CHAPTER 6

CONSTRUCTED WETLANDS - WASTEWATER TREATMENT

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6 CONSTRUCTED WETLANDS-WASTEWATER TREATMENT

6.1 INTRODUCTION

Wetland ecosystems can act as sources, sinks, or transformers of nutrients and carbon (Mitsch and Gossenlink, 1993). This ability of wetlands has led to a widespread use of natural and constructed wetlands for water quality improvement (Brix, 1997).

Constructed wetlands systems are fully human-made wetlands for wastewater treatment, which apply various technological designs, using natural wetland processes, associated with wetland hydrology, soils, microbes and plants. Thus, 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” (Vymazal, 2007). In general the size of constructed wetlands is varied from 5,000 m^2 to 34,000 m^2.

"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. In general the size of semi-natural treatment wetlands is approximately 405,000 m^2.

If freshwater and coastal wetlands are modified to semi-natural treatment wetlands, compilers should check with relevant land-use category in this supplement to avoid double-counting.

APPLICATION OF CONSTRUCTED WETLANDS FOR WASTEWATER TREATMENT

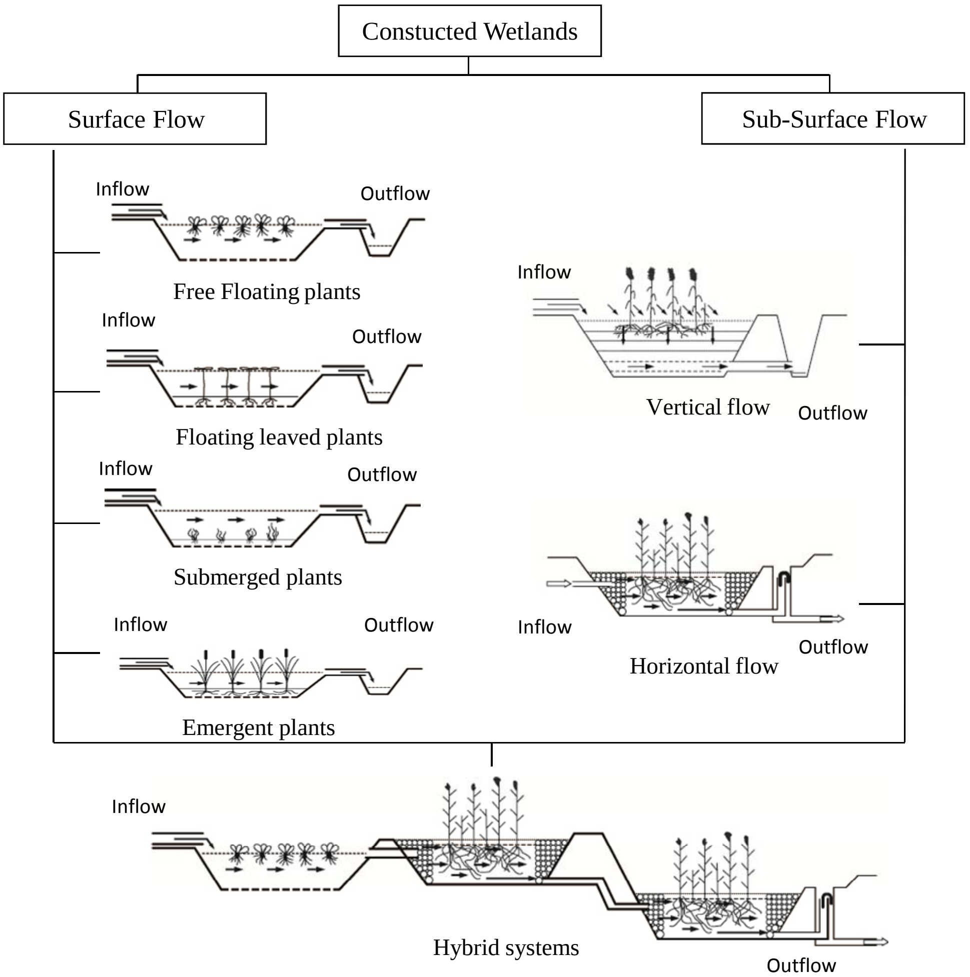
Constructed wetlands are used to improve the quality of water polluted from point and nonpoint sources of water pollution, including stormwater runoff, domestic wastewater, agricultural wastewater, and mine drainage. Constructed wetlands are also being used to treat petroleum refinery wastes, compost and landfill leachates, aquaculture discharges, and pre-treated 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, 1995).

