CHAPTER 7

WETLANDS

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7 WETLANDS

7.1 INTRODUCTION

This section has further elaboration.

This chapter provides guidance on estimating and reporting greenhouse gas (GHG) emissions from managed wetlands. Wetlands include any land that is covered or saturated by water for all or part of the year, and that does not fall into the Forest Land, Cropland, or Grassland categories. Managed wetlands will be restricted to wetlands where the water table is artificially changed (e.g., drained or raised) or those created through human activity (e.g., damming). Emissions from unmanaged wetlands are not estimated.

Methodologies are provided for:

- Peatlands cleared and drained for production of peat for energy, horticultural and other uses (Section 7.2). The estimation methodology, although essentially the same as in the IPCC report on Good Practice Guidance for Land use, Land-Use Change and Forestry (*GPG-LULUCF*), now includes emissions from the use of horticultural peat.
- Reservoirs or impoundments, for energy production, irrigation, navigation, or recreation (Section 7.3). The scope of the assessment now includes CO_2 emissions from all lands converted to permanently Flooded Lands. Flooded Lands exclude regulated lakes and rivers unless a substantial increase in water area has occurred.
- Other human-made waterbodies including agricultural ponds, ditches and aquaculture ponds.

For simplicity, the remainder of this section will refer to peatlands managed for peat extraction as peatlands, and lands flooded in reservoirs and other human-made water bodies as Flooded Lands. Table 7.1 clarifies the scope of the assessment, and the corresponding sections of this chapter.

TABLE 7.1
SECTIONS ADDRESSING MAJOR GREENHOUSE GAS EMISSIONS FROM MANAGED WETLANDS

Land-use category/GHG	Peatlands	Flooded Land
Wetlands Remaining Wetlands		
CO_2	Section 7.2.1.1	No Guidance [1]
CH_4	No Guidance [2]	New Guidance, Section 7.3
N_2O	Section 7.2.1.2	No Guidance [3]
Lands Converted to Wetlands		
CO_2	Section 7.2.2.1	New Guidance, Section 7.3
CH_4	No Guidance [2]	New Guidance, Section 7.3
N_2O	Section 7.2.2.2	No Guidance [3]

NOTES:

[1] CO_2 emissions from *Flooded land Remaining Flooded land* are covered by carbon stock change estimates of land uses and land-use change (e.g., soils) upstream of the Flooded Land.

[2] Methane emission from peatlands is negligible after drainage during conversion and peat extraction.

[3] N_2O emissions from Flooded Land are included in the estimates of indirect N_2O from agricultural or other run-off, and waste water.

Wetlands are frequently managed for other uses, such as forest and grassland management, or croplands. Scientific level of knowledge on greenhouse gas balances of different kind of wetlands is still, in general, rather low and uncertain, but the area is continuously studied further (e.g., see Annex 7.1). Table 7.2 indicates where to find the guidance relative to these managed wetlands.

TABLE 7.2
GUIDANCE ON EMISSIONS FROM WETLANDS MANAGED FOR OTHER USES

Land-use category	Volume/Section in these Guidelines
Wetlands already converted or being converted to:	
Cropland, including “bogs” for cranberry and other ericaceous fruits	Volume 4, Chapter 5 (Section 5.3)
Managed Grassland	Volume 4, Chapter 6 (Section 6.3)
Managed Forest Land, including drained or undrained forested wetlands according to national definitions	Volume 4, Chapter 4 (Section 4.3)
Rice cultivation	Volume 4, Chapter 5 (Section 5.5)

Some uses of wetlands are not covered, because adequate methodologies are not available. These include manure management ponds, industrial effluent ponds. Countries where these activities are significant should consider research to assess their contribution to greenhouse gas emissions or removals. N_2O emissions from wetlands managed for the filtration of non-point source agricultural effluents, such as fertilizers and pesticides, are included in indirect emissions from soil amendments (Volume 4, Chapter 11).

Most ecological classifications of wetlands, including those of the Ramsar Convention on Wetlands, consider many of these lands as Wetlands, even those disturbed by human activities or artificially built. The Wetlands classification adopted by the Ramsar Convention (Ramsar, 1996) is widely used to address management issues. Table 7.3 relates wetland classes in this report to selected definitions in the Ramsar Convention.

TABLE 7.3
RAMSAR CLASSES OF HUMAN-MADE WETLANDS

RAMSAR class	Corresponding wetlands sub-categories in the IPCC terminology	Methodological guidance
Aquaculture	Flooded Land	Yes (this chapter)
Ponds	Flooded Land	Yes (this chapter)
Irrigated land (if cultivated)	Cropland	No [2]
Seasonally flooded agricultural land	Rice Cultivation	Yes (Vol. 4, Chapter 5)
Seasonally flooded agricultural land	Pasture	Yes (Wetland Supplement, Chapter 5)
Salt exploitation sites	---	No [1]
Water storage areas	Flooded Land	Yes (this chapter)
Excavations (partly)	Peatlands managed for peat extraction	Yes (this chapter)
Wastewater treatment areas	“Constructed wetlands” or Waste Sector	No [3]
Canals and drainage channels, ditches.	Flooded Land	Yes (this chapter)[3]

NOTES:

[1] No suitable default methodologies are available for these sources.

[2] The Cropland Chapter includes this source.

[3] Emissions of CH_4 and N_2O from wastewater discharges to canals, rivers, lakes, seas, and drainage channels or ditches, as well as wastewater treatment areas, are covered in Volume 5, Chapter 3 though any additional emissions from new wetlands are not. Emissions of N_2O from leachate of nitrogenous fertilisers are covered in Volume 4, Chapter 11.

Source: Ramsar, 1996

Greenhouse gas emissions and removals from wetlands

No refinement, See the Wetland Supplement

7.2 MANAGED PEATLANDS

No refinement, See the 2013 Wetland Supplement

7.3 FLOODED LAND

This section provides new guidance.

Flooded land is comprised of water bodies where human activities create or change the amount of land area flooded with water, as well as changes to the hydrology of existing flooded lands that result in altered water residence times and/or sedimentation rates and cause changes to the sediment or water column flux of greenhouse gases Therefore, Flooded Land includes a broad variety of water bodies used to meet a number of important human needs (Table 7.7).

TABLE 7.7
TYPES OF FLOODED LAND AND THEIR HUMAN USES

Flooded Land types	Human Uses
Reservoirs (Open Water, Drawdown Zones, and Degassing/Downstream areas)	Hydroelectric Energy Production, Flood Control, Water Supply, Agriculture, Recreation, Navigation, Aquaculture
Canals	Water Supply, transport
Ditches	Agriculture (e.g. irrigation, drainage, and livestock watering)
Farm Ponds	Agriculture, aquaculture
Aquaculture Ponds	Aquaculture (fish, crustaceans)

Flooded Land emits CO_2, CH_4 and N_2O in significant quantities, depending on a variety of characteristic such as age, land-use prior to flooding, climate, upstream catchment characteristics and management practices. Emissions vary spatially and over time.

Reservoirs

Reservoirs are designed to store water over various time scales, ranging from hours to several years. Their use can be single or multiple, and the operation may vary depending on different user needs. Hydropower reservoirs can be divided in three categories: storage, run-of-the-river and pumped storage reservoirs. These categories generally describe the relationship between storage volume, inflow and residence time, but in reality, reservoirs exist on a spectrum. Natural lakes may also be used as reservoirs, often by damming to expand their volume and surface area. Flooded lands are exposed to natural or anthropogenic regulation on water levels, creating a drawdown zone. Greenhouse gas emissions from the drawdown zones are considered comparable to the emissions from the water surface and are therefore included when estimating greenhouse gas emissions from flooded lands. Lakes converted into reservoirs without substantial changes in area or residence times are not considered to be managed flooded lands, in accordance with the 2006 Guidelines.

Reservoirs are classified according to the length of time they have been flooded.:

(a) *Land Converted to Flooded Land* – includes reservoirs that were flooded less than 20 years ago.

(b) *Flooded Land Remaining Flooded Land* – includes reservoirs that were converted to flooded land more than 20 years ago.

Other flooded lands: Human-made ponds, ditches, aquaculture ponds and flooded pastures

Ponds are constructed by excavation and construction of walls to hold water in the landscape for a range of uses, including agricultural water storage, access to water for livestock, and aquaculture. They often receive high organic matter and nutrient loadings, have low oxygen levels, and exhibit substantial CH_4 emissions from anaerobic sediments. Artificial water bodies such as canals, irrigation channels and drainage ditches are also extensive in many agricultural, forest and settlement areas, and may also be significant sources of emissions in some circumstances.

Emissions of CO_2 from human-made water bodies, including ditches, canals, farm ponds, pastures and aquaculture ponds, are primarily the result of decomposition of soil organic matter and other organic matter within the water body or entering the water from the catchment, as well as from biological components (e.g. fish). No guidance is provided in this section on these emissions because they are either accounted for elsewhere (e.g. as soil carbon loss) or reflect short-term carbon cycling by the aquatic biota.

Emissions of CH_4 are primarily the result of new methanogenic production of CH_4 induced by anoxic conditions in the sediment. CH4 emissions are generally higher in water bodies with high organic matter loading and low oxygen status. Due to their high emission rates and large numbers, small ponds of area < 0.1 ha have been estimated to generate 40% of diffusive CH_4 emissions from open waters globally (Holgerson and Raymond, 2016). Whilst emissions from natural ponds can (at least in part) be considered natural, those from small constructed ponds cannot. High organic loadings and low oxygen levels can also occur in drainage ditches (Evans et al., 2016), agricultural ponds (e.g. Selvam et al. 2014), aquaculture ponds (Vnimelch and Ritvo 2003) and flooded pastures (Kroeger et al. 2017). Emissions from human-made waterbodies may exceed those from small natural waterbodies where nutrient loadings from agriculture or other sources are high (Yang et al. 2017), and may equal or exceed those observed in small lakes and reservoirs (Bastviken et al. 2010). Emissions from aquaculture ponds may be reduced where mixing or aeration occurs as part of aquaculture management (e.g. Vasanth et al. 2016, Yang et al. 2017). Because CH_4 emissions from artificial water bodies can be considered a direct consequence of the construction of that water body, guidance on reporting these emissions is provided in this chapter.

Flooded Lands Excluded Here, But Considered Elsewhere

Some rice paddies are cultivated through flooding of land, but because of the unique characteristics of rice cultivation, rice paddies are addressed in Chapter 5 (Cropland), Volume 4. Emissions from wetlands created or used for waste water treatment are considered in Chapter 6 of the Wetland Supplement (Constructed Wetlands for waste water treatment) and not considered in this chapter. Flooded pastures are formed from hydrological modifications that result in the creation or expansion of open water areas within a landscape and are significant sources of emissions (Kroeger et al. 2017). Flooded pastures may be coastal or inland, on mineral or organic soils. Guidance is provided in the Wetland Supplement for flooded pastures on land classified as either grasslands or wetlands on either organic or mineral soils.

