATURAL}$ were derived from 23 published studies reporting DOC fluxes for 26 sites in total, including natural boreal and temperate raised bogs and fens, temperate blanket bogs, and tropical peat swamp forests (Table 2A.2). Most data were derived from catchment-scale studies with natural drainage channels, for which accurate hydrological data are available, and to avoid double-counting of reactive DOC exports from peatlands that are rapidly converted to CH_4 or CO_2 within the ditch network (i.e., on-site emissions). Clear differences in flux were observed according to climate zone, with the lowest fluxes from boreal sites and the highest fluxes from tropical sites, supporting a simple Tier 1 classification system for natural DOC flux estimates based on this classification.

TABLE 2A.2
ANNUAL DOC FLUX ESTIMATES FROM NATURAL OR SEMI-NATURAL PEATLANDS USED TO DERIVE DEFAULT VALUES FOR $DOC_{FLUX-NATURAL}$

Climate zone	Country	Study	DOC flux ($t\ C\ ha^{-1}\ yr^{-1}$)
Boreal	Finland	Juutinen *et al.,* 2013	0.037
Boreal	Canada	Moore *et al.* , 2003	0.043
Boreal	Canada	Koprivnjak & Moore, 1992	0.052
Boreal	Canada	Moore *et al.* , 2003	0.060
Boreal	Finland	Kortelainen *et al.*, 2006	0.060
Boreal	Finland	Jager *et al.*, 2009	0.078
Boreal	Sweden	Agren *et al.*, 2007	0.099
Boreal	Finland	Rantakari *et al.*, 2010	0.120
Boreal	Sweden	Nilsson *et al.*, 2008	0.130
Boreal	Finland	Kortelainen *et al.*, 2006	0.159
Temperate	Canada	Strack *et al.*, 2008	0.053
Temperate	Canada	Roulet *et al.*, 2007	0.164
Temperate	USA	Urban *et al.*, 1989	0.212
Temperate	USA	Kolka *et al.*, 1999	0.235
Temperate	Canada	Moore *et al.* , 2003	0.290
Temperate	Canada	Clair *et al.*, 2002	0.360
Temperate	UK	Dawson *et al.*, 2004	0.194
Temperate	UK	Dinsmore *et al.*, 2011	0.260
Temperate	UK	Billett *et al.*, 2010	0.234
Temperate	UK	Billett *et al.*, 2010	0.276
Temperate	Ireland	Koehler *et al.* , 2009,2011	0.140
Temperate	Australia	Di Folco & Kirkpatrick, 2011	0.134
Tropical	Indonesia	Baum *et al.*, 2008	0.470
Tropical	Indonesia	Alkhatib *et al.*, 2007	0.549
Tropical	Malaysia	Yule *et al.*, 2009; Zulkifli, 2002	0.632
Tropical	Indonesia	Moore *et al.*, 2013	0.625

Estimation of $\Delta DOC_{DRAINAGE}$

A total of eleven published studies were identified which provided sufficient data to calculate ratios of either DOC concentration or DOC flux between comparable drained and un-drained peat sites (Table 2A.3). These included data from boreal and temperate raised bogs and fens, blanket bogs, and tropical peats, and drainage for both peat extraction and land-use change to agriculture. There is a reasonable degree of consistency among the studies included; all show an increase in DOC following drainage, with an overall range of 15% to 118%. Most of the published studies suggest a DOC increase close to the mean (across all studies) of 60%, and there was insufficient evidence to support the use of different Tier 1 $\Delta DOC_{DRAINAGE}$ values for different peat types, climate zones, drainage type or drainage intensity. The use of concentration data to estimate $\Delta DOC_{DRAINAGE}$ does, however, assume no corresponding change in total water flux as a result of drainage, which adds uncertainty to the calculated flux changes. This uncertainty should be relatively small for high-precipitation boreal/temperate bogs, as a large change in water flux could only occur if there is a correspondingly large change in evapotranspiration. For drier bog sites, drainage might be expected to increase water fluxes, therefore amplifying the observed concentration differences between drained and undrained sites (e.g., Strack and Zuback, 2013). However for fens, which are fed by external groundwater or surface water inputs rather than solely by precipitation, there is greater potential for drainage to lead to fundamental changes in hydrological functioning (e.g., by routing lateral water inputs around the fen rather than through it), thus altering the water flux. Consequently, although observed DOC concentration changes in drained fens are similar to those from drained bogs (Table 2A.3), the appropriate default value of $\Delta DOC_{DRAINAGE}$ for fens is more uncertain. At Tier 1, it could therefore be assumed that the DOC flux from a drained fen is unchanged from the natural flux (i.e., that $\Delta DOC_{DRAINAGE}$ is equal to zero, and the DOC export is thus equal to $DOC_{FLUX\text{-}NATURAL}$). At Tier 2 it may be possible to develop specific estimates of $\Delta DOC_{DRAINAGE}$ based on paired comparisons between reliable DOC flux measurements for undrained and drained fens, either on a country-specific basis or by pooling studies in different countries. Alternatively, direct measurements of DOC export flux could be used to derive Tier 2 EFs for DOC emissions from drained fens.

Overall, the available data support a Tier 1 default $\Delta DOC_{DRAINAGE}$ value of 0.60 for drained bogs and tropical organic soils. Given difficulties of quantifying the water budget of drained fens, there is greater uncertainty about the applicable value for $\Delta DOC_{DRAINAGE}$ for this organic soil type. Therefore, countries may choose to apply the same Tier 1 default value as in other soil types, or to make the assumption that DOC export does not increase with drainage from fens, i.e., to apply the natural DOC flux value to calculate EF_{DOC}. An exception may also be made where drainage channels are cut into underlying mineral soils, as this has been found to reduce DOC loss (e.g., Moore, 2007).

TABLE 2A.3
DOC CONCENTRATION (ABOVE) OR FLUX (BELOW) COMPARISONS BETWEEN DRAINED AND UNDRAINED ORGANIC SOILS, USED TO DERIVE DEFAULT VALUE FOR $\Delta DOC_{DRAINAGE}$

Organic Soil type	**Land-use**	**Country**	**Study**	**DOC**		**$\Delta DOC_{DRAINAGE}$ (%)**
				Undrained	**Drained**	
Concentration-based studies (DOC mg l^{-1})						
Boreal bog	Drainage (peat extraction)	Canada	Glatzel *et al.,* 2003	60	110	83%
Boreal fen	Drainage	Canada	Strack *et al.,* 2008	16	24.29	53%
Boreal fen	Drainage	USA	Kane *et al.,* 2010	56	71.7	29%
Boreal fen	Drainage (peat extraction)	Finland	Heikkinen, 1990	17	20	15%
Temperate bog	Drainage	Poland	Banaś & Gos, 2004	48	71	49%
Temperate bog	Drainage (peat extraction)	New Zealand	Moore & Clarkson, 2007	70	108	54%
Temperate bog	Drainage	Czech Republic	Urbanová *et al.,* 2011	36	53.9	51%
Temperate fen	Drainage	Czech Republic	Urbanová *et al.,* 2011	17	37.5	118%
Temperate blanket bog	Drainage	UK	Wallage *et al.,* 2006	28	42.9	55%
Flux-based studies (DOC g m^{-2} yr^{-1})						
Tropical peat	Drainage (sago palm)	Malaysia	Inubushi *et al.,* 1998	33	63	91%
Tropical peat	Drainage (agriculture)	Indonesia	Moore *et al.,* 2013	62	97	54%

Estimation of $Frac_{DOC-CO2}$

The significance of DOC export in terms of greenhouse gas estimation depends on its ultimate fate, i.e., whether it is returned to the atmosphere as CO_2 (or even CH_4), or deposited in stable forms such as lake or marine sediments. The latter simply represents a translocation of carbon between stable stores, and should not therefore be included in the estimation. The parameter $Frac_{DOC-CO2}$ sets the proportion of DOC exported from organic soils that is ultimately converted to CO_2. While uncertainty remains in the estimation of this parameter, there is growing evidence that fluvial systems process a high proportion of incoming terrestrial carbon, and that much of this is converted to CO_2 (e.g., Cole *et al.*, 2007; Wickland *et al.*, 2007; Battin *et al.*, 2009; Algesten *et al.*, 2003). Both Jonsson *et al.* (2007) and Algesten *et al.* (2003) estimated that around 50% of all terrestrially-derived organic carbon was mineralised within large, lake-influenced catchments in Sweden. Wickland *et al.* (2007) measured 6% to 15% conversion of pore-water DOC to CO_2, and 10% to 90% conversion of the vegetation-derived DOC, during one-month dark incubations, while Raymond & Bauer (2001) measured 63% biodegradation of riverine DOC during a one-year dark incubation. Multiple studies showing a strong correlation between lake DOC concentration and dissolved CO_2 concentrations (e.g., Sobek *et al*., 2003; Stutter *et al*., 2011 and references therein) all suggest widespread conversion of DOC to CO_2 in lakes. Dawson *et al.* (2001) estimated that 12-18% of DOC was removed within a 2 km stream reach, Experiments undertaken on light-exposed samples of peat-derived waters (Köhler *et al.*, 2002; Worrall *et al.*, 2013; Jones *et al.*, 2013) consistently show rapid and extensive DOC loss, with averages ranging from 33% to 75% over periods of up to 10 days. Both Köhler *et al. (*2002) and Jones *et al.* (2013) found that peat-derived DOC was more susceptible to photo-degradation compared to DOC from other water sources, and Köhler *et al.* (2002) found that most of the DOC lost was converted to CO_2 (e.g., Opsahl and Benner, 1998). Jones *et al.* (2013) observed that since much of this degradation occurs within the first 48 hours, this would be sufficient to convert most peat-derived DOC to CO_2 before it enters the sea. Overall, Algesten *et al.* (2003) estimated that 90% of the DOC removal in their large catchments was due to mineralisation to CO_2, with only 10% buried in lake sediments. Terrestrially-derived DOC which does reach the sea largely appears to be photo-chemically or microbially processed in the marine system, mostly within years to decades (Bianchi, 2011; Opsahl and Benner, 1997).

In summary, there is strong evidence that a high proportion of peat-derived DOC is mineralized rapidly in headwaters; that this processing continues at a relatively high rate through rivers and lakes; and that any peat-derived DOC that does reach the sea will nevertheless largely be mineralized in the marine ecosystem. These observations support the use of a high value for $Frac_{DOC-CO2}$. Taking the ratio of mineralisation to sediment burial obtained by Algesten *et al.* (2003), and assuming that a similar ratio applies to any DOC exported to the ocean, would suggest that around 90% of peat-derived DOC is eventually converted to CO_2. On this basis a Tier 1 default value of 0.9 is proposed, with an uncertainty range of 0.8-1.0 to reflect uncertainties in the proportion of DOC returned to burial in lake or marine sediments.

There is some evidence that controlled burning (for moorland management) also increases DOC losses (e.g., Yallop *et al.,* 2010; di Folco & Kirkpatrick, 2011), although other experimental studies have shown no effect (e.g., Ward *et al.,* 2007; Worrall *et al.,* 2007). A precautionary estimate is that managed burning may increase mean DOC loss by 20-50%, but further work is required to resolve uncertainties on this issue (Holden *et al.*, 2012). Grazing levels on semi-natural vegetation have not been shown to affect DOC loss (Ward *et al.,* 2007; Worrall *et al.,* 2007), and data on the effects of more intensive agricultural (Grassland and Cropland) management on DOC loss are currently insufficient to estimate an emissions factor. Therefore, generic values for the effects of drainage may be used.

Annex 2A.4 Derivation of CO_2-C and non-CO_2 emission factors for emissions from burning of drained inland organic soils from scientific literature in Tables 2.6 and 2.7

CO_2 emission factors for fires on drained organic soils were obtained by a consideration of the available scientific literature. The data presented in Table 2.6 and Table 2.7 provide default values for mass of available fuel and emissions factors.

The data in Table 2.6 were obtained using a variety of different approaches to calculate the mass of fuel combusted. It should be noted that there are only a limited number of publications providing ground- or laboratory-based data on the depth (i.e. volume) of soil organic material consumed. Quantitative estimation of depth of burn as well as organic soil characteristics (i.e. bulk density and carbon content) are not easy to determine in the field, thus information on these key parameters is often based on theoretical assumptions or limited ground measurements. This knowledge gap contributes considerably to the overall uncertainties related to emissions from fires on organic soils because it is difficult to accurately assess the amount of fuel that is consumed. Field data of depth of burn are available from a number of studies of fires on organic soils in northern forests and peatlands in North America, Europe and Asia (e.g., Zoltai *et al.*, 1998; Turetsky & Wieder, 2001; Page *et al.,* 2002; Benscoter & Wieder, 2003; Ballhorn *et al.*, 2009; de Groot *et al.*, 2009; Turetsky *et al.,* 2011a, b), while in other cases, data have been extrapolated from previous studies.

Obtaining accurate field data on the depth of combustion on organic soils is problematic since there is usually a lack of reference data. Turetsky & Wieder (2001) developed a method for field assessment that considered the rooting depth of trees, while other studies have used comparison of adjacent unburned sites to quantify combustion depth (e.g., Kasischke*,* 2000; Page *et al.,* 2002; de Groot *et al.*, 2009; Turetsky *et al.,* 2011a) or measurement of fuel loads before and after experimental fires (e.g., Usup *et al*., 2004). The use of LiDAR remote sensing has also been applied in one study (Ballhorn *et al.,* 2009).

Nearly all the data presented in Table 2.6 for the boreal and temperate zones are actually from the boreal zone, with only one study in the temperate zone (Poulter *et al.,* 2006) and two studies in tropical zone (Ballon *et al.*, 2009; Page *et al.*, 2002). Most studies are of wildfires (i.e. unwanted and unplanned fires ignited other than by prescription (e.g., by lightning or as a result of human activities, including escaped prescribed fires as well as those started through negligence or by arson) and are for fires on undrained peatland organic soils. Only Turetsky *et al.* (2011b) provide depth of burn data for a wildfire on a drained boreal organic soil. In addition, there are no data for organic soil losses associated with prescribed fires in the boreal/temperate zone but some studies to suggest that DOC increases following fire (see also Annex 2A.2). Most prescribed (i.e. managed) fires on the vegetation of organic soils probably result in either no or only minimal ignition loss of soil carbon.

Fuel moisture content, depth of water table and burn history will all determine the extent of organic soil combustion during a prescribed fire but the scale of loss will often depend on the skill and experience of the fire manager. In some parts of the temperate zone, prescribed rotational burning of vegetation on organic soils is a long-established land management practice. In the UK it is carried out on about 18% of peatlands, predominantly in the uplands (Marsden & Ebmeier, 2012), with the aim of removing the older, less productive vegetation and encouraging new growth for livestock grazing and cover for game birds (Worrall *et al.* 2010). In North America, prescribed burning of vegetation on organic soils is also practiced, with a range of benefits including the reduction of wildfire hazards, improvement of wildlife habitats and restoration of ecosystem diversity and health (e.g., Christensen, 1977). Typically prescribed burning will be carried out when fuel moisture is high enough to prevent combustion of the organic soil but low enough to carry a surface fire, thus reducing the risk of soil ignition. Shifts in climate have narrowed the window of opportunity for prescribed burning and changes in weather patterns have resulted in unexpected drying of peatlands during on-going prescription burns. Some local fire managers have recognised this shift, but unfortunately this is a minimally studied area and little information exists on the scale of emissions arising from the combustion of organic soils during prescription burns. At Tier 1, it is assumed that there is either no or very little combustive loss of soil organic matter during prescribed fires on organic soils.

For tropical organic soils, the average depth of burn has not been explored in a consistent way that representatively covers the different geographical regions, vegetation types or the different fire types (i.e. wild vs. prescribed fires). There have been a limited number of field measurements of depth of burn and estimates of organic soil combustion losses. These have used either direct field measurements (e.g., Page *et al.,* 2002; Usup *et al.*, 2004) or a combination of field measurements and LiDAR data (e.g., Ballhorn *et al.,* 2009). There are only three studies of wildfires on drained organic soils and none in undrained organic soils, although studies have demonstrated that in an intact condition tropical peat swamp forest is at very low risk of fire (e.g., Page *et al.,* 2002). There have been a limited number of studies investigating depth of burn on drained organic soils under agricultural management (e.g., Saharjo & Munoz, 2005). Prescribed agricultural burning is undertaken on both a small and large scale to improve soil fertility and/or to remove forest or crop residues during land preparation activities. For example, traditional 'sonor' rice cultivation on shallow organic soils involves regular burning of crop residues along with the soil surface to enhance soil fertility. In addition to field measurements, there have been limited laboratory-based burn tests aimed at establishing the environmental controls on depth of organic soil combustion (e.g., Benscoter *et al.,* 2011). While more field and laboratory experiments to determine fuel consumption during fires on organic soils are needed (French *et al.,* 2004) there is also a need for improved remote sensing methods to aid burn severity mapping in peatlands (defined as the magnitude of ecological changes between pre- and post-fire conditions) which can provide an indication of the likely depth of burn. Burn severity is not easy to either investigate or quantify but there have been a limited number of studies using spectral indices to discriminate different levels of burn severity in boreal and temperate forests (e.g., van Wagtendonk *et al.,* 2004; Epting *et al.,* 2005; Hall *et al.,* 2008) but only one study to date of tropical organic soils (Hoscilo *et al.,* 2013). Even regionally developed consumption models can have large uncertainties with respect to organic soils consumption. The development of robust methodologies to assess burn severity and total organic soil consumption in wetlands would enable more accurate quantification of carbon emissions from both above and below-ground fires for reporting at higher tiers.

Accurate assessment of the volume of organic soil combusted during a fire will only be feasible at higher Tier 2 and Tier 3 levels, while at Tier 1 level some simplifying assumptions are required.

Appendix 2a.1 Estimation for Particulate Organic Carbon (POC) and Dissolved Inorganic Carbon (DIC) loss from peatlands and drained organic soils: Basis for future methodological development

This Appendix provides a basis for future methodological development rather than complete guidance.

Particulate Organic Carbon

Particulate organic carbon (POC) is generally a negligible component of the carbon balance of natural peatlands and organic soils. However, disturbance of organic soils through land-use change, including drainage (which can include the dredging of peat from drains and canals), burning (managed burning and wildfire), conversion to arable and peat extraction, can all result in high rates of POC loss via waterborne erosion and also wind erosion. In actively eroding blanket bogs, POC losses in excess of 100 g C m^{-2} yr^{-1} may represent the dominant form of soil carbon loss (e.g., Pawson *et al.,* 2008; Worrall *et al.,* 2011).

Available data suggest that the key determinant of POC loss is the proportion of the total area occupied by exposed (bare) peat, according to Equation 2A.1. The bare peat area, $PEAT_{BARE}$, would include unvegetated drainage ditches, erosion gullies, peat extraction surfaces, and areas of the soil surface exposed by burning, intensive grazing or the deposition of peat dredged from drainage channels onto the land surface. For Cropland, some estimation of the annual average proportion of the organic soil surface exposed over the full crop rotation would be required. Data from eroding UK blanket bogs suggest that waterborne POC exports can be reasonably well-predicted based on a POC flux from bare peat surfaces ($POC_{FLUX\_BAREPEAT}$) of around 4 t C ha^{-1} yr^{-1} (Goulsbra *et al.,* 2013). Further work is required to establish whether different values would be applicable to other soil types, land-use types and climate regimes (in particular whether it is dependent on precipitation amount or intensity). At present there are few data on which to base an estimate of airborne POC loss, and further work is required to quantify this loss term, which may be large in peat extraction and cropland sites.

Finally, there is limited information currently available from which to derive a value for the proportion of POC ultimately converted to CO_2, ($Frac_{POC\text{-}CO2}$). Unlike DOC, a substantial proportion of POC is mobilized from organic soils through physical erosion processes, and its reactivity in fluvial systems is uncertain. Some studies have shown fairly high rates of POC turnover in river and estuarine systems (e.g., Sinsabaugh and Findlay, 1995), and POC redeposited on floodplains may be subject to moderate rates of oxidation (Goulsbra *et al.,* 2013). However, it is likely that a significant proportion of waterborne POC loss from organic soils may simply be transferred to lake or coastal sediments, re-deposited on floodplains, or transported to other land areas via aeolian transport, rather than converted to CO_2. Further research is therefore needed to establish realistic ranges for $Frac_{POC\text{-}CO_2}$ in different systems.

EQUATION 2A.1

CALCULATION OF POC EXPORT FROM DRAINED ORGANIC SOILS

$$EF_{POC} = POC_{FLUX\_BAREPEAT} \bullet PEAT_{BARE} \bullet Frac_{POC-CO_2}$$

Where:

EF_{POC} = POC emission factor, t C ha^{-1} yr^{-1}

$POC_{FLUX\_BAREPEAT}$ = Flux of POC from a bare peat surface, t C ha^{-1} yr^{-1}

$PEAT_{BARE}$ = Proportion of the ground surface occupied by exposed peat

$Frac_{POC\text{-}CO2}$ = Conversion factor for the fraction of POC converted to CO_2 following export from site

Dissolved Inorganic Carbon

Waterborne carbon fluxes from organic soils, comprising bicarbonate ion (HCO_3^-), carbonate ions (CO_3^{2-}) and free CO_2, are collectively termed dissolved inorganic carbon (DIC). These different carbon species exist in equilibrium, depending primarily on the pH of the water. In water draining low-pH organic soils (i.e. bogs), almost all DIC exists is present as CO_2. Most of this CO_2 derives from autotrophic and heterotrophic respiration within organic soils, and is transferred laterally from soils into drainage waters, where it is consistently present at concentrations well in excess of atmospheric CO_2 concentrations. This supersaturated CO_2 will be emitted ('evaded' or 'degassed') to the atmosphere, typically within a few kilometres of its source (e.g., Hope *et al.,* 2001). Limited measurements of CO_2 evasion from natural peatlands suggest that this emission is a quantitatively significant component of the overall carbon budget. For example, Dinsmore *et al.* (2010) recorded a DIC flux of 0.12 to 0.16 t C ha^{-1} yr^{-1} at a Scottish peatland catchment, of which over 90% was evaded to the atmosphere within the first 5 km of the stream length. Although this may be considered an 'on site' emission, in practice it will not be measured as part of the terrestrial CO_2 emission using chamber-based methods, and is unlikely to be captured by eddy covariance methods. Consequently, direct measurements of CO_2 emissions from water bodies draining organic soils (e.g., using floating chambers or gas transfer coefficients linked to measurements of dissolved CO_2 within the water column) are likely to be required in order to obtain reliable estimates of this component of the carbon flux. Currently, only a few such measurements are available for undrained organic soils (e.g., Hope *et al.*, 2001; Billett and Moore, 2008; Dinsmore *et al.*, 2009; Dinsmore *et al.*, 2010; Wallin *et al.*, 2012). For drained organic soils, insufficient data are currently available to permit default emission factors to be developed. Further measurements of CO_2 evasion for a range of climate zones, soil types, land-use classes and drainage systems are therefore required to support future methodological development in this area. Care is required to avoid double-counting of CO_2 emissions associated with mineralisation of DOC within downstream water bodies, as opposed to the direct degassing of CO_2 released from the organic soil into the water body.

As noted above, other components of the DIC flux can be considered minor for bogs, due to their low pH. This is not the case for fens, which have a higher pH, so that HCO_3^- and CO_3^{2-} may form significant components of the total DIC export. However, a high proportion of this flux may derive from weathering processes external to the organic soil (i.e. in groundwater or river water inputs to the fen) and this geogenic flux cannot be considered a part of the internal carbon budget of the organic soil. On the other hand, autotrophic and heterotrophic respiration processes may also generate dissolved CO_2, which can then dissociate to form HCO_3^- and CO_3^{2-} in alkaline waters. This flux *does* form a component of the organic soil carbon balance, but further work is needed in order to i) quantify this flux (particularly for drained organic soils); ii) differentiate this biogenic DIC from geogenic DIC (for example using isotopic methods); and iii) determine the proportion of DIC exported from organic soils which is ultimately returned to the atmosphere as CO_2, rather than sequestered into sediments, such as marine carbonate deposits.

Finally, available data consistently suggest that, other than emissions from drainage ditches (see Section 2.2.2.1), on- or off-site emissions of dissolved CH_4 from water bodies represent a negligible component of the total carbon and greenhouse gas budget of organic soils (e.g., Hope *et al.*, 2001; Dinsmore *et al.*, 2010; Billett and Harvey, 2013).

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CHAPTER 3

REWETTED ORGANIC SOILS

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3 REWETTED ORGANIC SOILS

3.1 INTRODUCTION

What is rewetting, restoration, rehabilitation and how rewetting affects GHG

Definitions of wetlands and organic soils are provided elsewhere in this supplement (Chapter 1 and Glossary), and will not be repeated here. As in the remainder of this supplement, this chapter considers peatlands to be included in '(land with) organic soil'. Unless stated otherwise, statements referring to organic soils will include soils made of peat; in some instances, examples are provided that are specific to peat soils or peatlands and in such cases peatlands will be mentioned specifically.

Rewetting is the deliberate action of raising the water table on drained soils to re-establish water saturated conditions, e.g. by blocking drainage ditches or disabling pumping facilities. Rewetting can have several objectives, such as wetland restoration or allowing other management practices on saturated organic soils such as paludiculture.

Wetland restoration aims to permanently re-establish the pre-disturbance wetland ecosystem, including the hydrological and biogeochemical processes typical of water saturated soils, as well as the vegetation cover that pre-dated the disturbance (FAO 2005, Nellemann & Corcoran 2010). Normally, the restoration of previously drained wetlands is accompanied by rewetting, while the restoration of undrained, but otherwise disturbed wetlands may not require rewetting.

Rehabilitation, as defined by FAO (2005) and Nellemann & Corcoran (2010), can involve a large variety of practices on formerly drained organic soils, which may or may not include rewetting. The re-establishment of a vegetation cover on a drained site without rewetting is a form of site rehabilitation.

The focus of this chapter is the rewetting of organic soils; restoration and other management practices on rewetted organic soils are not specifically addressed. Rehabilitation as an activity separate from rewetting is not covered by this chapter. This chapter does not provide default guidance for the management of undrained inland organic soils or for restoration that does not necessitate rewetting.

The position of the water table is a major control of the biogeochemical processes responsible for GHG fluxes from wetlands (Reddy & DeLaune 2008, pages 162-163). Generally, rewetting decreases CO_2 emissions from organic soils compared to the drained condition, and under certain conditions leads to the recovery of a net ecosystem CO_2 sink (Komulainen et al., 1999, Tuittila et al., 1999, Waddington et al., 2010). Re-establishing the vegetation cover on rewetted organic soils is necessary to reinstate the carbon sink function that ultimately leads to soil C sequestration. After a vegetation succession promoted by rewetting, the CO_2 sink may reach the level typical of undrained ecosystems. However, during the first years after rewetting a site can remain a CO_2 source (Petrone et al. 2003; Waddington et al. 2010); upon restoration the ecosystem sink can temporarily be significantly larger (Soini et al., 2010,Wilson et al., 2013). The time needed for the recovery of the sink function may vary from years to several decades (Tuittila et al. 1999, Samaritani et al. 2011) depending on restoration methods and pre-rewetting and climate conditions.

Rewetting generally increases CH_4 emissions (e.g. Augustin & Chojnicki 2008, Waddington & Day 2007), although in some cases lower emissions have been measured (Tuittila et al., 2000, Juottonen et al., 2012) compared to the drained state. If all the other conditions (e.g., vegetation composition, site fertility) are equal, CH_4 emissions from rewetted sites are generally comparable to undrained sites after the first years following rewetting as shown later in this chapter. In temperate regions N_2O emissions are found to rapidly decrease close to zero after rewetting (Augustin & Merbach, 1998; Wilson et al., 2013).

Carbon is also lost from rewetted organic soils via water mainly in a form of dissolved organic carbon (DOC). Most of this carbon is eventually released into the atmosphere as CO_2. Rewetting is thought to decrease DOC leaching to a level comparable with undrained organic soil.

Generally the likelihood of fire occurrence in rewetted ecosystems is low, but real. The reader is referred to the default approach provided in Chapter 2 of this supplement to quantify this source of emissions for all GHGs.

High spatial variation in microtopography, water level and vegetation cover is typical of undrained organic soils and is also observed in GHG fluxes (Strack et al., 2006, Laine et al., 2007, Riutta et al., 2007, Maanavilja et al., 2011). Rewetting recreates this natural heterogeneity with blocked ditches forming the wetter end of the variation (Strack & Zuback 2013, Maanavilja et al., submitted). For this reason, in this chapter, (and in contrast to the approach in Chapter 2), former ditches are included as a part of rewetted sites and not treated separately.

Scope of this guidance: wetland types covered, gases, pools

This chapter provides guidance on rewetting of organic soils, with a focus on the soil pool. Organic soils can also support perennial woody vegetation. To avoid repeating guidance already provided, wherever appropriate the reader will be referred to existing guidance in the *2006 IPCC Guidelines*, especially on C stock changes in the woody biomass and dead wood pools.

The distinction between C pools in some wetland ecosystems can be difficult, especially between the herbaceous biomass (mosses, sedges, grasses), the dead organic matter derived from this biomass and soil pools. For example, the dead portion of mosses characteristic of many peatlands could be included in the dead organic matter or soil pool. The non-woody biomass on rewetted organic soils cannot be ignored as it is essential in the restoration of the carbon sink function that in turn results in the sequestration over time of large quantities of soil carbon. Because the default emission factors in this chapter were all derived from flux measurements over wetlands on organic soils with moss and/or herbaceous vegetation and/or dwarf shrubs, these default EFs integrate all C fluxes from the soil and the above- and belowground vegetation components other than trees. In all cases the guidance in this chapter will clarify which C pools are included in default EFs.

In this chapter boreal and temperate organic soil wetlands are divided into “nutrient poor” and “nutrient rich” categories (Rydin & Jeglum 2006). Most nutrient poor wetlands, whether undrained or rewetted, receive water and nutrients from precipitation only, while nutrient rich wetlands also receive water from their surroundings.

Tropical wetlands on organic soils include a great variety of contrasting ecosystems, from papyrus dominated sites in Africa to peat swamp forests in South East Asia. In general much less information is available for wetlands on organic soils in tropical regions than in temperate or boreal regions.

Rewetting activities in tropical regions have been reported from the USA, South Africa and Indonesia. Southeast Asia harbours the largest extent of tropical peatlands (Page et al., 2011) and several attempts at large scale rewetting have been undertaken here. Although successful rewetting of organic soils in tropical regions has been demonstrated, flux data from such sites are lacking. Therefore, a default EF for rewetted tropical organic soils was developed based on surrogate data. It is *good practice*, where significant areas of tropical organic soils have been rewetted, to develop science-based, documented, country-specific emission factors for CO_2, CH_4 and N_2O emissions.

As in the *2006 IPCC Guidelines*, guidance is provided for three GHGs: CO_2, CH_4 and N_2O.

How to use guidance in this chapter and relationship to reporting categories

Depending on circumstances and practices, rewetting may or may not involve a change in land use. Hence pre- and post-rewetting land use of organic soils can vary according to national circumstances, and be reported as Forest Land, Cropland, Grassland, Wetlands or Settlements. The guidance in this chapter should be applied regardless of the reporting categories. In particular, no recommendation is provided in relation to transition periods between land-use categories; countries can apply the existing transition period of appropriate land-use categories to rewetted organic soils. Because the functioning of these ecosystems has already been deeply altered due to management, reporting rewetted organic soils as unmanaged land is not consistent with *good practice*.

3.2 GREENHOUSE GAS EMISSIONS AND REMOVALS

Equation 2.3 in Chapter 2, Volume 4 of the *2006 IPCC Guidelines* illustrates how in general carbon-containing GHGs from an ecosystem can be calculated from the sum of C stock changes in each of the ecosystem carbon pools. This chapter provides additional guidance specifically for the soil pool term ΔC_{so} of equation 2.3 - in particular for saturated organic soils. When practices for the rewetting of organic soils also involve C stock changes in woody biomass or dead organic matter (DOM) pools, the appropriate default assumptions will be provided along with references to existing equations in the *2006 IPCC Guidelines* for the Tier 1 estimation of C stock changes for these pools.

With respect to the soil pool, this chapter elaborates on the estimations of CO_2 emissions or removals and CH_4 emissions from organic soils, regardless of the ultimate goal of the rewetting activity (e.g. restoration or other land management practices).

In the context of this chapter, Equation 3.1 below replaces Equations 2.24 and 2.26 in Chapter 2, Volume 4 of the *2006 IPCC Guidelines*; Equations 2.24 and 2.26 implicitly assumed that organic soils can only lose carbon, while in fact undrained or rewetted organic soils can accumulate soil organic carbon if covered with vegetation. Assuming that rewetting is successful in establishing the C sink function, the rewetted organic soils can gain substantial quantities of carbon. Equation 3.1 reflects the fact that the net C stock change of rewetted organic soils results from net gains or losses of C resulting from the balance between CO_2 and CH_4 emissions and removals.

In large carbon pools, such as organic soils, net CO_2 emissions (or removals via uptake by vegetation) are more accurately measured directly as a CO_2 flux (an emission is a positive flux, a removal a negative flux), as opposed to being derived from a change in C stocks. Likewise, CH_4 emissions are generally measured as fluxes. In this chapter these fluxes are denoted CO_2-C and CH_4-C, for the net C flux as CO_2 and as CH_4 respectively. This notation is consistent with that used in Chapter 7, Volume 4 of the *2006 IPCC Guidelines*.

EQUATION 3.1
NET GAINS OR LOSSES OF C RESULTING FROM THE BALANCE BETWEEN CO2 AND CH4 EMISSIONS AND REMOVALS

$$\Delta C_{rewetted\ org\ soil} = CO_2\text{-}C_{rewetted\ org\ soil} + CH_4\text{-}C_{rewetted\ org\ soil}$$

Where:

$\Delta C_{rewetted\ org\ soil}$ = Net C gain or loss in rewetted organic soils (tonnes C yr^{-1})

$CO_2\text{-}C_{rewetted\ org\ soil}$ = Net flux of CO_2 -C (emissions or removals) from the rewetted organic soil (tonnes C yr^{-1})

$CH_4\text{-}C_{rewetted\ org\ soil}$ = Net flux of CH_4 -C (commonly emissions) from the rewetted organic soil (tonnes C yr^{-1})

The notations CO_2-C and CH_4-C will facilitate reconciling net fluxes with C stock changes for estimation purposes. However, the reporting convention remains that used in the *2006 IPCC Guidelines*, where emissions and removals of CO_2 are reported as C stock changes, and emissions and removals of CH_4 in tonnes of CH_4. CH_4-C is converted to CH_4 using Equation 3.2.

EQUATION 3.2
NET CH_4 FLUX

$$CH_{4\ rewetted\ org\ soil} = CH_4\text{-}C_{rewetted\ org\ soil} \cdot 16/12$$

Where:

$CH_{4\ rewetted\ org\ soil}$ = net flux of CH_4 from the rewetted organic soil (tonnes CH_4 yr^{-1})

$CH_4\text{-}C_{rewetted\ org\ soil}$ = flux of CH_4 -C from the rewetted organic soil (tonnes C yr^{-1})

3.2.1 CO_2 Emissions/Removals from Rewetted Organic Soils

CO_2-C emissions/removals from rewetted organic soils have the following components:

EQUATION 3.3
CO_2-C EMISSIONS/REMOVALS FROM REWETTED ORGANIC SOILS

$$CO_2\text{-}C_{rewetted\ org\ soil} = CO_2\text{-}C_{composite} + CO_2\text{-}C_{DOC} + L_{fire}\text{-}CO_2\text{-}C$$

Where:

$CO_2\text{-}C_{rewetted\ org\ soil}$ = CO_2-C emissions/removals from rewetted organic soils, tonnes C yr^{-1}

CO_2- $C_{composite}$ = CO_2-C emissions/removals from the soil and non-tree vegetation, tonnes C yr^{-1}

$CO_2\text{-}C_{DOC}$ = off-site CO_2-C emissions from dissolved organic carbon exported from rewetted organic soils, tonnes C yr^{-1}

$L_{fire}\text{-}CO_2\text{-}C$ = CO_2-C emissions from burning of rewetted organic soils, tonnes C yr^{-1}

On-site emissions/removals: CO_2- $C_{composite}$

Since the default CO_2-C EFs in this chapter are all derived from flux measurements (see Annex 3A.1), the CO_2-$C_{composite}$ results from the net flux, emissions or removals, from the soil and non-tree vegetation taken together. CO_2 emissions are produced during the decomposition of the organic soil by heterotrophic organisms and are strongly controlled by oxygen availability within the soil and by soil temperature. The contribution from non-tree vegetation occurs via the two processes of photosynthesis (CO_2 uptake) and above- and below-ground autotrophic respiration (CO_2 emissions).

Consistent with the *2006 IPCC Guidelines*, the Tier 1 or default approaches assume that the woody biomass and woody DOM stocks and fluxes are zero on all lands except on Forest Land and on Cropland with perennial woody biomass. For rewetting on Forest Land or on Cropland with woody crops, the woody biomass and woody DOM pools are potentially significant and should be estimated in a way consistent with the guidance provided in Chapters 2 (generic methods), 4 (Forest Land) and 5 (Cropland) in Volume 4 of the *2006 IPCC Guidelines*. Inventory compilers are directed to Equations 2.7, 2.8 and the subsequent equations in Chapter 2 of the *2006 IPCC Guidelines* which split the C stock changes in the biomass pool or ΔC_B into the various gains and losses components, including harvest and fires.

If rewetting is accompanied by a change in land use that involves Forest Land or Cropland with perennial woody biomass, changes in C stocks in biomass and dead wood and litter pools are equal to the difference in C stocks in the old and new land-use categories (see Section 2.3.1.2, Chapter 2, Volume 4 of the *2006 IPCC Guidelines*). These changes occur mostly in the year of the conversion (carbon losses), or are uniformly distributed over the length of the transition period (carbon gains). Default values for C stocks in forest litter can be found in Chapter 4 (Forest biomass), Chapter 5 (Cropland) and Chapter 2 (Table 2.2 for forest litter) in Volume 4, of the *2006 IPCC Guidelines*.

Off-site CO_2 emissions: CO_2-C_{DOC}

The importance of waterborne carbon export (in all its different forms) as a pathway linking the organic soil C pool to the atmosphere is described in Chapter 2 of this supplement and the various sources, behaviour and fate of the different forms of waterborne C following rewetting can be found in Annex 3A.2. In all types of organic soils, including natural and rewetted ones, DOC has been shown to be the largest component of waterborne carbon loss that will be processed and almost entirely returned eventually to the atmosphere. It is therefore *good practice* to include DOC in flux-based carbon estimation methods to avoid under-estimation of soil C losses. CO_2- C_{DOC} is produced from the decomposition of dissolved organic carbon (DOC) lost from organic soils via aquatic pathways and results in off-site CO_2 emissions; a Tier 1 methodology is described below. Other forms of waterborne carbon (Particulate Organic Carbon and dissolved CO_2) may also be significant in the early years following rewetting but few data exist (see Annex 3A.2). It should be noted also that although generally not significant, DOC imports (e.g. from precipitation) should in theory be removed from net DOC fluxes.

Emissions from burning: L_{fire}-CO_2-C

While the likelihood of fires on rewetted organic soils is considered low (particularly in comparison to drained organic soils), fire risk may still be real. Any emissions from the burning of biomass, dead organic matter as well as from soil (L_{fire}-CO_2-C) should be included. Generic methodologies for estimating CO_2 emissions from the burning of vegetation and dead organic matter are provided in Chapter 2, Volume 4 of the *2006 IPCC Guidelines*, while methodologies specific to vegetation and DOM burning in Forest Land, Cropland, Grassland and Wetlands are provided in Chapters 4-7 in Volume 4 of the *2006 IPCC Guidelines*. Emissions from the burning of organic soils can be estimated following the methodologies in Equation 2.8 of Chapter 2 (this supplement) using the fuel consumption values estimated for undrained organic soils given in Table 2.6 (same value for all climates) as well as emission factors from Table 2.7

CHOICE OF METHOD

The decision tree in Figure 3.1 presents guidance in the selection of the appropriate Tier for the estimation of GHG emissions/removals from rewetted organic soils.

Tier 1

Under Tier 1, the basic methodology for estimating annual C emissions/removals from rewetted organic soils was presented in Equation 3.3 and can be compiled using Equations 3.4 and 3.5 where the nationally derived area of rewetted organic soils is multiplied by an emission factor, which is disaggregated by climate zone and where applicable by nutrient status (nutrient poor and nutrient rich).

Tier 1 methodology is applicable from the year of rewetting.

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EQUATION 3.4
ANNUAL ON-SITE CO_2-C EMISSIONS/REMOVALS FROM REWETTED ORGANIC SOILS

$$CO_2\text{-}C_{composite} = \sum_{c,\,n} \left(A \cdot EF_{CO_2}\right)$$

Where:

$CO_2\text{-}C_{composite}$ = CO_2-C emissions/removals from the soil and non-tree vegetation, tonnes C yr^{-1}

$A_{c,n}$ = area of rewetted organic soils in climate zone *c* and nutrient status *n*, ha

$EF_{CO_2\,c,n}$ = CO_2-C emission factor for rewetted organic soils in climate zone *c*, nutrient status *n,* tonnes C ha^{-1} yr^{-1}

EQUATION 3.5
ANNUAL OFF-SITE CO_2-C EMISSIONS DUE TO DOC LOSSES FROM REWETTED ORGANIC SOILS

$$CO_2\text{-}C_{DOC} = \sum_{c} \left(A \cdot EF_{DOC\_REWETTED}\right)$$

Where:

$CO_2\text{-}C_{DOC}$ = off-site CO_2-C emissions from dissolved organic carbon exported from rewetted organic soils, tonnes C yr^{-1}

A_c = area of rewetted organic soils in climate zone *c*, ha

$EF_{DOC\_rewetted,\,c}$ = CO_2-C emission factor from DOC exported from rewetted organic soils in climate zone *c* tonnes C ha^{-1} yr^{-1}

Tier 2

A Tier 2 methodology uses country-specific emission factors and parameters, spatially disaggregated to reflect regionally important practices and dominant ecological dynamics. It may be appropriate to sub-divide activity data and emission factors according to the present vegetation composition which is a representation of the water table depth and soil properties or by land use prior to rewetting (e.g. Forest, Grassland, Cropland, Wetland).

Available datasets from rewetted organic soils generally cover a period of 10 years or less after rewetting; for this reason it is difficult to identify clear temporal patterns in CO_2 fluxes. Available data demonstrate that the strength of the CO_2 sink may vary over a number of years. In the period immediately following rewetting, it is expected that soil oxidation rates are low as a consequence of the anoxic conditions, while most of the newly sequestered C is still contained within the non-woody biomass pool (leaves, stems, roots). Over longer time frames (a few decades) a decrease in the amount of CO_2 that is sequestered annually might be expected as the biomass pool eventually approaches a steady state C sequestration saturation point typical of natural, undrained organic soils. Countries are encouraged to develop more detailed EFs for rewetted organic soils that capture fully the transient nature of CO_2 fluxes in the time since rewetting and reflect the time needed for the ecosystem to reach CO_2 dynamics typical of natural, undrained organic soils. In particular, countries with a significant non-vegetated (bare organic soil) component (e.g. industrial cutaways or cutovers) at the time of rewetting are encouraged to develop detailed EFs that capture the expected decline in CO_2 emissions following rewetting (e.g. Tuittila et al. 1999, Bortoluzzi et al. 2006, Kivimaki et al. 2008, Waddington et al. 2010, Wilson et al. 2013).

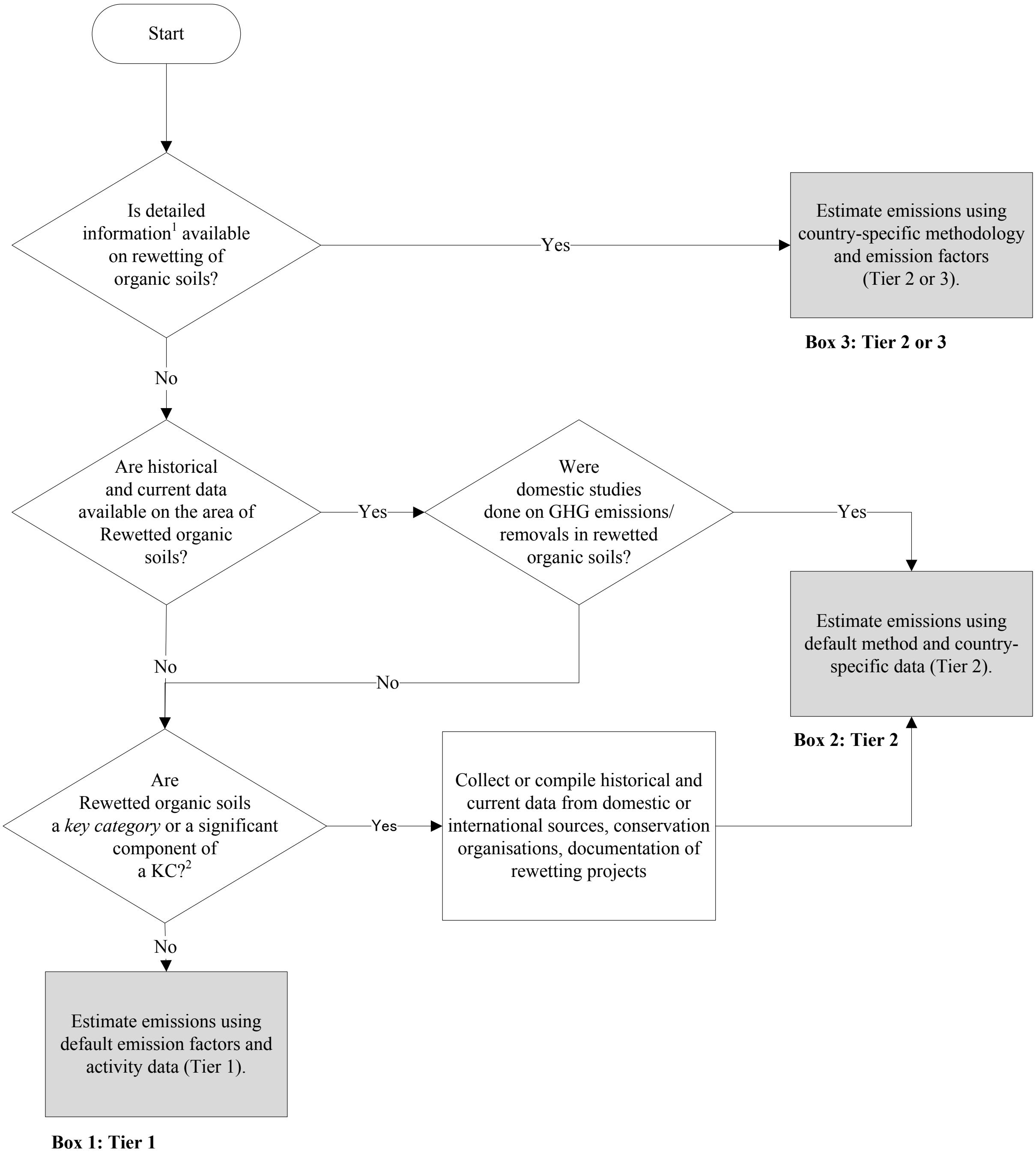
A Tier 2 methodology to derive an estimation of emissions from the decomposition of DOC should utilise country-specific information if experimental data are available to refine the emission factor, especially with regard to different types of natural/undrained and rewetted organic soils (e.g. peatlands with various nutrient status and development, such as raised bogs, blanket bogs, fens). Refined approaches to calculate EF_{DOC} are suggested below under Choice of EF: EF $_{DOC\_rewetted}$. On-site flux measurements will not capture C losses as DOC so it is *good practice* to explicitly add C losses as DOC to flux-based C estimation methods. If a soil subsidence approach is used to derive $CO_2\text{-}C_{composite}$ of Equation 3.3, DOC losses are included in the subsidence data and should not be added a second time.

Tier 2 (as well as Tier 3) methodologies may capture changes in the woody biomass pool as fluxes instead of separately reported stock changes; in such cases the woody biomass component is integrated with the other components of Equation 3.3. However, it is *good practice* to ensure that double counting does not take place in regard to the woody biomass and DOM pools on rewetted organic soils. Data collection using eddy covariance techniques (EC tower) and chamber measurements are adequate at higher tiers; however when CO_2 flux data have been collected with such techniques the C stock changes in perennial woody biomass and woody DOM may already be included and should not be added a second time.

Tier 3

A Tier 3 methodology involves a comprehensive understanding and representation of the dynamics of CO_2-C emissions and removals on rewetted organic soils, including the effect of site characteristics, soil characteristics, vegetation composition, soil temperature and mean water table depth. These could be integrated into a dynamic, mechanistic-based model or through a measurement-based approach (see choice of EF, Tier 3 below for examples of such models). These parameters, in addition to further parameters such as water flows and residence time of water, could also be used to describe fluvial C (DOC) lost from the system using process-based models that incorporate hydrology amongst other factors. A Tier 3 methodology might also include the entire DOC export from rewetted sites and consideration of the temporal variability in DOC release in the years following rewetting, which will also be dependent on the rewetting techniques used.

Figure 3.1 **Decision tree to estimate CO_2-C and CH_4-C emissions/removals from rewetted organic soils**



Note:

1. Detailed information typically includes national area of rewetted organic soils disaggregated by climate and nutrient status, complemented with documentation on previous land management and rewetting practices, and with associated measurements of GHG emissions and removals at high spatial and temporal resolution.

2. A key source/sink category is defined in Chapter 4, Volume 1 of the *2006 IPCC Guidelines*, "as *one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of greenhouse gases in terms of the absolute level, the trend, or the uncertainty in emissions and removals"*. The *2006 IPCC Guidelines* recommend that the key category analysis is performed at the level of land remaining in or converted to a land-use category. If CO_2 or CH_4 emissions/removals from rewetted organic soils are subcategories to a key category, these subcategories should be considered as significant if they individually account for 25-30% of emissions/removals for the overall key category (see Figures 1.2 and 1.3 in Chapter 1, Volume 4 of the *2006 IPCC Guidelines*.)

CHOICE OF EMISSION FACTORS

EF_{CO_2}

Tier 1

The implementation of the Tier 1 method requires the application of default EFs provided in Table 3.1, where they are disaggregated by climate zone (boreal, temperate, tropical) and for boreal and temperate organic soils only, by nutrient status (nutrient poor and nutrient rich).

Nutrient poor organic soils predominate in boreal regions, while in temperate regions nutrient rich sites are more common. In some cases, nutrient poor soil organic layers are underlain by nutrient rich layers; in some situations, after industrial extraction of the nutrient poor top layers the rewetted residual soil layers may be considered nutrient rich due to the influence of incoming water and the high nutrient status of the bottom layers.

If the nutrient status of rewetted organic soils in boreal or temperate zones is not known, countries should use the default nutrient poor EF for sites in the boreal zone, and nutrient rich EF for sites in the temperate zone (Table 3.1).

The derivation of the default EF values for CO_2 is fully described in Annex 3A.1, including the quality criteria for data selection. In summary, robust data indicated that CO_2 fluxes from both natural/undrained and rewetted organic soils are correlated with mean water table depth. Furthermore, it was ascertained that, in temperate and boreal regions, these correlations were not significantly different between the natural/undrained group and the rewetted group. These conclusions were also valid when the analysis was performed for sites under each of these climatic regions. Therefore in these regions CO_2 fluxes from natural/undrained sites were used in addition to CO_2 fluxes from rewetted sites to provide a robust estimation of the EFs shown in Table 3.1. There is currently insufficient evidence to support the use of different default EF values for different site conditions, previous land-use or time since rewetting.

Since no data are available for rewetted tropical organic soils, a default EF of zero is provided; this value is supported by observations in undrained sites and reflects the fact that successful rewetting effectively reduces the decay of soil organic matter stops the oxidation of soil organic material, but does not necessarily re-establish a soil C sequestration function (see Annex 3A.1).

TABLE 3.1

DEFAULT EMISSION FACTORS (EF_{CO_2}) AND ASSOCIATED UNCERTAINTY, FOR CO_2-C BY REWETTED ORGANIC SOILS (ALL VALUES IN TONNES CO_2-C HA^{-1} YR^{-1}).

Climate zone	Nutrient status	EF_{CO_2}	95% range
Boreal*	Poor	-0.34 (n=26)	-0.59 – -0.09
	Rich	-0.55 (n=39)	-0.77 – -0.34
Temperate**	Poor	-0.23 (n=43)	-0.64 – +0.18
	Rich	+0.50 (n=15)	-0.71 – +1.71
Tropical***	0		

Note: Negative values indicate removal of CO_2-C from the atmosphere. n = number of sites. 95% confidence interval is used to give the 95% range.

*Emission factors for boreal rewetted organic soils derived from the following source material (see Annex 3 A.1 for details): Bubier et al. 1999, Komulainen et al. 1999, Soegaard & Nordstroem 1999, Tuittila et al. 1999, Waddington & Price 2000, Waddington & Roulet 2000, Alm et al. 1997, Laine et al. 1997, Suyker et al. 1997, Whiting & Chanton 2001, Heikkinen et al. 2002, Harazono et al. 2003, Nykänen et al. 2003, Yli-Petäys et al. 2007, Kivimäki et al. 2008, Nilsson et al. 2008, Sagerfors et al. 2008, Aurela et al. 2009, Drewer et al. 2010, Soini et al. 2010, Maanavilja et al 2011.

**Emission factor for temperate rewetted organic soils derived from the following source material but is not significantly different from zero (see Annex 3 A.1 for details): Shurpali et al. 1995, Lafleur et al. 2001, Wickland 2001, Aurela et al. 2002, Schulze et al. 2002, Petrone et al. 2003, Roehm & Roulet 2003, Billett et al. 2004, Drösler 2005, Nagata et al. 2005, Bortoluzzi et al. 2006, Hendriks et al. 2007, Jacobs et al. 2007, Lund et al. 2007, Riutta et al. 2007, Roulet et al. 2007, Wilson et al. 2007, Augustin & Chojnicki 2008, Cagampan & Waddington 2008, Golovatskaya & Dyukarev 2009, Kurbatova et al. 2009, Drewer et al. 2010, Waddington et al. 2010, Adkinson et al. 2011, Augustin et al. in Couwenberg et al. 2011, Koehler et al. 2011, Christensen et al 2012, Urbanová 2012, Strack & Zuback 2013, Drösler et al. 2013, Herbst et al. 2013, Wilson et al. 2013.

*** For tropical rewetted organic soils where decayed organic material is not oxidised due to saturated conditions

Given the limitations in the available scientific literature, the Tier 1 basic methodology assumes that there is no *transient period* and that rewetted organic soils immediately behave like undrained/natural organic soils in terms of CO_2 flux dynamics. Combining observations in the temperate and boreal regions soon after rewetting with long-term ones was the simplest way to avoid any bias.

The default EF of rewetted tropical organic soils applies to sites where water saturation prevents further oxidation of the soil organic matter. Due to the lack of published scientific literature on CO_2 fluxes from rewetted tropical organic soils, the emission factor was derived from undrained tropical organic soils (Annex 3A.1). When rewetted tropical organic soils are a significant component of a *key category*, it is *good practice* to use country-specific EFs as opposed to the default EF in Table 3.1.

Tier 2 and 3

Countries applying Tier 2 methods should use country-specific emission factors. Empirical flux measurements (eddy covariance or chamber methods) should be carried out at temporal resolutions sufficiently defined to capture as wide a range as possible of the abiotic (e.g. irradiation, soil properties including soil temperature, mean water table depth) and biotic (e.g. vegetation composition) factors that drive CO_2 dynamics in rewetted organic soils. Subsidence measurements can also be used to determine the medium to long term losses/gains from rewetted organic soils. Emission factors could be developed further by taking into account other factors, such as ‘previous land-use’ or current vegetation composition as well as disaggregation by ‘time since rewetting’.

Countries where perennial woody biomass plays a significant role in the net CO_2-C exchange between rewetted organic soils and the atmosphere should develop country-specific methods that reflect C stock changes in the tree biomass and tree DOM pools under typical management practices and their interaction with the soil pool. Guidance can be found in Chapter 2, Volume 4 of the *2006 IPCC Guidelines*.

Tier 3 methods involve a comprehensive understanding and representation of the dynamics of CO_2 emissions/removals in rewetted organic soils, including the impacts of management practices. The methodology includes the fate of C in all pools and C transfers between pools upon conversion. In particular, the fate of the C contained within the biomass pool must also be taken into account, including its eventual release on-site through the decay of DOM, or off-site following harvest of woody biomass (e.g. paludiculture). Woody biomass is not accounted for in this chapter and care should be taken to avoid double-counting when using whole ecosystem data (e.g. eddy covariance measurements). Tier 3 methodologies may also distinguish between immediate and delayed emissions following rewetting. A Tier 3 approach could include the development of flux based monitoring systems and the use of advanced models which require a higher level of information of processes than required in Tier 2. It is *good practice* to ensure that the models are calibrated and validated against field measurements (Chapter 2, Volume 4, *2006 IPCC Guidelines*).

$EF_{DOC\_rewetted}$

Tier 1

Data show that natural/undrained organic soils export some DOC and these fluxes increase following drainage (see Chapter 2, this supplement). Available data from rewetted sites is scant but suggest that the level of DOC reduction after rewetting approximately equates to the DOC increase after drainage (Glatzel et al. 2003; O’Brien et al. 2008; Waddington et al. 2008; Armstrong et al. 2010, Strack and Zuback 2013,Turner et al. 2013). Consequently, it is assumed that rewetting leads to a reversion to natural DOC flux levels (see Annex 3A.2). Therefore, to make best use of available data, EFs for rewetted organic soils have been calculated using data from natural/undrained sites as well as from rewetted ones following Equation 3.6:

EQUATION 3.6

EMISSION FACTOR FOR ANNUAL EMISSIONS OF C AS CO_2 DUE TO DOC EXPORT FROM REWETTED ORGANIC SOILS

$$EF_{DOC\_REWETTED} = DOC_{FLUX} * Frac_{DOC\text{-}CO_2}$$

Where:

$EF_{DOC\_REWETTED}$ = Emission factor for DOC from rewetted organic soils, tonnes C ha^{-1} yr^{-1}

DOC_{FLUX} = Net flux of DOC from natural (undrained) and rewetted organic soils , tonnes C ha^{-1} yr^{-1}

$Frac_{DOC\_CO_2}$ = Conversion factor for proportion of DOC converted to CO_2 following export from site and equates to 0.9

A detailed description of the derivation of default values for Tier 1 is provided in Annex 2A.3. In summary, data show clear differentiation of natural DOC fluxes between boreal, temperate and tropical organic soils. Therefore, the DOC_{FLUX} values were calculated for each climate zone integrating data from rewetted sites where available (all DOC fluxes measured from rewetted sites were located in the temperate zone). The current data did not support disaggregation by nutrient status. The parameter $Frac_{DOC\_CO_2}$ sets the proportion of DOC exported from organic soils that is ultimately emitted as CO_2. An understanding of the fate of DOC export, i.e. whether it is returned to the atmosphere as CO_2 (or CH_4), is still poor but the form and amount are of significance in terms of GHG reporting. A value of zero would coincide with all the DOC export being deposited in stable forms in lake or marine sediments; as this would simply represent a translocation of carbon between stable stores, it would not need to be estimated. However, most data on DOC processing do indicate that a high proportion is converted to CO_2 in headwaters, rivers, lakes and coastal seas (see Annex 2A.3 for discussion). Reflecting this current scientific uncertainty, a Tier 1 default $Frac_{DOC\_CO_2}$ value of 0.9 is proposed, with an uncertainty range of 0.8 to 1.

$EF_{DOC\_REWETTED}$ values are provided in Table 3.2 and the derivation of these values is fully described in Annex 3A.2.

TABLE 3.2
DEFAULT DOC EMISSION FACTORS ($EF_{DOC\_REWETTED}$ IN TONNES CO_2-C HA^{-1} YR^{-1}) FOR REWETTED ORGANIC SOILS

Climate zone	DOC_{FLUX} (tonnes C ha^{-1} yr^{-1})	Number of sites	$EF_{DOC\_REWETTED}$ (tonnes CO_2-C ha^{-1} yr^{-1})
Boreal*	0.08 (0.06 – 0.11)	10 undrained	0.08 (0.05 – 0.11)
Temperate**	0.26 (0.17 – 0.36)	12 undrained and 3 rewetted	0.24 (0.14 – 0.36)
Tropical***	0.57 (0.49 – 0.64)	4 undrained	0.51 (0.40 – 0.64)

Values in parentheses represent 95% confidence intervals.

*Derived from the following source material (see Annex 3 A.2 for details): Koprivnjak & Moore 1992, Moore et al. 2003, Kortelainen et al. 2006, Agren et al. 2007, Nilsson et al. 2008, Jager et al. 2009, Rantakari et al. 2010, Juutinen et al. 2013.

**Derived from the following source material (see Annex 3 A.2 for details): Urban et al. 1989, Kolka et al. 1999, Clair et al. 2002, Moore et al. 2003, Dawson et al. 2004, Roulet et al. 2007, O'Brien et al., 2008, Strack et al. 2008, Waddington et al. 2008, Koehler et al. 2009, 2011, Billett et al. 2010, Dinsmore et al. 2011, Di Folco & Kirkpatrick 2011, Turner et al. 2013, Strack & Zuback 2013.

***Derived from the following source material (see Annex 3 A.2 for details): Zulkifli 2002, Alkhatib et al. 2007, Baum et al, 2008, Yule et al. 2009, Moore et al. 2013.

Note that all references above are listed in Chapter 2 – References.

Tier 2

A Tier 2 approach for estimation of DOC may follow the Tier 1 methodology provided above, but should use country–specific information where possible to refine the emission factors used as well as the conversion factor. Refinements could entail greater disaggregation as follows:

- Use of country-level measurements from natural and rewetted organic soils to obtain more accurate values of DOC_{FLUX} for that country. Since DOC production has been observed to vary with different vegetation composition and productivity as well as soil temperature, it would be important to develop specific values for different types of natural and rewetted organic soils (nutrient rich versus nutrient poor and for example raised bogs as well as blanket bogs).
- Use of country-level measurements from rewetted organic soils with various restoration techniques and initial status (peat degradation, previous land use) as well as time since rewetting. When sufficient long-term direct measurements of DOC fluxes from rewetted organic soils have been gathered, this could be used solely in Equation 3.6 to replace DOC_{FLUX} values with $DOC_{FLUX\ REWETTED}$ thus replacing the default assumption that rewetted organic soils revert to pre-drainage DOC fluxes).
- Use of alternative values for the conversion factor $Frac_{DOC\_CO_2}$ where evidence is available to estimate the proportion of DOC exported from rewetted organic soils that is transferred to stable long-term carbon stores, such as lake or marine sediments.

Tier 3

A Tier 3 methodology might include the use of process models that describe DOC release as a function of hydrology (in particular discharge), vegetation composition, nutrient levels, water table level, as well as temporal variability in DOC release in the years following rewetting and on-going management activity. Differences in DOC fluxes between undisturbed and rewetted organic soils could occur due to the presence or absence of vegetation on rewetted sites; the land-use category prior to rewetting; soil properties (fertility); vegetation composition that differs from the undisturbed organic soils or factors associated with restoration techniques, such as the creation of pools, the application of mulch to support vegetation re-establishment, or the use of biomass to infill ditches

3.2.2 CH_4 Emissions/Removals from Rewetted Organic Soils

CH_4 emissions and removals from the soils of rewetted organic soils result from 1) the balance between CH_4 production and oxidation and 2) emission of CH_4 produced by the combustion of soil organic matter during fire (Equation 3.7).

EQUATION 3.7
CH_4-C EMISSIONS/REMOVALS FROM REWETTED ORGANIC SOILS

$$CH_4\text{-}C_{rewetted\ org\ soil} = CH_4\text{-}C_{soil} + L_{fire}\text{-}CH_4\text{-}C$$

Where:

$CH_4\text{-}C_{\text{rewetted org soil}}$ = CH_4-C emissions/removals from rewetted organic soils, tonnes C yr^{-1}

$CH_4\text{-}C_{\text{soil}}$ = emissions/removals of CH_4-C from rewetted organic soils, tonnes C yr^{-1}

$L_{\text{fire}}\text{-}CH_4\text{-}C$ = emissions of CH_4-C from burning of rewetted organic soils, tonnes C yr^{-1}

The default EFs provided in this section will only cover $CH_4\text{-}C_{\text{soil}}$. These CH_4 emissions result from the decomposition of the organic soil by microbes under anaerobic conditions and are strongly controlled by oxygen availability within the soil and by soil temperature. Methane emissions also originate from the decay of non-tree vegetation; since these pools cannot be easily separated on organic soils they are combined here as $CH_4\text{-}C_{\text{soil}}$.

