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. Wetland mineral soils (WMS) are defined in 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 that are created or modified for wastewater treatment are addressed in Chapter 6 (Constructed Wetlands – Wastewater Treatment) of this Supplement.

Mineral soils are described as all soils that are not classified as organic soils in Chapter 3 Annex 3A.5 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 (USDA, 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. 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 (Chapter 2, Table 2.3, *2006 IPCC Guidelines*). They can occur in any of the six land use categories.

For the purposes of this Supplement, IWMS include those that have formed under restricted drainage, and may or may not be artificially drained due to management activities. Artificial drainage is 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 USDA, 1999). Additionally, guidance provided in this chapter applies to IWMS that have been artificially drained and subsequently allowed to re-wet for the purposes of "wetland restoration" and the artificial inundation of mineral soils for the purposes of "wetland creation".

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. 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 *2006 IPCC Guidelines* Volume 4, Chapter 2, Table 2.3), to be used for Tier 1 methods in all six land-use categories
- Default 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 wetland restoration on Cropland with IWMS.
- Providing methodologies and emission factors for CH_4 emissions from managed lands with IWMS under any land-use category that have undergone wetland restoration, 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	CH_4 Emissions
Land Remaining in a Land-use Category		
Forest Land	Updated SOC_{REF} for IWMS	$EF_{CH4\text{-}IWMS}$ for restored 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 wetland restoration	
Grassland	Updated SOC_{REF} for IWMS	
Settlements		
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 restoration	$EF_{CH4\text{-}IWMS}$ for restored and created wetlands on managed lands with mineral soils

*Existing guidance for managed lands that may have IWMS is provided in the *2006 IPCC Guidelines* for: CO_2, CH_4, and N_2O emissions from rice cultivation (Croplands, Chapter 4), and CO_2 and CH_4 from Flooded Lands (reservoirs, impoundments; Appendix 3).

5.1.1 General background on Inland Wetland Mineral Soils and management activities

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, 2010). 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, 2010). Climate regions having less than 0.20% WMS include Cool and Warm Temperate Dry, Tropical Dry, and Tropical Montane.

IWMS can occur in any of the six IPCC land-use categories (Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land). For example, depending on the national definitions, a riverine wetland with trees may be classified as a Forest Land, while a marsh may be used for grazing and be classified as Grassland. 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 dominant vegetation community, and can include trees, woody shrubs, emergent and non-emergent vascular plants, and/or bare ground.

Globally, more than 50% of lands with IWMS have been converted to other land uses, mostly by drainage (Bridgham *et al.*, 2006). Drainage of IWMS is a common practice in the preparation of land for agriculture. grazing, and forestry. Drainage leads to lower water levels which affects decomposition and vegetation productivity, and can significantly reduce IWMS carbon (C) 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 and ditches through wetlands for flood control, navigation and transportation, (Mitsch and Gosselink, 2007); management of river-floodplain systems through levee construction, channelization, flow manipulation by dams (Dynesius and Nilsson, 1994); 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 severely affect riparian wetlands in both upstream and downstream directions by minimizing 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), and on vegetation communities (Nilsson and Berggren, 2000).

An important agricultural use of lands with IWMS is rice cultivation, which is covered in the *2006 IPCC Guidelines* (Volume 4, Chapter 5: Cropland), and is not addressed in this Supplement. Other agricultural uses of lands with IWMS include lotus and mat rush cultivation, particularly in Asia (Seo *et al.*, 2010; Maruyama *et al.*, 2004). Currently there is little available information on C stock changes or GHG emissions for this type of cultivation. Grazing on lands with IWMS within grassland or forest landscapes is widespread (Liu *et al.*, 2009; Oates *et al.*, 2008; Wang *et al.*, 2009; Yao *et al.*, 2010). Forest management activities on forested wetlands 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 of forest management activities on C 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 wetland restoration, where lands with IWMS that were artificially drained are "re-wetted" by raising the water table level to pre-drainage conditions. Active approaches to wetland restoration include filling or blocking of drainage ditches, breaching levees, removal of dams and spillways, and contouring the land surface to mimic natural topography; passive approaches include the elimination of water controls and allowing natural flood events (Aber *et al.*, 2012). The re-wetting 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 restoration 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 restoring wetlands (Euliss *et al.*, 2006; Bridgham *et al.*, 2006). Restored wetlands may also have higher emissions of CH_4, potentially offsetting increased carbon storage (Bridgham *et al.,* 2006), although recent studies have suggested that created and restored wetlands can be net C sinks, after accounting for CH_4 emissions (Badiou *et al.*, 2011; Mitsch *et al.*, 2012).