Nitrous oxide emissions

Nitrous oxide emissions from Flooded Lands are largely related to input of organic or inorganic nitrogen from the watershed. These inputs from runoff/leaching/deposition are largely driven by anthropogenic activities such as land-use change, wastewater treatment or fertilizer application in the watershed. The current section will not consider these emissions in order to avoid double-counting of N_2O emissions already captured in other source categories, such as N_2O from managed soils (see Chapter 11, Volume 6) and wastewater management (see Chapter 6, Volume 5).

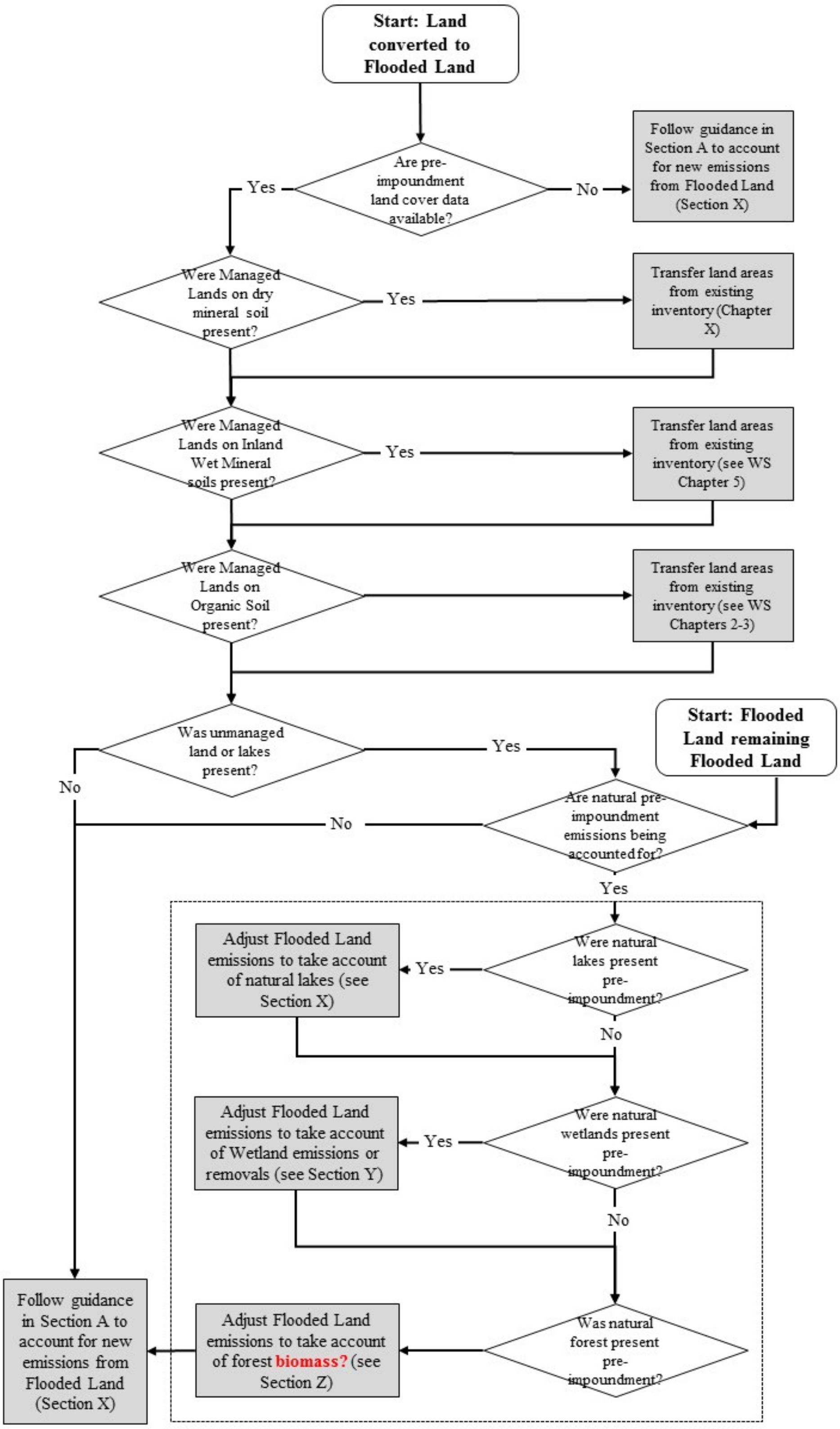
Nitrous oxide emission from aquaculture ponds constructed on coastal wetlands are given in Chapter 4 of the Wetland Supplement (Coastal Wetlands). CO_2 emissions from soils underlying aquaculture ponds built on coastal wetlands are described in Chapter 4 of the Wetland Supplement (Coastal Wetlands).

Decision tree for choice of method, activity data and emission factors

A decision tree is provided to facilitate guidance for choice of methods, activity data and emission factors (Figure 7.2). The tree highlights critical decisions guiding the inventory compilers through the processes of selecting an appropriate approach to estimate CH_4 emissions for *Flooded Land Remaining Flooded Land* and for *Land Converted to Flooded Land*. Tier selection and the level of spatial and temporal disaggregation will depend upon the availability of activity data and emission factors, as well as the importance of Flooded Lands as an emission source based on the key category analysis for a country's national greenhouse gas inventory.

The dotted lines in the Decision Tree shows were the choice of method deviates from the Managed Land Proxy as it this pathway enables compilers to account the possibilities of factoring out of emissions and removals that would otherwise occur in the absence of the flooded area. This is further described in Annex 7.1. Country-specific scientific evidence and data are always preferable to Tier 1 default data.

Figure 7.2 Decision tree to estimate CO_2 and CH_4 emissions from *Flooded Land remaining Flooded Land* and *Land Converted to Flooded Land*. The dotted lines in the Decision Tree shows were the method deviate from the Managed Land Proxy as it takes into account the possibilities of factoring out of emissions and removals that would otherwise occur in the absence of the flooded area. This is further described in the respective chapters and Annex 7.1. Country-specific scientific evidence and data are always preferable to Tier 1 default data.



7.3.1 Flooded Land Remaining Flooded Land

This section provides new *guidance*.

7.3.1.1 CO_2 EMISSIONS FROM LAND REMAINING FLOODED LAND

This section provides new guidance.

Initial effects of flooding can cause extra CO_2 emissions (see section 7.3). After this initial phase, the CO_2 emitted from flooded land is largely derived from carbon input from the catchment, and are accounted for elsewhere as emissions linked to lateral carbon fluxes. Therefore, no methodologies to report CO_2 emissions for *Flooded Land Remaining Flooded Land* are provided as it is assumed that any CO_2 emissions that are occurring result from C losses in the watershed that are already covered by methodologies in other land use sectors (i.e., forest land, cropland, grassland, settlements).

7.3.1.2 NON-CO_2 EMISSIONS FROM FLOODED LAND REMAINING FLOODED LAND

This section provides new guidance.

RESERVOIRS

Choice of Method

Methodology is provided for estimating CH_4 emissions from reservoirs > 20 years old. Tier 1 methodology includes diffusive and ebullitive CH_4 emissions from reservoirs over differing climate zones (Total $CH_{4\ (reservoir)}$). This method also includes adjustments for the area of flooded land prior to reservoir construction (see Decision Tree Figure 7.1) and degassing of CH_4 downstream of the reservoir. If CH_4 emissions from reservoirs are a key category, then it is good practice for the compiler to develop country-specific emission factors with application of a Tier 2 method to reduce overall uncertainty. Guidance on the development of country-specific factors and methods is provided below in the Tier 2 and 3 sections. For reservoirs < 20 years old, see section 7.3.2.3, within *Land Converted to Flooded Lands*.

Tier 1

A Tier 1 approach to calculate CH4 emissions from Flooded Lands Remaining Flooded Lands (flooded > 20 years prior to inventory):

EQUATION 7.10
ANNUAL CH_4 EMISSIONS FOR RESERVOIRS >20 YEARS OLD (*FLOODED LAND REMAINING FLOODED LAND*) AND < 20 YEARS OLD (*LAND CONVERTED TO FLOODED LAND*)

$$Total\ CH_4 = \sum_{1}^{i} Es_i \bullet (A_{i-flood} - A_{i-preflood} + R_{dgas} \bullet A_{i-flood})$$

Where:

Es_i = annual areal flux of methane from a reservoir surface in kg CH_4-C ha^{-1} yr^{-1}, which is the sum of diffusive and ebullitive CH_4 emission pathways disaggregated by climate zone (Table 7.8 - *Emissions factors table*)

$A_{i\text{-}flood}$ = area of flooded land after dam construction (ha) by climate zone

$A_{i\text{-}preflood}$ = area of land inundated prior to dam construction (ha) by climate zone, when unknown assumed to be zero

R_{dgas_i} = is the ratio of total degassing flux of methane (kg CH_4-C yr^{-1}) to the flux of methane from a reservoir's surface, from turbines and the downstream river, to the atmosphere (kg CH_4-C yr^{-1}) (Table 7.9 - a lookup table with R_{dgas} by climate zone)

Tier 2

CH_4 emissions from individual reservoirs can be estimated more accurately by application of the Greenhouse Gas Reservoir Tool (G-res) model with reservoir-specific data covering: reservoir morphometry, littoral vegetation, and local climate data including temperature and solar radiation. G-res is described in Annex 7.1.

Tier 3

Direct measurement of CH_4 fluxes across the reservoir surface provide the most accurate alternative to the Tier 1 and Tier 2 approaches. It is good practice to undertake measurements at sufficient different locations to capture the spatial variability of CH_4 emissions from a reservoir. CH_4 emissions are often highly spatially variable with 50-90 % of total reservoir emissions emanating from 10-30% of a reservoir's surface. Accuracy is improved when measurements are undertaken across a full seasonal cycle because methane dynamics are very temperature sensitive. The measurement data should be aerially weighted and seasonally averaged to provide the most accurate estimate of emissions from the reservoir as a whole. (See Annex 7.1 for details).

Choice of Emission Factors

Tier 1

CH_4 Emission Factor for Reservoirs (Es) are emission factors for CH_4 via diffusion and ebullition pathways, and from downstream emissions. Table 7.8 provides measured emissions for climate zones. To the extent possible given available research, these measured emissions integrate spatial (intra reservoir and regional variations) and temporal variations (dry/rainy and other seasonal, inter-annual variations) in the emissions from reservoirs (See Annex 7.1 for further explanations). When default data are not available, countries should use the closest default emission factors value (emissions of the most similar climatic region).