There are various types of constructed wetlands used for treatment of wastewater, and following paragraph 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) (Figure 6.1; 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 and configuration of constructed wetlands for wastewater treatment



Note: Adopted from Vymazal, 2007, 2011.

Constructed Wetlands with Surface Flow

Constructed wetlands with *surface flow* (SF), known as *free water surface constructed wetlands*, contain areas of open water and floating, submerged, and emergent plants (Kadlec and Wallace 2008). The shallow water depth, low flow velocity, and presence of the plant stalks and litter regulate water flow and, especially in long, narrow channels (Crites et al 2005), ensure better water purification. The most common application for SF 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). SF wetlands are suitable in all climates, including the far north (Mander and Jenssen 2003).

Constructed Wetlands with Subsurface Flow

Vertical subsurface flow constructed wetlands (VSSF CWs) comprise a flat bed of graded gravel topped with sand planted with macrophytes. VSSF CWs are fed with large intermittent wastewater flows, which flood the surface of the bed, then in VSSF CWs 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, VSSF CWs provide greater oxygen transfer into the bed, thus producing a nitrified (high NO_3^-) effluent (Cooper et al 1996; Cooper 2005). Consequently, VSSF CWs do not provide suitable conditions for denitrification to complete conversion to gaseous nitrogen forms, which then escape to the atmosphere.

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

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

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 (VSSF-HSSF system). The VSSF wetland is intended to remove organics and suspended solids and to promote nitrification, while in HSSF wetland denitrification and further removal of organics and suspended solids occur.

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

The VSSF-HSSF and HSSF-VSSF 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 such as methane (CH_4) and nitrous oxide (N_2O) are a "byproduct" of constructed wetlands, the importance of which has been increasing recently. Methane is produced in methanogenesis whereas nitrous oxide is product of denitrification and/or nitrification of N compounds by microorganisms. Among several environmental factors controlling the greenhouse gases emissions, availability of C and nutrients (especially N) which directly depend on wastewater loading, temperature, hydrological regime (pulsing vs steady-state flow), groundwater depth, moisture of filter material (water filled soil pores (WFSP)), and presence of aerenchymal plants plays 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/decrease (depends on conditions)	Increase
Pulsing hydrological regime (intermittent loading)	Clear decrease	Increase (decrease in some SF CWs)
Deeper water table (from surface) in HSSF CWs	Decrease	Increase

Soil temperature, oxidation reduction potential and the soil moisture (WFSP, depth of (ground) water level) are the most significant factors affecting emissions of CH_4 in constructed wetlands (Mander et al 2003; Van der Zaag et al 2010). Several investigations show that a water table deeper than 20 cm from the surface of wetlands and/or water-logged soils oxidizes most CH_4 fluxes (Soosaar et al 2011; Salm et al 2012). Fluxes of N_2O, however do not show a clear correlation with soil/air temperature, and significant emissions of N_2O from constructed wetlands have been observed in winter (Søvik et al 2006). Likewise, freezing and thawing cycles enhance N_2O emissions (Yu et al 2011). Hydrological regime also plays a significant role in greenhouse gases emissions from 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 decrease CH_4 emissions. N_2O emissions, in contrast, do not show a clear pattern regarding pulsing regime.

Table 6.2 shows CH_4 and N_2O conversion rates derived from the relationship between the initial (input) C and N loadings in and respective CH_4 and N_2O emissions from the main types of constructed wetlands. There is a significant positive correlation ($p < 0.05$) between the initial loadings and CH_4 and N_2O emissions from both SF and VSSF 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. The limited number of available data did not allow derivation of reliable relationships for HSSF constructed wetlands. These shares can be used as a base for the calculation of emission factors for Tier 1 and Tier 2 methodologies. The high emission factor for CH_4 in SF CWs (Table 6.4) is thought to be due to the additional CH_4 from sediments accumulated at the bottom of SF wetlands.