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 C in saline IWMS (Bai *et al.* 2007; Rodriguez-Murillo *et al.* 2011), and no studies have measured GHG fluxes from saline IWMS. At present the lack of data on saline IWMS prevents the determination of default C stock changes or GHG emission factors. If country specific data is available, it is *good practice* to use that data to estimate C pools in, and fluxes from, managed saline IWMS.

5.1.2 Reporting Inland Wetland Mineral Soils

IWMS can occur in any of the six broad IPCC land-use categories. While the *2006 IPCC Guidelines* do provide generic definitions, countries use their own country-specific definitions for classifying all land areas into these six broad land-use categories. Consequently, managed land with IWMS may be classified into any of the six broad land-use categories depending upon the national land-use classification system. Emissions and removals for areas of managed land on 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 conversion.

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 (Volume 4, Chapters 2 and Chapter 4-9) on stock changes in the carbon pools (above-ground and below-ground biomass, dead wood and litter, and soil organic carbon), and guidance on 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 soil organic carbon and non-CO_2 emissions from managed lands containing IWMS.

5.2.1 CO_2 emissions and removals

As explained in Volume 4, Chapter 2, CO_2 emissions and removals from land are estimated on the basis of changes in the carbon stocks in the carbon pools: above ground biomass, below-ground biomass, dead organic matter (i.e., 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 Volume 4, Chapter 2 of the *2006 IPCC Guidelines*, and will also apply to managed lands with IWMS.

Figure 1.2 in Volume 4, Chapter 1 of the *2006 IPCC Guidelines* shows a decision tree for the identification of appropriate methodological Tiers for *land remaining in the same land-use category*.

5.2.1.1 BIOMASS AND DEAD ORGANIC MATTER

Guidance for changes in the carbon pools in biomass (aboveground, belowground) 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.* It can be assumed that wetland vegetation does not have substantially different biomass carbon densities than upland vegetation (e.g. Bridgham *et al.*, 2006).

CHOICE OF METHOD AND EMISSION/REMOVAL FACTORS

As explained in the *2006 IPCC Guidelines*, inventories can be developed using Tiers 1, 2 and 3 approaches. The decision trees have been provided in the *2006 IPCC Guidelines* to guide the selection of appropriate methodological tiers for the estimation of changes in carbon stocks of biomass and dead organic matter (Volume 4, Chapter 2, Fig. 2.2 and Fig. 2.3). In general it is *good practice* to use higher Tier methods (Tiers 2 and 3) if carbon stock changes in biomass or dead organic matter are *key categories*. Guidance on the choice of emission/removal factors for change in biomass and dead organic matter for the six land-use categories are found in the sections on biomass and dead organic matter for *land remaining in a land use category* in the appropriate Chapter(s) in Volume 4 of the *2006 IPCC Guidelines*: Forest Land (Chapter 4), Cropland (Chapter 5), Grassland (Chapter 6), Settlements (Chapter 8), and Other Land (Chapter 9). 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. Tier 2 methods will involve using country-specific emission factors and parameters along with activity data at suitable disaggregation, while Tier 3 methods involve detailed modeling or measurement-based frameworks using highly disaggregated data. 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, or wetland restoration and creation. If there are reliable data for rates of biomass and/or dead organic matter change upon drainage or wetland restoration/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. Although no organization catalogues changes in area as a result of wetlands restored or created either nationally or globally, local activity data for restoration 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 wetland restoration projects.

