CHAPTER 6

CONSTRUCTED WETLANDS

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6 CONSTRUCTED WETLANDS

6.1 INTRODUCTION

DEFINITION

Wetland ecosystems can act as sources, sinks, or transformers of nutrients and carbon (Mitsch and Gossenlink, 1993). This ability of wetlands has lead to a widespread use of natural and constructed wetlands for water quality enhancement.

Natural wetlands are characterized by anaerobic conditions and low turnover rates for organic matter, and are thus important terrestrial sinks for carbon and nitrogen (Augustin et al., 1998). Polluted water may be discharged into wetland sites and a significant improvement in water quality obtained (Brix, 1997). "Semi-natural treatment wetlands" for wastewater treatment are natural wetland systems that have been modified for this purpose. The modifications made within these systems usually are based on increasing the volume reserved (i.e. dams) and constructing channels for targeting the influent and effluent. These systems can be found in both freshwater and coastal wetlands.

Constructed wetlands systems are fully human-made wetlands for wastewater treatment, which apply various technological designs, using natural wetland processes, associated with wetland hydrology, soils, microbes and plants. Thus, constructed wetlands are engineered systems that have been designed and constructed to utilize the natural processes involving wetland vegetation, soils, and their associated microbial assemblages to assist in treating wastewater. Synonymous terms to “constructed” include “man-made”, “engineered” or “artificial” wetlands (Vymazal, 2007).

APPLICATION OF CONSTRUCTED WETLANDS FOR WASTEWATER TREATMENT

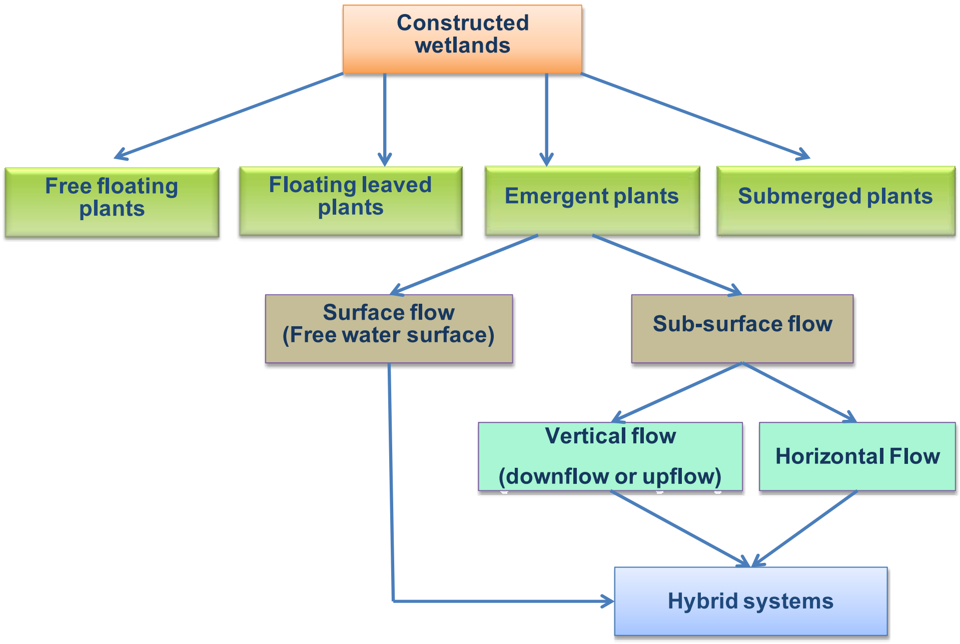
Constructed wetlands are used to improve the quality of point and nonpoint sources of water pollution, including stormwater runoff, domestic wastewater, agricultural wastewater, and coal mine drainage. Constructed wetlands are also being used to treat petroleum refinery wastes, compost and landfill leachates, fish pond discharges, and pretreated industrial wastewaters, such as those from pulp and paper mills, textile mills, and seafood processing. For some wastewaters, constructed wetlands are the sole treatment; for others, they are one component in a sequence of treatment processes (US EPA, 2000).

There are various types of constructed wetlands used for treatment of different wastewater, and following subchapter highlights the main classification of constructed wetlands.

TYPE OF CONSTRUCTED WETLANDS FOR WASTEWATER TREATMENT

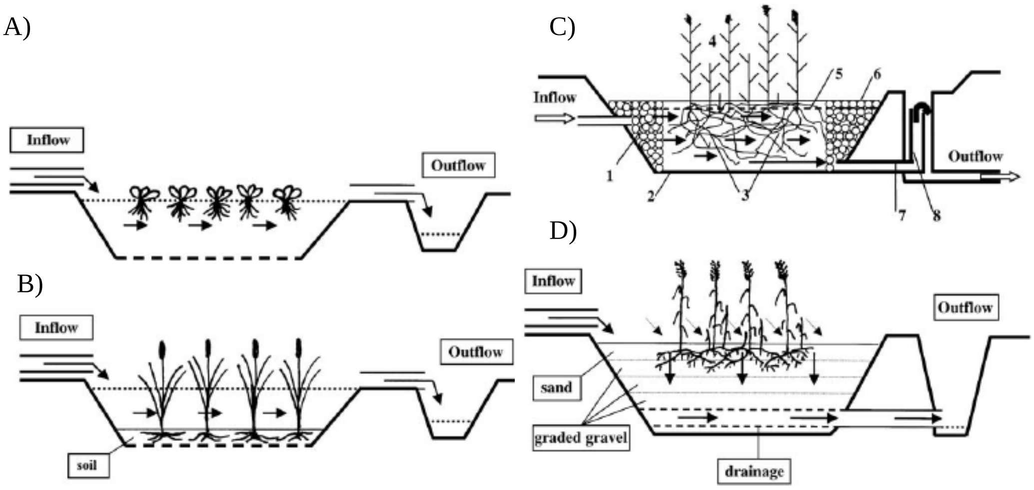
Constructed wetlands may be categorized according to the various design parameters, but the three most important criteria are hydrology (water-surface flow and subsurface flow), macrophyte growth form (emergent, submerged, free-floating) and flow path (horizontal and vertical) (Fig. 6.2 and Fig. 6.3; Vymazal 2007, 2011). Different types of constructed wetlands may be combined (which are called hybrid or combined systems) to utilize the specific advantages of the different systems. For instance, to guarantee more effective removal of ammonia and total nitrogen, during the 1990s and 2000s an enhanced design approach combined vertical and horizontal flow constructed wetlands to achieve higher treatment efficiency (Vymazal, 2011).