TABLE 6.2
INFLUENT TOTAL ORGANIC CARBON (TOC) AND TOTAL NITROGEN (TN) VALUES, RELEVANT CH_4-C AND N_2O-N EMISSIONS, AND SHARE (%) OF CH_4-C AND N_2O-N IN THE INITIAL LOADING OF TOC AND TN IN CONSTRUCTED WETLANDS

Type of CW	Influent TOC* mg C m^{-2} h^{-1}	CH_4-C emission* mg CH_4-C m^{-2} h^{-1}	CH_4-C/TOC** %	Influent TN* mg N m^{-2} h^{-1}	N_2O-N emission* mg N_2O-N m^{-2} h^{-1}	N_2O-N/TN** %
SF	31 (6) [a-n]	6 (1.2) [a-n]	40 (5.9; 7-07; 27)	127 (31) [b,f-h,j,k,m, x-aa]	0.12 (0.03) [b,f-h,j,k,m,x-aa]	0.24 (0.10; 0.01-2.19; 25)
VSSF	1670 (285) [f,h,k,o-q]	31 (9) [f,h,k,o-q]	1.44 (0.24; 0.32-3.42; 18)	919 (155) [f,h,k,m,o-q]	0.14 (0.03) [f,h,k,m,o-q]	0.021 (0.005; 0.001-0.058; 21)
HSSF	1118 (858) [h,k,o,r-w]	3.6 (0.7) [h,k,o,r-w]	26.1 (14.2; 0.03-129.5; 11)	124 (48) [f,k,o,r-t,w,ab,ac]	0.33 (0.13) [f,k,o,m,r-t,w,ac]	1.0 (0.5; 0.04-3.01; 7)

* Average and standard error (in bracket).

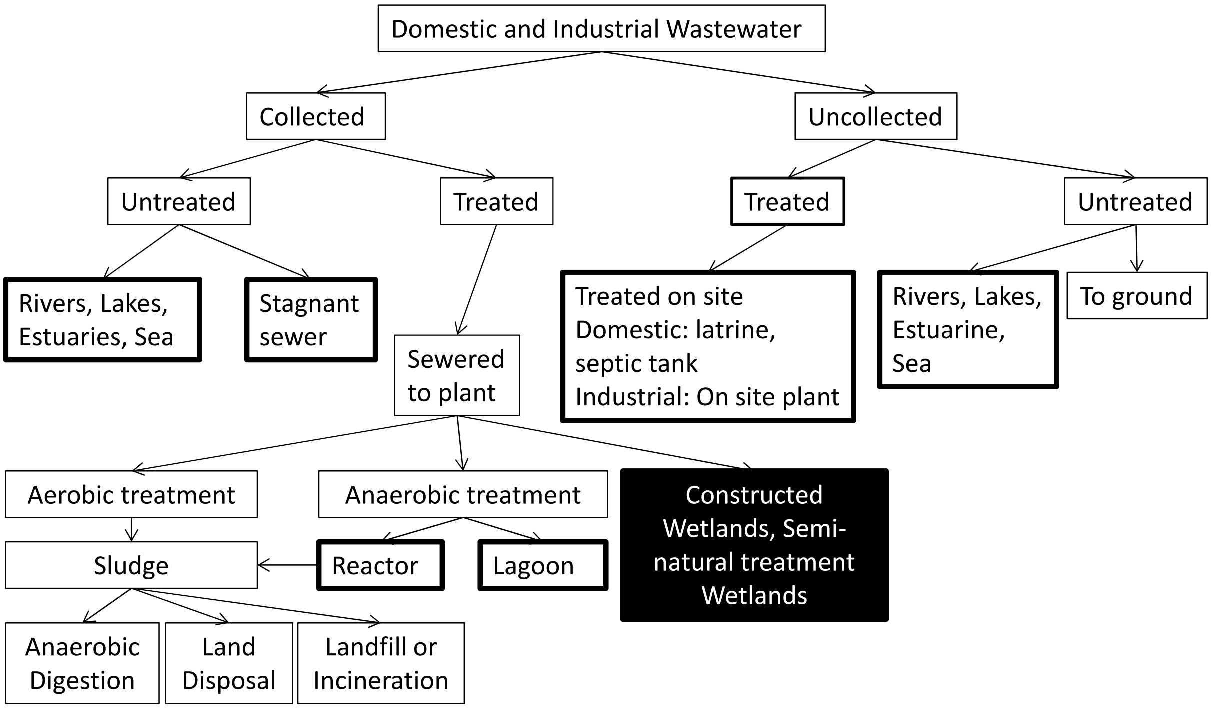
** Average, and standard error, range of values and number of sites studied (in bracket)

