CHAPTER 5

INLAND WETLAND MINERAL SOILS

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5 INLAND WETLAND MINERAL SOILS

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). Information on Tier 1 default methods for Wetland Mineral Soil (WMS) 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) 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 Box 5.1 of this Chapter), or reservoirs. Guidance on methane (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 provided in the *2006 IPCC Guidelines* for emissions and removals of carbon dioxide (CO_2), and emissions of CH_4, and provides additional information to be used in the application of the methodologies. Review of the current literature suggests there is insufficient data to provide robust emission factors and methodology to update the guidance on nitrous oxide (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; and
- 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:

[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 new default SOC stock change factors for land-use (F_{LU}) for rewetting of drained IWMS classified as Cropland; and
- 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 that 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 the 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	$EF_{CH4-IWMS}$ 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 rewetting of drained IWMS.	$EF_{CH4-IWMS}$ 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.

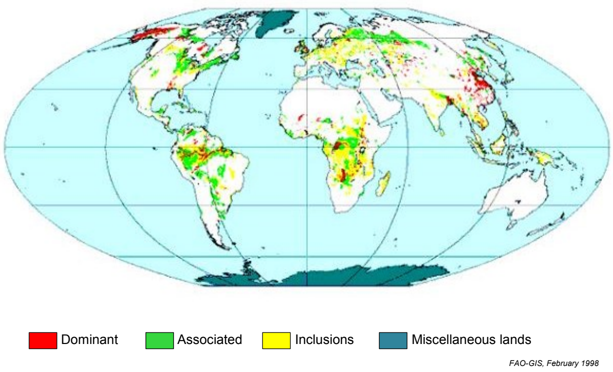
C Existing guidance on CH_4 emissions from rice cultivation given in Chapter 5, Volume 4 of the *2006 IPCC Guidelines* will continue to apply.

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

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%; and 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).



One 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, the carbon stocks and CO_2, CH_4 and N_2O fluxes were not discussed (Shaw and Bryant, 2011). A broader review of the 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 yet measured GHG emissions and removals from saline IWMS. At present, the lack of data on saline IWMS prevents the determination of their default carbon stock changes or GHG emission factors. Countries are therefore encouraged to seek country-specific data in order 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 both 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). The hydrology of IWMS may be altered in many ways: by dredging of canals for navigation and ditches through wetlands for flood control and to increase vegetation productivity (Mitsch and Gosselink, 2007); by management of river-floodplain systems through levee construction, channelization, and flow manipulation by dams (Dynesius and Nilsson, 1994); by irrigation systems that lower water tables; and by water level control for wildlife management by dikes, weirs, control gates, and pumps (Mitsch and Gosselink, 2007). Dams for hydroelectric generation and flood control can create riparian wetlands upstream and influence existing riparian wetlands by altering the frequency and duration of flood pulses, which impacts 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.*, 2010). 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 information available about the impacts of grazing or forest management activities on carbon stock changes or GHG emissions on lands with IWMS to allow us to provide new guidance.

One specific management activity that occurs on managed lands with IWMS is "rewetting", where lands with IWMS that were previously drained are subsequently rewetted by raising the water table level to pre-drainage conditions. Active approaches to rewetting include the 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 various 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. installation of large dams) 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 a great potential for increasing carbon storage by the rewetting of wetlands (Euliss *et al.*, 2006; Bridgham *et al.*, 2006). Rewetted wetlands may also have higher emissions of CH_4, however, potentially offsetting the increased carbon storage (Bridgham *et al.,* 2006), although recent studies have shown that created and rewetted wetlands can be net carbon sinks, even 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 those lands that have not undergone any land-use conversion for a default period of at least 20 years. 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 organic matter), 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 reference stocks, 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, the 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 Tier 1, 2 and 3 methods. The decision trees have been provided in the *2006 IPCC Guidelines* to guide the selection of the 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 use the default emission factors along with 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 the 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 currently no robust scientific information to support 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, then 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. The total areas should be determined according to the 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 by overlays of land-use onto 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 wider scales where more detailed soil information is lacking. Although no organisation 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 organisations, or other government sources. In addition, organisations such as the Society for Ecological Restoration (http://www.ser.org), the 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 the 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. Specific recommendations on how to reduce uncertainties are included in 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 in 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 forests that are prone to paludification (Lavoie *et al.*, 2005), and the 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), thus reducing sediment deposition rates in floodplains (Hupp, 1992; Kleiss, 1996). Only a small number of studies, however, have quantified the 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 relating to the impacts of hydrologic alteration on soil carbon stocks of IWMS in floodplains at this time. Similarly, very little information is available on the impacts of other common management practices, such as grazing, on IWMS soil carbon stocks. Therefore, guidance provided in this chapter is largely based upon and updates the guidance provided 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 is provided in Section 2.3.3, Chapter 2, Volume 4 of the *2006 IPCC Guidelines* and should be used along with the 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} values for IWMS (e.g. wetland soils), for use in any land-use category; and
- 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 that is 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 in Section 2.3.3.1, Chapter 2, Volume 4 of the *2006 IPCC Guidelines*): (i) Over time, SOC reaches a spatially-averaged, stable value that is 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 onto 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 Tier 1 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 such changes in management that impact the SOC. Equation 2.25, Chapter 2, Volume 4 of the *2006 IPCC Guidelines* ($\Delta C_{mineral}=(SOC_0-SOC_{(0-T)})/D$; see 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 stocks are estimated for the beginning and the 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), the management regime (MG) and the 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 region and soil type. 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 in Chapter 2, Volume 4 of the *2006 IPCC Guidelines*), but country-specific information is incorporated to improve the accuracy of the stock change factors, reference SOC stocks, climate regions, soil types, and/or land management classification systems.