The probability of fire occurrence in rewetted organic soils is likely small if water table position is near the surface, but possible soil emissions from fires are included here for completeness. If rewetting or restoration practices involve biomass burning, CH_4 emissions from biomass burning must be estimated in a way consistent with the guidance provided in Chapters 2 (generic methods), 4 (Forest Land) and 5 (Cropland), Volume 4 of the *2006 IPCC Guidelines*. Emissions from soil burning ($L_{\text{fire}}\text{-}CH_4\text{-}C$) should be estimated using the guidance provided in Section 2.2.2.3 of this supplement applying the fuel consumption value for wildfire on undrained organic soil (Table 2.6) and CH_4 emission factors given in Table 2.7. The EF of Table 2.7 should be multiplied by 12/16 to obtain tonnes of CH_4-C yr^{-1}.

Care should be taken to report fire emissions only once to avoid double-counting fire emissions.

CHOICE OF METHOD

Refer to Figure 3.1 for the decision tree to select the appropriate Tier for the estimation of CH_4 emissions or removals from rewetted organic soils.

Tier 1

The default methodology covers CH_4 emissions from rewetted organic soils (Equation 3.7).

As in Section 3.2.1, the basic approach makes no distinction on the basis of the objectives of site rewetting (restoration or other management activities). In addition, as in Section 3.2.1 the Tier1 methodology assumes there is no transient period for rewetted organic soils and therefore default EFs are applicable from the year of rewetting.

EQUATION 3.8
ANNUAL CH_4-C EMISSIONS FROM REWETTED ORGANIC SOILS

$$CH_4\text{-}C_{soil} = \frac{\sum_{c,n}\left(A \cdot EF_{CH_4\,soil}\right)_{c,n}}{1000}$$

Where:

$CH_4\text{-}C_{soil}$ = CH_4 -C emissions from rewetted organic soils, tonnes C yr^{-1}

$A_{c,n}$ = area of rewetted organic soils in climate zone c and nutrient status n, ha

$EF_{CH_4\,soil}$ = emission factor from rewetted organic soils in climate zone c and nutrient status n, kg CH_4-C ha^{-1} yr^{-1}

Rewetted areas should be subdivided by climate zone (boreal, temperate or tropical) and the appropriate emission factors should be applied. Thus far flux data on CH_4-C emissions from successfully rewetted tropical sites are lacking. Thus, the default EF has been developed from data on undrained tropical peat swamp forests in SE Asia which represent the largest extent of peatland in the tropics (Joosten 2009, Page et al., 2010). The representativeness of this default EF should be assessed prior to its application outside peat swamp in Southeast Asia. Annex 3A.3 describes the derivation method. Data on methane fluxes from other tropical organic soils, like for example the *Papyrus* marshes of Africa or the peatlands of Panama and the Guianas and other parts of the Americas, are lacking. When information is available on the nutrient status of the organic soil, it is recommended to further subdivide the rewetted area into nutrient-poor and nutrient-rich, multiply each one by the appropriate emission factor and sum the products for the total CH_4 emissions.

Tier 2 and 3

Tier 2 calculations use country-specific emission factors and parameters, spatially disaggregated to reflect regionally important ecosystems or practices such as papyrus, Sago palm or reed cultivation, and dominant ecological dynamics. In general, CH_4-C fluxes from wet organic soils are extremely skewed, approaching a log-normal (right-tailed) distribution (see Annex 3A.3). This asymmetry towards rare, but high efflux values causes high mean values compared to the most likely encountered median values. Nevertheless, use of the mean value will give an unbiased estimate of total emissions from the area in question. For countries where rewetted organic soils are a significant component of a *key category* it is *good practice* to develop EFs based on measurements or experiments within the country and thus contribute to better scientific understanding of CH_4 effluxes from rewetted organic soils. Possible factors to consider for disaggregation of rewetted organic soil area include water table depth, the prior land use, time since rewetting, the presence/absence of a vegetation cover and of ditches (see Box 3.1).

BOX 3.1
CONTROLS ON CH_4 EMISSIONS FROM REWETTED ORGANIC SOILS

CH_4 fluxes from organic soils strongly depend on the depth of the water table (Annex 3A.3). Both low and high flux values have been observed from saturated organic soils (Augustin & Chojnicki 2008; Couwenberg & Fritz 2012; Glatzel et al., 2011). It is *good practice*, when developing and using country-specific CH_4 emission factors, to examine their relationship with water table position. In this case, activity data on mean annual water table position and its distribution in space would also be required.

Prior land use (e.g. agriculture, peat extraction, forestry) can influence CH_4 fluxes from rewetted organic soils. For example, CH_4 emissions following the flooding of some agricultural land with nutrient enriched top-soil appear higher compared to average emission factors (Augustin & Chojnicki, 2008; Glatzel et al., 2011) whereas rewetted boreal cutover peatlands may have CH_4 emissions below the average emission factors (Waddington and Day, 2007). It may therefore increase accuracy to subdivide activity data and emission factors according to previous land-use. The influence of previous land use may diminish over time and countries are encouraged to monitor emissions/removals of CH_4 from rewetted organic soils to evaluate this effect.

As noted in Chapter 2, emissions of CH_4-C from drainage ditches can be much higher than the surrounding drained fields. Few data are available on CH_4-C emissions from ditches of rewetted organic soils and in some cases ditches are filled during rewetting activities. Moreover, rewetting reduces the hydrological differences between fields and neighboring ditches creating a more homogeneous surface from which CH_4 is emitted/removed. In some cases rewetting practices may retain ditches (e.g. Waddington et al., 2010) and when ditches remain, it is *good practice* to include estimates of CH_4-C ditch emissions using methodology provided in Chapter 2 (Equation 2.6) and country-specific emission factors. Table 2A.1 can also be consulted for guidance on emission factors for remaining ditches.

The number of long-term rewetting studies is limited and changes in CH_4 flux over time remain unclear. Research on restored cutover peatlands in Canada indicates a steady increase in CH_4 emissions in the years immediately after rewetting as the emerging vegetation cover provides fresh substrates for CH_4 production (Waddington and Day, 2007). In contrast, rewetting of intensively used grassland on fen peat suggests that CH_4 emissions may decline over time as litter inundated during rewetting activities is rapidly decomposed in the first few years (Limpens et al. 2008). Changes in CH_4 emissions and removals over time appear to be linked to vegetation succession (e.g. Tuittila et al., 2000) and thus understanding the pattern of emissions over time would require the inclusion of vegetation information.

Several studies in both undisturbed and rewetted organic soils indicate the important role that vegetation may play for providing substrate for CH_4 production and for transporting CH_4 from the saturated soil to the atmosphere (e.g. Bubier 1995; Shannon et al., 1996; Marinier et al., 2004; Tuittila et al., 2000; Wilson et al., 2009; Dias et al., 2010 ;). Species known to transport CH_4 from the soil to the atmosphere include, but are not limited to *Alnus*, *Calla, Carex, Cladium, Eleocharis, Equisetum, Eriophorum, Glyceria, Nuphar, Nymphaea, Peltandra, Phalaris, Phragmites, Sagittaria, Scheuchzeria, Scirpus, Typha* and various peat swamp forest trees (Sebacher *et al.,* 1985, Brix et al., 1992; Chanton *et al.,* 1992, Schimel 1995, Shannon *et al.,* 1996, Frenzel & Rudolph 1998, Rusch & Rennenberg 1998, Verville *et al.,* 1998, Yavitt & Knapp 1998, Grünfeld & Brix 1999, Frenzel & Karofeld 2000, Tuittila et al., 2000, Arkebauer *et al.,* 2001, Gauci et al., 2010, Armstrong & Armstrong 2011, Askaer *et al.,* 2011; Konnerup et al., 2011; Pangala et al., 2012). The presence of these aerenchymous shunt species has a significant effect on CH_4 efflux from organic soils (Couwenberg & Fritz 2012). Countries are encouraged to develop nationally specific emission factors that address vegetation composition (see Riutta et al., 2007, Dias et al., 2010, Couwenberg et al., 2011; Forbrich et al., 2011). The effect of biomass harvesting on CH_4 fluxes from rewetted organic soils has thus far remained unstudied.

A Tier 3 approach involves a comprehensive understanding and representation of the dynamics of CH_4 emissions on rewetted organic soils, including the representation of interactions between the dominant drivers of CH_4 dynamics, as described above and potentially addressing different flux pathways, including ebullition (Strack et al. 2005). Possible methods include detailed country-specific monitoring of CH_4-C emissions/removals across rewetted organic soils representing a variety of water table positions, prior land use and time since rewetting. CH_4 emissions/removals could also be estimated using process-based models including factors described above (see e.g. Walter et al., 2001, Frolking et al., 2002, Van Huissteden et al., 2006, Baird et al., 2009, Li et al., 2009, Meng et al., 2012).

CHOICE OF EMISSION FACTORS

Tier 1

The implementation of the Tier 1 method requires the application of default emission factors EF_{CH4} provided in Table 3.3, where they are disaggregated by climate zone (boreal, temperate, tropical) and nutrient status (nutrient poor, rich). If the nutrient status of rewetted organic soils in boreal or temperate zones is not known, countries should use the default nutrient poor EF for sites in the boreal zone, and the nutrient rich EF for sites in the temperate zone The emission factor for rewetted tropical organic soils assumes a near surface water table throughout the year. For tropical areas experiencing a distinct dry season, where water tables drop below 20 cm below surface, the emission factor in Table 3.3 should be multiplied by the number of wet months divided by 12. Annex 3A.3 provides more details on the derivation of the default EFs and references used for their determination.

TABLE 3.3
DEFAULT EMISSION FACTORS FOR CH_4 FROM REWETTED ORGANIC SOILS
(ALL VALUES IN KG CH_4-C HA^{-1} YR^{-1})

Climate zone	Nutrient Status	EF_{CH_4}	95% range
Boreal*	Poor	41 (n=39 sites)	0.5 – 246
	Rich	137 (n=35 sites)	0 – 493
Temperate**	Poor	92 (n=42 sites)	3 – 445
	Rich	216 (n=37 sites)	0 – 856
Tropical***		41 (n= 11 sites)	7 – 134

* Derived from the following source material (see Annex 3 A.3 for details): Alm et al., 1997; Bubier et al., 1993; Clymo & Reddaway, 1971; Drewer et al., 2010; Gauci & Dise 2002; Juottonen et al., 2012; Komulainen et al., 1998; Laine et al., 1996 ; Nykänen et al., 1995; Tuittila et al., 2000; Urbanová et al., 2012; Verma et al., 1992; Waddington & Roulet 2000; Whiting & Chanton 2001; Yli-Petäys et al., 2007; Strack & Zuback 2013.

** Augustin & Merbach 1998; Augustin 2003; Augustin et al., 1996; Augustin in Couwenberg et al., 2011; Bortoluzzi et al., 2006; Cleary et al., 2005; Crill in Bartlett & Harris 1993; Dise & Gorham 1993; Drösler 2005; Drösler et al. 2013; Flessa et al., 1997; Glatzel et al., 2011; Harriss et al., 1982; Hendriks et al., 2007; Jungkunst & Fiedler 2007; Koehler et al., 2011; Nagata et al., 2005; Nilsson et al., 2008; Roulet et al., 2007; Scottish Executive, 2007; Shannon & White 1994; Sommer et al., 2003; Tauchnitz et al., 2008; Von Arnold 2004; Waddington & Price 2000; Wickland, 2001; Wild et al., 2001; Wilson et al., 2009, 2013; Beetz et al. 2013.

*** Derived from the following source material from undrained sites (see Annex 3 A.3 for details): Furukawa et al., 2005; Hadi et al., 2001, 2005; Inubushi et al., 1998; Jauhiainen et al., 2001, 2004, 2005, 2008; Melling et al., 2012; Pangala et al., 2012.

Tier 2 and 3

It is *good practice* to develop country-specific emission factors for each climate zone and nutrient status. Differences in water table position explain a large proportion of variation in annual CH4 flux between sites (Annex 3A.3). Thus, estimation of CH_4-C emissions/removals using country-specific EFs related to water table position will greatly improve estimation. Estimates of CH_4-C emissions/removals from rewetted organic soils can be further improved by implementing scientific findings relating CH_4-C emissions to specific cropping practices, prior land use, vegetation cover and time since rewetting.

Default emission factors are not provided for specific wet cropping practices, such as for Sago, Taro or reed plantations on wet organic soils where the scientific evidence is insufficient to support a globally applicable EF. Where such practices are nationally important, it is *good practice* to derive country-specific emission factors from pertinent publications (e.g. Inubushi et al., 1998, Melling et al., 2005, Watanabe et al., 2009, Chimner & Ewel 2004), taking into account water table dynamics. Emission factors for rice cropping on organic soils should follow the guidance provided in the *2006 IPCC Guidelines*.

3.2.3 N_2O Emissions from Rewetted Organic Soils

The emissions of N_2O from rewetted organic soils are controlled by the quantity of N available for nitrification and denitrification, and the availability of the oxygen required for these chemical reactions. Oxygen availability is in turn controlled by the depth of the water table. Raising the depth of the water table will cause N_2O emissions to decrease rapidly, and fall practically to zero if the depth of the water table is less than 20cm below the surface (Couwenberg et al., 2011). Saturated conditions may promote denitrification and the consumption of N_2O, but in practice this effect is very small and considered negligible in this chapter. This is because anoxic conditions and low NH_4^+ availability reduce the rates of mineralisation and nitrification, two processes that are prerequisites for denitrification.

Equation 3.9 includes the essential elements for estimating N_2O emissions from rewetted organic soils:

EQUATION 3.9
N_2O-N EMISSIONS FROM REWETTED ORGANIC SOILS

$$N_2O_{\text{rewetted org soil}}\text{-}N = N_2O_{\text{soil}}\text{-}N + L_{fire}\text{-}N_2O\text{-}N$$

Where:

$N_2O_{\text{rewetted org soil}}$-N = N_2O-N emissions from rewetted organic soils, kg N_2O-N yr^{-1}

N_2O_{soil}-N = N_2O-N emissions from the soil pool of rewetted organic soils, kg N_2O-N yr^{-1}

L_{fire}-N_2O-N = N_2O-N emissions from burning of rewetted organic soils, kg N_2O-N yr^{-1}

Generic methodologies for estimating N_2O emissions from the burning of vegetation and dead organic matter are provided in Chapter 2, Volume 4 in the *2006 IPCC Guidelines*, while methodologies specific to vegetation and DOM burning in Forest land, Cropland, Grassland and Wetlands are provided in Chapters 4-7, Volume 4 in the *2006 IPCC Guidelines*. If rewetting practices involve burning, N_2O emissions from the burning of organic soils should in theory be estimated. Published data are insufficient to develop default N_2O emission factors for the burning of organic soils (See Chapter 2 in this supplement); therefore L_{fire}-N_2O-N of Equation 3.9 is not considered in this section.

Tier 1

Under Tier 1, emissions of nitrous oxides from rewetted soils are assumed to be negligible (Hendriks et al., 2007, Wilson et al., 2013).

Tier 2 & 3

Countries where rewetted organic soils are a significant component of a *key category* should take into account patterns of N_2O emissions from these sites, particularly where the nitrogen budget of the watershed is potentially influenced by significant local or regional N inputs such as in large-scale farmland development.

Country-specific emission factors should take into account fluctuations of the water table depth, which controls oxygen availability for nitrification, and previous land use, which may have resulted in top soil enrichment (Nagata et al., 2005; 2010). The development of country-specific emission factors should take into consideration that significant N inputs into rewetted ecosystems may originate from allochtonous (external) sources, such as fertilizer use in the surrounding watershed. Measurement protocols should be designed in such a way as to allow separating such inputs, to avoid double-counting N_2O emissions that may already be reported as indirect emissions from anthropogenic N input within the watershed (Chapter 11, Volume 4 of *2006 IPCC Guidelines*). N_2O emissions from soil fires on rewetted organic soils should be estimated on the basis of scientific evidence.

3.2.4 Choice of Activity Data

All methodological Tiers require data on areas of rewetted organic soils, broken down by climate zone and nutrient status (nutrient poor or nutrient rich) as appropriate. This section clarifies further data requirements and suggests potential data sources.

Activity data used in the calculations can be obtained from various sources: scientific publications, databases and soil map references, reports on rewetting projects, official communications. This information may have been developed in government agencies, conservation organizations, research institutions and industry, subject to any confidentiality considerations. It is *good practice*, when collecting activity data, to also obtain protocols for data collection (frequency, measurement methods and time span), estimation methods, and estimates of accuracy and precision. Reasons for significant changes in activity data and inter-annual fluctuations should be explained.

Tier 1

The default methodology assumes that a country has data on the area of rewetted organic soils, the nutrient status of organic soils in temperate and boreal climates, and basic information on rewetting practices – such as the duration of the phase without vegetation and any remnant ditches - consistent with the guidance above on the applicability of default emission factors.

Rewetted organic soils have been previously drained. A potential first step to determine the occurrence and location of rewetted organic soils is to investigate historical information on drained organic soils; chapter 2 provides guidance to identify such information.

Depending on national circumstances, it may be more effective to directly identify rewetted organic soils. The data can be obtained from domestic soil statistics and databases, spatial or not, land cover (in particular wetlands), land use and agricultural crops (for example specialty crops typically grown on organic soils); this information can be used to identify areas with significant coverage of organic soils. Useful information on existing or planned activities may be available from the domestic peat extraction industry, regional or national forestry or agricultural agencies or conservation organisations. Agricultural, forestry or other type of government extension services may be able to provide specific information on common management practices on organic soils, for example for certain crop production, forest or plantation management or peat extraction. Information relative to rewetting practices is more likely available from regional practitioners, either in extension services, conservation organizations or environmental engineering firms. Data may also exist on water monitoring or management, including water management plans, areas where water level is regulated, floodplains or groundwater monitoring data. Such information could be available from government agencies involved in water management or the insurance industry, and be used in the determination of areas where the water level is naturally high, has been lowered or is managed for various purposes.

Remote sensing can also be used for wet area detection and mapping of vegetation type, biomass, and other characteristics. Time series of remotely-sensed imagery (e.g. aerial photography, satellite imagery etc.) can assist in the detection of rewetted organic soils and in the determination of time since rewetting. Such imagery may be produced either by research institutes, departments or agencies, universities or by the private sector.

In the absence of domestic data on soils, it is recommended to consult the International Soil Reference and Information Centre (ISRIC; www.isric.org; FAO/IIASA/ISRIC/ISSCAS/JRC, 2012. Harmonized World Soil Database (version 1.2). FAO, Rome, Italy and IIASA, Laxenburg, Austria). Inventory compilers should also investigate available documentation on rewetting or restoration projects with the International Peat Society (Commission V: Restoration, rehabilitation and after-use of peatlands, www.peatsociety.org), the International Mire Conservation Group (www.imcg.net) and the Verified Carbon Standard (v-c-s.org).

When information is gathered from a variety of sources, cross-checks should be made to ensure complete and consistent representation of land management practices and areas. For example, an area should not be counted twice if it is subject to several management practices over the course of a year. Rather, the combined effect of these practices should be estimated as a single rewetting for the area in question.

Tier 2

Tier 2 mehodology is likely to involve a more detailed spatial stratification than in Tier 1, and further sub-divisions based on time since rewetting, previous land use history, current land use and management practices as well as vegetation composition. It is *good practice* to further sub-divide default classes based on empirical data that demonstrate significant differences in GHG fluxes among the proposed categories. At Tier 2, higher spatial resolution of activity data is expected and can be obtained by disaggregating global data in country-specific categories, or by collecting country-specific activity data.

Domestic data sources are generally more appropriate than international ones to support higher tiered estimation approaches. In some cases relevant information must be created; it is *good practice* to investigate potential institutional arrangements to optimize the efficiency and effectiveness of data creation efforts, as well as plan for regular updates and long-term maintenance of a domestic information system.

To make use of remote sensing data for inventories, and in particular to relate land cover to land use, it is *good practice* to complement the remotely sensed data with ground reference data (often called ground truth data). Land uses that are rapidly changing over the estimation period or that are easily misclassified should be more intensively ground-truthed than other areas. This can only be done by using ground reference data, preferably from actual ground surveys collected independently. High-resolution aerial photographs or satellite imagery may also be useful. Further guidance can be found in Chapter 3, Volume 4, *2006 IPCC Guidelines*.

More sophisticated estimation methodologies will require the determination of annual average water table depth; land use and management practices prior to rewetting; and vegetation composition and the succession changes in vegetation community composition and biomass with time since rewetting. This type of information can be obtained by long-term monitoring of rewetted sites under various conditions, and should be combined with an enhanced understanding of the processes linking GHG emissions or removals to these factors. Depending on climate and site conditions, it may be appropriate to assess variations in water table depth over annual, seasonal, monthly or even weekly period; the development of cost-effective higher tier methods may involve both monitoring and modelling of water table variations over time.

Tier 3

For application of a direct measurement-based inventory in Tier 3, similar or more detailed data on the combinations of climate, soil, topographic and management data are needed, relative to the Tier 1 and 2 methods. Comprehensive field sampling, where appropriate combined with remote sensing systems repeated at regular time intervals, will provide high spatial resolution on organic soils, time since rewetting, and land-use and management activity data.

Scientific teams are usually actively involved in the development of Tier 3 methods. The viability of advanced estimation methodologies relies in part on well-designed information systems that are able to provide relevant activity data with the appropriate spatial and temporal coverage and resolution, have well-documented data collection protocols and quality control, and are supported with a long-term financial commitment for update and maintenance.

3.2.5 Sources of Uncertainty

Uncertainty in estimated GHG emissions/removals from rewetted organic soils will arise from uncertainties in EFs and other parameters, uncertainties in activity data, and model structure/parameter error for Tier 3 model-based methods. Further guidance on error estimation and the combination of errors is given in Volume 1, Chapter 3 of the *2006 IPCC Guidelines*.

For Tier 1, uncertainty level for default emission factors represent the 95% confidence interval for CO_2-C and DOC as presented in Tables 3.1 and 3.2. Due to the skewed distribution of CH_4-C emissions/removals data, the uncertainty is given as the (asymmetric) range of 95% of the data as outlined in Chapter 3, Volume 1 of the *2006 Guidelines*. While there may be still considerable uncertainty around each datapoint used in the derivation of the EFs, the 95% confidence interval values presented in Table 3.1 and Table 3.2 primarily reflect the uncertainty of the use of a single default EF that has been derived from many rewetted and undrained sites that may vary considerably from each other in terms of (1) their current abiotic and biotic characteristics and (2) their land use prior to rewetting. The confidence intervals also capture the uncertainty associated with the spatial variation reported in fluxes from the various study sites. Uncertainty also arises from inter-annual variability, although it has been reduced by using the mean of multi-year datasets from the same site).

Sources of uncertainty when using default emission factors also include under-represented environmental conditions in the dataset (including initial conditions and rewetting practices), lack of data representative of various phases and end-points of the rewetting process (e.g. a transient period).

Countries developing emission factors for their inventories at higher tiers should assess the uncertainty of these factors. Possible sources of uncertainty in country-specific emission factors include limited data for GHG emissions/removals on rewetted organic soils in a given region, application of emission factors measured in a small number of rewetted areas to wide areas with different land-use and rewetting histories, application of emission factors derived from short duration studies regardless of the time since rewetting. It is *good practice* for countries using numerical models for estimating GHG emissions/removals at Tier 3 to estimate uncertainty of these models.

Uncertainty in activity data will depend on its source. Aggregated land-use area statistics for activity data (e.g. FAO), may require a correction factor to minimize possible bias. Sources of uncertainty about activity data may include the omission or duplication of rewetted areas, especially if data are gathered from a variety of sources, missing historical data on rewetted organic soils, insufficient information on rewetting practices, post-rewetting vegetation succession, variation on the water table depths, and on the end-point(s) of the rewetting process. Accuracy can be improved by using country-specific activity data from various national, regional and local institutions, with uncertainty estimated based on data collection method and expert judgment. When information regarding activity data is gathered from a variety of sources, cross-checks should be made to ensure complete and consistent representation of land management practices and areas.

3.3 COMPLETENESS, TIME SERIES CONSISTENCY, AND QA/QC

3.3.1 Completeness

Complete GHG inventories will include estimates of emissions from all GHG emissions and removals on rewetted organic soils for which Tier 1 guidance is provided in this chapter, for all types of organic soils that occur on the national territory.

Not all drained soils in the national territory may have been rewetted, but all rewetted sites were drained at some point in the past. A complete inventory will include all drained organic soils, as well as those that have been subsequently rewetted.

Information should be provided, for each land-use category, on the proportion of drained and rewetted areas with organic soils. Overall, the sum of rewetted areas with organic soils reported under each land-use categories should equal the total national area of rewetted organic soils.

3.3.2 Quality Assurance and Quality Control (QA/QC)

Quality assurance/quality control (QA/QC) procedures should be developed and implemented as outlined in Chapter 7 of this supplement.

It is *good practice* that countries using Tier 1 methods critically assess the applicability of the default assumptions to their national circumstances. For example, countries are encouraged to determine in what way, if any, drainage or rewetting with no change in land use affects biomass and dead-organic matter pools and adjust assumptions or methods to incorporate their findings in estimates. In light of their strong influence on GHG emissions, the frequency and any periodicity of possible water table fluctuations in rewetted ecosystems should be factored into the assessment or development of emission factors.

Higher tier methods should be carefully designed to ensure that resulting estimates are compatible across different pools. In particular, potential double-counting of emissions or removals could occur if estimates derived from flux-based emission factors are combined to estimates calculated from stock change; this could occur for example if C uptake by vegetation is included in both a net flux to/from the atmosphere and the stock change in the biomass pool. Likewise, a net flux and the stock change of the dead organic matter pool could both include emissions to the atmosphere as a result of DOM decay. It is useful to incorporate scientific expertise actively in the design of domestic methods and the development of country-specific parameter values to ensure that C transfers to and from carbon pools, and between the biosphere and the atmosphere, are all captured to the extent possible and not double-counted. Where country-specific emission factors are being used, they should be based on high quality field data, developed using a rigorous measurement programme, and be adequately documented, preferably in the peer-reviewed, scientific literature. Documentation should be provided to establish the representativeness and applicability of country-specific emission factors to the national circumstances, including regionally significant rewetting and restoration practices and relevant ecosystems.

It is *good practice* to develop additional, category-specific quality control and quality assurance procedures for emissions and removals in this category. Examples of such procedures include, but are not limited to, examining the time series of the total area of managed land on organic soils across all land-use categories to ensure there is no unexplained gains or losses of land; conducting a comparative analysis of emission factors applied to rewetted land on organic soils and fluxes from un-drained similar ecosystems; ensuring consistency of the area and location of rewetted organic soils with the information provided on drained organic soils.

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Annex 3A.1 Estimation of default emission factors for CO_2-C in rewetted organic soils

Methodologies

An extensive literature review was conducted to collate all CO_2 studies that are currently available for (1) rewetted organic soils (as defined in the Introduction of this Chapter and including rewetted, restored and wet managed sites) and (2) natural/undrained organic soils. Literature sources included both published and non-peer reviewed (grey literature) studies. In the case of the latter the study was reviewed by all Lead Authors in this Chapter and expert judgement was exercised as to whether the study was scientifically acceptable for inclusion. In total, 3 non-peer reviewed studies were included.

All studies included in the database reported CO_2 flux based estimation methodologies using either the chamber or eddy covariance (EC) techniques. The chamber method involves the measurement of gas fluxes at high spatial resolution and is widely employed in conditions where the vegetation is either low or absent. The EC towers are typically used at sites that are relatively flat and homogeneous which includes open and treed organic soils. For a more detailed description of both methodologies see Alm et al. (2007). A detailed database of annual CO_2 fluxes was then constructed to determine the main drivers (if any) of CO_2 dynamics in rewetted organic soils. When available, the following parameters were extracted from the literature source and included in the database for analysis: climate zone (see Table 4.1, Chapter 4, Volume 4 of the *2006 IPCC Guidelines*), nutrient status, mean water table depth (WTD), median water table depth (as well as minimum and maximum), soil pH, thickness of the organic soil layer, C/N ratio, degree of humification, soil moisture, soil bulk density, plant cover and species, previous land-use and time since rewetting.

The CO_2 flux database initially contained a total of 216 annual flux estimates taken from 52 locations. At each study location a number of sites could be identified with similar dominant vegetation and hydrology, and each as such represented an entry in the database. For multi-year studies from the same site, annual flux estimates were averaged over the years. The final number of entries came to 126 and was distributed as follows:

(i) Degradation status (Natural/undrained = 80; Rewetted= 46)

(ii) Climate zone (Boreal = 65; Temperate = 61)

(iii) Nutrient status (Nutrient rich = 54; Nutrient poor = 72).

The criteria for inclusion in the database were as follows: (1) the study reported CO_2 fluxes from either rewetted organic soils, abandoned and naturally rewetted organic soils or natural undrained organic soils. All natural sites that had a water table deeper than 30 cm were not included in the final database to calculate the EF, as these were assessed as not being 'wet'. In other words, only natural sites with a WTD of -30 cm (negative values indicate a mean WTD below the peat/soil surface) or shallower (i.e. close to or above the soil surface) were deemed suitable as a proxy for rewetted sites since the mean water table depths recorded at all the rewetted sites in our database was always at, or shallower than -30 cm. The mean WTD is calculated over one year where the flux measurements cover the full 12 months. In boreal regions, the mean WTD applies to the growing season only. (2) The study had to report either seasonal or annual CO_2 fluxes. Studies in the database that reported daily CO_2 flux values were not used as upscaling to an annual flux value would have led to very high under- or over-estimations. Seasonal CO_2 fluxes (typically reported for the snow free May to October growing period) were converted to annual fluxes using 15% of the seasonal ecosystem respiration data from each study to estimate CO_2 fluxes from the non-growing season, although this may represent a slight overestimation given that photosynthesis (and hence C uptake) may have occurred for a short time following the ending of those seasonal studies. For studies where such data were not available, a value of 30g CO_2-C m^{-2} for non-growing season fluxes was used. (3) Studies had to indicate a mean WTD for each annual CO_2 flux reported. In some cases, this information was available from other publications and the CO_2 flux value was accepted for inclusion. (4) For studies using the EC technique, care was taken not to use annual CO_2 fluxes that included a woody biomass pool (e.g. treed organic soils) as this would have resulted in double accounting at the Tier 1 level. Calculated default EFs for CO_2 exclude woody biomass.

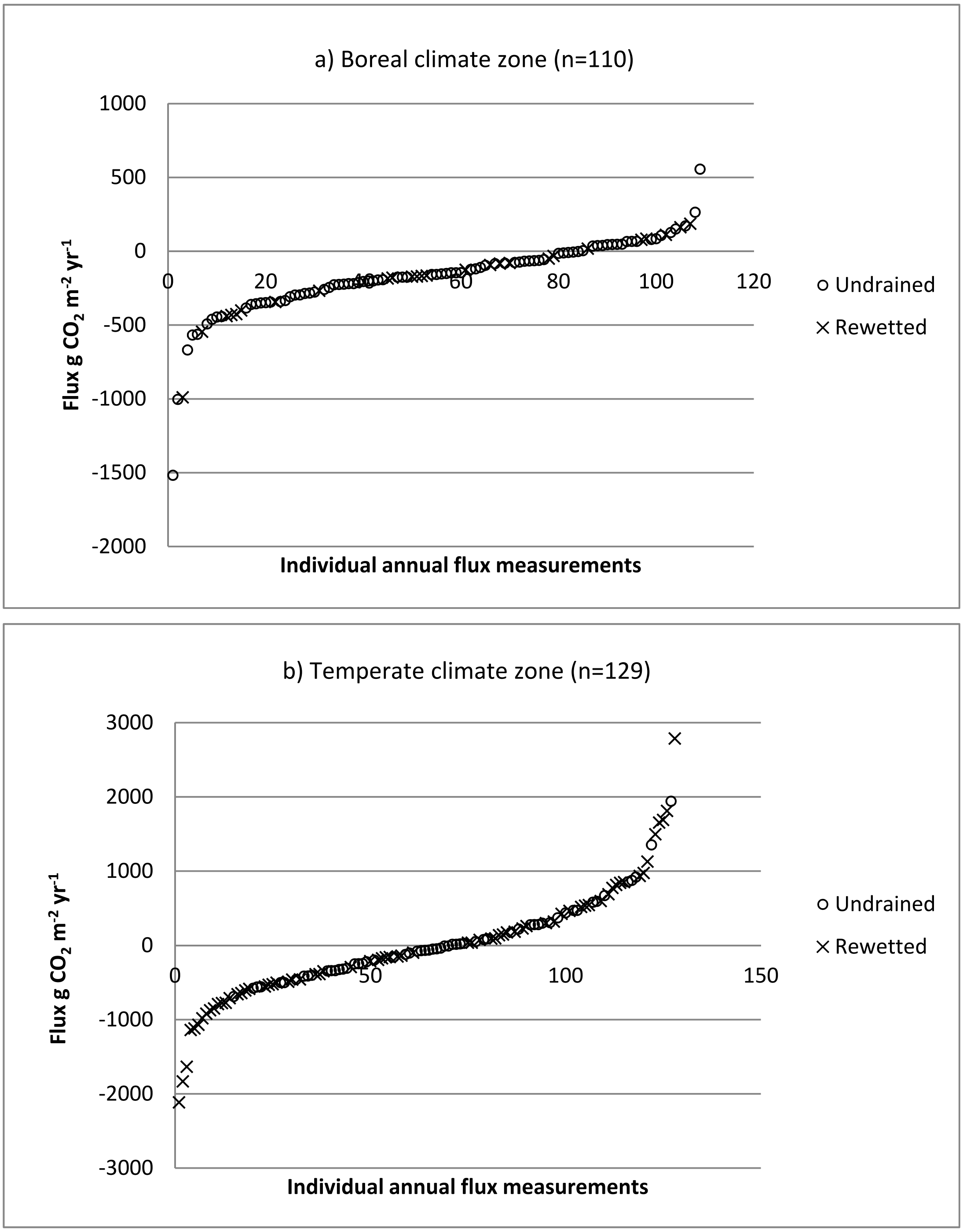
Results

To determine Tier 1 CO_2-C EFs, descriptive statistics allowed the data to be grouped by (1) *climate zone* and in some cases by (2) *nutrient status* (poor or rich) and descriptive analysis for each group was computed.

1) Temperate and boreal sites

A comparison was made between individual annual net CO_2 fluxes from rewetted sites and natural/undrained sites as found in the literature (see reference list in footnote of Table 3.1 in the main text). The wide range of fluxes recorded in rewetted sites can be explained by a number of factors such as 1) vegetation cover (includes non-vegetated surfaces), 2) average annual water table depth, 3) restoration practices (other than rewetting). While noting this large variation, especially within the temperate climate zone (-2115 to 2786 g CO_2-C m^{-2} yr^{-1}), the array from both groups, natural/undrained vs rewetted is analogous (Figure 3A.1a and b).

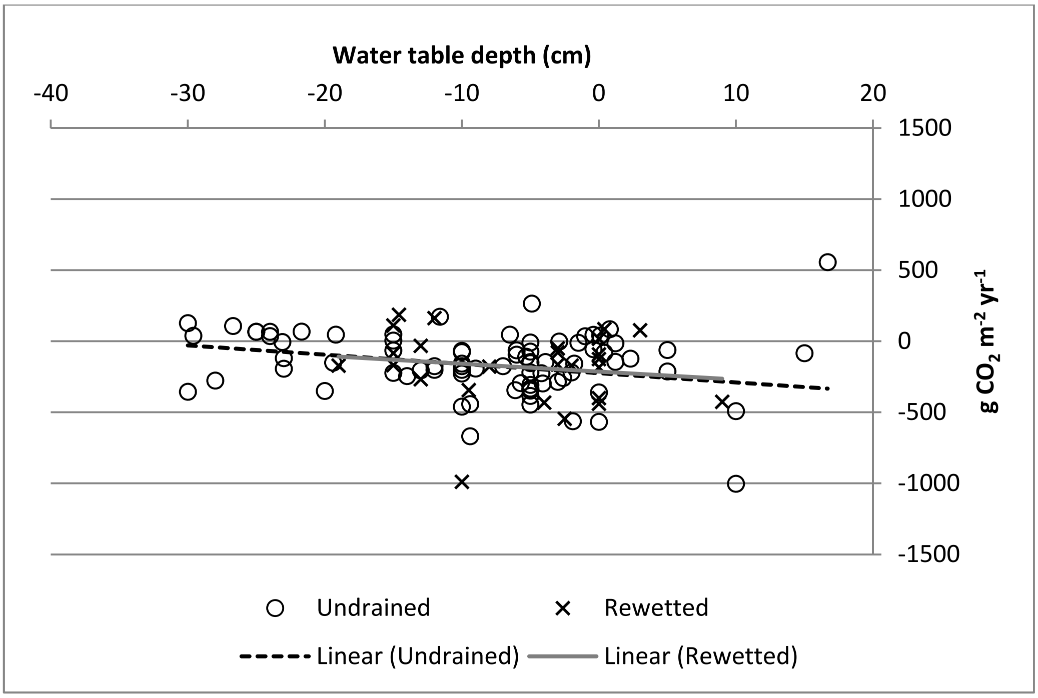
Figure 3A.1 **Ranges of CO_2 flux values (g CO_2 m^{-2} yr^{-1}) found in the published literature for natural/undrained and rewetted organic soils in (a) boreal and (b) temperate climate zones. Positive flux values indicate CO_2 emissions from the ecosystem to the atmosphere and negative flux values indicate removal of CO_2 from the atmosphere by the ecosystem. References used to compile graph are to be found in Table 3.1.**



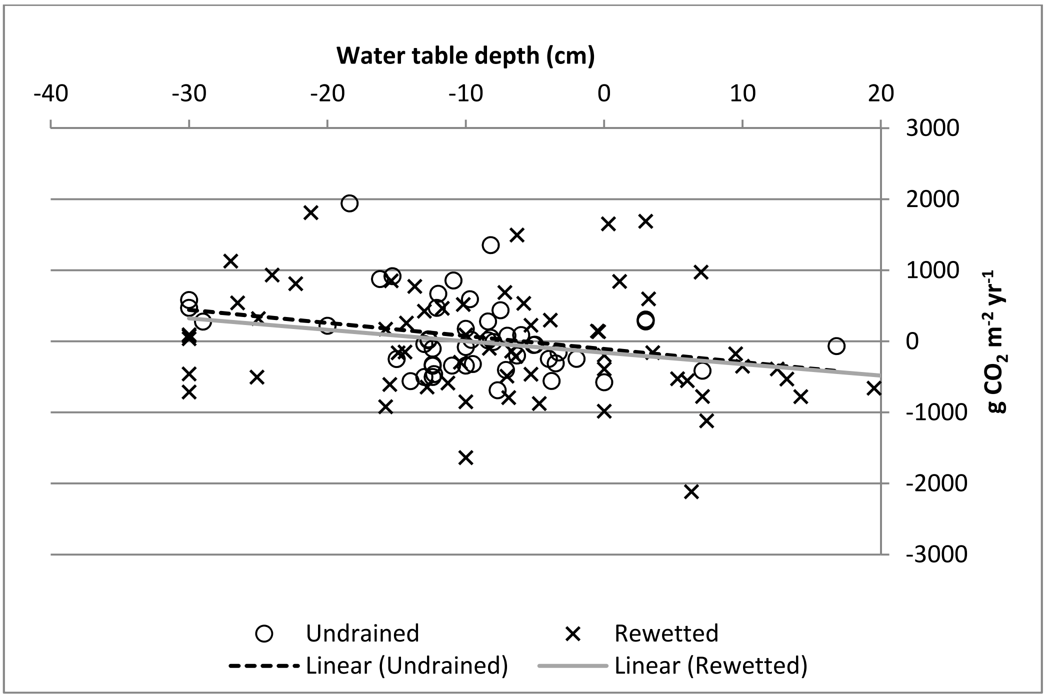
Mean water table depth (WTD) was plotted against annual CO_2 flux. The fitted regression lines (CO_2 flux = a+b1*WTD) were compared between rewetted and natural/undrained organic soils for each climate zone (see Figures 3A.2a and b). The groups were treated as being non-significantly different when it was ascertained statistically that b1 ±S.E. (rewetted) fitted within b1-S.E. and b1+S.E for the natural/undrained group. This was the case for both boreal and temperate organic soils. Therefore, EFs were calculated using rewetted and natural/undrained data points for each climatic zone. Means of fluxes with their 95% confidence interval were calculated for each of the categories.

Figure 3A.2 **Relationship between annual CO_2 fluxes and mean annual water table depth (cm) for both undrained and rewetted organic soils in (a) boreal and (b) temperate climate zones**

a) Boreal climate zone



b) Temperate climate zone



Note:

1. fitted regression line is CO_2 flux = a+b1*WTD.

2. Negative water table values indicate a mean water table position below the soil surface and positive values indicate a mean water table position above the soil surface.

Nutrient rich sites generally display a wider range of flux values than nutrient-poor sites. This wider range can be explained by the higher diversity of nutrient rich sites. For example, plant associations in rich fens are diverse, commonly dominated by brown mosses, sedges and grasses. The majority of the nutrient rich organic soils used in the calculation of the EF for the boreal zone are sedge rich fens which are known to be highly productive ecosystems (Bellisario et al., 1998, Alm et al., 1997, Bubier et al., 1999, Yli-Petäys et al., 2007). The wider range of flux values can also be explained by the diversity of previous land-uses as nutrient rich organic soils have been used more intensively than nutrient poor sites, especially across the temperate zone.

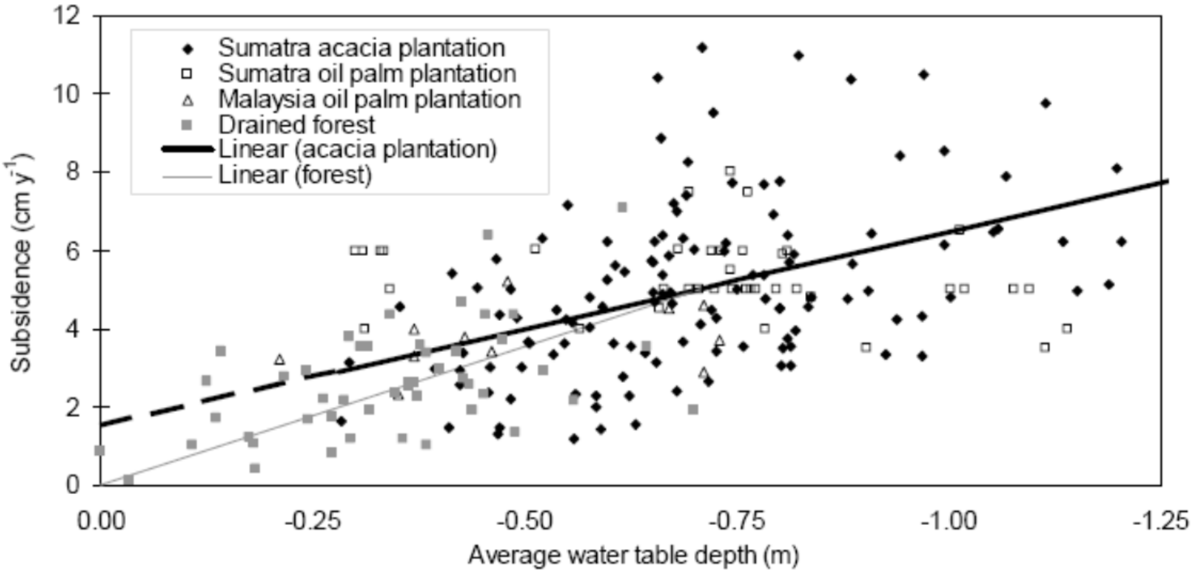
Some studies on natural/undrained nutrient rich organic soils in the temperate zone have reported net annual carbon sources (Nagata et al. 2005, Wickland 2001, Drösler et al 2013), although this may appear inconsistent with the fact that they hold large, long-term stores of carbon. Considerable uncertainty is attached to individual data points used in the derivation of the default EF, as the studies are generally of a short duration (1-2 years) and do not take into account the longer-term natural variation. It should be re-affirmed that over longer time-scales, natural and successfully rewetted nutrient rich organic soils (i.e. with vegetation that accumulates SOM) are CO_2 sinks unless another anthropogenic activity is impacting on the site (e.g. pollution, atmospheric deposition, climate change).

By contrast, nutrient poor organic soils displayed less variation in CO_2 fluxes across both boreal and temperate zones; the associated EFs suggest that for both boreal and temperate (Table 3.1), they are net long-term sinks for atmospheric CO_2, confirming that natural/undrained and rewetted nutrient poor organic soils play as important a role in the contemporary global C cycle as they have in the past.

2) Tropical sites

Data on net CO_2-C fluxes from successfully rewetted tropical organic soils are lacking. Subsidence measurements provide a good measure of carbon losses from drained organic soils (see Chapter 2 of this supplement) and in tropical organic soils subsidence is near zero when the water table approaches the surface (Figure 3A.3; Hooijer et al. 2012, see also Couwenberg et al. 2010). In undrained/natural conditions tropical organic soils constitute a CO_2-C sink of 0.3 – 1.1 t CO_2-C ha^{-1} y^{-1} (Lähteenoja et al. 2009, 2011; Dommain et al. 2011). In light of the available evidence the Tier1 default EF is set at 0 t CO_2-C ha^{-1} y^{-1}. This value is consistent with observations on subsidence and reflects the fact that rewetting effectively stops soil organic matter oxidation but does not necessarily re-establish the soil C sink function.

Figure 3A.3 **Subsidence rates as measured in drained tropical organic soils in relation to water table depth. From Hooijer et al. 2012.**



Annex 3A.2 Estimation of default emission factors for off-site CO_2 emissions via waterborne carbon losses (CO_2-DOC) from rewetted organic soils

Waterborne carbon export has been found to be an important pathway linking the organic soils carbon pool to the atmosphere as there is a growing evidence that aquatic system is characterised by high levels of allochthonous Dissolved Organic Carbon (DOC) , a high proportion of which is processed and converted to CO_2. A full characterisation of waterborne C losses comprises not only DOC, but also particulate organic carbon (POC), the dissolved gases CO_2 and CH_4 and the dissolved carbonate species: HCO_3^- and CO_3^{2-}. Particulate inorganic carbon (PIC) losses are considered negligible from all types of organic soils.

The various sources, behaviour and fate of these different forms of waterborne C within organic soil systems are further described in Chapter 2 (Annex 2A.3). However, in temperate and boreal, natural/undrained sites, as well as rewetted organic soils, DOC has been found to be by far the major component of fluvial C export, while POC, DIC and dissolved CO_2 are minor components of the total land-atmosphere CO_2 exchange and are therefore not estimated here .

Very little data exist pertaining to POC losses from rewetted organic soils and these losses are likely to be site-specific. However, while in-stream processing of POC (respiration/evasion) may be occurring, the greater proportion may be simply translocated from the rewetted organic soil to other stable C stores, such as freshwater or marine sediments where it will not lead to CO_2 emission. Therefore, due to current scientific uncertainty of the ultimate fate of POC export, no estimation methodology is presented here for emissions produced from the decomposition of POC lost from rewetted organic soils (see Appendix 2a.1 for future methodological development to estimate POC).

This section describes the methodology that has been used to derive emission factors for DOC losses from rewetted organic soils as this has been shown to be the largest component of waterborne carbon loss from all types of organic soils (see Chapter 2). Collated data from seven rewetting studies suggest a median DOC reduction of 36%, with a range of 1-83% (Table 3A.1). While the number of studies is limited, and results are variable, the median reduction is almost exactly equivalent to the observed increase following drainage (a 33% decrease in DOC would be required to fully reverse a 50% increase).

Some studies observed similar DOC concentrations in rewetted and restored bogs (previously used for peat extraction) as in a nearby intact reference bog. Therefore, there is some evidence to suggest that rewetting will return DOC loss fluxes to natural levels. It should be noted here that this reversal is likely to occur after an initial pulse of DOC associated with disturbance during the rewetting process, depending on the techniques used. This hypothesis is proposed as an explanation behind the variability shown in Table 3A.1, where some measurements were made less than a year or during the first two years after rewetting.

While there are a limited number of published studies of rewetting impact on DOC loss, a larger number of studies are available that provide reliable DOC flux estimates from natural/undrained organic soils. These were combined with rewetted sites to derive best estimates of the DOC flux (Table 3A.2).

Finally, the proportion of DOC exported from organic soils which is ultimately converted to CO_2, called here ($Frac_{DOC\_CO_2}$) is also explained in Annex 2A.3 of Chapter 2.

TABLE 3A.1
DOC CONCENTRATION (ABOVE) OR FLUX (BELOW) COMPARISONS BETWEEN DRAINED AND REWETTED ORGANIC SOILS WITH CHANGES IN DOC FOLLOWING REWETTING

Previous land-use	Climate zone	Study	DOC (mg l^{-1})		$\Delta DOC_{Rewetting}$ (%)
			Drained	**Rewetted**	
Peat extraction bog	Boreal	Glatzel *et al.*(2003)	110	70	-36%
Drained blanket bog	Temperate	Wallage *et al.* (2006)	43	13	-69%
Drained blanket bog	Temperate	Armstrong *et al.* (2010)	34	30	-10%
Drained blanket bog	Temperate	Gibson *et al.* (2009)	39	39	-1%
Drained agricultural fen	Temperate	Höll *et al.* (2009)	86	57	-34%
Drained extraction bog	Temperate	Strack & Zuback (2013)	100	86	-14%
			DOC (g C m^{-2} yr^{-1})		
			Drained	**Rewetted**	
Peat extraction bog	Temperate	Waddington *et al.,* (2008)	7.5	3.5	-53%
		Strack & Zuback (2013)	29	5	-83%
Drained blanket bog	Temperate	O'Brien *et al.* (2008)	7.0	4.1	-41%
Drained blanket bog	Temperate	Turner et al., (2013)	79	61	-23%

TABLE 3A.2
ANNUAL DOC FLUX ESTIMATES FROM NATURAL/UNDRAINED AND REWETTED ORGANIC SOILS USED TO DERIVE DEFAULT VALUES FOR DOC_{FLUX}

Climate zone	Country	Study	Status	DOC flux (t C ha^{-1} yr^{-1})
Boreal	Finland	Juutinen et al (2013)	Natural/undrained	0.037
Boreal	Canada	Moore (2003)	Natural/undrained	0.043
Boreal	Canada	Koprivnjak & Moore (1992)	Natural/undrained	0.052
Boreal	Canada	Moore (2003)	Natural/undrained	0.060
Boreal	Finland	Kortelainen et al (2006)	Natural/undrained	0.060
Boreal	Finland	Jager et al (2009)	Natural/undrained	0.078
Boreal	Sweden	Agren et al (2007)	Natural/undrained	0.099
Boreal	Finland	Rantakari et al (2010)	Natural/undrained	0.120
Boreal	Sweden	Nilsson et al (2008)	Natural/undrained	0.130
Boreal	Finland	Kortelainen et al (2006)	Natural/undrained	0.159
Temperate	Canada	Strack et al (2008)	Natural/undrained	0.053
Temperate	Canada	Roulet et al (2007)	Natural/undrained	0.164
Temperate	USA	Urban et al (1989)	Natural/undrained	0.212
Temperate	USA	Kolka et al (1999)	Natural/undrained	0.235
Temperate	Canada	Moore et al (2003)	Natural/undrained	0.290
Temperate	Canada	Clair et al (2002)	Natural/undrained	0.360
Temperate	UK	Dawson et al (2004)	Natural/undrained	0.194
Temperate	UK	Dinsmore et al (2011)	Natural/undrained	0.260
Temperate	UK	Billett et al (2010)	Natural/undrained	0.234
Temperate	UK	Billett et al (2010)	Natural/undrained	0.276
Temperate	Ireland	Koehler et al (2009,2011)	Natural/undrained	0.140

Temperate	Australia	Di Folco & Kirkpatrick (2011)	Natural/undrained	0.134
Temperate	Canada	Waddington et al (2008), Strack & Zuback (2013)	Rewetted	0.043
Temperate	UK	O'Brien et al (2008)	Rewetted	0.041
Temperate	UK	Turener et al (2013)	Rewetted	0.609
Tropical	Indonesia	Baum et al (2008)	Natural/undrained	0.470
Tropical	Indonesia	Alkhatib et al (2007)	Natural/undrained	0.549
Tropical	Malaysia	Yule et al (2009), Zulkifli (2002)	Natural/undrained	0.632
Tropical	Indonesia	Moore et al (2013)	Natural/undrained	0.625

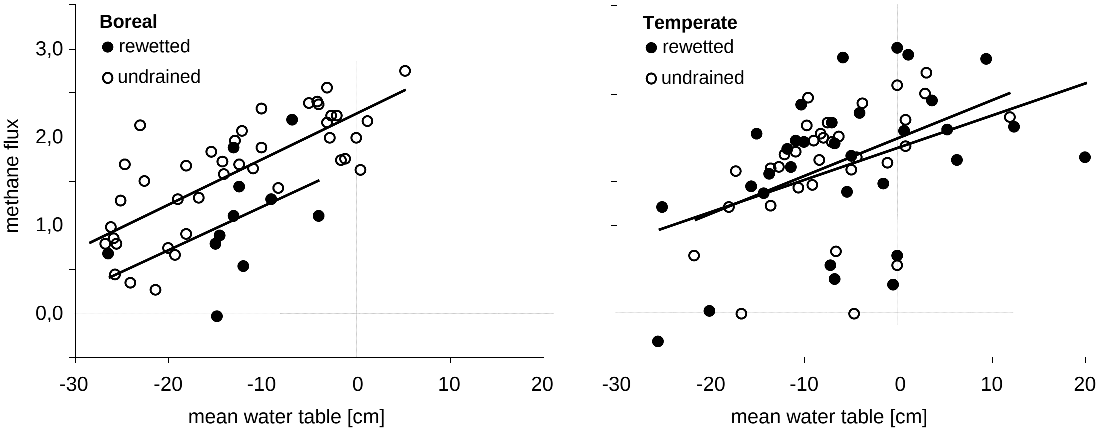
Annex 3A.3 Estimation of default emission factors for CH_4-C in rewetted organic soils

The same literature database and general approach were used to develop default CH_4 emission factors as was described in Annex 3A.1. A detailed database of annual CH_4 fluxes was constructed to determine the main drivers (if any) of CH_4 emissions in rewetted organic soils. The collated data are based on closed chamber and eddy covariance flux measurements with a temporal coverage of at least one measurement per month during the snow-free period. Seasonal fluxes (typically May to October) were converted to annual fluxes by assuming that 15% of the flux occurs in the non-growing season (Saarnio et al., 2007). For tropical Southeast Asia, annual data are scarce and direct, non-annualized measurement values were used. Similar to CO_2 flux measurements, data from undrained organic soils only were available and used as proxy for rewetted organic soils.

Where possible, the analysis considered the same parameters as those described in Annex 3A.1: climate zone (latitude), nutrient status, mean annual water table, median annual water table (as well as minimum and maximum), soil pH, organic soil thickness, soil C/N ratio, degree of humification, soil moisture, soil bulk density, plant cover and species, previous land-use and time since rewetting. For all subsets mentioned below the collected data show a near log-normal distribution, which, however, did not allow for derivation of standard deviation as a measure of variance. Variance pertains to the 95% interval of the observed data.

Methane fluxes from rewetted boreal organic soils (mean 76.3 kg CH_4-C ha^{-1} yr^{-1}; variance -0.1 – 338.7; n=17[1]) are not significantly different from undrained sites (mean 80.6 kg CH_4-C ha^{-1} yr^{-1}; variance 0.3 – 420.0; n=68[2]). The increase in efflux with rising water table (Figure 3A.4) does not differ significantly between undrained (n=41 data pairs) and rewetted sites (n= 11 pairs). Methane efflux from rewetted nutrient rich organic soils (mean 161.6 kg CH_4-C ha^{-1} yr^{-1}; variance -0.1 – 338.7; n=6) is half an order of magnitude higher than efflux from rewetted nutrient poor organic soils (mean 36.5 kg CH_4-C ha^{-1} yr^{-1}; variance 3.6 – 155; n=8), which is mirrored by efflux values from undrained nutrient rich organic soils (mean 131.5 kg CH_4-C ha^{-1} yr^{-1}; variance 0.2 – 492.8; n=29) and poor organic soils (42.5 kg CH_4-C ha^{-1} yr^{-1}; variance 0.3 – 245.9; n=31). The derived emission factors for nutrient rich (n=35) and poor sites (n=39) are based on the total respective datasets.

Figure 3A.4 Methane flux from boreal and temperate rewetted and undrained organic soils in relation to mean annual water table. Fluxes are expressed as ^{10}log(1+measured flux) [kg CH_4-C ha^{-1} yr^{-1}].



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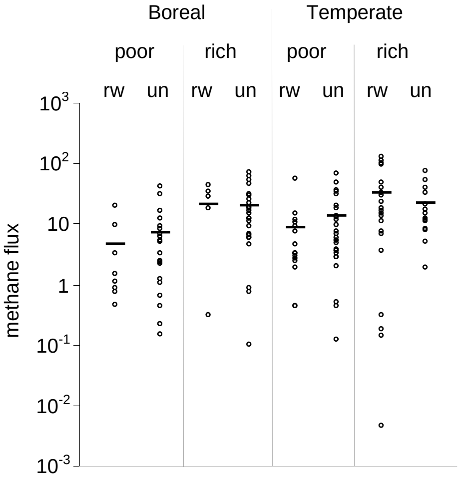
[1] Juottonen et al., 2012; Komulainen et al., 1998; Tuittila et al., 2000 ; Urbanová et al., 2012 ; Yli-Petäys et al., 2007 ; Strack & Zuback 2013

[2] Alm et al., 1997; Bubier et al., 1993; Clymo & Reddaway, 1971; Drewer et al., 2010; Gauci & Dise 2002; Laine et al., 1996 ; Nykänen et al., 1995 ; Verma et al., 1992 ; Waddington & Roulet 2000 ; Whiting & Chanton 2001 ; Strack & Zuback, 2013

Whereas methane fluxes from rewetted temperate organic soils (mean 173.8 kg CH_4-C ha^{-1} yr^{-1}; variance 0 – 856.3; n=38)[3]) are considerably higher than from undrained organic soils (mean 117.6 kg CH_4-C ha^{-1} yr^{-1}; variance 0 – 528.4; n=48)[4]), this finding is based mainly on inclusion of sites that were slightly flooded during rewetting. Extremely high efflux values from sites on enriched agricultural soil that were turned into shallow lakes during rewetting are not included (Augustin & Chojnicki 2008; Glatzel et al., 2011). The increase in efflux with rising water table is not significantly different between undrained (n=33 pairs) and rewetted sites (n=33 pairs). Methane effluxes from rewetted temperate nutrient poor organic soils (mean 69.1 kg CH_4-C ha^{-1} yr^{-1}; variance 3.5 – 444.5; n=15) are lower than from rewetted nutrient rich organic soils (mean 242.2 kg CH_4-C ha^{-1} yr^{-1}; variance -0.5 – 1027.5; n=23). Combined, the increase in efflux with rising water table in undrained and rewetted sites does not show a significant difference between nutrient poor organic soils (n=32 pairs) and nutrient rich ones (n=33 pairs). The emission factors presented are based on the total dataset of rewetted and undrained nutrient poor (n=28) and nutrient rich sites (n=33). Because nutrient poor sites have more relatively dry microsites and the dataset for nutrient rich sites includes the high values mentioned above, the EF for temperate nutrient poor sites is lower than for nutrient rich sites.

Figure 3A.5 Methane flux from boreal and temperate, poor and rich, rewetted (rw) and undrained (un) organic soils. Fluxes (in kg CH_4-C ha^{-1} yr^{-1}) are expressed on a logarithmic scale.



Note:

1. Negative and zero flux values are not included in the graph (n=9).
2. Bars indicate mean values.
3. Note that in derivation of EFs, data for rewetted and undrained sites were lumped.

Similar to boreal and temperate organic soils, methane fluxes from tropical swamp forest organic soils in Southeast Asia depend on water table with high methane efflux restricted to high water tables (Couwenberg et al., 2010). To derive the emission factor for rewetted swamp forest peat in Southeast Asia, flux data were compiled from literature. Data were limited to measurements associated with wet conditions (water table ≤30 cm below surface), either based on actual water table data or if wet conditions could reasonably be assumed (Table 3A.3). Flux data from rice paddy on organic soil are comparable to current IPCC estimates (Couwenberg 2011) and

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[3] Augustin & Merbach 1998; Augustin 2003; Augustin in Couwenberg et al., 2011; Cleary et al., 2005; Drösler 2005; Drösler et al. 2013; Flessa et al., 1997; Glatzel et al., 2011; Hendriks et al., 2007; Jungkunst & Fiedler 2007; Waddington & Price 2000; Wild et al., 2001; Wilson et al., 2009; Wilson et al., 2013

[4] Augustin & Merbach 1998; Augustin 2003; Augustin et al., 1996; Augustin in Couwenberg et al., 2011; Bortoluzzi et al., 2006; Crill in Bartlett & Harris 1993; Dise & Gorham 1993; Drösler 2005; Drösler et al. 2013; Harriss et al., 1982; Koehler et al., 2011; Nagata et al., 2005; Nilsson et al., 2008; Roulet et al., 2007; Scottish Executive, 2007; Shannon & White 1994; Sommer et al., 2003; Tauchnitz et al., 2008; Von Arnold 2004; Waddington & Price 2000; Wickland, 2001; Wilson et al., 1989

were excluded from the analysis. Methane flux data from tropical organic soils outside Southeast Asia are currently not available. Because of the recalcitrance of the woody peat, methane fluxes from tropical swamp forest organic soils in Southeast Asia are considerably lower than from boreal and temperate organic soils (Couwenberg et al., 2010).

TABLE 3A.3
CH_4-C FLUX DATA FROM WET SWAMP FOREST ON ORGANIC SOILS

Site	mg CH_4-C m^{-2} h^{-1} (range)	n	Reference
Drained forest	0.13 (0 – 0.35)	9*	Furukawa et al., 2005
Swamp forest	0.67	1	
Swamp forest	0.74 (0.58 – 0.91)	2	
Secondary forest	0.14	1	Hadi et al., 2001
Secondary forest	0.46 (0 – 2.29)	13	Hadi et al., 2005
Secondary forest	0.85	1	Inubushi et al., 1998
Conservation swamp forest	0.22 (0.03 – 0.70)	20*	Jauhiainen et al., 2001, 2005
Drained and selectively logged forest	0.05 (-0.09 – 0.38)	76*	Jauhiainen et al., 2004, 2008
Young secondary forest	0.19 (0.10 – 0.26)	6*	Jauhiainen et al., 2004
Tropical peat swamp forest	1.53 (1.28 – 1.78)	2	Melling et al., 2012
Conservation swamp forest	0.14	1	Pangala et al., 2012
Mean	**0.47 (0.05 – 1.53)**		
	kg CH_4-C ha^{-1} y^{-1})		
Annual flux	**41.2 (7.0 – 134.0)**		

Note:

n denotes number of observations

*only measurements pertaining to wet site conditions (water table ≤30 cm below the surface) are considered

CHAPTER 4

COASTAL WETLANDS

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4.1 INTRODUCTION

This chapter provides guidance on estimating and reporting anthropogenic greenhouse gas (GHG) emissions and removals from managed coastal wetlands. Coastal wetlands hold large reservoirs of carbon (C) in biomass and especially soil, (Global stocks: Mangroves, ~8 Pg carbon; (Donato et al., 2011), tidal marshes, ~0.8 Pg carbon (midrange; Pendleton et al. 2012), and seagrass meadows, 4.2 – 8.4 Pg carbon (Fourqurean et al., 2012). Soil carbon originates largely *in situ*, from root biomass and litter, and can result in a significant pool in coastal wetlands, especially when compared with terrestrial forests (Pidgeon 2009).

Coastal wetlands generally consist of organic and mineral soils that are covered, or saturated, for all or part of, the year by tidal freshwater, brackish or saline water (Annex 4A.1) and are vegetated by vascular plants. The boundary of coastal wetlands may extend to the landward extent of tidal inundation and may extend seaward to the maximum depth of vascular plant vegetation. Countries need to develop a nationally appropriate definition of coastal wetland taking into account national circumstances and capabilities. This chapter refers specifically to tidal freshwater[1] and salt marshes, seagrass meadows, and mangroves. For non-tidal inland mineral wetland soils refer to Chapter 5, this supplement.