Source: a - Tanner et al 1997; b - Wild et al 2001; c - Tai et al 2002; d - Johansson et al 2004;e - Stadmark & Leonardson 2005; f - Søvik et al 2006; g - Søvik & Kløve 2007; h - Gui et al 2007; i - Altor & Mitsch 2008; j - Ström et al 2008; k - Liu et al 2009; l - Nahlik & Mitsch 2010; m - Van der Zaag 2010; n - Sha et al 2011; o - Teiter & Mander 2005; p - Inamori et al 2007; q - Wang et al 2008; r - Mander et al 2005; s - Mander et al 2008, t - Liikanen et al 2006; u - Garcia et al 2007; v - Picek et al 2007; w - Chiemchaishri et al 2009; x - Xue et al 1999; y - Johansson et al 2004; aa - Wu et al 2009; ab - Inamori et al 2008; ac - Fey et al 1999

6.1.1 Relation to 2006 IPCC Guidelines

This chapter is a supplement to Chapter 6 WASTEWATER TREATMENT AND DISCHARGE in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. The *2006 IPCC Guidelines* include a section to estimate CH_4 emissions from uncollected wastewater. The section is expanded in this supplement to cover CH_4 emissions from constructed wetlands and semi-natural treatment wetlands. This *Wetlands Supplement* includes guidance on estimation of 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 those treating domestic wastewater treating ones. CO_2 emissions are not included in greenhouse gases emissions from wastewater treatment as CO_2 from wastewater is considered biogenic.

Figure 6.2 Wastewater treatment systems and discharge pathways



Note: Emissions from boxes with bold frames are accounted for 2006 IPCC Guidelines. Supplement provides EF for black-colored 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* provides guidance on estimation of CH_4 and N_2O emissions from domestic wastewater with emission factors based on treatment technology. Constructed wetland in this supplement is an additional treatment technology. The emission factors provided in this chapter cover constructed wetlands and semi-natural treatment wetlands (collected and treated) see Figure 6.2.

The methodology is provided for estimation of CH_4 and N_2O emissions from both domestic and industrial wastewater. The indirect N_2O emissions from N leaching and 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 from solid waste landfill leachate have already been considered in solid waste disposal on land in Chapter 3, Volume 5 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 GREENHOUSE GAS EMISSIONS FROM CONSTRUCTED WETLANDS

Type of Wastewater	Methane	Nitrous oxide
Domestic wastewater	Included in this supplement with provision of methane correction factor (MCF)	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	Included in this supplement with provision of EF
Collected runoff from agricultural land	Collected runoff waters can be considered as industrial wastewater and are covered in this supplement	Collected runoff waters can be considered as industrial wastewater and are covered in this supplement Note: Indirect N_2O emissions from N leaching and runoff from agricultural land are considered in Chapter 11, Volume 4 of the 2006 IPCC Guidelines and the amount of nitrogen flow into CWs must be subtracted to avoid double counting.
Leachate from landfill	The amount of DOC leached from the SWDS is not considered in the estimation of DOC_f. Generally the amounts of DOC lost with the leachate are less than 1 percent and can be neglected in the calculations (Chapter 3, Volume 5, 2006 IPCC Guidelines) and not considered in this supplement	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.

Three tiers of methods for estimation of 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 is used by countries with good data and advanced methodologies. A more advanced country-specific method could be based on treatment system-specific data such as plant species and composition of wastewater.