Tier 3

Tier 3 approaches may use empirical, process-based or other types of models as the basis for estimating annual carbon stock changes. Examples include the Century ecosystem model (Parton *et al.*, 1987, 1994, 1998; Ogle *et al.*, 2010), and the Wetland-DNDC model (Zhang *et al.*, 2002). Estimates from models are computed using equations that estimate the net change in soil carbon. Key criteria in selecting an appropriate model include its capability to represent all of the relevant management practices/systems for the land-use category; model inputs (i.e. driving variables) that 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 for 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.

[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 compared to 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* .

D "n/a" indicates that information is not available.

The updated SOC_{REF} values for WMS presented 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 of the *2006 IPCC Guidelines:*

- Forest Land (Chapter 4): Section 4.2.3, Tier 1;
- Cropland (Chapter 5): Section 5.2.3, Tier 1; and
- 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*. Similarly, default stock change factors for land-use (F_{LU}), input (F_I), and management (F_{MG}) that apply to managed land with 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 those values in Table 5.5 of Chapter 5 of Volume 4 of the *2006 IPCC Guidelines* for temperate/boreal moist climate but lower than the temperate/boreal dry climate values. 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 are provided in Annex 5A.1. The default time period for stock changes (D) is 20 years, and management practices are assumed to influence stocks up to 30 cm depth, although greater 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 may 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 where crop production may or may not continue. Note that the factor applies to all climate regions, with the caveat that this value is likely to be 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 a further 20 years and will reach the reference SOC stock level (SOC_{REF} values in Table 5.2) after 40 years. 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 should be used for two sets of 20 year periods (i.e. 0–20 and 21–40 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, for 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 percentage 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 21–40 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 to *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 provided 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 should 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 should be used for *Cropland Remaining Cropland* according to the following:
    - o 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 used for estimating the initial SOC stocks ($SOC_{(0\text{-}T)}$) will correspond to the Cropland land use (long-term cultivated, perennial, etc.) and management and input regimes prior to rewetting.
    - o For the next set of 20 years (i.e. 21–40 years since the initial year of rewetting), F_{LU} = 1 should 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 ($SOC_{(0\text{-}T)}$) will correspond to the rewetted Cropland land-use (F_{LU} = 0.8) and management and input regimes at 20 years following rewetting.

- For the period longer than 40 years following the initial year of rewetting, F_{LU} will remain 1. The changes in SOC stocks as a result of 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*.

Box 5.3 shows 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

In a Tier 3 approach, 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 of the *2006 IPCC Guidelines* for further discussion.