Figure 6.1 Classification of constructed wetlands for wastewater treatment



Note: Adopted from Vymazal, 2001

Figure 6.2 Constructed wetlands for wastewater treatment



Note: Adopted from Vymazal, 2001. A) constructed wetland with free-floating plants (FFP), B) constructed wetland with free water surface and emergent macrophytes (FWS), C) constructed wetland with horizontal sub-surface flow (HSSF, HF), D) constructed wetland with vertical sub-surface flow (VSSF, VF)

Constructed Wetlands with Surface Flow

Constructed wetlands with surface flow (SF), known as *free water surface constructed wetlands* (FWS CWs), contain areas of open water and floating, submerged, and emergent plants (Kadlec and Wallace 2008). The shallow water depth, low flow velocity, and presence of the plant stalks and litter regulate water flow and, especially in long, narrow channels, ensure plug-flow conditions (Crites et al 2005). The most common application for FWS constructed wetlands is for tertiary treatment of municipal wastewater and also for stormwater runoff and mine drainage waters (Kadlec and Knight 1996; Kadlec and Wallace 2008). FWS wetlands are suitable in all climates, including the far north (Mander and Jenssen 2003).

Constructed Wetlands with Subsurface Flow

In *horizontal subsurface flow constructed wetlands* (HF CWs), the wastewater is fed in at the inlet and flows slowly through the porous medium under the surface of the bed planted with emergent vegetation to the outlet where it is collected before leaving via a water level control structure (Vymazal et al 1998). During passage the wastewater comes into contact with a network of aerobic, anoxic, and anaerobic zones. Most of the bed is anoxic/anaerobic due to permanent saturation of the beds. The aerobic zones occur around roots and rhizomes that leak oxygen into the substrate (Brix 1987). HF CWs are commonly sealed with a liner to prevent seepage and to ensure the controllable outflow. HF CWs are commonly used for secondary treatment of municipal wastewater but many other applications have been reported in the literature (Vymazal and Kröpfelova 2008). The oxygen transport capacity in these systems is insufficient to ensure aerobic decomposition, thus, anaerobic processes play an important role in HF CWs (Vymazal and Kröpfelova 2008). HF CWs having the ability to insulate the surface of the bed are capable of operation under colder conditions than FWS systems (Mander and Jenssen 2003).

Vertical flow Constructed Wetlands

Vertical flow constructed wetlands (VF CWs) comprise a flat bed of graded gravel topped with sand planted with macrophytes. Contrary to HF CWs, VF CWs are fed intermittently with large batches, thus flooding the surface. Wastewater then percolates down through the bed and is collected by a drainage network at the bottom. The bed drains completely which allows air to refill the bed. Thus, VF CWs provide greater oxygen transfer into the bed, thus producing a nitrified (high NO_3^-) effluent (Cooper et al 1996; Cooper 2005). On the other hand, VF CWs do not provide suitable conditions for denitrification to complete conversion to gaseous nitrogen forms which escape to the atmosphere.

In recently developed tidal (“fill and drain”) flow systems better contact of wastewater with the microorganisms growing on the media is guaranteed. This significantly enhances the purification processes (Vymazal 2011).

Hybrid Constructed Wetlands

Various types of constructed wetlands may be combined to achieve higher removal efficiency, especially for nitrogen. The design consists of two stages, several parallel VF beds followed by 2 or 3 HF beds in series (VF-HF system). The VF wetland is intended to remove organics and suspended solids and to provide nitrification, while in the HF wetland denitrification and further removal of organics and suspended solids occurs.

Another configuration is the HF-VF system. The large HF bed is placed first to remove organics and suspended solids and to provide denitrification. An intermittently loaded small VF bed is used for additional removal of organics and suspended solids and to nitrify ammonia to nitrate. To maximize removal of total nitrogen, however, the nitrified effluent from the VF bed must be recycled to the sedimentation tank (Vymazal 2011).

The VF-HF and HF-VF constructed wetlands are the most common hybrid systems, but in general, any kind of constructed wetlands could be combined to achieve higher treatment effect (Vymazal 2007).

GREENHOUSE GASES EMISSIONS FROM VARIOUS TYPES OF CONSTRUCTED WETLANDS

Emissions of greenhouse gases (GHGs) such as methane (CH_4) and nitrous oxide (N_2O) are a “byproduct” of constructed wetlands which importance has been increasing recently. Among several environmental factors controlling the GHG emissions, availability of C and nutrients (especially N) which directly depends on wastewater loading, temperature, hydrological regime (pulsing vs steady-state flow), groundwater depth, moisture of filter material (water filled soil pores (WFSP)) , and presence of aerenchymal plants play a significant role (see Table 6.1).