Table 4.1 Specific Management Activities in Coastal Wetlands

Activity	*Subactivity*	*Vegetation types affected*
Activities relevant to CO_2 emissions and removals		
Forest management practices in mangroves	Planting, thinning, harvest, wood removal, fuelwood removal, charcoal production[1]	Mangrove[2]
Extraction	Excavation to enable port, harbour and marina construction and filling or dredging to facilitate raising the elevation of land	Mangrove, Tidal marsh, Seagrass meadow[4]
	Aquaculture (construction)	Mangrove, Tidal marsh
	Salt production (construction)	Mangrove, Tidal marsh
Drainage	Agriculture, forestry, mosquito control	Mangrove, Tidal marsh
Rewetting, revegetation and creation[3]	Conversion from drained to saturated soils by restoring hydrology and reestablishment of vegetation	Mangrove, Tidal marsh
	Reestablishment of vegetation on undrained soils	Seagrass meadow[4]
Activities relevant to non-CO_2 emissions		
Aquaculture (use)	N_2O emissions from aquaculture use	Mangrove, Tidal marsh, Seagrass meadow
Rewetted soils	CH_4 emissions from change to natural vegetation following modifications to restore hydrology	Mangrove, Tidal marsh

[1] Including conversion to Forest Land or conversion from Forest Land to other land uses.

[2] It is *good practice* to report mangroves in the appropriate national land-use category according to the national forest definition and to consider when forest management practices may occur on mangroves classified under land-use categories other than Forest Land (similar types of examples in inventory reporting include wood harvest from orchards or other perennial Cropland or harvest of trees from Wetlands).

[3] The term revegetation is used to refer to practices within the framework of UNFCCC reporting.

[4] Countries need to report on emissions from extraction and revegetation only if necessary data are available.

It is *good practice* that inventory compilers determine a country-specific definition of coastal wetlands, recognizing national circumstances. Having applied the country-specific definition, the specific management activities (Table 4.1) need to be identified and emissions and removals reported using the methodologies

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[1] At the present time, insufficient data are available to provide generic default data for C pools in tidal freshwater swamps.

provided in this chapter. When identifying the nature and location of these activities, inventory compilers need only report GHG emissions or removals for activities where the anthropogenic contribution dominates over natural emissions and removals. Management activities resulting in extraction of soils, such as construction of aquaculture ponds, can result in large carbon dioxide (CO_2) emissions in mangroves and tidal marshes. Nitrous oxide (N_2O) emissions can be significant from aquaculture activities. Rewetting of drained freshwater tidal systems increases methane (CH_4) emissions, whilst increasing C accumulation in mangrove biomass, dead wood and soils.

Coastal wetlands can potentially occur in any land-use category defined in Chapter 3, Volume 4 of the *2006 IPCC Guidelines*and the management activity may or may not result in a land-use change (see Box 4.1). Regardless of whether a land-use change occurs, it is *good practice* to quantify and report significant emissions and removals (Table 4.1) resulting from management activities on coastal wetlands in line with the country-specific definition. To cover all potential reporting options, new Wetland subcategories *Other Wetlands Remaining Other Wetlands* and *Land Converted to Other Wetlands* are included. Coastal wetlands can also occur on areas that are not part of the total land area of the country. Emissions and removals from these areas should be reported separately under the relevant land-use category, however the associated land areas should be excluded from the total area of the land-use category (refer to Chapter 7, this supplement). In this way, countries need not be concerned with areas of coastal wetland, with small impacts on C stock changes and emissions of non-CO_2 gases, which are not included in the total land area.

Readers are referred to Volume 4 of the *2006 IPCC Guidelines* for many of the basic equations to estimate greenhouse gas emissions, and new guidance is provided in this chapter, as necessary. The decision tree (Figure 4.1) guides the inventory compiler to the appropriate estimation methodology for each of the specific management activities covered in this chapter.

COVERAGE OF THIS CHAPTER

This Chapter updates guidance contained in the *2006 IPCC Guidelines* to:

- provide default data for estimation of C stock changes in mangrove living biomass and dead wood pools for coastal wetlands at Tier 1.

This Chapter gives new:

- guidance for CO_2 emissions and removals from organic and mineral soils for the management activities of extraction (including construction of aquaculture and salt production ponds), drainage and rewetting and revegetation.
- default data for estimation of anthropogenic CO_2 emissions and removals for soils in mangrove, tidal marsh and seagrass meadows.
- guidance for N_2O emissions during aquaculture use
- guidance for CH_4 emissions for rewetting, revegetation and creation of mangroves, tidal marshes and seagrass meadows

The Appendix to this Chapter provides the basis for future methodological development to address:

- Anthropogenic emissions and removals associated with dissolved or particulate carbon (DOC, POC) loss during drainage as affected by tidal exchange.

For constructed wetlands that occur in coastal zones that are modified to receive and treat waste water, refer to Chapter 6 (this supplement). Chapter 6 also covers semi-natural treatment wetlands which are natural wetlands where wastewater has been directed for treatment but the wetland is otherwise unmodified.

While countries will follow their own national definitions of coastal wetlands, some general features that may help in consistent identification can be found throughout this guidance. It is *good practice* to maintain consistent identification of lands for the purpose of reporting.

BOX 4.1. THE FOLLOWING EXAMPLES REPRESENT DIFFERENT MANAGEMENT PRACTICES WHICH MAY RESULT IN A CHANGE OF A LAND-USE CATEGORY, DEPENDING ON HOW COUNTRIES DEFINE MANGROVES AND OTHER COASTAL WETLANDS

For Land remaining in a Land-use category:

Seagrass meadows or tidal marshes classified as Wetlands remain reported as Wetlands following introduction of aquaculture activity.

Mangroves classified as Forest Land according to the national forest definition undergoes selective harvesting or biomass clearing remain reported as Forest Land unless it undergoes a land-use change.

Mangroves do not meet all thresholds of a country's definition of forest, but are coastal wetlands with trees. In such case, mangroves are classified as Wetlands and when subject to selective harvesting or biomass clearing remain reported as Wetlands.

Conversely, management activities may result in a change in reporting category; for example:

Seagrass meadows are initially classified as Wetlands, but are considered a Settlement following introduction of aquaculture activity.

When tidal marshes are classified as Wetlands and are drained for agriculture and subsequently classified as a Cropland or Grassland.

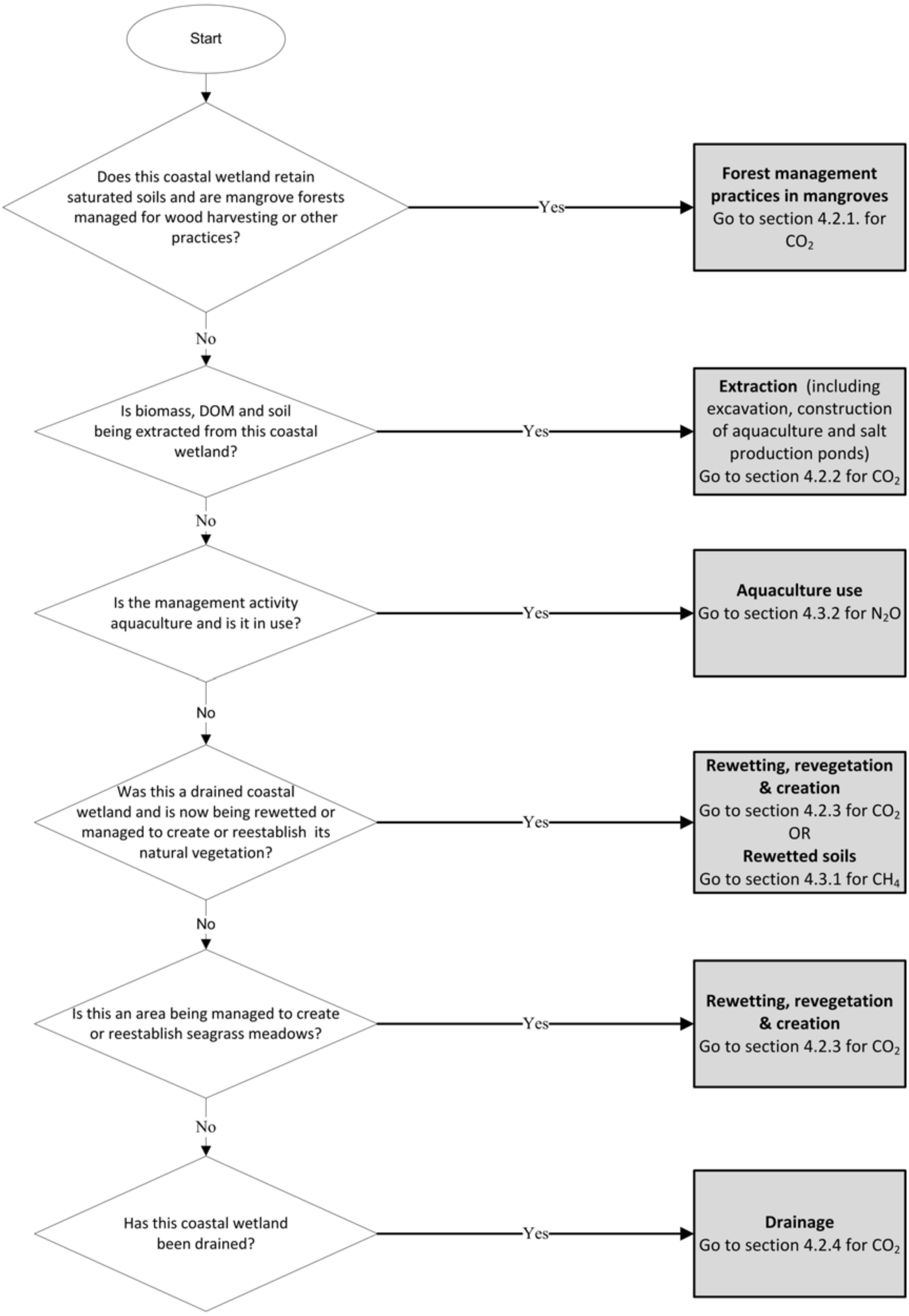
When mangroves are classified as Forest Land and undergo clearing, or drainage and converted to another land-use category.

MANAGEMENT ACTIVITIES IN COASTAL WETLANDS

Coastal wetlands that have been modified by anthropogenic activities are often reduced in area. Globally about 35% of the area of mangroves has disappeared since 1980, with a current global areal rate of loss of between 0.7 and 3% yr^{-1} (Pendelton et al., 2012). The management activities that have led to the majority of mangrove loss include forestry activities (26%) and aquaculture, comprising the construction (and extraction of soil) for shrimp ponds (38%) and fish farms (14%) (Vaiela et al., 2009). Other management activities may lead to the removal of mangrove biomass without necessarily resulting in mangrove clearance i.e. harvesting for fuelwood, charcoal and construction. The current global areal rate of loss of tidal marsh is estimated to be between 1 and 2% yr^{-1} (Pendelton et al., 2012). Draining for agriculture, diking to separate marsh from tides, filling (after extraction) with imported sediment, and the extraction of soil during the construction of ponds for salt production are common management activities affecting tidal marshes. Seagrass meadows are experiencing a global areal rate of loss currently, of between 0.4 and 2.5% yr^{-1} (Pendelton et al., 2012). Globally, the main reasons for seagrass loss are management activities such as dredging, leading to the excavation of soil to raise the elevation of land in low lying areas and contribute to new land areas for settlement and aquaculture.

Revegetation efforts with mangroves, tidal marsh plants and seagrass, have been made worldwide to compensate or mitigate for coastal wetland loss resulting from management activities (e.g. Bosire et al., 2008; Orth et al., 2011). Recovery of vegetation that characterised the coastal zone generally requires reinstatement of the pre-existing environmental setting, such as rewetting (restored hydrology) to maintain saturated soils and facilitate plant growth. Management activities do not always, affect all vegetation types (i.e. mangroves, tidal marsh plants and seagrasses) or occur in all countries and not all coastal wetlands will be managed**.** To identify areas affected refer to respective sections on Activity Data and throughout this supplement.

Figure 4.1 Decision tree to indicate relevant section for Tier 1 estimation of greenhouse gas emissions and removals due to specific management activities in coastal wetlands[2].



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[2] Extraction activities estimate CO_2 emissions and removals for the initial change in C stocks that occur during the year the extraction activities take place. Once the activity/activities is/are completed, these lands are continually tracked but CO_2 emissions and removals are reported as zero at Tier 1. Forest management practices in mangroves, drainage and rewetting are reported, based on the area of land where it occurs, lands tracked and CO_2 emissions and removals subsequently reported in the annual inventory.

The following sections provide some general information on the specified management activities in coastal wetlands that result in large anthropogenic emissions and removals.

Forest management practices in mangroves

Removal of wood occurs throughout the tropics where mangrove forests are harvested for fuelwood, charcoal, and construction (Ellison and Farnsworth 1996; Walters et al., 2008). The wood removal can range from extensive forest clearing to more moderate, selective harvesting of individual trees, or to minimally invasive activities such as bark removal. Natural disturbances are another form of biomass C stock loss. There may also be conversion to forest land where mangrove replanting can take place on rewetted, or already saturated, soils.

Extraction

Extraction collectively refers to:

(A) Excavation of saturated soils leading to unsaturated (drained) soils and removal of biomass and dead organic matter. Activities that lead to the excavation of soil often lead to loss of coastal wetlands. The excavated or dredged soil is also commonly used to help develop coastal infrastructure where there is a need to raise the elevation of land in low lying areas and/or contribute to new land areas for settlement.

(B) Excavation during the “construction” phase of aquaculture and salt production ponds in mangroves and tidal marshes followed by the “use” of these facilities.

Aquaculture and salt production are common activities in the coastal zone and similarly require excavation of soil and removal of biomass and dead organic matter for construction. There is a range of aquaculture practices, but the most important are fish farming and production from shrimp ponds (World Bank 2006). Salt production, from the evaporation of seawater, is also a widespread activity with sites along tropical and subtropical coasts worldwide, some of which have been producing salt for centuries (Oren 2009, Thiery and Puente 2002). In both activities, ponds are constructed in mangroves and tidal marshes by clearing vegetation, levelling the soil and subsequently excavating the surface soils to build berms where water is held. Depending on the type of aquaculture (intensive, extensive etc.) and the species stocked in the ponds (shrimp, fish) the soils can be excavated to make ponds of 0.5 m to 2.5 m depth (Cruz, 1997; Kungvankij et al., 1986; Wang 1990; Robertson and Phillips 1995). In a similar manner the depth of salt production ponds can vary between depths of about 0.5 to 2.5m (e.g. Ortiz-Milan 2006, Madkour & Gaballah 2012).

Construction is only the first phase in aquaculture and salt production. The second phase, termed “use” is when fish ponds, cages or pens are stocked and fish production occurs. In seagrass meadows, aquaculture is maintained by housing fish in floating cages or pens that are anchored to the sediment (Alongi et al., 2009) and these settings are considered during the use phase. N_2O is emitted from aquaculture systems primarily as a by-product of the conversion of ammonia (contained in fish urea) to nitrate through nitrification and nitrate to N_2 gas through denitrification. The N_2O emissions are related to the fish production (Hu et al., 2012). When use of the aquaculture systems has been stopped, often due to disease or declining water clarity (Stevenson et al., 1999), the systems transition to a final phase i.e.”discontinued”. All three phases (construction, use and discontinued) of aquaculture and salt production are considered together with the other extraction activities, because the activity data are linked. However, only construction is addressed at Tier 1 for CO_2, with higher tiers addressing use and discontinued phases. For non-CO_2, only the use phase is considered at Tier 1.

Rewetting, revegetation and creation

Rewetting is a pre-requisite for vegetation reestablishment and/or creation of conditions conducive to purposeful planting of vegetation characteristic of coastal wetlands. This activity is also used to describe the management activities designed to reestablish vegetation on undrained soils in seagrass meadows. Once the natural vegetation is established, soil carbon accumulation is initiated at rates commensurate to those found in natural settings (Craft et al., 2002, 2003; Osland et al. 2012).

Rewetting in mangroves and tidal marshes occurs where hydrologic modifications reverse drainage or remove impoundments or other obstructions to hydrologic flow (e.g. levee breach). Also included in this activity are mangroves and tidal marshes that have been created, typically by raising soil elevation or removing the upper layer of upland soil or dredge spoil and grading the site until the appropriate tidal elevation is reached to facilitate reestablishment of the original vegetation. Revegetation can occur by natural recolonisation, direct seeding and purposeful planting. Alternatively, created wetlands with mangroves can be found where high riverine sediment loads lead to rapid sediment accumulation, so that previously sub-aqueous soils can be elevated above tidal influence. This naturally created land can be reseeded or purposefully vegetated**.**

The rewetting of tidal marshes and mangroves through reconnection of hydrology may lead to CH_4 emissions (Harris 2010), particularly at low salinities, with an inverse relationship between CH_4 emissions and salinity (Purvaja & Ramesh 2001; Poffenbarger et al., 2011).

In coastal wetlands where seagrass loss has occurred, due to anthropogenic activities, soils remain saturated. Initiatives to allow revegeation can include natural or purposeful dispersal of seed or planting of seagrass modules (Orth et al., 2011). These same techniques can also be used to create (rather than re-establish) seagrass meadows (Jones et al., 2012).

Drainage

Mangroves and tidal marshes have been diked and drained to create pastures, croplands and settlements since before the 11th century (Gedan et al., 2009). The practice continues today on many coastlines. On some diked coasts, groundwater of reclaimed former wetlands is pumped out to maintain the water table at the required level below a dry soil surface while on other coasts drainage is achieved through a system of ditches and tidal gates. Due to the substantial C reservoirs of coastal wetlands, drainage can lead to large CO_2 emissions.

4.2 CO_2 EMISSIONS AND REMOVALS

This section provides the methodology to estimate CO_2 emissions and removals from human activities in coastal wetlands comprising forest management practices in mangroves, extraction, drainage and rewetting on CO_2 emissions and removals. The methodological guidance provided here is consistent with methods for biomass and dead organic matter in Volume 4 of the *2006 IPCC Guidelines* and are in large part based on that methodological guidance : (1) for forest management practices in mangroves, methods for biomass and dead organic matter are in large part based on Chapter 4 of Volume 4; (2) for extraction activities, the methodological guidance is generally consistent with guidance for peat extraction Chapter 7 of Volume 4; and (3) for rewetting and drainage activities, updated methodological guidance found in other Chapters of this Supplement is consistent with the methodologies presented here. Activities covered by this chapter are described in Table 4.1. Separate guidance is provided on estimation of changes in C stock from the five C pools.

Depending on circumstances, practices and definitions, specific coastal wetland management activities may or may not involve a change in land-use. The guidance in this chapter needs to be applied regardless of the reporting categories. In particular, no recommendation is provided in relation to transition periods between land use categories; countries can apply the existing transition period of appropriate land use categories.

Consistent with the *2006 IPCC Guidelines*, the Tier 1 default approach assumes that the change in biomass and dead organic matter C stocks are zero on all lands except on Forest Land or on Cropland, Grassland and Wetlands with perennial woody biomass. On Forest Land and on Cropland, Grassland, or Wetlands with woody biomass, the woody biomass and woody dead organic matter pools are potentially significant and need to be estimated in a manner consistent with the guidance provided in Chapters 2 (generic methods), 4 (Forest Land), 5 (Cropland), 6 (Grassland) and 7 (Wetlands) in Volume 4 of the *2006 IPCC Guidelines*. Guidance provided here refers to Equations 2.7, 2.8 and the subsequent equations in Chapter 2 of the *2006 IPCC Guidelines* which split the C stock changes in the biomass pool or ΔC_B into the various possible gains and losses.

If specific management activities in coastal wetlands (Table 4.1) are accompanied by a change in land use that involves Forest Land or Cropland, Grassland or Wetlands with perennial woody biomass, changes in C stocks in biomass, dead wood and litter pools are equal to the difference in C stocks in the old and current land-use categories (see Section 2.3.1.2, Chapter 2, Volume 4 of the *2006 IPCC Guidelines*). These changes in C stock occur only in the year of the conversion (extraction activities), or are uniformly distributed over the length of the transition period (e.g. planting, harvesting). In soils the change in C stocks for extraction activities occurs in the year of conversion, while for drainage, emissions persist as long as the soil remains drained or as long as organic matter remains, following the methodological guidance in this chapter.

4.2.1 Forest management practices in mangroves

This section deals with CO_2 emissions and removals associated with forest management practices in mangroves. It is *good practice* to follow a country’s national definition of forest, but also to apply the appropriate guidance when mangrove wetlands have trees, but that do not necessarily satisfy all thresholds of the national definition of forest. Depending on how the land is classified, forest management practices in mangroves may or may not lead to a change in land-use category (examples provided in Box 4.1). For estimation methodologies refer to the generic guidance provided in Chapter 2 of Volume 4 and more specific guidance in the relevant chapters of the *2006 IPCC Guidelines* for reporting CO_2 emissions and removals for above-ground biomass, below-ground biomass and dead organic matter (litter and dead wood).

4.2.1.1 BIOMASS

Biomass can be stored in mangroves that contain perennial woody vegetation. The default methodology for estimating carbon stock changes in woody biomass is provided in Section 2.2.1, Chapter 2, Volume 4 of the *2006 IPCC Guidelines*. The change in biomass is only estimated for perennial woody vegetation of mangroves. Changes in mangrove biomass may be estimated from either: 1) annual rates of biomass gain and loss (Equation 2.7, Chapter 2) or 2) changes in carbon stocks at two points in time (Equation 2.8, Chapter 2). The first approach (Gain-Loss method) can be used for Tier 1 estimation (with refinements at higher tiers) whereas the second approach can be used for Tier 2 or 3 estimations. It is *good practice* for countries to strive to improve inventory and reporting approaches by advancing to the highest possible tier given national circumstances. For coastal wetlands with non-woody vegetation (i.e. seagrass meadows and many tidal marshes), increase in biomass stocks in a single year is assumed equal to biomass losses from mortality in that same year leading to no net change.

CHOICE OF METHOD

Tier 1

If the land satisfies 1] a country's definition of forest or 2] is a mangrove wetland with trees, that nonetheless do not meet the national definition of forest, and is managed for forest activities where no land-use change has occurred, guidance is provided in "Section 2.3.1.1 Land Remaining in a Land-Use Category" and in the specific guidance in Volume 4, of the *IPCC 2006 Guidelines* and applied using the default data provided in this chapter (Table 4.2 – 4.6) and specific guidance below. Examples may include Forest Land to Forest Land, Wetlands to Wetlands or Other Wetlands to Other Wetlands.

If the land satisfies 1] a country's definition of forest or 2] is a mangrove wetland with trees, and is managed for forest activities where land-use change has occurred or trees have been cleared, guidance is provided in "Section 2.3.1.2 Land Converted to a Another Land-Use Category" and in the specific guidance in the relevant chapters of Volume 4 of the *2006 IPCC Guidelines* and applied using the default data provided in this chapter (Table 4.2 – 4.6) and specific guidance below.

When either the biomass stock or its change in a category (or sub-category) is significant or a key category, it is *good practice* to select a higher tier for estimation. The choice of Tier 2 or 3 methods depends on the types and accuracy of data and models available, level of spatial disaggregation of activity data and national circumstances.

If using activity data collected via Approach 1 (see Chapter 3 of Volume 4 in the *2006 IPCC Guidelines*), and it is not possible to use supplementary data to identify land converted from and to the respective land category, the inventory compiler needs to estimate C stocks in biomass following Section 2.3.1.1 and specific relevant guidance as indicated above.

Because a biomass conversion and expansion factor (BCEF) is not available for mangroves, when BCEF is applied for determination of above-ground biomass from merchantable growing stock, for conversion of net annual increment or for conversion of woody and fuelwood removal volume to above-ground biomass removal, the same BCEF is applied and derived from wood density (Table 4.6) and a default value of BEF (Table 3A.1.10- Annex 3A.10 of the *Good Practice Guidance for Land Use, Land-use Change, and Forestry*) following Equation 4.1 and as described in Box 4.2 of Chapter 4, Volume 4 of the *2006 IPCC Guidelines.*

EQUATION 4.1

ESTIMATION OF BCEF USING BEF AND WOOD DENSITIES

$$BCEF = BEF \bullet D$$

(Section 2.3.1.1, Chapter 2 of the *2006 IPCC Guidelines*)

where

BCEF = biomass conversion and expansion factor for conversion of growing stock, net annual increment or wood removals into above-ground biomass, above-ground biomass growth or biomass removals (tonnes d.m. m^{-3}).

BEF = biomass expansion factor (dimensionless), to expand the dry weight of the merchantable volume of growing stock, net annual increment or wood removals, to account for non-merchantable components.

D = wood density (tonnes d.m. m^{-3})

Tier 2

As in Tier 1 the Gain-Loss can be applied using country-specific data. In addition, the Stock-Difference method can also be applied using country-specific emission factors. If using the Stock-Difference method, country-specific BEF or BCEF data or species specific wood density values (provided in Table 2 of Annex 4.2) could be applied. For Tier 2, countries may also modify the assumption that biomass immediately following conversion to another land-use category, or after mangrove trees are cleared, are zero. Refer to the relevant sections in Volume 4 of the *2006 IPCC Guidelines* for further guidance on Tier 2 methodologies for forest management practices in mangroves.

Tier 3

Tier 3 approach for biomass carbon stock change estimation allows for a variety of methods including process- based models that simulate the dynamics of biomass C stock changes. Country-defined methodology can be based on estimates of above-ground biomass through use of allometric equations (Annex 4.2) or include detailed inventories based on permanent sample plots (Annex 4.2). Tier 3 could also involve substantial national data on disaggregation by vegetation type, ecological zone and salinity. Tier 3 approaches can use growth curves stratified by species, ecological zones, site productivity and management intensity. If developing alternative methods, these need to be clearly documented. Refer to the relevant sections in Chapter 4, Volume 4 of the *2006 IPCC Guidelines* for further guidance on Tier 3 methodologies for forest management practices in mangroves. Spaceborne optical and radar data can be used for mapping changes in the extent of mangroves and transitions to and from other land covers. Such techniques currently cannot routinely provide estimate to a sufficient level of accuracy although this may become more feasible in the future (refer to Activity data section).

CHOICE OF EMISSION/REMOVAL FACTORS

Tier 1

For countries using the Gain-Loss method as a Tier 1 approach, the estimation of the annual carbon gains in living biomass requires the following: carbon fraction of above-ground biomass, average above-ground biomass per hectare, mean annual above-ground biomass growth, ratio of below-ground biomass to above-ground biomass and average wood density. The default values for these parameters are provided in Tables 4.2-4.6, respectively. It is *good practice* to apply annual growth rates that lead neither to over- nor underestimates. Losses due to wood removals, fuelwood removals and disturbances are also needed (refer to Choice of Activity Data for Tier 1 and uncertainty analysis in this section).

Tier 2

National data could include country specific values of any parameter used in the Tier 1 method or values that permit biomass C stock changes using the Stock-Difference method. Refer also to the relevant sections of Volume 4 of the *2006 IPCC Guidelines* for further guidance.

Tier 3

Tier 3 methods may employ the use of data that are of higher order spatial disaggregation and that depend on variation in salinity or further disaggregation of regional differences within a country. Forest growth rates of specific age ranges could be applied. Refer also to the relevant sections of Volume 4 of the *2006 IPCC Guidelines* for further guidance.

Table 4.2 Carbon fraction of above-ground mangrove biomass (tonnes C (tonnes d.m.)$^{-1}$) [2]

Component	%C	95% CI[3]	Range
Leaves + wood[1]	45.1 (n = 47)	42.9, 47.1	42.2-50.2

[1] Spain and Holt, 1980; Gong and Ong, 1990; Twilley et al., 1992; Bouillon et al., 2007; Saenger, 2002; Alongi et al., 2003; 2004; Kristensen et al., 2008

[2] This Table provides supplementary values to those presented in Table 4.3 chapter 4, volume 4 of the *2006 IPCC Guidelines*.

[3] 95%CI of geometric mean

Table 4.3 Above-ground biomass in mangroves (tonnes d.m. ha^{-1}) [4]

Domain	Region	Above-ground biomass	95%CI	Range
Tropical	Tropical Wet	192 (n=49)[1]	187, 204	8.7-384
	Tropical Dry	92 (n = 13)[2]	88, 97	3.2-201
Subtropical		75 (n= 10)[3]	66, 84	3.9-129

[1] References: Golley et al., 1975; Christensen, 1978; Ong et al., 1982; Putz and Chan, 1986; Tamai et al., 1986; Komiyama et al., 1987, 1988, 2000, 2008; Lin et al., 1990; Mall et al., 1991; Amarasinghe and Balasubramaniam, 1992; Kusmana et al., 1992; Slim et al., 1996; Fromard et al., 1998; Norhayati and Latiff, 2001; Poungparn, 2003; Sherman et al., 2003; Juliana and Nizam, 2004; Kirui et al., 2006; Kairo et al., 2008; Fatoyinbo et al. 2008; Camacho et al., 2011; Kauffman et al., 2011;Thant and Kanzaki, 2011.

[2] References: Golley et al, 1962; Briggs, 1977; Suzuki and Tagawa, 1983; Steinke et al., 1995; Alongi et al., 2003; Medeiros and Sampoia, 2008; Khan et al., 2009.

[3] References: Lugo and Snedaker, 1974; Woodroffe, 1984; Lee, 1990; Mackey, 1993; Tam et al., 1995; Saintilan, 1997; Ross et al., 2001; Coronado-Molina et al., 2004; Simard et al., 2006; Fatoyinbo et al., 2008; Komiyama et al., 2008; Abohassan et al., 2012.

[4] This Table provides supplementary values to those presented in Table 4.7-4.9 Chapter 4, Volume 4 of the *2006 IPCC Guidelines*.

[5] 95%CI of the geometric mean

Table 4.4 Above-ground biomass growth in mangroves (tonnes d.m. ha^{-1} yr^{-1})[1, 2, 3]

Domain	Region	Above-ground biomass growth	95%CI[4]	Range
Tropical	Tropical Wet	9.9 (n=23)	9.4, 10.4	0.1-27.4
	Tropical Dry	3.3 (n = 6)	3.1, 3.5	0.1-7.5
Subtropical		18.1 (n= 4)	17.1, 19.1	5.3-29.1

[1] Ajonina 2008; Kairo et al., 2008; Alongi 2010

[2] Biomass growth rates are from forests of varying age and such default values should only pertain to forests until the C biomass stock (Table 4.3) is reached.

[3] This Table provides supplementary values to those presented in Table 4.10 Chapter 4, Volume 4 of the *2006 IPCC Guidelines*.

[4] 95%CI of the geometric mean

Table 4.5 Ratio of below-ground biomass to above-ground biomass (R) in mangroves[4]

Domain	Region	R [tonne root d.m. (tonne shoot d.m.)$^{-1}$]	95%CI[5]	Range
Tropical	Tropical Wet	0.49 (n=18)[1]	0.47, 0.51	0.04-1.1
	Tropical Dry	0.29 (n = 9)[2]	0.28, 0.30	0.09-0.79
Subtropical		0.96 (n= 18)[3]	0.91, 1.0	0.22-0.267

[1] Golley et al., 1975; Tamai et al., 1986; Komiyama et al., 1987, 1988; Gong and Ong, 1990; Lin et al., 1990; Poungparn, 2003

[2] Golley et al, 1962; Alongi et al., 2003; Hoque et al., 2010.

[3] Briggs, 1977; Lin, 1989; Tam et al., 1995; Saintilan, 1997.

[4] This Table provides supplementary values to those presented in Table 4.4, Chapter 4, Volume 4 of the *2006 IPCC Guidelines*

[5] 95%CI of the geometric mean

Table 4.6. Average density (tonnes m^{-3}) mangrove wood[1]

	EF	95% CI[2]	range	n
Wood	0.71	0.64, 0.74	0.41-0.87	85

[1] Source: Global Wood Density Database http://datadryad.org/resource/doi:10.5061/dryad.234/1?show=full; Saenger 2002; Komiyama et al. 2005; Donato et al. 2012

[2] 95%CI of the geometric mean

CHOICE OF ACTIVITY DATA

All tiers require information on areas of forest management practices in mangroves. Information on mangrove forest types as well as soil types can be obtained from national wetland and soil type maps (if available) or the International Soil Reference and Information Centre; www.isric.org). Mangrove distributions for most countries can be obtained from the RAMSAR web site (www.ramsar.org). When information is gathered from multiple sources, it is *good practice* to conduct crosschecks to ensure complete and consistent representation and avoid omissions and double-counting.

Tier 1

For Tier 1, these data can be obtained from one of the following sources (also see Annex 4A.3):

FAOSTAT http://faostat.fao.org/

Global Mangrove Database & Information System: http://www.glomis.com/

The UNESCO Mangrove Programme: http://www.unesco.org/csi/intro/mangrove.htm

Mangrove and the Ramsar Convention: http://www.ramsar.org/types_mangroves.htm

USGS Global Mangrove Project http://lca.usgs.gov/lca/globalmangrove/index.php

Mangrove.org: http://mangrove.org/

Mangrove Action Project: http://www.mangroveactionproject.org/

FAO Mangrove Management: http://www.fao.org/forestry/mangrove/en/

USGS National Wetlands Research Center: http://www.nwrc.usgs.gov/index.html

World Atlas of Mangrove: http://data.unep-wcmc.org/datasets/22

World Distribution of Coral Reefs and Mangroves: http://www.unep-wcmc.org

For Tier 1 estimation, FAO data sources can be used to estimate wood removal and fuelwood removal. Further sources of activity data can be found in the relevant sections of Volume 4 of the *2006 IPCC Guidelines*. Additional resources can be found in IPCC (2010).

Global mangrove cover has been mapped by the United States Geological Service (USGS) for three epochs “1975” (1973-1983), “1990” (1989 – 1993), and “2000” (1997 -2000) and is available for download at http://edcintl.cr.usgs.gov/ip/mangrove/download.php. Global distribution of Mangroves (V3.0, 1997) has been compiled by UNEP World Conservation Monitoring Centre (UNEP-WCMC) in collaboration with the International Society for Mangrove Ecosystems (ISME).

The Kyoto & Carbon Initiative of the Japan Aerospace Exploration Agency (JAXA) Global Mangrove Watch project, has used Synthetic Aperture Radar mosaics to create maps of global mangrove extent for the years 1995 and 2007-2010 (JAXA 2010a), and maps of annual changes in mangrove areas between the years 1995-2007, 2007-2008, 2008-2009 and 2009-2010. (http://www.eorc.jaxa.jp/ALOS/en/kyoto/mangrovewatch.htm).

Resources providing recent trends in coastal wetland area can help countries understand circumstances of those trends and what management activities contribute to them (FAO 2007; Green and Short 2003 http://archive.org/stream/worldatlasofseag03gree#page/n5/mode/2up; JAXA 2010b; Sifleet et al. 2011, http://nicholasinstitute.duke.edu/publications?topics=34; Fatoyinbo & Simard 2013). If these links do not work, either paste into your browser or do a simple web search for the resources or institution.

Sources providing international data can be verified, validated and updated data with national sources.

Tiers 2 and 3

At Tiers 2 and 3, country-specific activity data is applied and at Tier 3, at the resolution required for Tier 3 methods. At higher tiers, information of these data may be obtained from local, state or regional government department websites as many countries and regional government authorities report these data. Countries also have their own remote sensing systems which can be used for land change mapping (Nasciemto et al., 2013) Wood density values (Annex 4.4) of specific species need to be applied at Tiers 2 and 3. Areas of extensive harvesting of mangroves may be assessed with aerial imagery. When the ALOS-2 satellite is operational, generation of annual radar mosaics and mangrove extent and change maps is planned (http://www.eorc.jaxa.jp/ALOS/en/kyoto/mangrovewatch.htm).

UNCERTAINTY ASSESSMENT

The major sources of uncertainty for all wetland types, but especially mangroves, are dominant species-specific differences in carbon content and differences due to forest age, species composition, intertidal location, soil fertility and community structure. The confidence intervals presented in Tables 4.2 to 4.6, range from about 24% to 200%. To reduce uncertainty, countries are encouraged to develop country- or region specific BEFs and BCEFs. In case country- or regional-specific values are unavailable, it is *good practice* to check the sources of default parameters and their correspondence with species present, as well as with the conditions in country.

The causes of variation of annual increment of mangrove growth include climate, site growth conditions, and soil fertility. Artificially regenerated and managed stands are less variable than natural forests. One of the ways to improve accuracy of estimates of these wetlands includes the application of country-specific or regional estimates of growth stratified by the dominant species present. If the default values of growth increments are used, the uncertainty of the estimates need to be clearly indicated and documented.

For mangroves, data on commercial fellings are relatively accurate, although they may be incomplete or biased due to illegal fellings and under-reported due to tax regulations. Traditional wood that is gathered and used directly, without being sold, is not likely to be included in any statistics. Countries must carefully consider these issues. The amount of wood removed from forests after storm breaks and pest outbreaks varies both in time and volume. No default data can be provided on these types of losses. The uncertainties associated with these losses can be estimated from the amount of damaged wood directly withdrawn from the forest or using data on damaged wood subsequently used for commercial and other purposes. If fuelwood gathering is treated separately from fellings, the relevant uncertainties might be high, due to the level of uncertainty associated with traditional gathering.

4.2.1.2 DEAD ORGANIC MATTER

The guidance for changes in the carbon pools in dead organic matter (DOM; dead wood and litter) in mangroves provided in the *2006 IPCC Guideline* remains unchanged. Dead roots ≤2 cm diameter are included in the soil pool and not considered within the dead organic matter pool. This fraction of dead roots turns over rapidly (Alongi 2009) with the assumption of approximating steady state. Dead organic matter C stocks can vary depending on tidal inundation and frequency, as well as soil oxidation and vegetation cover. Fine litter can be exported with tidal activity (Alongi 2009) while a larger fraction of senesced woody biomass is buried or decomposed *in-situ*. In wetlands, decomposition of DOM, especially wood, is slow (Robertson and Daniel 1989) and accumulates as soil organic matter. Careful consideration of pools is needed in estimating inputs, outputs or changes of dead organic matter C stocks to avoid double-counting. Consistent with the *2006 IPCC Guidelines*, it is *good practice* to consider dead organic matter C stock changes when management activities in coastal wetlands result in changes in mangrove cover due to human-induced impacts.

CHOICE OF METHOD

Tier 1

If the land (1) satisfies a country's definition of forest or (2) is a mangrove wetland with trees, that nonetheless do not meet the national definition of forest, and is managed for forest activities, where no land-use change has occurred, guidance is provided in "Section 2.3.1.1 Land Remaining in a Land-Use Category" and in the specific guidance in Volume 4, of the *IPCC 2006 Guidelines* and applied using the default data provided in this chapter (Table 4.7) and specific guidance below. Examples may include Forest land to Forest land, Wetlands to Wetlands or Other Wetlands to Other Wetlands.

If the land (1) satisfies a country's definition of forest or (2) is a mangrove wetland with trees, and is managed for forest activities where land-use change has occurred or trees have been cleared, guidance is provided in "Section 2.3.1.2 Land Converted to a Another Land-Use Category" and in the specific guidance in the relevant chapters of Volume 4 of the *IPCC 2006 Guidelines* and applied using the default data provided in this chapter (Table 4.7) and specific guidance below.

Tier 2

Estimation methodologies for Tier 2 can follow Tier 1 methods, but apply country-specific data. The Stock-Difference method (Chapter 4, Volume 4 of the *2006 IPCC Guidelines*) could also be applied if countries have sample plot data from forest inventories for two points in time. Literature data or C databases may provide more feasible and cost-effective data to apply this method.

Tier 3

Loss estimates of dead wood and litter exports due to tidal movement can also be considered (Appendix 4.1). Tier 3 methods may further employ stratification by ecological zone or disturbance regime to reduce uncertainties. It is *good practice* to report and sum changes in both dead wood and litter to obtain changes in total dead organic matter. Additional Tier 3 guidance is provided in Chapter 4, Volume 4 of the *2006 IPPC Guidelines*.

CHOICE OF EMISSION/REMOVAL FACTORS

Tier 1

Default values are provided in Table 4.7 of this Supplement for use in Tier 1 assessment of emissions and removals.

Tier 2

Tier 2 methods using country-specific data if such country-specific data can be acquired at reasonable cost.

Tier 3

Tier 3 emission factors include model output and validation and disaggregated data sources. Field measurements can be developed and used to inform and validate model output at Tier 3. For mangroves, Tier 3 methodologies can employ empirical relationships to provide estimates of canopy litter fall and census of downed wood lying on the forest floor.

TABLE 4.7 TIER 1 DEFAULT VALUES FOR LITTER AND DEAD WOOD CARBON STOCKS

Domain	Ecosystem type	Litter carbon stocks of mature mangrove stands (tonnes C ha^{-1}) with 95% CI[1]	Dead wood carbon stocks of mature mangrove stands (tonnes C ha^{-1}) with 95% CI[1]
Tropical/Subtropical	mangroves	0.7 (0-1.3)	10.7 (6.5-14.8)

Litter: Utrera-Lopez and Moreno-Casasola 2008, Liao et al 1990, Chen et al 2008, Richards et al 2011, Ramose-Silva et al 2007, Twilley et al 1986

Dead Wood: Kauffman et al 2011, Donato et al 2012, Allen et al 2000, Steinke et al 1995, Robertson et al 1989, Tam et al 1995, Krauss et al 2005

[1] 95%CI of the geometric mean.

CHOICE OF ACTIVITY DATA

Tier 1

C stock changes in dead organic matter are generally not reported at Tier 1when management activities in coastal wetlands do not result in changes in mangrove cover due to human-induced impacts (following guidance in Section 4.2.2.3 of Chapter 4, Volume 4 of the *2006 IPCC Guidelines*), and thus no activity data are required. If a land-use change has occurred resulting from an increase in woody biomass stock, it is *good practice* to report the change in dead organic matter C stock. For Tier 1 method, the annual rate of conversion to Forest Land or other Land-use categories with woody mangrove biomass is required, following Section 4.3.2.3 of Chapter 4, Volume 4 of the *2006 IPCC Guidelines*. Activity data should be consistent with those used for estimating changes in carbon stock.

Tier 2 and Tier 3

Inventories using higher tiers will require more comprehensive information on the establishment of new forests, using climate, for example, as a disaggregating factor and at higher spatial and temporal resolution. Additional resources can be found in IPCC (2010).

UNCERTAINTY ASSESSMENT

The uncertainty assessment given in section 4.2.2.5 in Chapter 4, Volume 4 of the *2006 IPCC Guidelines* identifies sources of uncertainty in estimates of C stock changes in the dead organic matter pool of mangroves. Other sources of uncertainty include output of dead organic matter due to decomposition or tidal export.

4.2.1.3 SOIL CARBON

The Tier 1 default assumption is that soil CO_2 emissions and removals are zero (EF=0) for forest management practices in mangroves. This assumption can be modified at higher tiers. At higher tiers, it is recommended to consider CO_2 emissions from soils due to forest clearing in C stock estimations (Alongi et al. 1998). It should also be considered that at Tier 1 rewetting (section 4.2.3) and drainage activities (section 4.2.4) can occur as a result of forest management practices. In this case, follow the guidance for estimating CO_2 emissions and removals from soil C stock changes (Sections 4.2.3.3 and 4.2.4.3, respectively).

4.2.2 Extraction

Extraction refers collectively to the following activities (A) excavation: associated with dredging used to provide soil for raising the elevation of land, or excavation to enable port, harbour and marina construction and filling, and both (B) the construction of aquaculture ponds and (C) salt production ponds, where soil is excavated to build berms where water is held. Each of these extraction activities is associated with the removal of biomass, dead organic matter and soil, which results in significant emissions when their removal is from saturated (water-logged) to unsaturated (aerobic) conditions (World Bank 2006). The Tier 1 methodology assumes that the biomass, dead organic matter and soil are all removed and disposed of under aerobic conditions where all carbon in these pools is emitted as CO_2 during the year of the extraction and that no subsequent changes occur. Tier 1 guidance is given here for reporting the intial changes in carbon (Table 4.1). Regardless of whether the extraction activities results in a change in land-use category, CO_2 emissions and removals associated with extraction are the same, following Equation 4.2 below. This approach follows the methodology applied for peat extraction in Chapter 7, Volume 4 of the *2006 IPCC Guidelines*.

EQUATION 4.2

TIER 1 ESTIMATION OF INITIAL CHANGE IN CARBON STOCKS WITH EXTRACTION (ALL C POOLS)

$$\Delta C_{EXT} = \Delta C_{excav} + \Delta C_{aq\text{-}constr} + \Delta C_{sp\text{-}constr}$$

Where

ΔC_{EXT} = Changes in C stocks from all extraction activities; tonnes C

ΔC_{excav} = Initial change in biomass, dead organic matter and soil carbon stocks from extraction due to excavation; tonnes C

$\Delta C_{aq\text{-}constr}$ = Initial change in biomass, dead organic matter and soil carbon stocks from extraction during construction of aquaculture ponds; tonnes C

$\Delta C_{sp\text{-}constr}$ = Initial change in biomass, dead organic matter and soil carbon stocks from extraction during construction of salt production ponds; tonnes C

Equation 4.2 is applied to the total area of coastal wetland where extraction activities take place. The terms ΔC_{excav}, $\Delta C_{aq\text{-}constr}$, and $\Delta C_{sp\text{-}constr}$ are estimated as $\Delta C_{CONVERSION}$ (Equations 4.4 - 4.6) for intial change in carbon stocks of each of the C pools for each of the respective activities comprising extraction. Equation 4.3 is applied for each of the extraction activities (and A-C as described above) to estimate the intial change in stocks of each of the C pools.

EQUATION 4.3

INITIAL CHANGE IN CARBON STOCKS WITH EXCAVATION (ALL C POOLS)

$$\Delta C_{excav} = \Delta C_{excav\text{-}AB} + \Delta C_{excav\text{-}BB} + \Delta C_{excav\text{-}DOM} + \Delta C_{excav\text{-}SO}$$

where:

ΔC_{excav} = sum of the initial changes in C stock with excavation, tonnes C

$\Delta C_{excav\text{-}AB}$ = initial change in above-ground biomass C stock changes with excavation, tonnes C

$\Delta C_{excav\text{-}BB}$ = initial change in below-ground biomass C stock changes with excavation, tonnes C

$\Delta C_{excav\text{-}DOM}$ = initial change in dead organic matter C stock changes with excavation, tonnes C

$\Delta C_{excav\text{-}SO}$ = initial change in soil C stock changes with excavation as annual CO_2 emissions and removals, tonnes C

At Tier 1,

$\Delta C_{excav\text{-}AB} + \Delta C_{excav\text{-}BB} = \Delta C_{B\text{-}CONVERSION}$ (equation 4.4, section 4.2.2.1)

$\Delta C_{excav\text{-}DOM} = \Delta C_{DOM\text{-}CONVERSION}$ (equation 4.5, Section 4.2.2.2)

$\Delta C_{excav\text{-}SO} = \Delta C_{SO\text{-}CONVERSION}$ (equation 4.6, Section 4.2.2.3).

Equation 4.3 provides the formulation to estimate the initial change in carbon stock in each C pool for the specific extraction activity, excavation. To estimate the initial changes in intial C stock change for these pools for construction of aquaculture and salt production ponds, replace ΔC_{excav} with $\Delta C_{aq\text{-}constr}$ and $\Delta C_{sp\text{-}constr}$ in Equation 4.3, respectively.

The Tier 1 methodology assumes that the biomass, dead organic matter and soil are all removed and disposed of under aerobic conditions where all carbon in these pools is emitted as CO_2 during the year of the extraction (consistent with the assumption applied for peat extraction in Section 7.2.1.1, Chapter 7, Volume 4 of the *2006 IPCC Guidelines*) and that no subsequent changes occur.

Table 4.8 summarizes the Tier level guidance provided for extraction activities, which deals with excavation in general and excavation during the construction phase of aquaculture and salt production, in particular. Estimates are not made at Tier 1 for possible CO_2 emissions and removals while (1) fish ponds are stocked and salt production is occuring (use phase) or (2) when the activity has ceased (discontinued phase), although they are considered together with other extraction activities because the activity data are linked.

TABLE 4.8 SUMMARY OF TIER 1 ESTIMATION OF INITIAL CHANGES IN C POOLS FOR EXTRACTION ACTIVITIES

			Carbon pools			
			Mangrove biomass, dead wood and litter[1]	Soils		
				Mangrove & Tidal Marsh		Seagrass
				Organic	Mineral	Mineral[2]
Extraction activities	**Excavation**		Tier 1	Tier 1	Tier 1	Tier 1
	Aquaculture and Salt Production	Construction	Tier 1	Tier 1	Tier 1	NA[3]
		Use	No guidance[4]			
		Discontinued	No guidance[4]			

[1] Removal of biomass resulting from extraction activities is estimated at Tier 1 level in mangroves only.

[2] Tier 1 assumption is that all seagrass soils are mineral.

[3] Extraction activity, aquaculture construction, is not applicable for fish pens or cages in seagrass meadows.

[4] No suitable Tier 1 methodologies are available for C pools during these phases/activities.

4.2.2.1 BIOMASS

This section addresses estimation of changes in living (above and below-ground) biomass pools associated with extraction activities comprising excavation, and construction of aquaculture and salt production ponds in coastal wetlands. For extraction in coastal wetlands with tidal marshes and seagrass meadows, changes in biomass carbon stocks, are reported only Tier 2 or higher estimations. It is *good practice* to report the conversion of above-ground and below-ground biomass that occurs with extraction of mangroves.

CHOICE OF METHOD

Following Box 4.1 extraction may, or may not, result in a change in land-use category, however, the same methodologies apply for mangrove wetlands with forest regardless of how the land is classified.

Tier 1

Changes in carbon stock in living biomass during extraction are associated with clearing and removal of vegetation. The area applied is that of a certain year in which the conversion occurs. Regardless of the land category, the loss in biomass associated with extraction activities is estimated as $\Delta C_{conversion}$ following the methodology for peat extraction (Chapter 7, Volume 4 of the *2006 IPCC Guidelines*), modified here as Equation 4.4:

EQUATION 4.4

TIER 1 ESTIMATION OF INITIAL CHANGE IN BIOMASS CARBON STOCKS DUE TO EXTRACTION ACTIVITIES

$$\Delta C_{B\text{-}CONVERSION} = \sum_{v,c}\{B_{AFTER} * (1+R) - B_{BEFORE} * (1+R)\}_{v,c} * CF * A_{CONVERTEDv,c}$$

Where,

$\Delta C_{B\text{-}CONVERSION}$ = Changes in biomass stock from conversion due to extraction activities; tonnes C

B_{AFTER} = Stock in above-ground biomass per unit of area immediately after the conversion by vegetation type (v) and climate (c); tonnesd.m. ha^{-1}; default value = 0

B_{BEFORE} = Stock in above-ground biomass per unit of area immediately before the conversion tonnes d.m. ha^{-1}

R = ratio of below-ground biomass to above-ground biomass by vegetation type (v) and climate (c); tonnes DM below-ground biomass (tonnes d.m. above ground biomass)$^{-1}$.

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

$A_{CONVERTED}$ = Area of conversion by veg type (v) and climate (c): ha

The Tier 1 methodology assumes that the biomass is removed and disposed of under aerobic conditions where all carbon is emitted as CO_2 during the year of the extraction and that no subsequent changes occur. At Tier 1, initial change in C stocks of biomass $\{B_{AFTER} * (1+R) - B_{BEFOREv} * (1+R)\}_{v,c}$ is assumed to be zero for coastal wetlands without perennial biomass or trees. For mangrove wetlands with perennial biomass or trees, the stock after the conversion (B_{AFTER}) at Tier 1 is taken to be zero.

Tier 2

At Tier 2, changes of C stock in living above-ground biomass of tidal marsh and seagrass meadow vegetation can be estimated and reported for the specified activities employing the equation for $\Delta C_{B\text{-}CONVERSION}$, using country-specific emission factors and default values for R given in Tables 4.9 and 4.10, in conjunction with country-specific data on above-ground biomass. At Tier 2, the Gain-Loss or Stock-Difference methods can be applied to estimate biomass C stock changes of mangrove in lands where extraction activities (aquaculture and salt production) are discontinued (i.e. regrowth). Tier 2 approaches could also include evaluation of the assumption of instantaneous oxidation of the converted biomass pool.

Tier 3

In Tier 3, estimation could include methods to incorporate data on the fraction of biomass C stock that is retained under saturated conditions to improve estimation of proportion of C that is oxidized.

CHOICE OF EMISSION/REMOVAL FACTORS

Tier 1

Default data for Tier 1 method is provided for mangroves in Tables 4.2-4.6, Section 4.2.1, including above-ground biomass C stock, C fraction and below-ground to above-ground ratio, for the different climate domains and regions, where applicable.

Tier 2

Under Tier 2, countries apply country specific data to estimate changes in C stock in above-ground biomass. The conversion of above-ground and below-ground biomass that occurs with extraction activities from tidal marsh and seagrass meadows may be estimated using Tables 4.9 and 4.10 for tidal marshes and seagrass meadows respectively. These data are to be used in conjunction with the carbon fraction of dry matter alongside country-specific data on above-ground biomass stock.

TABLE 4.9 RATIO OF BELOW-GROUND BIOMASS TO ABOVE-GROUND BIOMASS (R) FOR TIDAL MARSHES

Domain	R [tonne root d.m. (tonne shoot d.m.)$^{-1}$]	95%CI[5]	Range	n
Mediterranean[1]	3.63	3.56, 3.7	1.09-7.15	5
subtropical [2]	3.65	3.56, 3.74	2.23-9.41	5
temperate fresh tidal [3]	1.15	1.12, 1.18	0.36-3.85	7
temperate [4]	2.11	2.07, 2.15	0.33-10.15	17

[1] Scarton et al . 2002; Neves et al. 2007; Boyer et al. 2000

[2] Lichacz et al. 1984; da Cunha Lana et al. 1991

[3] Birch and Cooley1982; Whigham et al.1978

[4] Kistritz et al 1983; Hussey and Long 1982; Smith et al. 1979; Dunn 1981; Connor and Chmura 2000; Gross et al. 1991; Whigham et al.1978; Elsey-Quirk et al. 2011; Adams et al. 2012

[5] 95%CI of the geometric mean.

TABLE 4.10 RATIO OF BELOW-GROUND BIOMASS TO ABOVE-GROUND BIOMASS (R) FOR SEAGRASS MEADOWS

Domain	R [tonne root d.m. (tonne shoot d.m.)$^{-1}$]	95%CI[4]	Range	n
Tropical[1]	1.7[1]	1.5, 1.9	0.05 – 25.62	396
Subtropical[2]	2.4[2]	2.3, 2.6	0.07 – 16.8	391
Temperate[3]	1.3[3]	1.1, 1.5	0.14 – 13.8	91

[1] Aioi & Pollard 1993, Brouns 1985, Brouns 1987, Coles et al. 1993, Daby 2003, Devereux et al. 2011, Fourqurean et al. 2012, Halun et al. 2002, Holmer et al. 2001, Ismail 1993, Lee 1997, Lindeboom & Sandee 1989, McKenzie 1994, Mellors et al. 2002, Moriarty et al. 1990, Nienhuis et al. 1989, Ogden & Ogden 1982, Paynter et al 2001, Poovachiranon & Chansang 1994, Povidisa et al. 2009, Rasheed 1999, Udy et al. 1999, van Lent et al. 1991, van Tussenbroek 1998, Vermaat et al. 1993, Vermaat et al. 1995, Williams 1987.

[2] Aioi 1980, Aioi et al. 1981, Asmus et al. 2000, Bandeira 2002, Boon 1986, Brun et al 2009, Collier et al. 2009, de Boer 2000, Devereux et al. 2011, Dixon & Leverone 1995, Dos Santos et al. 2012, Dunton 1996, Fourqurean et al. 2012, Hackney 2003, Herbert and Fourqurean 2009, Herbert & Fourqurean 2008, Holmer & Kendrick 2012, Jensen & Bell 2001, Kim et al. 2012, Kirkman & Reid 1979, Kowalski et al. 2009, Larkum et al. 1984, Lee et al. 2005, Lee et al. 2005b, Lipkin 1979, Longstaff et al. 1999, Masini et al. 2001, McGlathery et al. 2012, mcMahan 1968, Meling-Lopez & Ibarra-Obando 1999, Mukai et al. 1979, Paling & McComb 2000, Park et al. 2011, Powell 1989, Preen 1995, Schwarz et al. 2006, Stevensen 1988, Townsend & Fonseca 1998, Udy & Dennison 1997, van Houte-Howes et al. 2004, van Lent et al. 1991, van Tussenbroek 1998, Walker 1985, West & Larkum 1979, Yarbro & Carlson 2008.

[3] Agostini et al. 2003, Cebrian et al. 2000, Fourqurean et al. 2012, Hebert et al. 2007, Holmer & Kendrick 2012, Larned 2003, Lebreton et al. 2009, Lillebo et al. 2006, Marba & Duarte 2001, McRoy 1974, Olesen & Sand-Jensen 1994, Rismondo et al. 1997, Sand-Jensen & Borum 1983, Terrados et al. 2006

[4] 95%CI of the geometric mean

Tier 3

Field measurements can be developed and used to inform and validate model output at Tier 3. It is expected that data improvements for excavation activities such as ground-truth estimates of overall area impacted, the depth at which removal of biomass has occurred, or the fraction of biomass removal, could be used to develop and verify models.

CHOICE OF ACTIVITY DATA

Extraction: Submissions of licenses for prospecting and exploitation and associated environmental impact assessments (EIAs) can be used to obtain areas under extraction activities. Relevant regulation for extraction can be found at international and national levels. International regulation is covered by the UN Convention on the Law of the Sea (UNCLOS) 1982 (www.un/org/Depts/los/index.htm). Contracting Parties are under the obligation to publish/communicate reports on monitoring and assessment of potential harmful effects of extraction. The OSPAR Convention 1992 (www.ospar.org) provides guidance for programmes and measures for the control of the human activities in the North-East Atlantic region. The "Agreement on Sand and Gravel Extraction" provides that authorisation for extraction of marine soils from any ecologically sensitive site should be granted after consideration of an EIA. The HELSINKI Convention 1992 (www.helcom.fi) covers the Baltic Sea Area and requires EIAs to be carried out as part of the extraction process and that "monitoring data" and "results of EIA's………be made available for scientific evaluation". The Barcelona Convention 1995 (www.unepmap.org), covers the regulatory framework for the Mediterranean. The ICES Convention 1964 (www.ices.dk) provides data handling services to OSPAT and Helsinki Commissions. An overview of the regulation of marine aggregate operations in some European Union Member States is reported in in Radzevicius et al. (2010) and includes relevant EC Directives and national legislation/regulation. Other such sources of activity data include, for example, statistics on sand and gravel extraction for the OSPAR martime area (e.g. www.ospar.org/documents/dbase/publications/p0043) as well as information on sand & gravel activities and related statistics for North Sea Continental Shelfs & UK waters (http://www.sandandgravel.com/).

If time series data back to 1990 are unavailable, it is suggested that surrogate data be used, derived from statistical reports/databases containing information on temporal changes in proxy factors such as human population density; port or marina development; port revenue; shipping tonnage; commodity exports; such data can be obtained from the internet, e.g. for the Asia-Pacific region from the UN ESCAP Commission (http://www. unescap.org/stat/) and for the Baltic from http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/themes. Data on shipping indices can be obtained from http://www.worldshipping.org/about-the-industry/global trade/trade-statistics. Such data for most countries can also be obtained from http://datacatalog.worldbank.org.

Aquaculture and salt production: Annual data (1950 – present) providing statistics on aquaculture production is collated by the FAO Fisheries and Aquaculture Department. Additional data on type aquaculture (e.g. freshwater or brackish) and area under production is summarized in country profiles enabling stratification of aquaculture into those occurring in coastal wetlands (http://www.fao.org/fishery/countryprofiles/search/en).

Similar project information for salt production activities can be obtained from the Salt Institute at www.saltinstitute.org. As local regulations typically apply for developing new aquaculture activites (i.e licensing, permitting), regulations also typically apply to report such activities to the Ministry of Fisheries and Marine Affairs (or country equivalent). For example an aquaculture farm needs to get a license (or permission) to operate. Depending on the country, it is given by the regional (e.g. in Spain it is the autonomic -e.g. Balearic- government who approves it) or local (e.g. at Bolinao, The Philipines) and maybe in others the national government. For example, in Indonesia local government must be consulted on land use change including aquaculture pond construction and are obliged to report activities to the Ministry of Fisheries and Marine Affairs.

Literature sources can also provide national area change statisitics from aerial photographs of ponds or structures used for aquaculture and salt production.

A map of available tidal marsh distribution (with area data) is in production by the World Conservation and Monitoring Center, http://data.unep-wcmc.org/, currently holding layers for Europe, the United States, Australia and China. It is the intent to expand mapping of tidal marsh to global coverage.

A map of global distribution of seagrasses (V2.0, 2005) is also available at the World Conservation and Monitoring Center (WCMC) (http://data.unep-wcmc.org/) and prepared in collaboration with Dr. Frederick T. Short. Other regional and national maps are also available, e.g. http://www.ospar.org/documents/dbase/publications/p00426_zostera_beds. A tabulated list of web sites for existing seagrass monitoring programmes is given in Borum et al., (2000), http://www.seagrasses.org/handbook/european_seagrasses_high.pdf.

These data sources, and those provided in Section 4.2.1.1, can be used in conjunction with activity data described above to improve estimations of areas of mangroves, tidal marsh and seagrass meadow undergoing extraction activities.

UNCERTAINTY ASSESSMENT

For uncertainty assessment for mangroves, see Section 4.2.1 (this chapter). The uncertainties involved in extraction and mangroves also follow those outlined in Section 4.3.1.5 of Chapter 4, Volume 4 of the *2006 IPCC Guidelines*. Variability in tidal marsh biomass will be due to differences in dominant species and competition between species, as well as salinity of flood waters, frequency of tidal flooding and climate. For example, the high biomass in Mediterranean climates is due to the frequent dominance of perennial shrubs. For all vegetation there can be considerable yearly variability in production of biomass and seasonal variability in standing biomass that contributes to uncertainty in ratios of above-ground-below-ground ratios. Most empirical data are available from temperate regions and North America and there are limited data available for tidal freshwater and boreal and subtropical tidal marshes. The average below-ground to above-ground biomass for seagrass is variable depending on the dominant species, and fertility of the soil. The data are mainly derived from observations along the coasts of North America, Western Europe and Australia. Data were scarce from South America and Africa.

4.2.2.2 DEAD ORGANIC MATTER

Previously saturated DOM, which is exposed to aerobic conditions, can contribute to large sources of CO_2 emissions from extraction activities. Consistent with the *2006 IPCC Guidelines* for Forest Land, in coastal wetlands, it is *good practice* to consider dead organic matter C stock changes when extraction activities result in changes in mangrove cover due to these human-induced impacts.

CHOICE OF METHOD

Tier 1

During extraction activities, existing dead organic matter pools may be reduced due to zero as vegetation is cleared and removed at the same time no new C enters the dead organic matter pool. At Tier 1, changes in carbon stock in dead organic matter in tidal marshes and seagrass meadows are assumed to be zero. It is noted, however, that extraction activities that result in vegetation or soil disturbance in tidal marsh with perennial woody biomass may have significant impacts on C emissions and removals and it is *good practice* for country specific methods to be developed to cover these cases, if feasible. Regardless of the land category, the loss in dead organic matter associated with extraction activities is estimated as $\Delta C_{conversion}$ following the methodology applied for peat extraction (Chapter 7, Volume 4 of the *2006 IPCC Guidelines*), modified here as Equation 4.5:

EQUATION 4.5

TIER 1ESTIMATION OF INITIAL CHANGE IN DEAD ORGANIC MATTER CARBON STOCKS DUE TO EXTRACTION ACTIVITIES

$$\Delta C_{DOM\text{-}CONVERSION} = \sum_{v}(DOM_{AFTER} - DOM_{BEFORE})_{v} \cdot A_{CONVERTED_{v}}$$

Where,

$\Delta C_{DOM\text{-}CONVERSION}$ = Initial changes in dead organic matter stock from conversion due to extraction activities by vegetation type (v) and climate (c); tonnes C

DOM_{AFTER} = Stock in dead organic matter per unit of area immediately after the conversion by vegetation type (v) tonnes d.m. ha^{-1}; default value = 0

DOM_{BEFORE} = Stock in dead organic matter per unit of area immediately before the conversion by vegetation type (v) tonnes d.m. ha^{-1}

$A_{CONVERTED}$ = Area of conversion by veg type (v) and climate (c): ha

The Tier 1 methodology assumes that the dead organic matter is removed and disposed of under aerobic conditions where all carbon is emitted as CO_2 during the year of the extraction and that no subsequent changes occur. The choice of method follows that in Section 4.2.2.

Tiers 2 and 3

The choice of method follows that in Section 4.2.2. For these management activities that impact dead organic matter pools in tidal marshes with perennial or woody biomass, Tier 2 and higher estimation methods are recommended and these values reported.