Table 7.8

CH_4 EMISSIONS FOR RESERVOIRS – DRAFT ONLY

Climate	CH_4 Emissions **Es** (kg C-CH_4 ha^{-1} $year^{-1}$)					References
	Mean	Upper 95% CI, % of the mean	Lower 95% CI, % of the mean	N_m	N_{res}	
Boreal	TBA					
Cool Temperate	TBA					
Warm temperate dry	TBA					
Warm Temperate moist	TBA					
Tropical dry/montane	TBA					
Tropical moist/wet	TBA					

The values in the second column are medians of CH_4 emissions reported in the literature, which themselves are arithmetic means of fluxes measured from individual reservoirs. The means are used because the frequency distributions of underlying flux measurements are not normal, and their arithmetic means are already skewed by extreme values. Nm = number of measurements; Nres = number of reservoirs sampled. TBA – to be updated based on the literature provided in Annex 7.1.

TABLE 7.9

RATIO OF TOTAL DEGASSING FLUX OF METHANE (KG CH_4-C HA $^{-1}$ YR^{-1}) TO THE FLUX OF METHANE FROM A RESERVOIR'S SURFACE TO THE ATMOSPHERE (KG CH_4-C HA $^{-1}$ YR^{-1}) – RDGAS

Climate zone	Rdegas
Boreal	TBA
Cool temperate	TBA
Warm temperate dry	TBA
Warm temperate moist	TBA
Tropical dry/montane	TBA
Tropical moist/wet	TBA
Note: TBA – to be updated based on the literature and analyses provided in Annex 7.1.	

Tier 2

Under Tier 2, country-specific emission factors are developed that may account for factors including size and depth of reservoir, environmental and management factors.

Additional estimates of winter emissions and CH_4 bubble emissions are also needed, which will require the development of country-specific emission factors. It is anticipated that a mix of default values and country-specific emission factors will be used when the latter do not cover the full range of environmental and management conditions. The development of country-specific emission factors is discussed in Annex 1. The derivation of country-specific factors should be clearly documented.

Tier 3

Under Tier 3, emission factors derived from mechanistic or statistical models are used instead of the default equations and/or default factors (see Annex 1). Additional estimates of winter emissions and CH_4 bubble emissions could also be included at the Tier 3 level, which will require the development of reservoir or regional emission factors. It is anticipated that a mix of country-specific emission factors and modelled values will be used when the latter do not cover the full range of environmental and management conditions. The development of reservoir or region-specific emission factors that are influenced by eutrophication are discussed below. The derivation of reservoir or region-specific factors should be clearly documented.

Eutrophication and GHG emissions from flooded lands

Flooded lands with high inputs of nutrients and high rates of biological production (eutrophic systems) generally emit methane to the atmosphere more rapidly on a per-area basis than less productive (meso- or oligotrophic) systems. This relationship is seen in meta-analyses examining fluxes from many reservoirs (Narvenkar et al., 2013, Deemer et al., 2016), and a positive relationship between local primary production and methane emission has also been demonstrated in laboratory assays using sediments from individual lakes (West et al., 2015). One plausible explanation for this relationship is that eutrophic systems tend to promote anaerobic conditions, which is required for methane production (which also inhibit methane consumption), more often than meso- or oligotrophic systems. Therefore, when possible, we recommend that countries include an estimate of trophic status in their estimates of reservoir CH_4 emissions. Trophic status designation is generally achieved using either total phosphorus or chlorophyll *a* data and latitude-specific classification cut-offs (Cunha et al. 2013).

One recent review of available data found that, on average globally, per-area CH_4 fluxes are 8.0 times higher for eutrophic reservoirs than for mesotrophic reservoirs, which in turn have CH_4 fluxes that are, on average, 1.7 times as high as those from oligotrophic systems (Deemer et al., 2016). If a country has characterized the trophic status of its reservoirs, a compiler can improve estimates of CH_4 emissions from these systems by multiplying default CH_4 emission factors (from Table 7.1) for eutrophic systems by 8 and default CH_4 emission factors for oligotrophic systems by 0.6. If sufficient data are available locally to determine a country-specific relationship between trophic status and CH_4 fluxes, then local values should be used in equation 7.8 rather than these global averages. A more involved, but generally more accurate approach can be applied in regions where reservoir chlorophyll *a* concentrations [Chl *a*] have been measured. Here compilers can use the observed linear relationship between ln ([Chl *a*]) and ln (CH_4 emissions; Annex Fig. x.2) to scale standard emissions factors to [Chl *a*], using the equation:

EQUATION 7.11

EQUATION USED TO SCALE CH4 EMISSION FACTORS FOR THE INFLUENCE OF EUTROPHICATION USING MEASURED VALUES OF CHLOROPHYLL A

$$EF_{correction} = \frac{(e^{(0.98*ln(chla)+1.86)}-1)}{22.84}$$

Where:

$EF_{correction}$ is a correction factor applied to the recommended emission factor by multiplication, *chla* is chlorophyll *a* concentration in ug L^{-1}, *ln* is the natural log, and *e* is Euler's number.

Some have suggested that eutrophication can enhance CO_2 uptake and burial (Pacheco et al., 2015), but there is no evidence that this occurs consistently, and, when it does occur, the magnitude of this effect is generally much smaller on CO_2 than that of eutrophication's effect on CH_4 emissions (Deemer et al., 2016).

Choice of Activity Data

Several different types of activity data may be needed to estimate flooded land emissions, depending on the Tier and the known sources of spatial and temporal variability within the national territory.

Tier 1

Flooded land area

Country-specific data on area of reservoirs within each climate zone are required to estimate diffusive and bubble emissions from flooded lands. Estimates of flooded land area for reservoirs can be obtained from the International Commission on Large Dams (ICOLD, 1998) or from the World Commission on Dams report (WCD, 2000).

Tier 2

Estimates of flooded land area for reservoirs can be obtained from a drainage basin cover analysis or from a national dam database. Since flooded land area could change over time, countries should use updated and recent data from national databases in order to obtain more accurate emission estimates. Reservoir databases could include mean area, min area, max area, area variation over time, mean and max depths of the reservoir basin, depth change over time, year of flooding, and reservoir location.

Tier 3

Estimates of emissions can be more accurate if they incorporate degassing emissions from outflow areas and spillways of reservoirs. Such estimates can be calculated using a CH_4 mass balance that requires knowledge of CH_4 concentrations in the reservoir at the level of the outlet (outflow) and at the surface (spill) and in the river downstream of the dam.

Outflow/Spillway volume

Reservoir discharge data are required. These data are typically available from dam operators.

CH_4 concentrations upstream and downstream of dams

Under Tiers 2 and 3, CH_4 concentrations upstream and downstream of dams are needed for estimating degassing emissions. Information on how to measure these data can be obtained from the references cited in Annex 7.1.

OTHER HUMAN-MADE WATER BODIES (DITCHES, CANALS, AGRICULTURAL PONDS, AQUACULTURE PONDS)

The procedure presented here expands the methodology developed for quantifying CH_4 emissions from drainage ditches in organic soils for the 2013 Wetland Supplement (IPCC, 2014), to include all other human-made waterbodies. The approach described here allows for the reporting of emissions from human-made ponds and channels as Flooded Land. Inventory compilers may also choose to 'embed' emissions from small channels such as drainage ditches within their reporting of other Managed Land categories (applying the methodology described here, together with Equation 2.6 of the Wetland Supplement[1]). The same emissions should however not be included in both categories.

[1] Note that the approach described to account for ditch CH_4 emissions in the Wetland Supplement combined these emissions with those from adjacent terrestrial areas, to provide a single emission estimate. Implicitly, this considered ditches to form part of the terrestrial land-use category, rather than as a separate Flooded Land category.

Choice of Method

Methodology is provided for estimating CH_4 emissions from constructed water bodies, which include ditches, aquaculture ponds and agriculture ponds. If CH_4 emissions from other constructed water bodies are a key category, then it is good practice for the compiler to develop country-specific emission factors with application of a Tier 2 method or develop a country specific method with a Tier 3 approach to reduce overall uncertainty. Guidance on the development of country-specific factors or methods are provided below in Tier 2 and Tier 3 approaches.

Tier 1

The Tier 1 method extends the methodology developed for quantifying CH_4 emissions from drainage ditches in organic soils for the 2013 Wetland Supplement (IPCC, 2014, Section 2.2.2.1) to include a wider range of human-made waterbodies.

Total emissions are calculated for a given waterbody type using Equation 7.3.

EQUATION 7.12

ANNUAL CH_4 EMISSION FROM HUMAN-MADE PONDS AND CHANNELS

$$CH_{4\_Other\ human-made} = \sum_{w,c,n} \left(A_{w,c,n} \bullet EF_{CH_4\_w,n} \bullet Fn \right)$$

Where:

$CH_{4\_other\ human\text{-}made}$ = Annual CH_4 emission from constructed ponds and channels, kg CH_4 yr^{-1}

$A_{w,c,n}$ = Area of small constructed waterbody of type *w*, ha

$EF_{CH_4\_w,c,n}$ = Emission factor for CH_4 emission for water type *w* and nutrient status *n*, kg CH_4 ha^{-1} yr^{-1}

Fn = Multiplier to take account of nutrient status, dimensionless.

Tier 2

The Tier 2 approach for CH_4 emissions from human-made ponds and channels incorporates country-specific information in Equation 7.3 to estimate the emissions. Tier 2 emission factors may be further stratified by sub-classifying waterbodies according to type (w) and nutrient status (n). In addition, it may be possible to incorporate additional modifiers such as soil type (e.g. mineral versus organic); water flow rate; presence of emergent vegetation (which may increase emissions) and species (for aquaculture); or take account of site management activities that may increase or decrease overall CH_4 emissions (e.g., controlling organic matter loadings or aeration, including pond drainage).

Tier 3

A Tier 3 approach for constructed ponds and channels used for agricultural purposes may take account of soils and land-use within the catchment area of each waterbody as controls on organic matter and nutrient inputs. It could also disaggregate the different components of CH_4 emissions (diffusive flux across the water surface, ebullition and plant-mediated emissions) and the associated controlling factors in order to provide more site-specific emission estimates. Compilers may also consider within and between-year variation in emissions as a function of climatic or land-management variability, or maintenance activities such as dredging. Tier 3 approaches are likely to require the development of a process-based model to address these additional variables and activities influencing emissions. For aquaculture ponds, Tier 3 approaches could also include models incorporating management practices (e.g. species, yield, aeration, drainage regimes).

