# CHAPTER 6

# WASTEWATER TREATMENT AND DISCHARGE

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# 6 WASTEWATER TREATMENT AND DISCHARGE

## 6.1 INTRODUCTION

This chapter presents an update of the Wastewater Treatment and Discharge chapter of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). The refinements laid out in this chapter provide clarity over how to apply the *2006 IPCC Guidelines* and definitions of treatment systems presented, and introduce new and improved default values and emission factors based on further scientific research into the mechanisms associated with greenhouse gas emissions from wastewater treatment (including sludge treatment that occurs within the wastewater treatment plant). In addition, these refinements present an updated section on nitrous oxide emissions to better address emissions from domestic wastewater, including centralized treatment plants and plants that use biological nutrient removal techniques, and to include emissions from industrial wastewater.

This chapter is intended to be used in conjunction with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, as well as the 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (IPCC 2014). This document is organized in the same manner as the *2006 IPCC Guidelines*; however, in some cases, we note where the proposed refinements expand on the existing Guidelines and present additional subsections to address that refinement. The remainder of this introduction provides elaboration to the 2006 IPCC Guidelines by presenting a summary of the refinements compared to the *2006 IPCC Guidelines* and an updated Figure 6.1 and Table 6.1 noting where refinements have been added.

### CHANGES COMPARED TO 2006 IPCC GUIDELINES

The *2006 IPCC Guidelines* included combined equations to estimate $CH_4$ emissions from wastewater and from sludge removed from the wastewater. However, in some cases, this combined equation caused confusion among inventory compilers when calculating $CH_4$ emissions from aerobic systems with anaerobic sludge digestion. In these cases, some compilers estimated zero $CH_4$ emissions from well operated wastewater treatment systems, and then subtracted emissions associated with sludge digestion operations without first estimating the $CH_4$ emissions from sludge treatment, resulting in negative emissions. In this refinement, we elaborate on the proper way to use the equation in such situations, and we present an update to provide guidelines on the calculation of the organic component removed in sludge.

In addition, certain emission factors for $CH_4$ emissions from domestic and industrial wastewater treatment have been updated to reflect additional measurement data on emissions from septic systems and centralized treatment plants.

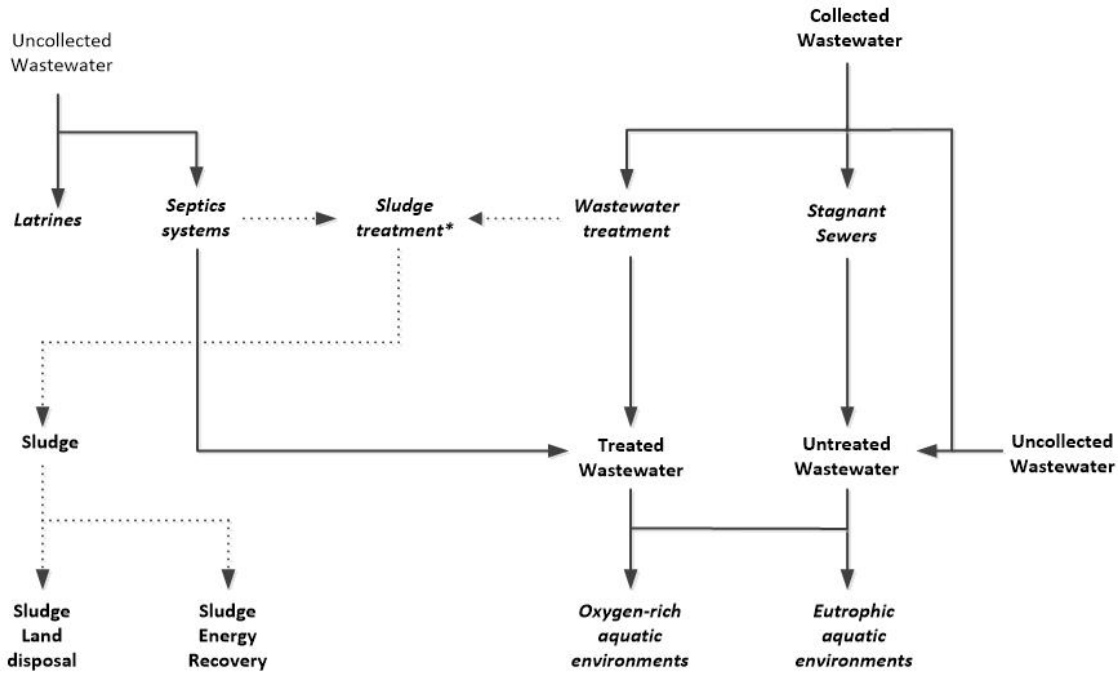
The *2019 Refinement* also includes new guidance on how to estimate $N_2O$ emissions from industrial wastewater, and presents updated guidance to estimate direct $N_2O$ emissions from centralized wastewater treatment plants. Furthermore, the $N_2O$ emission factors for wastewater discharged to aquatic environments have been updated and the calculation of $N_2O$ emissions from effluent discharged to aquatic systems has been updated to reflect the removal of nitrogen that occurs during treatment.

The remainder of this section includes additional discussion of the types of wastewater and sludge treatment systems in use, and the potential of those systems to generate $CH_4$ and $N_2O$ emissions. Figure 6.1 and Table 6.1 has been updated to reflect the $CH_4$ and $N_2O$ emission potential of wastewater and sludge treatment systems.

### UPDATED FIGURE 6.1 AND TABLE 6.1

Figure 6.1 has been simplified and Table 6.1 has been updated to reflect the main wastewater treatment and discharge systems in developed and developing countries. Figure 6.1 depicts the emissions that are captured in this chapter, and Table 6.1 discusses their potential to emit $CH_4$ and $NO_2$.

128 **Figure 6.1 Updated wastewater treatment systems and discharge pathways**




***Note: Bold, italicised items are included here in Volume 5, Chapter 6. Sludge treatment is included when performed at centralised wastewater treatment facilities, otherwise see Volume 5, Chapter 4.**

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**UPDATED TABLE 6.1**
**$CH_4$ AND $N_2O$ EMISSION POTENTIALS FOR WASTEWATER AND SLUDGE TREATMENT AND DISCHARGE SYSTEMS**

| Types of treatment and disposal | | | | $CH_4$ and $N_2O$ emission potentials |
|---|---|---|---|---|
| **Discharge from Collected or Uncollected Systems** | Untreated or Treated Systems | River discharge | | While modulated by oxygen status, $CH_4$ is generated in a range of freshwater and estuarine environments. Among them, stagnant, oxygen deficient environments are probable sources of $N_2O$. |
| **Collected** | Untreated | Sewers (closed and under ground) | | Potential source of $CH_4/N_2O$. However, little data exist to quantify. |
| | | Sewers (open) | | Stagnant, overloaded open collection sewers or ditches/canals are likely significant sources of $CH_4$. |
| | Treated | Aerobic treatment | Centralized aerobic wastewater treatment plants | May produce limited $CH_4$ from anaerobic pockets.<br>Poorly designed or managed aerobic treatment systems produce higher $CH_4$ due to reduced removal of organics in sludge.<br>Advanced plants with nutrient removal (nitrification and denitrification) are sources of $CH_4$ and $N_2O$. |
| | | | Sludge anaerobic treatment in centralized aerobic wastewater treatment plant | Sludge may be a significant source of $CH_4$ if emitted $CH_4$ is not recovered and flared. |

**UPDATED TABLE 6.1**
**$CH_4$ AND $N_2O$ EMISSION POTENTIALS FOR WASTEWATER AND SLUDGE TREATMENT AND DISCHARGE SYSTEMS**

| | | | | |
|---|---|---|---|---|
| | | | Aerobic shallow ponds | Unlikely source of $CH_4$/$N_2O$.<br>Poorly designed or managed aerobic systems produce $CH_4$. |
| | | Anaerobic treatment | Anaerobic lagoons | Likely source of $CH_4$.<br>Not a source of $N_2O$. |
| | | | Anaerobic reactors | May be a significant source of $CH_4$ if emitted $CH_4$ is not recovered and flared. |
| **Uncollected** | Septic tanks | | | Frequent solids removal reduces $CH_4$ production. |
| | Open pits/Latrines | | | Pits/latrines are likely to produce $CH_4$ when temperature and retention time are favourable. |

## CENTRALIZED TREATMENT SYSTEMS

Centralized wastewater treatment systems may include a variety of processes, ranging from lagooning to advanced tertiary treatment technology for removing nutrients. Some wastewater may also be treated through the use of constructed (or semi-natural) wetland systems, which may be used as the primary method of wastewater treatment, or as a tertiary treatment step following settling and biological treatment. Constructed wetlands develop natural processes that involve vegetation, soil, and associated microbial assemblages to trap and treat incoming contaminants (IPCC 2014).

Soluble organic matter is generally removed using biological processes in which microorganisms consume the organic matter for maintenance and growth. The resulting biomass (sludge) is removed from the effluent prior to discharge to the receiving stream. Microorganisms can biodegrade soluble organic material in wastewater under aerobic or anaerobic conditions, where the latter condition produces $CH_4$. During collection and treatment, wastewater may be accidentally or deliberately managed under anaerobic conditions. In addition, the sludge may be further biodegraded under aerobic or anaerobic conditions, such as with anaerobic digestion.

The generation of $N_2O$ may also result from the treatment of domestic wastewater during both nitrification and denitrification of the nitrogen (N) present, usually in the form of urea, ammonia, and proteins. These compounds are converted to nitrate ($NO_3$) through the aerobic process of nitrification. Denitrification occurs under anoxic conditions (without free oxygen), and involves the biological conversion of nitrate into nitrogen gas ($N_2$), which is the main product of nitrification/denitrification processes. $N_2O$ is an intermediate product of both processes, but has typically been associated with denitrification. Research suggests that higher emissions of $N_2O$ may in fact originate from nitrification (Ahn et al. 20100), and that $N_2O$ may also result from other types of wastewater treatment operations (Chandran 2012).

A typical centralized treatment system configuration is a conventional plug flow activated sludge wastewater treatment system. Following grit removal and primary treatment for solids removal, wastewater is sent to a plug flow activated sludge reactor for carbonaceous biochemical oxygen demand (CBOD) removal, followed by secondary clarification where solids are allowed to settle from the wastewater. Clarified effluent is often disinfected prior to discharge. Secondary clarifier sludge is pumped out from the bottom of the clarifier. Of this sludge, a portion is sent back to the plug flow activated sludge treatment process (return activated sludge) and the remainder (waste activated sludge) is combined with primary sludge before being sent to sludge handling (such as gravity thickening). The sludge may be processed onsite in an anaerobic digester followed by further dewatering by centrifuge. Filtrate from the gravity thickener, centrate from the centrifuge, and supernatant from the anaerobic digester are returned to the influent stream at the headworks to the wastewater treatment system. Although the $CH_4$ emissions from well managed centralized aerobic plants may be small, they are not zero. These refinements introduce a new MCF associated with these systems. In addition, the $N_2O$ emission factor from centralized treatment presented in the *2006 Guidelines* represents this type of system.