CHOICE OF EMISSION/REMOVAL FACTORS

Tier 1

Default values of dead organic matter carbon stock (for dead wood and litter) for mangroves are provided in Table 4.7 of this supplement for use in Tier 1 estimations. In tidal marsh and seagrass meadows the Tier 1 assumption is that carbon stocks in the dead organic matter pools resulting from extraction activities are zero.

Tier 2

At Tier 2, the assumption that all dead organic matter lost in the year of conversion is oxidized can be reassessed. Tier 2 assumption of zero for dead organic matter after can also be assessed. It is *good practice* for countries, in such cases, to use national estimates for dead organic matter C stocks for mangroves and tidal marshes with perennial biomass, if such country-specific data can be acquired at reasonable cost

Tier 3

Tier 3 emission factors include model output and validation and disaggregated data sources.

CHOICE OF ACTIVITY DATA

Choice of activity data follows from guidance above provided in Section 4.2.2.1. The area in which the extraction activities occur will be the same area applied for each C pool, especially forest biomass.

UNCERTAINTY ASSESSMENT

The discussion on uncertainty outlined in Section 4.3.2.5 of Chapter 4, Volume 4 of the *2006 IPCC Guidelines* is also relevant for extraction of mangroves. Management activities in tidal marshes and seagrass meadows (without woody, perennial biomass) do not result in changes in dead organic matter.

4.2.2.3 SOIL CARBON

Extraction activities that occur within coastal wetlands can influence organic and mineral stocks of C in soils and both soil types are covered at Tier 1(Table 4.11). During extraction activities, the stock of soil C that is removed depends on the soil type (i.e. C stock is higher in organic soils). For Tier 1 estimation, in the absence of soil map data or other resources to differentiate soil type, the following assumptions can be applied:

i. Assume that soils in which seagrass grow are mineral.

ii. Assume all soils, regardless of dominant vegetation in or at the mouth of estuaries or adjacent to any river characterised by a large and/or mountainous catchment and high flow, are mineral. For all other mangroves and tidal marshes the soils are organic. See Durr et al. (2011) for additional national level guidance.

iii. If soils cannot be dissagregated into organic and mineral, use the aggregated default data given in Table 4.11

CHOICE OF METHOD - ORGANIC AND MINERAL SOILS

Tier 1

Regardless of the land category, the loss in soil carbon associated with extraction activities is estimated as $\Delta C_{conversion}$ following the methodology applied for peat extraction (Chapter 7, Volume 4 of the *2006 IPCC Guidelines*), modified here as Equation 4.6

EQUATION 4.6

TIER 1 ESTIMATION OF INITIAL CHANGE IN SOIL CARBON STOCKS DUE TO EXTRACTION ACTIVITIES

$$\Delta C_{SO\text{-}CONVERSION} = \sum_{v,s}(SO_{AFTER} - SO_{BEFORE})_{v,s} \cdot A_{CONVERTED\,v,s}$$

Where,

$\Delta C_{SO\text{-}CONVERSION}$ = Initial changes in soil carbon stock from conversion due to extraction activities by vegetation type (v) and soil type(s); tonnes C

SO_{AFTER} = Carbon stock in soil per unit of area, immediately after the conversion, by vegetation type (v) and soil type (s); tonnes C ha^{-1}; default value = 0

SO_{BEFORE} = Carbon stock in soil per unit of area, immediately before the conversion, by vegetation type (v) and soil type (s); tonnes C ha^{-1}

$A_{CONVERTED}$ = Area of conversion by veg type (v) and climate (c): ha

At Tier 1, soil extraction depth to 1m approximates the mid-range of the extraction depth for construction of aquaculture and salt production ponds (see extraction activities in section 4.1). Countries may modify the assumption of 1m extraction depth at higher tiers.

The Tier 1 methodology assumes that the soil is removed and disposed of under aerobic conditions where the C stock is emitted as CO_2 (oxidised) during the year of the extraction. The C stock is taken as all soil carbon except any refractory (unoxidisable) carbon. In mangrove soils 4% of the C stock is refractory (Annex 4A.4) and this is taken to be representative of the refractory carbon in tidal marshes and seagrass meadows as well. Therefore, after the initial conversion of the soil pool in the year in which the activity occurs, CO_2 emissions are reported as zero. It is *good practice* to track these lands to consider management activities that may occur on those lands in the future and for higher tier estimations. The choice of method follows that in Section 4.2.2. For Tier 1, CO_2 emissions are reported as the conversion in soil C where this activity occurs and the type of vegetation and the availability of activity data to distinguish between organic and mineral soils, determines which data is applied from Table 4.11.

Tier 2

At Tier 2, methodology can be applied to disaggregate by vegetation type and soil type. For the specific extraction activity, countries may use national data to determine their particular extraction processes and the volume of soil removed, if sufficient data are available. Because tidal marshes can occur in a range of climates, disaggregating by climate may also be applied to improve estimates if those country-specific data are available. Tier 2 may also define the area of the aquaculture and salt production activity to refine the estimate for the soil C stock that is excavated to construct the pond, including specific information on the depth of pond excavated during the construction phase.

Tier 3

Tier 3 methods can employ models to estimate CO_2 emissions based on the effect of temperature and salinity on soil oxidation both seasonally and with climate and vegetation type. At Tier 3 it is *good practice* for countries to validate models with field measurements. Tier 3 methods may also include site specific measurements of e.g. C-content, BD, clay content, salinity, redox etc. to determine the underlying processes of emissions.

CHOICE OF EMISSION FACTORS - ORGANIC AND MINERAL SOILS

Tier 1

Default Tier 1 soil C stocks(to 1m depth) for mangrove, tidal marsh and seagrass meadows to be used in the calculation of CO_2 emissions , are given in Table 4.11 for the three major vegetation types in coastal wetlands. These values are to be used in conjunction with Equation 4.6 to estimate emissions. If soil type is not known, a generic default value for aggregated organic and mineral soils can be applied (Table 4.11).

TABLE 4.11 SOIL CARBON STOCKS FOR MANGROVE, TIDAL MARSH AND SEAGRASS MEADOWS FOR EXTRACTION ACTIVITIES

ORGANIC SOILS (TONNES C HA^{-1})				
Vegetation type	**SO_{BEFORE}**	**95% CI[1]**	**range**	**n**
Mangrove	471[2]	436, 510	216 – 935	43
Tidal marsh	340[3]	315, 366	221 – 579	35
Seagrass meadow	NA[4]			
MINERAL SOILS (TONNES C HA^{-1})				
Vegetation type	**SO_{BEFORE}**	**95% CI[1]**	**range**	**n**
Mangrove	286[5]	247, 330	55 - 1376	77
Tidal marshes	226[6]	202, 252	15.6 – 623	82
Seagrass meadow[8]	108[7]	84,139	9.1 – 829	89
AGGREGATED ORGANIC AND MINERAL SOILS (TONNES C HA^{-1})				
Vegetation type	**SO_{BEFORE}**	**95% CI[1]**	**range**	**n**
Mangrove	386	351,424	55 - 1376	119
Tidal marsh	255	254,297	15.6-623	117

[1] 95%CI of the geometric mean

[2] Adame et al., 2012, Breithaupt et al. 2012, Chmura et al. 2003, Donato et al. 2011, Kauffman et al. 2011, Osborne et al. 2011, Vegas-Vilarrúbia et al. 2010 .

[3] Anisfeld et al. 1999, Callaway et al. 1996, Callaway et al. 2012, Chmura & Hung 2004, Craft et al. 1988, Craft 2007, Hussein et al. 2004, Kearney & Stevenson 1991, Orson et al. 1998, Markewich et al. 1998, McCaffrey & Thomson 1980.

[4] Seagrass meadows assumed to be on mineral soils.

[5] Donato et al. 2011, Chmura et al. 2003, Breithaupt et al. 2012, Fujimoto et al. 1999, Adame et al. 2012, Perry & Mendelssohn 2009, Ren et al. 2010, Kauffman et al. 2011, Ray et al. 2011, Zhang et al. 2012, Khan et al. 2007, Matsui 1998.

[6] Cahoon et al. 1996, Callaway et al. 2012, Chmura & Hung 2004, Connor et al. 2001, Craft et al. 1988, Craft 2007, Hatton 1981, Kearney & Stevenson 1991, Livesley & Andrusiak 2012, Loomis & Craft 2010, Morris & Jensen 2003, Oenema & DeLaune 1988, Patrick & DeLaune 1990, Roman et al. 1997, Yu & Chmura 2009.

[7] Fourqurean et al., 2012

[8] For Extraction only

Tier 2

Tier 2 includes the use of country specific emission factors that can be applied to disaggregate by soil type and vegetation type to improve on Tier 1 estimates that were calculated using a generic default value. Country-specific data may include incorporation of excavation depth to improve estimation of soil extracted.

Tier 3

A Tier 3 approach could use models that take into account the time-dependent nature of the CO_2 fluxes over a range of timescales. For example, during the construction phase a pulse of CO_2 efflux from soil directly after mangrove clearing and prior to excavation, followed by a logarithmic decline in CO_2 fluxes over time has been shown to occur (Lovelock et al., 2011). For fish and shrimp ponds, the actual area excavated and the depth to which soil is excavated, could be taken into account as this varies with aquaculture and salt production practices.

CHOICE OF ACTIVITY DATA

Choice of activity data follows from guidance above provided in Section 4.2.2.1 as the area in which the extraction activities occur will be the same area applied for each C pool.

UNCERTAINTY ASSESSMENT

Variability in soil C stocks will derive from a number of sources. The soil stock represents global averages and may therefore under or over-estimate emissions and removals when applied to specific countries. Deriving country-specific C stocks can reduce uncertainties using Tier 2 methodology. There may also be significant within country differences due to: (1) the dominant species present in mangrove, tidal marsh or seagrass meadows, (2) climatic conditions and (3) general environmental setting in which the vegetation is found, all of which may influence the C stock. When deriving global emission factors, uncertainties can also be introduced by areas where there is greater prevalence of data from specific regions of the globe. The change in C stock on extraction is dependent on the value assigned to the percent refractory organic carbon. The value applied is taken from soil in mangrove and may not be fully representative of the value for tidal marsh and seagrass meadows.

4.2.3 Rewetting, revegetation[3] and creation of mangroves, tidal marshes and seagrass meadows

This section addresses the C stock changes and CO_2 emissions and removals for the rewetting, revegetation and creation activities relating to mangroves, tidal marshes and seagrass meadows.

The rewetting and revegetation activity refers collectively to the following (1) rewetting, which saturates the soil of drained sites previously colonised by mangrove and tidal marshes and is a prerequisite for, and thus facilitates, reestablishment of the original vegetation by natural recolonisation, direct seeding and/or purposeful planting, (2) raising or lowering the soil elevation to facilitate reestablishment of the original vegetation by natural recolonisation, direct seeding and/or purposeful planting, (3) creation of coastal wetlands where it may be difficult to identify where they previously occurred and are in proximity to the coastal margin, and (4) reestablishment of seagrass on undrained soils by natural recolonisation, direct seeding and/or purposeful planting.

4.2.3.1 BIOMASS

The initiation of soil C accumulation is only possible with the presence of vegetation, which is introduced by purposeful seeding/planting or natural recolonisation For mangroves, methodological guidance for estimating carbon stock changes in the biomass pool, including choice of method and choice of emission and removal factors, follows Section 4.2.1.1 of this Chapter. For tidal marshes and seagrasses, changes in biomass carbon stocks, are reported only for Tier 2 or higher estimations. Guidance for estimating biomass C stock changes for tidal marshes and seagrass meadows follow those presented in Volume 4, Section 6.2.1.1 of the *2006 IPCC Guidelines* (Grassland Remaining Grassland) for Gain-Loss and Stock-Difference methods. These are used with country-specific data on above-ground biomass stocks and above-ground-below-ground (R) ratio provided in Tables 4.9 and 4.10. Refer to Volume 4, Section 6.2.1.4 of the *2006 IPCC Guidelines* for calculation steps useful in applying these methods.

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[3] The term revegetation is used to refer to practices within the framework of UNFCCC reporting.

4.2.3.2 DEAD ORGANIC MATTER

For mangroves, methodological guidance for estimating carbon stock changes in the dead organic matter pool, including choice of method and choice of emission and removal factors, follows Section 4.2.1.2 of this Chapter. For tidal marshes and seagrasses, changes in biomass carbon stocks, are reported only for Tier 2 or higher estimations. Guidance for estimating dead organic matter C stock changes for tidal marshes and seagrass meadows follow those presented in Volume 4, Section 6.2.2.1 of the *2006 IPCC Guidelines* (Grassland Remaining Grassland) for Gain-Loss and Stock-Difference methods. These are used with country-specific data. Refer to Volume 4, Section 6.2.2.4 of the *2006 IPCC Guidelines* for calculation steps useful in applying these methods.

4.2.3.3 SOIL CARBON

The guidance provided in this section on soils differs from that in Chapter 3 (this supplement) because, on coastal wetland soils, revegetation leads to the accumulation of soil organic carbon when vegetation is reestablished and a CO_2 sink is then developed. The CO_2 emission factor is approximated as zero when resaturated soils are devoid of vegetation. This is consistent with the default EFs for rewetted soils for temperate and tropical regions (but not the boreal region) presented in Chapter 3 of this supplement. Based on information for natural fluxes from rewetted organic soils, it is consistent with data illustrating that rewetting effectively stops soil organic matter oxidation but does not necessarily reestablish the soil C sink function.

Guidance for inventories of rewetting and revegetation activities of coastal wetlands follows the assumptions at Tier 1 level of estimation that:

i. upon rewetting and revegetation of previously drained soil, creation of a mangrove or tidal marsh or on establishment of a seagrass meadow, soil C accumulation is initiated when natural vegetation becomes established.

ii. the rate of soil C accumulation is instantaneously equivalent to that in natural settings.

Craft et al., (2003) found that (a) soil C accumulation, developed almost instantaneously with the establishment of vegetation along a chronosequence of 1- to 28-yr old constructed marshes and (b) a similar soil C accumulation rate over 10 years in a natural and created marsh (Craft et al., 2002) and over 20 years in a created mangrove (Osland et al., 2012). Given this equivalence, estimates of soil carbon accumulation rates in mangroves, tidal marshes and seagrass meadows (Chmura et al., 2003, Breithaupt et al., 2012, Duarte et al., 2013) make it possible to quantify C gains at sites characterised by rewetting and revegetation activities. A transition time for soil C stocks to become equivalent to those in natural/undrained settings with vegetation (Table 4.11) will exceed the default land-use transition time of the typically used land-use category conversions (i.e. 20 years). Instead it is suggested to apply the EF for soil C accumulation as long as the soil remains rewtted and vegetated, until such time as stocks are equivalent to soil C stocks in natural/undrained settings with vegetation (Table 4.11) or there is a change in management practice.

CHOICE OF METHOD

Changes in soil carbon resulting from rewetting, revegetation and creation activities for mangroves, tidal marshes and seagrass meadows are estimated because they represent potentially large C removals from the atmosphere.

Tier 1

At Tier 1, the default method, EF_{RE} values are to be used in conjunction with Equation 4.7 to estimate CO_2 emissions.

EQUATION 4.7

CO_2 EMISSIONS FROM REWETTING, REVEGETATION AND CREATION OF COASTAL WETLANDS

$$CO_{2SO-RE} = \sum_{,v,s,c}(A_{RE} * EF_{RE})_{v,s,c}$$

where,

CO_{2SO-RE} = CO_2 emissions associated with rewetting,revegetation and creation activities by vegetation type (v), soil type(s) and climate (c); tonnes C yr^{-1}

$A_{RE}{}^{1}$ = Area of soil that has been influenced by rewetting,revegetation and creation activities by vegetation type (v), soil type(s) and climate (c); ha

EF_{RE}^{1} = CO_2 emissions from aggregated mineral and organic soils that have been influenced by rewetting and revegetation activities by vegetation type (v), soil type (s) and climate (c); tonnes C ha^{-1} yr^{-1}

[1] $EF_{RE} = 0$ for rewetted and naturally saturated soils where no vegetation has been re-estabished or where re-establishment is expected to occur by recolonization.

At Tier 1, EF_{RE} is applied (Table 4.12) when vegetation has been established through replanting or reseeding. If, however, re-establishment of vegetation is expected to occur by recolonization, a Tier 1$EF_{RE} = 0$ is applied. It is *good practice* to document the basis on which the EF_{RE} is applied. When vegetation has been established the EF_{RE} is disaggregated with respect to vegetation type. Organic and mineral soils are not differentiated at Tier 1 within any particular vegetation type, as the organic C inputs mainly derive from the production of above-ground and below-ground biomass under similar conditions of soil saturation. Land area estimates should be based on land classification within the new land category (if applicable) to apply Tier 1 EF_{RE}.

Tier 2

Under the Tier 2 method, country specific C accumulation rates could be dissagregated with respect to area of organic and mineral soils. Where such country-specific data can be acquired and used to improve estimations, disaggregation by climate zone could also be applied.

Tier 3

Under the Tier 3 method, the land use prior to rewetting, its climate and vegetation type could be taken into account. A comprehensive understanding and representation of the dynamics of CO_2 gas emission factors, based on field measurements (such as C-content, bulk density, clay content, salinity, redox) could be employed at Tier 3. A Tier 3 approach could also use empirical measurements and models that take into account the time-dependent nature of the CO_2 fluxes over a range of timescales (Morris et al., 2012), location relative to the low to high intertidal zone (Alongi 2010) or other dynamics (Craft 2007).

CHOICE OF EMISSION/REMOVAL FACTORS

Tier 1

The choice of EFs at Tier 1 is applied based on the coastal wetland vegetation type being established through the rewetting, revegetation or creation activity. It is assumed that within each vegetation type, CO_2 emissions are the same regardless of how the suitable conditions for revegetation are facilitated. If vegetation is reestablished through direct reseeding or purposeful planting, apply EF_{RE} in Table 4.12. If the rewetting, revegetation or creation activity is associated with recolonization (no direct replanting or reseeding), apply $EF_{RE} = 0$. It is *good practice* to evaluate and document these activities (See Choice of Activity Data below) and modify what EF is applied, as appropriate. If the rewetting and revegetation activity results in patchy or patches of biomass (if coverage data are available), $EF_{RE} > 0$ should only be applied when the mangrove, tidal marsh plant or seagrass canopy covers at least 10% of the overall area. This consideration follows the definition of forest (Table 4.2, Chapter 4, Volume 4, *2006 IPCC Guidelines).*

TABLE 4.12 ANNUAL EMISSION FACTORS ASSOCIATED WITH REWETTING (EF_{RE}) ON AGGREGATED ORGANIC AND MINERAL SOILS (TONNES C HA^{-1} YR^{-1}) AT INITIATION OF VEGETATION REESTABLISHMENT

Ecosystem	EF_{REWET}^{1}	95% CI[5]		range	n
Mangrove	-1.62^{2}	1.3	2.0	0.10 – 10.2	69
Tidal marsh	-0.91^{2}	0.7	1.1	0.05 – 4.65	66
Seagrass meadow	-0.43^{4}	0.2	0.7	0.09 – 1.12	6

[1] Negative values indicate removal of C.

[2] Breithaupt et al. 2012, Chmura et al. 2003, Fujimoto et al. 1999, Ren et al. 2010.

[3] Anisfeld et al 1999, Cahoon et al. 1996, Callaway et al 1996, Callaway et al 1997, Callaway et al 1998, Callaway et al 1999, Callaway et al. 2012, Chmura & Hung 2003, Hatton 1981, Craft 2007, Kearney & Stevenson 1991, Markewich et al. 1998, Oenema & DeLaune 1988, Orson et al 1998, Patrick & DeLaune 1990, Roman et al 1997.

[4] Mateo & Romero 1997, Serrano et al. 2012

[5] 95% CI of the geometric mean

Tier 2

In a Tier 2 approach, country-specific emission factors for the rewetting, revegetation or creation activities could be applied and the assumption of EF_{RE}=0 in areas where vegetation had not been established could also be reassessed. Country-specific emission factors could be applied based on disaggregation of organic and mineral soils and climate.

Tier 3

In a Tier 3 approach, field measurement of soil organic carbon content and CO_2 emissions from areas where rewetting and revegetation activities occur could be used to develop an empirical relationship (for example, a simple regression equation) that can be used across other sites where rewetting and revegetation activities occur within a particular area or country. Country-specific values can be developed to model possible time-dependent changes in CO_2 emissions. Soil C accumulation rates will likely change, as vegetation grows and biomass matures. Increased inundation and soil saturation, as a result of intertidal location in tidal marshes and mangroves, will accelerate development of soil characteristics of revegetated soils. Thus, rates of CO_2 emissions in these tidal wetlands will vary in relation to a combination of these factors and consideration of them would result in more accurate estimation of CO_2 emissions.

CHOICE OF ACTIVITY DATA

Historical photos and coastal wetland maps, if available at the appropriate spatial resolution, may be used to estimate the pre-restored wetland area. Information on regional wetland restoration and creation projects worldwide can be obtained from the Global Gateway to Geographic Information Systems of the FAO (www.fao.org) as well as from the websites, www.wetlands.org and www.globalrestorationnetwork.org. Within a given country, government agencies responsible for issuance of permits for restoration/creation/alteration of wetland are to be consulted for information of area data on the wetlands being considered. In addition, many countries may have a process for reporting rewetting and revegetation activities as permission is often required. For example, in Australia, the Environmental Protection Agency in Western Australia approves revegetation projects as part of their Ministerial Conditions. The Australian Government Department of Sustainability, Environment, Water, Population and Communities also directs the Federal Minister to approve or reject revegetation programs. The establishment of vegetation and/or change in areal extent can be reviewed on a five year period and assessed for accurate implementation of the appropriate soil EF. If data are lacking, expert judgement about success rates of projects implemented under similar conditions could be used for intital assessments (examples are size of project, vegetation type, tidal range, proximity to coast, climate). In general, for rewetting activities that include purposeful planting or direct reseeding, an EF_{RE} (using Table 4.12) is appropriate for Tier 1 estimation. Information on which the choice in EF is based should be documented.

UNCERTAINTY ASSESSMENT

Uncertainties in estimating CO_2 emissions and removals from rewetting, revegetation and creation of mangroves, tidal marshes and seagrass meadows largely lie in the underlying assumptions and area to which the EFs are applied. The EF_{REWET} in Table 4.12 represent global averages and have large uncertainties associated with their value due to variability in soil C accumulation rate with 1) depth of the intertidal zone, 2) the dominant species type, its morphology and rate of growth, 3) climate. The underlying assumption of EF_{RE}=0 for rewetted/saturated soils where vegetation has not been re-established may introduce uncertainty into estimates. Also, the assumption of complete areas with or without vegetation cover could introduce under- or overestimates.

4.2.4 Drainage in mangroves and tidal marshes

This section addresses the changes in C stock and CO_2 emissions and removals for drainage in mangroves and tidal marshes. Drainage may be accompanied by land clearing, also resulting in changes in biomass and dead organic matter pools. If burning accompanies drainage, it is good practice to report emissions from changes in those C pools. For methods to estimate changes in carbon stock in biomass, and for default data, refer to Section 4.2.1 of this report for guidance on mangroves and Section 4.2.2 for guidance on tidal marshes. It is important to retain information about drained coastal wetlands so that guidance in this supplement can be applied if a reversal of drainage conditions occurs.

Drainage causes soils to dry and ordinarily increases rates of organic matter decomposition, resulting in loss of soil carbon via CO_2 release (Armentano and Menges 1986). This response varies with climate (Pozo and Colino 1992) and locally with soil salinity and texture, and the quantity of labile organic matter available (Setia et al., 2011). Activities associated with extensive lowering of the water table are often linked to the construction of drainage channels leading to CO_2fluxes due to oxidation of DOC and POC in the water carried by drainage channels. However, there is currently not enough information to provide emission factors for DOC and POC export (see Appendix 4a.1 on Future methodological development).

4.2.4.1 BIOMASS

Methodological guidance for estimating carbon stock changes in the biomass pool, including choice of method and choice of emission and removal factors, follows Section 4.2.3.1 of this Chapter. For tidal marshes, increase in biomass stocks in a single year is assumed equal to biomass losses from mortality in that same year at Tier 1.

4.2.4.2 DEAD ORGANIC MATTER

Methodological guidance for estimating carbon stock changes in the dead organic matter pool, including choice of method and choice of emission and removal factors, follows Section 4.2.3.2 of this Chapter. For tidal marshes, the CO_2 emissions and removals from change in biomass and dead organic matter pools is reported as zero at Tier 1.

4.2.4.3 SOIL CARBON

Annual C losses from drained mineral and organic soils are applied similarly for mangroves and tidal marshes (note: not applicable to seagrass meadows) at Tier 1 level of estimation (Table 4.14). Data on CO_2 emissions from drainage in mangroves is limited, however, the CO_2 emission rate from drainage in tidal marshes was considered to provide an appropriate Tier 1 default emission factor. This value is also consistent with drained forest default EF presented in Chapter 2 of this supplement.

CHOICE OF METHOD

Tier 1

Guidance for inventories on drainage in coastal wetlands follows the assumptions at Tier 1 level of estimation that:

i. emissions persist as long as the soil remains drained or as long as it takes for soil C stocks equivalent to those in natural/undrained settings with vegetation (Table 4.11) to be oxidised

ii. the drainage condition is characterized by full drainage (i.e. the water table has been changed to 1 m below the soil surface for organic and mineral soils), consistent with the Tier 1 approach in Chapter 2, this supplement.

Emissions from drained coastal wetland soils are estimated at Tier 1 for mangrove forests and tidal marshes are estimated using Equation 4.8.

EQUATION 4.8

CO_2 EMISSIONS ON DRAINED ORGANIC AND MINERAL SOILS

$$CO_{2-SO-DR} = (A_{DR} \bullet EF_{DR})$$

where:

$CO_{2-SO-DR}$ = CO_2 emissions from aggregated organic and mineral soil C associated with drainage; tonnes C yr^{-1}

A_{DR} = land area under drainage; ha

$EF_{DR,}$ = CO_2 emissions from organic or mineral soil C associated with drainage; tonnes C ha^{-1} yr^{-1}

As described above, the Tier 1 emission factor is applied until the soil C stock (Table 4.11) is depleted which determines the time frame for emissions due to drainage regardless of whether a land-use change occurs. Once depleted, guidance from the 2006 IPCC Guidelines applies.

Tier 2

The Tier 2 estimation method is the same as the Tier 1 method, but national data can be used to additionally disaggregate by vegetation, soil type and regional climatic factors, if such data are available at reasonable cost.

Tier 3

Tier 3 methods could take account of differences in the management of the drained wetland. Empirical measurements of gas flux based on site-specific measurements of e.g. C-content, bulk density, clay content, salinity, redox etc. to determine the underlying processes of emissions could be included. Site differences in frequency of drainage activity could also be considered at Tier 3 methods. Other factors that could be used to apply disaggregated data include salinity and tidal export of DOC and POC (Appendix 4a.1).

CHOICE OF EMISSION/REMOVAL FACTORS

Tier 1

At Tier 1, a generic default emission factor is applied for drainage, regardless of vegetation or soil type (Table 4.13). That is, the same EF is applied regardless of the management activity involving soil drainage.

TABLE 4.13 ANNUAL EMISSION FACTORS ASSOCIATED WITH DRAINAGE (EF_{DR}) ON AGGREGATED ORGANIC AND MINERAL SOILS (TONNES C HA^{-1} YR^{-1})

Ecosystem	EF_{DR}	95% CI	Range	N
Tidal marshes and mangroves	7.9[1]	5.2, 11.8	1.2 – 43.9	22

[1] Camporese et al. (2008), Deverel & Leighton (2010), Hatala et al. (2012), Howe et al. (2009), Rojstaczer & Deverel (1993)

[2] 95%CI of the geometric mean

Tier 2

Tier 2 emission factors apply country-specific data disaggregated by soil type, vegetation type, and climate, where feasible. Data to address any change in emissions since initiation of drainage could additionally be implemented.

Tier 3

In a Tier 3 approach, field measurements of soil organic carbon content and CO_2 emissions from the drained site would be useful to develop an empirical relationship (for example, a simple regression equation of soil carbon content versus rate of carbon removal) that can be used across other drained sites within a particular area or country. Country-specific values can thus be developed to model possible time-dependent changes in CO_2 emissions such as changes in relation to timing and rate of soil drainage, depth of drainage and additional national information about mean annual water table and land-use type or intensity. A comprehensive understanding and representation of the dynamics of CO_2 gas emission factors, based on field measurements (such as C-content, bulk density, clay content, salinity, redox) could be employed at Tier 3.

CHOICE OF ACTIVITY DATA

Tier 1

The Tier 1 approach requires area data of drained land for each land-use category that have been identified in coastal wetlands. Classification systems for activity data that form the basis for a Tier 1 inventory are provided in the respective land-use Chapters of the *2006 IPCC Guidelines*. For coastal wetlands, the predominant land-use category conversion is to Cropland and Grassland.

Tier 2 and 3

Activity data for higher tier estimates are generally derived following the methods presented in Chapter 3 of the *2006 IPCC Guidelines.* To disaggregate by soil type and vegetation type, several institutions, including ISRIC and FAO have country-specific and global maps that include organic soils (http://www.fao.org/geonetwork/srv/en/main.home or http://www.isric.org/). A global consortium has been formed to make a new digital soil map of the world at fine resolution (http://www.globalsoilmap.net/). Other activity data for

Drainage is assumed to result in persistent emissions from soils as long as the management system remains in place. Activity data may be spatially explicit and could be disaggregated by type of management, if appropriate emissions factors are available.

The combination of land-use databases and soil maps or spatially explicit data allow delineation of combinations of land-use categories, climate domains, and management systems and their changes over time on organic soils.

Information sources about drainage with adequate disaggregation may include:

- National land-use statistics, land-use maps and soil maps, maps of water and nature conservation zones with restrictions for water management, wetlands.
- National water management statistics: in most countries, the agricultural land base including Croplands is usually surveyed regularly, providing data on distribution of different land-uses and other aspects of management, often at sub-national regional level. These statistics may originate, in part, from remote sensing methods, from which additional information about wetness or periods with seasonal flooding could be extracted.
- Inventory data from a statistically based, plot-sampling system of water table wells, ditches and surface waters on organic soils: water table is monitored at specific permanent sample plots either continuously or on plots that are revisited on a regular basis. It has to be documented that the water data represent the water table in the organic soil and for what land-use and drainage stratum and that the data cover a representative period, which represents a multi-year mean annual water table.
- Water management plans and documentation from water management installations.
- Drainage maps.

UNCERTAINTY ASSESSMENT

Three broad sources of uncertainty exist in estimating emissions and removals from drainage: 1) uncertainties in land-use and environmental data; 2) uncertainties in the emission/removal factors for Tier 1 or 2 approaches; and 3) model structure/parameter error for Tier 3 model-based approaches, or measurement error/sampling variability associated with Tier 3 measurement-based inventories. In general, precision of an inventory is increased and confidence ranges are smaller with more sampling to estimate values for these categories, while accuracy is more likely to be increased through implementation of higher Tier methods that incorporate country-specific information.

For Tier 1, the default uncertainty level of emissions/removal factors is the 95% confidence interval in Table 4.13. Countries developing specific emission factors for their inventories at higher tiers should assess the uncertainty of these factors.

If using aggregate land-use area statistics for activity data (e.g., FAO data), the inventory agency may have to apply a default level of uncertainty for the land area estimates, for example. It is *good practice* for the inventory compiler to derive uncertainties from country-specific activity data instead of using a default level of uncertainty. Uncertainties in activity data may be reduced through a better national system, such as developing or extending a ground-based survey with additional sample locations and/or incorporating remote sensing to provide additional coverage. Uncertainties in activity data and emission/removal factors need to be combined using an appropriate method, such as simple error propagation equations. Details are given in Chapter 3, Volume 1 of the *2006 IPCC Guidelines* and in Chapter 5 of the *GPG-LULUCF*.

4.3 NON-CO_2 EMISSIONS

This section provides methods for estimating the emissions of CH_4 emissions from rewetted mangroves and tidal marshes and N_2O from aquaculture.

4.3.1 CH_4 emissions from rewetted soils and created mangrove and tidal marsh

Rewetting of drained soils, through reconnection of hydrology, shifts microbial decomposition from aerobic to anaerobic conditions, increasing the potential for CH_4 emissions (Harris et al 2010). In environments where low salinity also occurs (especially <5 ppt), microbial decomposition of organic matter may result in production of CH_4. However, in soils saturated with seawater, microbial reduction of sulfate to sulfide will generally occur before methanogens produce CH_4 regardless of the organic matter content. A strong inverse relationship between CH_4 emissions and salinity of mangrove soils exists (Purvaja & Ramesh, 2001). A review by Poffenbarger et al. (2011) showed that CH_4 emissions decrease as salinity in tidal marshes increases.

Guidance for estimating CH_4 emissions associated with rewetting land previously characterised by mangrove and tidal marsh vegetation differs from that for estimation of CO_2 emissions in that, at Tier 1 level of estimation, the EF remains the same for CH_4, regardless of extant vegetation.

4.3.1.1 CHOICE OF METHOD

Tier 1

In the case of rewetting of lands that had been previously been in agricultural (or any other drained) land-use category, the Tier 1 method estimates CH_4 emissions without considering the land-use prior to rewetting.

EQUATION 4.9

CH_4 EMISSIONS FROM REWETTED SOILS AND CREATED TIDAL MARSHES AND MANGROVES

$$CH_{4SO\text{-}REWET} = \Sigma_v (A_{REWET} * EF_{REWET})_v$$

where,

$CH_{4SO\text{-}REWET}$ = CH_4 emissions associated with rewetted and created coastal wetlands by vegetation type (v) kg CH_4 yr^{-1}

A_{REWET} = Area of soil that has been rewetted (including tidal marsh or mangrove wetland creation), by vegetation type (v); ha

EF_{REWET} = CH_4 emissions from mineral and organic soils that have been rewetted by vegetation type (v); kg CH_4 ha^{-1} yr^{-1}

Tier 2

At Tier 2, country-specific data can be applied. Improved estimates can be produced if country-specific data could include more disaggregation by salinity and vegetation type.

Tier 3

At Tier 3, country-specific values can be used and developed to model possible time-dependent changes in CH_4 emissions. Tier 3 methods may also consider vegetation composition and density, as plants can act as a conduit for gas exchange between the soil and atmosphere (e.g. Burdick 1989, Purrvaja and Ramesh 2001, Kristensen et al., 2008).

4.3.1.2 CHOICE OF EMISSION FACTORS

Tier 1

The Tier 1 CH_4, emission factors are found in Table 4.14 and should be used in conjunction with Equation 4.9 to estimate emissions taking into account vegetation type (and associated salinity level). The choice of emission factor at Tier 1 is based on the difference between rewetting by freshwater and brackish water (<18ppt) and saline waters (>18ppt,Annex 4.1. Rates of CH_4 emissions approximating 0 in saline water marshes and mangroves but are greater than zero in freshwater tidal and brackish marshes and mangroves (Table 4.14). For rewetting that results in salinities >18 ppt), the Tier 1 assumption is to apply an annual CH_4 emission rate = 0. Within each vegetation type, CH_4 emissions are the same regardless of the management activity involving rewetting at Tier 1.

TABLE 4.14 EMISSION FACTORS FOR CH_4 (EF_{REWET}) FOR TIER 1 ESTIMATION OF REWETTED LAND PREVIOUSLY VEGETATED BY TIDAL MARSHES AND MANGROVES

Vegetation Type	Salinity (ppt)	EF_{rewet} (kg CH_4 ha^{-1} y^{-1})	EF_{rewet} Range (kg CH_4 ha^{-1} y^{-1})	95%CI[4]
Tidal freshwater and brackish marsh and mangrove[1]	<18	193.7[2]	10.95 – 5392	99.8, 358
Tidal saline water marsh and mangrove[1]	>18	0[3]	0-40	

[1] Annex 4A.1

[2] Keller et al., 2013; Ma et al., 2012; Poffenbarger et al., 2011; Sotomayor et al., 1994; Tong et al., 2010.

[3] Marshes and mangroves with salinities >1 ppt approximate an order of magnitude lower rates than from tidal freshwater rand brackish marsh (as defined here salinity <18ppt), so a tier 1 assumption is to apply 0.

[4] 95%CI of the geometric mean.

Tier 2

In a Tier 2 approach, country-specific CH_4 emissions are encouraged to be used and will provide better estimates based on the salinity of water used to rewet the mangrove or tidal marsh, particularly to determine CH_4 emissions from tidal brackish marshes.

Tier 3

In a Tier 3 approach, field measurements of soil salinity and CH_4 emissions from the rewetted site could be used to develop an empirical relationship (for example, a simple regression equation of salinity versus rate of methane emission) and applied across other rewetted sites within a particular area or country. Country-specific values can thus be developed to model possible time-dependent changes in CH_4 emissions such as changes in relation to frequency of tidal inundation, frequency of the rewetting activity and elevation from the water's edge. Such considerations would result in more accurate estimation of CH_4 emissions.

4.3.1.3 CHOICE OF ACTIVITY DATA

To estimate emissions using CH_4 emission factors refer, in part, to the guidance for rewetting in section 4.2.3 above. The EF should be applied to the specific type of vegetation that will be reestablished, which is associated with salinity. When salinity data are not available the type and location of rewetting may be used as a proxy for salinity. For example, breaching of sea walls and rewetting in an estuarine setting will result in rewetting with saline waters. If rewetting occurs with freshwatera salinity of <18ppt is likely. When applying guidance for tidal freshwater marsh, it is *good practice* to determine the inland boundary for rewetting of tidal freshwater wetlands as based on national circumstances, and to consistently apply these conditions to identifying these rewetted lands. If more information is available on salinity concentrations associated with the area being rewetted, better estimates of CH_4 emissions can be determined. Information used for these assessments should be documented.

4.3.1.4 UNCERTAINTY ASSESSMENT

There have been few empirical measurements upon which to base emission factors disaggregated by factors such as temperature, tidal frequency or duration of inundation which introduce uncertainty in global default emission factors. However, higher tier approaches can take these factors into account to improve estimations. Few reports are available to give specifics of the types of rewetting activities that may vary geographically. Because activity data may be limited in terms of delineating salinity boundaries to apply more constrained CH_4 emission factors, aggregation of data to produce Tier 1 emission factors was based upon expert knowledge. There is also uncertainty in the time, depth of soil affected, and the contribution of vegetation to rate of CH_4 loss.

4.3.2 N_2O emissions during aquaculture use in mangroves, tidal marshes and seagrass meadows

The most significant activity contributing to N_2O emissions from managed coastal wetlands is aquaculture. One-third of global anthropogenic N_2O emissions are from aquatic ecosystems, and nearly 6% of anthropogenic $N_2O{-}N$ emission is anticipated to result from aquaculture by 2030 at its current annual rate of growth (Hu et al., 2012). Shrimp and fish cultivation increases nutrient loads in culture ponds. As opposed to indirect N_2O emissions originating from activities on terrestrial lands or as wastewater treatment, coastal wetland aquaculture occurs as a direct source of N_2O from coastal wetlands, including mangroves and tidal marshes from aquaculture pond use. In seagrass meadows, this direct N_2O source arises from N added to fish cages (eg. off-shore installations). While this differentiation should assure no double-counting, it is *good practice* to evaluate this assessment considering national circumstances. As such, this new activity fills a gap in the current reporting on direct and indirect sources of N_2O emissions. A country can exclude N_2O emissions from estimation thatoccur during aquaculture activities where no mangroves, tidal marsh or seagrass meadows exist (i.e. out coastal wetland areas).

N_2O is emitted as a by-product of the conversion of ammonia (contained in fish urea) to nitrate through nitrification and nitrate to N_2 gas through denitrification (Hu et al., 2012). N_2O emissions can readily be estimated from fish production data.

4.3.2.1 CHOICE OF METHOD

TIER 1

N_2O emissions from aquaculture ponds can be estimated based on fish/shrimp production of the aquaculture activity. N_2O emission estimation follows a modified form of Equation 11.1 from Chapter 11, Volume 4 of the *2006 IPCC Guidelines* and is presented here in (Equation 4.10).

EQUATION 4.10

DIRECT N_2O EMISSIONS FROM AQUACULTURE USE

$$N_2O\text{-}N_{AQ} = F_F * EF_F \text{ (based on fish production)}$$

where:

$N_2O\text{-}N_{AQ}$ = annual direct N_2O-N emissions from aquaculture use, kg N_2O-N yr^{-1}

F_F = annual fish production, kg fish yr^{-1}

EF_F = emission factor for N_2O emissions from fish produced, kg N_2O-N (kg fish produced)$^{-1}$

TIER 2

Tier 2 estimation methodology follows that of Tier 1 with the added information provided by country-specific data.

TIER 3

Tier 3 estimation methodology could include the consideration of fish/shrimp type, type of feed and stocking density, category of aquaculture (fish/shrimp species or feed stuff), aquaculture use intensity, and impact of environmental factors e.g. climate zone, season, and salinity.

4.3.2.2 CHOICE OF EMISSION FACTORS

TIER 1

Hu et al. (2012) used the relationship between in-coming nitrogen loads and N_2O emissions from waste-water plants to estimate that 1.8% of the is emitted as N_2O (0.00169 kg N_2O-N is emitted per kg fish produced). The EF_F is applied during the, in use, phase of aquaculture (Table 4.15). In the construction and discontinued phases, non-CO_2 emissions are assumed negligible, EF=0. At Tier 1, countries could consider applying this EF to other species groups under aquaculture production. Because the EF is developed for fish, application may introduce additional uncertainty.

TABLE 4.15 EMISSION FACTOR (EF_F) FOR N_2O EMISSION FROM AQUACULTURE USE IN MANGROVES, TIDAL MARSHES AND SEAGRASS MEADOWS

Default EF (kg N_2O-N per kg fish produced)	95% CI[1]	Reference
0.00169 kg N_2O-N per kg fish produced	0-0.0038	Hu et al., 2012

[1] 95%CI of the geometric mean.

Note: Approach used by Hu et al., 2012 using N in feed to fish biomass: Hargreaves 1998; Protein content of fish biomass: USDA nutrient database for Standard Reference Nutrient Data Laboratory; N content of protein: Nelson & Cox 2013; N to N_2O conversion: Hu et al., 2013, Kong et al., 2013, Kampschrew et al., 2008, Ahn et al., 2010 (refer to Annex 4A.5)

TIERS 2 AND 3

Under Tier 2 method, country specific emission factors for N_2O are applied. At Tier 2, these country-specific emission factors could incorporate a different value for the proportion of N emitted as N_2O as specified at Tier 1. For Tier 3 emission factors, comprehensive understanding and representation of the dynamics based on direct field measurements or models is involved, which estimates emission factors considering the category of aquaculture (fish/shrimp species or feed stuff), aquaculture use intensity, and impact of environmental factors e.g. climate zone, season, and salinity.

4.3.2.3 CHOICE OF ACTIVITY DATA

Data for fish and shrimp production are needed. These data can be obtained from FAO (http://www.fao.org/fishery/statistics/global-aquaculture-production/en). For additional guidance, see Section 4.2.1

4.3.2.4 UNCERTAINTY ASSESSMENT

Emission factors for N_2O emissions from aquaculture systems are based on protein content of fish, relationships between total nitrogen content and wet weight of fish and the percent of nitrogen load emitted as N_2O. There are no such data for shrimp production so using fish data as a proxy adds a high level of uncertainty. The fish-related factors can vary greatly, and in part on environmental conditions, so high variation can occur among fish aquaculture systems. Decreased uncertainty can be achieved at Tier 2 and 3 to reflect variability in N_2O emissions based on shrimp and fish species and type of food (pellets vs trash fish). Uncertainties in N_2O emissions associated with stocking of aquaculture facilities can be reduced greatly by better estimation of shrimp and fish production.

4.4 COMPLETENESS, TIME SERIES, CONSISTENCY, AND QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC)

4.4.1 Completeness

General guidance on completeness are provided by Chapter 7 of this supplement.

4.4.2 Time series consistency

It is good practice that countries clearly define coastal wetlands and use this definition consistently over time.

Consistent time series require that the same methodology is used for the entire time series. Whenever new methodologies are used previous estimates should be recalculated using the new methods for all years in the time series. It is also *good practice* to report why the new estimates are regarded as more accurate or less uncertain.

One potential problem in recalculating previous estimates is that certain data sets may not be available for the earlier years. There are several ways of overcoming this limitation and they are explained in detail in Chapter 5, Volume 1, of the *2006 IPCC Guidelines*. Time series consistency is discussed further in Chapter 7.6 of the *Wetlands Supplement* and Chapter 5, Volume 1, (Time series consistency and recalculations) of the *2006 IPCC Guidelines*.

4.4.3 Quality assurance/quality control (QA/QC)

Quality assurance/quality control (QA/QC) procedures should be developed and implemented as outlined in Chapter 7 of this supplement.

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Annex 4A.1 Salinity-based definitions

Common description	**Salinity (ppt)**[1]
Tidal fresh water	<0.5
Brackish water	0.5 - 18
Saline water	>18

[1] ppt is parts per thousand (‰) and is roughly equivalent to grams of salt per litre of water.

Annex 4A.2 Estimation of above-ground mangrove biomass: higher tier methodology

Because of field conditions and heavy weight of wood, an accurate survey of a mangrove forest is difficult and time-consuming. Allometric methods (Soares and Schaeffer-Novelli, 2005; Komiyama *et al.*, 2008) estimate the whole or partial weight of a tree from measurable tree dimensions, notably trunk diameter and height, using allometric relations developed from empirical measurement of weight of individual tree components (leaves, branches, stem). Use of allometric equations is favored because it is non-destructive and is therefore useful for estimating temporal changes in forest biomass by means of subsequent stem diameter measurements over subsequent years.

Up until recently, the major drawback of this method has been the site- and species-specific differences in allometric relations, necessitating the use of different allometric equations for different sites (e.g., Smith and Whelan, 2005) and, at a minimum, different species. However, a number of workers, using global datasets, have developed a common allometric equation applicable for all tropical tree species, with the most applicable equations for above-ground biomass being those developed for all tropical trees by Chave *et al.* (2005) and for all mangrove species by Komiyama et al. (2005):

$$W_{top} = 0.168 p \mathrm{DBH}^{2.47} \text{ (Chave \textit{et al.} 2005)}$$

$$W_{\mathrm{top}} = 0.251 p \mathrm{D}^{2.46} \text{ (Komiyama \textit{et al.} 2005)}$$

where W_{top} = above-ground tree weight in kg DW; D = tree diameter; DBH = diameter-at-breast height. The relative error of each equation varies among species, but is typically within the range of -10% to +10%. There are, of course, arguments to be made that empirical measurements should be made in all mangrove forests, considering the significant allometric differences between species and for the same species at different locations (Smith and Whelan, 2005; Soares and Schaeffler-Novelli, 2005). However, this idea is impractical for inventory compliers; a relative error of ± 10% is acceptable being within the range of error for allometric relations within a forest where biomass has been weighted.

Comparing the two equations, the Chave estimation gives lower above-ground weight estimates than that of the Komiyama equation. Presuming that a complete census of all trees, with species identified, and their diameter have been undertaken from replicate plots within a given forest, these numbers can then be used in either equation to derive individual tree weight.

Annex 4A.3 Wood density of mangrove species

Species	**n**	**Average density (tonnes m^{-3})**	**Standard error**
Brugueria gymnorrhiza	8	0.81	0.07
Xylocarpus granatum	7	0.61	0.04
Sonneratia apetala	2	0.50	0.01
Sonneratia alba	6	0.47	0.12
Rhizophora mucronata	9	0.83	0.05
Rhizophora mangle	7	0.87	0.02
Rhizophora apiculata	4	0.87	0.06
Laguncularia racemosa	3	0.60	0.01
Heritiera littoralis	6	0.84	0.05
Heritiera fomes	3	0.86	0.14
Excoecaria agallocha	7	0.41	0.02
Ceriops tagal	7	0.85	0.04
Ceriops decandra	2	0.87	0.10
Avicennia officinalis	3	0.63	0.02
Avicennia marina	6	0.62	0.06
Avicennia germinans	5	0.72	0.04
Average		**0.71**	**0.02**
Source: Global Wood Density Database http://datadryad.org/resource/doi:10.5061/dryad.234/1?show=full; Saenger, 2002; Komiyama *et al.,* 2005; Donato *et al.,* 2012			

Annex 4A.4 Percent refractory carbon

Percent refractory carbon in organic/mineral soils were estimated for mangrove soils based on either the amount of phenolic compounds/lignins in soils or % TOC in mangrove soils deeper than 1 m if there was no further decline in TOC concentration.

PERCENT REFRACTORY CARBON APPLIED TO ESTIMATE % C OXIDATION FOR MANGROVE SOILS (% BY SOIL DRY WEIGHT)	
Mean	3.98
Median	3.4
N	16
Prasad and Ramanathan, 2009; Marchand *et al*. 2003; Dittmar and Lara, 2001; Koch *et al.,* 2011; Ranjan *et al.,* 2010; Marchand *et al.,* 2005), which is similar to that in tidal marshes (Filip *et al*. 1988; Alberts *et al*., 1988; Reddy and DeLaune 2008)	

Annex 4A.5 Derivation of N_2O emission factor for aquaculture

The emission factor of 0.00169 kg N_20-N per kg fish produced in Table 4.15 is based on the following. Firstly, the protein content of fish is estimated from 80 values in various cultured fish species as 17.72 ± 2.97% (USDA nutrient database for Standard Reference Nutrient Data Laboratory). Using the protein content of fish and the average N content of protein (16%; Nelson and Cox, 2013) implies an N content of 2.84 ± 1.33% of fish biomass; i.e. one metric tonne of fish contains 2.84 x 10^4 g N. Secondly, the % N in aquaculture fish feed that is incorporated into fish biomass averages 23.22 ± 5.88% (Hargreaves 1998). This value is based on results from four aquaculture production methods in which 18 individual estimates for the conversion of fish biomass to fish N were obtained from 11 different cultured fish species.

Following Hu *et al*,. 2012 (and references therein), it is assumed that all the feed is ingested by fish and the N input as ammonia to the aqueous phase to produce 1 metric tonne of fish is 12.23 x 10^4 g - 2.84 x 10^4 g = 9.39 ± 4.69 x 10^4 g. Given that on average, during N transformation in the aqueous phase, 1.8 ± 0.7% of the N is converted to N_2O (Kong *et al*., 2013; Kampschreur *et al*. 2008; Ahn *et al*., 2010; Hu *et al*., 2013), the amount of N emitted to the atmosphere as N_2O-N is 1.69 X 10^3 g.Thus the average N_2O emission factor of an aquaculture system is 1.69 g N_2O-N per kg fish or 0.00169 kg N_2O-N per kg fish produced. The uncertainty range is estimated using standard error propagation through the calculations indicated.

Appendix 4a.1: Future methodological development for estimating C export

The amount of dissolved and particulate carbon potentially available for export is highly variable among coastal wetlands, depending on a large number of factors such as: net primary productivity, tidal range, the ratio of wetland to watershed area, lateral trapping of tidal water, the presence of high salinity plugs in the tropical dry season, total wetland area, frequency of storms, amount of precipitation, and volume of water exchange Each ecosystem is unique; some wetlands export DOC but import POC, others import DOC and POC but export DIC, while other systems import or export all forms of dissolved and particulate carbon. The direction of net exchange also usually varies within the same estuary with change in season. Emerging evidence indicates that DIC (derived from CO_2 by heterotrophic organisms and/or carbonate dissolution) is exported from coastal wetlands by the physical processes of tidal drainage of soils and subsequent advection to adjacent waterways (Alongi, 2009; Perillo *et al*., 2009). For instance, in mangroves, tidal export of respiratory-derived DIC may equate to as much as one-third of carbon fixed by the forests. However, available data are still too few to allow for generalization, and the scant data are highly variable with tidal amplitude being a major driver of soil DIC drainage.

Estimation of tidal exchange in a particular wetland is not a straightforward process. Many workers have provided rough estimates by multiplying carbon concentrations suspended in wetland creeks and waterways by the tidal range multiplied by the creek/waterway cross-sectional area. Estimates derived from such simple calculations are invalid and misleading for a number of reasons, including the inherent assumption that there are differences in carbon concentrations between ebb and flood tide stages and that the tidal prism is symmetrical. In fact, carbon concentrations in many wetland waters do not show significant differences between tides. Further, tides in most wetlands are characterized by a pronounced asymmetry between ebb and flood tides with the ebb most often being of shorter duration but with stronger current velocity than the flood tide. Also, tidal velocities vary across a waterway with faster surface current velocities mid-stream than those just above the creekbed or proximal to the wetland.

For these reasons, it is not possible to make simple generalizations regarding dissolved and particulate organic and inorganic total carbon export from mangroves, seagrasses or tidal marshes and, in fact, comparatively few such measurements have been made properly. The correct method would be to measure water volume and velocity over entire tidal cycles over several seasons in relation to position in the water-column to derive an overall annual estimate of average water flow by volume. This involves fairly complex instrument measurements and sophisticated mathematical modelling as well as extensive and expensive repetitive measurements of dissolved and particulate carbon concentrations. For mangroves, net exchange of carbon has been properly measured in only twelve systems (DIC has only been measured in four systems), with no clear exchange patterns among locations, although it does appear that most mangroves export POC as litter but with rates ranging widely from 0.1-27.7 mol C m^{-2} yr^{-1} (Alongi, 2009). This export equates globally to only about 10% of total carbon fixed by trees; respiration to the atmosphere is by far the largest loss of C to the atmosphere. Such appears to be the case for tidal marshes (Chmura *et al*., 2003) and subtidal seagrass beds (Fourqurean *et al*., 2012). Some recent syntheses and literature do hold promise for future development of model relationships that can be used for estimating C export (Adame and Lovelock 2011; Maher *et al*., 2013).

CHAPTER 5

INLAND WETLAND MINERAL SOILS

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5.1 INTRODUCTION

This chapter provides supplementary guidance for estimating and reporting greenhouse gas (GHG) emissions and removals from managed lands with Inland Wetland Mineral Soils (IWMS) for all land-use categories (see Chapter 1 and decision tree in Chapter 1 in this supplement for what is specifically covered in this chapter in relationship to other chapters in this supplement). Wetland mineral soil (WMS) information for Tier 1 default methods is found in Table 2.3, Chapter 2, Volume 4 of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (*2006 IPCC Guidelines*). This chapter covers "inland" managed lands with WMS; coastal lands with WMS are addressed in Chapter 4 (Coastal Wetlands) of this supplement. The distinction between "inland" and "coastal" zones is defined in Chapter 4. Constructed wetlands with IWMS are addressed in Chapter 6 (Constructed Wetlands for Wastewater Treatment) of this Supplement.

Mineral soils are described as all soils that are not classified as organic soils in Annex 3A.5, Chapter 3, Volume 4 of the *2006 IPCC Guidelines*. The *2006 IPCC Guidelines* provide a default mineral soil classification for categorizing mineral soil types based on the USDA taxonomy (Soil Survey Staff, 1999) in Figure 3A.5.3, and based on the World Reference Base for Soil Resources Classification (FAO, 1998) in Figure 3A.5.4, where both classifications produce the same default IPCC soil types for Tier 1 methods. Under these soil classification schemes, Wetland Soils (e.g. Wetland Mineral Soils) are classified as Aquic soil (USDA) or Gleysols (World Reference Base), and are described as having restricted drainage leading to periodic flooding and anaerobic conditions (Table 2.3, Chapter 2, Volume 4, *2006 IPCC Guidelines*). They can occur in any of the six land-use categories (Forest Land, Grassland, Cropland, Wetlands, Settlements and Other Land) depending upon the national land-use classification system. Emissions and removals from areas of managed land with IWMS should be reported in the land-use category under which they are classified, according to Volume 4 of the *2006 IPCC Guidelines*. Note that a change in management practice may, or may not, be accompanied by land-use conversion. For higher tier methods, countries may use country-specific national classification systems as long as they are transparently documented.

For the purposes of this supplement, IWMS comprise those that have formed under restricted drainage, and may or may not be artificially drained due to management activities. Guidance provided in this chapter applies to: (i) artificial drainage, defined here as the removal of free water from soils having aquic conditions to the extent that water table levels are changed significantly in connection with specific types of land-use (adapted from Soil Survey Staff, 1999); (ii) to IWMS that have been artificially drained and subsequently allowed to re-wet (hereafter called "rewetting"); and (iii) the artificial inundation of mineral soils for the purposes of "wetland creation." There is no guidance provided for other IWMS such as saline IWMS (See Section 5.1.1 of this chapter) or reservoirs. Guidance on CH_4 emissions from rice cultivation on IWMS is given in Chapter 5, Volume 4 of the *2006 IPCC Guidelines.* Guidance on carbon stock changes in *Land Converted to Flooded Land*[1] with IWMS is given in Chapter 7, Volume 4 of the *2006 IPCC Guidelines*[2]. This supplement does not update this guidance.

This chapter supplements guidance and methodologies in the *2006 IPCC Guidelines* for emissions and removals of carbon dioxide (CO_2), and emissions of methane (CH_4), and provides additional information to be used in applying the methodologies. The review of the current literature suggests there is insufficient data to provide robust emission factors and methodology to update the guidance on N_2O emissions from IWMS provided in Chapter 11, Volume 4 of the *2006 IPCC Guidelines* at this time (see Appendix 5A of this chapter for additional discussion). This chapter should be read in conjunction with Volume 4 of the *2006 IPCC Guidelines.*

This chapter updates the *2006 IPCC Guidelines* for:

- Default reference soil organic carbon stocks (SOC_{REF}) for IWMS under all climate regions (referring to Table 2.3, Chapter 2, Volume 4 of the *2006 IPCC Guidelines* ,), to be used for Tier 1 methods in all six land-use categories.
- Default Soil Organic Carbon (SOC) stock change factor (F_{LU}) for long-term cultivation of Cropland with IWMS.

This chapter gives new guidance not contained in the *2006 IPCC Guidelines,* by:

- Providing new default SOC stock change factors for land-use (F_{LU}) for rewetting of drained IWMS classified as Cropland.

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[1] In the *2006 IPCC Guidelines*, "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."

[2] Appendices 2 and 3 of Volume 4 of the *2006 IPCC Guidelines* contain information on CO_2 emissions from *Land Converted to Permanently Flooded Land* and CH_4 emissions from Flooded Land as a basis for future methodological development.

- Providing methodologies and emission factors (EFs) for CH_4 emissions from managed lands with drained IWMS under any land-use category that has undergone rewetting, and from inland mineral soils that have been inundated for the purpose of wetland creation (Note: CH_4 emissions from wetlands created for the purpose of wastewater treatment are addressed in Chapter 6 of this supplement).

Table 5.1 clarifies the scope and corresponding sections of this chapter, as well as guidance for IWMS provided in the *2006 IPCC Guidelines* and in other chapters of this supplement.

TABLE 5.1
UPDATED AND NEW GUIDANCE PROVIDED IN CHAPTER 5

IPCC Land-use category	Soil Organic Carbon^{A,B} (SOC)	CH_4 emissions^{C,D}
Land Remaining in a Land-use Category		
Forest Land	Updated SOC_{REF} for IWMS	$EF_{CH4\text{-}IWMS}$ for rewetting of drained IWMS, and created wetlands on managed lands with mineral soils
Cropland	Updated SOC_{REF} for IWMS; SOC stock change factors for land-use (F_{LU}) for long-term cultivation, and rewetting of drained IWMS	
Grassland	Updated SOC_{REF} for IWMS	
Wetlands	Updated SOC_{REF} for IWMS	
Settlements	Updated SOC_{REF} for IWMS	
Land Conversion to a New Land-use Category		
All land-use conversions	Updated SOC_{REF} for IWMS; SOC stock change factors for land-use (F_{LU}) for long-term cultivation, and wetland rewetting	$EF_{CH4\text{-}IWMS}$ for rewetting of drained IWMS, and created wetlands on managed lands with mineral soils

A The overall guidance as provided in Chapters 2 and 4-9 in the *2006 IPCC Guidelines* will continue to apply along with elements mentioned in this table.

B Guidance on SOC will apply to all wetlands with IWMS except Flooded Land.

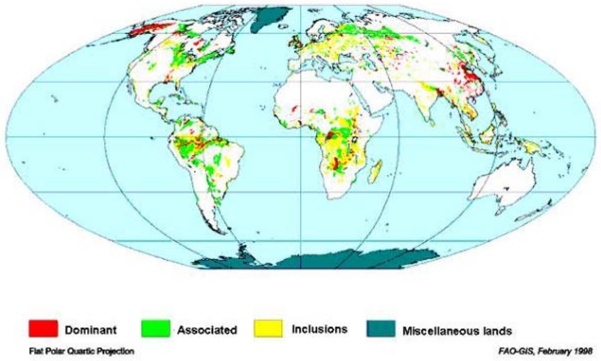
C Existing guidance on CH_4 emissions from rice cultivation given in Chapter 5, Volume 4 of the *2006 IPCC Guidelines* will continue to apply.

D Guidance on CH_4 emissions from managed lands with IWMS does not apply to Flooded Land.

BOX 5.1
DISTRIBUTION OF WETLAND MINERAL SOILS

Wetland mineral soils (WMS), including both coastal and inland WMS, are estimated to cover ~5.3% of the world's land surface, or 7.26 x 10^6 km^2 (Batjes, 2010a). The distribution of the world's WMS across climate regions are as follows: Boreal (moist plus dry): 2.07%, Tropical moist: 0.67%, cool temperate moist: 0.63%, tropical wet: 0.61%, polar (moist plus dry): 0.60%, warm temperate moist: 0.23% (Batjes, 2010a). Climate regions having less than 0.20% WMS include cool and warm temperate dry, tropical dry, and tropical montane (See Figures 3A.5.1 and 3A.5.2, Chapter 3, Volume 4 of the *2006 IPCC Guidelines* for climate zone definitions). Figure 5.1 shows the global distribution of gleysols (WMS) based on the World Reference Base for Soil Resources (WRB) and the FAO/UNESCO soil map of the world. IWMS are found in a variety of landscape settings, including basins, channels, flats, slopes, and highlands (Semeniuk and Semeniuk, 1995). It is common to find IWMS adjacent to flowing waters and lake and pond margins (riparian wetlands). Lands containing IWMS are often classified by predominant vegetation community, and can include trees, woody shrubs, emergent and non-emergent vascular plants, and/or bare ground.

Distribution of Gleysols (Wetland Mineral Soils; source: http://www.isric.org).



A specific type of land containing IWMS, Saline IWMS, is not covered in this chapter. Saline IWMS are generally defined as having salinity >5000 mg L^{-1} when wet (Shaw and Bryant, 2011). Also known as playas, pans, salt lakes, brackish wetlands, salinas, and sabkhas, these lands are important parts of arid landscapes across the globe (Shaw and Bryant, 2011). In a recent review of the literature characterizing known information on pans, playas and salt lakes, carbon stocks and CO_2, CH_4 and N_2O fluxes were not discussed (Shaw and Bryant, 2011). A review of the broader literature on lands containing saline IWMS indicates that only two studies have assessed soil carbon in saline IWMS (Bai *et al.*, 2007; Rodriguez-Murillo *et al.*, 2011), and no studies have measured GHG emissions and removals from saline IWMS. At present the lack of data on saline IWMS prevents the determination of default carbon stock changes or GHG emission factors. Countries are encouraged to seek country specific data to estimate changes in carbon pools in, and emissions and removals from, managed saline IWMS.

BOX 5.2
MANAGEMENT ACTIVITIES ON INLAND WETLAND MINERAL SOILS

Drainage of IWMS is a common practice in the preparation of land for agriculture, grazing, and forestry. Drainage leads to lower water levels, which increases decomposition and vegetation productivity, but the balance generally favors decomposition leading to reduced IWMS carbon stocks over time (Bedard-Haughn *et al.*, 2006; Huang *et al.*, 2010; Page and Dalal, 2011). Hydrology of IWMS may be altered due to dredging of canals for navigation and ditches through wetlands for flood control and to increase vegetation productivity, (Mitsch and Gosselink, 2007); management of river-floodplain systems through levee construction, channelization, and flow manipulation by dams (Dynesius and Nilsson, 1994); irrigation systems that lower water tables; and water level control for wildlife management by dikes, weirs, control gates, and pumps (Mitsch and Gosselink, 2007). Dams for hydroelectric generation and flood control influence newly created riparian wetlands upstream and riparian wetlands by altering the frequency and duration of flood pulses, which has impacts on sediment deposition and nutrient loading to wetlands (Brinson and Malvárez, 2002; Noe and Hupp, 2005, Nilsson and Berggren, 2000).