TABLE 6.1
SELECTED FACTORS IMPACTING CH_4 AND N_2O EMISSIONS IN CONSTRUCTED WETLANDS

Factors/processes	CH_4	N_2O
Higher water/soil/air temperature	Increase in most cases	No clear relationship
Higher moisture of soil or filter material (higher value of WFSP)	Clear increase	Decrease
Higher wastewater loading	Increase	Increase
Presence of aerenchymal plants	Increase	Increase
Pulsing hydrological regime (intermittent loading)	Clear decrease	Increase (decrease in some FWS CWs)
Deeper water table (from surface) in HSSF CWs	Decrease	Increase

Table 6.2 shows CH_4 and N_2O conversion rate derived from literature-based relationship between the initial (input) C and N loading and respective CH_4 and N_2O emissions in main types of constructed wetlands. There is a significant positive correlation ($p < 0.05$) between the initial loading and CH_4 and N_2O emissions in both FWS and VSSF constructed wetlands, whereas no correlation was found for HSSF types. Seemingly, high variability of conditions and combination of several factors in HSSF constructed wetlands may be the reason for that. Also, limited number of data did not allow derive reliable relationship for HSSF constructed wetlands. These shares can be used as base for calculation of emision factors for Tier 1 and Tier 2. High emission factor for CH_4 in FWS CWs (Table 6.4) is caused by the additional CH_4 from sediments accumulated in the bottom of surface flow wetlands . Due to the lack of data, no clear relationship has been found between the emission of CH_4 and N_2O other environmental factors.

TABLE 6.2
CONVERSION RATE OF CH_4-C AND N_2O-N IN THE INITIAL LOADINGS OF TOC AND TN

Type of CW	CH_4-C	N_2O-N
FWS	40 (5.9)	0.24 (0.10)
VSSF	1.44 (0.24)	0.021 (0.005)
HSSF	5.1 (2.4)	1.0 (0.5)

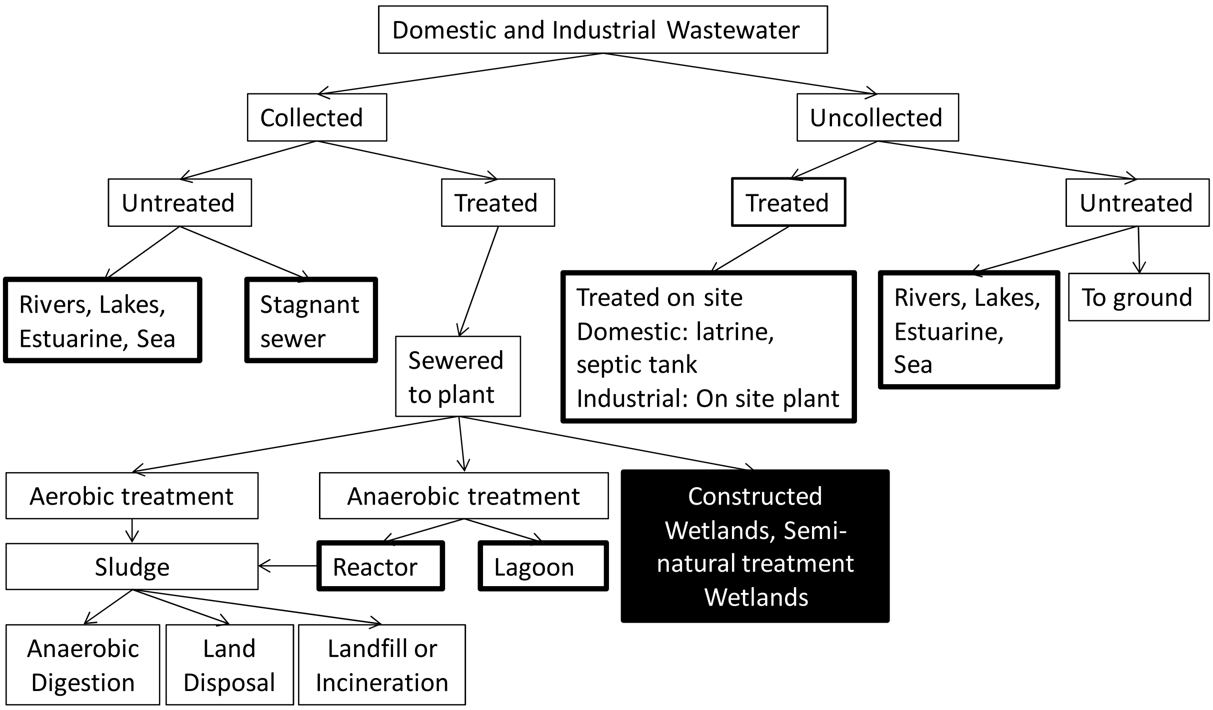
Note: Average and standard error (in brackets) are presented

Soil/air temperature and the soil moisture (WFSP, depth of (ground) water level) are the most significant factors affecting emission of CH_4 in constructed wetlands (Mander et al 2003; Van der Zaag 2010). Several investigations show that the water table deeper than 20 cm from the surface of wetlands and/or water-logged soils oxidizes most CH_4 fluxes (Soosaar et al 2011; Salm et al 2012). Fluxes of N_2O, however do not show clear correlation with soil/air temperature and significant emissions of N_2O from constructed wetlands has been observed in winter (Søvik et al 2006). Likewise, freezing and thawing cycles enhance N_2O emissions (Yu et al 2011). Hydrological regime also plays a significant role in GHG emissions from constructed wetlands. Altor and Mitsch (2008) and Mander et al (2011) demonstrated that the intermittent loading (pulsing) regime and fluctuating water table in constructed wetlands enhance CO_2 emissions and significantly decreases CH_4 emissions. N_2O emission, in contrary, does not show a clear pattern regarding pulsing regime.

6.1.1 Relation to 2006 IPCC Guidelines

This chapter is a supplement to Chapter 6 WASTEWATER TREATMENT AND DISCHARGE in the 2006 Guidelines. *The 2006 Guidelines* (2006 Guidelines, IPCC, 2006) included a new section to estimate CH_4 emissions from uncollected wastewater. This section is expanded to cover CH_4 emissions from constructed wetlands and semi-natural treatment wetlands. This *Supplement* on Wetland includes nitrous oxide (N_2O) emissions from constructed wetlands and semi-natural treatment wetlands. Emission factors of CH_4 and N_2O from constructed wetlands and semi-natural treatment wetlands treating industrial wastewater are the same as domestic wastewater treating ones. CO_2 emissions are not included in GHG emissions from wastewater treatment as CO_2 from wastewater is considered biogenic.