CHOICE OF ACTIVITY DATA

At a minimum, 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. In addition, the areas of Cropland with IWMS subject to rewetting need to be stratified by time since rewetting (0–20 or 21–40 years since rewetting) for the correct application of stock change factors. If the compiler does not have sufficient information to disaggregate areas of rewetted Cropland with IWMS by the time since conversion, all rewetted Cropland with IWMS areas can be assumed to be within 0–20 years of rewetting, and thus F_{LU} = 0.8 could be applied to the entire rewetted Cropland with IWMS. Total areas should be determined according to the 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 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. As an initial approach, available land cover/land-use maps, either country-specific or 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). 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 Database 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 a Tier 1 approach. Although no organisation 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 the creation of wetlands may be obtained from agricultural, forestry, or natural resources agencies, non-governmental conservation organisations, or other government sources. In addition, organisations such as the Society for Ecological Restoration (http://www.ser.org), the 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 approaches 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 may be obtained by disaggregating global data into 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 this case more detailed data on climate, soils, and management practices are needed, as compared 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), as well as 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, $SOC_{(0-T)}$ and net soil organic carbon stock change per hectare for managed land with 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 relating to 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 and then dividing by the time dependence of the stock change factors (D) which is 20 years for 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 CROPLAND WITH IWMS, AND REWETTING OF LONG-TERM CULTIVATED CROPLAND 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 a depth of 30 cm. From Table 5.2, it can be seen that the reference SOC for this climate region 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 represents 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 it 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). In the Tier 1 method, the SOC is assumed to accrue linearly from years 21–40. The difference between the 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} between years 21 and 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 as a result of 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 different management activities, for example; this has been an issue since inventory methods were first developed (Cowardin, 1982), and still continues even with advances in technology and remote sensing techniques (Arnesen *et al.*, 2013). As mapping techniques tend to rely on vegetation and soils information, defining the area of IWMS is especially difficult because their vegetation range from marsh to forested systems, and soils range from near organic to near non-wetland mineral. Moreover, the extent of areas subject 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 alongside 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 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 need to apply a default level of uncertainty for the land area estimates (±50%). It is *good practice* to apply country-specific uncertainty estimates to country-specific area estimates rather than use a default level. Default reference SOC stocks and stock change factors for mineral soils can have inherently high uncertainties when applied to specific countries. The defaults represent globally averaged values of land-use and management impacts or reference SOC stocks that may deviate 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 activities 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 that alter the water table level on lands containing IWMS can impact CH_4 emissions from those areas. Two common management activities that involve raising water table levels include the rewetting of previously drained IWMS, and the creation of wetlands on wet or dry mineral soils. 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 estimating 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 the large spatial variability, as well as to seasonal and interannual variability in the 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 variations in topography (Ding *et al.*, 2003; Saarnio *et al.*, 2009). In addition, there are very few studies into 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 will necessarily have large uncertainties. Due to the relative lack of data on rewetted and created wetlands with IWMS, we have 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-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

$EF_{CH4-IWMS,\,c}$ = 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 such as river discharge in the case of riparian wetlands, as well as 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 emissions, by facilitating transport from inundated soils to the atmosphere, and by providing a substrate for CH_4 production. Possible methods to determine the importance of these drivers to CH_4 emissions, and thus to 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, as they were derived from studies covering a range of inundation durations, therefore capturing a degree of variability in CH_4 emissions (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 the t distribution, according to the degrees of freedom. These are not expressed as a percentage of the mean.

B Bridgham *et al.* (2006)

C This 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 organisation 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 the creation of wetlands may be obtained from agricultural, forestry, or natural resources agencies, non-governmental conservation organisations, or other government sources. In addition, organisations such as the Society for Ecological Restoration (http://www.ser.org), the 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 used as sources of information for rewetting and/or wetland creation projects. In addition to the above, Tier 2 and Tier 3 methods generally require the areas of managed lands with IWMS stratified by annual average water table level, and the seasonal and/or interannual changes in inundation. For the development of country-specific emission factors and models, areas may be further stratified by vegetation community composition, vegetation biomass, soil temperature, and previous land-use. 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 $EF_{CH4\text{-}IWMS}$, 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 2, Chapters 4-9, Volume 4) for estimating 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 guidance provided in the *2006 IPCC Guidelines* 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 used to estimate the annual carbon stock changes of carbon pools in land remaining in a land-use category for managed lands with IWMS are given in Chapter 2, Volume 4 of the *2006 IPCC Guidelines*, and these will also apply to managed lands with IWMS for land converted to a new land-use category.

Figure 1.3, Chapter 1, Volume 4 of the *2006 IPCC Guidelines* presents a decision tree for the identification of appropriate methodological Tier 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* should 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* should 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* should 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 land converted to a new land-use category in the *2006 IPCC Guidelines* should be used.

5.3.1.2 SOIL CARBON

Conversion of land on IWMS to other land uses can result in an increase in SOC stocks (e.g. in Forest Land; see Chapter 4, Volume 4 of the *2006 IPCC Guidelines*) or a decrease in SOC stocks (e.g. in Cropland; see Chapter 5, Volume 4 of the *2006 IPCC Guidelines*). In general, the guidance provided in Section 5.2.1.2 also applies to land 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* should be used.

CHOICE OF METHOD

The guidance provided in Section 5.2.1.2 also applies to land 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* should be used.

CHOICE OF EMISSION/REMOVAL FACTORS

The guidance provided in Section 5.2.1.2 also applies to all land 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 rewetting of Cropland with IWMS provided 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 provided in this supplement should 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 of 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:
    - o 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 used for estimating the initial SOC stocks ($SOC_{(0-T)}$) should correspond to the land use, management and input regimes before the land-use conversion.
    - o For Cropland with IWMS subject to rewetting undergoing land-use conversion to any other land-use category, F_{LU} = 1 should be used for a period of 21–40 years, or more than 40 years since the first year of rewetting activity respectively, along with relevant stock change factors corresponding to the management and 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) should be used to determine the final SOC stock (SOC_0) along with relevant stock change factors corresponding to the management and input regimes following the land-use conversion.
    - o The guidance in sections pertaining to land converted to a new land-use category in the *2006 IPCC Guidelines* should also 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 the time since rewetting

(0–20 or 21–40 years since rewetting) for the correct application of stock change factors. If the compiler does not have sufficient information to disaggregate the areas of rewetted Cropland with IWMS by the time since conversion, all the areas of rewetted Cropland with IWMS can be assumed to be within 0–20 years of rewetting, and therefore F_{LU} = 0.8 may be applied to the entire rewetted Cropland with IWMS. The guidance provided in Section 5.2.1.2 also applies to land 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 land 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 land converted to a new land-use category in the *2006 IPCC Guidelines* should also be used.