Grazing on lands with IWMS within grassland or forest landscapes is widespread (Liu *et al.*, 2009; Oates *et al.*, 2008; Yao *et al.*, 2012). Forest management activities on Wetlands with forest can vary in management intensity depending on the silvicultural system. The intensity may range from selective cutting treatments to large area clearcuts. There is currently not enough available information about the impacts of grazing or forest management activities on carbon stock changes or GHG emissions on lands with IWMS to provide new guidance.

A specific management activity that occurs on managed lands with IWMS is "rewetting", where lands with IWMS that were drained are rewetted by raising the water table level to pre-drainage conditions. Active approaches to rewetting include removal of drain tiles, filling or blocking of drainage ditches, breaching levees, removal of river dams and spillways, and contouring the land surface to mimic natural topography; passive approaches include the elimination of water control structures and allowing natural flood events (Aber *et al.*, 2012). The rewetting of managed lands with IWMS is common in the conversion of agricultural lands back to wetlands, and may occur when active regulation of river hydrology is discontinued. A related management activity that occurs on mineral soils (wet or dry) is wetland creation, where lands are artificially inundated for the purposes of supporting a wetland ecosystem (Aber *et al.*, 2012). Wetlands are created for purposes such as water-quality enhancement (treatment of wastewater, stormwater, acid mine drainage, agricultural runoff; Hammer, 1989), flood minimization, and habitat replacement (Mitsch *et al.*, 1998). Wetlands may be created unintentionally when regulation of river flows (i.e. large dam installation) results in periodic inundation of lands that did not experience inundation prior to regulation (Chen *et al.*, 2009; Yang *et al.*, 2012). Wetland creation and rewetting of drained soils are common activities in response to significant wetland loss and degradation on a global scale (Mitsch *et al.*, 1998). There is great potential for increased carbon storage from rewetting wetlands (Euliss *et al.*, 2006; Bridgham *et al.*, 2006). Rewetted wetlands may also have higher emissions of CH_4, potentially offsetting increased carbon storage (Bridgham *et al.,* 2006), although recent studies have shown that created and rewetted wetlands can be net carbon sinks, after accounting for CH_4 emissions (Badiou *et al.*, 2011; Mitsch *et al.*, 2012).

5.2 LAND REMAINING IN A LAND-USE CATEGORY

The *2006 IPCC Guidelines* define land remaining in a land-use category as lands that have not undergone any land-use conversion for a period of at least 20 years as a default period. The *2006 IPCC Guidelines* provide generic and land-use category specific guidance (Chapters 2 and Chapter 4-9, Volume 4) on stock changes in the carbon pools (above-ground and below-ground biomass; dead wood and litter; and soil carbon), and non-CO_2 emissions for land remaining in a land-use category for all land-use categories including those containing mineral soils. This Chapter updates the *2006 IPCC Guidelines* for guidance on SOC stock change factors and non-CO_2 emissions from managed lands with IWMS.

5.2.1 CO_2 emissions and removals

As explained in Chapter 2, Volume 4 of the *2006 IPCC Guidelines*, CO_2 emissions and removals from managed lands are estimated on the basis of changes in the carbon stocks in the carbon pools: biomass (above and below-ground biomass), dead organic matter (dead wood and litter) and soil organic carbon. The set of general equations to estimate the annual carbon stock changes of carbon pools for land remaining in a land-use category are given in Chapter 2, Volume 4 of the *2006 IPCC Guidelines*, and also apply to managed lands with IWMS.

Figure 1.2 in Chapter 1, Volume 4 of the *2006 IPCC Guidelines* shows a decision tree for the identification of appropriate methodological tiers for land remaining in a land-use category.

5.2.1.1 BIOMASS AND DEAD ORGANIC MATTER

Guidance for changes in the carbon pools in biomass (above-ground, below-ground) and dead organic matter (dead wood, litter) is provided in the *2006 IPCC Guidelines*, and remains unchanged for land remaining in a land-use category for managed lands with IWMS in this supplement. For managed lands with IWMS classified as land remaining in a land-use category in Forest Land, Cropland, Grassland, Settlements, or Other Land, changes in biomass and dead organic matter are to be determined using the guidance provided in the corresponding chapters (Chapters 4-9) in Volume 4 of the *2006 IPCC Guidelines.*

CHOICE OF METHOD AND EMISSION/REMOVAL FACTORS

As explained in the *2006 IPCC Guidelines*, inventories can be developed using Tiers 1, 2 and 3 methods. The decision trees have been provided in the *2006 IPCC Guidelines* to guide the selection of appropriate methodological tier for the estimation of changes in carbon stocks of biomass and dead organic matter (Fig. 2.2 and Fig. 2.3, Chapter 2, Volume 4). The Tier 1 methods will use the default emission factors, and parameters relating to biomass and dead organic matter provided for specific land-use categories. These will also apply to managed lands with IWMS in any of these land-use categories. For lower Tier methods it may be assumed that wetland vegetation does not have substantially different biomass carbon densities than upland vegetation (e.g., Bridgham *et al.*, 2006). However, if country specific data is available, it is *good practice* to use that data to estimate biomass carbon densities. There is no robust scientific information to support the development of emission factors for biomass and dead organic matter for specific management activities such as drainage of lands with IWMS, rewetting of drained IWMS, or wetland creation. If there are reliable data for rates of biomass and/or dead organic matter change upon drainage or rewetting/wetland creation, country-specific estimates may be derived using a Tier 2 method.

CHOICE OF ACTIVITY DATA

For Tier 1 methods, activity data consist of areas of managed lands with IWMS in land remaining in a land-use category stratified by land-use category, climate region, soil type, and management practices. Total areas should be determined according to approaches outlined in Chapter 3 of the *2006 IPCC Guidelines*, and should be consistent with those reported under other sections of the inventory. Stratification of land-use categories according to climate region, based on default or country-specific classifications can be accomplished with overlays of land-use on climate and soil maps. A global GIS database that shows the spatial distribution of generalized soil classes used for IPCC Tier 1 is available for download and use at http://isirc.org/data/ipcc-default-soil-classes-derived-harmonized-world-soil-data-base-ver-11. The database is derived from the Harmonized World Soil Data Base and FAO soil classifications, and includes the seven default IPCC soils classes including Wetland Soils (termed “Wetland Soils” in the *2006 IPCC Guidelines,* and “Wetland Mineral Soils” in this Supplement) (Batjes, 2010b). This dataset may be used at national and broader scales where more detailed soil information is lacking. Although no organization catalogues changes in area as a result of rewetting or wetland creation either nationally or globally, local activity data for wetlands with rewetted IWMS may be obtained from agricultural, forestry, or natural resources agencies, non-governmental conservation organizations, or other government sources. In addition, organizations such as the Society for Ecological Restoration International (http://www.ser.org), Global Restoration Network (http://www.globalrestorationnetwork.org), Wetlands International (http://www.wetlands.org), and the Ramsar Convention on Wetlands (http://www.ramsar.org) may be sources of information for rewetting and/or wetland creation projects.

Higher Tier methods may use activity data suitably stratified by criteria such as vegetation type and/or water table level and hydroperiod (e.g., continuously inundated vs. intermittently inundated).

UNCERTAINTY ASSESSMENT

Sources of uncertainty for changes in biomass and dead organic matter in managed lands with IWMS vary depending on the specific land-use category. In general, uncertainty can arise from 1) uncertainties in the mapping of lands, land-use classification and/or management activity data, and 2) uncertainties in carbon gain and loss, carbon stocks, and other parameters used for the estimation of carbon stock changes in biomass and dead organic matter such as biomass expansion factors. For specific recommendations for reducing uncertainties, consult the appropriate land-use category chapter in the *2006 IPCC Guidelines* under which managed lands with IWMS are classified.

5.2.1.2 SOIL CARBON

Soil carbon stocks in managed IWMS are primarily influenced by drainage and other management practices on Cropland, Forest Land, and Grassland (including long-term cultivation, drainage to improve production, and grazing), and rewetting after removal from active cropping and restoration of natural hydrologic conditions (e.g., removal of drainage tiles, plugging of drainage ditches, or similar activities). Other management practices that can significantly change IWMS soil carbon stocks include harvesting in forest prone to paludification (Lavoie *et al.*, 2005) management of river-floodplain systems through the construction of dams, levees, and river channelization which can disconnect floodplains from hydrologic interaction with rivers (Poff *et al.*, 1997), reducing sediment deposition rates in floodplains (Hupp, 1992; Kleiss, 1996). Only a small number of studies, however, have quantified impacts of hydrologic alteration on soil carbon accumulation rates in IWMS in floodplains (Noe and Hupp, 2005; Cabezas *et al.*, 2009). Therefore it is not possible to develop robust emission factors related to impacts of hydrologic alteration on soil carbon stocks of IWMS in floodplains at this time. Similarly, very little information is available with regard to impacts of other common management practices, such as grazing, on IWMS soil carbon stocks. Therefore, guidance provided in this chapter is largely based on and updates the guidance in the *2006 IPCC Guidelines*.

General information about mineral soil classification is provided in Chapters 2 and 3, Volume 4 of the *2006 IPCC Guidelines*. The generic methodological guidance for estimation of changes in the carbon stocks in the SOC pool in mineral soils provided in Section 2.3.3, Chapter 2, Volume 4 of the *2006 IPCC Guidelines* and should be used along with land-use category specific methodological guidance provided in Chapters 4 to 9, Volume 4 of the *2006 IPCC Guidelines*. This supplement updates the guidance on IWMS provided in the *2006 IPCC Guidelines* with regard to the following:

- Table 5.2 provides updated default SOC_{REF} for IWMS (e.g., wetland soils) for use in any land-use category;
- Table 5.3 provides an updated stock change factor for land-use (F_{LU}) associated with long term cultivation of Cropland with IWMS, and a new stock change factor for land-use (F_{LU}) for rewetting of drained IWMS in Cropland.

To account for changes in IWMS SOC stocks associated with changes in relevant management practices on land remaining in a land-use category, countries need at a minimum, estimates of the area of managed land with IWMS in a land remaining in land-use category affected by changes in relevant management practices at the beginning and end of the inventory time period. Two assumptions are made for mineral soils (see details on Section 2.3.3.1, Chapter 2, Volume 4 of the *2006 IPCC Guidelines*): (i) over time, SOC reaches a spatially-averaged, stable value specific to the soil, climate, land-use and management practices; and (ii) SOC stock changes during the transition to a new equilibrium SOC occurs in a linear fashion. If land-use and management data are limited, aggregate data, such as FAO statistics on land-use (http://www.fao.org/home/en/), can be used as a starting point, along with expert knowledge about the approximate distribution of land management systems. Managed land with IWMS must be stratified according to climate regions, which can either be based on default or country-specific classifications. This can be accomplished with overlays of land-use on suitable climate and soil maps.

CHOICE OF METHOD

Inventories can be developed using a Tier 1, 2, or 3 approach, with each successive tier requiring more detail and resources than the previous one. A decision tree is provided for mineral soils in the *2006 IPCC Guidelines* (Figure 2.4, Section 2.3.3.1, Chapter 2, Volume 4) to assist inventory compilers with selection of the appropriate tier for their soil carbon inventory.

Tier 1

The estimation method for mineral soils in land remaining in a land-use category, including IWMS, is based on changes in SOC stocks over a finite transition period following changes in management that impact SOC. Equation 2.25 ($\Delta C_{mineral}$=(SOC_0-$SOC_{(0\text{-}T)}$)/D; see Chapter 2, Volume 4 of the *2006 IPCC Guidelines* for full equation) is used to estimate change in SOC stocks in mineral soils by subtracting the SOC stock in the last year of an inventory time period (SOC_0) from the C stock at the beginning of the inventory time period ($SOC_{(0\ -T)}$) and dividing by the time dependence of the stock change factors (D). SOC are estimated for the beginning and end of the inventory time period using default reference carbon stocks (SOC_{REF}) (Table 5.2) and default stock change factors (F_{LU}, F_{MG}, F_I), based on the land-use (LU), management regime (MG) and input of organic matter (I) at the time of the inventory. In practice, country-specific data on land-use and management must be obtained and classified into appropriate land management systems, and then stratified by IPCC climate regions and soil types. The Tier 1 assumptions for carbon stock changes in mineral soils in land remaining in a land-use category for specific land-use categories will also apply to managed lands with IWMS in those land-use categories.

Tier 2

For Tier 2, the same basic equations are used as in Tier 1 (Equation 2.25), but country-specific information is incorporated to improve the accuracy of the stock change factors, reference C stocks, climate regions, soil types, and/or the land management classification system.

Tier 3

Tier 3 approaches may use empirical, process-based or other types of models as the basis for estimating annual carbon stock changes, such as the Century ecosystem model (Parton *et al.*, 1987, 1994, 1998; Ogle *et al.*, 2010), or the Wetland-DNDC model (Zhang *et al.*, 2002). Estimates from models are computed using equations that estimate the net change of soil carbon. Key criteria in selecting an appropriate model include its capability of representing all of the relevant management practices/systems for the land-use category; model inputs (i.e., driving variables) are compatible with the availability of country-wide input data; and verification against experimental, monitoring or other measurement data (e.g., Ogle *et al.,*2010).

A Tier 3 approach may also be developed using a measurement-based approach in which a monitoring network is sampled periodically to estimate SOC stock changes. A much higher density of benchmark sites will likely be needed than with models to adequately represent the combination of land-use and management systems, climate, and soil types. Additional guidance is provided in Section 2.3.3.1 of Chapter 2 of this supplement.

CHOICE OF EMISSION FACTORS

Tier 1

Table 5.2 gives updated default reference SOC stocks (SOC_{REF}) for IWMS[3]. Inventory compilers should use the stock change factors provided in the appropriate chapters addressing the six land-use categories (Chapters 4-9) in Volume 4 of the *2006 IPCC Guidelines* in conjunction with the data in Table 5.2 for Tier 1 methods.

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[3] These values are given under “wetland soils” in Table 2.3, Chapter 2, Volume 4 of the *2006 IPCC Guidelines.*

TABLE 5.2
DEFAULT REFERENCE SOIL ORGANIC CARBON STOCKS (SOC_{REF}) FOR WETLAND MINERAL SOILS[A] UNDER NATIVE VEGETATION (0-30 CM DEPTH).

Climate region	tonnes C ha^{-1}	Standard deviation	Error (95% confidence interval[B])	Number of sites
Boreal	116	94	±99	6
Cold temperate, dry	87[C]	n/a[D]	n/a[D]	n/a[D]
Cold temperate, moist	128	55	±17	42
Warm temperate, dry	74	45	±13	49
Warm temperate, moist	135	101	±39	28
Tropical, dry	22	11	±4	32
Tropical, moist	68	45	±12	55
Tropical, wet	49	27	±9	33
Tropical, montane	82	73	±46	12

A Batjes (2011) presents revised estimates (means, standard deviations) of the 2006 IPCC Guidelines SOC stocks for wetland mineral soils (gleysols) under natural vegetation based on an expanded version of the ISRIC-WISE database (Batjes, 2009) which contains 1.6 times the number of soil profiles of the databases used in the 2006 IPCC Guidelines SOC stocks estimate.

B The 95% confidence interval is calculated from the mean, standard deviation, and the critical values of t distribution according to the degrees of freedom.

C No revised estimate was presented in Batjes (2011); values are from Table 2.3, Chapter 2, Volume 4 of the *2006 IPCC Guidelines* for National Greenhouse Gas Inventories.

D "n/a" indicates information is not available.

The updated SOC_{REF} values in Table 5.2 for WMS should be used for calculating SOC stock changes in IWMS when soils are classified as "wetland soils", for land remaining in a land-use category in the following sections in the *2006 IPCC Guidelines:*

- Forest Land (Chapter 4): Section 4.2.3, Tier 1;
- Cropland (Chapter 5): Section 5.2.3, Tier 1;
- Grassland (Chapter 6): Section 6.2.3, Tier 1.

Default stock change factors for land-use (F_{LU}), input (F_I), and management (F_{MG}) that apply to managed land on IWMS in the *Cropland Remaining Cropland* land-use category are presented in Table 5.5 , Chapter 5, Volume 4 of the *2006 IPCC Guidelines*; default stock change factors for land-use (F_{LU}), input (F_I), and management (F_{MG}) that apply to managed land on IWMS in the *Grassland Remaining Grassland* land-use category are presented in Table 6.2, Chapter 6, Volume 4 of the *2006 IPCC Guidelines*.

Table 5.3 in this supplement provides an updated Tier 1 default stock change factor for land-use (F_{LU}) that should be applied to Cropland with IWMS under "long-term cultivation." Note that the updated factor applies only to long-term cultivated land-use in the temperate or boreal dry and moist climate regions. All other default stock change factors in the *2006 IPCC Guidelines* are unchanged. The updated value is similar to the Temperate/Boreal Moist climate but lower than the Temperate/Boreal Dry climate values in Table 5.5, Chapter 5, Volume 4 of the *2006 IPCC Guidelines*. Consequently, this update should reduce uncertainties associated with estimating soil carbon stock changes for IWMS in dry climates. The method and studies used to derive the updated default stock change factor is provided in Annex 5A.1. The default time period for stock changes (D) is 20 years, and management practices are assumed to influence stocks to 30 cm depth although lower depths can also be affected. As a result, for Tier 1 and 2 methods, SOC stocks for mineral soils are computed to a default depth of 30 cm. Greater soil depth can be selected and used at Tier 2 if data are available.

A new default stock change factor for land-use (F_{LU}) following rewetting of Cropland with IWMS is also provided in Table 5.3 for a Tier 1 approach. This factor applies to Cropland with IWMS where natural hydrology has been restored, and crop production may or may not continue. Note that the factor applies to all climate regions, with the caveat that this value is likely more representative of rewetting activities in temperate and boreal climates, as it is derived from studies limited to these regions (see Annex 5A.1 for method and studies). The default time period for stock changes (D) is 20 years, however additional C gain from restoring natural hydrology continues for another 20 years and will reach the reference SOC stock level after 40 years (i.e.,

SOC_{REF} values in Table 5.2). It is also important to note that the long-term cultivation factor is used for areas that have been drained and are cultivated for crop production. If the high water table is restored, i.e., in the case of rewetted Cropland, then F_{LU} for rewetting are used for two sets of 20 year periods (i.e., 0-20 and 20-40 years).

TABLE 5.3
RELATIVE STOCK CHANGE FACTORS FOR LAND-USE (F_{LU}) FOR LONG TERM CULTIVATION ON CROPLAND WITH IWMS OVER 20 YEARS) AND REWETTING OF CROPLAND WITH IWMS (OVER 20 YEARS AND 40 YEARS)

Factor value type	Management	Temperature regime	Moisture regime	Default	Error[A]	Description
Land-use (F_{LU})	Long-term cultivated[B]	Temperate/ Boreal	Dry and Moist	0.71	41%	Represents Cropland with IWMS that has been continuously managed for > 20 years, to predominantly annual crops.
Land-use (F_{LU})	Rewetting (Years 1-20)	Boreal, Temperate, and Tropical	Dry and Moist	0.80	10%	Represents cropland with IWMS that has undergone rewetting (restoration of natural hydrology) and may or may not be under active crop production.
	Rewetting (Years 21-40)			1.0	N/A	

A ± two standard deviations, expressed as a percent of the mean.

B The long-term cultivation factor is used for areas that have been drained and are cultivated for crop production. In the case of rewetted Cropland, stock-change factors for land-use (F_{LU}) for rewetting are used for two sets of 20 year periods (i.e., 0-20 and 20-40 years since rewetting).

The following are the key considerations in the application of the new stock change factors to Cropland with IWMS subject to long-term cultivation and rewetting (Table 5.3) for land remaining in a land-use category:

- The stock change factors for SOC in mineral soils provided for Forest Land, Cropland, Grassland, and Settlements in the *2006 IPCC Guidelines* are applicable for *all* managed lands with IWMS classified as land remaining in a land-use category under any of the land-use categories.
- The new stock change factors for long-term cultivation and rewetting of Cropland with IWMS in this Supplement (Table 5.3) should be applied to *Cropland remaining Cropland* with *IWMS* taking account of the following:

  (i) The new stock change factor for land-use (F_{LU}) for Cropland with IWMS under long-term cultivation in this supplement will be used in place of the existing stock change factor for Cropland under long-term cultivation for all mineral soil types provided in Table 5.5, Chapter 5, Volume 4, in the *2006 IPCC Guidelines.*

  (ii) The stock change factors for land-use (F_{LU}) for Cropland with IWMS subject to rewetting are to be used for *Cropland remaining Cropland* according to the following:

    - For Cropland with IWMS subject to rewetting, for the first 20 years following the initial year of rewetting, the final SOC stock i.e., SOC stocks in the last year of an inventory time period (SOC_0) is determined using $F_{LU} = 0.80$ along with the other stock change factors for management and input. The stock change factors for estimating the initial SOC stocks ($SOC_{(0-T)}$) will correspond to the Cropland land-use (long-term cultivated, perennial etc.), management and input regimes prior to rewetting.
    - For the next set of 20 years (i.e., 20-40 years since the initial year of rewetting), $F_{LU} = 1$ will be used to estimate the final SOC stock (SOC_0) along with appropriate stock change factors for management and input. The stock change factors for estimating the initial stocks ($SOC_{(0-T)}$) will correspond to rewetted Cropland land-use ($F_{LU} = 0.8$) management and input regimes at 20 years following rewetting.

- For the period beyond 40 years following the initial year of rewetting, F_{LU} will remain equal to 1. The changes in SOC stocks due to changes in management/input regimes in Cropland with IWMS may be estimated using appropriate stock change factors from Table 5.2, Chapter 5, Volume 4 in the *2006 IPCC Guidelines*.

See Box 5.3 (Calculation Steps for Tier 1) for an example calculation using the stock change factors for land-use (F_{LU}) for Cropland with IWMS under long-term cultivation, and for Cropland with IWMS subject to rewetting.

Tier 2

A Tier 2 approach involves the estimation of country-specific stock change factors. It is *good practice* to derive values for a higher resolution classification of management and climate if there are significant differences in the stock change factors among more disaggregated categories based on an empirical analysis. Reference SOC stocks can also be derived from country-specific data in a Tier 2 approach. Additional guidance is provided in Section 2.3.3.1, Chapter 2, Volume 4 of the *2006 IPCC Guidelines*.

Tier 3

Constant stock change rate factors *per se* are less likely to be estimated in favour of variable rates that more accurately capture land-use and management effects. See Section 2.3.3.1, Chapter 2, Volume 4 for further discussion.

CHOICE OF ACTIVITY DATA

Activity data consist of areas of managed lands with IWMS remaining in a land-use category stratified by land-use category, climate region, soil type, and management practices, at a minimum. The area of Cropland with IWMS subject to rewetting need to be stratified by time since rewetting (0-20 or 20-40 years since rewetting) for correct application of stock change factors. If the compiler does not have sufficient information to disaggregate areas of rewetted Cropland with IWMS by time since conversion, all rewetted Cropland with IWMS areas could be assumed to be within 0-20 years since rewetting and F_{LU} = 0.8 could be applied to the entire rewetted Cropland with IWMS. Total areas should be determined according to approaches outlined in Chapter 3, Volume 4 of the *2006 IPCC Guidelines*, and should be consistent with those reported under other sections of the inventory. Stratification of land-use categories according to climate region, based on default or country-specific classifications, can be accomplished with overlays of land-use on climate and soil maps. In the case of using methods such as models, and/or use of data as proxies for estimation, clear and complete documentation is encouraged for transparency.

Tier 1

The Tier 1 approach requires area of managed land on IWMS for each land-use category stratified by climate region and soil type. Available land cover/land-use maps, either country-specific maps or maps based on global datasets such as IGBP_DIS (http://daac.ornl.gov), can be joined with soil and climate maps (country-specific, or global maps such as ISRIC, http://www.isric.org, or FAO, http://www.fao.org/home/en) as an initial approach. A global GIS database that shows the spatial distribution of generalized soil classes used for IPCC Tier 1 is available for download and use at http://isirc.org/data/ipcc-default-soil-classes-derived-harmonized-world-soil-data-base-ver-11. The database is derived from the Harmonized World Soil Data Base and FAO soil classifications, and includes the seven default IPCC soils classes including Wetland Soils (termed “Wetland Soils” in the *2006 IPCC Guidelines*, and “Wetland Mineral Soils” in this supplement) (Batjes, 2010b). This dataset may be used at national and broader scales where more detailed soil information is lacking.

Classification systems for activity data for a Tier 1 inventory are provided in the respective land-use chapters of the *2006 IPCC Guidelines*. Land-use activity data and management activity data specific to the respective land-use category are typically required for the Tier 1 approach. Although no organization catalogues changes in area as a result of rewetted or created wetlands either nationally or globally, local activity data for rewetting of managed lands with IWMS or creation of wetlands may be obtained from agricultural, forestry, or natural resources agencies, non-governmental conservation organizations, or other government sources. In addition, organizations such as the Society for Ecological Restoration International (http://www.wer.org), Global Restoration Network (http://www.globalrestorationnetwork.org), Wetlands International (http://www.wetlands.org), and the Ramsar Convention on Wetlands (http://www.ramsar.org) may be sources of information for rewetting and wetland creation projects.

Tier 2

Tier 2 approaches are likely to involve a more detailed stratification of management systems, under the respective land-use category, than Tier 1 if sufficient data are available. This may include further divisions of management practices, and finer stratification of climate regions. At Tier 2, a higher spatial resolution of activity data is required, and can be obtained by disaggregating global data in country-specific categories, or by collecting country-specific activity data.

Tier 3

Tier 3 approaches may include the use of empirical, process-based or other types of models and/or direct measurement-based inventories, in which case more detailed data on climate, soils, and management practices are needed relative to Tier 1 and 2 methods. The exact requirements will be dependent on the model or measurement design. Examples of model input data include activity data on cropland management practices (crop type, tillage practices, fertilizer and organic amendments), climate, soil, biomass, and water table position (Ogle *et al.*, 2010; Zhang *et al.*, 2002).

CALCULATION STEPS FOR TIER 1

The steps for estimating SOC_0 and $SOC_{(0-T)}$ and net soil organic carbon stock change per hectare for managed land on IWMS for land remaining in a land-use category are as follows:

Step 1: Organize data into time series according to the years in which activity data were collected.

Step 2: Classify land into the appropriate management system in accordance with its respective land-use category.

Step 3: Determine areas of managed land with IWMS under each land-use category for lands remaining in that land-use category, disaggregated according to climate region at the beginning of the first inventory time period. The first year of the inventory time period will depend on the time step of the activity data (0-T; e.g., 5, 10, or 20 years ago).

Step 4: Assign a native reference SOC stock value (SOC_{REF}) for IWMS from Table 5.2 based on climate region.

Step 5: Assign a land-use factor (F_{LU}), management factor (F_{MG}), and organic matter input factor (F_I) based on the management classification for the respective land-use category (Step 2). Values for F_{LU}, F_{MG}, and F_I are provided in the respective chapters for land-use categories; an updated value for long-term cultivation F_{LU} is given in Table 5.3 for IWMS in Cropland.

Step 6: Multiply the appropriate stock change factors (F_{LU}, $F_{MG,}$ F_I) by SOC_{REF} to estimate an 'initial' SOC stock ($SOC_{(0-T)}$) for the inventory time period.

Step 7: Estimate the final SOC stock (SOC_0) by repeating Steps 1 to 5 using the same SOC_{REF}, but with land-use, management, and input factors that represent conditions for the managed land in the last (year 0) inventory year.

Step 8: Estimate the average annual change in SOC stocks for managed land on IWMS remaining in a land-use category ($\Delta C_{Mineral}$) by subtracting the $SOC_{(0-T)}$ from SOC_0, then dividing by the time dependence of the stock change factors (D) (i.e. 20 years using the default factors). If an inventory time period is greater than 20 years, then divide by the difference in the initial and final year of the time period.

Step 9: Repeat steps 2 to 8 if there are additional inventory time periods.

BOX 5.3
EXAMPLE CALCULATIONS FOR SOC STOCKS IN LONG-TERM CULTIVATED CROPLANDS WITH IWMS, AND REWETTING OF LONG-TERM CULTIVATED CROPLANDS WITH IWMS

Assume an area with a cold temperate, dry climate. A crop is newly cultivated on an IWMS. For the first 20 years after the initiation of cultivation the SOC will decrease linearly by 71% (see 0.71 as default value in Table 5.3) down to 30 cm. From Table 5.2 it is shown that the SOC for a reference condition is 87 tonnes C ha^{-1}. After 20 years of cultivation the amount of SOC will be 61.8 tonnes C ha^{-1} (87 tonnes C ha^{-1} X 0.71 = 61.8 tonnes C ha^{-1}), which is a loss of 25.2 tonnes C ha^{-1} over the 20 years or 1.26 tonnes C ha^{-1} yr^{-1}. After 20 years it is assumed that the SOC is stable at 61.8 tonnes C ha^{-1}.

If we take this same soil and rewet following drainage for crop production, the SOC will be 80% of the reference condition after 20 years or 69.6 tonnes C ha^{-1} (87 tonnes C ha^{-1} X 0.80 = 69.6 tonnes C ha^{-1}). The increase from 61.8 tonnes C ha^{-1} (from calculation above) is 7.8 tonnes C ha^{-1} or 0.39 tonnes C ha^{-1} yr^{-1}for the first 20 years. From year 21-40 the SOC will increase an additional 20% (1.0-0.8 from Table 5.3) so that at year 40 the SOC is at the reference level of 87 tonnes C ha^{-1} (Table 5.2). The SOC is assumed to accrue linearly from years 21-40 using the Tier 1 method. The difference in SOC at year 20 (69.6 tonnes C ha^{-1}) and year 40 (87.0 tonnes C ha^{-1}) is 17.4 tonnes C ha^{-1}, thus the annual accrual rate is 0.87 tonnes C ha^{-1} yr^{-1} over years 21-40.

UNCERTAINTY ASSESSMENT

Three broad sources of uncertainty exist in soil C inventories: 1) uncertainties in land-use and management activity, and environmental data; 2) uncertainties in reference soil carbon stocks if using a Tier 1 or 2 approach, or initial conditions if using a Tier 3 approach; and 3) uncertainties in the stock change/emission factors for Tier 1 or 2 approaches, model structure/parameter error for Tier 3 model-based approaches, or measurement error/sampling variability associated with Tier 3 measurement-based inventories. In general, precision of an inventory is increased and confidence ranges are smaller with more sampling to estimate values for the three broad sources of uncertainty, while reducing bias (i.e., improve accuracy) is more likely to occur through the development of a higher tier inventory that incorporates country-specific information. An additional source of uncertainty arises from the difficulty in accurately mapping wetlands for the purposes of classification under soil or vegetation types and management activities, for example; this has been an issue since inventory methods were first developed (Cowardin, 1982), and still continue even with advances in technology and remote sensing techniques (Arnesen *et al.*, 2013). Because mapping techniques tend to rely on vegetation and soils information, defining the area of IWMS is especially difficult because their vegetation ranges from marsh to forested systems and soils range from near organic to near non-wetland mineral across their range. Moreover, areas subjected to water table variation and flooding may increase or decrease frequently depending on interannual climate variability and management activities. However, given no dramatic changes in hydrology, wetland soil and vegetation properties will remain consistent over time, even with interannual climate variability, and mapped areas should remain relatively unchanged.

For Tier 1, uncertainties are provided with the reference SOC stocks in Table 5.2, and stock change factors in the respective land-use category chapters in the *2006 IPCC Guidelines* and Table 5.3 for the updated F_{LU}. Uncertainties in land-use and management data will need to be addressed by the inventory compiler, and then combined with uncertainties for the default factors and reference SOC stocks using an appropriate method, such as simple error propagation equations. If using aggregate land-use area statistics for activity data (e.g., FAO data), the inventory compiler may have to apply a default level of uncertainty for the land area estimates (±50%). It is *good practice* to apply country-specific uncertainty estimates for country-specific area estimates instead of using a default level. Default reference SOC stocks and stock change factors for mineral soils can have inherently high uncertainties when applied to specific countries. Defaults represent globally averaged values of land-use and management impacts or reference SOC stocks that may vary from region specific-values (Powers *et al.*, 2004; Ogle *et al.*, 2006). Bias can be reduced by deriving country-specific factors using a Tier 2 method or by developing a Tier 3 country-specific estimation system. The underlying basis for higher Tier approaches will be experiments or soil carbon monitoring data in the country or neighbouring regions that address the effect of land-use and management on soil carbon and/or can be used to evaluate model predictions of soil carbon change (e.g., Ogle *et al.*, 2010). Further reduction in bias can be obtained by accounting for significant within-country differences in land-use and management impacts, such as variation among climate regions and/or soil types, even at the expense of reduced precision in the factor estimates (Ogle *et al.*, 2006). Bias is considered more problematic for reporting stock changes because it is not necessarily captured in the uncertainty range (i.e., the true stock change may be outside of the reported uncertainty range if there is significant bias in the factors).

Uncertainties in land-use activity statistics may be reduced through a better national system, such as developing or extending a ground-based survey with additional sample locations and/or incorporating remote sensing to provide additional coverage. It is *good practice* to design a classification that captures the majority of land-use and management activity with a sufficient sample size to minimize uncertainty at the national scale.

5.2.2 CH_4 emissions from managed lands with IWMS

Management activities on lands containing IWMS that alter the water table level can impact CH_4 emissions. Two common management activities that involve raising water table levels include rewetting of previously drained IWMS, and the creation of wetlands on mineral soils (wet or dry). Both rewetting and wetland creation are often undertaken as conservation efforts for habitat and wildlife. Studies have shown that raising water table levels on managed lands with IWMS, through rewetting and/or wetland creation, can increase CH_4 emissions (Pennock *et al.*, 2010; Badiou *et al.*, 2011; Nahlik and Mitsch, 2010; Herbst *et al.*, 2011; Yang *et al.*, 2012). Here we provide guidance for CH_4 emissions as a result of raising the water table level on managed lands with IWMS; drainage and lowering water tables typically results in lower or negligible CH_4 emissions (Morse *et al.*, 2012). In a modeling study of global CH_4 emissions, Spahni *et al.* (2011) suggest that IWMS that are not inundated, but have soil moisture content above a critical threshold, can still be a net CH_4 source. Due to the lack of studies, however, we are unable to develop guidance for CH_4 emissions from drained IWMS at this time.

Although our current understanding of the processes involved in CH_4 production and emission is improving, it remains difficult to estimate CH_4 emissions with a high degree of confidence due mainly to large spatial variability, and to seasonal and interannual variability in controlling factors such as water level and temperature. Studies show high spatial variability in CH_4 emissions across large areas that have similar climate, vegetation, and topography, and within small areas that have microscale variation in topography (Ding *et al.*, 2003; Saarnio *et al.*, 2009). In addition, there are very few studies of CH_4 emissions from rewetted or created wetlands on managed lands with IWMS in Europe (Saarnio *et al.*, 2009), tropical regions (Mitsch *et al.*, 2010), and certain regions of North America. Therefore, the default emission factors we present necessarily have large uncertainties. Due to the relative lack of data on rewetted and created wetlands with IWMS, we included studies of CH_4 emissions from natural wetlands on IWMS in the development of default emission factors (see Annex 5A.2 for further details).

5.2.2.1 CHOICE OF METHOD

Tier 1

CH_4 emissions from managed lands on IWMS, or dry mineral soils, where management activities have resulted in the water table being raised to, or above, the land surface are estimated using a simple emission factor approach (Equation 5.1), stratified by climate region. The default methodology considers boreal, temperate, and tropical climate regions.

EQUATION 5.1
ANNUAL CH_4 EMISSIONS FROM REWETTED AND CREATED WETLANDS ON MANAGED LANDS WITH IWMS

$$CH_{4-IWMS} = \sum_{c} (A_{IWMS} \bullet EF_{CH_4-IWMS})_c$$

Where:

$CH_{4\text{-}IWMS}$ = Annual CH_4 emissions from managed lands on IWMS where management activities have raised the water table level to or above the land surface, kg CH_4 yr^{-1}

$A_{IWMS,\ c}$ = Total area of managed lands with mineral soil where the water table level has been raised in climate region *c*, ha

$EF_{CH4\text{-}IWMS,\ c}$ = Emission factor from managed lands with mineral soil where water table level has been raised in climate region *c*, kg CH_4 ha^{-1} yr^{-1}

The area of managed lands with IWMS, or dry mineral soil, where water table level has been raised, should be stratified by climate region (boreal, temperate, or tropical), and the appropriate emission factor applied.

Tier 2

The Tier 2 approach uses country-specific emission factors based on information on important parameters such as water table level and hydroperiod. It is *good practice* when developing and using country-specific emission factors to consider the water table position and its relationship to CH_4 emissions. Annual CH_4 emissions from IWMS are generally larger when the water table is continuously at or above the land surface, rather than intermittently at or below the land surface (Annex 5A.2). Seasonal and interannual changes in water table position, and duration above the land surface, are determined by multiple variables including fluctuations in water source (e.g., river discharge in the case of riparian wetlands), evapotranspiration and precipitation.

Tier 3

A Tier 3 approach involves a detailed consideration of the dominant drivers of CH_4 emission from IWMS, including but not limited to water table position, seasonal changes in inundation, temperature of soils, importance of CH_4 ebullition, and vegetation community dynamics. CH_4 ebullition is a poorly quantified component of CH_4 emission from inundated soils, but has been shown to be a significant contributor to annual CH_4 emission in some systems (Wilson *et al.*, 1989). Vegetation can have important implications for CH_4 emission by facilitating transport from inundated soils to the atmosphere, and by providing substrate for CH_4 production. Possible methods to determine the importance of these drivers to CH_4 emission, and thus reduce uncertainty in emission factors, include detailed field studies of CH_4 emission and/or the use of models specific to carbon cycling in wet soils such as the Wetland-DNDC model (Zhang *et al.*, 2002; http://www.globaldndc.net).

5.2.2.2 CHOICE OF EMISSION FACTORS

Tier 1

The default emission factors for IWMS ($EF_{CH4-IWMS}$), stratified by climate region, are provided in Table 5.4. The Tier 1 emission factors do not distinguish between continuous and intermittent inundation. The emission factors were derived from studies covering a range of inundation duration, therefore capturing a degree of variability in CH_4 emission (Annex 5A.2). The uncertainties in the EFs can be reduced by using country-specific EFs that incorporate information on water table position and period of inundation at higher Tier levels.

TABLE 5.4
DEFAULT EMISSION FACTORS FOR CH_4 FROM MANAGED LANDS WITH IWMS WHERE WATER TABLE LEVEL HAS BEEN RAISED

Climate Region	$EF_{CH4-IWMS}$ (kg CH_4 ha^{-1} yr^{-1})	95% Confidence Interval[A]	Number of Studies
Boreal	76	±76[B]	1[C]
Temperate	235	±108	21
Tropical	900	±456	18

AThe 95% confidence interval is calculated from the mean, standard deviation, and the critical values of t distribution according to the degrees of freedom. These are not expressed as a percentage of the mean.

B Bridgham *et al.* (2006)

CThis study (Bridgham *et al.*, 2006) is a synthesis of numerous studies; see publication for details.

5.2.2.3 CHOICE OF ACTIVITY DATA

The Tier 1 method requires data on areas of managed lands with IWMS where the water table level has been raised, for instance as in rewetting or wetland creation, stratified by climate region. Although no organization catalogues changes in area as a result of rewetting or wetland creation either nationally or globally, local activity data for rewetting of managed lands with IWMS or creation of wetlands may be obtained from agricultural, forestry, or natural resources agencies, non-governmental conservation organizations, or other government sources. In addition, organizations such as the Society for Ecological Restoration International (http://www.wer.org), Global Restoration Network (http://www.globalrestorationnetwork.org), Wetlands International (http://www.wetlands.org), and the Ramsar Convention on Wetlands (http://www.ramsar.org) may be sources of information for rewetting and/or wetland creation projects. In addition to the above, Tier 2 and Tier 3 methods generally require areas of managed lands with IWMS stratified by annual average water table level, and seasonal and/or interannual changes in inundation. Areas may be further stratified by vegetation community composition, vegetation biomass, soil temperature data, and previous land-use, for the development of country-specific emission factors and models. The use of Synthetic Aperture Radar (SAR) on the Japanese Satellite JERS, for example, can improve the accuracy of the quantification of inundated areas, by overcoming the bias caused by clouds in more common satellite imagery on the visible spectrum (e.g., Landsat images). Also, higher resolution satellite images (e.g., QuickBird) can reduce uncertainties in land-use and vegetation classifications.

5.2.2.4 UNCERTAINTY ASSESSMENT

Estimates of uncertainty for $EF_{CH4-IWMS}$, as ± 95% Confidence Interval, are provided in Table 5.4 for each climate region. Major sources of uncertainty in these values are the small number of studies on which the estimates are based, and the combination of studies with different inundation periods (continuously inundated and intermittently inundated). The development of country-specific emission factors will aid in reducing uncertainty.

5.3 LAND CONVERTED TO A NEW LAND-USE CATEGORY

The *2006 IPCC Guidelines* define land converted to a new land-use category as lands that have been converted in the last 20 years as a default period. The *2006 IPCC Guidelines* provide generic and land-use category specific guidance (Chapters 4-9, Chapters 2, Volume 4) for carbon stock changes in the carbon pools and non-CO_2 emissions from managed land on mineral soils for land converted to a new land-use category for all land-use categories. This chapter updates the *2006 IPCC Guidelines* for guidance on changes in SOC stocks and non-CO_2 emissions from managed lands with IWMS that have been classified as land converted to a new land-use category in all six land-use categories.

5.3.1 CO_2 emissions and removals

The set of general equations to estimate the annual C stock changes of C pools for land remaining in a land-use category for managed lands with IWMS are given in Volume 4, Chapter 2 of the *2006 IPCC Guidelines*, and will also apply to managed lands with IWMS for land converted to a new land-use category.

Figure 1.3 in Volume 4, Chapter 1 of the *2006 IPCC Guidelines* shows a decision tree for the identification of appropriate methodological Tiers for the inventory of land converted to a new land-use category.

5.3.1.1 BIOMASS AND DEAD ORGANIC MATTER

The guidance provided in section 5.2.1.1 also applies to lands converted to a new land-use category for managed lands with IWMS. The guidance in sections pertaining to land converted to a new land-use category in the *2006 IPCC Guidelines* are to be used.

CHOICE OF METHOD AND EMISSION/REMOVAL FACTORS

The guidance provided in section 5.2.1.1 also applies to lands converted to a new land-use category for managed lands with IWMS. The guidance in sections pertaining to land converted to a new land-use category in the *2006 IPCC Guidelines* are to be used.

CHOICE OF ACTIVITY DATA

The activity data consist of areas of managed lands with IWMS in land converted to a new land-use category stratified by land-use category, climate region, soil type, and management practices, at a minimum. The guidance provided in Section 5.2.1.1 also applies to lands converted to a new land-use category for managed lands with IWMS. The guidance in sections pertaining to land converted to a new land-use category in the *2006 IPCC Guidelines* are to be used.

UNCERTAINTY

The guidance provided in Section 5.2.1.1 also applies to lands converted to a new land-use category for managed lands with IWMS. The guidance in sections pertaining to lands converted to a new land-use category in the *2006 IPCC Guidelines* are to be used.

5.3.1.2 SOIL CARBON

Conversion of land on IWMS to other land-uses can increase (in Forest Land, for example, Volume 4, Chapter 4 in *2006 IPCC Guidelines*) or decrease SOC stocks (in Cropland, for example, Chapter 5 of Volume 4 in *2006 IPCC Guidelines*). In general, the guidance provided in section 5.2.1.2 also applies to lands converted to a new land-use category for managed lands with IWMS. However, there are specific applications of the new SOC stock change factors for rewetting depending on the specific land-use conversion (see Choice of Emission/Removal Factors below for details). The guidance in sections pertaining to land converted to a new land-use category in the *2006 IPCC Guidelines* are to be used.

CHOICE OF METHOD

The guidance provided in section 5.2.1.2 also applies to lands converted to a new land-use category for managed lands with IWMS. The guidance in sections pertaining to land converted to a new land-use category in the *2006 IPCC Guidelines* are to be used.

CHOICE OF EMISSION/REMOVAL FACTORS

The guidance provided in section 5.2.1.2 also applies to all lands converted to a new land-use category for managed lands with IWMS in any land-use category, including the updated SOC_{REF} for IWMS (Table 5.2) and the updated and new stock change factors (F_{LU}, Table 5.3). The following are the key considerations in the application of stock change factors for managed lands with IWMS:

- The stock change factors for SOC stock changes in mineral soils provided for Forest, Cropland, Grassland, and Settlements in the *2006 IPCC Guidelines* are applicable for *all* land-use conversions (both to and from) involving managed lands with IWMS classified under any of the land-use categories;
- The new stock change factors for long-term cultivation and wetland rewetting of Cropland with IWMS in this supplement (Table 5.3) can be applied to land-use conversions involving Cropland taking account of the following:

(i) The new stock change factor for land-use (F_{LU}) for Cropland with IWMS under long-term cultivation in this supplement will be used in place of the existing stock change factor for Cropland under long-term cultivation for all mineral soil types provided in Table 5.5, Chapter 5, Volume 4 in the *2006 IPCC Guidelines*.

(ii) The stock change factors for land-use (F_{LU}) for Cropland with IWMS subject to rewetting can be used for land-use conversions involving Cropland in the following ways:

- For land-use conversion to Cropland with IWMS subject to rewetting the final SOC stock (SOC_0) is determined using F_{LU} = 0.80 for a period of 0-20 years following the first year of rewetting along with the relevant stock change factors corresponding to the management and input regimes after land-use conversion. The stock change factors for estimating the initial SOC stocks ($SOC_{(0-T)}$) will correspond to the land-use, management and input regimes before land-use conversion.
- For Cropland with IWMS subject to rewetting undergoing land-use conversion to any other land-use category, F_{LU} = 1 be used for a period of 20-40 years or more than 40 years since the first year of rewetting activity respectively, along with relevant stock change factors corresponding to the management/input regime before conversion. The stock change factors for land-use, management and input for the new land-use category (e.g., Forest Land or Grassland) will be used to determine the final SOC stock (SOC_0) along with relevant stock change factors corresponding to the management and input regimes following land-use conversion.
- The guidance in sections pertaining to land converted to a new land-use category in the *2006 IPCC Guidelines* are to be used.

CHOICE OF ACTIVITY DATA

The activity data consist of areas of managed lands with IWMS in land converted to a new land-use category stratified by land-use category, climate region, soil type, management practices, and time since conversion, at a minimum. The area of Cropland with IWMS subject to rewetting need to be stratified by time since rewetting (0-20 or 20-40 years since rewetting) for correct application of stock change factors. If the compiler does not have sufficient information to disaggregate areas of rewetted Cropland with IWMS by time since conversion, all rewetted Cropland with IWMS areas could be assumed to be within 0-20 years since rewetting and F_{LU} = 0.8 could be applied to the entire rewetted Cropland with IWMS. The guidance provided in Section 5.2.1.2 *also* applies to lands converted to a new land-use category for managed lands with IWMS.

UNCERTAINTY

The guidance provided in Section 5.2.1.2 also applies to *lands converted to a new land-use category* for managed lands with IWMS where the water table has been raised. The guidance in sections pertaining to lands converted to a new land-use category in the *2006 IPCC Guidelines* are to be used.

5.3.2 CH_4 emissions

The guidance provided in Section 5.2.2 also applies to lands converted to a new land-use category for managed lands with IWMS.

5.3.2.1 CHOICE OF METHOD AND EMISSION FACTORS

The guidance provided in Section 5.2.2 also applies to lands converted to a new land-use category for managed lands with IWMS.

5.3.2.2 CHOICE OF ACTIVITY DATA

The activity data consist of areas of managed lands with IWMS in land converted to a new land-use category stratified by land-use category, climate region, soil type, and management practices, at a minimum. The guidance provided in Section 5.2.2 also applies to lands converted to a new land-use category for managed lands with IWMS.

5.3.2.3 UNCERTAINTY ASSESSMENT

The guidance provided in Section 5.2.2 also applies to lands converted to a new land-use category for managed lands with IWMS.

5.4 COMPLETENESS, REPORTING AND DOCUMENTATION

5.4.1 Completeness

It is *good practice* to disaggregate the type of managed lands with IWMS according to national circumstances and employ country-specific emission factors if possible. It is suggested that flooded lands (including reservoirs), peatlands, and coastal wetlands are clearly excluded from land with IWMS and this separation is applied consistently throughout the reporting period.

Guidance not provided for IWMS in this chapter for some lands, some climates, some carbon pools, and some GHGs is the result of lack of relevant data to develop emission factors. Countries are encouraged to develop new research and accounting practices to fill gaps to better account for changes in carbon stocks and GHG emissions and removals from drained wetlands, rewetted wetlands, or created wetlands on lands with IWMS.

General guidance on consistency in time-series is given in Chapter 7 of this Supplement. The classification of land, criteria for using activity data and emission factors and inventory methods should be consistent with the generic methodologies described in Volume 4 of the *2006 IPCC Guidelines* and in this supplement. Chapter 6 in Volume 1 of the *2006 IPCC Guidelines* and Chapter 7 of this supplement provide general guidance on the issues concerning Quality Assurance and Quality Control (QA/QC).

5.4.2 Reporting and Documentation

General guidance on reporting and documentation is given in Chapter 8 of Volume 1 of the *2006 IPCC Guidelines*. Section 7.4.4, Chapter 7, Volume 4 of the *2006 IPCC Guidelines* states the following for reporting and documentation:

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.

Annex 5A.1 Estimation of default stock change factors for long-term cultivated Cropland and rewetting with Inland Wetland Mineral Soil carbon emissions/removals

Default stock change factors are provided in Table 5.3 that were computed using a dataset of experimental results for land-use. The land-use factor for long-term cultivation represents the loss of SOC that occurs after 20 years of continuous cultivation. The rewetting factor represents the effect of the restoration of natural hydrology of cultivated cropland with IWMS (such as through the removal of drainage tiles, or plugging of drainage ditches), which may or may not have continued crop production. The influence of this change on IWMS SOC stocks may continue for a period of time that may extend to 40 years. Experimental data (citations listed below, and provided in reference list) were analysed in linear mixed-effects models, accounting for both fixed and random effects (Ogle *et al.* 2005). Fixed effects included depth and number of years since the management change. For depth, data were not aggregated but included SOC stocks measured for each depth increment (e.g., 0-5 cm, 5-10 cm, and 10-30 cm) as a separate point in the dataset. Similarly, time series data were not aggregated, even though those measurements were conducted on the same plots. Consequently, random effects were used to account for the dependencies in times series data and among data points representing different depths from the same study. If significant, a country level random effect was used to assess an additional uncertainty associated with applying a global default value to a specific country (included in the default uncertainties). The long-term cultivation factor represents the average loss of SOC at 20 years or longer time period following cultivation of IWMS. Users of the Tier 1 method can approximate the annual change in SOC storage by dividing the inventory estimate by 20. The rewetting factor represents the average net gain in SOC after rewetting of cultivated cropland at 20 and 40 years following the first year of rewetting. Variance was calculated for each of the factor values, and can be used with simple error propagation methods or to construct probability distribution functions with a normal density.

TABLE 5A.1.1
STUDIES USED FOR THE DERIVATION OF DEFAULT SOC STOCK CHANGE FACTORS

Study	**Location**	**Stock Change Factor (LC = Long term cultivation; R = Rewetting)**
Badiou *et al.*, 2011	Saskatchewan, Alberta, Manitoba, Canada	LC, R
Ballantine *et al.*, 2009	New York, USA	R
Bedard-Haughn *et al.*, 2006	Saskatchewan, Canada	LC
Besasie *et al.*, 2012	Wisconsin, USA	LC, R
David *et al.*, 2009	Illinois, USA	LC
Euliss *et al.*, 2006	North Dakota, South Dakota, Minnesota,	LC, R
Gleason *et al.*, 2009	North Dakota, USA	R
Huang *et al.*, 2010	Sanjiang Plain, China	LC
Hunter *et al.*, 2008	Louisiana, USA	LC, R
Jacinthe *et al.*, 2001	Ohio, USA	LC
Lu *et al.*, 2007	Lake Taihu, China	LC, R
Meyer *et al.*, 2008	Nebraska, USA	LC, R
Morse *et al.*, 2012	North Carolina, USA	LC
Norton *et al.*, 2011	California, USA	LC
Wang *et al.*, 2012	Sanjiang Plain, China	LC, R
van Wesemael *et al.*, 2010	Belgium	LC

Annex 5A.2 Estimation of CH_4 emission factors for managed lands with Inland Wetland Mineral Soils, or dry mineral soils, where the water table has been raised

The Tier 1 default emission factors in Table 5.4 were derived from the published studies listed in Table 5A.2.1. The number of studies of CH_4 emission from rewetted IWMS as a result of rewetting of drained IWMS, and from wetted mineral soils as a result of wetland creation, is very limited. They are also restricted to the temperate climate regions. Thus studies of CH_4 emission from natural IWMS were included to derive emission factors from boreal and tropical regions, and to supplement the number of studies in the temperate region. Studies varied in their reporting of emissions; some reported annual fluxes, while others reported seasonal fluxes or mean daily fluxes. In the case of seasonal or daily flux reporting, an annual flux was estimated by assuming no emission occurred during cold seasons and/or by applying mean daily fluxes to part or all of the annual period depending on climate region and/or specific recommendation by study authors.

TABLE 5A.2 .1

CH_4 EMISSIONS FROM RESTORED AND CREATED WETLANDS WITH IWMS WHERE WATER TABLE LEVEL HAS BEEN RAISED, AND NATURAL WETLANDS, USED TO DERIVE DEFAULT VALUE FOR EF_{CH4}

Climate region	Wetland type	Location	Annual period of inundation	CH_4 emission (kg CH_4 ha^{-1} yr^{-1})	CH_4 Flux measurement method	CH_4 Flux reported	Reference
Boreal	Natural wetlands	Canada	unspecified	76	Chamber, EC	Annual	Bridgham *et al.*, 2006
Temperate	Restored wetlands, previous use Cropland	Canada	Intermittent	49	Chamber	Mean daily	Badiou *et al.*, 2011
Temperate	Restored wetlands, previous use Cropland	Canada	Intermittent	349	Chamber	Annual (modified for diurnal variation as stated in study)	Pennock *et al.*, 2010
Temperate	Restored wetlands, previous use Cropland	North Dakota, USA	Intermittent	142	Chamber	Mean daily	Gleason *et al.*, 2009
Temperate	Restored wetlands, previous use Cropland	North Carolina, USA	Intermittent	7	Chamber	Annual	Morse *et al.*, 2012
Temperate	Restored wetland, previous use Cropland	Denmark	Intermittent	110	EC	Annual (minus emissions from cattle on-site as stated in study)	Herbst *et al.*, 2011
Temperate	Created wetlands, riparian	China	Intermittent	13	Chamber	Annual (diffusive and ebullitive fluxes combined)	Yang *et al.*, 2012
Temperate	Created wetlands	Ohio, USA	Continuous	402	Chamber	Annual (mean of two different years from same site)	Nahlik and Mitsch, 2010; Altor and Mitsch, 2008
Temperate	Natural wetland, marsh	Nebraska	Continuous	800	EC	Annual	Kim *et al.*, 1999

Temperate	Natural wetlands, marshes	Sanjiang Plain, NE China	Continuous	468	Chamber	Annual	Ding and Cai, 2007
Temperate	Natural wetlands, *Carex* marshes	Sanjiang Plain, NE China	Continuous	434	Chamber	Annual (as reported in Ding and Cai, 2007)	Song *et al.*, 2003
Temperate	Natural wetland, riparian	Ohio, USA	Continuous	758	Chamber	Annual	Nahlik and Mitsch, 2010
Temperate	Natural wetlands, *Deyeuixa* marshes	Sanjiang Plain, NE China	Intermittent	289	Chamber	Annual (as reported in Ding and Cai, 2007)	Song *et al.*, 2003
Temperate	Natural wetlands, riparian	Georgia, USA	Intermittent	226	Chamber	Annual	Pulliam, 1993
Temperate	Natural wetlands, marshes	Sanjiang Plain, NE China	Intermittent	225	Chamber	Annual	Huang *et al.*, 2010
Temperate	Natural wetlands, marsh	Sanjiang Plain, NE China	Intermittent	58	Chamber	Annual	Song *et al.*, 2009
Temperate	Natural wetlands, shrub swamp	Sanjiang Plain, NE China	Intermittent	3	Chamber	Annual	Song *et al.*, 2009
Temperate	Natural wetlands, swamps	Global	Intermittent	113	Chamber	Mean daily	Bartlett and Harriss, 1993
Temperate	Natural wetlands, marshes	Global	Intermittent	105	Chamber	Mean daily	Bartlett and Harriss, 1993
Temperate	Natural wetlands, floodplains	Global	Intermittent	72	Chamber	Mean daily	Bartlett and Harriss, 1993
Temperate	Natural wetlands	Continental USA	unspecified	76	Chamber, EC	Annual	Bridgham *et al.*, 2006
Tropical	Natural wetlands, rainforest swamp	Costa Rica	Continuous	2930	Chamber	Annual	Nahlik and Mitsch, 2011
Tropical	Natural wetlands, alluvial marsh	Costa Rica	Intermittent	3500	Chamber	Annual	Nahlik and Mitsch, 2011
Tropical	Natural wetlands, swamps	Global	Intermittent	297	Chamber	Mean daily	Bartlett and Harriss, 1993
Tropical	Natural wetlands, marshes	Global	Intermittent	419	Chamber	Mean daily	Bartlett and Harriss, 1993

Tropical	Natural wetlands, floodplains	Global	Intermittent	328	Chamber	Mean daily	Bartlett and Harriss, 1993
Tropical	Natural wetlands, floodplains	Amazon, Upper Negro Basin	Intermittent	54	Chamber, Ebullition funnel	Annual	Belger *et al.*, 2011
Tropical	Natural wetlands, floodplains	Pantanal, Brazil (Arara-Azul)	Intermittent	516	Chamber	Mean daily	Marani and Alvala, 2007
Tropical	Natural wetlands, floodplains	Pantanal, Brazil (Bau)	Intermittent	1033	Chamber	Mean daily	Marani and Alvala, 2007
Tropical	Natural wetlands, floodplains	Pantanal, Brazil (Sao Joao)	Intermittent	510	Chamber	Mean daily	Marani and Alvala, 2007
Tropical	Natural wetlands, flooded forests	Solimoes/Amazon floodplain	Intermittent	567	Chamber	Annual (as reported in Melack et al., 2004)	Melack and Forsberg, 2001
Tropical	Natural wetlands, aquatic macrophytes	Solimoes/Amazon floodplain	Intermittent	184	Chamber	Annual (as reported in Melack et al., 2004)	Melack and Forsberg, 2001
Tropical	Natural wetlands, flooded forests	Jau River basin floodplains/Amazon	Intermittent	306	Chamber	Annual (as reported in Melack et al., 2004)	Rosenqvist *et al.*, 2002
Tropical	Natural wetlands, floodplains	Mojos basin/Amazon	Intermittent	948	Chamber	Annual	Melack *et al.*, 2004
Tropical	Natural wetlands, floodplains	Roraima/ Amazon	Intermittent	1341	Chamber	Annual	Melack *et al.*, 2004
Tropical	Natural wetlands, floodplains	Bananal	Intermittent	954	Chamber	Annual	Melack *et al.*, 2004
Tropical	Natural wetlands, floodplains	Orinoco	Intermittent	951	Chamber	Annual	Melack *et al.*, 2004
Tropical	Natural wetlands, floodplains	Pantanal	Intermittent	949	Chamber	Annual	Melack *et al.*, 2004
Tropical	Natural wetlands, flooded forest,	Solimoes/Amazon floodplain	Continuous & Intermittent	404	Chamber	Annual	Melack *et al.*, 2004

The climate region with the greatest number of studies is the temperate region, including natural and created/rewetted wetlands, and sites under continuous inundation and intermittent inundation. We tested for differences in CH_4 emission factors between wetland types (natural vs. created/rewetted) and hydrologic regime (continuous vs. intermittent inundation) using paired Student's t-test, two-tailed, at a significance level of $\alpha=0.05$ to: 1) determine whether it is valid to include studies of natural wetlands in the development of CH_4 emission factors from created/rewetted wetlands, and 2) determine whether there is a significant difference in CH_4 emission between continuously and intermittently inundated wetlands.

There is no significant difference in the CH_4 emissions for natural vs. created/rewetted wetlands located in temperate regions (Table 5A2.2; t-test value = 0.24). Therefore the inclusion of studies of natural wetlands in the development of the CH_4 emission factors for created/rewetted wetlands on IWMS is valid for temperate regions. There are not enough studies on created/rewetted wetlands on IWMS in the boreal or tropical regions to do the same analysis; we make the assumption that there is similarly no significant difference between CH_4 emissions from natural and created/rewetted wetlands in boreal or tropical regions, and thus we include studies of natural wetlands in the development of the CH_4 emission factors.

TABLE 5A.2.2

CH_4 EMISSIONS FROM TEMPERATE, CREATED/REWETTED WETLANDS AND NATURAL WETLANDS WITH IWMS

Climate region	Wetland type	Mean CH_4 emission ($kg\ CH_4\ ha^{-1}\ yr^{-1}$)	Standard deviation	95% confidence interval^A	Number of studies
Temperate	Created/Rewetted	153	160	±148	7^B
	Natural	136	99	±83	8^C

Note: Values are derived from studies of temperate wetlands listed in Table 5A2.1.

A The 95% confidence interval is calculated from the mean, standard deviation, and the critical values of t distribution according to the degrees of freedom.

B The studies used to determine this value are listed in Table 5A2.1; Altor and Mitsch, 2008 *and* Nahlik and Mitsch, 2010 (mean value for the same system determined by two studies); Gleason et al., 2009; Pennock et al., 2010; Badiou et al., 2011; Herbst et al., 2011; Morse et al., 2012; Yang et al., 2012.

C The studies used to determine this value are listed in Table 5A2.1; Pulliam, 1993; Bartlett and Harriss, 1993 (n=3 wetland types); Song et al., 2003; Song et al., 2009 (n=2 wetland types); Huang et al., 2010.

There is a significant difference in CH_4 emissions for temperate region wetlands (created/rewetted and natural wetlands are combined) under the two hydrologic regimes (Table 5A2.2; t-test value = 6.47, $p<0.0001$). This highlights the importance of period of inundation in annual CH_4 emission (Table 5A.2.3). The development of country-specific emission factors that incorporate period of inundation will reduce uncertainties.

TABLE 5A.2.3

CH_4 EMISSIONS FROM TEMPERATE, REWETTED, CREATED AND NATURAL WETLANDS WITH IWMS, STRATIFIED BY PERIOD OF INUNDATION

Climate region	Annual period of inundation	Mean CH_4 emission ($kg\ CH_4\ ha^{-1}\ yr^{-1}$)	Standard deviation	95% confidence interval^A	Number of studies
Temperate	Continuous	572	191	±125	5^B
	Intermittent	126	108	±75	14^C

Note: Values are derived from studies of Temperate wetlands listed in Table 5A.2.1.

A The 95% confidence interval is calculated from the mean, standard deviation, and the critical values of t distribution according to the degrees of freedom.

B The studies used to determine this value are listed in Table 5A2.1; Kim et al., 1998; Song et al., 2003 (*Carex* marshes); Ding and Cai, 2007; Altor and Mitsch, 2008*;* Nahlik and Mitsch, 2010.

C The studies used to determine this value are listed in Table 5A2.1; Pulliam, 1993; Bartlett and Harriss, 1993 (n=3 wetland types); Song et al., 2003 (*Deyeuxia* marshes); Song et al., 2009 (n=2 wetland types); Huang et al., 2010; Badiou et al., 2011; Pennock et al., 2010; Gleason et al., 2009; Morse et al., 2012; Herbst et al., 2011; Yang et al., 2012.

Appendix 5a.1 Future methodological development

Lands with IWMS occupy significant areas in some countries and are important carbon stock compartments. Conversion of this land to other uses and management practices potentially affect these stocks. However, at the time of preparation of this supplement, except for changes in SOC stocks and CH_4 emissions for rewetted/created wetlands on lands with IWMS, and changes in SOC stocks as a result of long-term cultivation and rewetting on Croplands with IWMS, little information was available to provide emission factors specific to different land-uses and management practices, or to derive emission factors for N_2O.