Choice of Emission Factors

Tier 1

Tier 1 emission factors for human-made ponds and channels are provided in Table 7.4. At present, available data are not sufficient to derive emission factors for agricultural ponds and agricultural ditches by climate zone. Further disaggregation by surrounding land-use, nutrient loading and/or yield is not currently possible, but these variables can be addressed in a Tier 2 analysis. For ditches in organic soils, the Tier 1 emissions factors presented in Table 2.4 of the Wetland Supplement may be used.

Table 7.10
Default CH_4 emission factors for human-made ponds and channels

Waterbody type	Climate zone	EF_{CH4} (kg CH_4 ha^{-1} yr^{-1})	Uncertainty 95% confidence intervals as a % of the mean	No. of sites	References
Aquaculture ponds	All	354	423	32	See Annex 7.1
Agricultural ponds	All	347	298	49	See Annex 7.1
Agricultural ditches	All	722	204	27	See Annex 7.1

The values are means of CH_4 emissions reported in the literature, which themselves are arithmetic means of fluxes measured from individual studies. Arithmetic means are often skewed by extreme values associated with ebullition. The uncertainty range are the 95% confidence intervals and are provided as an indication of variability. Number of sites are provided. Values for Agricultural ditches is the mean from Table 2.4 of the Wetlands Supplement.

Tier 2

At Tier 2, country-specific emission factors may be further stratified according to waterbody type, nutrient status or other potential explanatory factors (e.g. management practices or yield for aquaculture), as described in the preceding section.

Tier 3

To develop a model-based Tier 3 approach for human-made flooded lands used for agricultural purposes, additional empirical data are needed to define relationships between each component of the CH_4 emission and the relevant explanatory variables. These could include the effects of temperature, organic matter and nutrient supply on CH_4 production; effects of salinity, water depth and flow on methane oxidation within the water column; relationships between sediment composition and bubble production; and influence of vegetation type and cover on plant-mediated emissions.

Choice of Activity Data

All human-made ponds and ditches are assumed to emit CH_4 at a constant rate for as long as the land remains flooded. However, they may move between emission categories as a function of changes in site factors if higher tier approaches are applied. Activity data consist of the total area of (non-reservoir) constructed waterbodies, stratified according to the waterbody type and any additional factors used to disaggregate emissions. Since flooded land area could change over time, countries should use updated and recent data. Tier 2 and Tier 3 approaches are preferably based on a national database to track flooded land surface area in order to obtain more accurate emission estimates. For aquaculture ponds, additional data on product yields from ponds or management could be collected and related to CH_4 emissions to derive more accurate emission estimates.

Tier 1

Activity data required to support Tier 1 reporting are either complete mapping data for all constructed waterbodies, or alternatively a reliable estimate of the proportion of land area occupied by each waterbody type. For agricultural ponds, it may be possible to evaluate small representative areas within a larger land category in order to estimate the total proportion (and therefore total area) of ponds present. In many cases, drainage occurs at regular spacing within agricultural landscapes, such that the proportion of ditches in an area ($Frac_{ditch}$) can be estimated from data on mean ditch width and spacing, as described in Section 2.2.2.1 of the Wetland Supplement. For irregularly distributed ditches or other human-made channels such as canals, it may be possible to estimate overall extent and area by digitizing or estimating total channel length within representative areas. For area of aquaculture ponds, estimates of area are available from FAO (http://www.fao.org/fishery/statistics/global-aquaculture-production/en).

Tier 2

Additional activity data required to apply a Tier 2 approach are likely to include information on waterbody distribution (e.g. from remotely sensed imagery), waterbody type, nutrient status, flow rates, vegetation and other factors as described in the Choice of Method section. For aquaculture ponds national databases of pond area or yields, disaggregated by region or species cultivated could be used.

Tier 3

Tier 3 approaches could include dynamic modelling of emissions with models that are adequately evaluated from monitoring of greenhouse gas concentrations and fluxes in representative systems. Additional activity data required to apply a Tier 3 approach are likely to include information on waterbody distribution from remotely sensed imagery, waterbody type, nutrient status, flow rates, vegetation and other factors as described above. National level information capturing the effect of pond management (e.g. drainage, Yang et al. 2015) or activity (Gusmawati et al. 2017) may also be appropriate to use with a Tier 3 method.

7.3.2 Land Converted to Flooded Land

This section provides new guidance.

7.3.2.1 CO_2 EMISSIONS FROM LAND CONVERTED TO FLOODED LAND

RESERVOIRS

The time elapsed since flooding has a significant influence on greenhouse gas fluxes from flooded lands and also on the partition of the gases. Recent statistical analyses on reservoirs worldwide indicate that there is a rapid surge of emissions immediately following flooding, after which emissions return to a relatively stable level (Tremblay *et al.*, 2005; Therrien *et al.*, 2005; Soumis *et al.*, 2005; and Huttunen *et al.*, 2002, 2003). The rate of the post flooding decrease in emissions may depend on the region in which a reservoir is located, but seems to vary in about a 10-year period (Delmas *et al.*, 2005; Abril *et al.*, 2005; Tremblay *et al.*, 2005).

Evidence suggests that CO_2 emissions for approximately the first ten years after flooding are the results of decay of some of the organic matter on the land prior to flooding. The easily degradable carbon and nutrients are made available to producer organisms upon flooding and metabolized. Beyond this time period, CO_2 emissions are sustained by the decomposition of organic matter in soils and the input of organic material transferred into the flooded area from the watershed (Houel, 2003; Hélie, 2004; Cole and Caraco, 2001). To avoid double-counting of CO_2 emissions, which may already been captured in the greenhouse gas budget of managed lands in the watershed and in the absence of conclusive evidence on the longer term impact of flooding on these emissions, the default methodology only considers the first 20 years of post-flooding for estimating CO_2 emissions.

Conversion of lands to flooded land is a disturbance that affects all five terrestrial C pools in the area impounded (above-ground biomass, below-ground biomass, litter, dead wood and soil organic matter; see 2006 IPCC GL - Fig. 2.1). The 2006 IPCC GL and 2013 Wetlands Supplement, in addition to Chapter 4 of this volume give guidance on how to estimate the five carbon pools in the lands to be flooded, and harvested wood products (HWP). This Chapter gives new guidance on emissions related to the land use conversion and the subsequent emissions from the newly flooded land.

Since reporting of flooded land may be a new reporting category for countries, refer to 2006 IPCC GL –Volume 1, Chapter 5 indicates how to recalculate the inventory time series.

The amount and fate of flooded biomass depends largely on management decisions prior to flooding. The biomass may be partly or totally removed or burned prior to flooding, or left in the impoundment. Carbon stock changes in the 5 pools that occur prior to *Land Converted to Flooded Land* (LCF) (2006 IPCC GL V4 Ch. 2) need to be taken into account using the 2006 IPCC Guidelines and Chapter 2 of this volume (Equation X.X).

In addition, unmanaged land such as peatland, water bodies and other land cover types not considered as managed land may be converted to flooded land (see Decision tree in Section 7.3.1). This guidance describes methods for reporting emissions from each land use / land cover type converted to flooded land.

Choice of Method

There are alternative methodologies for estimating CO_2 emissions from newly flooded lands (<20 years old). Methodologies can utilize C stock estimates using existing IPCC methodologies when possible.

It is likely not possible to draw data from scientific literature on how much C is lost from all land use / land cover types when converted to flooded land. It is also not possible to know the proportion of each of the organic C pools listed above in equation 7.3 that is contributing to the surge of emissions immediately following flooding, before emissions return to a relatively stable level. The most important factors considered for estimating on-site CO2 emissions upon conversion to flooded lands are climate and land use. Therefore, the Tier 1 methodologies developed in this chapter are based on these factors. The scientific background for the approach is described in Annex 7.1.

Tier 1

The basic methodology for estimating annual carbon loss as $CO_2\text{-}C_{fl}$ on recently flooded land (<20 years old) is specified in Equation 7.13.

EQUATION 7.13
ANNUAL ON-SITE CO_2-C EMISSIONS/REMOVALS FROM NEWLY FLOODED LAND

$$CO_2\text{-}C_{fl} = \Sigma_c (A_i * EF)_c$$

Where:

$CO_2\text{-}C_{fl}$ = Annual on-site CO_2-C emissions/removals from newly flooded land, tonnes C yr^{-1}

A_i = area of newly flooded land, ha

EF = Emission factors for flooded inland organic soils, by climate domain c, tonnes C ha^{-1} yr^{-1}, (Table 7.11-emissions factor table)

Guidance on CO_2 emissions from removal of mangrove and tidal marsh vegetation for aquaculture is given in the Wetland Supplement.

Tier 2

Tier 2 methods for determining annual CO_2 emissions/removals from newly flooded land would include knowledge of country and climate zone emission factors in equations 7.12. Tier 2 uses the same procedural steps for calculations as provided for Tier 1. Improvements to the Tier 1 approach may include: 1) a derivation of country-specific emission factors; 2) specification of climate sub-domains considered suitable for refinement of emission factors; 3) a finer, more detailed classification of management systems with a differentiation of pre-flooding land-uses; 4) differentiation of emission factors by time since flooding, 6) a finer, more detailed classification of nutrient status, e.g. by nitrogen, phosphorus or pH.

It is *good practice* to derive country-specific emission factors if measurements representing the national circumstances are available. Countries need to document that methodologies and measurement techniques are compatible with the scientific background for Tier 1 emission factors in Annex 7.1. Moreover, it is *good practice* for countries to use a finer classification for climate and management systems. Note that any country-specific emission factor must be accompanied by sufficient national or regional land-use/management activity and environmental data to represent the appropriate climate sub-domains and management systems for the spatial domain for which the country-specific emission factor is applied.

Tier 3

CO_2 emissions/removals at Tier 3 would use detailed data of soil carbon and other remaining carbon pools prior to flooding and time series of CO_2 emissions after flooding for a range of reservoirs that encompass an appropriate range of environmental conditions. Details are discussed in Annex 7.1.

Choice of Emission Factor

Tier 1

CO_2 emission factors for flooded soils are provided for land flooded in different climate zones (Table 7.11).

Table 7.11
CO_2 Emission factors for soils after flooding of land. DRAFT ONLY – to be updated

Climate / Vegetation Zone	Soil Emission Factor (t CO_2-C ha^{-1} a^{-1}) for 20 years post-flooding	95% Confidence Interval (as a % of the mean)		Std error	No. Sites	Citations
Boreal	TBA					
Cool temperate	TBA					
Warm temperate dry	TBA					
Warm temperate moist	TBA					
Tropical dry/montane	TBA					
Tropical wet/moist	TBA					

Note. TBA to be updated. For data sources see Annex 7.1.