Figure 6.3 Wastewater treatment systems and discharge pathways



Note: Emissions from boxes with bold frames are accounted for 2006GLs. Supplement provides EF for black color box; Constructed Wetlands and semi-natural treatment wetlands for treatment of collected wastewater.

Coverage of wastewater types and gases

Chapter 6 of the 2006 IPCC Guidelines provide guidance on estimation of CH_4 and N_2O emissions from domestic with emission factor based on treatment technology. Constructed wetland is an additional treatment technology in this supplement to 2006 IPCC Guidelines. The emission factors described in this chapter cover constructed wetlands and semi-natural treatment wetlands (collected and treated) see Fig. 6.1.

The methodology is provided for calculation of CH_4 and N_2O emissions from both domestic and industrial wastewater. The indirect N_2O emissions from potential wastewater such as runoff from agricultural land are covered in the 2006 IPCC Guidelines. Emissions from agro-industrial wastewater (except manure management) and mine drainage are considered as industrial wastewater. As for solid waste landfill leachate, CH_4 emissions have already been taken into account in solid waste disposal on land (6A) in the 2006 IPCC Guidelines, and are not included in section 6.2, while N_2O emissions are considered in section 6.3”

TABLE 6.3
COVERAGE OF WASTEWATER TYPES AND GHG GASES

Type of Wastewater	Methane	Nitrous oxide
Domestic wastewater	Included in this supplement with provision of MCF and correction factors for temperature and vegetation	Included in this supplement with provision of EF
Industrial wastewater including agro-industrial and dairy farm wastewater	Included in this supplement with provision of MCF and correction factors for temperature and vegetation	Included in this supplement with provision of EF
Runoff from agricultural land	Negligible	Covered in 2006 IPCC Guidelines (Vol.4 Chapter 11)
Leachate from landfill	Covered in the 2006 IPCC Guidelines	Included in this supplement

6.2 METHANE EMISSIONS FROM CONSTRUCTED WETLANDS

6.2.1 Methodological issues

Methane emissions are a function of the organic materials loaded into constructed wetlands and an emission factor to which the waste generate CH_4.

Three tier methods for CH_4 from constructed wetlands are summarized below.

The Tier 1 method applies default values for the emission factor and activity parameters. This method is considered *good practice* for countries with limited data.

The Tier 2 method follows the same method as Tier 1 but allows for incorporation of country specific emission factor and country specific activity data. For example, a specific emission factor based on field measurements can be incorporated under this method.

The Tier 3 method could be used by countries with good data and advanced methodologies. A more advanced country-specific method could be based on plant-specific data from operating constructed wetland treatment system.

Constructed wetlands can be operated under anaerobic and aerobic conditions. But CH_4 generated at such facilities is not usually recovered and combusted in a flare or energy device. So CH_4 recovery is not considered here.

The amount of vegetation harvesting from constructed wetland is generally very small and their impact to total emissions from constructed wetlands is considered insignificant. Moreover, the harvesting is usually not performed on regular basis and the quantity of harvested biomass is commonly not recorded so it is not considered in this supplement.

Emissions from semi-natural treatment wetlands treating uncollected wastewater are also estimated using the same methodology.

6.2.1.1 CHOICE OF METHOD

A decision tree for domestic or industrial wastewater is included in the Figure 6.4.

The general equation to estimate CH_4 emissions from constructed wetland treating domestic or industrial wastewater is as follows.

EQUATION 6.1

CH_4 EMISSIONS FROM CONSTRUCTED WETLANDS

$$CH_4 \text{ Emissions} = TOW \bullet EF$$

Where:

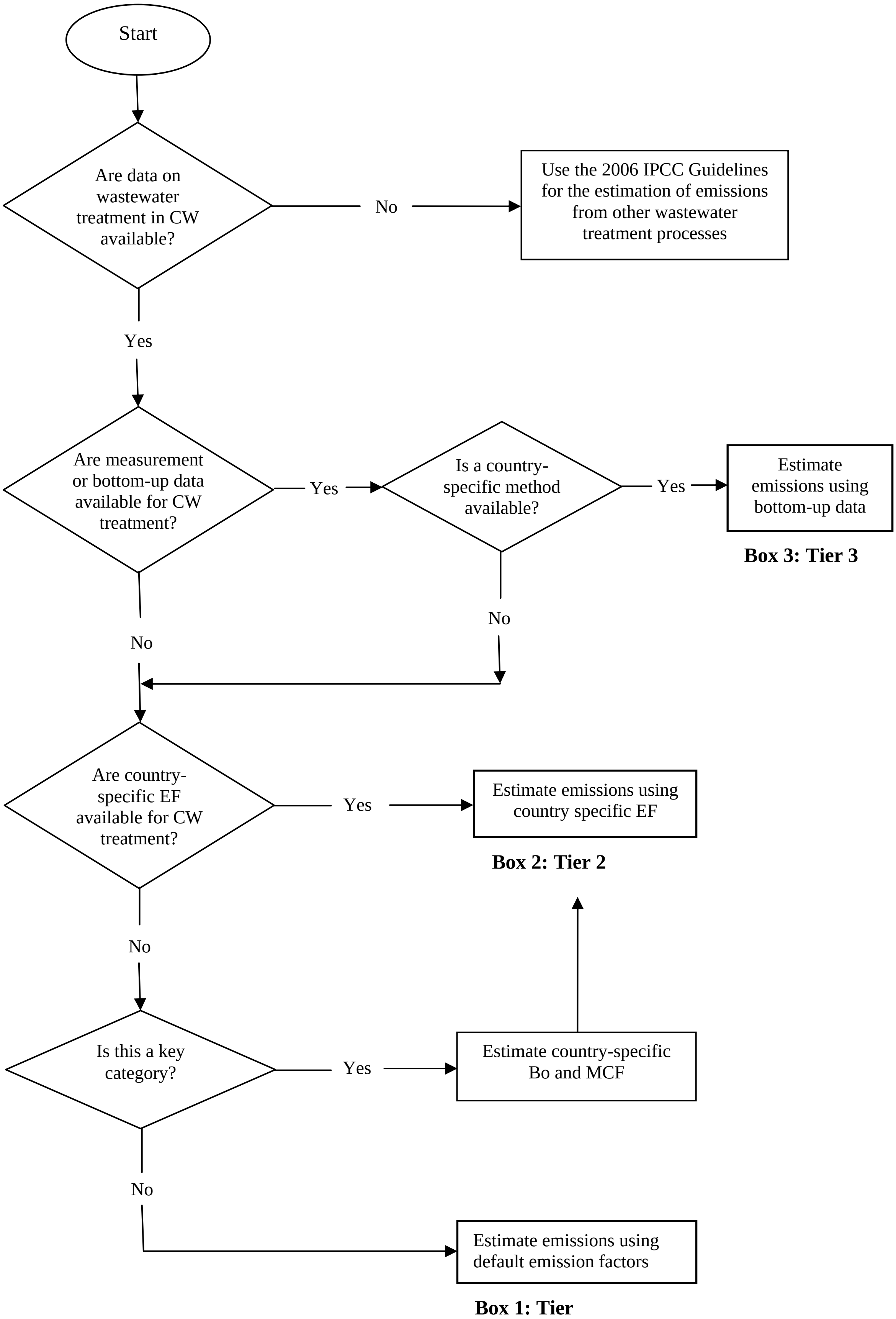
CH_4 emissions = CH_4 emissions in inventory year, kg CH_4/yr