Particular effort should be employed to differentiate multiple uses on lands with IWMS (e.g., wetland forest, wetland grasslands) for future methodological improvements. A good example of the methodological approach necessary for this task can be found in the United States Fish and Wildlife Service Report to the Congress (Dahl, 2011). This document describes how wetland inventories have been made in the United States and, although not providing figures for SOC stock changes, gives reference for future work to obtain such data with the National Wetland Condition Assessment (NWCA), with methods described in detail at www.epa.gov/wetlands/survey. Another example of a methodological approach for assessing carbon stocks and GHG fluxes at a national level is found in a United States Geological Survey Scientific Investigations Report 2010 (Zhu *et al.*, 2010). While this document describes SOC stock changes and GHG emissions from managed and unmanaged lands, it may serve as a useful example for a national-level carbon assessment. Synthetically, surveys to quantify the areas of land on IWMS under different land-use and management practices in conjunction with carbon pool quantification allows the future use of general equations for carbon stock-changes described in the *2006 IPCC Guidelines*.

Other databases are available that have flux information (mainly CO_2 measured with the eddy covariance technique) at the ecosystem level, including IWMS (e.g., www.ghg-europe.eu, fluxnet.ornl.gov, ameriflux.ornl.gov, www.tern-supersites.net.au, fluxnet.ccrp.ec.gc.ca).

New research is needed to fill a number of gaps for IWMS. Additional studies are needed to evaluate the effect of IWMS conversion on SOC stock changes following conversion to Grassland, Forest Land, Settlements and Other Land. Moreover, new research is needed to understand the effect of IWMS conversion on other carbon stocks (biomass, dead organic matter) as well as CH_4 and N_2O fluxes. Although we were able to develop guidance for IWMS CH_4 fluxes for some climate regions, specific guidance for climate and region combinations would improve our estimates of CH_4 fluxes. New research assessing N_2O fluxes following conversion of IWMS to other land-uses, especially Cropland, would add considerably to our ability to assess GHG impacts and develop Tier 2 methods for GHG fluxes. N_2O emissions from IWMS are typically very low, unless there is a significant input of organic or inorganic nitrogen from runoff. Such inputs typically result from anthropogenic activities such as agricultural fertilizer application (Hefting *et al.*, 2006; Phillips and Beeri, 2008; DeSimone *et al.*, 2010), or Grassland management (Chen *et al.*, 2011; Oates *et al.*, 2008; Liebig *et al.*, 2012; Jackson *et al.*, 2006; Holst *et al.*, 2007; Walker *et al.*, 2002). The review of the current literature suggests there is insufficient data to provide robust emission factors and methodology to estimate N_2O emissions from IWMS at this time. We suggest that N_2O emissions be more thoroughly addressed in future updates of this guidance as research on this topic progresses. For future methodological improvement of N_2O emission factors, it is important to avoid double-counting N_2O emissions already accounted for properly according to *2006 IPCC Guidelines,* Chapter 11.

Fully functional models that consider the influence of changes in hydrology on carbon cycling and GHG fluxes cannot be developed or tested until more databases are available for IWMS. Process-based models like Wetland-DNDC (Zhang *et al.*, 2002) have substantial capabilities but have not been tested or calibrated across IWMS. Future model testing and development on IWMS could lead to Tier 3 approaches for IWMS.

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CHAPTER 6

CONSTRUCTED WETLANDS FOR WASTEWATER TREATMENT

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6 CONSTRUCTED WETLANDS FOR WASTEWATER TREATMENT

6.1 INTRODUCTION

6.1.1 Constructed Wetlands for Wastewater Treatment

Wetland ecosystems can act as sources, sinks, or transformers of nutrients and carbon (C) (Mitsch and Gossenlink, 1993). This ability of wetlands has led to a widespread use of natural and constructed wetlands (CWs) for water quality improvement (Brix, 1997).

Constructed wetlands systems are fully human-made wetlands for wastewater treatment, which apply various technological designs, using natural wetland processes, associated with wetland hydrology, soils, microbes and plants. Thus, CWs are engineered systems that have been designed and constructed to utilize the natural processes involving wetland vegetation, soils, and their associated microbial assemblages to assist in treating wastewater. Synonymous terms to “constructed” include “man-made”, “engineered” or “artificial” (Vymazal, 2007).

"Semi-natural treatment wetlands" (SNTWs) for wastewater treatment are natural wetland systems that have been modified for this purpose. The modifications made within these systems usually are based on increasing the volume of water reserved (i.e. dams) and constructing channels for targeting the influent and effluent. These systems can be found in both freshwater and coastal wetlands. The functioning of SNTWs is similar to that of surface flow CWs.

This chapter only provides guidance for CWs and SNTWs for wastewater treatment. Decision tree for finding the appropriate guidance chapter within this supplement or the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (*2006 IPCC Guidelines*) is provided as Figure 1.1 in Chapter 1 of this supplement.

It is *good practice* that reporting of emissions from wastewater treatment be complete, covering all domestic and industrial wastewater. CW is a wastewater treatment pathway not described specifically in *2006 IPCC Guidelines*. It is *good practice* that countries apply the guidance in this chapter on ‘constructed wetlands’, if emissions from CWs represent a key wastewater treatment pathway. In accordance with Chapter 4 of Volume 1, those subcategories that together contribute more than 60 percent to a *key category* should be treated as significant[1]. When wastewater treatment is identified as a *key category*, key pathways are identified in the same way as significant subcategories. In case countries have access to data and information on wastewater treatment by CWs, it is a *good practice* to use this guidance to estimate emissions from CWs.

Emissions from CWs and SNTWs must be reported in waste sector. If freshwater and coastal wetlands are modified to SNTWs, inventory compilers should check with relevant land-use category in this supplement to avoid double-counting. Constructed wetlands and SNTWs can be used to improve the quality of collected wastewater including domestic wastewater, industrial wastewater such as wastewater from processing factories of agricultural products and dairy farm, collected runoff from agricultural land and leachate from landfill. For some wastewaters, CWs are the sole treatment; for others, they are one component in a sequence of treatment processes (US EPA, 1995).

There are various types of CWs used for treatment of wastewater, and the following paragraphs highlight the main classification of CWs.

TYPE OF CONSTRUCTED WETLANDS FOR WASTEWATER TREATMENT

Constructed wetlands may be categorized according to the various design parameters, but the three most important criteria are hydrology (water surface flow and subsurface flow), macrophyte growth form (emergent, submerged, free-floating, and floating leaved plants) and flow path (horizontal and vertical) (see Figure 6.1; Vymazal 2007, 2011). Different types of CWs may be combined (which are called hybrid or combined systems) to utilize the specific advantages of the different systems. For instance, to guarantee more effective removal of ammonia and total nitrogen (N), during the 1990s and 2000s an enhanced design approach combined vertical and horizontal flow CWs to achieve higher treatment efficiency (Vymazal, 2011).

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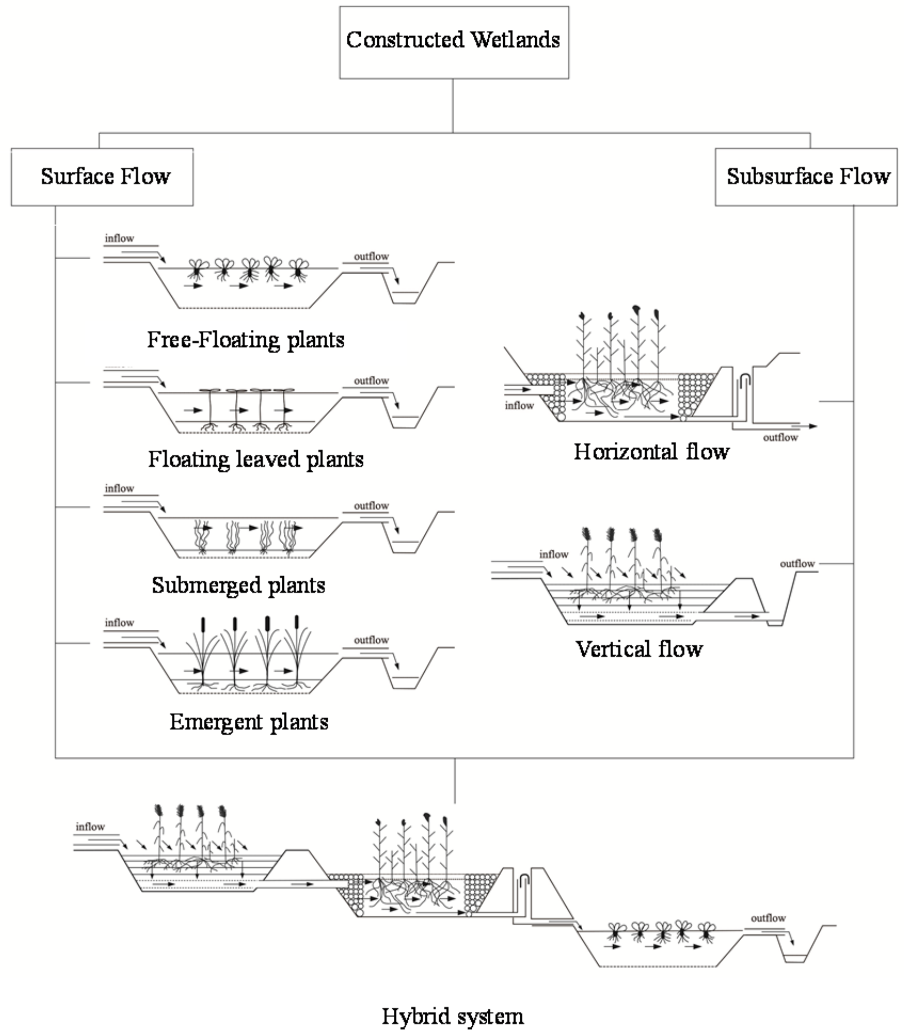
[1] An assessment of significance can be based on expert judgment following the protocol described in Annex 2A.1 of Chapter 2, Volume 1 of *2006 IPCC Guidelines* (Protocol for Expert Elicitation). Information concerning the percentage of population connected to wastewater treatment, which may facilitate expert judgment can be obtained from international sources (notably UNSTAT or FAO).

Figure 6.1 Classification and configuration of constructed wetlands for wastewater treatment



Note: Adapted from Vymazal, 2007, 2011. Lower part is original. Most of SNTWs represent surface flow type wetlands.

Constructed Wetlands with Surface Flow

Constructed wetlands with *surface flow* (SF), known as *free water surface CWs*, contain areas of open water and floating, submerged, and emergent plants (Kadlec and Wallace 2008). The shallow water depth, low flow velocity, and presence of the plant stalks and litter regulate water flow and, especially in long, narrow channels (Crites *et al*. 2005), ensure better water purification. The most common application for SF CWs is for tertiary treatment of municipal wastewater and also for stormwater runoff and mine drainage waters (Kadlec and Knight 1996; Kadlec and Wallace 2008). SF CWs are suitable in all climates, including the far north (Mander and Jenssen 2003).

Constructed Wetlands with Subsurface Flow

In *horizontal subsurface flow constructed wetlands* (HSSF CWs), the wastewater flows from the inlet and flows slowly through the porous medium under the surface of the bed planted with emergent vegetation to the outlet where it is collected before leaving via a water level control structure (Vymazal *et al*., 1998). During passage the wastewater comes into contact with a network of aerobic, anoxic, and anaerobic zones. Most of the bed is anoxic/anaerobic due to permanent saturation of the beds. The aerobic zones occur around roots and rhizomes that leak oxygen into the substrate (Brix 1987). HSSF CWs are commonly sealed with a liner to prevent seepage and to ensure the controllable outflow. HSSF CWs are commonly used for secondary treatment of municipal wastewater but many other applications have been reported in the literature (Vymazal and Kröpfelova 2008). The oxygen transport capacity in these systems is insufficient to ensure aerobic decomposition, thus, anaerobic processes play an important role in HSSF CWs (Vymazal and Kröpfelova 2008). Some HSSF CWs, having the ability to insulate the surface of the bed, are capable of operation under colder conditions than SF systems (Mander and Jenssen 2003).

Vertical subsurface flow constructed wetlands (VSSF CWs) comprise a flat bed of graded gravel topped with sand planted with macrophytes. VSSF CWs are fed with large intermittent wastewater flows, which flood the surface of the bed, then percolate down through the bed and are collected by a drainage network at the bottom. The bed drains completely which allows air to refill the bed. Thus, VSSF CWs provide greater oxygen transfer into the bed, producing a nitrified (high NO_3^-) effluent (Cooper *et al.*, 1996; Cooper 2005). Consequently, VSSF CWs do not provide suitable conditions for denitrification to complete conversion to gaseous nitrogen forms, which then escape to the atmosphere.

In recently developed tidal (“fill and drain”) flow systems better contact of wastewater with the microorganisms growing on the media is guaranteed. This significantly enhances the purification processes (Vymazal 2011).

Hybrid Constructed Wetlands

Various types of CWs can be combined to achieve higher removal efficiency, especially for nitrogen. The design consists of two stages, several parallel vertical flow (VF) beds followed by 2 or 3 horizontal flow (HF) beds in series (VSSF-HSSF system). The VSSF wetland is intended to remove organics and suspended solids and to promote nitrification, while in HSSF wetland denitrification and further removal of organics and suspended solids occur.

Another configuration is a HSSF-VSSF system. The large HSSF bed is placed first to remove organics and suspended solids and to promote denitrification. An intermittently loaded small VF bed is used for additional removal of organics and suspended solids and for nitrification of ammonia into nitrate. To maximize removal of total N, however, the nitrified effluent from the VF bed must be recycled to the sedimentation tank (Vymazal 2011).

The VSSF-HSSF and HSSF-VSSF CWs are the most common hybrid systems, but in general, any kind of CWs could be combined to achieve higher treatment effect (Vymazal 2007).

GREENHOUSE GASES EMISSIONS FROM VARIOUS TYPES OF CONSTRUCTED WETLANDS

Emissions of greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O) are a byproduct of CWs, the importance of which has been increasing recently. Methane is produced in methanogenesis whereas N_2O is a product of denitrification and/or nitrification of N compounds by microorganisms. Among several environmental factors controlling the greenhouse gases emissions, availability of C and nutrients (especially N) which directly depend on wastewater loading, temperature, hydrological regime (pulsing vs steady-state flow), groundwater depth, moisture of filter material (water filled soil pores (WFSP)), and presence of aerenchyma plants play a significant role (see Table 6.1).

Soil temperature, oxidation reduction potential and the soil moisture (WFSP, depth of ground water level) are the most significant factors affecting emissions of CH_4 from CWs (Mander *et al.*, 2003; Van der Zaag *et al.*, 2010). Several investigations show that a water table deeper than 20 cm from the surface of wetlands and/or water-logged soils oxidizes most CH_4 fluxes (Soosaar *et al.*, 2011; Salm *et al.*, 2012). Fluxes of N_2O, however do not show a clear correlation with soil/air temperature, and significant emissions of N_2O from CWs have been observed in winter (Søvik *et al.*, 2006). Likewise, freezing and thawing cycles enhance N_2O emissions (Yu *et al.*, 2011). Hydrological regime also plays a significant role in greenhouse gases emissions from CWs. Altor and Mitsch (2008) and Mander *et al.*, (2011) demonstrated that the intermittent loading (pulsing) regime and fluctuating water table in CWs enhance CO_2 emissions and significantly decrease CH_4 emissions. N_2O emissions, in contrast, do not show a clear pattern regarding pulsing regime.

Table 6.2 shows CH_4 and N_2O conversion rates derived from the relationship between the initial (input) C and N loadings and respective CH_4 and N_2O emissions from the main types of CWs. There is a significant positive correlation ($p < 0.05$) between the initial loadings and CH_4 and N_2O emissions from both SF and VSSF CWs, whereas no correlation was found for HSSF types. Seemingly, high variability of conditions and combination of several factors in HSSF CWs may be the reason for that. The limited number of available data did not allow derivation of reliable relationships for HSSF CWs. These shares (%) can be used as a base for the calculation of emission factors for Tier 1 and Tier 2 methodologies. The high emission factor for CH_4 in SF CWs (Table 6.4) is thought to be due to the additional CH_4 from sediments accumulated at the bottom of SF CWs.

TABLE 6.1
SELECTED FACTORS IMPACTING CH_4 AND N_2O EMISSIONS IN CONSTRUCTED WETLANDS

Factors/processes	CH_4	N_2O
Higher water/soil/air temperature	Increase in almost all cases [1-6] with few exceptions [7]	No clear relationship [1-4, 7, 8]
Higher moisture of soil or filter material (higher value of WFSP)	Clear increase [9, 10]	Decrease [9, 10]
Higher wastewater loading	Increase [1-4, 11, 12]	Increase [1, 2, 4, 13]
Presence of aerenchymal plants	Increase [14-16] Decrease (depends on conditions) [17]	Increase [16, 18] Decrease [16, 19]
Pulsing hydrological regime (intermittent loading)	Clear decrease [9, 20]	Increase [9, 21, 22] Decrease in some SF CWs [23]
Deeper water table (from surface) in HSSF CWs	Decrease [9, 10]	Increase [9, 10]

Source:

[1] Mander and Jenssen 2003; [2] Mander *et al*., 2005; [3] Teiter and Mander 2005; [4] Søvik *et al*., 2006; [5] Kayranli et al., 2010; [6] Van der Zaag *et al*., 2010; [7] Søvik and Kløve 2007; [8] Fey *et al*., 1999; [9] Mander *et al*., 2011; [10] Yang *et al*., 2013; [11] Tanner *et al*., 1997; [12] Tai *et al*., 2002; [13] Hunt *et al*., 2009; [14] Inamori *et al*., 2007; [15] Inamori *et al*., 2008; [16] Wang *et al*., 2008; [17] Maltais-Landry *et al*., 2009; [18] Rückauf *et al*., 2004; [19] Silvan *et al*., 2005; [20] Altor and Mitsch 2008; [21] Jia *et al*., 2011; [22] Van de Riet *et al*., 2013; [23] Hernandez and Mitsch 2006

TABLE 6.2
INFLUENT TOTAL ORGANIC CARBON (TOC) AND TOTAL NITROGEN (TN) VALUES, RELEVANT CH_4-C AND N_2O-N EMISSIONS, AND SHARE (%) OF CH_4-C AND N_2O-N IN THE INITIAL LOADING OF TOC AND TN IN CONSTRUCTED WETLANDS

Type of CW	Influent TOC* (mg C m^{-2} h^{-1})	CH_4-C emission* (mg CH_4-C m^{-2} h^{-1})	CH_4-C/ TOC** (%)	Influent TN* (mg N m^{-2} h^{-1})	N_2O-N emission* (mg N_2O-N m^{-2} h^{-1})	N_2O-N/TN** (%)
SF	1.04-173.6 (10) [1-11]	0.15-181.0 (10.7) [1-11]	42 (20)	0.76-202.8 (12) [2, 3, 6-11, 21-23]	0.009-0.65 (0.03) [2, 6-11, 21-23]	0.13 (0.02)
HSSF	15.0-2190.2 (177) [8, 10-12, 15-20]	0.048-17.5 (1.7) [8, 10, 11, 15-20]	12 (6.9)	1.04-295.20 (40) [6, 10, 12, 15-17, 24, 25]	0.014-0.89 (0.10) [6, 10-12, 15-17, 25]	0.79 (0.4)
VSSF	17.88-1417.50 (317) [6, 8, 10, 12]	0.3-5.4 (1.3) [6, 8, 10, 12]	1.17 (0.33)	102.5-2105.0 (155) [6, 8, 10, 12-14]	0.033-0.424 (0.03) [6, 8, 10, 11, 12-14]	0.023 (0.005)

* Range and standard error (in bracket)

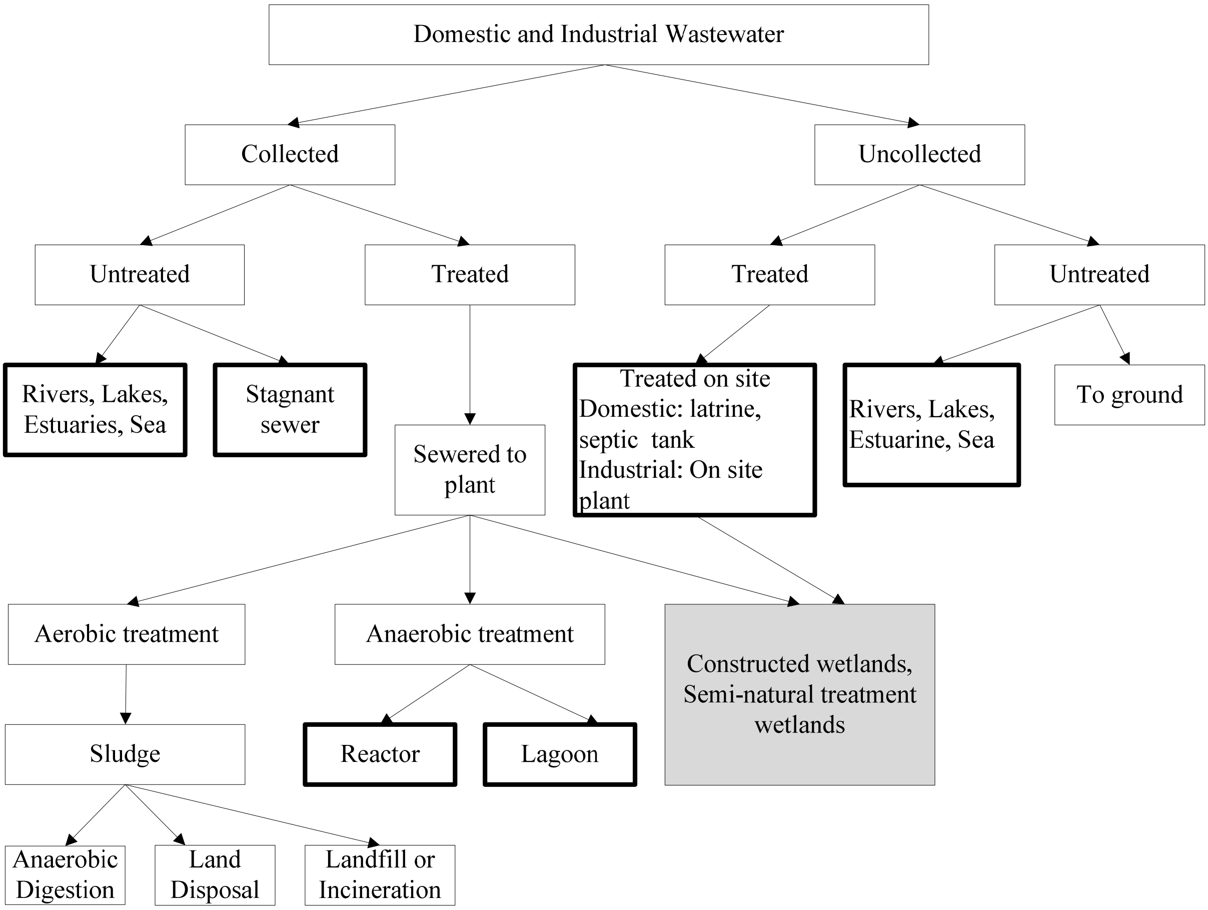
** Average and standard error (in bracket)

Source: [1] Tanner *et al*., 1997; [2] Wild *et al*., 2001; [3] Tai *et al*., 2002; [4] Johansson *et al*., 2004; [5] Stadmark and Leonardson 2005; [6] Søvik *et al.*, 2006; [7] Søvik and Kløve 2007; [8] Gui *et al*., 2007; [9] Ström *et al*., 2006; [10] Liu *et al*., 2009; [11] Van der Zaag *et al*., 2010; [12] Teiter and Mander 2005; [13] Inamori *et al*., 2007; [14] Wang *et al*., 2008; [15] Mander *et al*., 2003; [16] Mander *et al*., 2008, [17] Liikanen *et al*., 2006; [18] Garcia *et al*., 2007; [19] Picek *et al*., 2007; [20] Chiemchaisri *et al*., 2009; [21] Xue *et al*., 1999; [22] Johansson *et al*., 2003; [23] Wu *et al*., 2009; [24] Inamori *et al*., 2008; [25] Fey *et al*., 1999

6.1.2 Relation to 2006 IPCC Guidelines

This chapter is a supplement to Chapter 6 Wastewater Treatment and Discharge of the Volume 5 of the *2006 IPCC Guidelines.* The *2006 IPCC Guidelines* include a section to estimate CH_4 emissions from uncollected wastewater. This *Wetlands Supplement* includes guidance on estimation of CH_4 and N_2O emissions from CWs and SNTWs. Emission factors of CH_4 and N_2O emissions from CWs and SNTWs treating industrial wastewater are the same as those treating domestic wastewater. CO_2 emissions are not included in greenhouse gases emissions from wastewater treatment as CO_2 from wastewater is considered biogenic.

Figure 6.2 Wastewater treatment systems and discharge pathways



Note: This figure was modified from the *2006 IPCC Guidelines*. Emissions from boxes with bold frames are accounted for in the *2006 IPCC Guidelines*. This supplement provides emission factors for gray-colored box: CWs and SNTWs for treatment of collected- and uncollected wastewater.

Coverage of wastewater types and gases

Chapter 6 of the Volume 5 of the *2006 IPCC Guidelines* provides guidance on estimation of CH_4 and N_2O emissions from domestic wastewater with emission factors based on treatment technology. Constructed wetlands in this supplement are an additional treatment technology. The emission factors provided in this chapter cover CWs and SNTWs (collected/uncollected and treated; see Figure 6.2).

The methodology is provided for estimation of CH_4 and N_2O emissions from both domestic and industrial wastewater (Table 6.3). The indirect N_2O emissions from N leaching and runoff from agricultural land are covered in Chapter 11, Volume 4 of the *2006 IPCC Guidelines*. Emissions from processing factories of agricultural products and dairy farm wastewater, collected runoff from agricultural land and leachate from landfill are considered as industrial wastewater. According to Chapter 3 of the Volume 5 in the *2006 IPCC Guidelines*, all amount of degradable organic carbon (DOC) in solid waste is subjected to estimation of CH_4 in landfill site, and carbon loss with leachate is not considered because of its low percentage. That means that CH_4 emissions from leachate treatment are already covered, and are not included in Section 6.2, while N_2O emissions are considered in Section 6.3 of this supplement. If CH_4 emission from CWs is accounted, the amount of DOC in leachate must be subtracted from that in solid waste to avoid double counting. Because C in leachate is normally indicated in terms of COD, conversion rate from COD in leachate to TOC in solid waste is required in order to subtract the amount of DOC entering CWs from that in solid waste. This logic can be applied in Tier 2 or 3 estimation.

TABLE 6.3
COVERAGE OF WASTEWATER TYPES AND GREENHOUSE GAS EMISSIONS FROM CONSTRUCTED WETLANDS

Type of Wastewater	Methane	Nitrous oxide
Domestic wastewater	Included in this supplement (section 6.2) with provision of methane correction factors (MCFs)	Included in this supplement (Section 6.3) with provision of default emission factors
Industrial wastewater including wastewater from processing factories of agricultural products and dairy farm *	Included in this supplement (Section 6.2) with provision of MCFs	Included in this supplement (Section 6.3) with provision of default emission factors
Collected runoff from agricultural land	Emissions can be calculated using same methodology as industrial wastewater and are covered in this supplement (Section 6.2)	Emissions can be calculated using same methodology as industrial wastewater and are covered in this supplement (Section 6.3) Note: Indirect N_2O emissions from N leaching and runoff from agricultural land are considered in Chapter 11, Volume 4 of the *2006 IPCC Guidelines*. If agricultural runoff is collected and treated by CWs or SNTWs, the amount of N flows into CWs or SNTWs must be subtracted to avoid double counting.
Leachate from landfill	The amount DOC leached from the solid waste disposal site is not considered in the estimation of DOC_f. Generally the amount of DOC lost with the leachate are less than 1 percent and can be neglected in the calculations (Chapter 3, Volume 5, *2006 IPCC Guidelines*) and not considered in this supplement	Emissions can be calculated using same methodology as industrial wastewater and are covered in this supplement (Section 6.3)

*Dairy farm wastewater does not cover manure itself but comes from other activities in the farm.

6.2 METHANE EMISSIONS FROM CONSTRUCTED WETLANDS

6.2.1 Methodological issues

Methane emissions are a function of the organic materials loaded into CWs and an emission factor.

Three tiers of methods for estimation of CH_4 from CWs are summarized below.

The Tier 1 method applies default values for the emission factor and activity parameters. This method is considered *good practice* for countries with limited data.

The Tier 2 method follows the same method as Tier 1 but allows for incorporation of country-specific emission factor and country-specific activity data. For example, a specific emission factor based on field measurements can be incorporated under this method.

The Tier 3 method is used by countries with good data and advanced methodologies. A more advanced country-specific method could be based on treatment system-specific data such as plant species, climate, temperature, seasonal effects and composition of wastewater.

In general anaerobic conditions occur in CWs. However, CH_4 generated by CWs is not usually recovered and combusted in a flare or energy device, and so CH_4 recovery is not considered here.

The amount of vegetation harvested from CWs is generally very small and its impact on total emissions from CWs is considered insignificant. Moreover, the harvesting is usually not performed on regular basis and the quantity of harvested biomass is commonly not recorded so it is not considered in this supplement.

6.2.1.1 CHOICE OF METHOD

A decision tree for domestic or industrial wastewater is shown in Figure 6.3.

The general equation to estimate CH_4 emissions from CWs treating domestic or industrial wastewater is given in Equation 6.1.

EQUATION 6.1

CH_4 EMISSIONS FROM CONSTRUCTED WETLANDS

$$CH_4Emissions = \sum_{j} \left(TOW_j \cdot EF_j\right) + \sum_{i,j} \left(TOW_{i,j} \cdot EF_j\right)$$

Where:

CH_4 emissions = CH_4 emissions in inventory year, kg CH_4/yr

TOW_j = total organics in wastewater entering CW in inventory year, kg BOD/yr or kg COD/yr

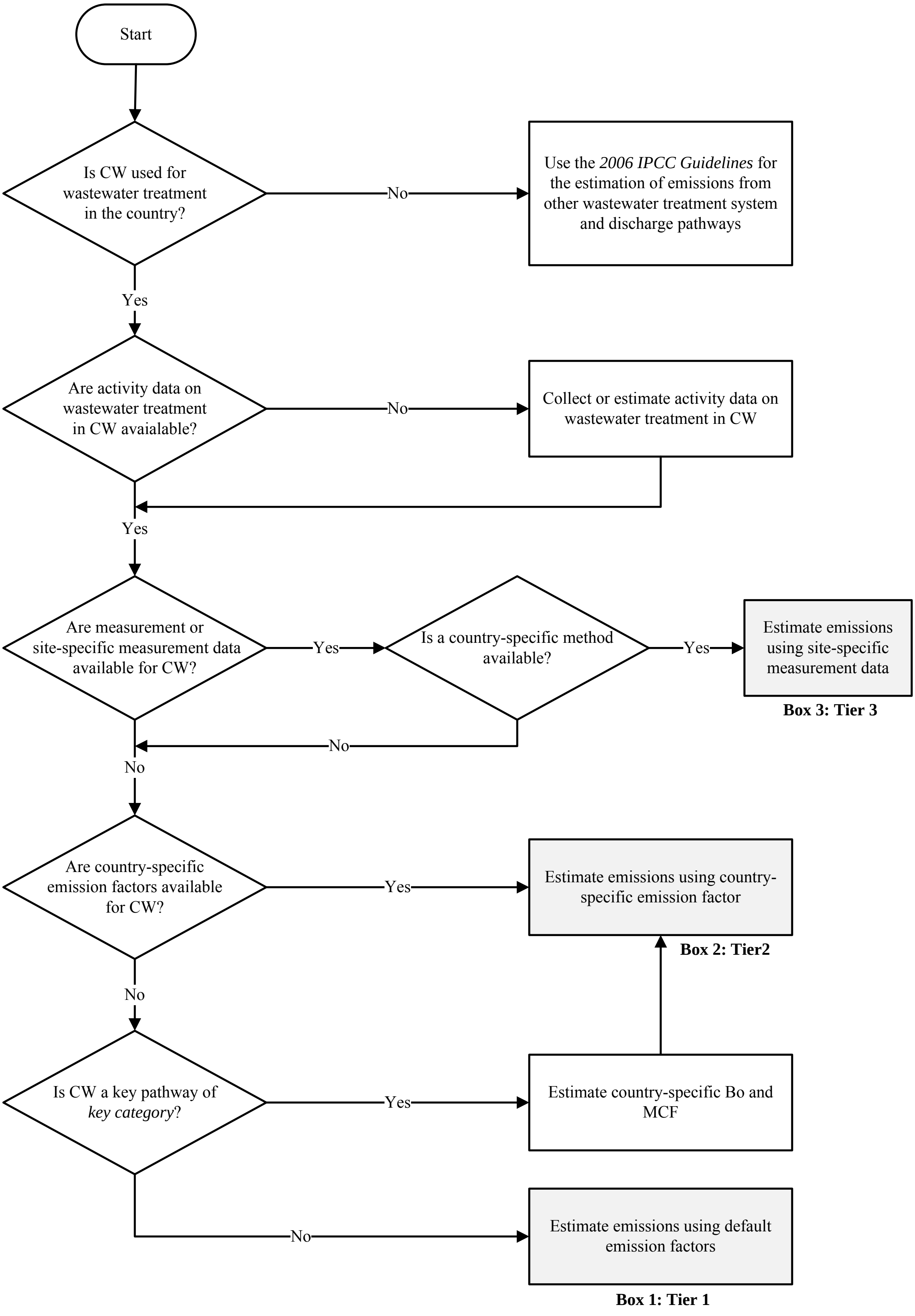
EF_j = emission factor, kg CH_4/kg BOD (for domestic wastewater only) or kg CH_4/kg COD (for both domestic and industrial wastewater)

If more than one type of CW is used in an industrial sector this factor would need to be a $TOW_{i,j}$-weighted average.

i = industrial sector

j = type of CW

Figure 6.3 Decision tree for CH_4 emissions from constructed wetlands



6.2.1.2 CHOICE OF EMISSION FACTORS

The emission factor for wastewater treatment using CWs is a function of maximum CH_4 producing potential (B_o) and the methane correction factor (MCF).

EQUATION 6.2
CH_4 EMISSION FACTOR FOR CONSTRUCTED WETLANDS

$$EF_j = B_o \cdot MCF_j$$

Where:

EF_j = emission factor, kg CH_4/kg BOD or kg CH_4/ kg COD

j = type of CWs

B_o = maximum CH_4 producing capacity, kg CH_4/kg BOD or kg CH_4/ kg COD

MCF_j = methane correction factor (fraction), See Table 6.4

Good practice is to use country-specific data for B_o, where available, expressed in terms of kg CH_4/kg BOD removed for domestic wastewater or kg CH_4/kg COD removed for industrial wastewater to be consistent with the activity data. If country-specific data are not available, the following default values can be used.

The *2006 IPCC Guidelines* provide default B_o values for domestic and industrial wastewater: 0.6 kg CH_4/kg BOD and 0.25 kg CH_4/kg COD.

The MCF indicates the extent to which B_o is realized in each type of CWs. It is an indication of the degree to which the system is anaerobic. The proposed MCFs for SF, HSSF and VSSF are provided in Table 6.4 and derived from literature-based analysis of CH_4 conversion rates. Each MCF in Table 6.4 is calculated from the relation of initial TOC loading to CH_4 emission flux derived from references provided in Table 6.2.

TABLE 6.4
METHANE CORRECTION FACTORS (MCF) BY TYPE OF CONSTRUCTED WETLAND (CW)

CW type	MCF	Range
Surface flow (SF)	0.4	0.08-0.7
Horizontal subsurface flow (HSSF)	0.1	0.07-0.13
Vertical subsurface flow (VSSF)	0.01	0.004-0.016

These MCF values are based on actual measurement data derived under different operating and environmental conditions thus factors such as vegetation types and temperature effect have been taken into account. Based on the reported scientific data, there was insufficient information to differentiate the MCF values by vegetation types and operating temperatures. Nevertheless, these influencing factors can be considered for the estimation using higher tier approach. There was insufficient actual measurement data of hybrid systems to derive default MCF values. If the area fractions of SF, VSSF and HSSF for hybrid systems can be determined, the MCF values of the hybrid systems can be estimated as the area-weighted average of the MCFs for SF, VSSF and HSSF. Most commonly, SNTWs are surface flow type (Kadlec and Wallace, 2008), therefore, the default MCF of 0.4 can be used. If the type of CW cannot be recognized, the MCF of surface flow can be used in order to be conservative. Otherwise country-specific data should be used in higher tier method.

6.2.1.3 CHOICE OF ACTIVITY DATA

The activity data for this source category is the amount of organic materials (TOW) in the wastewater treated by CW. This parameter is a function of the population served by the CW system, and the biochemical oxygen demand (BOD) generation per person per day. BOD default values for selected countries are provided in the *2006 IPCC Guidelines* (Table 6.4, Chapter 6 of Volume 5 of the *2006 IPCC Guidelines*). In the case of industrial wastewater, COD loading to the CW system per day (kg COD/day) can be used. Examples of industrial wastewater data from various industries are provided in Table 6.9, Chapter 6, Volume 5 of the *2006 IPCC Guidelines*.

If industrial wastewater is released into domestic sewers, it is estimated together with domestic wastewater.

The equations for TOW are:

EQUATION 6.3
TOTAL ORGANICALLY DEGRADABLE MATERIAL IN DOMESTIC WASTEWATER

$$TOW_j = P_j \cdot BOD \cdot I \cdot 0.001 \cdot 365$$

EQUATION 6.4
TOTAL ORGANICALLY DEGRADABLE MATERIAL IN INDUSTRIAL WASTEWATER

$$TOW_{i,j} = COD_i \cdot W_{i,j} \cdot 365$$

Where:

TOW_j = total organics in domestic wastewater treated in the CW in inventory year (kg BOD/year)

$TOW_{i,j}$ = total organics in wastewater from industry *i* treated in the CW in inventory year (kg COD/year)

i = industrial sector

P_j = population whose wastewater treated in CW. Population should be subtracted from total population used in an Equation 6.3 in Chapter 6, Volume 5 in the 2006 IPCC Guidelines to avoid double-counting.

BOD = per capita BOD generation in inventory year (g BOD/person/day)

I = correction factor for additional industrial BOD discharged into sewers (for collected the default is 1.25, for uncollected the default is 1.00 as given in the *2006 IPCC Guidelines*)

COD_i = COD concentration in wastewater from industry *i* entering CW in the inventory year (kg COD/m^3)

$W_{i,j}$ = daily flow rate of industrial wastewater treated by CW, m^3/day

6.2.2 Time series consistency

The same method and data sets should be used for estimating CH_4 emissions from CWs treating wastewater for each year. The MCF for different treatment systems should not change from year to year, unless such a change is justifiable and documented. If the share of wastewater treated in different treatment systems changes over the time period, the reasons for these changes should be documented.

For activity data that are derived from population data, countries must determine the fraction of the population served by CW systems. If data on the share of wastewater treated are missing for one or more years, the splicing techniques such as surrogate data and extrapolation/interpolation described in Chapter 5, Time Series Consistency, Volume 1 of the *2006 IPCC Guidelines* can be used to estimate emissions. Emissions from wastewater treated in CWs typically do not fluctuate significantly from year to year.

6.2.3 Uncertainties

Chapter 3 in Volume 1 of the *2006 IPCC Guidelines* provides guidance on quantifying uncertainties in practice. It includes guidance on eliciting and using expert judgments which in combination with empirical data can provide overall uncertainty estimates. Table 6.5 provides default uncertainty ranges for emission factors and activity data for domestic and industrial wastewater. The following parameters are believed to be very uncertain:

- The quantity of wastewater that is treated in CWs or SNTWs.
- The fraction of organics that is converted anaerobically to CH_4 during wastewater collection. This will depend on hydraulic retention time and temperature in the wastewater collection pipeline, and on other

factors including the presence of anaerobic condition in the wastewater collection pipeline and possibly components that are toxic to anaerobic bacteria in some industrial wastewater.

- The amount of industrial TOW from small or medium-scale industries and rural domestic wastewater that is discharged into CWs in developing countries.
- Different plant species applied in CWs that are involved in gas exchange.

TABLE 6.5
DEFAULT UNCERTAINTY RANGES FOR DOMESTIC AND INDUSTRIAL WASTEWATER

Parameter	Uncertainty range*
Emission factor	
Maximum CH_4 producing capacity (B_o)	± 30%
Methane correction factor (MCF)	SF: ± 79% HSSF: ± 31% VSSF: ± 56%
Activity data	
Human population	± 5%
BOD per person	± 30%
Correction factor for additional industrial BOD discharged into sewers (I)	For uncollected, the uncertainty is zero %. For collected the uncertainty is ± 20%
COD loading from industrial wastewater	-55%, +103%

* Uncertainty of MCF calculated as 95% confidence interval is shown in Table 1 in Annex. Uncertainty of COD loading from industrial wastewater is calculated based on Table 6.10 in Chapter 6 in Volume 5 of the *2006 IPCC Guidelines*. Others are the same to Tables 6.7 in Chapter 6 in Volume 5 of the *2006 IPCC Guidelines*.

6.2.4 QA/QC, Completeness and Reporting

It is *good practice* to conduct quality control (QC) checks and quality assurance (QA) procedures as outlined in Chapter 6, QA/QC and Verification, Volume 1 of the *2006 IPCC Guidelines*. Some fundamental QA/QC procedures include:

Activity Data

- Make sure that the sum of wastewater flows of all types of wastewater treatment processes including CWs equal 100 percent of wastewater collected/uncollected and treated in the country.
- Inventory compilers should compare country-specific data on BOD in domestic wastewater to IPCC default values. If inventory compilers use country-specific values they should provide documented justification why their country-specific values are more appropriate for their national circumstances.

Emission Factors

- For domestic wastewater, inventory compilers can compare country-specific values for B_o with the IPCC default value (0.25 kg CH_4/kg COD or 0.6 kg CH_4/kg BOD). As there are no IPCC default values for the fraction of wastewater treated anaerobically, inventory compilers are encouraged to compare values for MCFs against those from other countries with similar wastewater handling practices.
- Inventory compilers should confirm the agreement between the units used for organically degradable material in wastewater (TOW) with the units for B_o. Both parameters should be based on the same units (either BOD or COD) in order to calculate emissions. This same consideration should be taken into account when comparing the emissions.
- For countries that use country-specific parameters or higher-tier methods, inventory compilers should crosscheck the national estimates with emissions estimated using the IPCC default method and parameters.
- For industrial wastewater, inventory compilers should cross-check values for MCFs against those from other national inventories with similar CW types.

COMPLETENESS

Completeness can be verified on the basis of the degree of utilization of a treatment or discharge system or pathway (T) for all wastewater treatment system used. The sum of T should equal 100 percent. It is a *good practice* to draw a diagram for the country to consider all potential anaerobic treatment and discharge systems and pathways, including collected and uncollected, as well as treated and untreated. Constructed wetlands and SNTWs are under treated and collected/uncollected pathway. In general, the amount of vegetation harvested from CWs is very small. If vegetation biomass is removed for the purpose of composting, incineration and burning, disposal in landfills or as fertilizer on agricultural lands, the amount of biomass should be consistent with data used in the relevant sectors.

Completeness for estimating emissions from industrial wastewater depends on an accurate characterization of industrial sectors that produce organic wastewater and the organic loading applied to CW systems. So inventory compilers should ensure that these sectors are covered. Periodically, the inventory compilers should re-survey industrial sources, particularly if some industries are growing rapidly. This category should only cover industrial wastewater treated onsite. Emissions from industrial wastewater released into domestic sewer systems should be addressed and included with domestic wastewater.

REPORTING

Methane emission from CWs for wastewater treatment is reported in waste sector under the categories of domestic or industrial wastewater. Methane emission from CWs treating collected runoff from agricultural land is to be reported under the category of industrial wastewater.

6.3 NITROUS OXIDE EMISSIONS FROM CONSTRUCTED WETLANDS

6.3.1 Methodological issues

Nitrous oxide (N_2O) emissions can occur as direct emissions from wastewater treatment in CWs through nitrification and denitrification. Emissions are calculated based on the total nitrogen loaded into CWs and emission factor.

Three tier methods for N_2O from this category are summarized below.

The Tier 1 method applies default values for the emission factor and activity parameters. This method is considered *good practice* for countries with no country-specific data.

The Tier 2 method follows the same method as Tier 1 but allows for incorporation of country-specific emission factors and country-specific activity data.

The Tier 3 method is used by countries with good data and advanced methodologies. A more advanced country-specific method is based on treatment system-specific data such as plant species and composition of wastewater.

The methodology provided assumes typical vegetation harvesting practices. However, the amount of vegetation harvested from CWs (studied until now) is generally very small and the harvested plant biomass is commonly not recorded so the harvesting practice is not considered as an influencing factor in the estimation of emissions.

Emissions from SNTWs treating collected/uncollected wastewater are estimated using the same methodology. Indirect N_2O emissions from domestic wastewater treatment effluent that is discharged into aquatic environments has already been covered in the *2006 IPCC Guidelines*.

6.3.1.1 CHOICE OF METHOD

A decision tree for domestic or industrial wastewater is shown in the Figure 6.4.

The general equation to estimate N_2O emissions from CWs treating domestic or industrial wastewater is shown in Equation 6.5.

EQUATION 6.5

N_2O EMISSIONS FROM CONSTRUCTED WETLANDS

$$N_2O\ Emissions = \sum_j \left(N_j \cdot EF_j \cdot 44/28\right) + \sum_{i,j} \left(N_{i,j} \cdot EF_j \cdot 44/28\right)$$

Where:

N_2O emissions = N_2O emissions in inventory year, kg N_2O/yr

N_j = total nitrogen in domestic wastewater entering CWs in the inventory year, kg N/year

$N_{i,j}$ = total nitrogen in industrial wastewater entering CW in the inventory year, kg N/year

EF_j = emission factor, kg N_2O-N/kg N

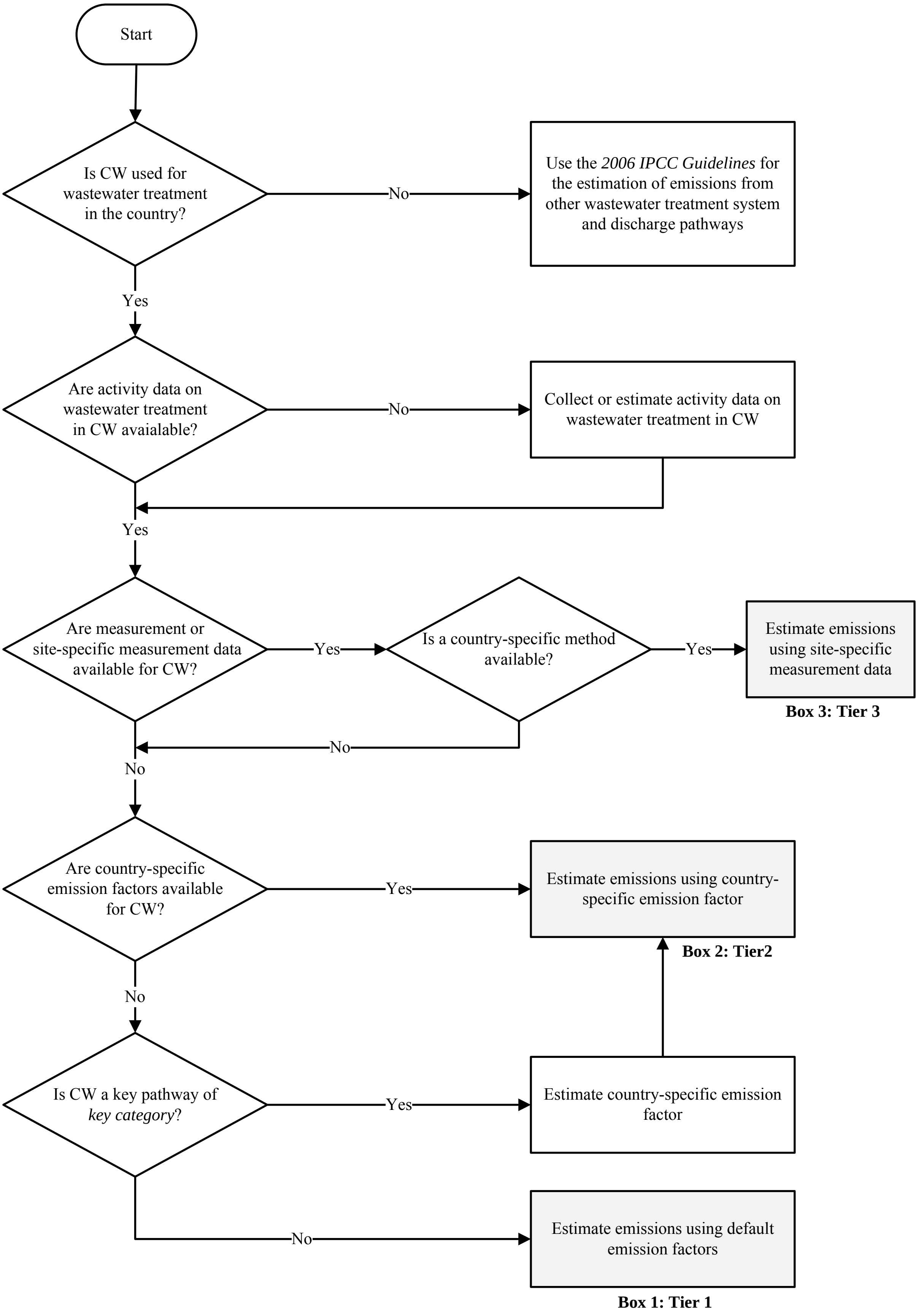
If more than one type of CW is used in an industrial sector this factor would need to be a $N_{i,j}$-weighted average.

i = industrial sector

j = type of CWs

The factor 44/28 is the conversion of kg N_2O-N into kg N_2O.

Figure 6.4 **Decision tree for N_2O emission from constructed wetland**



6.3.1.2 CHOICE OF EMISSION FACTORS

The default emission factors for N_2O emitted from domestic and industrial wastewater treated by CWs are 0.0013 kg N_2O-N/kg N for SF, 0.0079 kgN_2O-N/kg N for HSSF and 0.00023 kgN_2O-N/kg N for VSSF. These values are based on data provided in the literatures (Table 6.2) and influenced by the extent of nitrification and denitrification taking place in CWs, the coverage of vegetation in CWs and climatic conditions. There was insufficient actual measurement data of hybrid systems to derive emission factors. If the area fractions of SF, VSSF and HSSF for hybrid systems can be determined, the emission factors of the hybrid systems can be estimated as the area-weighted average of the emission factors for SF, VSSF and HSSF CWs. *Good practice* is to use country-specific data for emission factor, where available, expressed in term of kg N_2O-N/kg N loaded for domestic and industrial wastewater to be consistent with the activity data. The amount of N associated with N_2O emissions from CWs must be back calculated and subtracted from the $N_{EFFLUENT}$ (Equation 6.7 in Chapter 6, Volume 5 of the *2006 IPCC Guidelines*).

6.3.1.3 CHOICE OF ACTIVITY DATA

The activity data for this source category are the amount of nitrogen in the wastewater entering CWs (TN). This parameter is a function of the population served by the CW system, annual per capita protein consumption (protein) and a factor for non-consumed nitrogen added to the wastewater for domestic wastewater. In case of industrial wastewater, TN loading to the constructed wetland system in the inventory year (kg N) can be used directly. The equations for determining TN for domestic and industrial wastewater are:

EQUATION 6.6
TOTAL NITROGEN IN DOMESTIC WASTEWATER

$$N_j = P_j \cdot Protein \cdot F_{NPR} \cdot F_{NON-CON} \cdot F_{IND-COM}$$

EQUATION 6.7
TOTAL NITROGEN IN INDUSTRIAL WASTEWATER

$$N_{i,j} = TN_i \cdot W_{i,j}$$

Where:

N_j = total nitrogen in domestic wastewater entering CW in inventory year (kg N/year)

N_i = total nitrogen in wastewater from industry *i* entering CW in inventory year (kg N/year)

i = industrial sector

P_j = human population whose wastewater entering CWs

Protein = annual per capita protein consumption, kg/person/yr

F_{NPR} = fraction of nitrogen in protein (default is 0.16 kg N/ kg protein as given in the *2006 IPCC Guidelines*)

$F_{NON-CON}$ = factor for non-consumed nitrogen added to the wastewater (default is 1.1 for countries with no garbage disposals, 1.4 for countries with garbage disposals as given in the *2006 IPCC Guidelines)*

$F_{IND-COM}$ = factor for industrial and commercial co-discharged protein into sewer system (default is 1.25 as given in *2006 IPCC Guidelines*)

TN_i = total nitrogen concentration in wastewater from industry *i* entering CWs in inventory year (kg N/m^3)

$W_{i,j}$ = flow rate of industrial wastewater entering CW, m^3/yr

N_i is a function of total N concentration and flow rate which can be estimated by multiplying industrial product P (tons/yr), wastewater generation (m^3/ton-product) (Table 6.9, Chapter 6, Volume 5 in *2006 IPCC Guidelines*) and N content in Table 6.6 of this supplement.

TABLE 6.6
EXAMPLE OF N CONTENT IN SOME NITROGEN-RICH INDUSTRIAL WASTEWATER

Industry type	Wastewater generation W (m^3/ton-product)	N content (kg/m^3)
Alcohol refining	24 (16-32)[1]	2.40 (0.94-3.86)[2]
Fish processing industry	5 (2-8)[2]	0.60 (0.21-0.98)[3]
Seasoning source industry	NA	0.60 (0.22-1.00)[3]
Meat & poultry	13 (8-18)[1]	0.19 (0.17-0.20)[3]
Starch production	9 (4-18)[1]	0.90 (0.80-1.10)[4]
Nitrogen fertilizer plant	2.89 (0.46-8.3)[2]	0.50 (0.10-0.80)[2]
Landfill leachate	15-20% of annual precipitation in well compacted landfill site. 25-50% of annual precipitation for not well compacted landfill site[6].	0.74 (0.01-2.50)[5]

Note: Average value and range (in brackets) are presented

Sources: [1] *IPCC 2006*; [2]Samokhin (1986); [3] Pilot Plant Development and Training Institute (1994); [4] Hulle *et.al*. (2010); [5] Kjeldsen *et al*. (2002); [6] Ehrig (1983)

6.3.2 Time series consistency

The same method and data sets should be used for estimating N_2O emissions from CWs for each year. If a country decides to change the estimation method from the default methodology (Tier 1) to country-specific (Tier 2), this change must be made for the entire time series.

6.3.3 Uncertainties

Large uncertainties are associated with the default emission factors for N_2O emissions from CWs due to limited available data (Table 6.7).

TABLE 6.7
NITROUS OXIDE METHODOLOGY DEFAULT UNCERTAINTIES

Parameter	Default value	Range
Emission factor (kg N_2O-N/kg N)	0.0013 for SF 0.0079 for HSSF 0.00023 for VSSF	± 90% for SF ± 79% for HSSF ± 70% for VSSF
Activity data		
Human population	Country-specific	± 10%
Annual per capita protein consumption	Country-specific	± 10%
Fraction of nitrogen in protein	0.16	0.15-0.17
Factor for non-consumed nitrogen	1.1 for countries with no garbage disposals, 1.4 for countries with garbage disposals	1.0-1.5
TN loading from industrial wastewater	Country-specific	-55%, +103%

* Uncertainties of emission factors calculated as 95% confidence interval is shown in Table 6A1.1 in Annex. Uncertainty of TN loading from industrial wastewater is the same to that of COD loading from industrial wastewater (Expert judgement by Authors of this chapter). Others are derived from Tables 6.11 in Chapter 6 in Volume 5 of the *2006 IPCC Guidelines*.

6.3.4 QA/QC, Completeness and Reporting

This method makes use of several default parameters. It is recommended to solicit experts' advice in evaluating the appropriateness of the proposed default factors. The methodology for estimating emissions is based on N associated with domestic and industrial discharge either collected into the collection system and treated in

CWs/SNTWs or uncollected and discharged into CWs/SNTWs. This estimate can be seen as conservative and covers the entire source associated with domestic and industrial wastewater discharge.

REPORTING

Nitrous oxide emission from CWs for wastewater treatment is reported in waste sector under the categories of domestic or industrial wastewater. Nitrous oxide emissions from CWs treating collected runoff from agricultural land and landfill leachate are to be reported under the category of industrial wastewater. If agricultural runoff is collected and treated by CWs or SNTWs, the amount of nitrogen flows into CWs/SNTWs must be subtracted to avoid double counting.

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Annex 6A.1 Estimation of default emission factors for CH_4 and N_2O in constructed wetlands for wastewater treatment

We reviewed about 150 papers published in international peer-reviewed journals indexed by the Thomson Reuters Web of Knowledge from 1994 to 2013. The terms “free water surface”, “surface flow”, constructed wetland(s)”, “artificial wetland(s)”, “treatment wetland(s)”, “subsurface flow wetland(s)”, “vertical flow” and “horizontal flow” in combination with the terms “carbon dioxide”, “CO_2”, “methane”, “CH_4”, “nitrous oxide” and “N_2O” were searched.

We found a total of 14 publications that provided information on emissions of either CH_4, N_2O or both gases in surface flow (SF) constructed wetlands (CWs). These publications presented information on 17 different SF CW systems, whereas for CH_4 and N_2O, there were 24 and 25 subsystems/measuring events respectively. Six SF CWs (Nykvarn, Lakeus, Ruka, Skjønhaug, Hässleholm, and Ibaraki) treated domestic wastewater (Johansson et al., 2003, 2004; Søvik et al., 2006, Ström et al., 2006; Gui et al., 2007; Søvik and Kløve, 2007; Liu et al., 2009), six CWs (mesocosms in Xue et al. (1999) paper, Donaumoos, Genarp, Görarp, Ormastorp, and Hovi) treated waters of agricultural non-point pollution (Xue et al., 1999; Wild et al., 2001; Stadmark and Leonardson, 2005; Søvik et al., 2006), two systems (Ngatea and Truro) were used for dairy farm wastewater treatment (Tanner et al., 1997; Van der Zaag et al., 2010), the Kompsasuo CW treated wastewater from a peat extraction area (Søvik et al., 2006), the Jiaonan CW (Tai et al., 2002) purified raw municipal wastewater, and synthetic wastewater is used in the Jinan laboratory mesocosms (Wu et al., 2009).

Regarding the vertical subsurface flow (VSSF) CWs, there were only 4 measurement periods presented for 3 CWs from which CH_4 emission data and ratios could be calculated: Kõo in Estonia (Teiter and Mander 2005; Søvik et al., 2006), Ski in Norway (Søvik et al., 2006), and Miho/Ibaraki, Japan (Gui et al., 2007; Liu et al., 2009). For N_2O emission, additionally laboratory microcosm experiments with different plant species from Ibaraki, Japan (Inamori et al., 2008; Wang et al., 2008) were included.

For CH_4 fluxes from horizontal subsurface flow (HSSF) CWs we could use data from two system in Estonia treating domestic wastewater, Kodijärve and Kõo (Mander et al., 2003, 2008; Teiter and Mander, 2005; Søvik et al., 2006), four CWs treating domestic wastewater in Ski, Norway (Søvik et al., 2006), Barcelona, Spain (Garcia et al., 2007), Miho/Ibaraki, Japan (Gui et al., 2007; Liu et al., 2007) and Slavosovice, Czech Republic (Picek et al., 2007), a HSSF treating wastewater from a peat extraction area in Kompsasuo, Finland (Liikanen et al., 2006), a HSSF treating landfill leachate in Bangkok, Thailand (Chiemchaisri et al., 2009), and a dairy farm wastewater treatment HSSF in Truro, Nova Scotia, Canada (Van der Zaag et al., 2010). For N_2O emissions from HSSFs, also a CW for dairy farm wastewater treatment in Friedelhausen, Germany (Fey et al., 1998) has been included.

Tanner et al., (1997) presented estimated values for inflow total organic carbon (TOC_{in}), Xue et al., (1999) for inflow total nitrogen (TN_{in}), and Søvik et al., (2006) for both TOC_{in} and TN_{in}. For most of the systems, TOC_{in} and TN_{in} values were calculated based on area, hydraulic load and inflow TOC and TN concentration data. For some systems only biological oxygen demand (BOD) values were usable, and for them the following approximation based on domestic wastewater data was used: TOC = 0.5 BOD (Garcia et al., 2007). For the calculations of emission factors, we used data series from one year or at least a vegetation period.

TABLE 6A1. 1

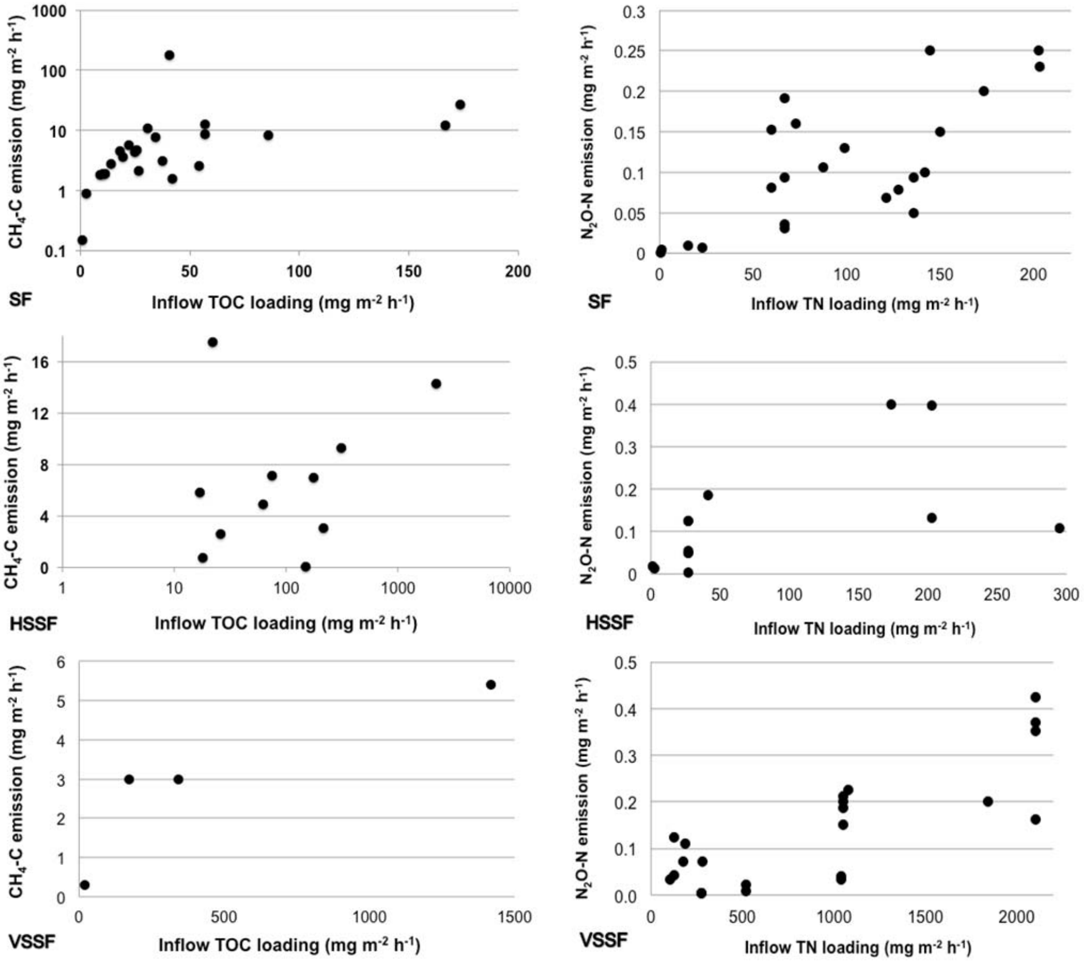
AVERAGE, STANDARD ERROR, MEDIAN, 2.5% AND 97.5% PERCENTILE VALUES OF CH_4-C AND N_2O-N EMISSION FACTORS (%) FOR DIFFERENT TYPES OF CONSTRUCTED WETLANDS

Types of CWs	Emission factor CH_4-C/TOC (%)					Emission factor N_2O-N/TN (%)				
	Average	Standard Error	Median	2.5%	97.5%	Average	Standard Error	Median	2.5%	97.5%
SF	42.2	20.4	18	4	446	0.13	0.024	0.11	0	0.47
HSSF	12.0	7.56	4.15	0.03	79	0.79	0.38	0.34	0.04	3.01
VSSF	1.17	0.33	1.28	0.38	1.73	0.023	0.005	0.018	0.001	0.096

Table 1 presents values of emission factors calculated based on literature sources described above.

In Figure 1, correlation between the inflow TOC loading and CH_4-C emission and between the inflow TN loading and N_2O emission in SF, HSSF and VSSF CWs is presented.

Figure 6A1.1 The relationship between inflow TOC loading and CH_4-C emission (left column) and between inflow TN loading and N_2O-N emission (right columns) in SF, HSSF, and VSSF CWs. In all cases, $p < 0.05$.