Tier 2

The Tier 2 approach for CO_2 emissions/removals from flooded land incorporates country-specific information with derivation of country-specific emission factors. The compiler may address other drivers of emissions including: 1) specification of climate sub-domains considered suitable for refinement of emission factors; 2) a finer, more detailed classification of management systems… 3) time-series data that incorporates seasonal variation in CO_2 emissions/removals.

Tier 3

Tier 3 method explicitly address the pre-flooding management of flooded land its impact on CO_2 emissions following flooding with process-based modelling and/or measurement-based approaches. These factors are discussed in Annex 7.1.

Choice of Activity Data

Tier 1

Areas of newly flooded lands are available from dam operators such as hydropower companies. In many cases recent impoundments have been extensively described in Environmental Impact Assessment (EIA) documents of specific projects. Those documents are often publicly available. In absence of such information sources, satellite images and aerial images taken during the past 20 years are commonly available and allow determination of flooded land areas by comparison of pre-impoundment and post-impoundment images.

Tiers 2 and 3

Tier 1 methods can be used for determining the areas of flooded lands. When more accurate management systems are identified with pre-impoundment land use characteristics of the flooded land, such information could be derived from project specific EIA documents, forest surveys from the pre-impoundment period, or remote sensed land cover assessments.

Many countries also monitor water quality parameters from watercourses under impact of management activities. Those include industrial effluents, mining, land drainage, wastewater treatment etc. In best cases time series of water quality parameters are available in national registers for over 20 years and may be useful for applying Tier 3 emission factors differentiated by those parameters.

OTHER HUMAN-MADE WATER BODIES (DITCHES, CANALS, FARM PONDS AND AQUACULTURE PONDS)

No methodologies are provided as there is insufficient CO_2 emission data for most constructed water bodies to quantify the impact of other constructed water bodies. However, compilers may estimate CO_2 emissions for coastal wetlands when they are converted to aquaculture ponds based on guidance in the Wetland Supplement (Chapter 4, Coastal Wetlands).

7.3.2.2 NON-CO_2 EMISSIONS FROM LAND CONVERTED TO FLOODED LAND

This section provides new guidance.

RESERVOIRS

In reservoirs, high levels of CH_4 emissions can occur in the first 20 years following inundation. Empirical data are available demonstrating in some reservoirs there is an exponential decline in CH_4 emissions following inundation, however there is insufficient data to provide emission factors that reflect this process (see Annex 7.1). The inventory compilers should use equations and emission factors provided in section 7.3.1 (*Flooded Land Remaining Flooded Land*, Refer to equation 7.10) to estimate CH_4 emissions from flooded lands.

Choice of Method

Tier 1

For Tier 1 Guidance refer to section 7.3.1 Non-CO_2 emissions from *Flooded Land Remaining Flooded Land*.

Tier 2

For Tier 2 Guidance refer to section 7.3.1 Non-CO_2 emissions from *Flooded Land Remaining Flooded Land*.

Tier 3

For Tier 3 Guidance refer to section 7.3.1 Non-CO_2 emissions from *Flooded Land Remaining Flooded Land*.

Choice Emission Factors

For Guidance refer to section 7.3.1 Non-CO_2 emissions from *Flooded Land Remaining Flooded Land*

Choice of Activity Data

Several different types of activity data may be needed to estimate emissions from *Land converted to Flooded Land*, depending on the Tier and the known sources of spatial and temporal variability within the national territory.

Flooded land area

Country-specific data on flooded land area are required for all tiers to estimate diffusive and bubble emissions. Alternatively, countries can obtain an estimate of their flooded land area for reservoirs from a drainage basin cover analysis, from a national dam database, from the International Commission on Large Dams (ICOLD, 1998) or from the World Commission on Dams report (WCD, 2000). Since flooded land area could change rapidly, countries should use updated and recent data. Tier 2 and Tier 3 approaches preferably rely on a national database to track flooded land surface area. For reservoirs databases may also include other parameters such as mean area, min area, max area, some descriptors of how area vary over time, reservoir mean and max depths of the reservoir basin, some descriptors of how the depth change over time, year of flooding and reservoir location.

Outflow/Spillway volume

Under Tiers 2 and 3, flooded land outflow and spillway volume are required to estimate degassing emissions of CH4.

CH4 concentrations upstream and downstream of dams

Under Tiers 2 and 3, CH4 concentrations upstream and downstream of dams would be needed for estimating degassing emissions. Information on how to measure these data can be obtained from the references cited in Annex 7.1.

HUMAN-MADE WATER BODIES (DITCHES, CANALS, FARM PONDS, AQUACULTURE PONDS)

No methodologies are provided as there is insufficient information to derive emission factors.

7.3.3 Uncertainty Assessment

This section has further elaboration of methods.

The two largest sources of uncertainty in the estimation of CH_4 emissions from Flooded Land are the quality of emission factors for the various pathways (diffusive, bubble and degassing) and estimates of the flooded land areas.

For reservoirs, national statistical information on the flooded area retained behind large dams (> 100km^2) should be available and will probably be accurate to within 10 percent. Where national database on dams are not available, and other information is used, the flooded land areas retained behind dams will probably have an uncertainty of more than 50 percent, especially for countries with large flooded land areas. Detailed information on the location, type and function of smaller dams may be also difficult to obtain, though statistical inference may be possible based on the size distribution of reservoirs for which data are available. Reservoirs are created for a variety of reasons that influence the availability of data, and, consequently, the uncertainty on surface area is dependent on country specific conditions. Uncertainty in biomass stocks is discussed in Chapters 4, 5 and 6.

Emission factors

As shown in Table 7.2, average diffusive emissions can vary by an order of magnitude in boreal and temperate regions, and by one to three orders of magnitude in tropical regions. The same variability in bubble emissions is observed in all regions (about one order of magnitude). Therefore, the use of any default emission factor will result in high uncertainty as reflected in the 95% confidence intervals and discussed in Annex 7.1.

CH_4 degasssing emissions occur primarily when hypoxic and methane-rich hypolimnetic water is withdrawn from a reservoir and passed through the dam structure, including turbines in hydropower reservoirs, and discharged to a downstream river. The magnitude of degassing emissions are therefore dependent upon both the limnology of the reservoir and engineered characteristics of the dam. For example, degassing emissions are typically negligible in cold well-oxygenated reservoirs (Diem et al. 2012) or those with epilimnetic withdrawal (Beaulieu et al. 2014), but can exceed emissions from the reservoir surface in thermally stratified systems with hypolimnetic withdrawal (Kemenes et al. 2007, Abril 2005). At the Tier 1 level, degassing emissions are estimated from Rd, defined as the average ratio of degassing to surface emissions reported by climate zone. Sources of uncertainty in Rd include differences among studies in how fluxes from the reservoir surface (i.e., diffusion only, diffusion + ebullition) and downstream components (i.e. just degassing at dam, dam degassing + downstream) were measured. Uncertainty can be reduced at the Tier 2 and 3 levels by accounting for the reservoir mixing patterns and withdrawal depths on a case-by-case basis.

To reduce the uncertainties on emissions factors, countries should develop appropriate, statistically-valid sampling strategies that take into account natural variability of the ecosystem under study. When applicable, the distinction between ice-free and ice-covered periods may be a significant improvement in accuracy (Duchemin *et al.*, 2005). Those sampling strategies should include enough sampling stations per reservoir, enough reservoirs and sampling periods. The number of sampling stations should be determined using recognized statistical approach.

Uncertainties in estimating emissions and removals from aquaculture ponds, ditches, canals and other water bodies are to a large extent derived from assumptions and uncertainties in the area to which the EFs are applied. The values for EF in Table 7.8, Table 7.10 and Table 7.11 represent global averages and have large uncertainties due to variability climate and management practices including depth of the water body, salinity of water, presence of emergent vegetation, recharge rate and for aquaculture the intensity of management, including fish feeding characteristics and pond aeration.

7.4 INLAND WETLAND MINERAL SOILS

This section provides new guidance.

For Wetlands Remaining Wetland and Land Converted to Wetlands, inventory compilers should estimate the change in carbon stocks for mineral soils. General information and guidance on estimating changes in soil C stocks are provided in Chapter 2, Section 2.3.3 (including equations), and need to be reviewed before proceeding with a consideration of specific guidelines below. Guidance is also provided in the 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands. Also, the guidance in this section is not for Flooded Lands (See section 7.3 for guidance on Flooded Lands).

7.4.1 Choice of method

Mineral soils

Tier 1

No Refinement. See 2013 Wetlands Supplement.

Tier 2

Refining Application of Default Equations

No Refinement. See 2013 Wetlands Supplement.

Three-Pool Steady-State C Model

The three-pool steady-state soil C model is based on estimating C inputs to soils and applying soil carbon pool specific decomposition rates that are modified by given environmental conditions and management practices. This model embraces more of the heterogeneity in soils, by subdividing soil C pool into different rates of turnover, i.e., fast (Active Pool), intermediate (Slow Pool), and long turnover times (Passive Pool).

Tier 3

No Refinement. See 2013 Wetlands Supplement.

7.4.2 Choice of stock change and emission factor

Mineral soils

Tier 1

No Refinement. See 2013 Wetlands Supplement.

Tier 2

Refining Application of Default Equations
No Refinement. See 2013 Wetlands Supplement.

Three-Pool Steady-State C Model

Default parameters are provided for the three-pool steady-state C pool equations (Chapter 2, Section 2.3.3.1, Table 2), but parameters may be revised if experimental data are available to test the model.

Tier 3

No Refinement. See 2013 Wetlands Supplement.

7.4.3 Choice of activity data

Mineral soils

Tier 1

No Refinement. See 2013 Wetlands Supplement.

Tier 2

Refining Application of Default Equations

No Refinement. See 2013 Wetlands Supplement.

Three-Pool Steady-State C Model

This method requires soil C input data based on the amount of biomass that is converted to dead organic matter annually. This rate will vary depending on the wetland type, management activity, and other environmental variables. Removals or reductions in dead organic matter are subtracted from the C input amount, which could occur with degradation of wetlands or fires during dry periods. Beyond the amount of C input, the average lignin and nitrogen contents of the new dead organic matter are also required to estimate the size of the three C pools.

Tier 3

No Refinement. See 2013 Wetlands Supplement.

7.4.4 Uncertainty Assessment

This section has new guidance.

Uncertainties in estimating soil C stock changes for Wetland mineral soils is due to: (i) uncertainties in land-use activity data; (ii) uncertainties in environmental variables; and (iii) uncertainties in the stock change/emission factors and other parameters for Tier 1 or 2 approaches (or equivalently for Tier 3, uncertainties due to model structure or parameter values, or in measurements with sample-based inventories). Uncertainties may be large at Tier 1 where global or nationally aggregated statistics are used for the inventory, and because of reliance on default reference carbon stocks.