TOW = total organics in wastewater treated by constructed wetland in inventory year, kg BOD/yr or kg COD/yr

EF = emission factor, kg CH_4/kg BOD or kg CH_4/kg COD

TOW and EF for estimation of CH_4 emissions from constructed wetlands can be integrated in equation 6.1 for emission from domestic wastewater and equation 6.4 for emission of industrial waste in 2006 IPCC Guidelines

Figure 6.4 Decision tree for CH_4 emissions from constructed wetland



6.2.1.2 CHOICE OF EMISSION FACTORS

The emission factor for a wastewater treatment by constructed wetland is a function of maximum CH_4 producing potential (B_o) and the methane correction factor (MCF).

EQUATION 6.2

CH_4 EMISSIONS FACTOR FOR CONSTRUCTED WETLANDS

$$EF = B_o \bullet MCF \bullet VCF \bullet TCF$$

Where:

EF = emission factor, kg CH_4/kg BOD or kg CH_4/ kg COD

B_o = maximum CH_4 producing capacity, kg CH_4/kg BOD or kg CH_4/ kg COD

MCF = methane correction factor (fraction)

VCF = vegetation correction factor (fraction)

TCF = temperature correction factor (fraction)

Good practice is to use country-specific data for B_o, where available, expressed in term of kg CH_4/kg BOD removed for domestic wastewater or kg CH_4/ kg COD removed for industrial wastewater to be consistent with the activity data. If country specific data is not available, the following default values can be used.

The 2006 IPCC Guidelines provide default maximum CH_4 producing capacity (B_o) for domestic and industrial wastewater: 0.6 kg CH_4/kg BOD and 0.25 kg CH_4/kg COD.

Methane Correction Factor (MCF) indicates the extent to which CH_4 producing capacity (Bo) is realized in each type of constructed wetland. It is an indication of the degree to which the system is anaerobic. The proposed MCF for each type of constructed wetland treating domestic and industrial wastewater, derived from literature based analysis of CH_4 conversion rate (table 6.2) is provided below.

TABLE 6.4
METHANE CORRECTION FACTORS BY TYPES OF CONSTRUCTED WETLANDS

CW type	MCF	Range
FWS	0.35	0.32-0.37
HSSF	0.1	0.064-0.227
VSSF (intermittent loading)	0.03	0.025-0.048

Vegetation Correction Factor (VCF) depends on the type of vegetation grown in constructed wetland. If aerenchymal plant types are used, default VCF of 1.0 can be used. For non-aerenchymal, VCF of 0.6 is assumed as a default value. Aerenchyma is an air channel in the root of some plants, which allows exchange of gases between the shoot and the root.

Temperature Correction Factor (TCF) varies according to the climate zone in which constructed wetland is located. For tropical or subtropical zone, TCF of 1.0 is assumed as the default value. For temperate and boreal climate, TCF of 0.6 is set as a default value.

Anaerobic condition generally occurred in wetlands. The unknown type of semi-natural treatment wetlands can use the default MCF of 0.35. CH_4 emission for wastewater treated by natural wetland and coastal wetland, MCF is considered to be also 0.35

6.2.1.3 CHOICE OF ACTIVITY DATA

The activity data for this source category is the amount of organic materials in the wastewater treated by constructed wetland (TOW). This parameter is a function of population served by constructed wetland system and biochemical oxygen demand (BOD) generation per person per day. BOD default values for selected countries are provided in the 2006 IPCC Guidelines (Table 6.4, Chapter 6). In case of industrial wastewater, COD loading to the constructed wetland system per day (kg COD/day) can be used. Examples of industrial wastewater data from various industries are provided in Table 6.9, Chapter 6 of the 2006 IPCC Guidelines.

If industrial wastewater is released into domestic sewers, it is estimated together with domestic wastewater.

The equation for TOW is:

EQUATION 6.3
TOTAL ORGANICALLY DEGRADABLE MATERIAL IN DOMESTIC WASTEWATER

$$TOW = P \bullet BOD \bullet I \bullet 0.001 \bullet 365$$

EQUATION 6.4
TOTAL ORGANICALLY DEGRADABLE MATERIAL IN INDUSTRIAL WASTEWATER

$$TOW = COD \bullet W \bullet 365$$

Where:

TOW = total organics in domestic or industrial wastewater treated in constructed wetland in inventory year (kg BOD/year or kg COD/year)

P = population in the country

BOD = country-specific per capita BOD generation in inventory year (g BOD/person/day)

I = correction factor for additional industrial wastewater discharged into sewers (for collected the default is 1.25, for uncollected the default is 1.00 as recommended in the 2006 IPCC Guidelines)

COD = COD concentration in industrial wastewater treated by constructed wetland in inventory year (kg COD/m^3)

W = Daily flow rate of industrial wastewater treated by constructed wetland, m^3/d

6.2.2 Time series consistency

The same method and data sets should be used for estimating CH4 emissions from constructed wetland treating wastewater for each year. The MCF for different treatment systems should not change from year to year, unless such a change is justifiable and documented. If the share of wastewater treated in different treatment systems changes over the time period, the reasons for these changes should be documented.