Sometimes conditions form that result in the wastewater treatment system becoming hydraulically or organically overloaded, which results in degraded performance of the plant. In these cases, organic matter and nutrients that would normally be removed by the system instead pass through and are discharged to the aquatic environment. In addition, anaerobic conditions can form with the treatment system increasing the potential for $CH_4$ generation from an otherwise aerobic system.

Other more advanced configurations of biological treatment have become more commonplace and are typically used for nutrient reduction. These “biological nutrient removal” (BNR) and “enhanced nutrient removal” (ENR) systems typically have a combination of aerobic, anaerobic, and anoxic treatment zones to further the removal of

nitrogen and phosphorus, which also results in higher potential for $CH_4$ and $N_2O$ emissions. Even higher potential for $N_2O$ emissions occurs with more advanced systems, such as membrane bioreactor systems. This refinement presents new emission factors associated with these types of systems.

## DECENTRALIZED TREATMENT SYSTEMS OF DOMESTIC WASTEWATER (ON-SITE SANITATION)

Depending on national circumstances, domestic wastewater not connected to a centralized wastewater treatment plant may be directly discharged in natural aquatic environments (rivers, lakes, oceans, etc.) or treated using on-site sanitation. The most common on-site treatment systems are holding tanks, septic systems and latrines.

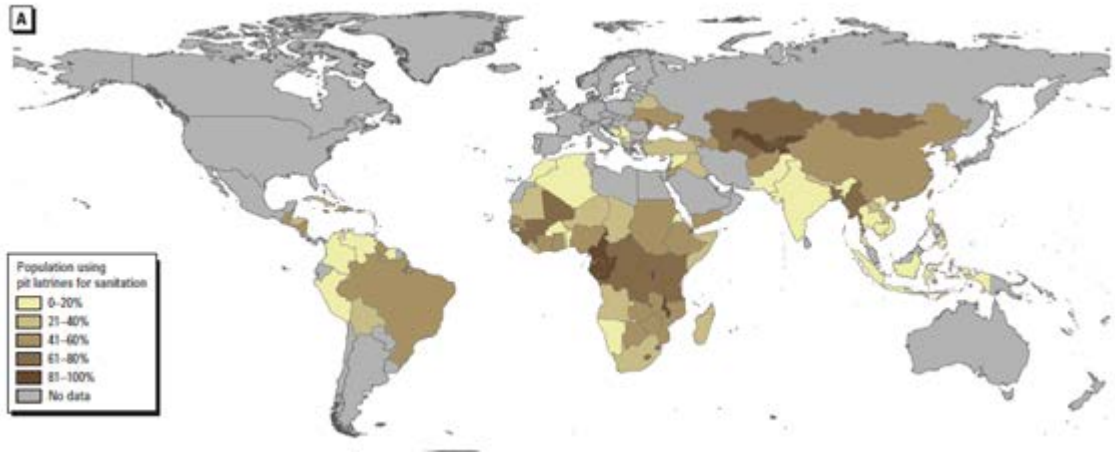
A septic system is usually composed of a septic tank, generally buried in the ground, and a soil dispersal system. Solids and dense materials contained in the incoming wastewater (influent) settle in the septic tanks as sludge. Floatable material (scum) are also retained in the tank. The sludge settled on the bottom of the tank undergo anaerobic digestion. Partially treated water is discharged in the dispersal system. The liquid fraction remains only some hours in the tank and the hydraulic retention time (HRT) varies from 24h to 72hr depending on the tank geometry. The solid fraction accumulates and remains in the tank undergoing anaerobic decomposition for several years. The solid retention time (SRT) depends on the sludge withdrawal frequency. The gas produced in the sludge during anaerobic digestion (mainly $CH_4$ and biogenic $CO_2$) rise to the liquid surface and are usually released through vents. The gas produced in the dispersal system (mainly $N_2O$ and biogenic $CO_2$) are released through the soil.

In some high-income countries, on-site aerated wastewater treatment systems are used and allow a more efficient treatment than septic tanks in reducing the organic load of domestic effluent. The process usually involves a first step of sedimentation and anaerobic digestion, a second step of aerobic treatment and last step of clarification and disinfection. The treated effluent is discharged into the environment via surface irrigation or absorption trench.

A latrine usually consists of a slab over a pit which may be 2 meters or more in depth. There is a wide range of options for latrines (simple pit latrines, ventilated latrines, composting latrines, etc.) having in common that no water is used to flush excreta into the pit or only a little (poor flush latrines in which water is poured by hand). Pit latrine are utilised by more than 1.5 billion people in the word especially in low-income countries. Pit latrines gas emissions depends in part on local groundwater level. Anaerobic conditions favourable to $CH_4$ emissions occur when the water table submerged the organic waste in the pit.

Where there are no latrines people resort to defecation in open areas. Open defecation is not considered as a source of $CH_4$ as there is no anaerobic condition.

**Figure 6.1a. Percentage of low-income country populations using pit latrines as a primary sanitation facility (Graham and Polizzotto, 2013)**




## DISCHARGE TO EUTROPHIC WATERS

Dissolved $CH_4$ and $N_2O$ that is generated in sewers or present in untreated or primary treated discharges has the potential to be released (Short et al, 2014; 2017). A strong correlation between the condition of the aquatic environment and the generation of $CH_4$ and $N_2O$ has been observed (e.g., Smith et al, 2017). Therefore, where wastewater is then discharged to aquatic environments with eutrophic conditions (i.e., water bodies which are rich in nutrients and very productive in terms of aquatic animal and plant life), the additional organic matter in the discharged wastewater is expected to increase emissions. Many waterways are naturally eutrophic, while others

have been altered by human impacts. In the case of $CH_4$, most freshwaters are highly supersaturated with methane irrespective of recipient condition, so this refinement does not distinguish between eutrophic and oligotrophic waters. On the other hand, data permits the use of a Tier 2 method that estimates higher $N_2O$ emissions for eutrophic waters. Inventory compilers will have to consider the condition of water bodies in their countries receiving wastewater discharge.

### 6.1.1 Changes compared to 1996 Guidelines and Good Practice Guidance

Elaboration on the changes compared to the *2006 IPCC Guidelines* are given in Section 6.1.

## 6.2 METHANE EMISSIONS FROM WASTEWATER

### 6.2.1 Methodological issues

### 6.2.2 Domestic wastewater

#### 6.2.2.1 CHOICE OF METHOD

This section is an update to the *2006 IPCC Guidelines* to resolve confusion in the use of Equation 6.1. In general, the overall steps for *good practice* in inventory preparation for $CH_4$ from domestic wastewater have been updated as follows:

**Step 1:** Use Equation 6.3 to estimate total organically degradable carbon in wastewater (TOW). Use new Equation 6.3A to estimate total organically degradable carbon in wastewater for each treatment/discharge pathway or system, *j*, and each income group fraction *i* in inventory year.

**Step 1A:** Use Equations 6.3B and 6.3C to estimate the amount of organic component removed in sludge, *S*, from aerobic treatment plants and septic systems for each treatment/discharge pathway or system, *j*, and each income group fraction, *i*, in the inventory year.

**Step 2:** Select the pathway and systems (See Figure 6.1) according to country activity data. Use Equation 6.2 to obtain the emission factor for each domestic wastewater treatment/discharge pathway or system.

**Step 3:** Use new Equation 6.1A to estimate emissions and adjust for possible sludge removal and/or $CH_4$ recovery of treatment/discharge pathway or system, *j*, for each income group fraction *i* in inventory year. Use new Equation 6.1B to sum the emissions across all income groups.

These updates are presented because, in some cases, the original Equation 6.1 caused confusion among inventory compilers when calculating $CH_4$ emissions across multiple wastewater treatment/discharge pathways or systems across multiple income groups. These updates allow for a more stepwise process in estimating emissions throughout the country.

Additional confusion arose in the estimation of emissions from aerobic systems with anaerobic sludge digestion. In these cases, some compilers estimated zero $CH_4$ emissions from well operated wastewater treatment systems, and then subtracted emissions associated with sludge digestion operations without first estimating the $CH_4$ emissions from sludge treatment, resulting in negative emissions. For systems where sludge separation is practiced and appropriate statistics are available, we encourage countries to treat the wastewater treatment system and sludge treatment system as separate pathways. As an example, for an activated sludge treatment process, calculate the emissions and any $CH_4$ recovery directly associated with the aerobic treatment system as one pathway, and calculate the emissions and any $CH_4$ recovery directly associated with the sludge digestion system as a separate pathway. Net emissions from both systems should be summed together. In no circumstances should a country reports negative emissions.

Lastly, the use of the activity data S, organic component removed as sludge, is not explained in detail in the *2006 IPCC Guidelines.* Please see Section 6.2.2.3 for additional guidance on how to estimate this value if country-specific data are not available.

**NEW EQUATION 6.1A**
**TOTAL $CH_4$ EMISSIONS FROM DOMESTIC WASTEWATER FOR EACH INCOME GROUP**

$$CH_4\ Emissions_i = \sum_j \left[ (TOW_{ij} - S_{ij}) \bullet EF_j - R_{ij} \right]$$

Where:

$CH_4$ Emissions$_i$ = $CH_4$ emissions in inventory year for income group fraction, *i*, kg $CH_4$/yr

$TOW_{ij}$ = organics in wastewater of treatment/discharge pathway or system, *j*, for each income group fraction *i* in inventory year, kg BOD/yr, See Equation 6.3A.