7.5 COMPLETENESS, TIMES SERIES CONSISTENCY, AND QA/QC

No Refinement

~~7.6 FUTURE METHODOLOGICAL GUIDANCE~~

This section from the 2006 Guidelines is no longer relevant with the guidance provided in the 2013 Wetlands Supplement and the Flooded Lands guidance provided in Section 7.3 of this chapter.

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Annex 7.1 Estimation of Default Emission Factor(s) for greenhouse gas emissions from flooded lands

1. RESERVOIRS

1.1 Introduction

Correctly estimating the anthropogenic component of GHG emissions from reservoirs requires a careful assessment of the source and fate of reservoir carbon fluxes as such estimates are prone to double counting and inappropriate attribution of fluxes to human activity (Prairie et al. (2017a). The GHG emission factors from flooded lands presented in this methodology report are composited output from an empirical model (Prairie et al., 2017b), developed and calibrated with field measurements from diverse types of reservoirs located in various regions of the world. The model allows us to annualize emissions that are often measured over short periods (e.g. during the ice-free period for boreal systems) and account for changes in reservoir GHG activity that have been observed to occur as reservoirs age. We anticipate that the models will continue to improve over time as more measurements are made and additional models become available, but at the time of this report, the modeling approach used here represents best available scientific knowledge.

1.2 Developing Tier 1 emission factors for non-CO_2 emissions from field measurements

Recent, largely overlapping, literature compilations of field GHG measurements from over 220 distinct reservoirs (Deemer et al. 2016, Prairie et al. 2017b) form the basis of the emissions factors in Table 3. The field measurements are a mixture of diffusive CO_2, CH_4 diffusive and/or bubble emissions and, for a new but smaller subset, degassing emissions for either or both gases. The method used to estimate GHG fluxes from reservoirs is critical because different techniques can give quite different flux estimates (Schubert et al. 2012; Deemer et al., 2016), and because some techniques integrate spatial and temporal variability to different degrees (Wik et al., 2016). Flux estimates used to derive reservoir EFs in Chapter 7 were attained in a variety of ways. For CO_2, diffusive fluxes were estimated using near-surface concentrations in combination with a thin boundary layer model for the majority of systems (Deemer et al., 2016), floating chambers, or, in a minority of cases, eddy flux measurements. For CH4, diffusive fluxes were estimated using near-surface concentrations in combination with a thin boundary layer model or chamber flux measurements. Bubble fluxes of CH_4 were estimated using inverted funnel traps and echosounders. Combined bubble and diffusive CH_4 fluxes were estimated using floating chambers or eddy flux techniques, or a combination of available methods. Degassing emissions for either or both gases were available for a subset of the study reservoirs.

Deriving Emission Factors directly from the compiled data is subject to a number of assumptions that can lead to potential biases. First, it requires an assumption that sampled systems are statistically representative of overall reservoir distribution, a potentially problematic assumption given that measurement campaigns may target systems and periods in time where or when GHG emissions are high (e.g. where CH_4 bubbling is visible). Second, it assumes that sampling of reservoirs is representative in time, potentially leading to biases as there is considerable evidence that GHG emissions decrease markedly as reservoirs age (Abril et al. 2005, Barros et al. 2011, Teodoru et al. 2012, Serça et al. 2014). Lastly, using reservoir surface GHG fluxes to estimate EFs implicitly assumes that all fluxes measured from the reservoir surface would not have occurred in the absence of the reservoir. This is problematic because most aquatic systems emit GHGs as part of their natural carbon cycling processes.

The approach used here to derive the Emissions Factors from reservoirs was developed to account for these potential biases. The GHG Reservoir (G-res) model (Prairie et al., 2017b) uses empirical relationships between environmental drivers and GHG emissions to estimate reservoir GHG fluxes from a large, diverse set of reservoirs (>6000 reservoirs with global distribution). Depending on available input data, the G-res model can also be used to make Tier 2 or Tier 3 estimates.

The methodology used to develop the G-res model and its usage to estimate reservoir GHG emissions is described in more details in Prairie et al. (2017b) but, briefly, consists of the following steps:

1) Data annualization: Field sampling campaigns reported in the literature are rarely carried through the entire annual cycle. For this reason, GHG data obtained over a sub-annual time periods were annualized by taking into account the annual temperature cycle at the reservoir site and the known temperature dependence of processes leading to the production of CO_2 and CH_4.
2) Identifying relationships between Annualized Flux estimates and Environmental variables: Environmental characteristics for each reservoir where GHG fluxes have been measured were extracted using available global database (GIS layers) and used as input variables for predictive models with an elastic net variable selection procedure. This statistical analysis of the relevant data yielded the following model equations:

CH_4 diffusive emission (mg C m^{-2} d^{-1}):

$$\log_{10}\mathrm{CH}_{4-\mathrm{diff}} = 0.88 - 0.012\ \mathrm{Age} + 0.048\ \mathrm{Temp} + 0.61\log_{10}(\%\mathrm{littoral\ area}) \qquad \text{Eq. 1}$$

CH_4 bubbling emission (mg C m^{-2} d^{-1}):

$$\log_{10}\left(\mathrm{CH}_{4-\mathrm{0gbbling}}\right) = -0.99 + 0.049\ \mathrm{Cumm\ Rad.} + 1.01\log_{10}(\%\mathrm{littoral\ area}) \qquad \text{Eq.2}$$

CO_2 diffusive emission (mg C m^{-2} d^{-1}):

$$\log_{10}(\mathrm{CO}_2) = 2.035 + 0.033\ \mathrm{Temp} - 0.293\log_{10}(\mathrm{Age}) + 1.78 \cdot 10^{-3}\mathrm{SOC} + 0.706\log_{10}(\mathrm{reservoir\ area}) \qquad \text{Eq. 3}$$

Here Age is reservoir age (in years since construction), %littoral area was operationally defined as the percent reservoir surface area shallower than 3m as derived from modeled reservoir bathymetry, SOC is surface Soil Organic Carbon (0-30cm), Temp is temperature and Cumm Rad. is cumulative radiance and reservoir area, the surface area of the reservoir (km^2). Further details on the statistical analysis, the input environmental variables, their definition and sources can be found in Prairie et al. (2017b). All resulting empirical models (Eq.1 to 3) were statistically highly significant and explained between 37 and 47% of the variation in the GHG flux component (log scale).

3) Application of the models to larger database. To enhance the robustness and wider applicability of the EFs, the empirical models described above were applied to a larger database (the GranD database, Lehner et al. 2011) consisting of 6684 reservoirs with capacity >0.1Mm3 located worldwide (Fig. 1). These reservoirs are estimated to comprise collectively over 75% of the global surface area of reservoirs and are distributed in all climatic zones (Table 1). The environmental variables required by the models were extracted for each reservoir as previously and were used as inputs in Eqs.1 to 3 to estimate the various components of GHG emissions. In total, GHG emissions could be estimated for more than 6000 reservoirs worldwide.

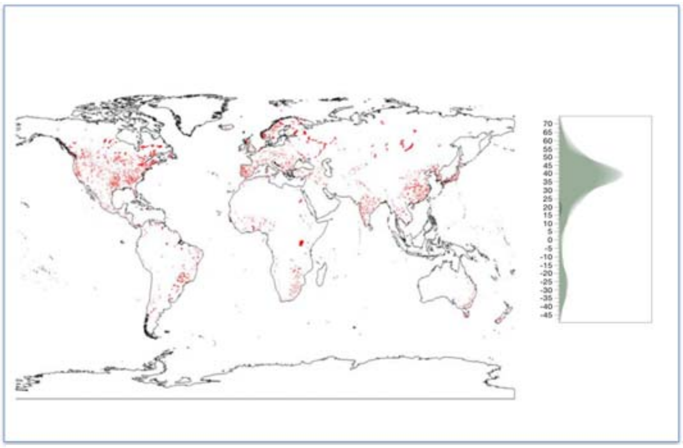

Figure A1. Location of the reservoirs in the GranD database and shadowgram of their latitudinal distribution.

Table A1. Number of reservoirs with GHG emission estimates in each IPCC climate zone.

IPCC Climate zone	N Rows
boreal dry	3
boreal moist	87
cool temperate dry	333
cool temperate moist	1746
polar moist	27
tropical dry	625
tropical moist	793
tropical montane	227
tropical wet	126
warm temperate dry	623
warm temperate moist	2072

4) Derivation of Emissions Factors:

Methane

CH4 emission is the sum of bubbling and diffusive emissions (Eqs 7.10 and 7.12). However, because the diffusive component is not constant in time but declines with age, eq. 7.10 was integrated to estimate the average annual emission over different periods. Based on the available literature, much of the initial GHG pulse occurs within the first 20 years following impoundment and this time interval was assumed to represent Lands converted to Flooded Lands. For Flooded Lands remaining Flooded Lands, the integration period was from 20 to 100 years post-impoundment. In addition to the diffusive and ebullitive emissions, CH4 released via degassing and downstream emissions are estimated as a multiplier (Rn, see Table 7.11) to the other emissions, thus yielding the following formulas:

Land converted to Flooded Land

$$\mathrm{EF} = \left[\frac{\int_0^{20} CH_{4-diff}\, dAge}{20} + CH_{4-bubbling}\right] \cdot (1 + R_n)$$

Flooded Land remaining Flooded Land

$$EF = \left[\frac{\int_{20}^{100} CH_{4-diff}\, dAge}{80} + CH_{4-bubbling}\right] \cdot (1 + R_n)$$

Rn is defined as the ratio of total CH_4 emissions (kg CH_4-C y-1) below the reservoir (i.e. degassing at the dam and emissions from the downstream river) to CH4 emissions from the surface of the reservoir (diffusion + ebullition; kg CH_4-C y-1). Downstream and degassing emissions are influenced by local climate, reservoir morphology, and design features of the dam and spillway (Deemer et al 2016). In general, these emissions will be large in thermally stratified reservoirs with anoxic, CH_4 rich bottom waters and hypolimnetic withdrawal (dos Santos et al 2017). These emissions can be further enhanced by high air-water gas exchange rates at the dam or spillway that promote the rapid evasion of CH_4 to the atmosphere before it can be oxidized to CO_2 in the downstream river (Abril et al. 2005). Accurately predicting downstream and degassing emissions requires detailed knowledge of the dam design (i.e. withdrawal depth) and operating conditions (i.e. withdrawal rates) and is beyond the scope of the Tier 1 methodology. However, these emissions can be estimated using climate zone specific Rn values reported in the literature.