CHAPTER 7

CROSS-CUTTING ISSUES AND REPORTING

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7 CROSS-CUTTING ISSUES AND REPORTING

7.1 INTRODUCTION

The *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (*Wetlands Supplement*) contains updated and new methodological guidance for greenhouse gas emissions and removals from drained inland and rewetted organic soils, specific human-induced changes in coastal wetlands and inland wetland mineral soils, and Constructed Wetlands for Wastewater Treatment.

The supplementary methodological guidance introduces changes to the estimation and reporting of emissions and removals according to the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (*2006 IPCC Guidelines*) in all land-use categories (Forest Land, Cropland, Grassland, Wetlands, Settlements, and Other Land), some sources of methane (CH_4) and nitrous oxide (N_2O) emissions from managed land in the Agriculture, Forestry and Other Land Use (AFOLU) Sector, and CH_4 and N_2O emissions from wastewater treatment (Constructed Wetlands for Wastewater Treatment) in the Waste Sector. The changes come from updated methodologies for existing categories and supplemental methodologies for categories not covered by the *2006 IPCC Guidelines*. The *Wetlands Supplement* maintains the approaches for estimation of emissions and removals in Volume 4 (AFOLU) of the *2006 IPCC Guidelines.* The general guidance in Volume 1 of the *2006 IPCC Guidelines* is also applicable.

This chapter provides guidance on cross cutting issues for the methodologies provided in Chapters 2 to 6 of this *Wetlands Supplement* by addressing the following:

- reporting and documentation
- uncertainty estimation
- key category analysis
- completeness
- time series consistency
- quality control (QC) and quality assurance (QA).

The chapter also summarises the *good practice* guidance on these cross-cutting issues found in Volume 1 of the *2006 IPCC Guidelines,* to which inventory experts need to refer for detailed guidance. Cross-cutting issues specific to the categories and methodologies included in Chapters 2 to 6 of the *Wetlands Supplement* are addressed in the specific chapters. This chapter summarises and complements the category-specific information.

7.2 REPORTING AND DOCUMENTATION

7.2.1 Changes to reporting categories in the 2006 IPCC Guidelines

Chapter 1 of the *Wetlands Supplement* gives an overview of the purpose and scope of this supplement as well as a description of its contents, including specific guidance on how to use this supplement in the context of the *2006 IPCC Guidelines.*

This chapter complements Chapter 1 with details on the reporting aspects of the *Wetlands Supplement*. The summaries of the methodologies of the *Wetlands Supplement* and the reporting of emissions and removals, as addressed in Sections 7.2.1.1 to 7.2.1.5 in this chapter, are based on the Tier 1 methodologies in Chapters 2 to 6 of the *Wetlands Supplement.*

The AFOLU and Waste Sector reporting tables given in Annex 8A.2, Chapter 8 in Volume 1 of the *2006 IPCC Guidelines* are updated and complemented to incorporate the changes required by the application of the *Wetlands Supplement* (see Annex 7A.2 in this chapter). The category names and numbering referred to in the following sections are those presented in Annex 7A.2 in this chapter.[1]

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[1] The Common Reporting Framework (CRF) tables used by Annex I Parties in reporting of greenhouse gas emissions and removals under United Nations Framework Convention on Climate Change (UNFCCC) are not identical to the reporting tables developed by the IPCC. Reporting tables used by the Parties to the UNFCCC are produced by the UNFCCC through negotiations, although they usually build on the *IPCC Guidelines* and good practice guidance. The UNFCCC CRF tables

7.2.1.1 DRAINED INLAND ORGANIC SOILS

Carbon dioxide (CO_2)

The guidance in Chapter 2 in the *Wetlands Supplement* for estimation of CO_2 emissions from drained inland organic soils implies changes for all land-use categories compared to the *2006 IPCC Guidelines*. The Tier 1 methodology in the *2006 IPCC Guidelines* for drained organic soils is simply a multiplication of the relevant areas covered with appropriate emission factors by land-use category and climate zone (boreal/temperate/tropical). The emission factors in the *2006 IPCC Guidelines* for peat extraction in boreal/temperate climate zones also take into account the nutrient status of the drained lands. The supplementary methodology in Chapter 2 uses the same approach as in the *2006 IPCC Guidelines* and provides updated CO_2 emission/removal factors according to land-use categories and climate zones. For some land-use categories, these are further disaggregated by the type of vegetation, nutrient-status of the organic soils (rich vs. poor) and depth of drainage (drained, shallow drained and deep drained). Nutrient status is, however, not taken into account in the default CO_2 emission factors for peat extraction. New guidance is provided for estimation of off-site CO_2 emissions from water-borne dissolved organic carbon (DOC), losses from drained organic soils and soil CO_2 emissions from fires on drained organic soils. Most of these methodological changes can be implemented without changes in the reporting or background tables in the *2006 IPCC Guidelines*. However, additional documentation would need to be provided in the national inventory report (see Section 7.2.3 and Annex 7A.2 in this chapter). Also, Background Table 3.4 (category 3C1) on burning has been modified to include emissions from the soil pool for organic soils (see Annex 7A.2 in this chapter).

Non-CO_2

The *2006 IPCC Guidelines* did not provide a methodology for the estimation of CH_4 emissions associated with drainage, whereas Chapter 2 provides a methodology to address CH_4 emissions from the land surface of drained organic soils and drainage ditches. The emission factors for CH_4 from the land surface are given by land-use category and climate zone. These are further disaggregated by the type of vegetation, depth of drainage, and nutrient status of the soil. The emission factors for CH_4 from drainage ditches are also given by land-use category and climate zone and for grasslands by drainage depth (shallow or deep). A default CH_4 emission factor for drainage ditches is provided separately for peat extraction. The estimation of CH_4 emissions from drained organic soils requires the area of the drained organic soils and the fraction occupied by ditches. Indicative default values are provided for these fractions. These CH_4 emissions would be reported in Table 3.9 under new categories (3C8 *CH_4 from drained organic soils* and 3C9 *CH_4 from drainage ditches on organic soils*) under appropriate headings highlighting the land-use category and other relevant specifications. The category 3C8 (*Other*) in the *2006 IPCC Guidelines* has been re-numbered to 3C14.

The methodology for direct N_2O emissions from organic soils is the same as in the *2006 IPCC Guidelines* but the default emissions factors are updated and more disaggregated. In accordance with the *2006 IPCC Guidelines,* the direct N_2O emissions from organic soils should be reported as aggregated to N_2O emissions from managed soils. If data are available, the emissions can be provided by land-use category. The N_2O emissions from drainage/management of organic soils are reported under category 3C4 (*Direct N_2O Emissions from Managed Soils*). An exception to this are direct N_2O emissions on peat extraction lands which are reported in category 3B4ai (*Peat Extraction Remaining Peat Extraction*[2]) or 3B4bi (*Land Converted for Peat Extraction*), depending if the peat extraction lands remain in the category, or are converted to it.

Chapter 2 in the *Wetlands Supplement* provides guidance on estimating CO_2, CH_4 and CO emissions from soil organic matter during fires on drained organic soils. N_2O emissions from these fires are addressed at higher tier levels. These emissions would be reported in the AFOLU category 3C1 (*Burning*) under relevant subcategories. Activity data and emissions by carbon pools should be provided in AFOLU Background Table 3.4, which is updated to include also emissions from soil burning (see Annex 7A.2 in this chapter).

7.2.1.2 REWETTED ORGANIC SOILS

Guidance on CO_2, CH_4 and N_2O emissions from rewetting of organic soils is not included in the *2006 IPCC Guidelines*. Chapter 3 of the *Wetlands Supplement* provides this guidance. Tier 1 methodologies are given for

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are currently being revised. A major difference in the UNFCCC CRF tables compared to the IPCC reporting tables is that the IPCC AFOLU sector will continue to be divided into the Agriculture sector and LULUCF sector in the reporting under the UNFCCC.

[2] This category has been renamed (Peatlands Remaining Peatlands in the *2006 IPCC Guidelines*) to take into account the guidance related to peatlands in this *Supplement*. The renaming is taken into account in the updated Table 3 AFOLU Sectoral Table and relevant AFOLU background tables in Annex 7A.2 in this chapter.

CO_2 emissions/removals from rewetted organic soils with moss and/or herbaceous vegetation, and also for dissolved organic carbon. Tier 1 guidance is also given for CH_4 emissions from rewetted organic soils. N_2O emissions from rewetted organic soils are considered negligible and assumed to be zero under Tier 1. Fires on rewetted organic soils are not likely but, in case they occur, the methods given in Chapter 2 for fires on drained organic soils can be used to estimate the emissions from the soil. When rewetted lands contain perennial woody vegetation, the guidance in Chapters 2, 4, and 5 in Volume 4 of the *2006 IPCC Guidelines*, should be used to estimate the emissions from the woody biomass and dead organic matter (DOM) pools.

The reporting of emissions/removals from rewetting depends on the land-use after the rewetting. Rewetted grassland could remain in the same land-use category, e.g. when agricultural land with organic soil is rewetted to form a grazing marsh. The rewetting could also involve a land-use change, e.g. when a forest with organic soil is rewetted and the tree coverage declines below the threshold of the national forest definition. It is *good practice* to report emissions/removals from rewetting under relevant land-use categories (Table 3, Annex 8A.2, Chapter 8 in Volume 1 of the *2006 IPCC Guidelines*). Additional information on carbon stock changes on these lands should be provided in the Background Table 3.2 and Table 3.3, which have been modified to allow also reporting of removals from organic soils. CH_4 should be included in Table 3.9 (*Non-CO_2 greenhouse gas emissions not included elsewhere*), under category 3C10 (*CH_4 from rewetting of organic soils*). When N_2O emissions from rewetting of organic soils are reported using higher-tier methods, these would be included under category 3C14 (*Other*).

7.2.1.3 COASTAL WETLANDS

Guidance on CO_2, CH_4 and N_2O emissions from managed coastal wetlands is not included in the *2006 IPCC Guidelines* but provided in Chapter 4 of this *Wetlands Supplement.* This guidance covers emissions/removals from mineral and organic soils vegetated by vascular plants that are covered or saturated for all or part of the year by tidal freshwater or salt water (>0.5 ppt). The guidance addresses CO_2 emissions/removals from specific activities in mangroves, seagrass meadows, and tidal marshes. These activities include forest management, extraction (including excavation, aquaculture and salt production), drainage and rewetting in coastal wetlands. New methods are presented for estimation of changes in soil carbon (Tier 1 level) whereas methods for biomass and dead organic matter follow those of the *2006 IPCC Guidelines*. Methods are also provided for CH_4 emissions from rewetting of mangroves and tidal marshes and N_2O emissions from aquaculture.

Coastal wetlands can occur in any of the six IPCC land-use categories but also in coastal areas which are not part of the total land area of the country. For example, a mangrove wetland with trees may be classified as Forest Land, a tidal marsh used for grazing may be classified as Grassland, while a seagrass meadow used for aquaculture may be classified as Settlements. Emissions/removals from coastal wetlands which are not part of the total land area (e.g. seagrass meadows) should be reported separately and the associated areas excluded from t the total land area and from the land use matrix[3]. For example, forest management activities in mangroves classified as Forest Land may need to be split between areas included in the total land area and not included in the total land area. In reporting the emissions/removals from mangrove forest management activities emissions/removals from both areas would be reported under Forest Land but only the land areas of the mangroves included in the total land area would be included in the total Forest Land areas and reported in the land area matrix. The classifications of coastal wetlands are country specific, but in all cases appropriate subcategories should be used in the reporting, to reflect the specific land use and management as well as to indicate whether the emissions come from areas included or excluded from the total land area of the country.

The emissions/removals from coastal wetlands would be reported under relevant land-use categories, and subcategories, of the AFOLU Sectoral Table 3. Two new categories 3B4aiii *Other Wetlands remaining Other Wetlands* and 3B4biii *Land Converted to Other Wetlands* have been added to this table to allow for complete reporting. Additional information on C stock changes on these lands should be provided in the Background Tables 3.2 and 3.3. CH_4 and N_2O emissions from coastal wetlands would be included in the Background Table 3.9, under category 3C11 (*CH_4 emissions from rewetting of mangroves and tidal marshes*) to category 3C12 (*N_2O emissions from aquaculture)* and specified by land-use category. For information to be included in the inventory report, see Section 7.2.2 below.

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[3] Documentation on consistent reporting of land areas for the six land-use categories includes the provision of a land-use matrix with data on lands remaining in the categories and conversions between them. Also unmanaged land areas are included in the matrix. The sum of the areas should match the total land area. Areas which are not part of the total land area of a country should not be included in the total areas of the land-use categories or the land-use matrix for this reason.

7.2.1.4 INLAND WETLAND MINERAL SOILS

In Volume 4 of the *2006 IPCC Guidelines*, generic guidance for estimating CO_2 emissions/removals from soils, including wet mineral soils, is provided in Section 2.3.3 and complemented with land-use category specific guidance in relevant sections of Chapters 3 to 6. Chapter 5 of the *Wetlands Supplement* complements and updates this guidance with new default values for reference soil carbon stock values for wetland mineral soils under all climate regions and carbon stock change factors for land-use for long-term cultivation of cropland with inland wetland mineral soils (IWMS). New default carbon stock change factors are provided for rewetting on Cropland with IWMS. In addition, Chapter 5 provides data on CH_4 emissions from IWMS under any land-use category that has undergone rewetting, and from mineral soils that have been inundated for the purpose of wetland creation. The chapter does not include guidance on emissions/removals from rice cultivation. That is covered in Section 5.5, Chapter 5 in Volume 4 of the *2006 IPCC Guidelines.*

IWMS can occur in any of the six IPCC land-use categories. For example, a riverine wetland with trees may be classified as Forest Land, while a riverine wetland without trees may be classified as Wetlands. The precise details of this classification are country specific so it is not possible to say exactly how IWMS may be classified. Appropriate subcategories should be used in the reporting, to reflect the specific land use and management as specified by a country.

The total emissions/removals from IWMS should be reported under relevant land-use categories and subcategories of the AFOLU sector in reporting Table 3 in Volume 1, Annex 8A.2. Additional information on carbon stock changes on these lands should be provided in Background Tables 3.2 and 3.3. CH_4 emissions from inland wetland mineral soils should be included in Background Table 3.9, under category 3C13 (*CH_4 emissions from rewetted and created wetlands on inland wetland mineral soils*). For information to be included in the inventory report, see Section 5.4 in Chapter 5 in this supplement and Section 7.2.2 below.

7.2.1.5 CONSTRUCTED WETLANDS FOR WASTEWATER TREATMENT

Supplementary guidance on CH_4 and N_2O emissions from wastewater treatment and discharge is provided in Chapter 6 on Constructed Wetlands for Wastewater Treatment. Constructed Wetlands for Wastewater Treatment are human-made wetlands and engineered systems, which apply various technologies, using natural wetland processes, wetland hydrology, soils, microbes and plants to assist in treating wastewater. In addition to Constructed Wetlands for Wastewater Treatment, methodologies in Chapter 6 cover natural wetland systems that have been modified for wastewater treatment (semi-natural treatment wetlands). Methodologies are based on the load of nitrogen and organic carbon into the systems. The CH_4 emissions are calculated based on biological or chemical oxygen demand data and emission factors related to the flows in these Constructed Wetlands for Wastewater Treatment (free water surface, vertical subsurface flow, and horizontal subsurface flow or hybrid systems). The N_2O emissions are calculated based on the amount of nitrogen in the wastewater.

CH_4 and N_2O emission from Constructed Wetlands for Wastewater Treatment are reported under category 4D *Wastewater Treatment and Discharge*. The emissions should be divided into Categories 4D1 (*Domestic wastewater treatment and discharge*) and 4D2 (*Industrial Wastewater treatment and discharge*) according to source of wastewater treated.

The areas of Constructed Wetlands for Wastewater Treatment would be reported as part of areas under Settlements, Wetlands, or other land-use categories, as appropriate. If the establishment of the Constructed Wetlands for Wastewater treatment involves a land-use category conversion, the area changes should be reported under appropriate land-use categories and the notation key “IE” should be used for the CH_4 and N_2O emissions under the category to which the land is converted, as these emissions are reported in the Waste sector. Any changes in carbon stocks due to the land-use conversion, *e.g.* due to cutting of trees or removal of other vegetation, should also be reported under the category to which the land is converted. Double-counting of CH_4 and N_2O emissions from the land areas should be avoided. The areas of Constructed Wetlands for Wastewater Treatment are often small, and, if thresholds for minimum areas for reporting are not exceeded, specific reporting in the AFOLU sector is not required.

No changes to the reporting tables and background tables in the *2006 IPCC Guidelines* are made for the inclusion of the emissions from Constructed Wetlands for Wastewater Treatment. Section 7.2.2 below addresses the information that should be included in the inventory report.

7.2.2 Mapping the changes to categories in the 2006 IPCC Guidelines

Table 7.1 below shows how the supplementary guidance and new categories introduced in the *Wetlands Supplement* are linked to the guidance and categories in the *2006 IPCC Guidelines*. This summarises the descriptions given in the above sections on the methodological changes introduced in Chapters 2 to 6 in this *Wetlands Supplement*.

TABLE 7.1
MAPPING BETWEEN THE CATEGORIES AND GUIDANCE IN THE *2006 IPCC GUIDELINES* AND THE CHANGES TO THOSE INTRODUCED BY THE *WETLANDS SUPPLEMENT*.

Source of emissions/ sink for removals	**2006 IPCC Guidelines**		**Wetlands Supplement**	
	Category	**Guidance by**	**Category**	**Guidance by**
Drained inland organic soils				
CO_2	3B1 to 3B6 Forest land, Cropland, Grassland, Wetlands, Settlements and Other land Category 3B4ai *Peatlands remaining peatlands*	• land-use category • climate zone • nutrient status for peat extraction lands	3B1 to 3B6 Forest land, Cropland, Grassland, Wetlands, Settlements and Other land Category 3B4ai renamed as *Peat extraction lands remaining peat extraction lands*, respective change to 3B4bi New source: off-site CO_2 emissions due to waterborne carbon losses	• land-use category • climate zone • drainage class (drained, shallow, deep) • nutrient status
CO_2	Category 3C1 *Biomass burning*	• pool excluding the soil organic matter	Category 3C1 renamed to *Burning* to take into account new guidance on CO_2 emissions from the soil pool from fires on drained organic soils	• pools (biomass, dead organic matter, soil organic matter)
CH_4	-	-	New source: 3C8 *CH_4 from drained organic soils*	• land-use category • climate zone • drainage class (drained, shallow, deep) • nutrient status
CH4	-	-	New source: 3C9 *CH_4 from drainage ditches on organic soils*	• land-use category • climate zone • drainage class (drained, shallow, deep)
N_2O	3C4 *Drainage/ management of organic soils (i.e., Histosols)*	• drained organic soils	3C4 *Drainage/ management of organic soils (i.e., Histosols)*	• land-use category • climate zone • drainage class (drained, shallow, deep) • nutrient status

Rewetted organic soils				
CO_2,	-	-	New sources/sinks under 3B1 to 3B6 Forest land, Cropland, Grassland, Wetlands, Settlements and Other land: *CO_2 emissions/removals from rewetted soils* and *CO_2 emissions due to dissolved organic carbon export from rewetted organic soils*	• climate zone • nutrient status (boreal climate zone)
CH_4	-	-	New category: 3C10 *CH_4 from rewetting of organic soils*	• climate zone • nutrient status (boreal and temperate climate zone)
N_2O	-	-	N_2O emissions from rewetted organic soils (only when higher-tier methods available) To be reported under 3C14 Other (Non-CO_2 GHG emissions not included elsewhere)	
Coastal wetlands				
CO_2,	-	-	New sources/sinks under 3B1 to 3B6 Forest land, Cropland, Grassland, Wetlands, Settlements and Other land from the following activities: • forest management in mangroves • extraction in mangroves, tidal marshes and seagrass meadows (including excavation, aquaculture and salt production) • rewetting, revegetation and creation in mangroves, tidal marshes and sea grass meadows • soil drainage in mangroves and tidal marches A new subcategory under Wetlands would need to be created to cover all potential reporting options:	• climate zone/region • vegetation type • salinity (where applicable/ available) • management activity

				3B4aiii (Other Wetlands Remaining Wetlands) or 3B4biii (Land Converted to Other Wetlands) NOTE: When activities and emissions occur on areas which are not included in the total land area of the country, the reporting should be split in to two parts: areas included in the total land area and areas not included in the total land area. The land-use change matrix should include only those areas which are part of the total land area.	
	CH_4	-	-	New category: 3C11 *CH_4 emissions from rewetting of mangroves and tidal marshes*	• wetland type • salinity
	N_2O	-	-	New category: 3C12 *N_2O emissions from aquaculture*	• fish-produced
Inland wetland mineral soils (IWMS)					
	CO_2	Guidance for estimating C stock changes in soils including inland mineral soil wetlands under all land-use categories 3B1 to 3B6 Forest land, Cropland, Grassland, Wetlands, Settlements and Other land	• land-use category • climate zone	Updated default reference soil organic carbon stocks (SOC) for inland wetland mineral soils under 3B1 to 3B6 Forest land, Cropland, Grassland, Wetlands, Settlements and Other Land	• climate zone/region • management activity
	CO_2	-	-	• New stock change factors for land-use for long term cultivation and rewetting of Cropland with IWMS	• climate zone • moisture regime
	CH_4	-	-	3C13 *CH_4 from rewetted or created wetlands on inland wetland mineral soils*	• climate zone
Constructed Wetlands for Wastewater Treatment					
	CH_4, N_2O	4 D Wastewater treatment and discharge	• wastewater type (domestic or industrial) • BOD/COD load • treatment	New treatment types under 4 D Wastewater treatment and discharge	• wastewater type (domestic or industrial) • BOD/COD load • treatment and disposal type including

			and disposal type		constructed wetlands and semi-natural treatment wetlands • flow type
	CO_2	3B4 to 3B6 Wetlands, Settlements and Other land	No specific guidance but C stock changes from land-use change covered by the general methodologies	3B4 to 3B6 Wetlands, Settlements and Other land	No specific guidance but C stock changes from land-use change covered by the general methodologies in the *2006 IPCC Guidelines*

7.2.3 Documentation

Chapter 8 in Volume 1 of the *2006 IPCC Guidelines* provides guidance on reporting complete, consistent, and transparent national greenhouse gas inventories. Category-specific guidance on documentation relevant to the supplementary guidance provided in this supplement is provided in Chapters 2 to 6.

Reporting in accordance with the *Wetlands Supplement* involves combining guidance from both this *Wetlands Supplement* and the *2006 IPCC Guidelines*. The estimation of emissions and removals requires, in some cases, a combination of methodologies which, if care is not taken, can lead to double-counting or omission of emissions or removals. The reporting of emissions and removals from specific activities, *e.g.* rewetting and drainage, is disaggregated among land-use categories and specific or generic categories for reporting of non-CO_2 emissions. National circumstances will also significantly affect reporting. In some countries, the categories will have a significant impact on total national emissions, but in others they will be insignificant.

It is *good practice* to provide the following information specific to the guidance in this *Wetlands Supplement* in the national inventory report:

- Methods for identifying activities and land areas;
- Classification of activities and land areas;
- Indication if emissions/removals are associated with areas that are not included in the total land areas.
- Disaggregated activity data and emission factors/parameters used by climate regime (temperature, precipitation), nutrient status, ecosystem type and activity/system, as relevant, and the level at which the emissions/removals are estimated.
- Information on how completeness has been assessed and double-counting avoided, i.e. in the following cases:
    - If the stock change method is used for a specific category/activity for estimation of CO_2 emissions/removals from soils and the default emission factors are used for dissolved organic carbon the latter emissions may be included in the stock change estimate.
    - Combining a country-specific method to estimate emissions/removals from below-ground biomass, litter or understory (vegetation such as mosses) with default emission factors for drainage and rewetting, which integrate all carbon fluxes from the soil and the above- and belowground vegetation components other than trees, could double-count the respective emissions/removals.
    - Documentation for Constructed Wetlands for Wastewater Treatment should show that total organics in wastewater includes but does not double-count the part of organics treated in these systems.
    - Documentation on country-specific methods taking into account e.g. the impact of grazing on rewetted soils in the estimation of N_2O emissions from these lands should show that the nitrogen input is not calculated also under category 3A2 (*Manure management*). Livestock emissions (CH_4 from enteric fermentation and N_2O from manure management) are by default not included under the land-use categories.
- When country-specific emission/removal factors or other parameters are used, documentation and references which justify their use should be provided. The documentation should show that the country-specific emission/removal factors or other parameters result in an improvement in the accuracy of the estimates.

7.2.4 Reporting tables

AFOLU sectoral reporting and background tables given in Annex 8A.2, Chapter 8 in Volume 1 of the *2006 IPCC Guidelines* are applicable with minor changes for reporting of emissions/removals for methodologies in this *Wetlands Supplement*. AFOLU Sectoral Table 3 and Background Tables 3.1, 3.2, 3.3, 3.4, 3.7 and 3.9, included in Annex 8A.2, Chapter 8 in Volume 1 of the *2006 IPCC Guidelines*, have been updated to cover the new categories introduced in this *Wetlands Supplement* (see Annex 7A.2 in this chapter).

Guidance on reporting, including a description of the changes made to the background tables, are presented above in Sections 7.2.2 and 7.2.3 by chapter of this *Wetlands Supplement*.

7.2.5 Worksheets

Annex 7A.1 provides also worksheets for each sub-category for which guidance is given in the Wetlands Supplement. The worksheets can be used to estimate emissions based on Tier 1 methods and appropriate emission/stock change factors and activity data.

7.3 UNCERTAINTIES

7.3.1 Overview of uncertainty analysis

Uncertainty is an expression of the degree to which the value of a variable is unknown (IPCC, 2007). In greenhouse gas inventories, uncertainty derives from quantifiable errors and variation in methods and data.

For greenhouse gas inventories, quantification of uncertainty is important because it allows inventory agencies to ascertain if estimated changes in greenhouse gas emissions and removals over two or more years are larger than the uncertainty of possible estimates for an individual year. In wetlands and drained soils, the magnitude of carbon stocks is often much larger than annual emissions or removals, so large uncertainties in carbon stock estimates may make it difficult to determine if estimated annual emissions or removals are real or a result of uncertainty. Uncertainty analysis can indicate areas for future improvement of inventory methods that can reduce the uncertainties.

In greenhouse gas inventories, major quantifiable sources of uncertainty include:

- field measurement errors
- remote sensing inaccuracies
- geographic and land cover map inaccuracies
- missing or incomplete data in time series
- misreporting or misclassification
- data bias or unrepresentative sampling
- random sampling error
- spatial variation
- spatial or temporal autocorrelation, when not properly considered
- model inaccuracies

Uncertainty analysis generally proceeds through these steps:

- Identification of primary sources of uncertainty.
- Estimation of uncertainties of individual variables.
- Combination of individual variable uncertainties into total uncertainty estimates of emissions or removals for a land-use category for a geographic area.

This section summarises scientific methods for the two approaches of uncertainty analysis set forth in the *2006 IPCC Guidelines*. This section aims to summarise material from Chapter 3 in Volume 1 and Chapter 7 in Volume 4 of the *2006 IPCC Guidelines*, summarise new methods for the categories and sub-categories described in Chapters 2 to 6 of this *Wetlands Supplement*, and assess methods across the wetlands and drained soilsubcategories. To the extent possible, it provides published examples. Inventory compilers should consult the detailed information in the *2006 IPCC Guidelines* and this *Wetlands Supplement*.

7.3.2 Methods for quantifying uncertainty

The measure of uncertainty for national greenhouse gas inventories is the 95% confidence interval (CI). It is *good practice* to report the 95% CI for individual variables, including activity data, emissions factors, biomass densities, other parameters, and total greenhouse gas emissions or removals from any key category or land-use category for a geographic area.

The *2006 IPCC Guidelines* set forth two approaches for quantifying uncertainty. Approach 1 is a basic approach that uses algebraic equations to combine individual variable uncertainties. Approach 2 is an advanced approach that uses Monte Carlo analysis.

Approach 1 - Use the measures of uncertainty for individual variables given in the default tables in this *Wetlands Supplement* and the *2006 IPCC Guidelines*. To combine individual variable uncertainties into total estimates of the uncertainty of emissions or removals for any key category or land-use category for a geographic area, use algebraic uncertainty combination methods (Mandel, 1984), identified in Chapter 3 in Volume 1 of the *2006 IPCC Guidelines*.

Use Equation 7.1 to calculate the uncertainty of a set of added variables:

EQUATION 7.1
ALGEBRAIC COMBINATION OF UNCERTAINTIES – ADDITION AND SUBTRACTION

$$U_{total} = \frac{\sqrt{(U_1 \times x_1)^2 + (U_2 \times x_2)^2 + \ldots + (U_n \times x_n)^2}}{\left|x_1 + x_2 + \ldots + x_n\right|}$$

Where:

U_{total} = uncertainty (95% CI) of the sum of the variables

U_i = uncertainty (95% CI) of a variable

x_i = value of a variable.

If the sum emissions and removals[4] in the denominator approaches zero, Equation 7.1 may give very high uncertainty values and not reflect the true value of underlying uncertainties of the individual emissions or removals estimates. In a time series, changes in the value given by Equation 7.1 may not necessarily reflect real changes in uncertainties of individual variables. In such cases, it may be better to use absolute uncertainty values of removals in the denominator. These absolute values can be combined with absolute values of the rest of the inventory to give overall inventory uncertainty.

Use Equation 7.2 to calculate the uncertainty of a set of multiplied variables:

EQUATION 7.2
ALGEBRAIC COMBINATION OF UNCERTAINTIES – MULTIPLICATION

$$U_{total} = \sqrt{U_1^2 + U_2^2 + \ldots + U_n^2}$$

Where:

U_{total} = uncertainty (95% CI) of the product of a set of variables

U_i = uncertainty (95% CI) of a variable

Refer to the *2006 IPCC Guidelines* for detailed steps of algebraic uncertainty combination, including calculation of uncertainties of temporal trends.

This *Wetlands Supplement* presents guidance to take into consideration the sources of uncertainty, either in activity data or emissions factors that are important specifically for wetlands and drained soils. The definitions of sub-categories for wetlands and drained soils, and delineation of their surface areas can, by themselves, be sources of uncertainty. While the *2006 IPCC Guidelines* generally stratify land-use categories by ecological zone (Chapter 3 in Volume 4) or climate zone, this *Wetlands Supplement* stratifies wetlands and drained soils into

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[4] Emissions are positive and removals negative values in greenhouse gas inventories

sub-categories based on their characteristics and human activities. The following list summarises particular sources of uncertainty for the sub-categories and new tables that provide inventory compilers with default uncertainty values.

- **Drained inland organic soils** – Particular uncertainties include the high spatial variability of soil organic carbon, variation of surface areas and emissions factors by drainage class, which requires estimates of the depth of the water table, the fraction of land area occupied by drainage ditches, which is the key parameter for estimating CH_4 emissions, and high spatial and temporal variability of N_2O emissions, which can generate large standard errors relative to mean fluxes. Particular sources of uncertainty for estimates of fire emissions include variability of fire behavior among vegetation types, variation of the fraction of fuel combusted among ecosystems, fires, years, and land management practices, partitioning of smoke among CO_2, CO, and other gases, and estimates of burned area and fuels.
    - Table 2.1 - Tier 1 CO_2 emission/removal factors for drained organic soils in all land-use categories
    - Table 2.2 - Default dissolved organic carbon (DOC) emission factors for drained peatlands and organic soils
    - Table 2.3 - Tier 1 CH_4 emission/removal factors for drained organic soils in all land-use categories
    - Table 2.4 - Default CH_4 emission factors for drainage ditches
    - Table 2.5 - Tier 1 N_2O emission/removal factors for drained organic soils in all land-use categories
    - Table 2.6 - Peat fuel consumption values for fires in a range of peatland types
    - Table 2.7 - Emission factors for peat fires
- **Rewetted organic soils** – The principal uncertainty is the high spatial variability of soil organic carbon.
    - Table 3.1 - Default emission factors (EF_{CO2}) and associated uncertainty, for CO_2-C by rewetted organic soils (all values in tonnes CO_2-C ha^{-1} yr^{-1})
    - Table 3.2 - Default DOC emission factors ($EF_{DOC\_REWETTED}$ in tonnes CO_2-C ha^{-1} yr^{-1}) for rewetted organic soils
    - Table 3.3 - Default emission factors for CH_4 from rewetted organic soils (all values in kg CH_4-C ha^{-1} yr^{-1})
- **Coastal wetlands** – Particular uncertainties include variation of aboveground biomass by mangrove or seagrass species, forest age, tide height, soil fertility, salinity of flood waters, and flood frequency and inter-annual variation of vegetation production.
    - Table 4.2 - Carbon fraction of aboveground mangrove forest biomass (tonnes C (tonnes d.m.)$^{-1}$)
    - Table 4.3 - Aboveground biomass in mangrove forests (tonnes d.m. ha^{-1})
    - Table 4.4 - Aboveground biomass growth in mangrove forests (tonnes d.m. ha^{-1} yr^{-1})
    - Table 4.5 - Ratio of belowground biomass to aboveground biomass (R) in mangroves forests
    - Table 4.6 - Average density (tonnes m^{-3}) mangrove wood
    - Table 4.7 - Tier 1 default values for litter and dead wood carbon stocks
    - Table 4.8 - Summary of Tier 1 estimation of initial changes in C pools for extraction activities
    - Table 4.9 - Ratio of belowground biomass to aboveground biomass (R) for tidal marshes
    - Table 4.10 - Ratio of belowground biomass to aboveground biomass (R) for seagrass meadows
    - Table 4.11 - Soil C stocks for mangrove and tidal marsh on organic soils (tonnes C ha^{-1}) for extraction activities
    - Table 4.12 - Annual emission factors (EF) associated with rewetting (EF_{REWET}) on aggregated organic and mineral soils (tonnes C ha^{-1}) at initiation of vegetation reestablishment
    - Table 4.13 - Annual emission factors (EF) associated with drainage (EF_{DR}) on aggregated organic and mineral soils (tonnes C ha^{-1} yr^{-1})
    - Table 4.14 - Emission factors for Tier 1 estimation of rewetted land previously vegetated by tidal marshes and mangroves
    - Table 4.15 - Emission factor (EF_F) for N_2O emission from aquaculture in mangroves, tidal marshes and seagrass meadows

Inland wet mineral soils – Some emissions are a function of time under management.

  - Table 5.2 - Default reference soil organic carbon stocks for wetland mineral soils under native vegetation
  - Table 5.3 - Relative stock change factors for land-use for long term cultivation on cropland with inland wet mineral soils (over 20 years) and wetland restoration of cropland with inland wet mineral soils (over 20 years and 40 years)
  - Table 5.4 - Default emission factors for CH_4 from managed lands with inland wet mineral soils where water table level has been raised

- **Constructed Wetlands for Wastewater Treatment** – Major sources of uncertainty include estimation of the quantity of treated wastewater, fraction of organics converted anaerobically to CH_4 during wastewater collection, amount of industrial organic wastewater from small or medium industries discharged into constructed wetlands, and differences in gas exchange by different plant species.
  - Table 6.2 - Influent total organic carbon (TOC) and total nitrogen (TN) values, relevant CH_4-C and N_2O-N emissions, and share (%) of CH_4-C and N_2O-N in the initial loading of TOC and TN in constructed wetlands
  - Table 6.5 - Default uncertainty ranges for domestic and industrial wastewater
  - Table 6.7 - Nitrous oxide methodology default uncertainties

It is *good practice* to use uncertainty estimates reported by or derived from the same data sources used for the emissions and removals estimates. For Tier 1 estimates, use the uncertainties given in the IPCC default tables. For Tier 2, the data sources of the country- or ecosystem-specific parameters would provide the most appropriate uncertainty estimates. In the absence of country- or ecosystem-specific uncertainty estimates, it is possible to use published uncertainty estimates for similar ecosystems or circumstances, such as listed in Table 7.2 below. These published uncertainty estimates can also provide useful data to check country- or ecosystem-specific uncertainty estimates.

TABLE 7.2
EXAMPLES OF WETLANDS AND DRAINED SOILS WITH PUBLISHED ESTIMATES OF UNCERTAINTIES OF PARAMETERS USED IN ESTIMATING GREENHOUSE GAS EMISSIONS AND REMOVALS

Continent	Country	Wetland or drained soil type	Reference
Africa	Botswana	Okavango Delta	Mladenov *et al.*, 2005
	Madagascar	estuary	Ralison *et al.*, 2008
	Senegal	estuary area	Sakho *et al.*, 2011
Asia	China	constructed wetland	Chen *et al.*, 2011
	Indo-Pacific	mangroves	Donato *et al.*, 2011
	Indonesia	peat swamps and oil palms	Murdiyarso *et al.*, 2010
North America	Canada	restored wetlands	Badiou *et al.*, 2011
	Costa Rica	tropical inland wetlands	Bernal and Mitsch. 2008
	USA	streams and rivers	Butman and Raymond, 2011
South America	Argentina	river marsh	Vicari *et al.*, 2011
	Brazil	Pantanal	Schöngart *et al.*, 2011
	Peru	Amazonian peatland	Lähteenoja *et al.*, 2012
Global	Global	coastal ecosystems	Mcleod *et al.*, 2011
	Global	freshwater wetlands	Kayranli *et al.*, 2010
	Global	freshwater wetlands methane	Bastviken *et al.*, 2011
	Global	mangroves	Breithaupt *et al.*, 2012
	Global	restored wetlands	Moreno-Mateos *et al.*, 2012
	Global	seagrass	Fourqurean *et al.*, 2012
	Global	tropical peatlands	Page *et al.*, 2011
	Global	wetlands carbon and methane	Mitsch *et al.*, 2010

Approach 2 – For an individual variable, calculate the 95% CI from the probability density function (PDF) of measurements of the variable. Derive the PDF from a random sample. Capture the principal forms of spatial and temporal variation in the sample or calculate different PDFs for the principal spatial and temporal strata. Section 3.2.2.4, Chapter 3 in Volume 1of the *2006 IPCC Guidelines* provides methods to develop PDFs.

To combine individual variable uncertainties into total estimates of emissions or removals for a land-use category or a geographic area, use the Monte Carlo method (Metropolis and Ulam, 1949), set forth by the *2006 IPCC Guidelines* as Approach 2. The Monte Carlo method is a statistical technique that quantifies the uncertainty of a variable based on a large number of randomized realizations of the value of the variable based on its mean value and the standard error of the mean (for a PDF that follows a normal distribution) or other appropriate measure of error (for other types of PDFs).

For example, the width of a ditch is an essential variable in estimating CH_4 emissions from drained organic soils (Equation 2.5 in Chapter 2 of this supplement). In a typical field survey, a person might measure the width of a ditch once and record the measurement. If the measurement were immediately repeated, the result may be slightly different due to the exact placement of the measuring device, judgment of the level of water, which defines the width, possible errors in transcribing or transmitting the value, and other factors. Repeating the measurement 100 or 1000 times would generate a PDF that might typically take the form of a normal distribution. The 95% CI of the distribution is a measure of the uncertainty of the ditch width measurement.

Monte Carlo analysis consists of running a calculation for a statistically significant number of replications, typically 100 to 10 000, producing a probability density function of the result, and calculating the 95% CI of the PDF. For any equation, the Monte Carlo form of a variable (Equation 7.3 below) can replace each of the variables in the equation. The large number of realizations effectively combines the uncertainties of individual variables.

EQUATION 7.3
MONTE CARLO ANALYSIS – GENERAL FORM OF A VARIABLE

$$x_i = mean_x + \left(random_i \times SE_x \right)$$

Where:

x_i = value of realization i of a variable,

i = statistically significant number of realizations, typically 100 – 10 000

$mean_x$ = mean value of a variable

$random_i$ = random number for realization i, from -1 to 1, taken from a set of random numbers that form a probability distribution function specific to the variable

SE_x = standard error of the mean value of the variable

Refer to the *2006 IPCC Guidelines* for detailed steps of Monte Carlo analysis, including selection of an appropriate PDF for a variable and its random numbers. Inventory compilers and scientists have quantified uncertainty in greenhouse gas inventories in a range of cases, including the national inventories of Austria (Winiwarter and Muik, 2010), Finland (Monni *et al.*, 2007), and the Netherlands (Ramírez *et al.*, 2008) and high-biomass ecosystems in California, USA (e.g. Gonzalez *et al.*, 2010) and Canada (*e.g.* Kurz *et al.*, 2008).

Ways to reduce uncertainty in both Approach 1 and Approach 2 include:

- **Organic soils** – Spatially disaggregated CO_2 flux measurements can provide data to develop local emission factors, correcting for carbon losses through leaching of dissolved organic carbon or runoff. Quantification of impacts of land-use and management on emissions can improve emissions estimates. Examples include organic matter additions to agricultural land that can increase substrate supply for methane production in ditches, short-term pulses of ditch CH_4 emission associated with land-use change, and nutrient-enriched soils that are a legacy of past land use.

- **Rewetted peatlands** – CO_2 and CH_4 emissions are often a function of present vegetation composition and previous land use history. So, stratification of an area by these properties can improve emissions estimates. Determination of spatial variation of peat type and depth, vegetation composition, soil temperature, mean water table depth, the provision by vegetation of substrates for CH_4 production, and transport by vegetation of CH_4 from saturated soil to the atmosphere can improve emissions estimates.

- **Coastal wetlands** – More detailed stratification of land by drainage and other management systems can improve emissions estimates. Quantification of the effects of coastal grassland management, including grazing, fire, liming, and fertilization, can improve emissions estimates.

- **Inland mineral soil wetlands** – Chapter 5 in the *Wetlands Supplement* does not identify uncertainty reduction methods.

- **Constructed Wetlands for Wastewater Treatment** – Provide separate estimates for domestic and industrial wastewater by type of constructed wetlands (surface flow (SF), horizontal subsurface flow (HSSF), and vertical subsurface flow (VSSF)).

7.4 IMPACT ON KEY CATEGORIES

7.4.1 Overview of key category analysis

A *key category* is a category that is prioritized within the national inventory system because its estimate has a significant influence on a country's total inventory of greenhouse gases in terms of the absolute level, the trend, or the uncertainty in emissions and removals. Whenever the term *key category* is used, it includes both source and sink categories.

Methodological choice (choice of tier) for individual source and sink categories is important in managing overall inventory uncertainty. Generally, inventory uncertainty is lower when higher-tier methods are used to estimate emissions and removals. However, higher-tier methods generally require extensive resources for data collection, so it may not be feasible to use these methods for every category. It is therefore *good practice* to identify those categories that have the greatest contribution to the total magnitude of inventory emissions, removals, and/or uncertainty, to make the most efficient use of available resources. By identifying the *key categories* in the national inventory, inventory compilers can prioritize their efforts and improve the overall estimates. The purpose, general rules, and approaches for the key category analysis of the whole greenhouse gas inventory are presented in Chapter 4 in Volume 1 of the *2006 IPCC Guidelines*.

According to Section 4.2 in Volume 1 of the *2006 IPCC Guidelines*, the general rules for performing the key category analysis are:

- The analysis should be performed at the level of IPCC categories or subcategories for which IPCC methods and/or decision trees are provided.
- Each greenhouse gas emitted from each category should be considered separately, unless there are specific methodological reasons for treating gases collectively.
- Emissions and removals from a category should also be considered separately, where possible and relevant.

Table 4.1 in Section 4.2 in Volume 1 of the *2006 IPCC Guidelines* gives a recommended level at which the key category analysis should be performed. Countries may however choose to perform the quantitative analysis at a more disaggregated level than suggested in the table.

Key category analyses are performed using two approaches. Approach 1 is based on level and trend assessments. In the level assessment under Approach 1, categories of the inventory are listed in the order of absolute values of their contribution to the sum of the absolute value of emissions and removals, and the largest categories contributing to 95% of this sum are considered *key categories*. The trend assessment under Approach 1 analyses the contribution of a category to the trend and if the trend of the category is significantly different from that of the inventory. The categories contributing most to 95% of the trend are considered *key categories*. Section 4.3.1 in Chapter 4 in Volume 1 of the *2006 IPCC Guidelines* presents the details on the key category analysis. Approach 2 is based on similar level and trend assessments but it also takes into account uncertainties of the categories included in the analysis (for details, see Section 4.3.2 in Chapter 4 in Volume 1 of the *2006 IPCC Guidelines*).

Countries are encouraged to undertake key category analysis using Approaches 1 and 2, because Approach 2 can provide additional insight, e.g. on the order in which to tackle categories identified in Approach 1.

Countries are also encouraged to include qualitative criteria in the key category analysis (see Section 4.3.3 in Chapter 4 in Volume 1 of the *2006 IPCC Guidelines*). If quantitative key category analysis has not been carried out due to lack of completeness in the inventory, it is *good practice* to use qualitative criteria to identify *key categories*.

7.4.2 Key category analysis including the categories affected by the Wetlands Supplement

According to Table 4.1 Chapter 4 in Volume 1 of the *2006 IPCC Guidelines*, the appropriate aggregation level for land use CO_2 emissions (carbon stock changes) is to distinguish the emissions or removals for lands remaining and lands converted to each of the six land-use categories. Thus, twelve categories need to be distinguished. This approach is considered appropriate, as the CO_2 emissions/removals from the land-use categories are generally estimated using the same or similar generic methodologies and also using the same activity data (area data).

The *Wetlands Supplement* introduces new sub-categories and more detailed guidance for some categories in the AFOLU Sector. Also, the Wastewater Treatment category in the Waste Sector is complemented with an additional treatment system (constructed wetlands). Despite these changes, inventory compilers should continue to perform the key category analysis at the level suggested in Table 4.1, Chapter 4 in Volume 1 of the *2006 IPCC Guidelines*. In addition, inventory compilers should determine which pools and subcategories are significant. The significance of the categories and sub-categories affected by the *Wetlands Supplement* should be assessed using the generic rule that a sub-category is significant if it accounts for 25-30% of its *key category* (see decision trees in Figures 1.2 and 1.3 in Chapter 1 in Volume 4 of the *2006 IPCC Guidelines*).

In the quantitative key category analysis, when emissions/removals from a specific activity, such as conversion of forest to other land-uses, are estimated using the same methodology, but spread out among different land-use change categories, inventory compilers should identify and sum up the emission/removal estimates for this activity and compare its magnitude with the smallest category identified as key. If this sum is larger than the smallest category identified as key, the activity in question should be considered key. Countries should assess whether this rule would be applicable to their circumstance for categories addressed in this *Wetlands Supplement*.

7.5 COMPLETENESS

Complete greenhouse gas inventories include estimates of emissions and removals from the sources and sinks for which methodological guidance is provided in the *2006 IPCC Guidelines* and the *Wetlands Supplement* unless the specific sources and sinks do not occur on the national territory. The decision tree in Figure 1.1 and Table 1.3 in Chapter 1 of this report provide guidance on the links between guidance in the *2006 IPCC Guidelines* and the *Wetlands Supplement* to help countries in ensuring complete coverage of all relevant categories in the inventory.

A country may consider that a disproportionate amount of effort would be required to collect data for a category or a gas from a specific category that would be insignificant in terms of the overall level and trend in national emissions. The *Wetlands Supplement* addresses sources and sinks for which the significance varies considerably by country. For instance, some wetland and drained soil types occur only in some regions of the world. The amount of organic soils may be very small in some countries and tidal effects on emissions would be applicable only to coastal countries. In circumstances where the supplementary guidance is not applicable to a country or emissions/removals are not reported due to their insignificance, they should use the notation keys “NO” (not occurring) and “NE” (not estimated) respectively. For details on the use of the notation keys, the inventory compilers should refer to Section 8.2.5 in Volume 1 of the *2006 IPCC Guidelines*. It is good practice to provide justification for each emission estimate for which the notation key “NE” is used.

7.6 TIME SERIES CONSISTENCY

7.6.1 Overview of time series issues

Greenhouse gas inventory methods should be consistent for an entire time series so that each year in the time series can be compared with other years. This provides countries with information to properly assess temporal trends in greenhouse gas emissions and removals and the effectiveness of emissions reduction measures. Issues that will affect time series consistency include:

- changes and refinements to scientific methods due to research advances
- addition of new categories
- data gaps
- correction of errors

In a consistent time series, changes in emissions or removals over time are due to real phenomena in the field rather than any influence of the above set of circumstances.

This *Wetlands Supplement* includes substantial changes to the *2006 IPCC Guidelines* methods for soil organic matter and refines the sub-categories within all land-use categories. This will make necessary the recalculation of results from previous years to produce a consistent time series.

This section summarises material from the *2006 IPCC Guidelines*, including Chapter 5 in Volume 1 and Chapter 7 in Volume 4. It also adds recent scientific information described in Chapters 2-6 of this *Wetlands Supplement*.

7.6.2 Methods for producing consistent time series

This section provides guidance for producing consistent time series of emissions and removals for the categories and sub-categories addressed in this *Wetlands Supplement*. It presents the information by the tiers that inventory compilers already use to estimate emissions and removals.

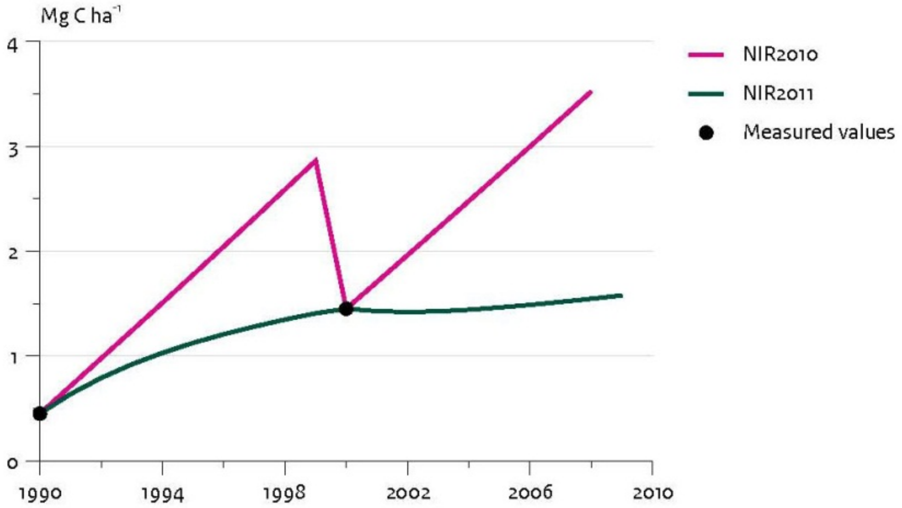
All tiers - Recalculate an entire data series when changing from the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, *2003 Good Practice Guidance for Land Use, Land-Use Change and Forestry*, and *2006 IPCC Guidelines* to the *Wetlands Supplement*, when methods are refined due to scientific advances, new data become available, QC finds errors in previous estimates, or a land classification changes. For data gaps, it is *good practice* to clearly report where an inventory presents measured or monitored results and where it presents model output.

Tier 1 – Use the activity data for years available in the default sources presented in the *Wetlands Supplement* and the *2006 IPCC Guidelines* or national data sources, where available, and fill gaps using appropriate methods in Section 5.3, Chapter 5 in Volume 1 of the *2006 IPCC Guidelines*.

Tiers 2 and 3 - To fill data gaps, examine available historical sources, administrative records, aerial photographs, or remote sensing and use appropriate methods in Section 5.3, Chapter 5 in Volume 1 the *2006 IPCC Guidelines*.

Alternatively, interpolate using a function that models empirical trends or underlying processes. Identify years where the inventory presents measured or monitored results and where it presents model output. Some examples of producing consistent time series include field validation of model dead wood time series in the Netherlands national greenhouse gas inventory (van der Maas *et al.*, 2011; Figure 7.1), data gap filling of CO_2 fluxes from Everglades National Park, USA (Barr *et al.*, 2010), and filling of night-time gaps in ecosystem respiration in Lake Victoria wetlands, Uganda (Saunders *et al.*, 2012). The case of the Netherlands is an example that illustrates recalculation of a time series to improve consistency. When field measurements of dead wood showed that modelled estimates were not accurate, the inventory agency revised the parameters in its dead wood model and recalculated the entire time series (van der Maas *et al.*, 2011; Figure 7.1). Refer to Section 5.3, Chapter 5 in Volume 1 of the *2006 IPCC Guidelines* for detailed steps of filling historical gaps by splicing and for the use of surrogate parameters.

Figure 7.1 Example of recalculation of a time series.



The 2011 national inventory report (NIR) for the Netherlands (van der Maas *et al.*, 2011) provided a more accurate time series of the carbon stock in dead wood than previous inventories. Measured values of dead wood stocks in the Netherlands national forest inventory (black dots) showed that national greenhouse gas inventories prior to 2011 (purple upper line) overestimated the build-up of the carbon stock. Inventory compilers found that their model underestimated the removal of dead wood from forests. Adjustment of that parameter generated a model time series (green lower line) that met the measured values.

7.7 QUALITY ASSURANCE AND QUALITY CONTROL

7.7.1 Overview of quality issues

Quality assurance and quality control are procedures to improve the accuracy, transparency, consistency, comparability, and completeness of inventories. Effectively implemented quality procedures can reduce uncertainties of greenhouse gas inventories. Quality control (QC) is a system of routine activities to assess, improve or maintain the quality of the inventory as it is being compiled. Quality assurance (QA) is a planned system of review procedures conducted by personnel not directly involved in the inventory and performed on a completed inventory. This section summarises material from the *2006 IPCC Guidelines,* including Volume 1, Chapter 6 and Volume 4, Chapter 7. It also adds recent scientific information described in Chapters 2-6 of this *Wetlands Supplement*.

7.7.2 Quality assurance and quality control methods

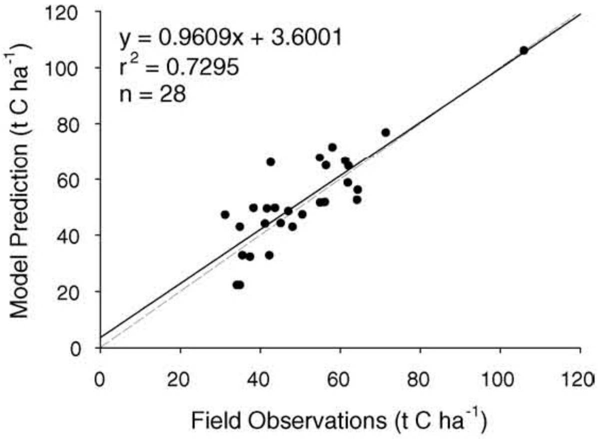
Provide routine and consistent checks to ensure data integrity, correctness, and completeness. Identify and address errors and omissions. Document and archive inventory material and record all QC activities. Check labelling, transcription, and other clerical issues related to data entry (See complete list in Table 6.1, Volume 1 of the *2006 IPCC Guidelines*). Double-check outlying values against data sources. Check final results against previous years and published values. Compare inventories with results from similar ecosystems in other countries. Conduct an area-balance for land-use category areas and, when applicable, a mass-balance for greenhouse gas emissions and removals. Develop automated data control procedures. It is *good practice* to prioritize key categories for more extensive QA and QC.

Where default values are used, it should be ensured that they reflect the country's conditions as inappropriate default values lead to an increase of the associated uncertainty.

Where higher tiers are used, estimations can be checked against local data sources for activity data, emissions factors, and other variables. Check scientific literature for any new scientific information.

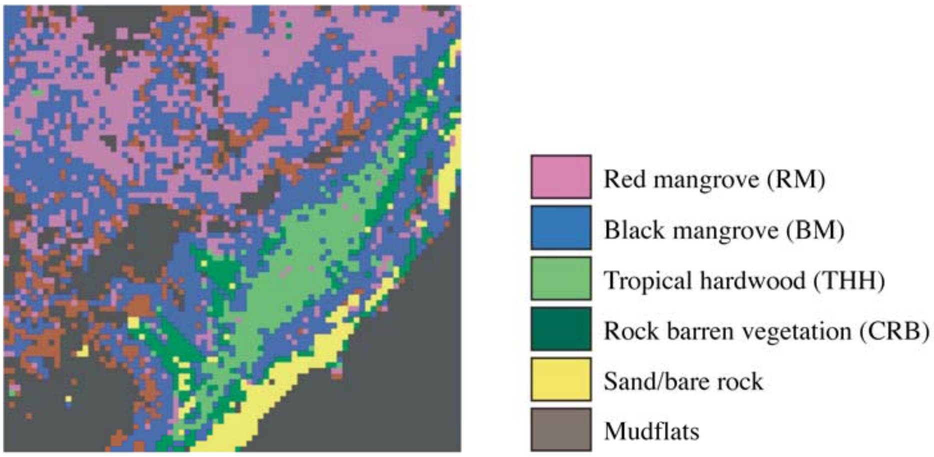
Computer models can be validated against field measurements and resulting difference should be included in the calculation of uncertainty (Section 7.2.1). The validation measure can be a correlation of predicted and measured values (Figure 7.2; Miehle *et al.*, 2006), fractional agreement of modelled and observed data (Figure 7.3; Chadwick, 2011), or other variable. Separate the data set used for calibration of a model from the data set used for validation of the model. When more than one model is available for a particular parameter, inter-comparison of model output can provide indications of the robustness of individual models. Comparison of Tier 3 models with estimates using Tier 1 and Tier 2 methods can serve that same purpose. IPCC (2011) provides numerous specific examples of model development, calibration, and validation.

Figure 7.2 Example of validation of a model for quality control



Values of aboveground biomass derived from field measurements of *Eucalyptus globulus* in Australia (x-axis) provide data to validate the accuracy of output from the Forest-Denitrification decomposition (DNDC) model (y-axis) (Miehle *et al.*, 2006). The correlation coefficient (r) and significance probability (not shown) are validation measures of the model. More observed values and a wider range of carbon densities would improve the validation.

Figure 7.3 Example of validation of remote sensing data for quality control



Class	RM	BM	THH	CRB	Sand/ Rock	Mudflats	Asphalt	Omission (%)
(*a*) IKONOS classification: overall accuracy = 83.3%; kappa coefficient = 0.79								
RM	**82.0**	10.3	6.2	0.43	0	1.1	0	18.0
BM	3.6	**77.6**	2.3	9.9	0.33	6.3	0	22.4
THH	7.1	6.9	**73.8**	11.7	0.48	0	0	26.2
CRB	0	3.3	1.3	**93.4**	2.0	0	0	6.6
Sand/Rock	0	0	0	0	**100**	0	0	0
Mudflat	1.5	1.5	0	1.4	6.0	**89.6**	0	10.5
Asphalt	0	0	0	0	13.51	0	**86.5**	13.5
Commission (%)	9.9	27.2	11.4	22.3	10.3	28.6	0	

The map shows wetlands cover in part of Florida, USA, derived from an Ikonos satellite image (Chadwick, 2011). The table is an error matrix that shows the fraction of pixels (%) where the Ikonos-derived wetlands cover class (columns) matches the class directly observed in the field (rows). The overall accuracy (83%) is the validation measure. The column "omission" gives the fraction of observed pixels that the Ikonos cover classification missed. The row "commission" gives the fraction of Ikonos-derived wetlands cover pixels that the classification incorrectly identified.

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ANNEX 7A.1

WORKSHEETS

This annex provides worksheets that can be used to estimate greenhouse gas emissions and removals based on Tier 1 methods given in the *Wetlands Supplement*. Most of the worksheets included in this annex are new ones that are not included in Annex 1, Volume 4 of the *2006 IPCC Guidelines*. However, the following 6 worksheets are to update or replace the existing worksheets in Annex 1, Volume 4 of the *2006 IPCC Guidelines*.

- Worksheet for Land Remaining in a Land-use Category or Land Converted to a New Land-use Category: Annual On-site Carbon Emissions and Removals from Drained Inland Organic Soils (Page 7.26)

  This sheet is to replace the existing worksheets for Annual Change in Carbon Stocks in Organic Soils for the six land-use categories (e.g., existing worksheets on pages A1.23 and A1.27, Annex 1, Volume 4) in the *2006 IPCC Guidelines*.

- Worksheet for Direct N_2O Emissions from Managed Soils (Page 7.29)

  This sheet is to update the existing worksheet for Direct N_2O Emissions from Managed Soils on page A1.58, Annex 1, Volume 4 of the *2006 IPCC Guidelines*.

- Worksheet for Cropland Remaining Cropland: Annual change in carbon stocks in mineral soils (Page 7.44)

  This sheet is to update the existing worksheet for Annual Change in Carbon Stocks in Mineral Soils for Cropland Remaining Cropland on page A1.22, Annex 1, Volume 4 of the *2006 IPCC Guidelines*.

- Worksheet for Land (non-Cropland) remaining in a Land-use Category: Annual change in carbon stocks in mineral soils (Page 7.45)

  This sheet is to update the existing worksheets for Annual Change in Carbon Stocks in Mineral Soils for land remaining in the same land-use category for land-use category other than Cropland (e.g., existing worksheet on page A1.28, Annex 1, Volume 4) in the *2006 IPCC Guidelines*.

- Worksheet for Land Converted to a Cropland: Annual change in carbon stocks in mineral soils (Pages 7.46-7.47)

  This sheet is to update the existing worksheet on Annual Change in Carbon Stocks in Mineral Soils for Land Converted to Cropland on page A1.26 Annex 1, Volume 4 of the *2006 IPCC Guidelines*.

- Worksheet for Land Converted to a New Land-use Category (non-Cropland): Annual change in carbon stocks in mineral soils (Page 7.48)

  This sheet is to update the existing worksheets for Annual Change in Carbon Stocks in Mineral Soils for land converted to a new land use category other than Cropland (e.g., existing worksheet on page A1.32, Annex 1, Volume 4) in the *2006 IPCC Guidelines*.

CHAPTER 2—DRAINED INLAND ORGANIC SOILS

Sector		**Agriculture, Forestry and Other Land Use**			
Category		**Land Remaining in a Land-use Category OR Land Converted to a New Land-use Category : Annual On-site carbon emissions and removals from drained Inland organic soils**			
Category code		**[To be specified by the inventory compiler][1]**			
Sheet		**2 of 3 (earlier was 2 of 2)**			
Equation		**Equation 2.2 (*2006 IPCC Guidelines*)**	**Equation 2.3 (*Wetlands Supplement*)**		
Land-use category		Subcategories for reporting year	Land area of drained inland organic soils in a land-use category in climate domain c, nutrient status n, and drainage class d	Emission factors for drained inland organic soils, by climate domain c, nutrient status n, and drainage class d	Annual on-site CO_2-C emissions/removals from drained inland organic soils
Initial land use[3]	Land use during reporting year		(ha)	(tonnes C ha^{-1} yr^{-1})	(tonnes C yr^{-1})
				Table 2.1 of the *Wetlands Supplement*	**CO_2-$C_{soil-onsite}$ = A * EF**
			A	**EF**	**CO_2-$C_{soil-onsite}$**
		(a)			
		(b)			
		(c)			
Total					

[1] This worksheet can be used for any category under 3B. Inventory compilers should specify an appropriate category code here. For example, when this worksheet is used to calculate emissions to be reported in the category Forest Land Remaining Forest Land, “3B1a” should be entered as category code.

[2] Sub-totals of emissions for each land pre-conversion land-use category will have to be calculated for conversion categories.

[3] For conversion categories, if data by initial land use are not available, use only "non-LU" in this column.

Sector		**Agriculture, Forestry and Other Land Use**			
Category		**Land Remaining in a Land-use Category OR Land Converted to a New Land-use Category : Annual off-site emissions from drained inland organic soils**			
Category code		**[To be specified by the inventory compiler][1]**			
Sheet		**3 of 3**			
Equation		**Equation 2.2 (*2006 IPCC Guidelines*)**	**Equation 2.5 (*Wetlands Supplement*)**		
Land-use category		Subcategories for reporting year	Land area of drained inland organic soils in a land-use category in climate zone c and nutrient status n	Emission factors for annual CO_2 emissions due to DOC export from drained inland organic soils, by climate zone c and nutrient status n	Annual off-site CO_2-C emissions from drained inland organic soils
Initial land use	Land use during reporting year		(ha)	(tonnes C ha^{-1} yr^{-1})	(tonnes C yr^{-1})
				Table 2.2 of the *Wetlands Supplement*	
			A	**EF**	**CO_2-C_{DOC} = A * EF**
		(a)			
		(b)			
		(c)			
Total					

[1] This worksheet can be used for any category under 3B. Inventory compilers should specify an appropriate category code here. For example, when this worksheet is used to calculate emissions to be reported in the category Forest Land Remaining Forest Land, “3B1a” should be entered as category code.