In general anaerobic condition occurs in CWs. However, CH_4 generated by constructed wetlands is not usually recovered and combusted in a flare or energy device, and so CH_4 recovery is not considered here.

The amount of vegetation harvesting from constructed wetland is generally very small and its impact on 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.

6.2.1.1 CHOICE OF METHOD

A decision tree for domestic or industrial wastewater is shown in Figure 6.3.

The general equation to estimate CH_4 emissions from constructed wetlands treating domestic or industrial wastewater is given in Equation 6.1.

EQUATION 6.1
CH_4 EMISSIONS FROM CONSTRUCTED WETLANDS

$$CH_4\ Emissions = TOW \bullet EF$$

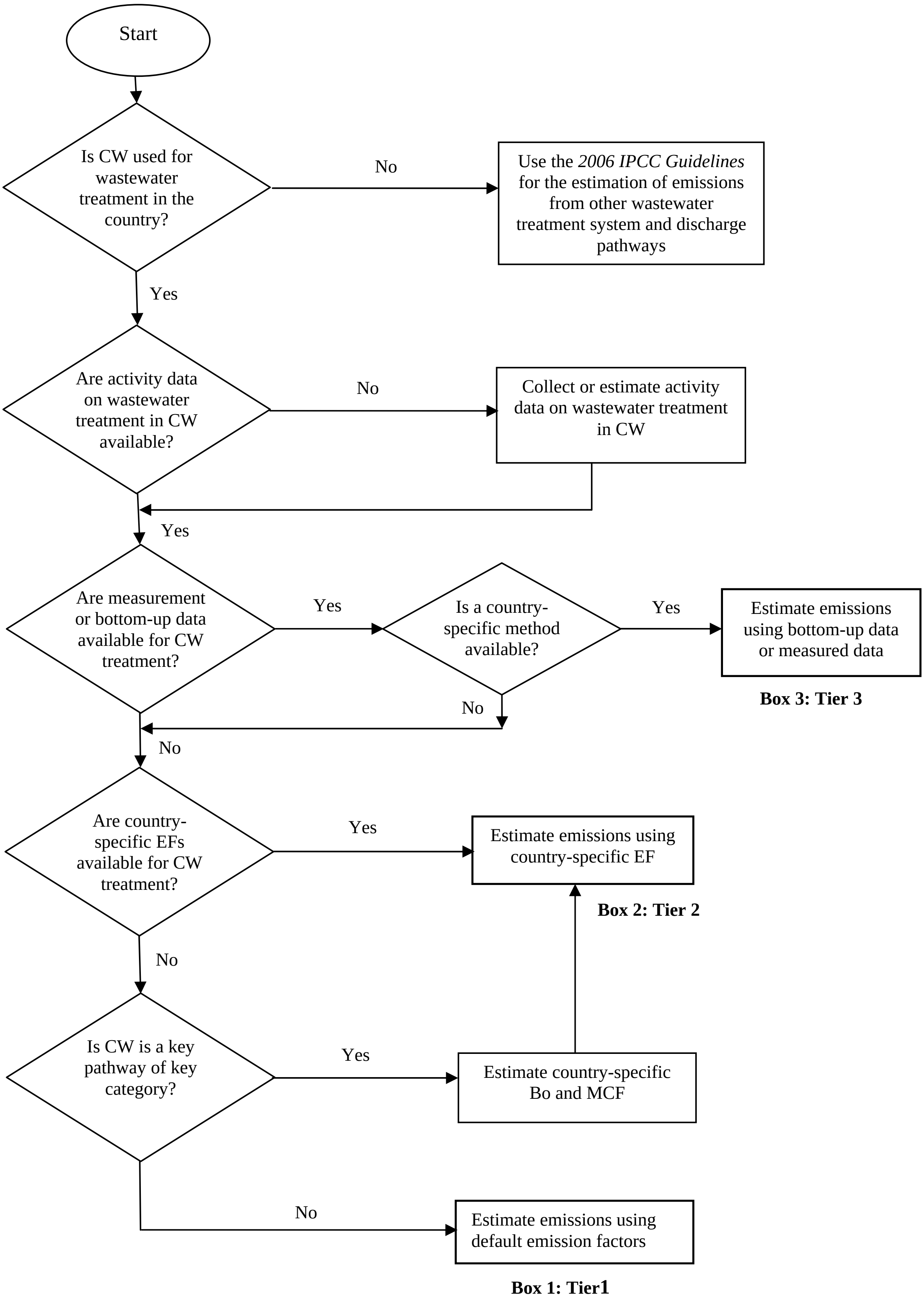
Where:

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

Figure 6.3 Decision tree for CH_4 emissions from constructed wetlands



6.2.1.2 CHOICE OF EMISSION FACTORS

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

EQUATION 6.2
CH_4 EMISSION FACTOR FOR CONSTRUCTED WETLANDS

$$EF = B_o \bullet MCF$$

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)

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

The *2006 IPCC Guidelines* provide default 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.

The Methane Correction Factor (MCF) indicates the extent to which CH_4 producing capacity (B_o) 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 is provided in Table 6.4, which is derived from literature-based analysis of CH_4 conversion rates: each MCF is calculated from the relation of initial TOC loading and methane emission flux derived from references provided in Table 6.2.

TABLE 6.4
METHANE CORRECTION FACTORS BY TYPE OF CONSTRUCTED WETLAND

CW type	MCF	Range
Surface flow (SF)	0.35	0.32-0.37
Horizontal subsurface flow (HSSF)	0.1	0.064-0.227
Vertical subsurface flow (VSSF)	0.03	0.025-0.048

These MCF values are derived based on actual measurement data and thus the operating and environmental conditions such as vegetation types and temperature effect have been taken into account. Based on the reported scientific data, there was insufficient information to distinguish the MCF value for different vegetation types and operating temperatures. Nevertheless, these influencing factors can be considered for the estimation using higher tier approach. Generally semi-natural treatment wetlands are surface flow type, therefore, the default MCF of 0.35 can be used. The highest MCF must be chosen if the type of constructed wetland cannot be recognized. Otherwise country-specific data should be used in higher tier method.

6.2.1.3 CHOICE OF ACTIVITY DATA

The activity data for this source category is the amount of organic materials (TOW) in the wastewater treated by constructed wetland. This parameter is a function of the population served by the constructed wetland system, and the biochemical oxygen demand (BOD) generation per person per day. BOD default values for selected countries are provided in the *2006 IPCC Guidelines* (Table 6.4, Chapter 6, Volume 5). In the 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, Volume 5 of the *2006 IPCC Guidelines*.

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

The equations for TOW are:

EQUATION 6.3
TOTAL ORGANICALLY DEGRADABLE MATERIAL IN DOMESTIC WASTEWATER

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

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 the constructed wetland in inventory year (kg BOD/year or kg COD/year)

P = population whose wastewater treated in CWs*

BOD = 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 wetlands in the inventory year (kg COD/m^3)

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

* Population should be subtracted from total population used in an Equation 6.3 in the *2006 IPCC Guidelines* to avoid double-counting.

6.2.2 Time series consistency

The same method and data sets should be used for estimating CH_4 emissions from constructed wetlands treating wastewater for each year. The MCF for different treatment systems should not change from year to year, unless such a change is justifiable and documented. If the share of wastewater treated in different treatment systems changes over the time period, the reasons for these changes should be documented.

For activity data that are derived from population data, countries must determine the fraction of the population served by constructed wetland systems. If data on the share of wastewater treated are missing for one or more years, the splicing techniques such as surrogate data and extrapolation/interpolation described in Chapter 5, Time Series Consistency, of Volume 1 General Guidance and Reporting of the *2006 IPCC Guidelines* can be used to estimate emissions. Emissions from wastewater treated in constructed wetlands typically do not fluctuate significantly from year to year.

6.2.3 Uncertainties

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

- The quantity of wastewater that is treated in constructed wetlands or semi-natural treatment wetlands.
- 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 wetlands in developing countries.

- Different plant species applied in constructed wetlands that are involved in gas exchange.