Downstream and degassing emissions have received much less attention than emissions from reservoir surfaces, but have been reported for 41 reservoirs distributed across 8 of the 12 IPCC climate zones (Table 2). It should be noted, however, that reported Rn values can be biased high or low, depending on study-specific methodological details. For example, several studies assumed that all excess dissolved CH_4 (i.e. difference between actual dissolved CH_4 concentration and atmospheric equilibrium) entering the dam would evade to the atmosphere via a combination of degassing at the dam and diffusion from the river surface (Beaulieu et al. 2014, Teodoru et al. 2012). This approach will overestimate Rn because up to 85% the CH_4 that enters the downstream river can be oxidized to CO_2 (Kemenes et al. 2007). Other studies only reported degassing emissions (i.e. did not estimate downstream emissions), thereby biasing Rn low (Maeck et al. 2013). Although methodological differences can bias Rn values, the effect of methodology was not apparent in the pooled data, likely because other factors, such as the depth of water withdrawal relative to the oxycline, were more important drivers of Rn. Countries can directly measure Rn at the Tier 2 and 3 levels using the methods discussed in the references cited in Table 2.

Table A2. Reservoirs and citations for measured Rn values.

System Name	IPCC climate zone	*Citation
Eastmain-1	boreal moist	Teodoru et al. (2012)
Gruyere	cool temperate moist	Diem et al. 2012
Lake Grimsel	cool temperate moist	Diem et al. 2012
Lake Luzzone	cool temperate moist	Diem et al. 2012
Lake Sihl	cool temperate moist	Diem et al. 2012
Wohlen	cool temperate moist	DelSontro et al. 2016, Diem et al. 2012
Serrig	cool temperate moist	Maeck et al. 2013
Dworshak	cool temperate moist	Soumis et al. 2004
Lake Kariba	tropical dry	Delsontro et al. 2011
Xingó	tropical dry	dos Santos et al. 2017

Tehri	tropical montane	Kumar and Sharma. 2017
Nam Leuk	tropical moist	Chanudet et al. 2011
Nam Ngum	tropical moist	Chanudet et al. 2011
Funil	tropical moist	dos Santos et al. 2017
Itaipu	tropical moist	dos Santos et al. 2017
Segredo	tropical moist	dos Santos et al. 2017
Serra da Mesa	tropical moist	dos Santos et al. 2017
Três Marias	tropical moist	dos Santos et al. 2017
Petit Saut	tropical wet	Abril et al. 2005
Koombooloomba	tropical wet	Bastien et al. 2013
Nam Theun 2	tropical wet	Deshmukh et al. 2016, Serca et al. 2016
Tucuruí	tropical wet	dos Santos et al. 2017
Samuel	tropical wet	Guerin et al. 2006
Balbina	tropical wet	Kemenes et al. 2007, dos Santos et al. 2017
F.D. Roosevelt	warm temperate dry	Soumis et al. 2004
New Melones	warm temperate dry	Soumis et al. 2004
Wallula	warm temperate dry	Soumis et al. 2004
William H Harsha Lake	warm temperate moist	Beaulieu et al. 2014
Allatoona	warm temperate moist	Bevelhimer et al. 2016
Douglas	warm temperate moist	Bevelhimer et al. 2016
Fontana	warm temperate moist	Bevelhimer et al. 2016
Guntersville	warm temperate moist	Bevelhimer et al. 2016
Hartwell	warm temperate moist	Bevelhimer et al. 2016
Watts Bar	warm temperate moist	Bevelhimer et al. 2016
Eguzon	warm temperate moist	Descloux et al. 2017
Lisdorf	warm temperate moist	Maeck et al. 2013
Mettlach	warm temperate moist	Maeck et al. 2013
Rehlingen	warm temperate moist	Maeck et al. 2013
Saarbrucken	warm temperate moist	Maeck et al. 2013
Oroville	warm temperate moist	Soumis et al. 2004
Shasta	warm temperate moist	Soumis et al. 2004

*See references section for full citations.

5) Grouping according IPCC climate zones

The resulting 6014 estimates of CH_4 emissions (Diffusive + Bubbling) from worldwide reservoirs were then grouped according to the IPCC climate regions. A regression tree approach permitted to lump certain climate categories together based on their abilities to separate groups with different CH4 emissions. The final grouping comprised 6 climate categories (Table 2).

Table A3. Aggregated climate zones based on differences in CH_4 emissions between categories.

boreal dry boreal moist polar dry polar moist	Boreal
cool temperate dry cool temperate moist	Cool temperate
warm temperate dry	Warm temperate dry
warm temperate moist	Warm temperate moist
tropical dry tropical montane	Tropical dry/montane
tropical moist tropical wet	Tropical moist/wet

1.3 Validation of the data-model approach

Model estimations and direct measurements are not strictly comparable in that the former have been annualized and represent the integrated average annual emissions of the first 20 years post-impoundment (plus bubbling emissions). Nevertheless, it is informative to compare the central tendency and variability in CH_4 emissions among reservoirs in each of the climate zones. Both model estimations and field measurements were highly variable and positively skewed in each of the climate zone (Fig. 2). While the distribution of modeled and measured GHG emission estimates generally overlapped in each climate zone, a more direct measure of correspondence is shown by the relationship between the geometric means (on arithmetic scales) of the Field measurements versus Model estimates of CH_4 emissions (Fig. 3). These comparisons collectively provide evidence that the model estimates capture both the variability and central tendency in GHG emission rates. Furthermore, because of the large number of reservoirs in each climate zone, the model estimates can provide more stable Emissions Factors for each climate zone.

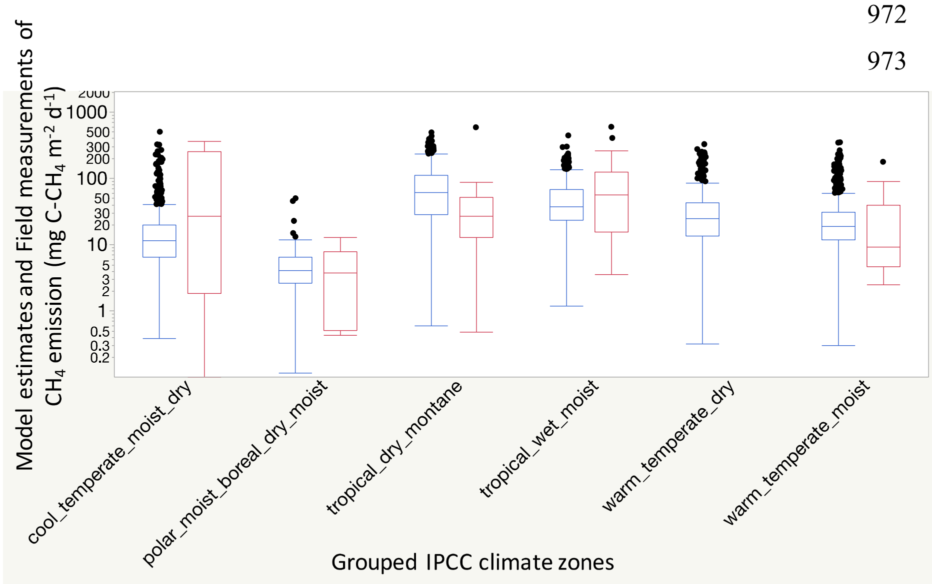

Figure A2. Box plots of model estimates (blue) and Field measurements (red) of CH_4 emissions (note logarithmic scale) in IPCC climate zones.

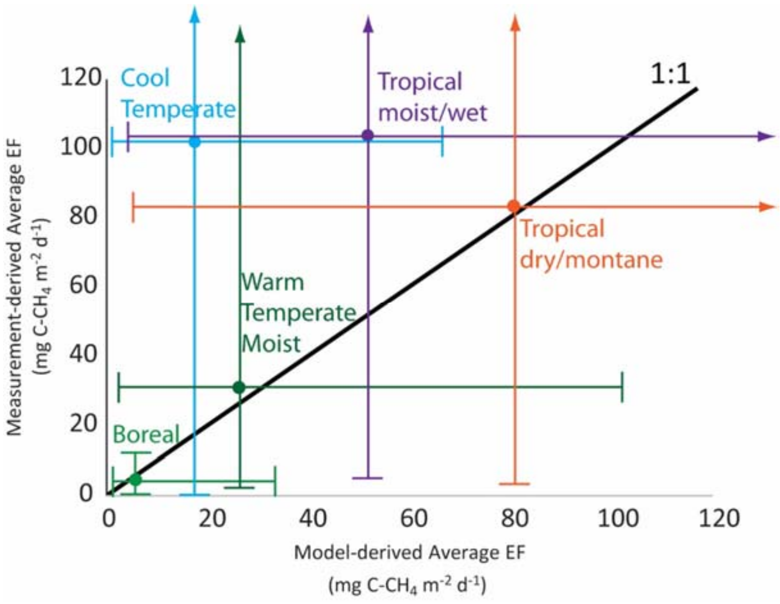

Figure A3. Model-based Emission Factors for CH_4 by climate zone vs. directly measurement-derived Emission Factors (arithmetic means). Confidence intervals are 5-95%-ile range of predictions for modelled values and entire range of measurements (min-max) in the case of EFs derived directly from measurements. Colours indicate means and ranges associated with each lumped IPCC climate zone (see Table 3).

1.4 Final derived emission factors for Tier 1

Table A4a. Tier 1 Emission Factors (model-based) for each climate zone for Land converted to Flooded Lands as derived from Eq. 4. Note that final numbers will be provided in next Draft.

IPCC climate zones	Lumped climate zones	Emission Factor (mg C-CH4 m-2 d-1)		
		Lower 95% CI	Average	Upper 95% CI
boreal dry boreal moist polar dry polar moist	Boreal	0.5	5.7	35.5
cool temperate dry cool temperate moist	Cool temperate	1.6	17.4	61.5
warm temperate dry	Warm temperate dry	4.1	40.2	198.5
warm temperate moist	Warm temperate moist	3.9	26.2	100.6
tropical dry tropical montane	Tropical dry/montane	5.8	80.6	282.5
tropical moist tropical wet	Tropical moist/wet	5.3	51.7	176.3

Table A4b. Tier 1 CH_4 Emission Factors (model-based) for each climate zone for *Flooded Land remaining to Flooded Land* as derived from Eq.5. Note that final numbers will be provided in next Draft.