$S_{ij}$ = organic component removed as sludge from treatment/discharge pathway or system, *j*, for each income group fraction *i* in inventory year, kg BOD/yr, See Equations 6.3B and 6.3C.

i = income group: rural, urban high income and urban low income

j = each treatment/discharge pathway or system

$EF_j$ = emission factor for treatment/discharge pathway or system, *j*, kg $CH_4$ / kg BOD

$R_{ij}$ = amount of $CH_4$ recovered from treatment/discharge pathway or system, *j*, for each income group fraction *i* in inventory year, kg $CH_4$/yr

**NEW EQUATION 6.1B**
**TOTAL $CH_4$ EMISSIONS FROM DOMESTIC WASTEWATER**

$$CH_4\ Emissions = \sum_i \left[ CH_4\ Emissions_i \right]$$

Where:

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

$CH_4$ Emissions$_i$ = $CH_4$ emissions in inventory year for income group fraction, *i*, kg $CH_4$/yr

i = income group: rural, urban high income and urban low income

## 6.2.2.2 CHOICE OF EMISSION FACTORS

This section represents an update to Section 6.2.2.2 of the *2006 IPCC Guidelines.*

As stated in the *2006 IPCC Guidelines,* it is *good practice* to use country-specific data for $B_o$, where available, expressed in terms of kg $CH_4$/kg BOD removed to be consistent with the activity data. However, if country-specific data are not available, a default value of 0.6 kg $CH_4$/kg BOD can be used. For domestic wastewater, a COD-based value of $B_o$ can be converted into a BOD-based value by multiplying with a factor of 2.4. Annex 6A.1 provides further explanation of the basis for these default Bo values to allow countries to consider if these values are appropriate for the specific characteristics of their waste streams.

In addition, the MCFs in Table 6.3 of the *2006 IPCC Guidelines* have been updated to reflect revisions to the following specific wastewater treatment and discharge pathways and systems.

### DISCHARGE FROM TREATED OR UNTREATED SYSTEMS

Table 6.3 presents an updated MCF associated with the discharge of wastewater to a water body of 0.27 and it is *good practice* to apply this MCF to discharges of both treated and untreated wastewater. The BOD of treated wastewater is typically 5-25 mg/L (Tchobanoglous et al, 2014; Hammer and Hammer, 2012), which provides sufficient conditions for the formation of $CH_4$ in a receiving water body. Furthermore, much of the dissolved $CH_4$ that is generated in sewers is released either in the treatment plant headworks or to the receiving water body in the case of untreated or primary treated discharges (Short et al, 2014; 2017). Recent research has demonstrated that even under oxic conditions, methanogenesis is feasible (Tang et al, 2016). Recent evidence points to the operation of both microbial and non-microbial methanogenic pathways in nature (e.g. Jugold et al, 2012) and strong relationships between the nutrient status of a receiving water body and the rate of generation of $CH_4$ have been observed (e.g. Smith et al, 2017). Despite this relationship, most rivers, estuaries and coastal waters are considerably supersaturated with $CH_4$, irrespective of their nutrient status (Grunwald et al, 2009; Lammers et al, 1995; Patra et al, 1998; Ward et al, 2017), while open oceans are slightly supersaturated (Tilbrook and Karl, 1995;

Oudot et al, 2002; Castro-Morales et al, 2014). So, while the conditions of the receiving water body play a modulating role in relation to the rate of methanogenesis, the addition of organic matter from sewer discharges is generally expected to increase $CH_4$ emissions in freshwater and coastal environments.

Using the same stoichiometric relationship as was used to calculate the default $B_o$ value, a ratio of 0.938 kg C per kg dissolved $O_2$ is obtained. Deemer et al (2016) performed an extensive review of measurements of $CH_4$ and $CO_2$ originating in aquatic systems, and independent measurements of both $CH_4$ and $CO_2$ emission fluxes around the world. Additional data were obtained from more recent publications (Smith et al, 2017; Wang et al, 2017; Yang et al, 2017) creating a set of 76 points in which emissions of both gases were measured. Using these data in combination with information on the partitioning of global carbon flows in freshwater systems (Tranvik et al, 2009) and a default $B_o$ of 0.25 kg $CH_4$/kg COD results in an MCF of 0.27.

## CENTRALIZED, AEROBIC TREATMENT PLANTS

The MCF for centralized aerobic treatment plants has been updated in Table 6.3 to reflect the potential for generation of $CH_4$ from these systems. In addition, the distinction between "well managed" and "not well managed" systems has been eliminated from the table and it is *good practice* to estimate $CH_4$ from all centralized, aerobic treatment plants.

Inventory compilers should evaluate if an aerobic wastewater treatment system is overloaded resulting in higher potential to form $CH_4$. To do this, compilers should compare the capacity for which the plant has been designed (i.e., the amount of influent BOD) with the population and/or influent BOD that is actually being serviced by the treatment system. When the influent BOD is over the capacity of the plant, it should be considered overloaded. In tourist areas, it is *good practice* to consider tourists in the evaluation of the overloaded status. In practice, this status could have a seasonal trend and the WWTP could be overloaded only during certain parts of the year. Alternatively, when detailed monitored data are available, it is good practice to evaluate if a system is overloaded by comparing the BOD treatment capacity (usually expressed in terms of g of BOD per day) to the effective average daily BOD in influent.

If a plant is overloaded, the removal of organic material as sludge will be reduced and should be reflected in the calculation of *S* in Equation 6.1A.

## ADVANCED BIOLOGICAL NUTRIENT REMOVAL SYSTEM

A new MCF for advanced biological nutrient removal systems, such as those described in Section 6.1, has been included Table 6.3 to reflect the increased potential for generation of $CH_4$ from these systems compared to aerobic treatment systems that are not optimized for nutrient removal. These advanced systems include anaerobic and anoxic zones to encourage the reduction of nitrogen, which increases the potential for generation and release of $CH_4$.

## IMPACT OF TEMPERATURE ON DECENTRALIZED TREATMENT SYSTEMS OF DOMESTIC WASTEWATER

Temperature affects wastewater treatment processes, in particular decentralized systems where no external supplemental heat is provided (uncontrolled temperature), and anaerobic digestion for which the optimal temperature is 30-38°C. At lower temperatures, the rate of anaerobic digestion decreases and $CH_4$ production becomes unlikely below 12°C. Inside septic tanks, the temperature is uncontrolled and is related to atmospheric temperature as well as hot and cold water used. There is a gradient of temperature inside the septic tank: warmer in the bottom (sludge layer) and colder at the top. Therefore, in countries having seasonal temperature trends, when the temperature in septic tanks is getting cooler, the rate of digestion slows, the solid retention time (SRT) increases, sludge accumulates, and $CH_4$ emissions decrease. When the liquid temperature is getting warmer, the rate of digestion increases, sludge accumulated during the cold season decomposes, gas solubility in the liquid decreases and $CH_4$ emissions increase. This situation corresponds to the 'spring boil' phenomenon (period of high emissions following a period of low emissions). Therefore, there is a seasonal variability of $CH_4$ emissions. [Leverenz 2010] However, at this time, insufficient data exist to establish a temperature-dependent emission factor associated with these systems. Countries that experience significant seasonal variations may wish to consider development of a country-specific emission factor.

First-order Draft

**UPDATED TABLE 6.3**
**DEFAULT MCF VALUES FOR DOMESTIC WASTEWATER**

| Type of treatment and discharge pathway or system | Comments | MCF [1] | Range |
|---|---|---|---|
| **Discharge from treated or untreated system** | | | |
| Sea, river and lake discharge | Most freshwater systems are supersaturated in $CH_4$. Nutrient oversupply will increase $CH_4$ emissions | 0.27 | 0.17 – 0.48 |
| **Untreated system** | | | |
| Stagnant sewer | Open and warm | 0.5 | 0.4 – 0.8 |
| Flowing sewer (open or closed) | Fast moving, clean. (Insignificant amounts of $CH_4$ from pump stations, etc) | 0 | 0 |
| **Treated wastewater treatment system** | | | |
| Centralized, aerobic treatment plant | Some $CH_4$ can be emitted from settling basins and other pockets. For treatment plants that are receiving wastewater beyond the design capacity, inventory compilers should judge the amount of organic material removed in sludge accordingly. | 0.005 | 0 – 0.1 |
| Advanced biological nutrient removal system | $CH_4$ can be emitted from anaerobic and anoxic zones in these systems. Specific emission rates are highly dependent on the specific treatment system configuration. | 0.05 | TBD |
| Anaerobic reactor | $CH_4$ recovery is not considered here. | 0.8 | 0.8 – 1.0 |
| Anaerobic shallow lagoon | Depth less than 2 metres, use expert judgment. | 0.2 | 0 – 0.3 |
| Anaerobic deep lagoon | Depth more than 2 metres | 0.8 | 0.8 – 1.0 |
| Septic system | Septic systems emit $CH_4$ from the tanks. | 0.5 | 0.4 – 0.72 |
| Latrine | Dry climate, ground water table lower than latrine, small family (3-5 persons) | 0.1 | 0.05 – 0.15 |
| Latrine | Dry climate, ground water table lower than latrine, communal (many users) | 0.5 | 0.4 – 0.6 |
| Latrine | Wet climate/flush water use, ground water table higher than latrine | 0.7 | 0.7 – 1.0 |
| Latrine | Regular sediment removal for fertilizer | 0.1 | 0.1 |
| **Sludge treatment system** | | | |
| Anaerobic digester for sludge | $CH_4$ recovery is not considered here. | 0.8 | 0.8 – 1.0 |

[1] Based on expert judgment by lead authors of this section.

TBD (to be determined): The default value(s) are being developed and will be provided in the second order draft (SOD).

## 6.2.2.3 CHOICE OF ACTIVITY DATA

This section is updated to include new equations for the calculation of total organics in wastewater by income group and treatment/discharge pathway or system, and the amount of organic component removed as sludge from aerobic treatment plants and from septic systems.

Inventory compilers should consider that sludge recovered from septic tanks may be transferred to centralised WWTPs. In these cases, it is *good practice* to include this additional organic load when estimating TOW in influent to the centralised WWTP.

The organic component removed as sludge, *S*, is not explained in detail in the *2006 IPCC Guidelines*. This section provides an update through the introduction of Equations 6.3B and 6.3C, which provide default calculations of S for aerobic treatment plants and septic systems, respectively. For aerobic treatment systems, some inventory compilers incorrectly defined the variable "S" in Equation 6.1 as the mass of sludge removed rather than the organic component of the sludge removed. It is important to note that the organic component removed from wastewater as sludge is not equivalent to the mass (tons) of sludge produced from wastewater treatment. Instead, the organic component removed as sludge is a function of sludge produced from wastewater treatment ($S_{MASS}$) and a sludge factor which indicates how much organic matter is removed from the treatment process per ton of sludge produced. Aerobic wastewater treatment plants with primary treatment remove about 30% of influent BOD by sedimentation as primary sludge. The aerobic stage of treatment removes 1.7 kg BOD per kg of secondary sludge. The sludge produced in aerobic wastewater treatment plant contains approximately 70% of primary sludge and 30% of secondary sludge by weight. Aerobic wastewater treatment plants without primary treatment removes about 1 to 1.5 kg BOD per kg of sludge, depending on process type.