Activity data that are derived from population data, which is available for all countries and all years, countries need to determine the fraction of population served by constructed wetland systems. If data on the share of wastewater treated are missing for one or more years, the surrogate data and extrapolation/interpolation splicing techniques described in Chapter 5, Time Series Consistency, of Volume 1 General Guidance and Reporting can be used to estimate emissions. Emissions from wastewater treated in constructed typically do not fluctuate significantly from year to year.

6.2.3 Uncertainties

Chapter 3, Uncertainties, in Volume 1 of 2006 IPCC Guidelines provides advice on quantifying uncertainties in practice. It includes guidance on eliciting and using expert judgments which in combination with empirical data can provide overall uncertainty estimates. Table 6.7 and 6.10 in Chapter 6 of Volume 5 provides default uncertainty ranges for emission factor and activity data of domestic and industrial wastewater respectively. The following parameters are believed to be very uncertain:

- The quantity of wastewater is treated in constructed wetland or semi-natural treatment wetlands receiving wastewater.
- The fraction of organics that is converted anaerobically to CH_4 during wastewater collection. This will depend on hydraulic retention time and temperature in the wastewater collection pipeline, and on other

factors including the presence of anaerobic condition in the wastewater collection pipeline and possibly components that are toxic to anaerobic bacteria in some industrial wastewater.

- The amount of industrial TOW from small or medium scale industries that is discharged into constructed wetland in developing countries might be difficult to quantify.
- Different types of vegetation applied in constructed wetlands that involved in gas exchange due to thiers physical structure of Aerenchyma.

TABLE 6.5
DEFAULT UNCERTAINTY RANGES FOR DOMESTIC AND INDUSTRIAL WASTEWATER

Parameter	Uncertainty range
Emission factor	
Maximum CH_4 producing capacity (Bo)	± 30%
Methane correction factor (MCF)	FWS: -8%,+14%, VSSF: -16%, +60% HSSF: -36%, +127%
Vegetation Correction Factor (VCF)	This data can be very uncertain depended on type of plant used in CWs. An uncertainty of -50% to +100% is suggested (Expert judgement : Authors)
Temperature Correction Factor (TCF)	* This data can be very uncertain depended on type of plant used in CWs. An uncertainty of -30% to +30% is suggested. (Expert judgement : Authors)
Activity data	
Human population	± 5%
BOD per person	± 30%
Correction factor for additional industrial BOD discharged into sewers (I)	For uncollected, the uncertainty is zero %. For collected the uncertainty is ± 20%
COD loading from industrial wastewater	± 30%

6.2.4 QA/QC, Completeness, Reporting and Documentation

It is *good practice* to conduct quality control checks and quality assurance procedures as outlined in Chapter 6, QA/QC and Verification, of Volume 1. Below, some fundamental QA/QC procedures include:

Activity Data

- Make sure that the sum of wastewater flows of all types of wastewater treatment processes including constructed wetland equal 100 percent of wastewater collected and treated in the country.
- Inventory compilers should compare country-specific data on BOD in domestic wastewater to IPCC default value. If inventory compilers use country-specific values they should provide documented justification why their country-specific values are more appropriate for their national circumstances.

Emission Factors

- For domestic wastewater, inventory compilers can compare country-specific values for B_o with the IPCC default value (0.25 kg CH4/kg COD or 0.6 kg CH_4/kg BOD). Although there are no IPCC default values for the fraction of wastewater treated anaerobically, inventory compilers are encouraged to compare values for MCFs against those from other countries with similar wastewater handling practices.
- Inventory compilers should confirm the agreement between the units used for degradable carbon in the waste (TOW) with the units for B_o. Both parameters should be based on the same units (either BOD or COD) in order to calculate emissions. This same consideration should be taken into account when comparing the emissions.

- For countries that use country-specific parameters or higher tier methods, inventory compilers should crosscheck the national estimates with emissions using the IPCC default method and parameters.
- For industrial wastewater, inventory compilers should cross-check values for MCFs against those from other national inventories with similar constructed wetland types

Completeness

Completeness can be verified on the basis of the degree of utilization of a treatment or discharge system or pathway (T) for all wastewater treatment system used. The sum of T should equal 100 percent. It is a *good practice* to draw a diagram for the country to consider all potential anaerobic treatment and discharge systems and pathways, including collected and uncollected, as well as treated and untreated. Any high strength wastewater treated in domestic wastewater treatment facilities should be included in the collected category. In general, the amount of vegetation harvested from constructed wetland is very small. If vegetation biomass is removed for the purpose of composting, incineration and burning, disposal in landfills or as fertilizer on agricultural lands, the amount of biomass should be consistent with data used in the relevant sectors.

Completeness for estimating emissions from industrial wastewater depends on an accurate characterization of industrial sectors that produce organic wastewater and the organic loading applied to constructed wetland system. So the inventory compilers should ensure that these sectors are covered. Periodically, the inventory compilers should re-survey industrial sources, particularly if some industries are growing rapidly. This category should only cover industrial wastewater treated onsite. Emissions from industrial wastewater released into domestic sewer systems should be addressed and included with domestic wastewater.

Reporting and documentation

It is *good practice* to document and report a summary of the methods used, activity data and emission factors. Worksheets are provided at the end of this volume. When country-specific methods and/or emission factors are used, the reasoning for the choices as well as references to how the country-specific data (measurements, literature, expert judgment, etc.) have been derived (measurements, literature, expert judgment, etc.) should be documented and included in the reporting.