TABLE 6.5
DEFAULT UNCERTAINTY RANGES FOR DOMESTIC AND INDUSTRIAL WASTEWATER

Parameter	Uncertainty range
Emission factor	
Maximum CH_4 producing capacity (Bo)	± 30%
Methane correction factor (MCF)	SF: -8%,+14%, VSSF: -16%, +60% HSSF: -36%, +127%
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 of the *2006 IPCC Guidelines*. Some fundamental QA/QC procedures include:

Activity Data

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

Emission Factors

- For domestic wastewater, inventory compilers can compare country-specific values for B_o with the IPCC default value (0.25 kg CH_4/kg COD or 0.6 kg CH_4/kg BOD). As there are no IPCC default values for the fraction of wastewater treated anaerobically, inventory compilers are encouraged to compare values for MCFs against those from other countries with similar wastewater handling practices.
- Inventory compilers should confirm the agreement between the units used for 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. Constructed wetlands and semi-natural treatment wetlands are under treated and collected pathway. In general, the amount of vegetation harvested from constructed wetlands 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 systems. So inventory compilers should ensure that these sectors are covered. Periodically, the inventory compilers should re-survey industrial sources, particularly if some industries are growing rapidly. This category should only cover industrial wastewater treated onsite. Emissions from industrial wastewater released into domestic sewer systems should be addressed and included with domestic wastewater.

Reporting 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 a constructed wetland through nitrification and denitrification. Emissions are a function of the total nitrogen loaded into constructed wetland and an emission factor.

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 factors and country-specific activity data.

The Tier 3 method is used by countries with good data and advanced methodologies. A more advanced country-specific method is based on treatment system-specific data such as plant species and composition of wastewater.

The methodology provided assumes typical vegetation harvesting practices. However, the amount of vegetation harvested from constructed wetlands (studied until now) is generally very small and the harvested plant biomass is commonly not recorded so the harvesting practice is not considered as an influencing factor in the estimation of emissions.

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

6.3.1.1 CHOICE OF METHOD

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

The general equation to estimate N_2O emissions from constructed wetlands treating domestic or industrial wastewater is shown in Equation 6.5.

EQUATION 6.5
N_2O EMISSIONS FROM CONSTRUCTED WETLANDS

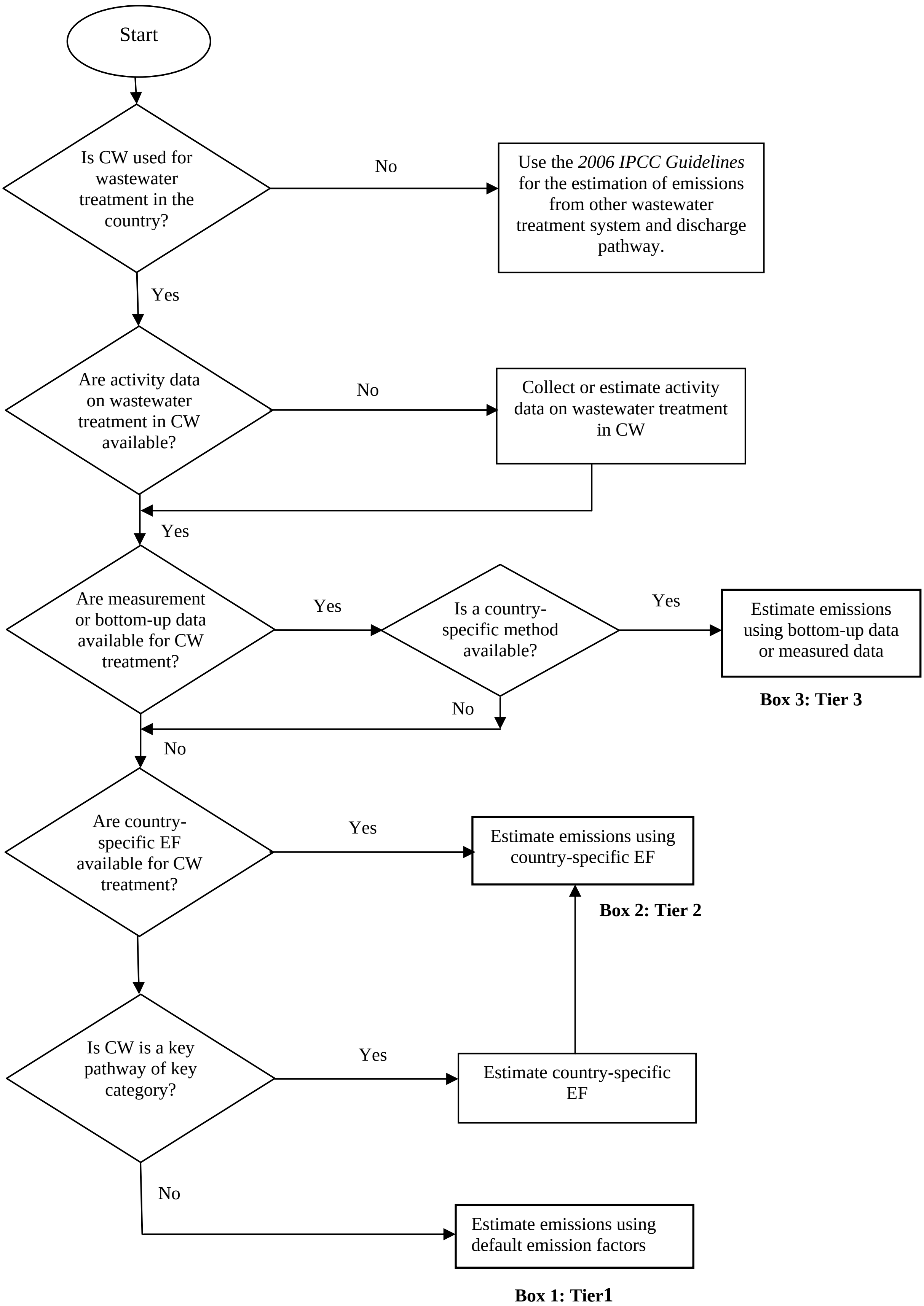
$$N_2O\ Emissions = N_{EFFLUENT} \bullet EF \bullet 44/28$$