**NEW EQUATION 6.3A**
**ORGANICALLY DEGRADABLE MATERIAL IN DOMESTIC WASTEWATER BY INCOME GROUP AND TREATMENT/DISCHARGE PATHWAY OR SYSTEM**

$$TOW_{ij} = TOW \bullet U_i \bullet T_{ij}$$

Where:

$TOW_{i,j}$ = total organics in wastewater in inventory year, kg BOD/yr, for income group i and treatment/discharge pathway or system, j. See Equation 6.2A.

TOW = total organics in wastewater in inventory year, kg BOD/yr, See Equation 6.2A.

$U_i$ = fraction of population in income group *i* in inventory year, See Table 6.5.

$T_{i,j}$ = degree of utilisation of treatment/discharge pathway or system, *j*, for each income group fraction

**NEW EQUATION 6.3B**
**ORGANIC COMPONENT REMOVED AS SLUDGE FROM AEROBIC TREATMENT PLANTS**

$$S_{aerobic} = \left(S_{mass} \bullet K_{rem}\right)$$

Where:

$S_{aerobic}$ = Organic component removed as sludge in aerobic treatment plants, kg BOD/yr

$S_{mass}$ = amount of sludge removed from waste water treatment, tons/year

$K_{rem}$ = sludge factor, kg BOD/kg sludge. The default factor is 0.8.

**NEW EQUATION 6.3C**
**ORGANIC COMPONENT REMOVED AS SLUDGE FROM SEPTIC SYSTEMS**

$$S_{Septic} = TOW_{Septic} \bullet F \bullet 0.5$$

Where:

$S_{septic}$ = Organic component removed as sludge in septic systems, kg BOD/yr

$TOW_{septic}$ = total organics in wastewater in septic systems inventory year, kg BOD/yr

F = fraction of the population managing their septic system complyingly with the removal instruction. The default value for F is 0 and corresponds to the situation where there is no removal of sludge from the septic system. It is good practice to apply the default value in countries where there is no regulation or administrative requirements for sludge removal in septic systems. In countries with such regulations or requirements, some evidence of maintenance controls must be provided (for instance the existence of a local public service responsible for on-site sanitation). It is good practice to assess the F value using a survey on sludge removal practices among population using septic systems.

### 6.2.2.4 TIME SERIES CONSISTENCY

No refinement

### 6.2.2.5 UNCERTAINTIES

This section provides an update to Table 6.7 to provide default uncertainty ranges for new or updated emission factor and activity data of domestic wastewater.

**UPDATED TABLE 6.7**
**DEFAULT UNCERTAINTY RANGES FOR DOMESTIC WASTEWATER**

| Parameter | Uncertainty Range |
|---|---|
| **Emission Factor** | |
| Maximum $CH_4$ producing capacity ($B_o$) | ± 30% |
| Fraction treated anaerobically (MCF) | The MCF is technology dependent. See Table 6.3. Thus the uncertainty range is also technology dependent. The uncertainty range should be determined by expert judgement, bearing in mind that MCF is a fraction and must be between 0 and 1. Suggested ranges are provided below.<br>Untreated systems and latrines, ± 50%<br>Lagoons, poorly managed treatment plants± 30%<br>Centralized well managed plant, digester, reactor, ± 10% |
| **Activity Data** | |
| Human population (P) | ± 5% |
| Biochemical oxygen demand (BOD) | ± 30% |
| Fraction of population income group (U) | Good data on urbanization are available, however, the distinction between urban high income and urban low income may have to be based on expert judgment. ± 15% |
| Degree of utilization of treatment/ discharge pathway or system for each income group ($T_{i,j}$) | Can be as low as ± 3% for countries that have good records and only one or two systems. Can be ± 50% for an individual method/pathway. Verify that total $T_{i,j}$ = 100% |
| Correction factor for additional industrial BOD discharged into sewers (I) | For uncollected, the uncertainty is zero %. For collected the uncertainty is ± 20% |
| Amount of sludge removed from waste water treatment ($S_{mass}$) | ± 30% |
| Sludge factor ($K_{rem}$) | ± 25% |
| Fraction of the population managing their septic system complyingly with the removal instruction (F) | Can be as low as ± 3% for countries that have good records on implementation. Can be ± 50% if based on expert judgement. |
| Amount of $CH_4$ recovered (R) | For systems with measured data, the uncertainty is equal to the uncertainty of the measurement system. |
| Source: Judgement by Expert Group (Authors of this section). | |

### 6.2.2.6 QA/QC, COMPLETENESS, REPORTING AND DOCUMENTATION

No refinement

## 6.2.3 Industrial wastewater

### 6.2.3.1 CHOICE OF METHOD

No refinement

### 6.2.3.2 CHOICE OF EMISSION FACTORS

This section represents an update to Section 6.2.3.2 of the *2006 IPCC Guidelines.*

As stated in the *2006 IPCC Guidelines,* there are significant differences in the $CH_4$ emitting potential of different types of industrial wastewater dependent on the type and form of constituents present in the wastewater. To the extent possible, data should be collected to determine the maximum $CH_4$ producing capacity ($B_o$) in each industry. However, if country-specific data are not available, Table 6.2a provides default values of $B_o$ for certain industry types.

In addition, the MCFs in Table 6.8 of the *2006 IPCC Guidelines* have been updated to reflect revisions to certain wastewater treatment and discharge pathways and systems, as described in Section 6.2.2.2.

**NEW TABLE 6.2A**
**DEFAULT MAXIMUM $CH_4$ PRODUCING CAPACITY ($B_O$) FOR INDUSTRIAL WASTEWATER**

| Industry Type | $B_0$ (kg CH4/kg COD) |
|---|---|
| Brewery | 0.25 |
| Food and Beverage | 0.22 |
| Meat processing | 0.26 |
| Potato Processing | 0.163 |
| Paper Production | 0.235 |
| Pulp Production | 0.196 |
| Wheat Starch Production | 0.206 |
| Yeast Wastewater | 0.106 |

Doorn, M.R.J., Strait, R., Barnard, W. and Eklund, B. (1997). Estimate of Global Greenhouse Gas Emissions from Industrial and Domestic Wastewater Treatment, Final Report, EPA-600/R-97-091, Prepared for United States Environmental Protection Agency, Research Triangle Park, NC, USA.

No range are provided.

**UPDATED TABLE 6.8**
**DEFAULT MCF VALUES FOR INDUSTRIAL WASTEWATER**

| Type of treatment and discharge pathway or system | Comments | MCF [1] | Range |
|---|---|---|---|
| **Discharge from treated or untreated system** | | | |
| Sea, river and lake discharge | Most freshwater systems are supersaturated in $CH_4$. Nutrient oversupply will increase $CH_4$ emissions. | 0.27 | 0.17 – 0.48 |
| **Treated wastewater treatment system** | | | |
| Centralized, aerobic treatment plant | Some $CH_4$ can be emitted from settling basins and other pockets. For treatment plants that are receiving wastewater beyond the design capacity, inventory compilers should judge the amount of organic material removed in sludge accordingly. | 0.005 | 0 – 0.1 |
| Advanced biological nutrient removal system | $CH_4$ can be emitted from anaerobic and anoxic zones in these systems. Specific emission rates are highly dependent on the specific treatment system configuration. | 0.05 | TBD |

| | | | |
|---|---|---|---|
| Anaerobic reactor (e.g., UASB, Fixed Film Reactor) | $CH_4$ recovery not considered here | 0.8 | 0.8 – 1.0 |
| Anaerobic shallow lagoon | Depth less than 2 metres, use expert judgment | 0.2 | 0 – 0.3 |
| Anaerobic deep lagoon | Depth more than 2 metres | 0.8 | 0.8 – 1.0 |
| **Sludge treatment system** | | | |
| Anaerobic digester for sludge | $CH_4$ recovery is not considered here. | 0.8 | 0.8 – 1.0 |
| [1] Based on expert judgment by lead authors of this section | | | |

TBD (to be determined): The default value(s) are being developed and will be provided in the second order draft (SOD).

#### 6.2.3.3 CHOICE OF ACTIVITY DATA

No refinement

#### 6.2.3.4 TIME SERIES CONSISTENCY

No refinement

#### 6.2.3.5 UNCERTAINTIES

Updated default values are in new Table 6.15, Section 6.4.3.

#### 6.2.3.6 QA/QC, COMPLETENESS, REPORTING AND DOCUMENTATION

No refinement

## 6.3 NITROUS OXIDE EMISSIONS FROM DOMESTIC WASTEWATER

This section refines Section 6.3 of the *2006 IPCC Guidelines* by providing elaboration and new guidance for estimating domestic $N_2O$ emissions from wastewater treatment plants, and provides new guidance on the estimation of indirect $N_2O$ emissions by accounting for losses of nitrogen prior to disposal.

### 6.3.1 Methodological issues

Nitrous oxide ($N_2O$) emissions can occur as direct emissions from wastewater treatment plants or from indirect emissions from wastewater after disposal of untreated wastewater or wastewater treatment effluent into aquatic environments. This section describes how to estimate the $N_2O$ produced, directly and indirectly, during wastewater treatment, sludge treatment that occurs within the wastewater treatment system, and disposal of the wastewater. More recent research and field surveys have revealed that direct emissions in sewer networks and from nitrification or nitrification-denitrification processes at wastewater treatment plants, previously judged to be a minor source, may in fact result in more significant emissions. $N_2O$ is generated as a by-product of nitrification or as an intermediate product of denitrification. There are many factors affecting direct $N_2O$ emissions at the treatment system such as the temperature and dissolved oxygen concentration of the wastewater, and the specific operational conditions of the treatment system. Direct emissions need to be estimated only for countries that have predominantly wastewater treatment plants with nitrification and/or denitrification steps.

Indirect emissions result from untreated wastewater or wastewater treatment effluent that is discharged into aquatic environments. It is important to note that emissions are dependent on the oxygenation level of the aquatic environment receiving the discharge. The current methodology in the *2006 IPCC Guidelines* appropriately captures discharge to well-oxygenated environments. However, in the case of discharge to hypoxic waters such as eutrophic lakes, estuaries and rivers, or locations where stagnant conditions occur, emissions can be significantly higher.

Three tier methods for $N_2O$ from this category are summarised 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 a country-specific emission factor and country-specific activity data. For example, a specific emission factor for a prominent treatment system based on field measurements could be incorporated under this method. The amount of sludge removed for incineration, landfills, and agricultural land should be taken into consideration.