Higher tier methods may use activity data suitably stratified by criteria such as vegetation type (annual vs. perennial species) and/or water table level and hydroperiod (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 land use and management activity data, and 2) uncertainties in carbon gain and loss, carbon stocks, and factor terms for 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 C stocks in IWMS are influenced by changes in water level (drainage, re-wetting), management practices on Cropland, Forest Land, and Grassland (including long-term cultivation, drainage to improve production, and grazing), and wetland restoration 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 C stocks include 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 C 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 C stocks of IWMS in floodplains at this time. Similarly, very little information is available with regards to impacts of other common management practices, such as grazing, on IWMS soil C 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 Volume 4, Chapters 2 and 3 of the *2006 IPCC Guidelines*. The generic methodological guidance for estimation of changes in the carbon stocks in the soil organic carbon pool in mineral soils provided in Volume 4, Chapter 2, Section 2.3.3 of the *2006 IPCC Guidelines* and should be used along with land-use category specific methodological guidance provided in Volume 4, Chapters 4 to 9. This Supplement updates the guidance on IWMS provided in the *2006 IPCC Guidelines* with regards to the following:

- Table 5.2 provides updated default soil organic carbon reference stocks (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 wetland restoration on Cropland with IWMS.

To account for changes in IWMS soil C stocks associated with changes in management 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* at the beginning and end of the inventory time period. If land-use and management data are limited, aggregate data, such as FAO statistics on land-use (http://www.fao.org), 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 (Figure 2.4) in Section 2.3.3.1, Chapter 2 of the *2006 IPCC Guidelines* to assist inventory compilers with selection of the appropriate tier for their soil C inventory.

Tier 1

The estimation method for mineral soils in *land remaining in a land-use category*, including IWMS, is based on changes in soil organic C stocks over a finite period following changes in management that impact soil organic C. Equation 2.25 (Chapter 2, *2006 IPCC Guidelines*) is used to estimate change in soil organic C stocks in mineral soils by subtracting the C 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). Soil organic C stocks (SOC) are estimated for the beginning and end of the inventory time period using default reference carbon stocks (SOC_{REF}) and default stock change factors (F_{LU}, F_{MG}, F_I). 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 C 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, 1998, 1994; 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 C. 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 soil organic C 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[1]. 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.

[1] These values are given under "wetland soils" in Volume 4, Chapter 2, Table 2.3 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}	Error (SD)	n
Boreal	116	±94	6
Cold temperate, dry	87[B]	±78	n/a
Cold temperate, moist	128	±55	42
Warm temperate, dry	74	±45	49
Warm temperate, moist	135	±101	28
Tropical, dry	22	±11	32
Tropical, moist	68	±45	55
Tropical, wet	49	±27	33
Tropical, montane	82	±73	12

[A]Batjes (2011) presents revised estimates 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]No revised estimate was presented in Batjes (2011); values are from Table 2.3 of the *2006 IPCC Guidelines* for National Greenhouse Gas Inventories, Volume 4.

The updated SOC_{REF} values in Table 5.2 for *Wetland Mineral Soils* should be used for calculating soil organic carbon 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 (when using Approach 1 activity data);
- 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 with IWMS in the *Cropland Remaining Cropland* land use category are presented in Table 5.5 (Chapter 5, *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, *2006 IPCC Guidelines*).

Table 5.3 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 values in Table 5.5 (Chapter 5, *2006 IPCC Guidelines*), but is lower than the Temperate/Boreal Dry climate value. Consequently, this update should reduce bias associated with estimating soil C 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 and References. The default time period for stock changes (D) is 20 years, and management practices are assumed to influence stocks to 30 cm depth.