More information on reporting and documentation can be found in the 2006 IPCC Guidelines in Volume 1, Chapter 6, Section 6.11 Documentation, archiving and reporting.

6.3 NITROUS OXIDE EMISSIONS FROM CONSTRUCTED WETLANDS

6.3.1 Methodological issues

Nitrous oxide (N_2O) emissions can occur as direct emissions from wastewater treatment constructed wetlands through nitrification and denitrification. Emissions are a function of the total nitrogen loaded into constructed wetland and an emission factor to which the wastewater generate N_2O.

Two tier methods for N_2O from this category are summarized below.

The Tier 1 method applies default values for the emission factor and activity parameters. This method is considered *good practice* for countries with no country specific data.

The Tier 2 method follows the same method as tier 1 but allows for incorporation of country specific emission factor and country specific activity data. For example, a specific emission factor based on field measurements can be incorporated under this method. Nitrogen is taken up by plant and the degree of vegetation coverage area in constructed wetlands affects the emission. The plant uptake of nitrogen reduces the potential of N_2O emission via nitrification and denitrification.

The methodology was provided assuming typical vegetation harvesting practice condition. However, the amount of biomass harvested from constructed wetland is generally very small and the harvested biomass is commonly not recorded so the harvesting practice is not considered as an influencing factor in the estimation of emission.

Emissions from semi-natural treatment wetland treating uncollected wastewater are also estimated using the same methodology. Indirect N_2O emission from domestic wastewater treatment effluent that is discharged into aquatic environments has already been covered in 2006 IPCC Guidelines.

6.3.1.1 CHOICE OF METHOD

A decision tree for domestic or industrial wastewater is included in the Figure 6.5.

The general equation to estimate N_2O emission from constructed wetland treating domestic or industrial wastewater is as follows:

EQUATION 6.5

N_2O EMISSIONS FROM CONSTRUCTED WETLANDS

$$N_2O\ Emissions = N_{EFFLUENT} \bullet EF \bullet 44/28$$

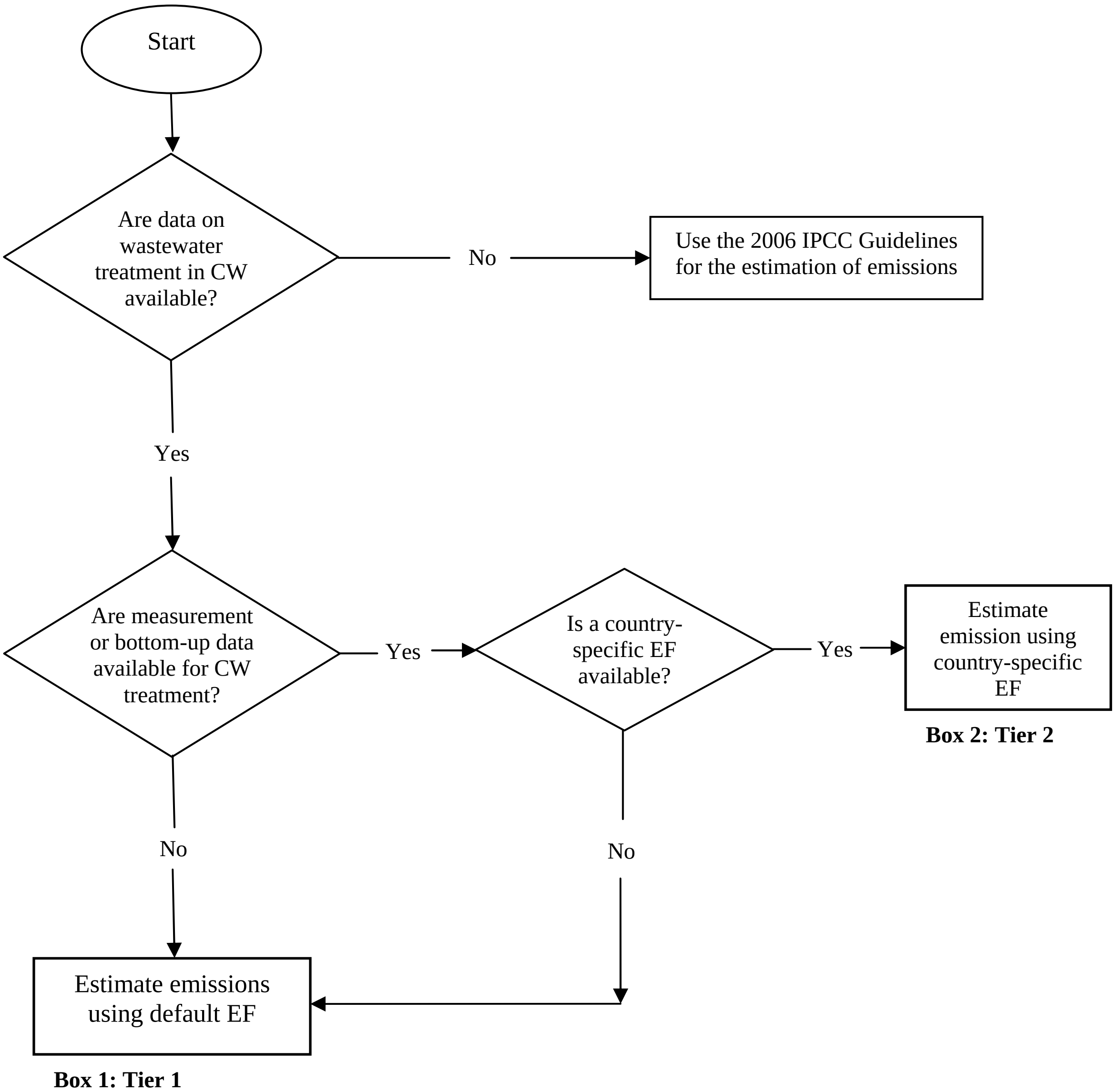
Where:

N_2O Emissions = N_2O emission in inventory year, kg N_2O/yr

$N_{EFFLUENT}$ = total nitrogen in wastewater treated by constructed wetland in inventory year, kg N/year

EF = emission factor, kg N_2O-N/kg N

Figure 6.5 Decision tree for N_2O emission from constructed wetland



6.3.1.2 CHOICE OF EMISSION FACTORS

The default IPCC emission factor for N_2O emissions from domestic and industrial wastewater is 0.00075 kg N_2O-N/kg N. This value is based on data provided in the literatures and can be used for different types of constructed wetlands. They are influenced by the extent of nitrification and denitrification taking place in constructed wetlands, the coverage of vegetation in constructed wetlands and climatic conditions. *Good practice* is to use country-specific data for emission factor, where available, expressed in term of kg N_2O-N/kg N loaded for domestic and industrial wastewater to be consistent with the activity data.