For a country with good data and advanced methodologies, a country-specific method could be applied as a Tier 3 method. A more advanced country-specific method could be based on plant-specific data from large wastewater treatment facilities.

Note that only a few countries may have sludge removal data. The default for sludge removal is zero.

#### 6.3.1.1 CHOICE OF METHOD

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

The steps for *good practice* in inventory preparation for $N_2O$ from domestic wastewater are as follows:

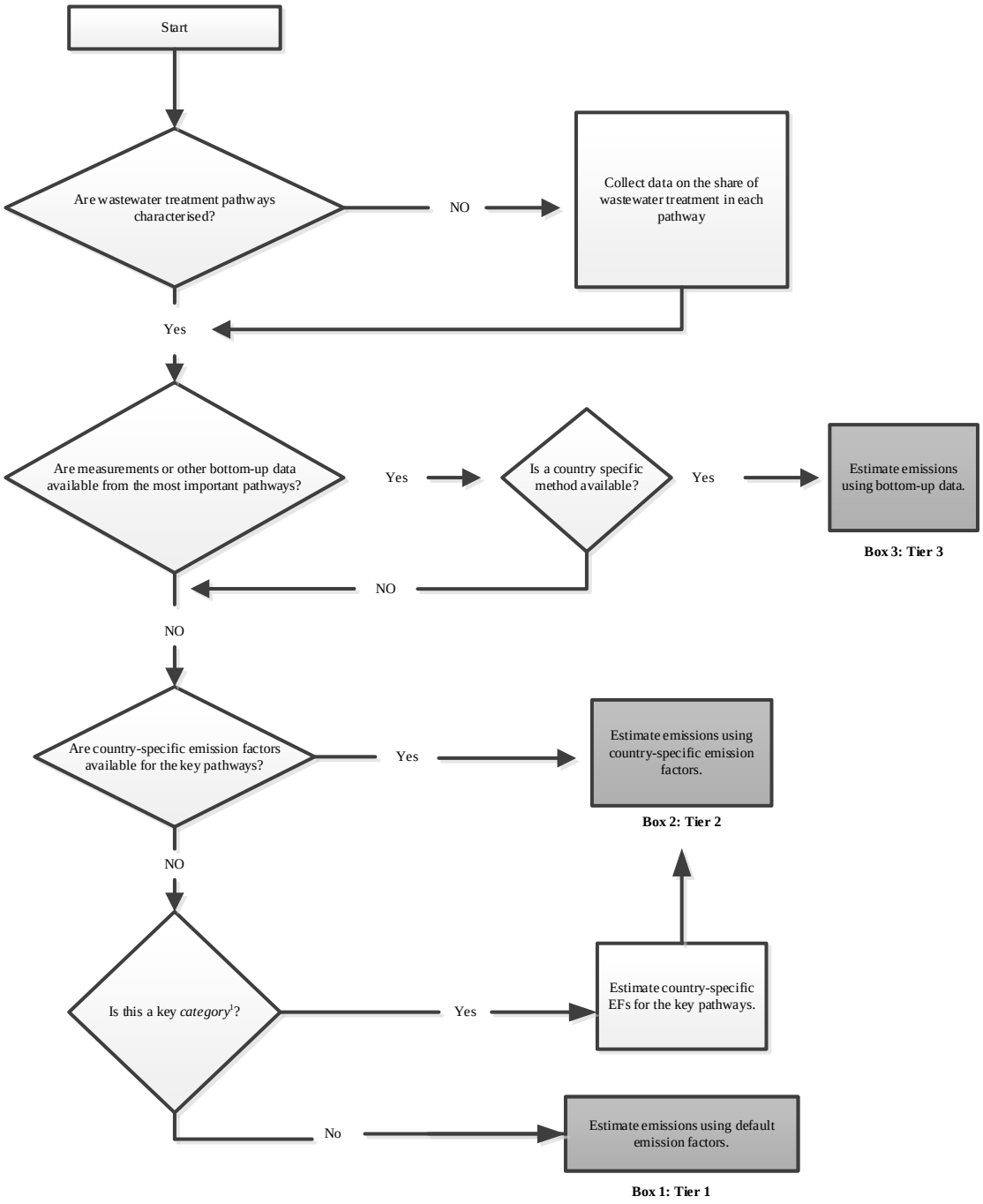
**Step 1:** Use Equation 6.10 to estimate total nitrogen in wastewater.

**Step 2:** Select the pathway and systems (See Figure 6.1) according to country activity data. Select the emission factor for each domestic wastewater treatment/discharge pathway or system.

**Step 3:** Use updated Equation 6.9 to estimate direct emissions from wastewater treatment, and sum the results for each pathway/system.

**Step 4:** Use updated Equation 6.7 to estimate indirect emissions from effluent, accounting for losses of nitrogen that occur within the wastewater treatment process including sludge removal, and sum the results for each pathway/system.

**New Figure 6.4 Decision tree for $N_2O$ emissions from domestic wastewater**




As described earlier, the wastewater characterisation will determine the fraction of wastewater treated or disposed of by a particular system. To determine the use of each type of treatment or discharge system, it is *good practice* to refer to national statistics (e.g., from regulatory authorities). If these data are not available, wastewater associations or international organisations such as the World Health Organization (WHO) may have data on the system usage.

Otherwise, consultation with sanitation experts can help, and expert judgement can also be applied (see Chapter 2, Approaches to Data Collection, in Volume 1). Urbanisation statistics may provide a useful tool, e.g., city sizes and income distribution.

**UPDATED EQUATION 6.9**
**DIRECT $N_2O$ EMISSIONS FROM DOMESTIC WASTEWATER TREATMENT PLANTS**

$$N_2O_{PLANTS,DOM} = \left[\sum_{i,j}\left(U_i \bullet T_{i.j} \bullet EF_j\right)\right] TN_{DOM}$$

Where:

$N_2O_{PLANTS, DOM}$ = Direct $N_2O$ emissions from domestic wastewater treatment plants in inventory year, kg $N_2O$/yr

$TN_{DOM}$ = total nitrogen in domestic wastewater in inventory year, kg N/yr. See Equation 6.10.

$U_i$ = fraction of population in income group *i* in inventory year, See Table 6.5.

$T_{i,j}$ = degree of utilisation of treatment/discharge pathway or system, *j*, for each income group fraction *i* in inventory year, See Table 6.5.

i = income group: rural, urban high income and urban low income

j = each treatment/discharge pathway or system

$EF_j$ = emission factor for treatment/discharge pathway or system, *j*, kg $N_2O$/kg N

It is also required to estimate indirect $N_2O$ emissions from wastewater treatment effluent that is discharged into aquatic environments. The methodology for emissions from effluent is similar to that of indirect $N_2O$ emissions explained in Volume 4, Section 11.2.2, in Chapter 11, $N_2O$ Emissions from Managed Soils, and $CO_2$ Emissions from Lime and Urea Application. The simplified general equation is as follows:

**UPDATED EQUATION 6.7**
**INDIRECT $N_2O$ EMISSIONS FROM DOMESTIC WASTEWATER EFFLUENT**

$$N_2O\ Emissions_{DOM} = N_{EFFLUENT,DOM} \bullet EF_{EFFLUENT} \bullet 44/28$$

Where:

$N_2O$ $Emissions_{DOM}$ = Indirect $N_2O$ emissions from domestic wastewater effluent in inventory year, kg $N_2O$/yr

$N_{EFFLUENT,DOM}$ = nitrogen in the effluent discharged to aquatic environments, kg N/yr. See updated Equation 6.8.

$EF_{EFFLUENT}$ = emission factor for indirect $N_2O$ emissions from wastewater discharged to aquatic systems, kg $N_2O$-N/kg N

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

### 6.3.1.2 CHOICE OF EMISSION FACTORS

Table 6.12 includes default EF values for direct and indirect $N_2O$ emissions. These refinements to the emission factors build on the current default value for $EF_{effluent}$ provided in Table 6.11 of the *2006 IPCC Guidelines.* This existing emission factor is adequate for discharges to well-oxygenated aquatic environments. However, it is expected to generate an underestimate of $N_2O$ emissions in the case of discharge to hypoxic waters such as eutrophic lakes, estuaries and rivers, or locations where stagnant conditions occur. Research published between 1978 and 2017 provide supporting data that higher $N_2O$ emissions occur when wastewater is discharged to estuarine or hypoxic marine environments, resulting in a new $EF_{effluent}$ of 0.018 g $N_2O$-N/g N (95% confidence limits 0.0041-0.091).

**NEW TABLE 6.12**
**DEFAULT EF VALUES FOR DOMESTIC WASTEWATER**

| Type of treatment and discharge pathway or system | Comments | Removal efficiency[1], $N_{rem}$ | EF[1] (kg $N_2O$-N/kg N) | Range |
|---|---|---|---|---|
| **Untreated system, $EF_{effluent}$ (Indirect $N_2O$)** | | | | |
| Sea, river and lake discharge | Based on limited field data and on specific assumptions regarding the occurrence of nitrification and denitrification in rivers and in estuaries | 0 | 0.005 | 0.0005 - 0.25 |
| Estuarine or hypoxic marine environments | Higher emissions are associated with hypoxic water such as eutrophic lakes, estuaries and rivers, or locations where stagnant conditions occur | 0 | 0.018 | 0.0041 – 0.091 |
| **Wastewater treatment system, $EF_{plants}$ (Direct $N_2O$)** | | | | |
| Conventional activated sludge processes | Nitrification and denitrification. Some $N_2O$ can be emitted from aeration tank and others. | TBD | 0.047 | TBD |
| Oxidation ditch processes | TBD | TBD | 0.005 | TBD |
| Anaerobic-aerobic processes | TBD | TBD | TBD | TBD |
| Sequencing Batch Reactors | TBD | TBD | 0.013 | TBD |
| Membrane bio-reactors | TBD | TBD | TBD | TBD |
| Anaerobic shallow lagoon | $N_2O$ can be emitted. | TBD | TBD | TBD |
| **Sludge treatment system** | | | | |
| Anaerobic digester for sludge | $N_2O$ is not significant. | -- | 0 | 0 |

[1] Based on expert judgment by lead authors of this section

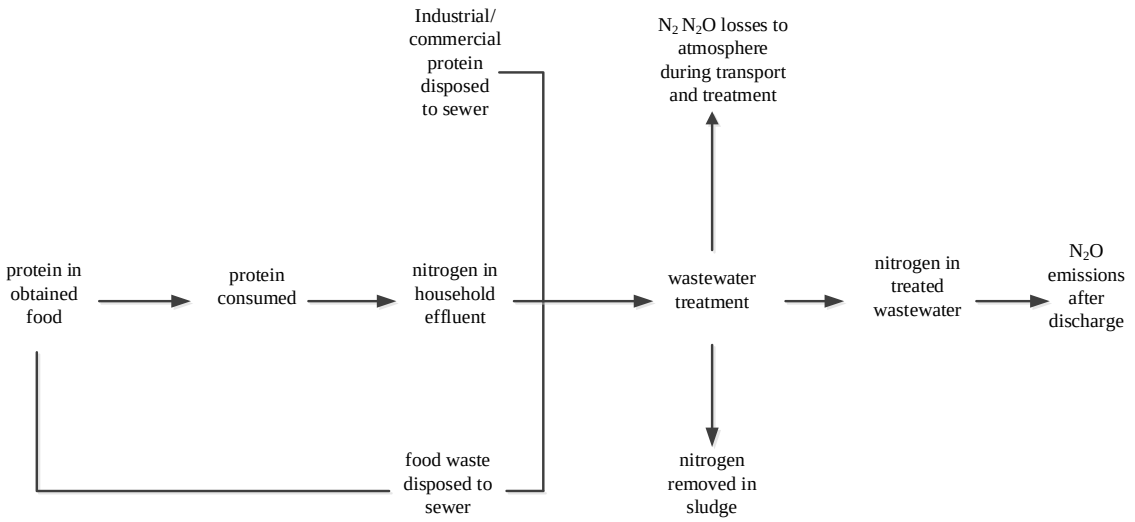
TBD (to be determined): The default value(s) are being developed and will be provided in the second order draft (SOD).