A new default stock change factor for land-use (F_{LU}) following wetland restoration in 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 restoration 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 carbon level after 40 years (i.e., the reference soil organic carbon stocks, Table 5.2).

TABLE 5.3
RELATIVE STOCK CHANGE FACTORS FOR LAND-USE (F_{LU}) FOR LONG TERM CULTIVATION ON CROPLAND WITH IWMS (OVER 20 YEARS) AND WETLAND RESTORATION OF CROPLAND WITH IWMS (OVER 20 YEARS AND 40 YEARS)

Factor value type	Level	Temperature regime	Moisture regime	Default	Error[1]	Description
Land use (F_{LU})	Long-term cultivated	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})	Wetland restoration (20 years)	Boreal, Temperate, and Tropical	Dry and Moist	0.80	10%	Represents cropland with IWMS that has undergone wetland restoration (restoration of natural hydrology) and may or may not be under active crop production.
	Wetland restoration (40 years)			1.0	N/A	

[1] ± two standard deviations, expressed as a percent of the mean.

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 wetland restoration (Table 5.3) for *land remaining in a land-use category*:

- The stock change factors for SOC stock changes 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 wetland restoration 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 Volume 4, Chapter 5, Table 5.5 in the *2006 IPCC Guidelines.*

  (ii) The stock change factors for land-use (F_{LU}) for Cropland with IWMS subject to restoration are to be used for *Cropland remaining Cropland* according to the following:

    - For Cropland with IWMS subject to wetland restoration, for a period of 0-20 years following restoration, the final SOC stock (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 before land-use conversion.
    - For the period between 20-40 years since the start of the restoration activity, 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 the Cropland land-use (long-term cultivated, perennial etc.), management and input regime at the start of the period.

- For the period beyond 40 years following restoration, 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 in the *2006 IPCC Guidelines*.

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 C stocks can also be derived from country-specific data in a Tier 2 approach. Additional guidance is provided in Chapter 2, Section 2.3.3.1 (*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 Chapter 2, Section 2.3.3.1 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. 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.

Tier 1

The Tier 1 approach requires area of managed land with 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) as an initial approach.

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 wetlands restored or created either nationally or globally, local activity data for restoration 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 wetland restoration 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 C 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 inventory time periods based on the years in which activity data were collected.

Step 2: Determine areas of managed land on 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 3: Classify land into the appropriate management system according to the respective land-use category.

Step 4: Assign a native reference C 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 C input levels (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 the reference soil C stock (SOC_{REF}) to estimate an 'initial' soil organic C stock ($SOC_{(0-T)}$) for the inventory time period.

Step 7: Estimate the final soil organic C stock (SOC_0) by repeating Steps 1 to 5 using the same native reference C stock (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 soil organic C stocks for managed land on IWMS remaining in a land-use category ($\Delta C_{Mineral}$) by subtracting the 'initial' soil organic C stock ($SOC_{(0-T)}$) from the final soil organic C stock (SOC_0), then dividing by the time dependence of the stock change factors (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.

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 C 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 board categories, 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; 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 (Hirano *et al.,* 2003). 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 on management activities.

For Tier 1, uncertainties are provided with the reference C stocks in Table 5.2, and stock change factors in the respective land-use category Chapters (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 C 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* for the inventory compiler to derive uncertainties from country-specific activity data instead of using a default level. Default reference C stocks and stock change factors for mineral soils can have inherently high uncertainties, particularly bias, when applied to specific countries. Defaults represent globally averaged values of land-use and management impacts or reference C 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 C monitoring data in the country or neighboring regions that address the effect of land use and management on soil C and/or can be used to evaluate model predictions of soil C change (e.g., Ogle *et al.,* 2010). In addition, it is *good practice* to further minimize bias 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

Methane (CH_4) is produced in IWMS soils during anaerobic decomposition of organic matter, and emitted to the atmosphere after diffusion or ebullition (i.e. episodic release of gas bubbles from soils) through the water column, or through plant-mediated transport. Several factors have been identified as important controls on CH_4 production and emission, including water level, oxygen availability, temperature, vegetation community and productivity, and microbial communities (Whiting and Chanton, 1993). Soil moisture content and water table level are critical to determining whether CH_4 is produced, and how much is emitted (Le Mer and Roger, 2001). In a synthesis of CH_4 flux from global hydromorphic organic soils, Jungkunst and Fiedler (2007) found that in general when water table was greater than 0.1 m below the soil surface CH_4 was not emitted.