Where:

N_2O Emissions	=	N_2O emissions in inventory year, kg N_2O/yr
$N_{EFFLUENT}$	=	Total nitrogen in wastewater treated by constructed wetlands in the inventory year, kg N/year
EF	=	Emission factor, kg N_2O-N/kg N

The factor 44/28 is the conversion of kg N_2O-N into kg N_2O.

Figure 6.4 Decision tree for N_2O emission from constructed wetland



6.3.1.2 CHOICE OF EMISSION FACTORS

The default IPCC emission factors for N_2O emitted from domestic and industrial wastewater treated by constructed wetlands are 0.0024 kg N_2O-N/kg N for SF, 0.01 kgN_2O-N/kg N for HSSF and 0.00021 kgN_2O-N/kg N for VSSF. These values are based on data provided in the literatures and 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 are the amount of nitrogen in the wastewater treated by constructed wetlands (TN). This parameter is a function of the population served by the constructed wetland system, annual per capita protein consumption (protein) and a factor for non-consumed nitrogen added to the wastewater for domestic wastewater. In case of industrial wastewater, TN loading to the constructed wetland system in the inventory year (kg N) can be used directly. The equations for determining TN for domestic and industrial wastewater are:

EQUATION 6.6
TOTAL NITROGEN IN DOMESTIC WASTEWATER EFFLUENT

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

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 the constructed wetland in inventory year (kg N/year)

P = human population whose wastewater treated by constructed wetlands

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/m^3)

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 5 in *2006 IPCC Guidelines*) 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 Guidelines*; [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 wetlands for each year. If a country decides to change the estimation method from the 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 available data.

TABLE 6.7 NITROUS OXIDE METHODOLOGY DEFAULT UNCERTAINTIES		
Parameter	**Default value**	**Range**
Emission factor (kg N_2O-N/kg N)	0.0024 for SF 0.01 for HSSF 0.00021 for VSSF	0.0001-0.0219 for SF 0.0004-0.0301 for HSSF 0.00001-0.00058 for VSSF
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 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 Section 6.11, Chapter 6, Volume 1 of the *2006 IPCC Guidelines*.

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