5.3.2 CH_4 emissions

The guidance provided in Section 5.2.2 also applies to land 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 land 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 land 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 land 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 types 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 that this separation is applied consistently throughout the reporting period.

Where guidance not provided for IWMS in this Chapter for some lands, some climates, some carbon pools, and some GHGs, it is the result of a lack of relevant data that allow the development of 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 also be consistent with the generic methodologies described in Volume 4 of the *2006 IPCC Guidelines* and in this supplement. Chapter 6, 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, Volume 1 of the *2006 IPCC Guidelines*. Section 7.4.4, Chapter 7, Volume 4 of the *2006 IPCC Guidelines* states the following with regard to reporting and documentation.

EMISSION FACTORS

The scientific basis for 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 including data sources, databases and soil map references, should be recorded, as well as communications with industry subject to any confidentiality considerations. This documentation should include the frequency of data collection and estimation, estimates of accuracy and precision, and reasons for any significant changes in emission levels.

TREND ANALYSIS

Any 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, then 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 that were computed using a dataset of experimental results for land use are provided in Table 5.3. 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 up to 40 years. Experimental data (citations listed below, and provided in the list of references) were analysed in linear mixed-effects models, accounting for both fixed and random effects (Ogle *et al.,* 2005). Fixed effects included depth and the number of years since a 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, despite those measurements being made 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. This is 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, 20 and 40 years after 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, Montana, Iowa, USA	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
van Wesemael *et al.*, 2010	Belgium	LC
Wang *et al.*, 2012	Sanjiang Plain, China	LC, R

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 emissions 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 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 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 that no emissions occurred during cold seasons and/or by applying mean daily fluxes to part or all of the annual period depending on the climate region and/or specific recommendations made by the 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,
Temperate	Natural wetland, marsh	Nebraska, USA	Continuous	800	EC	Annual	Kim *et al.*, 1999

TABLE 5A.2.1(CONTINUED)
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
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

TABLE 5A.2.1(CONTINUED)
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
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

TABLE 5A.2.1(CONTINUED)
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
Tropical	Natural wetlands, floodplains	Pantanal	Intermittent	949	Chamber	Annual	Melack *et al.*, 2004
Tropical	Natural wetlands, flooded forest, aquatic macrophytes, open water	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 and intermittent inundation. We tested for differences in CH_4 emission factors between wetland types (natural vs. created/rewetted wetlands under intermittent inundation) 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 under intermittent inundation 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. As there are not sufficient studies on created/rewetted wetlands on IWMS in boreal or tropical regions to carry out the same analysis, we make the assumption that, as above, there is no significant difference between the CH_4 emissions from natural and created/rewetted wetlands in boreal or tropical regions, and thus 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: All 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 5A.2.1: 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; and Yang *et al.*, 2012.

C The studies used to determine this value are listed in Table 5A.2.1; 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 5A.2.3; t-test value = 6.47, $p<0.0001$). This highlights the importance of the period of inundation in annual CH_4 emissions. Thus, the development of country-specific emission factors that incorporate the 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: All 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 the 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., 1999; 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 can potentially affect these stocks. However, at the time of preparation of this supplement, except for changes in SOC stocks and CH_4 emissions in 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 made to differentiate between multiple uses on lands with IWMS (e.g. wetland forest and 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 (Zhu *et al.*, 2010). This document describes SOC stock changes and GHG emissions from managed and unmanaged lands and it may serve as a useful example for a national-level carbon assessment. Surveys that quantify the areas of land on IWMS under different land use and management practices, in conjunction with carbon pool quantification, allow the future application of the general equations for carbon stock changes that are described in the *2006 IPCC Guidelines*.

Other databases are available that contain 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 and fluxnet.ccrp.ec.gc.ca).

New research is needed to fill a number of gaps for IWMS. Additional studies are needed to evaluate the effects of IWMS land-use 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 CH_4 fluxes from IWMS 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). A 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 should be more thoroughly addressed in future updates to 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 Chapter 11, Volume 4 of the *2006 IPCC Guidelines*.

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 such as 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 development of Tier 3 approaches for IWMS.

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