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 the restoration of wetlands on previously drained, cultivated, and/or degraded lands with IWMS, and the creation of wetlands on mineral soils (wet or dry). Wetland restoration often involves the cessation of active drainage by filling ditches and/or removing drainage tiles, whereas wetland creation often involves active modification of hydrologic regime where dry lands are purposely inundated. Both wetland restoration 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 wetland restoration and 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 fluxes for drained IWMS at this time.

Despite current understanding of the processes involved in CH_4 production and emission, it remains difficult to predict 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 restored 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 restored and created wetlands on 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 with 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 RESTORED 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 with mineral soil 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 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 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 above the land surface (Annex 5A.2). Seasonal and inter-annual changes in water table position, and duration above the land surface, are determined by multiple variables including fluctuations in water source (ex. river discharge in the case of riparian wetlands) 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 ($EF_{CH4\text{-}IWMS}$), stratified by climate region, are provided in Table 5.4. The emission factors assume a water table position at or above the land surface, but 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 Domain	$EF_{CH4\text{-}IWMS}$ (kg CH_4 ha^{-1} yr^{-1})	Uncertainty Range (95% Confidence Interval)
Boreal	76	10 – 142
Temperate	237	103 - 371
Tropical	900	345 - 1454

5.2.2.3 CHOICE OF ACTIVITY DATA

Tier 1 method requires data on areas of managed lands with IWMS where the water table level has been raised, for instance as in wetland restoration or wetland creation, stratified by climate region. Although no organization catalogues changes in area as a result of wetlands restored or created either nationally or globally, local activity data for restoration 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 wetland restoration 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 inter-annual 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. Remote sensing can be used for detection of areas of inundation, and for mapping of vegetation.

5.2.2.4 UNCERTAINTY ASSESSMENT

Ranges of uncertainty for $EF_{CH4-IWMS}$ are provided in Table 5.4 for each climate region. The 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 (Volume 4, Chapters 2 and Chapters 4-9) for carbon stock changes in the carbon pools and non-CO_2 emissions for 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 soil organic carbon and non-CO_2 emissions from managed lands containing 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 carbon stock changes of carbon 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* have 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* have 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* have 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* have to be used.

5.3.1.2 SOIL CARBON

Conversion of land with 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 wetland restoration 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* have 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* have 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 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 restoration 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 Volume 4, Chapter 5, Table 5.5 in the *2006 IPCC Guidelines*.
  - (ii) The stock change factors for land-use (F_{LU}) for Cropland with IWMS subject to restoration can be used for land-use conversions involving Cropland in the following ways:
    - For land-use conversion to Cropland with IWMS subject to wetland restoration the final SOC stock (SOC_0) is determined using F_{LU} = 0.80 for a period of 0-20 years following restoration 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 restoration undergoing land-use conversion to any other land-use category, F_{LU} values of 0.8 or 1 are to be used for a period of 20-40 years or more than 40 years since the start of the restoration 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* must 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 5.2.1.2 *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. The guidance in sections pertaining to lands converted to a new land-use category in the *2006 IPCC Guidelines* have 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. The guidance in sections pertaining to *land converted to a new land-use category* in the *2006 IPCC Guidelines* have to be used.

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. The guidance in sections pertaining to *land converted to a new land-use category* in the *2006 IPCC Guidelines* have to be used.