Sector		**Agriculture, Forestry and Other Land Use**					
Category		**Land Remaining in a Land-use Category OR Land Converted to a New Land-use Category[1]: Annual CH_4 emissions from drained inland organic soils**					
Category code		**[To be specified by the inventory compiler][2]**					
Sheet		**1 of 1**					
Equation		**Equation 2.2 (*2006 IPCC Guidelines*)**	**Equation 2.6 (*Wetlands Supplement*)**				
Land-use category		Subcategories for reporting year	Land area of drained inland organic soils in a land-use category in climate zone c, nutrient status n and peatland type p	Fraction of the total area of drained inland organic soil which is occupied by ditches[4]	Emission factors for direct CH_4 emissions from drained organic soils, by climate zone c and nutrient status n	Emission factors for CH_4 emissions from drainage ditches, by climate zone c and peatland type p	Annual CH_4-C loss from drained inland organic soils
Initial land use[3]	Land use during reporting year		(ha)	(dimensionless)	(tonnes CH_4 ha^{-1} yr^{-1})	(tonnes CH_4 ha^{-1} yr^{-1})	(tonnes CH_4 yr^{-1})
					Table 2.3 of the *Wetlands Supplement*	Table 2.4 of the *Wetlands Supplement*	
			A	$Frac_{ditch}$	EF_{CH4_land}	EF_{CH4_ditch}	$CH_4\text{-}C_{organic} = A * [(1-Frac_{ditch}) * EF_{CH4\_land} + Frac_{ditch} * EF_{CH4\_ditch}]$
		(a)					
		(b)					
		(c)					
Total							

[1] Sub-totals of emissions for each land pre-conversion land-use category will have to be calculated for conversion categories.

[2] This worksheet can be used for any category under 3B. Inventory compilers should specify an appropriate category code here. For example, when this worksheet is used to calculate emissions to be reported in the category Forest Land Remaining Forest Land, “3B1a” should be entered as category code.

[3] For conversion categories, if data by initial land use are not available, use only "non-LU" in this column.

[4] Table 2.4, Chapter 2 of the *Wetlands Supplement* contains indicative values of $Frac_{ditch}$

	Sector	**Agriculture, Forestry and Other Land Use**						
	Category	**Direct N_2O Emissions from Managed Soils**						
	Category code	**3C4**						
	Sheet	**2 of 2**						
	Equation	**Equation 11.1 of *2006 IPCC Guidelines* and Equation 2.7 of the *Wetlands Supplement***						
Anthropogenic N input type[1,2]		Annual area of managed/drained organic soils	Emission factor for N_2O emissions from drained/managed organic soils	Annual direct N_2O-N emissions produced from managed organic soils	Amount of urine and dung N deposited by grazing animals on pasture, range and paddock	Emission factor for N_2O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals	Annual direct N_2O emissions from urine and dung inputs to grazed soils	Annual direct N_2O emissions from urine and dung inputs to grazed soils
		(ha)	(kg N_2O-N ha^{-1} yr^{-1})	(kg N_2O-N yr^{-1})	(kg N yr^{-1})	[kg N_2O-N (kg N input)$^{-1}$]	(kg N_2O-N yr^{-1})	(kg N_2O-N yr^{-1})
			Table 11.1 (*2006 IPCC Guidelines*) and Table 2.5 (*Wetlands Supplement*)	$N_2O\text{-}N_{OS} = F_{OS} * EF_2$		Table 11.1	$N_2O\text{-}N_{PRP} = F_{PRP} * EF_{3PRP}$	$N_2O_{Direct}\text{-}N = N_2O\text{-}N_{N\ input} + N_2O\text{-}N_{OS} + N_2O\text{-}N_{PRP}$
		F_{OS}	**EF_2**	**$N_2O\text{-}N_{OS}$**	**F_{PRP}**	**EF_{3PRP}**	**$N_2O\text{-}N_{PRP}$**	**$N_2O_{Direct}\text{-}N$**
Managed organic soils	CG, Bor							
	CG, Temp							
	CG, Trop							
	F, Bor, NR							
	F, Bor, NP							
	F, Temp, NR							
	F, Temp, NP							
	F, Trop							
Urine and dung inputs to grazed soils	CPP							
	SO							
Total								

[1] The area must be disaggregated by Cropland and Grassland (CG), Forest (F), Temperate (Temp), Tropical (Trop), Nutrient Rich (NR), and Nutrient Poor (NP) categories, respectively, see Equation 11.1 of the *2006 IPCC Guidelines*.

[2] The amount must be disaggregated by CPP and SO, which refer to Cattle, Poultry and Pigs, and Sheep and Other animals, respectively. See Equation 11.1 of the *2006 IPCC Guidelines*.

<table>
<tr><td>Sector</td><td colspan="10">Agriculture, Forestry and Other Land Use</td></tr>
<tr><td>Category</td><td colspan="10">Emissions from Burning of Drained Inland Organic Soils in a Land-use Category (Land Remaining in a Land-use Category OR Land Converted to a New Land-use Category)</td></tr>
<tr><td>Category code</td><td colspan="10">[To be specified by the inventory compiler][1]</td></tr>
<tr><td>Sheet</td><td colspan="10">1 of 1</td></tr>
<tr><td colspan="2">Equation</td><td>Equation 2.2 (<i>2006 IPCC Guidelines</i>)</td><td colspan="8">Equation 2.8 (<i>Wetlands Supplement</i>)</td></tr>
<tr><td colspan="2">Land-use category</td><td rowspan="4">Subcategories for reporting year[3]</td><td>Area burnt</td><td>Mass of fuel available for combustion[4]</td><td>Combustion factor[4]</td><td colspan="2">Emission factor for each GHG</td><td>CO_2 emissions from fire</td><td>CH_4 emissions from fire</td><td>CO emissions from fire</td></tr>
<tr><td rowspan="3">Initial land use[2]</td><td rowspan="3">Land use during reporting year</td><td>(ha)</td><td>(tonnes ha^{-1})</td><td>(-)</td><td colspan="2">[g GHG (kg dm burnt)$^{-1}$]</td><td>(tonnes CO_2)</td><td>(tonnes CH_4)</td><td>(tonnes CO)</td></tr>
<tr><td></td><td>Table 2.6 of the Wetlands Supplement</td><td>Table 2.6 of the Wetlands Supplement</td><td colspan="2">Table 2.7 of the Wetlands Supplement</td><td>$L_{fire}\text{-}CO_2 = A * M_B * C_f * G_{ef} * 10^{-3}$</td><td>$L_{fire}\text{-}CH_4 = A * M_B * C_f * G_{ef} * 10^{-3}$</td><td>$L_{fire}\text{-}CO = A * MB * Cf * Gef * 10^{-3}$</td></tr>
<tr><td>A</td><td>M_B</td><td>C_f</td><td colspan="2">G_{ef}</td><td>$L_{fire}\text{-}CO_2$</td><td>$L_{fire}\text{-}CH_4$</td><td>$L_{fire}\text{-}CO$</td></tr>
<tr><td rowspan="6"></td><td rowspan="6"></td><td rowspan="3">(a)</td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td>CO_2</td><td></td><td></td><td></td><td></td></tr>
<tr><td>CH_4</td><td></td><td></td><td></td><td></td></tr>
<tr><td>CO</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">(b)</td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td>CO_2</td><td></td><td></td><td></td><td></td></tr>
<tr><td>CH_4</td><td></td><td></td><td></td><td></td></tr>
<tr><td>CO</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3" rowspan="3">Total</td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td colspan="2">CO_2</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">CH_4</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">CO</td><td></td><td></td><td></td></tr>
</table>

[1] This worksheet can be used for any category under 3B. Inventory compilers should specify an appropriate category code here. For example, when this worksheet is used to calculate emissions to be reported in the category Forest Land Remaining Forest Land, “3B1a” should be entered as category code.

[2] For conversion categories, similar tables should be completed separately for each initial land use, and subtotals must be added up. If data by initial land use are not available, use only "non-LU" in this column.

[3] For each subcategory, use separate lines for each non-CO_2 greenhouse gas.

[4] Where data for M_B and C_f are not available, a default value for the amount of fuel actually burnt ($M_B * C_f$) can be used (Table 2.6 of *Wetlands Supplement*). In this case, M_B takes the value taken from the table, whereas C_f must be 1.

CHAPTER 3—REWETTED ORGANIC SOILS

Sector	**Agriculture, Forestry and Other Land Use**
Category	**Annual carbon emissions or removals in rewetted organic soils**
Category code	**[To be specified by the inventory compiler]**[1]
Sheet	**1 of 2 : CO_2-C**

Equation				**Equation 3.4 (*Wetlands Supplement*)**		**Equation 3.5 (*Wetlands Supplement*)**		**Equation 3.3 (Wetlands Supplement)**
Land-use category		Subcategories for reporting year	Area of rewetted organic soils by nutrient status and climate zone	Emission/removal factor for on-site CO_2-C by nutrient status and climate zone	On-site CO_2-C emissions or removals in rewetted organic soils	Emission factor for DOC	Off-site CO_2-C emissions from DOC in rewetted organic soils	Annual CO_2-C emissions or removals by rewetted organic soils
Initial land use	Land use during reporting year		(ha)	(tonnes CO_2-C ha^{-1} yr^{-1})	(tonnes CO_2-C yr^{-1})	(tonnes CO_2-C ha^{-1} yr^{-1})	(tonnes CO_2-C yr^{-1})	(tonnes CO_2-C yr^{-1})
				Table 3. 1	**= A * EF_{CO2}**	Table 3. 2	**= A * $EF_{DOC\_REWETTED}$**	**= CO_2-$C_{composite}$ + CO_2-C_{DOC}**
			A	**EF_{CO2}**	CO_2-$C_{composite}$	**$EF_{DOC\_REWETTED}$**	**CO_2-C_{DOC}**	CO_2-$C_{rewetted\ org\ soil}$
		(a)						
		(b)						
		(c)						
Total								

[1] This worksheet can be used for any category under 3B. Inventory compilers should specify an appropriate category code here. For example, when this worksheet is used to calculate emissions to be reported in the category Forest Land Remaining Forest Land, “3B1a” should be entered as category code.

Sector		**Agriculture, Forestry and Other Land Use**				
Category		**Annual carbon emissions or removals in rewetted organic soils**				
Category code		**[To be specified by the inventory compiler]**[1]				
Sheet		**2 of 2 : CH_4**				
Equation				**Equation 3.8 (*Wetlands Supplement*)**		
Land-use category		Subcategories for reporting year	Area of rewetted organic soils by nutrient status and climate zone	Emission factor for CH_4-C by nutrient status and climate zone	On-site CH_4-C emissions or removals in rewetted organic soils	On-site CH_4 emissions or removals in rewetted organic soils
Initial land use	Land use during reporting year		(ha)	(kg CH_4-C ha^{-1} yr^{-1})	(tonnes CH_4-C yr^{-1})	(tonnes CH_4)
				Table 3. 3	**= A * EF_{CH4} / 1000**	**= CH_4-C_{soil} * 16/12**
			A	**EF_{CH4}**	**CH_4-C_{soil}**	**$CH_{4\ rewetted\ org\ soil}$**
		(a)				
		(b)				
		(c)				
Total						

[1] This worksheet can be used for any category under 3B. Inventory compilers should specify an appropriate category code here. For example, when this worksheet is used to calculate emissions to be reported in the category Forest Land Remaining Forest Land, “3B1a” should be entered as category code.

CHAPTER 4—COASTAL WETLANDS

Sector	**Agriculture, Forestry and Other Land Use**							
Category	**Coastal wetland with woody perennial biomass or Forest Land**							
Category code	**[To be specified by the inventory compiler]**[1]							
Sheet	**1 of 5**							
Equation			**Equation 2.9 (*2006 IPCC Guidelines*)**	**Equation 2.10 (*2006 IPCC Guidelines*)**			**Equation 2.9 (*2006 IPCC Guidelines*)**	
Land-use category		Subcategories for reporting year	Area	Average annual above-ground biomass growth	Ratio of below-ground biomass to above-ground biomass	Average annual biomass growth above- and below-ground	Carbon fraction of dry matter	Annual increase in biomass carbon stocks due to biomass growth
Initial land use	Land use during reporting year		(ha)	(tonnes dm ha^{-1} yr^{-1})	[tonnes bg dm (tonne ag dm)$^{-1}$]	(tonnes dm ha^{-1} yr^{-1})	[tonnes C (tonne dm)$^{-1}$]	(tonnes C yr^{-1})
			National statistics or international data sources	Table 4.4	Table 4.5	$G_{TOTAL} = GW * (1+R)$	Table 4.2	$\Delta C_G = A * G_{TOTAL} * CF$
			A	**G_W**	**R**	**G_{TOTAL}**	**CF**	**ΔC_G**
		(a)						
		(b)						
		(c)						
Total								

[1] This worksheet can be used for any category under 3B. Inventory compilers should specify an appropriate category code here. For example, when this worksheet is used to calculate emissions to be reported in the category Forest Land Remaining Forest Land, “3B1a” should be entered as category code.

Sector		**Agriculture, Forestry and Other Land Use**					
Category		**Coastal wetland with woody perennial biomass or Forest Land : Loss of carbon from wood removals**					
Category code		**[To be specified by the inventory compiler]**[1]					
Sheet		**2 of 5**					
Equation			**Equation 2.12 (*2006 IPCC Guidelines*) + Equation 4.1 (*Wetlands Supplement*)**				
Land-use category		Subcategories for reporting year	Annual wood removal	Biomass expansion factor and wood density for conversion of removals in merchantable volume to total biomass removals (including bark)	Ratio of below-ground biomass to above-ground biomass	Carbon fraction of dry matter	Annual carbon loss due to biomass removals
Initial land use	Land use during reporting year		(m^3 yr^{-1})	BEF * wood density = [tonnes of biomass removals (m^3 of removals) $^{-1}$]	[tonnes bg dm (tonne ag dm)$^{-1}$]	[tonnes C (tonne dm)$^{-1}$]	(tonnes C yr^{-1})
			National statistics or international data sources	Table 3A.1.10 (*2003 GPG*) and Table 4.6	Table 4.5	Table 4.2	$L_{wood\text{-}removals} = H * BCEF_R * (1+R) * CF$
			H	**BCEF**	**R**	**CF**	**$L_{wood\text{-}removals}$**
		(a)					
		(b)					
		(c)					
Total							

[1] This worksheet can be used for any category under 3B. Inventory compilers should specify an appropriate category code here. For example, when this worksheet is used to calculate emissions to be reported in the category Forest Land Remaining Forest Land, "3B1a" should be entered as category code.

Sector		**Agriculture, Forestry and Other Land Use**							
Category		**Coastal wetland with woody perennial biomass or Forest Land: Loss of carbon from fuelwood removals**							
Category code		**[To be specified by the inventory compiler]**[1]							
Sheet		**3 of 5**							
Equation		**Equation 2.2 (*2006 IPCC Guidelines*)**	**Equation 2.13 (*2006 IPCC Guidelines*) + Equation 4.1 (*Wetlands Supplement*)**						
Land-use category		Subcategories for reporting year	Annual volume of fuelwood removal of whole trees	Biomass expansion factor and wood density for conversion of removals in merchantable volume to total biomass removals (including bark)	Ratio of below-ground biomass to above-ground biomass	Annual volume of fuelwood removal as tree parts	Basic wood density	Carbon fraction of dry matter	Annual carbon loss due to fuelwood removal
Initial land use	Land use during reporting year		(m^3 yr^{-1})	BEF * wood density = [tonnes of biomass removals (m^3 of removals) $^{-1}$]	[tonnes bg dm (tonne ag dm)$^{-1}$]	(m^3 yr^{-1})	tonnes m^{-3}	[tonnes C (tonne dm)$^{-1}$]	(tonnes C yr^{-1})
			FAO or other statistics	Table 3A.1.10 (*2003 GPG*) and Table 4.6	Table 4.5	FAO or other statistics	Table 4.6	Table 4.2	$L_{fuelwood} = [FG_{trees} * BCEF_R * (1+R) + FG_{part} * D] * CF$
			FG_{trees}	**BCEF**	**R**	**FG_{part}**	**D**	**CF**	**$L_{fuelwood}$**
		(a)							
		(b)							
		(c)							
Total									

[1] This worksheet can be used for any category under 3B. Inventory compilers should specify an appropriate category code here. For example, when this worksheet is used to calculate emissions to be reported in the category Forest Land Remaining Forest Land, "3B1a" should be entered as category code.

Sector	**Agriculture, Forestry and Other Land Use**							
Category	**Coastal wetland with woody perennial biomass or Forest Land: Loss of carbon from disturbance**							
Category code	**[To be specified by the inventory compiler][1]**							
Sheet	**4 of 5**							
Equation			**Equation 2.14 (*2006 IPCC Guidelines*)**					**Equation 2.11 (*2006 IPCC Guidelines*)**
Land-use category			Area affected by disturbances	Average above-ground biomass of areas affected	Ratio of below-ground biomass to above-ground biomass	Carbon fraction of dry matter	Annual other losses of carbon	Annual decrease in carbon stocks due to biomass loss
Initial land use	Land use during reporting year	Subcategories for reporting year	(ha)	(tonnes dm ha^{-1})	[tonnes bg dm (tonne ag dm)$^{-1}$]	[tonnes C (tonne dm)$^{-1}$]	(tonnes C yr^{-1})	(tonnes C yr^{-1})
			National statistics or international data sources	Table 4.3	Table 4.5	Table 4.2	$L_{disturbances} = A * B_W * (1+R) * CF * fd$	$\Delta C_L = L_{wood-removals} + L_{fuelwood} + L_{disturbances}$
			$A_{disturbance}$	B_W	**R**	**CF**	$L_{disturbances}$	ΔC_L
		(a)						
		(b)						
		(c)						
Total								

Note: fd = fraction of biomass lost in disturbance; a stand-replacing disturbance will kill all (fd = 1) biomass while an insect disturbance may only remove a portion (e.g. fd = 0.3) of the average biomass C density.

[1] This worksheet can be used for any category under 3B. Inventory compilers should specify an appropriate category code here. For example, when this worksheet is used to calculate emissions to be reported in the category Forest Land Remaining Forest Land, “3B1a” should be entered as category code.

Sector	**Agriculture, Forestry and Other Land Use**					
Category	**Initial change in biomass carbon stocks due to extraction actvities (excavation, construction of aquaculture ponds, construction of salt production ponds)**					
Category code	**[To be specified by the inventory compiler][1]**					
Sheet	**5 of 5**					
Equation		**Equation 4.4 (*Wetlands Supplement*)**				
Activity	Sub-categories for reporting year (vegetation type)	Area converted[2]	Biomass C stock after conversion	Biomass C stock before converstion	Carbon fraction	Initial change in carbon stocks in biomass
		(ha)	(tonnes dm ha^{-1})	(tonnes dm ha^{-1})	tonnes C (tonnes dm)$^{-1}$	Gg C yr^{-1}
			default value is zero (0) or national statistics and Table 4.5 (R)	Table 4.3 and Table 4.5 (R) or national statistics	Table 4.2 or national statistics	$\Delta C_{B-CONVERSION} = (B_{AFTER} * (1+R) - B_{BEFORE} * (1+R)) * CF * A_{CONVERTED} * 10^{-3}$
		$\mathbf{A_{CONVERTED}}$	$B_{AFTER} * (1+R)$	$B_{BEFORE} * (1+R)$	CF	$\mathbf{\Delta C_{B-CONVERSION}}$
Excavation	Mangrove		0			
	Tidal Marsh[3]		0			
	Seagrass Meadow[3]		0			
Construction of aquaculture ponds	Mangrove		0			
	Tidal Marsh[3]		0			
	Seagrass Meadow[3]		0			
Construction of salt production ponds	Mangrove		0			
	Tidal Marsh[3]		0			
	Seagrass Meadow[3]		0			
Total						

[1] This worksheet can be used for any category under 3B. Inventory compilers should specify an appropriate category code here. For example, when this worksheet is used to calculate emissions to be reported in the category Forest Land Remaining Forest Land, “3B1a” should be entered as category code. Inventory compilers may choose “3C14” if this activity takes place outside the national total area.

[2] Report zero if activity or vegetation type does not occur

[3] Tier 2 and referring to Tables 4.9 and 4.10 to for R value

Sector	**Agriculture, Forestry and Other Land Use**				
Category	**Initial change in DOM carbon stocks due to extraction activities (excavation, construction of aquaculture ponds, construction of salt production ponds)**				
Category code	**[To be specified by the inventory compiler][1]**				
Sheet	**1 of 1**				
Equation		**Equation 4.5 (*Wetlands Supplement*)**			
Activity	Sub-categories for reporting year (vegetation type)	Area converted[2]	DOM_{AFTER}	DOM_{BEFORE}	Initial change in carbon stocks in DOM
		(ha)	(tonnes C ha^{-1})	(tonnes C ha^{-1})	Gg C yr^{-1}
			default value is zero (0)	Table 4.7 or national statistics	$\Delta C_{DOM\text{-}CONVERSION} = (DOM_{AFTER} - DOM_{BEFORE}) * A_{CONVERTED} * 10^{-3}$
		$\mathbf{A_{CONVERTED}}$	DOM_{AFTER}	DOM_{BEFORE}	$\mathbf{\Delta C_{DOM\text{-}CONVERSION}}$
Excavation	Mangrove		0		
Construction of aquaculture ponds	Mangrove		0		
Construction of salt production ponds	Mangrove		0		
Total					

[1] This worksheet can be used for any category under 3B. Inventory compilers should specify an appropriate category code here. For example, when this worksheet is used to calculate emissions to be reported in the category Forest Land Remaining Forest Land, “3B1a” should be entered as category code. Inventory compilers may choose “3C14” if this activity takes place outside the national total area..

[2]Report zero if activity or vegetation type does not occur

Sector	**Agriculture, Forestry and Other Land Use**			
Category	**CH_4 emissions from rewetting of mangroves and tidal marshes**			
Category code	**3C11**			
Sheet	**1 of 1**			
		Equation 4.9 (Wetlands Supplement)		
	Subcategories for reporting year	Area of land of rewetted soils	Emission factor for rewetted soils	Annual CH_4 emissions from rewetted soils
		(ha)	(kg CH_4 ha^{-1} yr^{-1})	(kg CH_4 yr^{-1})
			Table 4.14 (organic and mineral soils)	$CH_{4SO\text{-}REWET}$ = (A_{REWET} * EF_{REWET})
		A_{REWET}	**EF_{REWET}**	**$CH_{4SO\text{-}REWET}$**
	Tidal freshwater marsh			
	Tidal salt marsh and mangrove[1]			
Total				

[1] Apply same EF for tidal brackish marsh

Sector	**Agriculture, Forestry and Other Land Use**		
Category	**N_2O emissions from aquaculture**		
Category code	**3C12**		
Sheet	**1 of 1**		
		Equation 4.10 (Wetlands Supplement)	
	Amount of fish production (F)	Emission factor for N_2O emissions from fish produced (F) in aquaculture use	Annual N_2O emissions from aquaculture use
	(kg fish yr^{-1})	[kg N_2O-N (kg fish)$^{-1}$]	(kg N_2O-N yr^{-1})
		Table 4.15	$N_2O\text{-}N_{AQ} = F * EF$
	F_F	**EF_F**	**N_2O_{AQ}**
Total			

Sector	**Agriculture, Forestry and Other Land Use**				
Category	**Initial change in soil carbon stocks due to extraction actvities (excavation, construction of aquaculture ponds, construction of salt production ponds)**				
Category code	**[To be specified by the inventory compiler][1]**				
Sheet	**1 of 3**				
Equation		**Equation 4.6 (*Wetlands Supplement*)**			
Activity	Sub-categories for reporting year (vegetation type)	Area converted[2]	SO_{AFTER}	SO_{BEFORE}	Initial change in carbon stocks in soil
		(ha)	(tonnes C ha^{-1})	(tonnes C ha^{-1})	Gg C yr^{-1}
			default value is zero (0)	Table 4.11 or national statistics	$\Delta C_{SO\text{-}CONVERSION} = (SO_{AFTER} - SO_{BEFORE}) * A_{CONVERTED} * 10^{-3}$
		$\mathbf{A_{CONVERTED}}$	SO_{AFTER}	SO_{BEFORE}	$\mathbf{\Delta C_{SO\text{-}CONVERSION}}$
Excavation	Mangrove		0		
	Tidal Marsh		0		
	Seagrass Meadow		0		
Construction of aquaculture ponds	Mangrove		0		
	Tidal Marsh		0		
	Seagrass Meadow		0		
Construction of salt production ponds	Mangrove		0		
	Tidal Marsh		0		
	Seagrass Meadow		0		
Total					

[1] This worksheet can be used for any category under 3B. Inventory compilers should specify an appropriate category code here. For example, when this worksheet is used to calculate emissions to be reported in the category Forest Land Remaining Forest Land, “3B1a” should be entered as category code. Inventory compilers may choose “3C14” if this activity takes place outside the national total area.

[2] Report zero if activity or vegetation type does not occur

Sector	**Agriculture, Forestry and Other Land Use**
Category	**CO_2-C emissions from rewetting, revegetation and creation**
Category code	**[To be specified by the inventory compiler]**[1]
Sheet	**2 of 3**
Equation	**Equation 4.7 (*Wetlands Supplement*)**

Land-use category		Subcategories for reporting year (vegetation type)	Area of land in rewetting[2]	Emission factors for CO_2-C in rewetting	Area of land in rewetting, **revegetation and creation**[2]	Emission factors for CO_2-C in rewetting, **revegetation and creation**	CO_2-C emissions from rewetting, **revegetation and creation**
Initial land use	Land use during reporting year		(ha)	(tonnes C ha^{-1} yr^{-1})	(ha)	(tonnes C ha^{-1} yr^{-1})	Gg C yr^{-1}
				default value is zero or national data		Table 4.12 or national data	$CO_2\text{-}C_{\text{-SO-RE}} = (A_{RE\_1} * EF_{RE\_1} + A_{RE\_2} * EF_{RE\_2}) * 10^{-3}$
			A_{RE_1}	**EF_{RE_1}**	**A_{RE_2}**	**EF_{RE_2}**	**$CO_2\text{-}C_{\text{-SO-RE}}$**
		Mangrove					
		Tidal marsh					
		Seagrass meadow					
Total							

[1] This worksheet can be used for any category under 3B. Inventory compilers should specify an appropriate category code here. For example, when this worksheet is used to calculate emissions to be reported in the category Forest Land Remaining Forest Land, "3B1a" should be entered as category code. Inventory compilers may choose "3C14" if this activity takes place outside the national total area.

[2] Depending on how the activity is applied, either rewetting or rewetting**, revegetation and creation** data can be applied, providing national circumstances and country's available data

Sector		**Agriculture, Forestry and Other Land Use**			
Category		**CO_2-C emissions from drainage in coastal wetlands**			
Category code		**[To be specified by the inventory compiler][1]**			
Sheet		**3 of 3**			
Equation			**Equation 4.8 (*Wetlands Supplement*)**		
Land-use category		Subcategories for reporting year (vegetation type)	Area of land in drainage	Emission factors for CO_2-C in drainage	CO_2-C emissions from drainage
Initial land use	Land use during reporting year		(ha)	(tonnes C ha^{-1} yr^{-1})	Gg C yr^{-1}
				Table 4.13 or national data	$CO_2\text{-}C_{\text{-SO-DR}} = (A_{DR} * EF_{DR}) * 10^{-3}$
			A_{DR}	**EF_{DR}**	**$CO_2\text{-}C_{\text{-SO-DR}}$**
		Tidal marsh and mangrove			
Total					

[1] This worksheet can be used for any category under 3B. Inventory compilers should specify an appropriate category code here. For example, when this worksheet is used to calculate emissions to be reported in the category Forest Land Remaining Forest Land, “3B1a” should be entered as category code. Inventory compilers may choose “3C14” if this activity takes place outside the national total area.

CHAPTER 5—INLAND WETLAND MINERAL SOILS

Sector		**Agriculture, Forestry and Other Land Use**									
Category		**Cropland Remaining Cropland: Annual change in carbon stocks in mineral soils**									
Category code		**[To be specified by the inventory compiler]**[1]									
Sheet		**1 of 4**									
Equation		**Equation 2.2 (*2006 IPCC Guidelines*)**	**Equation 2.25, Formulation A in Box 2.1 of Section 2.3.3.1 (*2006 IPCC Guidelines*)**								
Land-use category		Sub-categories for reporting year	Area in the last year of an inventory period	Area at the beginning of an inventory period	Reference carbon stock in the last year of an inventory period	Reference carbon stock at the beginning of an inventory period	Time dependence of stock change factors (D) or number of years over a single inventory time period (T)	Stock change factor for land-use system or sub-system	Stock change factor for management regime	Stock change factor for input of organic matter	Annual change in carbon stocks in mineral soils
Initial land use	Land use during reporting year		(ha)	(ha)	(tonnes C ha^{-1})	(tonnes C ha^{-1})	(yr)	(-)	(-)	(-)	(tonnes C yr^{-1})
					Table 2.3 of *2006 IPCC Guidelines* for non-IWMS; Table 5.2 of *Wetlands Supplement* for IWMS[2, 4]	Table 2.3 of *2006 IPCC Guidelines* for non-IWMS; Table 5.2 of *Wetlands Supplement for IWMS*[2, 4]	(default is 20 yr; if T>D then use the value of T)	Table 5.5 of *2006 IPCC Guidelines* for non-IWMS; Table 5.5 of *2006 IPCC Guidelines* and Table 5.3 of *Wetlands Supplement* for IWMS[3,4]	Table 5.5 of *2006 IPCC Guidelines*	Table 5.5 of *2006 IPCC Guidelines*	$\Delta C_{Mineral}$ as in Equation 2.25 (*2006 IPCC Guidelines*)
			$A_{(0)}$	**$A_{(0-T)}$**	**$SOC_{ref(0)}$**	**$SOC_{ref(T-0)}$**	**D**	**F_{LU}**	**F_{MG}**	**F_{I}**	**$\Delta C_{Mineral}$**
$CL_{non\text{-}IWMS}$	$CL_{non\text{-}IWMS}$	(a)					20				
		(b)					20				
		(c)					20				
		Subtotal									
CL_{IWMS}	CL_{IWMS}	(a)					20				
		(b)					20				
		(c)					20				
		Subtotal									
Total											

[1] This worksheet can be used for any category under 3B. Inventory compilers should specify an appropriate category code here. For example, when this worksheet is used to calculate emissions to be reported in the category Forest Land Remaining Forest Land, “3B1a” should be entered as category code.

[2] Table 5.2, Chapter 5 of the *Wetlands Supplement* contains the revised default reference SOC stocks (SOC_{REF}) for Inland Wetland Mineral Soils.

[3] Table 5.3, Chapter 5 of the *Wetlands Supplement* contains the new values of stock change factors for land-use (FLU) for Inland Wetland Mineral Soils.

[4] IWMS = Inland Wetland Mineral Soils

Sector		**Agriculture, Forestry and Other Land Use**									
Category		**Land (non-Cropland) remaining in a Land-use Category : Annual change in carbon stocks in mineral soils**									
Category code		**[To be specified by the inventory compiler]**[1]									
Sheet		**2 of 4**									
Equation		**Equation 2.2 (*2006 IPCC Guidelines*)**	**Equation 2.25, Formulation A in Box 2.1 of Section 2.3.3.1**								
Land-use category		Sub-categories for reporting year	Area in the last year of an inventory period	Area at the beginning of an inventory period	Reference carbon stock in the last year of an inventory period	Reference carbon stock at the beginning of an inventory period	Time dependence of stock change factors (D) or number of years over a single inventory time period (T)	Stock change factor for land-use system or sub-system	Stock change factor for management regime	Stock change factor for input of organic matter	Annual change in carbon stocks in mineral soils
Initial land use	Land use during reporting year		(ha)	(ha)	(tonnes C ha^{-1})	(tonnes C ha^{-1})	(yr)	(-)	(-)	(-)	(tonnes C yr^{-1})
					Table 2.3 of *2006 IPCC Guidelines* for non-IWMS; Table 5.2 of *Wetlands Supplement* for IWMS[2, 3]	Table 2.3	(default is 20 yr; if T>D then use the value of T)	Table 5.5	Table 5.5	Table 5.5	$\Delta C_{Mineral}$ as in Equation 2.25
			$\mathbf{A_{(0)}}$	$\mathbf{A_{(0-T)}}$	$\mathbf{SOC_{ref(0)}}$	$\mathbf{SOC_{ref(T-0)}}$	**D**	$\mathbf{F_{LU}}$	$\mathbf{F_{MG}}$	$\mathbf{F_{I}}$	$\mathbf{\Delta C_{Mineral}}$
LU	LU	(a)					20				
		(b)					20				
		(c)					20				
Total											

[1] This worksheet can be used for any category under 3B. Inventory compilers should specify an appropriate category code here. For example, when this worksheet is used to calculate emissions to be reported in the category Forest Land Remaining Forest Land, “3B1a” should be entered as category code.

[2] Table 5.2, Chapter 5 of the *Wetlands Supplement* contains the revised default reference SOC stocks (SOC_{REF}) for Inland Wetland Mineral Soils.

[3] IWMS = Inland Wetland Mineral Soils

Sector		**Agriculture, Forestry and Other Land Use**									
Category		**Land Converted to a Cropland: Annual change in carbon stocks in mineral soils**									
Category code		**[To be specified by the inventory compiler][1]**									
Sheet		**3 of 4**									
Equation		**Eq. 2.2 *(2006 IPCC Guidelines)***	**Equation 2.25, Formulation B in Box 2.1 of Section 2.3.3.1 (*2006 IPCC Guidelines*)**								
Land-use category		Subcategories of unique climate, soil, land-use change and management combinations	Area for land-use change by climate and soil combination	Reference carbon stock for the climate/soil combination	Time dependence of stock change factors (D) or number of years over a single inventory time period (T)	Stock change factor for land-use system in the last year of an inventory time period	Stock change factor for management regime in last year of an inventory period	Stock change factor for C input in the last year of the inventory period	Stock change factor for land-use system at the beginning of the inventory time period	Stock change factor for management regime at the beginning of the inventory time period	Stock change factor for C input at the beginning of the inventory time period	Annual change in carbon stocks in mineral soils
Initial land use[2]	Land use during reporting year		(ha)	(tonnes C ha^{-1})	(yr)	(-)	(-)	(-)	(-)	(-)	(-)	(tonnes C yr^{-1})
				Table 2.3; Chap 2, Sec. 2.3.3.1 of *2006 IPCC Guidelines* & Table 5.2 of *Wetlands Supplement* for IWMS[3, 5]	(default is 20 yr; if T>D then use the value of T)	Table 5.5 of *2006 IPCC Guidelines* & Table 5.3 of *Wetlands Supplement* for IWMS[4,5]	Table 5.5 of *2006 IPCC Guidelines*	Table 5.5 of *2006 IPCC Guidelines*	Table 5.10 of *2006 IPCC Guidelines*	Table 5.10 of *2006 IPCC Guidelines*	Table 5.10 of *2006 IPCC Guidelines*	$\Delta C_{Mineral}$ as in Equation 2.25 (*2006 IPCC Guidelines*)
			$A_{(0)}$	SOC_{ref}	D	$F_{LU(0)}$	$F_{MG(0)}$	$F_{I(0)}$	$F_{LU(0-T)}$	$F_{MG(0-T)}$	$F_{I(0-T)}$	$\Delta C_{Mineral}$
FL	CL	(a)			20							
		(b)			20							
Sub-total												
GL	CL	(a)			20							
		(b)			20							
Sub-total												
WL	CL	(a)			20							
		(b)			20							

Sub-total												
SL	CL	(a)			20							
		(b)			20							
Sub-total												
OL	CL	(a)			20							
		(b)			20							
Sub-total												
Total												

[1] This worksheet can be used for any category under 3B. Inventory compilers should specify an appropriate category code here. For example, when this worksheet is used to calculate emissions to be reported in the category Forest Land Remaining Forest Land, “3B1a” should be entered as category code.

[2] If data by initial land use are not available, use only "non-CL" in this column.

[3] Table 5.2, Chapter 5 of the *Wetlands Supplement* contains the revised default reference SOC stocks (SOC_{REF}) for Inland Wetland Mineral Soils.

[4] Table 5.3, Chapter 5 of the *Wetlands Supplement* contains new values of default stock change factors for land-use (F_{LU}) for Inland Wetland Mineral Soils.

[5] IWMS = Inland Wetland Mineral Soils

Sector		**Agriculture, Forestry and Other Land Use**										
Category		**Land Converted to a New Land-use Category (non-Cropland): Annual change in carbon stocks in mineral soils**										
Category code		**[To be specified by the inventory compiler]**[1]										
Sheet		**4 of 4**										
Equation		**Equation 2.2 (*2006 IPCC Guidelines*)**	**Equation 2.25, Formulation B in Box 2.1 of Section 2.3.3.1 (*2006 IPCC Guidelines*)**									
Land-use category		Subcategories of unique climate, soil, land-use change and management combinations	Area for land-use change by climate and soil comb-ination	Reference carbon stock for the climate and soil combination	Time dependence of stock change factors (D) or number of years over a single inventory time period (T)	Stock change factor for land-use system in the last year of an inventory time period	Stock change factor for management regime in last year of an inventory period	Stock change factor for C input in the last year of the inventory period	Stock change factor for land-use system at the beginning of inventory time period	Stock change factor for management regime at the beginning of the inventory time period	Stock change factor for C input at the beginning of the inventory time period	Annual change in carbon stocks in mineral soils
Initial land use[2]	Land use during reporting year		(ha)	(tonnes C ha^{-1})	(yr)	(-)	(-)	(-)	(-)	(-)	(-)	(tonnes C yr^{-1})
				Table 2.3; Chap. 2, Sec. 2.3.3.1 of *2006 IPCC Guidelines* & Table 5.2 of Chapter 5 of the Wetlands Supplement for IWMS[3, 6]	(default is 20 yr; if T>D then use the value of T)	Table XX[5] of *2006 IPCC Guidelines*	Table 6.2	Table 6.2	Table 5.5 and Table 5.3 of the *Wetlands Supplement*[4] (Cropland); 1 for other uses	Table 5.5 (Cropland); 1 for other uses	Table 5.5 (Cropland); 1 for other uses	$\Delta C_{Mineral}$ as in Equation 2.25
			$A_{(0)}$	**SOC_{ref}**	**D**	**$F_{LU(0)}$**	**$F_{MG(0)}$**	**$F_{I(0)}$**	**$F_{LU(0-T)}$**	**$F_{MG(0-T)}$**	**$F_{I(0-T)}$**	**$\Delta C_{Mineral}$**
L	non-CL	(a)			20							
		(b)			20							
		(c)			20							
Sub-total												
Total												

[1] This worksheet can be used for any category under 3B. Inventory compilers should specify an appropriate category code here. For example, when this worksheet is used to calculate emissions to be reported in the category Forest Land Remaining Forest Land, “3B1a” should be entered as category code.

[2] If data by initial land use are not available, use only "non-GL" in this column.

[3] Table 5.2, Chapter 5 of the Wetlands Supplement contains the revised default reference SOC stocks (SOCREF) for Inland Wetland Mineral Soils.

[4] Table 5.3, Chapter 5 of the Wetlands Supplement contains new values of default stock change factors for land-use (FLU) for Inland Wetland Mineral Soils.

[5] Relevant tables from the land-use category chapters in the 2006 IPCC Guidelines

[6] IWMS = Inland wetland mineral soils

Sector		**Agriculture Forestry and Other Land Use (AFOLU)**		
Category		**Annual CH_4 emissions from restored and created wetlands on managed lands with IWMS**[1,2]		
Category code		**[To be specified by the inventory compiler]**[3]		
Sheet		**1 of 1**		
Equation		**Eq. 2.2 (*2006 IPCC Guidelines*)**	**Equation 5.1 *(Wetlands Supplement)***	
Initial land use	Land use during reporting year	Subcategories for reporting year[4]	Area of managed lands with IWMS	Emission factor from managed lands with IWMS where water level has been raised in climate region
			(ha)	(kg CH_4 ha^{-1} yr^{-1})
				Table 5.4 (*Wetlands Supplement*)
			A_{IWMS}	**$EF_{CH4\text{-}IWMS}$**
		(a)		
		(b)		
		(c)		
Total				

[1] IWMS = Inland wetland mineral soils

[2] This worksheet is to be used for CH_4 emissions from managed lands with IWMS other than rice cultivation areas. For CH_4 emissions from rice cultivation please use the worksheets for the category 3C7 (Rice Cultivation) in the *2006 IPCC Guidelines*.

[3] This worksheet can be used for any category under 3B. Inventory compilers should specify an appropriate category code here. For example, when this worksheet is used to calculate emissions to be reported in the category Forest Land Remaining Forest Land, “3B1a” should be entered as category code.

[4] Can be stratified according to climate domains for Tier 1 methods.

CHAPTER 6—CONSTRUCTED WETLANDS FOR WASTEWATER TREATMENT

Sector	**Waste**
Category	**Domestic Wastewater Treatment and Discharge**
Category Code	**4D1**
Sheet	**1 of 3 Estimation of Organically Degradable Material in Domestic Wastewater Treated in Constructed Wetlands**

STEP 1

Type of constructed wetland	A	B	C	D
	Population whose wastewater treated in constructed wetlands (P_i) cap	Degradable organic component (BOD) (kg BOD cap^{-1} yr^{-1}) [1]	Correction factor for industrial BOD discharged in sewers (I) [2]	Organically degradable material in wastewater (TOW_i) (kg BOD yr^{-1}) D = A x B x C
Surface Flow				
Vertical Subsurface Flow				
Horizontal Subsurface Flow				
Hybrid type				
Semi-natural Treatment Wetlands				
			Total	

[1] g BOD cap^{-1} day^{-1} x 0.001 x 365 = kg BOD cap^{-1} yr^{-1}

[2] Correction factor for additional industrial BOD discharged into sewers, (for collected the default is 1.25, for uncollected the default is 1.00) (see page 6.14).

Sector	**Waste**
Category	**Domestic Wastewater Treatment and Discharge**
Category Code	**4D1**
Sheet	**2 of 3 Estimation of CH_4 Emission Factor for Domestic Wastewater Treated in Constructed Wetlands**

STEP 2

Type of constructed wetland	A Maximum methane producing capacity (B_o) (kg CH_4 kg BOD^{-1})	B Methane correction factor (MCF_j)	C Emission factor (EF_j) (kg CH_4 kg BOD^{-1}) C = A x B
Surface Flow			
Vertical Subsurface Flow			
Horizontal Subsurface Flow			
Hybrid type			
Semi-natural Treatment Wetlands			

Note: MCF for hybrid type can be estimated as area-weighted average of the MCFs of the constructed wetland types in hybrid system

Sector	**Waste**		
Category	**Domestic Wastewater Treatment and Discharge**		
Category Code	**4D1**		
Sheet	**3 of 3 Estimation of CH_4 Emissions from Domestic Wastewater Treated in Constructed Wetlands**		
STEP 3			
Type of constructed wetlands	A	B	C
	Emission factor (EF_i) (kg CH_4 kg BOD^{-1}) Sheet 2 of 3	Organically degradable material in wastewater (TOW_i) (kg BOD yr^{-1}) Sheet 1 of 3	Methane emissions (CH_4) (kg CH_4 yr^{-1}) C=A x B
Surface Flow			
Vertical Subsurface Flow			
Horizontal Subsurface Flow			
Hybrid type			
Semi-natural Treatment Wetlands			
		Total	

Sector	**Waste**		
Category	**Industrial Wastewater Treatment and Discharge**		
Category Code	**4D2**		
Sheet	**1 of 3 Total Organic Degradable Material in Industrial Wastewater Treated in Constructed Wetlands**		
STEP 1			
Industrial Sector	A	B	C
	Yearly flow rate of industrial wastewater treated by constructed wetland ($W_{i,j}$) (m^3 yr^{-1})	Chemical Oxygen Demand (COD_i) (kg COD m^{-3})	Total organic degradable material in industrial wastewater treated in constructed wetland ($TOW_{i,j}$) (kg COD yr^{-1}) C=A x B
Industrial sector 1			
Industrial sector 2			
Industrial sector 3			
add as needed			
		Total	
Note: Emissions from collected runoff from agricultural land and landfill leachate treated in constructed wetlands should be reported in this worksheet			

Sector	**Waste**
Category	**Industrial Wastewater Treatment and Discharge**
Category Code	**4D2**
Sheet	**2 of 3 Estimation of CH_4 Emission Factor for Industrial Wastewater Treated in Constructed Wetlands**

STEP 2

Type of constructed wetland	A	B	C
	Maximum methane producing capacity (Bo) ($kg\ CH_4\ kg\ COD^{-1}$)	Methane correction factor (MCF_i) (-)	Emission factor (EF_i) ($kg\ CH_4\ kg\ COD^{-1}$)
			C = A x B
Surface Flow			
Vertical Subsurface Flow			
Horizontal Subsurface Flow			
Hybrid type			
Semi-natural Treatment Wetlands			

Note: MCF for hybrid type can be estimated as area-weighted average of the MCFs of the constructed wetland types in hybrid system

Sector	**Waste**		
Category	**Industrial Wastewater Treatment and Discharge**		
Category Code	**4D2**		
Sheet	**3 of 3 Estimation of CH_4 Emissions from Industrial Wastewater Treated in Constructed Wetlands**		
STEP 3			
Industrial Sector	A	B	C
	Emission Factor (EF_j)* (kg CH_4 kg COD^{-1}) Sheet 2 of 3	Organically degradable material in wastewater ($TOW_{i,j}$) (kg COD yr^{-1}) Sheet 1 of 3	Methane emissions (CH_4) (kg CH_4 yr^{-1}) C=A x B
Industrial sector 1			
Industrial sector 2			
Industrial sector 3			
add as needed			
		Total	

*If more than one type of CW is used in an industrial sector the EF would be TOWi,j-weighted average of EFs of the CWs used.

Sector	**Waste**
Category	**Domestic Wastewater Treatment and Discharge**
Category Code	**4D1**
Sheet	**1 of 2 Estimation of Nitrogen in Effluent Treated in Constructed Wetlands**

STEP1

Type of constructed wetlands	A Population whose wastewater treated in constructed wetlands (P_i) (people)	B Per capita protein consumption (Protein) (kg/person yr^{-1})	C Fraction of nitrogen in protein (F_{NPR}) (kg N kg $protein^{-1}$)	D Fraction of non-consumed protein ($F_{NON\text{-}CON}$) (-)	E Fraction of industrial and commercial co-discharged protein ($F_{IND\text{-}COM}$) (-)	F Total nitrogen in effluent (N) (kg N yr^{-1}) F = A x B x C x D x E
Surface Flow						
Vertical Subsurface Flow						
Horizontal Subsurface Flow						
Hybrid type						
Semi-natural Treatment Wetlands						
					Total	

Sector	**Waste**			
Category	**Domestic Wastewater Treatment and Discharge**			
Category Code	**4D1**			
Sheet	**2 of 2 Estimation of N_2O Emissions from Domestic Wastewater Treated in Constructed Wetlands**			
STEP 2				
Type of constructed wetlands	A	B	C	D
	Total nitrogen in effluent (N_i) (kg N yr^{-1}) Sheet 1 of 2	Emission Factor (EF_i) (kg N_2O-N kg N^{-1})	Conversion factor 44/28	Total N_2O emissions (kg N_2O yr^{-1}) D= A x B x C
Surface Flow				
Vertical Subsurface Flow				
Horizontal Subsurface Flow				
Hybrid type				
Semi-natural Treatment Wetlands				
			Total	
Note: EF for hybrid type can be estimated as area-weighted average of the EFs of the constructed wetland types in hybrid system				

Sector	**Waste**
Category	**Industrial Wastewater Treatment and Discharge**
Category Code	**4D2**
Sheet	**1 of 2 Estimation of N in Effluent Treated in Constructed Wetlands**

STEP 1

Industrial Sector	A	B	C
	Total nitrogen concentration in industrial wastewater treated by constructed wetlands (TN_i) (kg N m^{-3})	Yearly flow rate of industrial wastewater treated by constructed wetland ($W_{i,j}$)* (m^3 yr^{-1})	Total nitrogen effluent ($N_{i,j}$)* (kg N yr^{-1}) C=A x B
Industrial sector 1			
Industrial sector 2			
Industrial sector 3			
add as needed			
		Total	

Note: Indirect N_2O emissions from N leaching and runoff from agricultural land are considered in Chapter 11, Volume 4 of the 2006 IPCC Guidelines and the amount of nitrogen in collected runoff from agricultural land treated in constructed wetlands must be subtracted to avoid double counting

*If more than one type of CW is used in an industrial sector, W_{ij} and $N_{i,j}$ are sum of the Wi,j and Ni,j of the CWs used, respectively.

Sector	**Waste**			
Category	**Industrial Wastewater Treatment and Discharge**			
Category Code	**4D2**			
Sheet	**2 of 2 Estimation of N_2O Emissions from Industrial Wastewater Treated in Constructed Wetlands**			
	STEP 2			
Industrial sector	A	B	C	D
	Total nitrogen in effluent ($N_{i,j}$) (kg N yr^{-1}) Sheet 1 of 2	Emission Factor (EF_j)* (kg N_2O-N kg N^{-1})	Conversion factor 44/28	Total N_2O emissions (kg N_2O/year) D= A x B x C
Industrial sector 1				
Industrial sector 2				
Industrial sector 3				
add as needed				
			Total	

Note: EF for hybrid type can be estimated as area-weighted average of the EFs of the constructed wetland types in hybrid system

*If more than one type of CW is used in an industrial sector the EF would be Ni,j-weighted average of EFs of CWs used

ANNEX 7A.2

REPORTING TABLES

The *Wetlands Supplement* has only minor impacts on the Reporting Tables in Annex 8A.2 of Volume 1 of the *2006 IPCC Guidelines*. This annex includes the reporting tables, namely the Sectoral AFOLU Table 3 and Background Tables 3.2, 3.3, 3.4, 3.7 and 3.9, which have been updated to take into account the methodological guidance in the *Wetlands Supplement*. The changes are explained in Section 7.2.1

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Table 3 AFOLU Sectoral Table (1 of 2)

Categories	Net CO_2 emissions/ removals	Emissions				
		CH_4	N_2O	NO_x	CO	NMVOCs
	(Gg)					
3 AFOLU						
3A Livestock						
3A1 Enteric Fermentation						
3A1a Cattle						
3A1ai Dairy Cows						
3A1aii Other Cattle						
3A1b Buffalo						
3A1c Sheep						
3A1d Goats						
3A1e Camels						
3A1f Horses						
3A1g Mules and Asses						
3A1h Swine						
3A1j Other (please specify)						
3A2 Manure Management (1)						
3A2a Cattle						
3A2ai Dairy Cows						
3A2aii Other Cattle						
3A2b Buffalo						
3A2c Sheep						
3A2d Goats						
3A2e Camels						
3A2f Horses						
3A2g Mules and Asses						
3A2h Swine						
3A2i Poultry						
3A2j Other (please specify)						
3B Land[1]						
3B1 Forest Land						
3B1a Forest Land Remaining Forest Land						
3B1b Land Converted to Forest Land						
3B1bi Cropland Converted to Forest Land						
3B1bii Grassland Converted to Forest Land						
3B1biii Wetlands Converted to Forest Land						
3B1biv Settlements Converted to Forest Land						
3B1bv Other Land Converted to Forest Land						
3B2 Cropland						
3B2a Cropland Remaining Cropland						
3B2b Land Converted to Cropland						
3B2bi Forest Land Converted to Cropland						
3B2bii Grassland Converted to Cropland						
3B2biii Wetlands Converted to Cropland						
3B2biv Settlements Converted to Cropland						
3B2bv Other Land Converted to Cropland						
3B3 Grassland						
3B3a Grassland Remaining Grassland						
3B3b Land Converted to Grassland						
3B3bi Forest Land Converted to Grassland						
3B3bii Cropland Converted to Grassland						
3B3biii Wetlands Converted to Grassland						
3B3biv Settlements Converted to Grassland						
3B3bv Other Land Converted to Grassland						

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[1] Net CO_2 emissions/removals from land may include emissions from coastal wetlands which are not part of the total land area of the reporting country.

Table 3 AFOLU Sectoral Table (2 of 2)

Categories	Net CO_2 emissions/ removals	Emissions				
		CH_4	N_2O	NO_x	CO	NMVOCs
	(Gg)					
3B4 Wetlands						
3B4a Wetlands Remaining Wetlands						
3B4ai Peat Extraction remaining Peat Extraction						
3B4aii Flooded Land Remaining Flooded Land						
3B4aiii Other Wetlands Remaining Other Wetlands						
3B4b Land Converted to Wetlands						
3B4bi Land Converted for Peat Extraction						
3B4bii Land Converted to Flooded Land						
3B4biii Land Converted to Other Wetlands						
3B5 3B5 Settlements						
3B5a Settlements Remaining Settlements						
3B5b Land Converted to Settlements						
3B5bi Forest Land Converted to Settlements						
3B5bii Cropland Converted to Settlements						
3B5biii Grassland Converted to Settlements						
3B5biv Wetlands Converted to Settlements						
3B5bv Other Land Converted to Settlements						
3B6 3B6 Other Land						
3B6a Other Land Remaining Other Land						
3B6b Land Converted to Other Land						
3B6bi Forest Land Converted to Other Land						
3B6bii Cropland Converted to Other Land						
3B6biii Grassland Converted to Other Land						
3B6biv Wetlands Converted to Other Land						
3B6bv Settlements Converted to Other Land						
3C Aggregate Sources and Non-CO_2 Emissions Sources on Land (2)						
3C1 Burning						
3C1a Burning in Forest Land						
3C1b Burning in Cropland						
3C1c Burnings in Grassland						
3C1d Burnings in All Other Land						
3C2 Liming		▨	▨			
3C3 Urea Fertilization		▨	▨			
3C4 Direct N_2O Emissions from Managed Soils (3)	▨	▨				
3C5 Indirect N_2O Emissions from Managed Soils	▨	▨				
3C6 Indirect N_2O Emissions from Manure Management	▨	▨				
3C7 Rice Cultivations	▨					
3C8 CH_4 from drained organic soils						
3C9 CH_4 from drainage ditches on organic soils						
3C10 CH_4 from rewetting of organic soils						
3C11 CH_4 emissions from rewetting of mangroves and tidal marshes						
3C12 N_2O emissions from aquaculture						
3C13 CH_4 emissions from rewetted and created wetlands on inland wetland mineral soils						
3C14 Other (please specify)						
3D Other						
3D1 Harvested Wood Products		▨				
3D2 Other (please specify)						

(1) Indirect N_2O emissions are not included here (see category 3C6).

(2) If CO_2 emissions from Biomass Burning are not already included in Table 3.2 (Carbon stock changes background table), they should be reported here.

(3) Countries may report by land categories if they have the information.

* Cells to report emissions of NO_x, CO, and NMVOC have not been shaded although the physical potential for emissions is lacking for some categories.

Documentation box:

Table 3.2 AFOLU Background Table: 3B Carbon stock changes, emissions, and removals in AFOLU (1 of 2)

Categories	Surface Area			Net carbon stock change and CO_2 emissions/removals									Net CO_2 emissions
				Biomass				Dead organic matter			Soils		
	Mineral soils	Organic soils[4]	Total	Increase	Decrease	Carbon emitted as CH_4 and CO from fires (1)	Net carbon stock change	Net carbon stock change	Carbon emitted as CH_4 and CO from fires (1)	Net carbon stock change	Net carbon stock change in mineral soils (2)	Net carbon emissions /removals in organic soils[5]	
	(ha)			(Gg C)									(Gg CO_2)
3B Land[2]													
3B1 Forest Land													
3B1a Forest Land Remaining Forest Land													
3B1b Land Converted to Forest Land													
3B1bi Cropland Converted to Forest Land													
3B1bii Grassland Converted to Forest Land													
3B1biii Wetlands Converted to Forest Land													
3B1biv Settlements Converted to Forest Land													
3B1bv Other Land Converted to Forest Land													
3B2 Cropland													
3B2a Cropland Remaining Cropland													
3B2b Land Converted to Cropland													
3B2bi Forest Land Converted to Cropland													
3B2bii Grassland Converted to Cropland													
3B2biii Wetlands Converted to Cropland													
3B2biv Settlements Converted to Cropland													
3B2bv Other Land Converted to Cropland													
3B3 Grassland													
3B3a Grassland Remaining Grassland													
3B3b Land Converted to Grassland													
3B3bi Forest Land Converted to Grassland													
3B3bii Cropland Converted to Grassland													
3B3biii Wetlands Converted to Grassland													
3B3biv Settlements Converted to Grassland													
3B3bv Other Land Converted to Grassland													

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[2] Net carbon stock change and CO_2 emissions/removals from land may include emissions from coastal wetlands which are not part of the total land area of the reporting country. Land areas should be specified as included or not included in the total land area. The sum of the land areas for the six land-use categories included only those areas which are part of the total land area of the country.

Table 3.2 AFOLU Background Table: 3B Carbon stock changes, emissions, and removals in AFOLU (1 of 2)

Categories		Surface Area			Net carbon stock change and CO_2 emissions/removals									Net CO_2 emissions
					Biomass				Dead organic matter			Soils		
		Mineral soils	Organic soils[4]	Total	Increase	Decrease	Carbon emitted as CH_4 and CO from fires (1)	Net carbon stock change	Net carbon stock change	Carbon emitted as CH_4 and CO from fires (1)	Net carbon stock change	Net carbon stock change in mineral soils (2)	Net carbon emissions /removals in organic soils[5]	
		(ha)			(Gg C)									(Gg CO_2)
3B4	**Wetlands (3)**													
3B5	**Settlements**													
3B5a	Settlements Remaining Settlements													
3B5b	Land Converted to Settlements													
3B5bi	Forest Land Converted to Settlements													
3B5bii	Cropland Converted to Settlements													
3B5biii	Grassland Converted to Settlements													
3B5biv	Wetlands Converted to Settlements													
3B5bv	Other Land Converted to Settlements													
3B6	**Other Land**													
3B6a	Other Land Remaining Other Land													
3B6b	Land Converted to Other Land													
3B6bi	Forest Land Converted to Other Land													
3B6bii	Cropland Converted to Other Land													
3B6biii	Grassland Converted to Other Land													
3B6biv	Wetlands Converted to Other Land													

(1) Where the carbon contained in the emissions of CH_4 and CO is significant part of the sectoral emissions, this should be copied from the corresponding columns in the Sectoral Background Table 3.4. This amount of carbon emitted as CH_4 and CO is then subtracted from carbon stock change to avoid double counting (see Volume 4, Section 2.2.3).

(2) The activity data used for this column correspond to the difference between the column Area and the Area of organic soils.

(3) CO_2 Emissions from Wetlands are reported in a separate background table (Table 3.3) that includes all gases emitted from Wetlands.

(4) Areas of organic soils include drained, rewetted and restored organic soils as well as coastal wetlands with organic soils. Details of the subdivision and related emission/removal factors should be given in the national inventory report.

(5) The net loss/gain from all types of organic soils should be reported here (see also footnote 4).

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Table 3.3 AFOLU Background Table: Emissions in Wetlands (3B4)

Categories	**Activity data**	**Net emissions/removals**	**Emissions**	
	Area	**CO_2**	**CH_4**	**N_2O**
	(ha)	**(Gg)**		
3B4 Wetlands				
3B4a Wetlands Remaining Wetlands				
3B4ai Peat Extraction remaining Peat Extraction				
3B4aii Flooded Land Remaining Flooded Land				
3B4aiii Other Wetlands Remaining Other Wetlands[1]				
3B4b Land Converted to Wetlands				
3B4bi Land Converted for Peat Extraction				
3B4bii Land Converted to Flooded Land				
3B4biii Land Converted to Other Wetlands[1]				

Documentation box:

(1) Detailed information on Other Wetlands should be included in the national inventory report.

Table 3.4 AFOLU Background Table: Burning (3C1)

Categories [(1)]	Activity data			Emissions											Information item: Carbon emitted as CH_4 and CO [(5)]	
	Description[(2)]	Unit	Values	CO_2[(3)]			CO[(4)]			CH_4 [(4)]			NO_x	N_2O	Biomass	DOM
				Bio-mass	DOM	SOM [(6)]	Bio-mass	DOM	SOM [(6)]	Bio-mass	DOM	SOM [(6)]				
		(ha or kg dm)		(Gg)											(Gg C)	
3C1 Burning																
Burning in Forest Land																
Controlled Burning																
Wildfires																
Burning in Cropland																
Burning in Cropland Remaining Cropland																
Controlled Burning																
Wildfires																
Burning in Forest Land Converted to Cropland																
Controlled Burning																
Wildfires																
Burning in Non Forest Land Converted to Cropland																
Controlled Burning																
Wildfires																
Burning in Grassland																
Burning in Grassland Remaining Grassland																
Controlled Burning																
Wildfires																
Burning in Forest Land Converted to Grassland																
Controlled Burning																
Wildfires																
Burning in Non Forest Land Converted to Grassland																

Table 3.4 AFOLU Background Table: Burning (3C1)

Categories (1)	**Activity data**			**Emissions**											**Information item: Carbon emitted as CH_4 and CO (5)**	
	Description(2)	**Unit**	**Values**	**CO_2(3)**			**CO(4)**			**CH_4 (4)**			**NO_x**	**N_2O**	**Biomass**	**DOM**
				Bio-mass	**DOM**	**SOM (6)**	**Bio-mass**	**DOM**	**SOM (6)**	**Bio-mass**	**DOM**	**SOM (6)**				
		(ha or kg dm)		**(Gg)**											**(Gg C)**	
Controlled Burning																
Wildfires																
Burning in All Other Land																
Burning in Other Land Remaining All Other Land																
Controlled Burning																
Wildfires																
Burning in Forest Land Converted to All Other Land																
Controlled Burning																
Wildfires																
Burning in Non Forest Land Converted to All Other Land																
Controlled Burning																
Wildfires																

(1) Parties should report both Controlled/Prescribed Burning and Wildfires emissions, where appropriate, in a separate manner.

(2) For each land type data should be selected between area burned or biomass/soil carbon burned. Units for area will be in hectare (ha) and for biomass/soil carbon burned in kilogram dry matter (kg dm).

(3) If CO_2 emissions from burning are not already included in Table 3.2 and 3.3 (Carbon stock changes background table), they should be reported here. Carbon stock changes associated with burning should not also be reported in Table 3.2 and 3.3 to avoid double counting.

(4) CO_2, CH_4 and CO emissions from biomass burning, DOM and SOM are reported separately.

(5) Where the carbon contained in the emissions of CH_4 and CO is a significant part of the sectoral emissions this should be transferred to the corresponding columns in the Sectoral Background Table 3.2. This amount of carbon emitted as CH_4 and CO is then subtracted from carbon stock change to avoid double counting. The conversion factors to convert CH_4 and CO to C (as input to Table 3.2) are 12/16 for CH_4 and 12/28 for CO. (see Volume 4, Section 2.2.3).

(6) Emissions from soil organic matter are occurring when organic soils and peatlands are burned but are not relevant for mineral soils.

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Table 3.7 AFOLU Background Table: Direct N_2O emissions from Managed Soils (3C4)

Categories (1)	**Activity data**	**Emissions**
	Total amount of nitrogen applied	**N_2O**
	(Gg N yr^{-1})	**(Gg)**
3C4 Direct N_2O Emissions from Managed Soils		
Inorganic N fertilizer application		
Forest Land		
Cropland		
Grassland		
Wetlands		
Settlements		
Other Land		
Organic N applied as fertilizer (manure and sewage sludge)		
Forest Land		
Cropland		
Grassland		
Wetlands		
Settlements		
Other Land		
Urine and dung N deposited on pasture, range and paddock by grazing animals (2)		
N in crop residues[3]		
	Area	
	(ha)	
N mineralization/immobilization associated with loss/gain of soil organic matter resulting from change of land use or management of mineral soils		
Drainage/management of organic soils (i.e., Histosols)		

(1) Countries will report at the aggregation level if their activity data allows them within each category. If country has disaggregated data by land use, reporting is also possible using this table.

(2) Only for Grassland.

(3) Only for Cropland.

Table 3.9 AFOLU Background Table: Non-CO_2 GHG emissions not included elsewhere (3C7 to 3C14)

Categories	**Activity data**	**Emissions**	
		CH_4	**N_2O**
	(ha)	**(Gg)**	
3C7 Rice Cultivations (1)			
3C8 CH_4 from drained organic soils(2)(3)			▨
3C9 CH_4 from drainage ditches on organic soils(2)			▨
3C10 CH_4 from rewetting of organic soils(2)			
3C11 CH_4 emissions from rewetting of mangroves and tidal marshes(2)			
3C12 N_2O emissions from aquaculture(2)			
3C13 CH_4 emissions from rewetted and created wetlands on inland wetland mineral soils(2)			
3C14 Other (please specify)			

(1) If a country wishes to report direct N_2O emissions from N fertilizer application to rice field, it should be reported here. Otherwise, in Table 3.7.

(2) Use appropriate subcategories highlighting e.g. land-use category and/or other relevant specifications.

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