IPCC climate zones	Lumped climate zones	Emission Factor (mg C-CH4 m-2 d-1)		
		Lower 95% CI	Average	Upper 95% CI
boreal dry boreal moist polar dry polar moist	Boreal	0.2	2.8	31.6
cool temperate dry cool temperate moist	Cool temperate	0.6	11.1	54
warm temperate dry	Warm temperate dry	1.6	31	174.4
warm temperate moist	Warm temperate moist	1.9	16.5	89.3
tropical dry tropical montane	Tropical dry/montane	2.5	58.3	244.2
tropical moist tropical wet	Tropical moist/wet	1.9	29.2	125

1.5 CO_2 emission factors for Land Converted to Flooded Land.

The creation of reservoirs as well as other flooded lands often involves the flooding of terrestrial ecosystems and their organic matter pools. A portion of these pools is rapidly degraded by microbial activity generating a CO_2 pulse that diminishes steadily during the 10-20 years following inundation until the flooded land attains a new steady state emission rate (Abril et al, 2005; Barros et al, 2011; Teodoru et al. 2012). The new steady state emission rate generally falls in the range typical of other freshwater ecosystems that have remained flooded for > 20 years (Prairie et al. 2017).

The carbon stocks of the land prior to impoundment are specific for each land use / land cover, and the default Tier 1 estimates for these pools can be derived from 2006 IPCC GL, as refined in this volume, and 2013 WS, while masses for dry matter in undrained and drained peatlands are given in 2013 WS Table 2.6. The guidelines recognize five terrestrial C pools: Biomass, belowground biomass, soil, litter and dead wood. The easily decomposable organic matter fractions (litter, foliage, twigs, fine roots, organic soils) contribute to the post-flooding CO_2 pulse while the more recalcitrant fractions (tree boles, mineral soils) are, for the most part, preserved. However, it is noteworthy that following inundation, the mineral soil layer rapidly becomes (and remains indefinitely) anoxic below a depth of a few mm (Lorke et al. 2003). Anaerobic remineralisation occurs very slowly and below this depth, organic carbon can be considered permanently buried for practical inventory accounting purposes. In organic soils and in humus layers of accumulating peat, inundation may produce an analogous anaerobic zone. In thermally stratified reservoirs, remineralisation of organic matter will be retarded in anoxic hypolimnia.

The surge in CO_2 emission post-flooding is caused by the remineralisation of pre-inundation organic matter pools and it can be considered as a net loss of the carbon stock from the previous land use. Due to the difficulty of measuring C stocks in a reservoir, there is a paucity of post-flooding pool-specific C stock data. Therefore, at the moment, there is little information to quantify how individual terrestrial organic carbon pools contribute to the post-flooding CO_2 surge. Nevertheless, the amount of reservoir emission measurements for young (< 20 y) reservoirs are abundant (Deemers 2016), hence an emission factor approach is developed for Tier 1.

The approach used to derive the Emissions Factors from reservoirs is based on the GHG Reservoir (G-res) model (Prairie et al., 2017b) which uses empirical relationships between environmental drivers and GHG emissions to estimate reservoir GHG fluxes from a large, diverse set of reservoirs (>6000 reservoirs with global distribution). More details are provided in Appendix 1.5 Section 1.2. Data are annualized to take into consideration changes in temperature that may not be the same year-round as the one occurring at the moment when empirical measurements were conducted in the field. Emissions Factors presented in Table A.5 are net post-flooding emissions, they take into account and factor out the emissions that would have occurred in the pre-impoundment waterbodies over 20-year post-flooding. Freshwater systems are active sites of carbon processing and transport and receive important quantities of carbon-rich organic material from the terrestrial landscape they drain (Prairie et al. 2017). Only the net changes in CO_2 fluxes caused by flooding should be accounted for since the amounts of organic carbon leaving terrestrial are already accounted for in the respective terrestrial land-uses.

Table A5 Tier 1 C-CO_2 Emission Factors for each climate zone. Note that final numbers will be provided in next Draft.

		Emission Factor (g C-CO2 m-2 y-1)		
IPCC climate zones	Lumped climate zones	20 years integration		
		Lower 95% CI	Average	Upper 95% CI
boreal dry boreal moist polar dry polar moist	Boreal	6.7	26.8	61.2
cool temperate dry cool temperate moist	Cool temperate	12.9	29.1	50.5
warm temperate dry	Warm temperate dry	28.2	48.4	78.1
warm temperate moist	Warm temperate moist	44.6	78.9	132.7
tropical dry tropical montane	Tropical dry/montane	34.5	83.9	158
tropical moist tropical wet	Tropical moist/wet	44.6	78.9	132.7

1.6 Data sources

Data sources used for the directly measured methane emissions are within Table A6. A full list of citations is provided in Table A7. Data sources used to develop models (Eqs 1, 2 and 3) can be found in Annex VI of Prairie et al. (2017b) and are also provided in Table A8.

Table A6. Data sources used for modelling CH_4 emissions from reservoirs within different climate zones.

IPCC Climate Type Group	Latitude Band	Number of systems with CH_4 measurements in category	Citations
Cool temperate moist and dry	Temperate	16	5,18,32-35,49,52,53,59,64,68,83,84
Warm temperate moist	Temperate	14	13,14,18,44,52,64,71-80,98,108
Polar moist, boreal dry and moist	Boreal_Polar	6	3,5,27-31,48,50,51,53,100
Tropical dry and montane	Tropical	13	15,19,37,38,41,47,54,60,85,86,101,103,105
Tropical wet and moist	Tropical	26	2-4,8,9,10,12-14,17,19-21,38-40,54,57,58,63,65-67,81,109

Table A7. List of articles used to model CH_4 emissions from reservoirs within different climate zones cited in Table A6.

Reference Number	Citation
2	Therrien, J., Tremblay, A. & Jacques, R. B. in Greenhouse Gas Emissions- Fluxes and Processes: Hydroelectric Reservoirs and Natural Environments (eds. Tremblay, A., Varfalvy, L., Roehm, C. & Garneau, M.) (Springer, 2005).

Tremblay, A., Therrien, J., Hamlin, B., Wichmann, E. & LeDrew, L. J. in Greenhouse gas emissions-- fluxes and processes hydroelectric reservoirs and natural environments (eds. Tremblay, A., Varfalvy, L., Roehm, C. & Garneau, M.) 209–232 (Springer, 2005). at <http://public.eblib.com/choice/publicfullrecord.aspx?p=304099>

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Wang, F. et al. Carbon dioxide emission from surface water in cascade reservoirs–river system on the Maotiao River, southwest of China. Atmos. Environ. 45, 3827–3834 (2011).

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2 OTHER HUMAN-MADE WATER BODIES (DITCHES, AGRICULTURAL AND AQUACULTURE PONDS)

Many forms of agricultural and silvicultural land management involve the creation of artificial water bodies. For example, ditches are often used for land drainage or irrigation; small constructed ponds are used for small scale irrigation or as a water source for livestock; and canal systems are used for water level management, water transfers and navigation. Aquaculture ponds and flooded pastures can occupy extensive areas on the landscape (Yang et al. 2017, Kroeger et al. 2017).

Similar to reservoirs, CO_2 emissions from smaller volume human-made water bodies including ditches, canals, farm ponds and aquaculture ponds, are the result of decomposition of soil organic matter and other organic matter within the water body or entering the water from the catchment, as well as from biological components (e.g. fish). No guidance is provided here since these emissions are either accounted for elsewhere (e.g. as soil carbon loss) or represent short-term natural carbon cycling (e.g. biological turnover).

CH_4, emissions are primarily the result of new methanogenic production of CH_4 induced by anoxic conditions, which occurs when water bodies have high organic matter loading and low oxygen status. These conditions often occur in small constructed water bodies, such as ditches (Evans et al., 2016), agricultural ponds (Selvam et al. 2014) and aquaculture ponds, but may be lower where mixing or aeration occurs as part of aquaculture management (e.g. Vasanth et al. 2016). Emissions from these constructed water bodies may equal or exceed those observed in small lakes and reservoirs (Bastviken et al. 2010; see above). Furthermore, the CH_4 emissions from artificial water bodies are a direct consequence of the construction of the water body.

CH_4 emission factors from agricultural ponds, ditches, aquaculture ponds and flooded pastures (Table 7.4) are based on review of the peer reviewed literature using appropriate search terms. Literature was obtained using Web of Science and Google Scholar. In some cases (e.g. PhD Theses), data were obtained directly from authors. For each study or sites within studies, a mean CH_4 flux was extracted from tables, figures or text. Fluxes were converted to annual fluxes by simple scaling (e.g. multiplying per day rates by 365 days), or if more information was provided (e.g. days per cropping cycle and cropping cycles per year), data were annualized using this additional information. Methane emissions from the land sector are rarely normally distributed data sets due to ebullition processes, thus 95% confidence intervals can be large

2.1 Data sources

Table A9. Data sources for CH_4 emissions from Ditches, Ponds and Aquaculture ponds.

Ditches	Ponds	Aquaculture ponds
Selvam (2014)	Grinham (unpubl)	Huang (2016) PhD thesis
Wang (2009)	Selvam et al (2014)	Castilo et al. 2017
Harrison (2003)	Martinez-Cruz (2017)	Strangmann, A., Bashan, Y., & Giani, L. (2008).
Chamberlain (2015)	Merbach (1996)	Yang, P., He, Q., Huang, J., & Tong, C. (2015).
Yu (2017)	Baker-Blocker et al (1997)	Cameron C, unpublished
Evans (2017)	Stadmark and Leonardson (2005)	Xiong, Y., Wang, F., Guo, X., Liu, F., & Dong, S. (2017)
Peacock (2017)	Singh et al (2000)	Hu, Z., Wu, S., Ji, C., Zou, J., Zhou, Q., & Liu, S. (2016).
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Annex 7.2 Sedimentation and carbon burial in reservoirs

While reservoirs are often sites of significant sediment deposition (Clow et al. 2013), it is generally inappropriate to consider impoundments as carbon sequestering ecosystems for many reasons. First, because of the altered hydrodynamics sediments trapped in reservoirs would otherwise have been transported and/or stored further downstream. As a result, only the portion of the carbon buried in reservoir sediments that would not have been stored elsewhere in the hydrological network, including the coastal ocean, could potentially be considered as an offset to reservoir GHG emissions. Second, from a mass balance point of view, carbon burial resulting from *in situ* primary production is already taken into account in the gas exchange occurring at the air-water interface. Subtracting C sedimentation from the air-water exchange, as has been suggested, would thus amount to double counting of the carbon sequestration resulting from in situ primary production. Lastly, in many reservoirs, maintenance operations involve the sluicing of excess sediments to the downstream river by opening gates located at the base of the dam, thereby releasing large amounts of accumulated sediment carbon over a short period. As a result of the processes described above and the difficulty in quantifying them, Tier I methodology cannot be developed for reporting of sediment carbon accumulation.

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