6.3.1.3 CHOICE OF ACTIVITY DATA

The activity data for this source category is the amount of nitrogen in the wastewater treated by constructed wetland (TN). This parameter is a function of population served by constructed wetland system, annual per capita protein consumption (Protein) and factor for non-consumed nitrogen added to the wastewater for domestic wastewater. In case of industrial wastewater, TN loading to the constructed wetland system in inventory year (kg N) can be used directly. The equations for determining TN for domestic and industrial wastewater are:

EQUATION 6.6
TOTAL NITROGEN IN DOMESTIC WASTEWATER EFFLUENT

$$N_{EEFLUENT,\ DOM} = P \bullet Protein \bullet F_{NPR} \bullet F_{NON\text{-}CON} \bullet F_{IND\text{-}COM}$$

EQUATION 6.7
TOTAL NITROGEN IN INDUSTRIAL WASTEWATER EFFLUENT

$$N_{EFFLUENT,\ IND} = TN \bullet W \bullet 365$$

Where:

$N_{EFFLUENT,\ DOM\ or\ IND}$ = total nitrogen in municipal or industrial wastewater treated in constructed wetland in inventory year (kg N/year)

P = human population in the country

Protein = annual per capita protein consumption, kg/person/yr

F_{NPR} = fraction of nitrogen in protein, default = 0.16 kg N/ kg protein

$F_{NON\text{-}CON}$ = factor for non-consumed nitrogen added to the wastewater

$F_{IND\text{-}COM}$ = correction factor for additional industrial wastewater discharged into sewers (for collected the default is 1.25, for uncollected the default is 1.00 as recommended in 2006 IPCC Guidelines

TN = total nitrogen concentration in the industrial wastewater treated by constructed wetland in inventory year (kg N/m3)

W = daily flow rate of industrial wastewater treated by constructed wetland, m^3/d

TN loading can be estimated by multiplying total volume of wastewater (Table 6.9 Chapter 6,Volume 4 in 2006 IPCC guideline) and N content in Table 6.6.

TABLE 6.6
EXAMPLE OF N CONTENT IN SOME NITROGEN-RICH INDUSTRIAL WASTEWATER

Industry type	Wastewater generation W (m^3/ton)	N Range (kg/m^3)
Alcohol refining	24 (16-32)[1]	2.40 (0.94-3.86)[2]
Fish processing industry	5 (2-8)[2]	0.60 (0.21-0.98)[3]
Seasoning source industry	NA	0.60 (0.22-1.00)[3]
Meat & Poultry	13 (8-18)[1]	0.19 (0.17-0.20)[3]
Starch Production	9 (4-18)[1]	0.90 (0.80-1.10)[4]
Nitrogen Fertilizer Plant	2.89 (0.46-8.3)[2]	0.50 (0.10-0.80)[2]
Landfill leachate	15-25% of annual precipitation[6]	0.74 (0.01-2.50)[5]

Note: Average value and range (in brackets) are presented

Sources:[1] 2006 IPCC GL; [2]Samokhin (1986); [3]Pilot Plant Development and Training Institute (1994); [4]Hulle et.al (2010): [5] Kjeldsen et al (2002); [6] Ehrig (1983)

6.3.2 Time series consistency

The same method and data sets should be used for estimating N_2O emissions from constructed wetland treating wastewater for each year. If a country decides to change the estimation method from default methodology (Tier 1) to country specific emission data (Tier 2), this change must be made for the entire time series.

6.3.3 Uncertainties

Large uncertainties are associated with the IPCC default emission factors for N_2O emissions from constructed wetlands due to limited number of available data.

TABLE 6.7
NITROUS OXIDE METHODOLOGY DEFAULT UNCERTAINTIES

Parameter	Default value	Range
Emission factor	0.00075 kg N_2O-N/kg N	0.00015-0.03
Activity data		
Human population	Country-specific	± 5%
Annual per capita protein consumption	Country-specific	± 10%
Fraction of nitrogen in protein	0.16	0.15-0.17
Factor for non-consumed nitrogen	1.1 for countries with no garbage disposals, 1.4 for countries with garbage disposals	1.0-1.5
TN loading from industrial wastewater	Country-specific	± 30%

6.3.4 QA/QC, Completeness, Reporting and Documentation

This method makes use of several default parameters. It is recommended to solicit experts' advice in evaluating the appropriateness of the proposed default factors. The methodology for estimating emissions is based on nitrogen associated with domestic and industrial discharge either collected into the collection system and treated in constructed wetland or uncollected and discharged into semi-natural treatment wetland. This estimate can be seen as conservative estimate and covers the entire source associated with domestic and industrial wastewater discharge.

Reporting and documentation

It is *good practice* to document and report a summary of the methods used, activity data and emission factors. Worksheets are provided at the end of this volume. When country-specific methods and/or emission factors are used, the reasoning for the choices as well as references to how the country-specific data (measurements, literature, expert judgment, etc.) have been derived (measurements, literature, expert judgment, etc.) should be documented and included in the reporting.

More information on reporting and documentation can be found in Volume 1, Chapter 6, Section 6.11 Documentation, archiving and reporting.

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