### 6.3.1.3 CHOICE OF ACTIVITY DATA

The methodology to calculate the amount of nitrogen content in wastewater effluent ($N_{effluent}$) presented in Equation 6.8 of the *2006 IPCC Guidelines* currently does not account for the removal of ammonia-N via denitrification processes in the sewer and the wastewater treatment plant, or the removal of nitrogen in sludge, which can result in a significant overestimate of nitrogen discharged to aquatic systems. Typical total nitrogen concentrations in raw urban sewage is about 35 mg/L (range 20-70 mg/L) (Tchobanoglous et al, 2014) whereas effluent treated in conventional activated sludge facilities (with nitrification) is about 25 mg/L. Plants with biological nutrient removal (with denitrification) regularly achieve 5 mg/L. The difference is due both to nitrogen removed in sludge (nitrogen is about 3.3 % of sludge by dry weight) (Tchobanoglous et al, 2014) and the remainder to atmosphere (see Figure 6.5).

This section refines the methodology presented in the *2006 IPCC Guidelines* to estimate the amount of nitrogen content in wastewater entering treatment ($TN_{DOM}$), the loss or removal of nitrogen through the treatment process (either through biological conversion or removal with sludge) ($N_{removal}$), and the nitrogen content in wastewater discharged to aquatic systems ($N_{effluent}$).

**New Figure 6.5 Nitrogen in domestic wastewater treatment**




## NITROGEN IN DOMESTIC WASTEWATER ($TN_{DOM}$)

The activity data that are needed for estimating $TN_{DOM}$ in domestic wastewater include the population associated with the wastewater, the average annual per capita protein consumed (kg/person/yr), and factors to account for non-consumed protein entering the wastewater and other nitrogen from industrial and commercial sources co-discharged into the sewer system. The total nitrogen in wastewater is estimated as follows:

**NEW EQUATION 6.10**
**TOTAL NITROGEN IN DOMESTIC WASTEWATER**

$$TN_{DOM} = \left( P_{treatment} \bullet Protein \bullet F_{NPR} \bullet F_{NON-CON} \bullet F_{IND-COM} \right)$$

Where:

$TN_{DOM}$ = total annual amount of nitrogen in domestic wastewater, kg N/yr

$P_{TREATMENT}$ = human population who are served with treatment systems, person/yr

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

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

$F_{NON-CON}$ = factor for non-consumed protein added to the wastewater, kg N/kg N

$F_{IND-COM}$ = factor for industrial and commercial co-discharged protein into the sewer system, kg N/kg N

Per capita "protein supply quantity" is published in Food Balance Sheets of FAOSTAT. This information represents the total amount of protein available to the population but must be adjusted to reflect the fraction of protein consumed. FAOSTAT may have country-specific data available on protein consumed in the published Indicators from Household Surveys. A default value for the fraction of protein consumed is 0.85.

Food (waste) that is not consumed may be washed down the drain (e.g., as result of the use of food waste disposals in some countries). Bath and laundry water can be expected to contribute an additional 10% to nitrogen loadings as well. These factors influence the amount of nitrogen in domestic wastewater and are included in the updated values of $F_{NON-CON}$, as shown in Table 6.13. Two sets of $F_{NON-CON}$ were prepared, depending if the activity data are based on protein available or protein consumed.

First-order Draft

**NEW TABLE 6.13**
**DEFAULT FACTORS FOR DOMESTIC WASTEWATER**

| Basis of Protein Activity Data | Disposal of food waste | $F_{NON-CON}$[1] |
|---|---|---|
| Protein available | In-sink disposal | 1.1 |
| | Waste bin disposal | 1 |
| Protein consumed | In-sink disposal | 1.25 |
| | Waste bin disposal | 1.1 |

[1] Based on expert judgment by lead authors of this section

584

585 Wastewater from industrial or commercial sources that is discharged into the sewer may contain protein (e.g., from
586 grocery stores and butchers). The default for this fraction is 1.25.

587

588 **NITROGEN IN WASTEWATER EFFLUENT ($N_{EFFLUENT}$)**

589 The total nitrogen in the effluent is estimated as follows:

590

591 **UPDATED EQUATION 6.8**
592 **TOTAL NITROGEN IN DOMESTIC WASTEWATER EFFLUENT**

593 $$N_{EFFLUENT,DOM} = \left( TN_{DOM} \times N_{REM} \right)$$

594 Where:

595 $N_{EFFLUENT,DOM}$ = total annual amount of nitrogen in the wastewater effluent, kg N/yr

596 $TN_{DOM}$ = total annual amount of nitrogen in domestic wastewater, kg N/yr

597 $N_{REM}$ = factor for removal of nitrogen from wastewater effluent, %, See Table 6.12.

## 598 6.3.2 Time series consistency

599 No refinement

## 600 6.3.3 Uncertainties

601 Large uncertainties are associated with the IPCC default factors for $N_2O$. Updated Table 6.11 below includes
602 uncertainty ranges based on expert judgment.

603

**UPDATED TABLE 6.11**
**$N_2O$ METHODOLOGY DEFAULT DATA**

| | Definition | Default Value | Range |
|---|---|---|---|
| **Emission Factor** | | | |
| EF | $N_2O$ emission factor | See Table 6.12 | See Table 6.12 |
| **Activity Data** | | | |
| P | Number of people in country | Country-specific | ± 10 % |
| Protein | Annual per capita protein consumption | Country-specific | ± 10 % |
| $F_{NPR}$ | Fraction of nitrogen in protein (kg N/kg protein) | 0.16 | 0.15 – 0.17 |
| $T_{plant}$ | Degree of utilization of large WWT plants | Country-specific | ± 20 % |
| $F_{NON-CON}$ | Factor to adjust for non-consumed protein, based on available protein | 1.0 for countries with no in-sink disposals, 1.1 for countries with in-sink disposals | 0.9 – 1.2 |
| | Factor to adjust for non-consumed protein, based on consumed protein | 1.1 for countries with no in-sink disposals, 1.25 for countries with in-sink disposals | 1.0 – 1.4 |
| $F_{IND-COM}$ | Factor to allow for co-discharge of industrial nitrogen into sewers. For countries with significant fish processing plants, this factor may be higher. Expert judgment is recommended. | 1.25 | 1.0 – 1.5 |
| $N_{REM}$ | Factor to account for losses of nitrogen prior to discharge. | See Table 6.12 | TBD |

TBD (to be determined): The default value(s) are being developed and will be provided in the second order draft (SOD).

## 6.3.4 QA/QC, Completeness, Reporting and Documentation

No refinement

# 6.4 NITROUS OXIDE EMISSIONS FROM INDUSTRIAL WASTEWATER

## 6.4.1 Methodological issues

This section refines the *2006 IPCC Guidelines* by adding guidance for estimating $N_2O$ emissions from industrial wastewater treatment plants, and refines the estimation of indirect $N_2O$ emissions by accounting for losses of nitrogen prior to disposal.

### 6.4.1.1 CHOICE OF METHOD

A decision tree for industrial wastewater is included in Figure 6.6.

The steps for *good practice* in inventory preparation for $N_2O$ from industrial wastewater are as follows:

**Step 1:** Use new Equation 6.13 to estimate total nitrogen in wastewater.

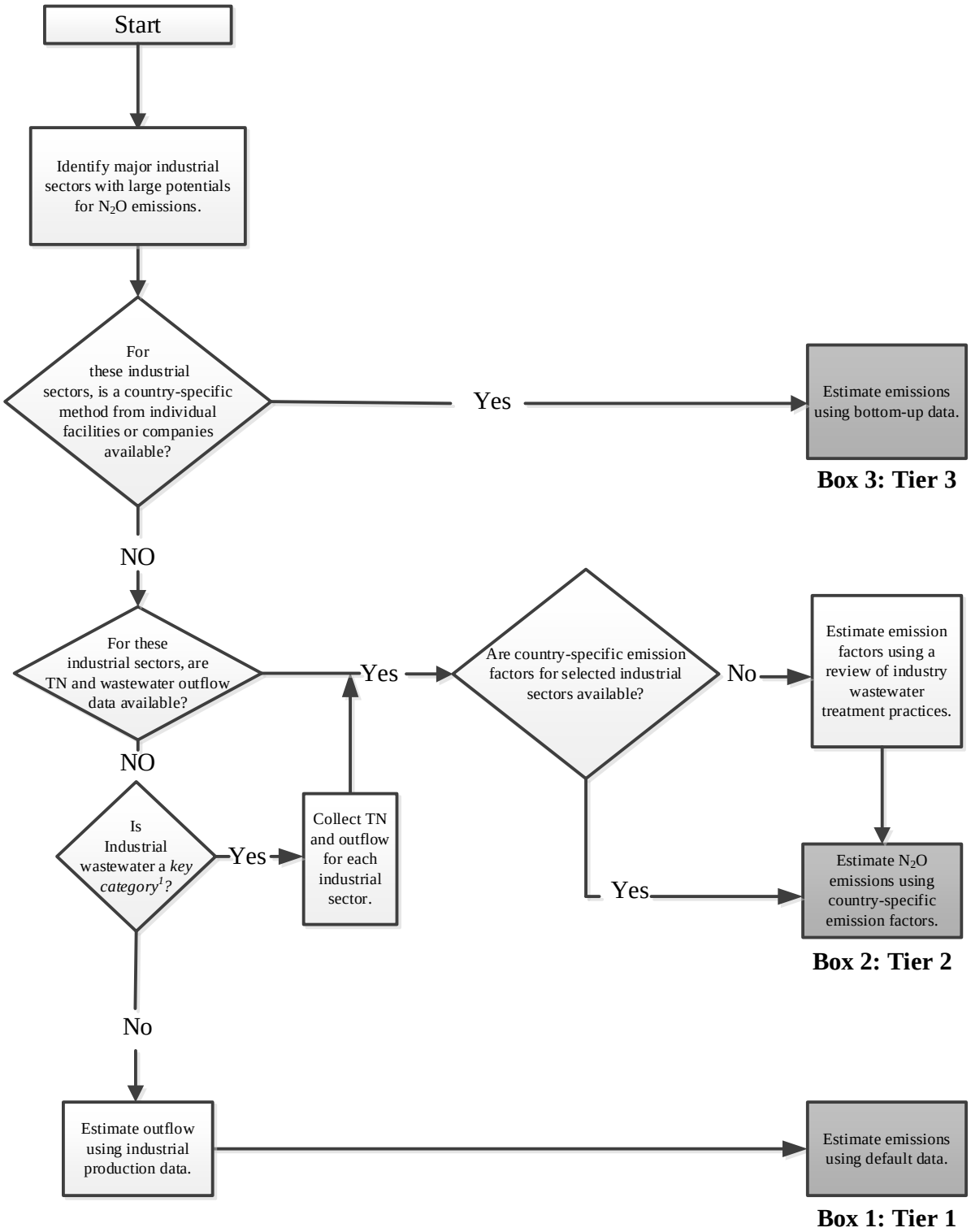
**Step 2:** Select the pathway and systems (See Figure 6.1) according to country activity data. Select the emission factor for each domestic wastewater treatment/discharge pathway or system.

**Step 3:** Use new Equation 6.11 to estimate direct emissions from wastewater treatment, and sum the results for each pathway/system.

**Step 4:** Use new Equation 6.12 to estimate indirect emissions from effluent, accounting for losses of nitrogen that occur within the wastewater treatment process including sludge removal, and sum the results for each pathway/system.

As described earlier, the wastewater characterisation will determine the fraction of wastewater treated or disposed of by a particular system. To determine the use of each type of treatment or discharge system, it is *good practice* to refer to national statistics (e.g., from regulatory authorities). If these data are not available, industry associations may have data on the system usage. Otherwise, consultation with industry experts can help, and expert judgement can also be applied (see Chapter 2, Approaches to Data Collection, in Volume 1).

**New Figure 6.6 Decision tree for $N_2O$ emissions from industrial wastewater**



**NEW EQUATION 6.11**
**DIRECT $N_2O$ EMISSIONS FROM INDUSTRIAL WASTEWATER TREATMENT PLANTS**

$$N_2O_{PLANTS,IND} = \left[ \sum_i (T_{i.j} \bullet EF_j \bullet TN_{INDi}) \right]$$

Where:

$N_2O_{PLANTS,IND}$ = Direct $N_2O$ emissions from industrial wastewater treatment plants in inventory year, kg $N_2O$/yr

$TN_{INDi}$ = total nitrogen in wastewater from industry *i* in inventory year, kg N/yr. See Equation 6.13.

Nremoval = nitrogen removal efficiency in inventory year, %

$T_{i,j}$ = degree of utilisation of treatment/discharge pathway or system, *j*, for each industry *i* in inventory year

i = industry

j = each treatment/discharge pathway or system

$EF_j$ = emission factor for treatment/discharge pathway or system, *j*, kg $N_2O$/kg N

It is also required to estimate indirect $N_2O$ emissions from wastewater treatment effluent that is discharged into aquatic environments. The methodology for emissions from effluent is like that of indirect $N_2O$ emissions explained in Volume 4, Section 11.2.2, in Chapter 11, $N_2O$ Emissions from Managed Soils, and $CO_2$ Emissions from Lime and Urea Application. The simplified general equation is as follows:

**NEW EQUATION 6.12**
**INDIRECT $N_2O$ EMISSIONS FROM INDUSTRIAL WASTEWATER EFFLUENT**

$$N_2O\ Emissions_{IND} = N_{EFFLUENT,IND} \bullet EF_{EFFLUENT} \bullet 44/28$$

Where:

$N_2O$ emissions = indirect $N_2O$ emissions from industrial wastewater effluent in inventory year, kg $N_2O$/yr

$N_{EFFLUENT, IND}$ =nitrogen in the industrial wastewater effluent discharged to aquatic environments, kg N/yr. See updated Equation 6.14.

$EF_{EFFLUENT}$ = emission factor for indirect $N_2O$ emissions from wastewater discharged to aquatic systems, kg $N_2O$-N/kg N

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

## 6.4.1.2 CHOICE OF EMISSION FACTORS

Table 6.12 includes default EF values for direct and indirect $N_2O$ emissions.

## 6.4.1.3 CHOICE OF ACTIVITY DATA

### NITROGEN IN INDUSTRIAL WASTEWATER ($TN_{IND}$)

The activity data for this source category is the amount of nitrogen in the industrial wastewater entering treatment ($TN_{IND}$). This parameter is a function of industrial output (product) P (tons/yr), wastewater generation W ($m^3$/ton of product), and total nitrogen concentration in the untreated wastewater (kg TN/$m^3$). See Equation 6.13. The following steps are required for determination of TN:

(i) Identify the industrial sectors that generate wastewater with large quantities of nitrogen, by evaluating total industrial product, nitrogen in the wastewater, and wastewater produced.

(ii) Identify industrial sectors that use treatment systems with $N_2O$ emissions factors (see Table 6.12). Experience has shown that usually three or four industrial sectors are *key*.

For each selected sector estimate total nitrogen in the industrial wastewater (TN).

**NEW EQUATION 6.13**
**TOTAL NITROGEN IN INDUSTRIAL WASTEWATER**

$$TN_{IND_i} = P_i \bullet W_i \bullet TN_i$$

Where:

$TN_{INDi}$ = total nitrogen in wastewater entering treatment for industry *i*, kg TN/yr

i = industrial sector

$P_i$ = total industrial product for industrial sector *i*, t/yr

$W_i$ = wastewater generated for industrial sector *i*, $m^3/t_{product}$

$TN_i$ = total nitrogen in untreated wastewater for industrial sector *i*, kg TN/$m^3$

Industrial production data and wastewater generation rates may be obtained from national statistics, regulatory agencies, wastewater treatment associations or industry associations. In some cases, quantification of the nitrogen loading in the wastewater may require expert judgement. In some countries, nitrogen content and total water usage per sector data may be available directly from a regulatory agency. Table 6.14 provides examples that could be used as default values. These should be used with caution, because they are industry-, process-, and country-specific.

**NEW TABLE 6.14**
**EXAMPLES OF INDUSTRIAL WASTEWATER DATA**

| Industry Type | Wastewater Generation W ($m^3$/ton) | Range for W ($m^3$/ton) | Total Nitrogen (TN) (kg/$m^3$) | TN Range (kg/$m^3$) |
|---|---|---|---|---|
| Alcohol Refining | 24 | 16 – 32 | 2.4 | 0.94 – 3.86 |
| Explosives Manufacturing | TBD | TBD | TBD | TBD |
| Fish Processing | 5 | 2 – 8 | 0.60 | 0.21 – 0.98 |
| Iron and Steel Manufacturing | TBD | TBD | TBD | TBD |
| Landfill leachate | 15-20% of annual precipitation in well compacted landfill site<br>25-50% of annual precipitation for not well compacted landfill site | NA | 0.74 | 0.01 − 2.50 |
| Meat & Poultry | 13 | 8 − 18 | 0.19 | 0.17 − 0.20 |
| Nitrogen Fertilizer | 2.89 | 0.46 – 8.3 | 0.5 | 0.1 – 0.8 |
| Organic Chemicals | 67 | 0 – 400 | TBD | TBD |
| Petroleum Refineries | 0.6 | 0.3 − 1.2 | TBD | TBD |
| Plastics & Resins | 0.6 | 0.3 − 1.2 | TBD | TBD |
| Pulp & Paper (combined) | 162 | 85 – 240 | TBD | TBD |
| Starch Production | 9 | 4 – 18 | 0.9 | 0.8 – 1.10 |

[1] Based on expert judgment by lead authors of this section

TBD (to be determined): The default value(s) are being developed and will be provided in the second order draft (SOD).

## NITROGEN REMOVED FROM WASTEWATER ($N_{REMOVED}$)

Nitrogen removal by different treatment facilities can range from 10-85 percent. Default values for the fraction of nitrogen removed by type of wastewater treatment system are presented in Table 6.12.

## NITROGEN IN WASTEWATER EFFLUENT ($N_{EFFLUENT}$)

The total nitrogen in the industrial wastewater effluent is estimated as follows:

**NEW EQUATION 6.14**
**TOTAL NITROGEN IN INDUSTRIAL WASTEWATER EFFLUENT**

$$N_{EFFLUENT,IND} = \left( \sum_i (TN_{INDi} - N_{REMOVED}) \right)$$

Where:

$N_{EFFLUENT, IND}$ = total annual amount of nitrogen in the industrial wastewater effluent, kg N/yr

$TN_{INDi}$ = total nitrogen in wastewater entering treatment for industry *i*, kg TN/yr

$N_{REMOVED}$ = nitrogen removal efficiency in inventory year, %

## 6.4.2 Time series consistency

Once an industrial sector is included in the inventory calculation, it should be included for each subsequent year. If the inventory compiler adds a new industrial sector to the calculation, then he or she should re-calculate the entire time series so that the method is consistent from year to year. General guidance on recalculation of estimates through time series is provided in Volume 1, Chapter 5, Time Series Consistency.

If a country decides to incorporate plant emissions into the estimate, this change must be made for the entire time series. Potential sludge removal should be treated consistently across years in the time series.

## 6.4.3 Uncertainties

Uncertainty estimates for EF, P, W and TN are provided in Table 6.15. The estimates are based on expert judgement.