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. The guidance in sections pertaining to lands converted to a new land-use category in the *2006 IPCC Guidelines* have to be used.

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

5.4.1 Completeness

Complete GHG inventories will include estimates of carbon stock changes and emissions and sinks of GHG from all managed land with IWMS for which methodological guidance is provided in the *2006 IPCC Guidelines* and this Supplement.

Because multiple activities or land uses (e.g., cropping, forest) may occur on land with IWMS, countries are encouraged to monitor land use changes and activities to avoid double counting. For example, if a forested wetland has been reported as a forest it should be reported as a forest during the entire time series. Also, when inputs from other land uses such as drainage waters carrying nitrogen from Croplands to managed lands with IWMS it is *good practice* to ensure that sources are accounted for under the proper land use where they are produced.

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, 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 C 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 C stocks and GHG fluxes from drained wetlands, restored wetlands, or created wetlands on lands with IWMS.

5.4.2 Developing a consistent time series

General guidance on consistency in time series is given in Chapter 7 of this Supplement. It is essential for the consistency of time series that estimation methods are comparable from one year to another in the time series. 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 2 of the *2006 IPCC Guidelines* and in this *2013 Supplement*. It is expected that when countries use country-specific data, changes in methods and/or emission or removal factors occur between years as a result of the development of new methodologies and/or availability of new information. In these cases inventory agencies should assure that new developments do not create methodological artefacts that do not represent real changes in trends (see Section 7.6.2 I). It is *good practice* to recalculate the entire time series when new country-specific methodologies are developed as well as document, preferably on a peer-review basis, the consistency between different methods.

5.4.3 Quality Assurance and Quality Control

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 Control (QA/QC). All steps in the inventory should be clearly documented for revision by inventory compilers and non-inventory reviewers. It is *good practice* for countries to verify the applicability of default emission factors and activity data to their specific inventories and special attention should be given to cross-referencing country-specific data to values reported in the scientific literature or reported by other countries. Classification of land use based on remotely obtained information has progressed rapidly and it is *good practice* for countries to search for available imagery which can improve the accuracy of area estimates and reduce uncertainties in activity data.

5.4.4 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 in Chapter 7 of 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.

5.5 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 soil C stocks and CH_4 emissions for restored/created wetlands on lands with IWMS, and changes in soil C stocks as a result of long-term cultivation and wetland restoration 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. forested wetlands, wet grasslands) for future methodological improvements. A good example of the methodological approach necessary for this task can be found in USFWS (United States Fish and Wildlife Service) Report to the Congress entitled "Status and Trends of Wetlands in the Conterminous United States – 2004 to 2009" (http://www.fws.gov/wetlands/Documents/Status-and-Trends-of-wetlands-in-the-Conterminuous-United-States-2004-to-2009.pdf). This document describes how wetland inventories have been made in the United States and, although not providing figures for C stock changes, gives reference for future work to obtain such data at 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 C stocks and GHG fluxes at a national level is found in the USGS (United States Geological Survey) Scientific Investigations Report 2010-5233 entitled "A Method for Assessing Carbon Stocks, Carbon Sequestration, and Greenhouse-Gas Fluxes in Ecosystems of the United States Under Present Conditions and Future Scenarios" (Zhu et al., 2010; http://pubs.usgs.gov/sir/2010/5233). While this document describes C stock changes and GHG emissions from managed and unmanaged lands, it may serve as a useful example for a national-level C assessment. Synthetically, surveys to quantify the areas of land with IWMS under different land use and management practices in conjunction with C pools quantification allows the future use of general equations for C stock-changes described in the *2006 IPCC Guidelines*.

New research is needed to fill a number of gaps for IWMS. Additional studies are needed to evaluate the effect of IWMS conversion on soil C stock changes following conversion to Grassland, Forest Land, Settlements and Other Lands. Moreover, new research is needed to understand the effect of IWMS conversion on other C 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 Croplands, 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.*, 2011; 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 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 emission already included in the estimates of indirect N_2O from agricultural or other runoff, and waste water (see Volume 4, Chapter 11 of the *IPCC 2006 IPCC Guidelines*)

Fully functional models that consider the influence of changes in hydrology on C 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.

Annex 5A.1 Estimation of default stock change factors for long-term cultivated Cropland and wetland restoration with Inland Wetland Mineral Soil C 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 carbon that occurs after 20 years of continuous cultivation. The wetland restoration 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 carbon 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 analyzed 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 C 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 carbon at 20 years or longer time period following cultivation of IWMS. Users of the Tier 1 method can approximate the annual change in carbon storage by dividing the inventory estimate by 20. The wetland restoration factor represents the average net gain in carbon after restoration of cultivated cropland at 20 and 40 years following restoration. 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; WR = Wetland restoration)
Badiou *et al.*, 2011	Saskatchewan, Alberta, Manitoba,	LC, WR
Ballantine *et al.*, 2009	New York, USA	WR
Besasie *et al.*, 2011	Wisconsin, USA	LC, WR
Bedard-Haughn *et al.*, 2006	Saskatchewan, Canada	LC
David *et al.*, 2009	Illinois, USA	LC
Euliss *et al.*, 2006	North Dakota, South Dakota,	LC, WR
Gleason *et al.*, 2009	North Dakota, USA	WR
Huang *et al.*, 2010	Sanjiang Plain, China	LC
Hunter *et al.*, 2008	Louisiana, USA	LC, WR
Jacinthe *et al.*, 2001	Ohio, USA	LC
Lu *et al.*, 2007	Lake Taihu, China	LC, WR
Meyer *et al.*, 2008	Nebraska, USA	LC, WR
Morse *et al.*, 2012	North Carolina, USA	LC
Norton *et al.*, 2011	California, USA	LC
Wang *et al.*, 2012	Sanjiang Plain, China	LC, WR
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 re-wetted IWMS as a result of wetland restoration, 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.

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})	Reference
Boreal	Natural wetlands	Canada	unspecified	76	Bridgham *et al.*, 2006
Temperate	Restored wetlands, previous use Cropland	Canada	Intermittent	49	Badiou *et al.*, 2011
Temperate	Restored wetlands, previous use Cropland	Canada	Intermittent	349	Pennock *et al.*, 2010
Temperate	Restored wetlands, previous use Cropland	North Dakota, USA	Intermittent	142	Gleason *et al.*, 2009
Temperate	Restored wetlands, previous use Cropland	North Carolina, USA	Intermittent	7	Morse *et al.*, 2012
Temperate	Restored wetland, previous use Cropland	Denmark	Intermittent	110	Herbst *et al.*, 2011
Temperate	Created wetlands, riparian	China	Intermittent	13	Yang *et al.*, 2012
Temperate	Created wetlands	Ohio, USA	Continuous	402	Nahlik and Mitsch, 2010; Altor and Mitsch, 2008
Temperate	Natural wetland, marsh	Nebraska	Continuous	800	Kim *et al.*, 1998
Temperate	Natural wetlands, marshes	Sanjiang Plain, NE China	Continuous	468	Ding and Cai, 2007
Temperate	Natural wetlands, *Carex* marshes	Sanjiang Plain, NE China	Continuous	434	Song *et al.*, 2003

Temperate	Natural wetlands, *Deyeuixa* marshes	Sanjiang Plain, NE China	Continuous	289	Song *et al.*, 2003
Temperate	Natural wetland, riparian	Ohio	Continuous	758	Nahlik and Mitsch, 2010
Temperate	Natural wetlands, riparian	Georgia, USA	Continuous	266	Pulliam, 1993
Temperate	Natural wetlands, marshes	Sanjiang Plain, NE China	Continuous	225	Huang *et al.*, 2010
Temperate	Natural wetlands, marsh	Sanjiang Plain, NE China	Intermittent	58	Song et a., 2009
Temperate	Natural wetlands, shrub swamp	Sanjiang Plain, NE China	Intermittent	3	Song et a., 2009
Temperate	Natural wetlands, swamps	Global	Intermittent	113	Bartlett and Harriss, 1993
Temperate	Natural wetlands, marshes	Global	Intermittent	105	Bartlett and Harriss, 1993
Temperate	Natural wetlands, floodplains	Global	Intermittent	72	Bartlett and Harriss, 1993
Temperate	Natural wetlands	Continental USA	unspecified	76	Bridgham *et al.*, 2006
Tropical	Natural wetlands, rainforest swamp	Costa Rica	Continuous	2930	Nahlik and Mitsch, 2011
Tropical	Natural wetlands, alluvial marsh	Costa Rica	Intermittent	3500	Nahlik and Mitsch, 2011
Tropical	Natural wetlands, swamps	Global	Intermittent	297	Bartlett *et al.*, 1993
Tropical	Natural wetlands, marshes	Global	Intermittent	419	Bartlett *et al.*, 1993
Tropical	Natural wetlands, floodplains	Global	Intermittent	328	Bartlett *et al.*, 1993
Tropical	Natural wetlands, floodplains	Amazon, Upper Negro Basin	Intermittent	54	Belger *et al.*, 2011

Tropical	Natural wetlands, floodplains	Pantanal, Brazil (Arara-Azul)	Intermittent	516	Marani *et al.* 2007
Tropical	Natural wetlands, floodplains	Pantanal, Brazil (Bau)	Intermittent	1033	Marani *et al.* 2007
Tropical	Natural wetlands, floodplains	Pantanal, Brazil (Sao Joao)	Intermittent	510	Marani *et al.* 2007
Tropical	Natural wetlands, flooded forests	Solimoes/Amazon floodplain	Intermittent	567	Melack and Forsberg, 2001
Tropical	Natural wetlands, aquatic macrophytes	Solimoes/Amazon floodplain	Intermittent	184	Melack and Forsberg, 2001
Tropical	Natural wetlands, flooded forests	Jau River basin floodplains/Amazon	Intermittent	306	Rosenqvist *et al.*, 2002
Tropical	Natural wetlands, floodplains	Mojos basin/Amazon	Intermittent	948	Melack *et al.*, 2004
Tropical	Natural wetlands, floodplains	Roraima/ Amazon	Intermittent	1341	Melack *et al.*, 2004
Tropical	Natural wetlands, floodplains	Bananal	Intermittent	954	Melack *et al.*, 2004
Tropical	Natural wetlands, floodplains	Orinoco	Intermittent	951	Melack *et al.*, 2004
Tropical	Natural wetlands, floodplains	Pantanal	Intermittent	949	Melack *et al.*, 2004
Tropical	Natural wetlands, flooded forest, aquatic macrophytes,	Solimoes/Amazon floodplain	Continuous & Intermittent	404	Melack *et al.*, 2004

Studies for temperate region sites are roughly equal in number for continuous inundation and intermittent inundation, so the emission factors were compared for the two hydrologic regimes (Table 5A2.2).

TABLE 5A.2.2
CH_4 EMISSIONS FROM TEMPERATE RESTORED, CREATED AND NATURAL WETLANDS WITH IWMS, STRATIFIED BY PERIOD OF INUNDATION

Climate region	Annual Period of Inundation	EF (kg CH_4 ha^{-1} yr^{-1})	95% confidence interval	n
Temperate	Continuous	455	182	8
	Intermittent	93	65	11

Note: Values are derived from studies of Temperate wetlands listed in Table 5A.2.1, n = number of studies.

There is a significant difference in EF for the two hydrologic regimes (ANOVA, $p<0.000$). This highlights the importance of period of inundation in annual CH_4 emission. The development of country-specific emission factors that incorporate period of inundation will reduce uncertainties.

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