**NEW TABLE 6.15**
**DEFAULT UNCERTAINTY RANGES FOR INDUSTRIAL WASTEWATER**

| Parameter | Uncertainty Range |
|---|---|
| **Emission Factor** | |
| $N_2O$ emission factor (EF) | ± 30% |
| **Activity Data** | |
| Industrial production (P) | ± 25%<br>Use expert judgement regarding the quality of data source to assign more accurate uncertainty range. |
| Wastewater/unit production (W) | These data can be very uncertain as the same sector might use different waste handling procedures at different plants and in different countries. The product of the parameters (W•TN) is expected to have less uncertainty. An uncertainty value can be attributed directly to TN concentration. –50 %, +100% is suggested (i.e., a factor of 2). |
| TN/unit wastewater (TN) | |

Source*:* Expert Judgement by Authors.

## 6.4.4 QA/QC, Completeness, Reporting and Documentation

### QA/QC

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:

- For industrial wastewater, inventory compilers may review the secondary data sets (e.g., from national statistics, regulatory agencies, wastewater treatment associations or industry associations), that are used to estimate and rank industrial TN waste output. Some countries may have regulatory control over industrial discharges, in which cases significant QA/QC protocols may already be in place for the development of the wastewater characteristics on an industry basis.

- For industrial wastewater, inventory compilers should cross-check values for EFs against those from other national inventories with similar wastewater characteristics.
- If sludge removal is reported in the wastewater inventory, check for consistency with the estimates for sludge applied to agriculture soils, sludge incinerated, and sludge deposited in solid waste disposal.
- For countries that use country-specific parameters or higher tier methods, inventory compilers should cross-check the national estimates with emissions using the IPCC default method and parameters.

## COMPLETENESS

Completeness for estimating emissions from industrial wastewater depends on an accurate characterization of industrial sectors that produce nitrogen laden wastewater. In most countries, approximately 3-4 industrial sectors will account for the majority of the nitrogen wastewater volume, 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.

Some sludge from industrial wastewater treatment may be incinerated or deposited in landfills or on agricultural lands. This constitutes an amount of nitrogen that should be subtracted from effluent nitrogen. It is *good practice* to be consistent across sectors: the amount of nitrogen that is removed as sludge should be equal to the amount of sludge disposed at landfills, applied to agricultural soils, incinerated or treated elsewhere.

## REPORTING AND DOCUMENTATION

It is *good practice* to document and report a summary of the methods used, activity data and emission factors. 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 judgement, etc.) have been derived (measurements, literature, expert judgement, etc.) should be documented and included in the reporting.

If sludge is incinerated, landfilled, or spread on agricultural lands, the quantities of sludge and associated emissions should be reported in the waste incineration, SWDS, or agricultural categories, respectively.

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

# Annex 6A.1 Derivation of the maximum $CH_4$ producing potential ($B_o$) for domestic wastewater

The maximum $CH_4$ producing potential ($B_o$) for domestic wastewater is calculated theoretically by the anaerobic decomposition of glucose:

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$$

One mole of glucose weighs 180 g and produces 3 moles of methane which weighs 3 x 16 = 48 g. Therefore, the methane production rate per gram of glucose is 48 g /180 g = 0,27 g methane / g glucose.

The complete oxidation of one mole of glucose (180 g) requires six moles of oxygen (6 x 32 g = 192 g)

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

Then, the oxygen demand rate per gram of glucose is 192 g / 180 g = 1,067 g oxygen / g glucose

Finally, the maximum $CH_4$ producing potential (Bo) for domestic wastewater based of COD content is 48 g $CH_4$ / 192 gr oxygen = 0.25 kg $CH_4$ / kg COD.

The BOD / COD ratio of a specific wastewater indicates the amount of organic matter difficult to degrade. For domestic wastewater, a typical BOD / COD ratio is 2.4 based on empirical tests. However, the ratio between the components in any given domestic wastewater stream may vary due to contributions from other sources, particularly wastewater contributions from commercial or industrial sources. The expected range of BOD / COD ratios is between 1.5 and 3.5 (Mogens Henze 2008).

Inventory compilers should compare country-specific data on BOD / COD ratio in domestic wastewater to IPCC default values of 2.4. If inventory compilers use country-specific values, they should provide documented justification why their country-specific values are more appropriate for their national circumstances.

# Annex 6A.2 Abiogenic (fossil) $CO_2$ emissions from wastewater treatment and discharge

The *2006 IPCC Guidelines* assume that organic carbon present in wastewater derives from modern (biogenic) organic matter in human excreta or food waste (Doorn et al., 2006). Consequently, $CO_2$ emissions from wastewater treatment are also considered wholly biogenic and are discounted from international greenhouse gas accounting inventories, since they do not represent a transfer of carbon from the lithosphere to the atmosphere. In comparison, fossil organic carbon (that with turnover timescales exceeding $10^6$ years) is considered to have a role in climate change and is accounted for in international greenhouse gas emissions inventories. In the *2006 Guidelines*, it is assumed that emissions from biogas flaring are not significant because the $CO_2$ emissions are of biogenic origin and the $CH_4$ and $N_2O$ emissions are very small so *good practice* in the Waste Sector does not require their estimation. If countries wish to report such emissions, they should be reported under the Waste Sector. (A discussion of emissions from flares and more detailed information are given in Volume 2, Energy, Chapter 4.2.) However, the presence of fossil organic carbon in sewage also implies the emission of additional fossil $CO_2$ from wastewater treatment facilities, sludge management, and environmental recipients of treated or untreated wastewater.

Data emerging since the *2006 IPCC Guidelines* indicate that wastewater contains an appreciable amount of abiogenic (fossil) organic carbon, with this fossil carbon thought to be derived from the use of petroleum-based products (domestically and commercially). These products include: cosmetics; pharmaceuticals; surfactants; detergents and food additives (Law et al., 2013). Additionally, direct dosing of synthetic organic substrates (e.g., methanol) can occur at wastewater treatment plants to enhance denitrification performance (Schneider et al., 2015). Despite early indications of the potential for significant fossil organic carbon fractions in sewage sludge (Turekian and Benoit, 1981), fossil carbon in wastewater was first detailed by Griffith et al. (2009) following the sampling of treated effluent from 12 predominantly domestic wastewater treatment plants within the Hudson and Connecticut River watersheds, USA. Since then, several studies have surveyed fossil organic carbon in wastewater from Japan (Nara et al., 2010; Toyoda et al., 2011), Australia (Law et al., 2013), Denmark (Yoshida et al., 2014) and North America (Schneider et al., 2015).

Research published since the *2006 IPCC Guidelines* (Griffith et al., 2009; Law et al., 2013; Yoshida et al., 2014; Schneider et al., 2015; Tseng et al., 2016) gives an emerging consensus figure for the fossil wastewater organic carbon fraction at some 4–14%; although more recent work suggests this can be as high as 28% (Tseng et al., 2016) or 51% (Nara et al, 2010; recalculated by Tseng et al, 2016) in some influents. Schneider et al. (2015) put the fossil content of activated sludge process off-gases at 10–15%. Law et al. (2013) put the subsequent fossil carbon fraction in anaerobic digester biogas $CO_2$ at 2.1±0.2% due to greater recalcitrance of fossil carbon during anaerobic digestion, and total additional scope 1 wastewater treatment plant emission load from previously unaccounted fossil carbon somewhere between 2–12%. Tseng et al. (2016) put this figure at some 13 to 24% higher without and with energy recovery respectively.

Based on the above data, countries are encouraged to evaluate if such emissions should be reported, particularly those countries that have higher levels of fossil carbon in wastewater. In addition, future improvements to the *Guidelines* should include a method for estimating these non-biogenic emissions associated with wastewater treatment operations and wastewater discharges.

813 **TABLE 6A.1 SUMMARY OF LITERATURE INVESTIGATING FOSSIL ORGANIC CARBON IN WASTEWATER**

| Wastewater treatment system | Detection/measurement approach | Fossil C fraction in various wastewater streams | Reference | Comments |
|---|---|---|---|---|
| Effluent from 12 WWTPs (using conventional activated sludge) sampled, USA | Effluent grab samples; $^{14}C$ analysed via isotope ratio mass spectrometry | 25% of treated wastewater dissolved organic carbon (DOC) and 14% of treated wastewater particulate organic carbon (POC) | Griffith et al. (2009) | WWTPs handle predominantly domestic wastewater. Secondary treated effluent sampled only (i.e. not raw influent), so results may overestimate true fossil carbon fraction in raw sewage, since heterotrophic bacteria are known to preferentially utilize young ($^{14}C$-enriched) carbon for assimilation (Raymond and Bauer, 2001). Average reported effluent DOC concentration was 8.7 mg $L^{-1}$. |
| Four large activated sludge WWTPs in Brisbane, Australia (two receiving domestic sewage and two receiving 15% industrial load) | Range of sampling locations (influent, primary- and secondary-treated effluent, waste activated sludge (WAS), digested biosoids) | Fossil fraction of total organic carbon (TOC) in domestic WWTP influent 4–7% and 8–14% for WWTPs receiving 15% industrial load (5–14% overall range); ≈29–50% of this influent fossil C is transformed to CO2 during secondary activated sludge treatment (1.4–6.3% of influent TOC). Higher fossil C fraction in WAS from WWTPs receiving industrial load (8–14%) versus domestic WWTPs (6–7%). 2.1(±0.2)% of biogas CO2 is fossil in origin. | Law et al. (2013) | Higher fossil C fractions in WWTPs receiving industrial wastewater load. Equivalent concentrations of fossil organic carbon in raw wastewater were between 6–35 mg L−1. Majority of fossil organic carbon in raw wastewater is present in particulate form (>80%; 5–to 29 mg L−1), whereas dissolved fossil carbon levels are relatively small (1–6 mg L−1). |
| Influent to Avedøre WWTP, Denmark | Single 24-hour flow proportionate composite influent sample collected February, 2013. Radiocarbon isotope ratio method (ASTM-D6866-12). | 14(±3)% in influent wastewater | Yoshida et al. (2014) | Avedøre WWTP receives 15% industrial load from adjacent pharmaceuticals industry. Figure of 14% is corrected for cellulosic biogenic carbon from toilet paper which may contain elevated levels of 14C due to historical atomic bomb detonations and underestimate fossil C fraction. |
| Modified Ludzack–Ettinger (MLE) activated sludge process with biological nitrification–denitrification, USA | 14C content of emitted CO2 measured twice a day for five days in early spring using floating chambers | 11.4–15.1% (mean 12.83%) based on measured CO2 emissions from secondary treatment reactor | Schneider et al. (2015) | |
| Three municipal WWTPs and waste stabilisation ponds, two industrial WWTPs | Raw and partially treated wastewater, gas and sludge samples taken during 2010–2013 | 2–28% in the primary influent | Tseng et al. (2016) | Article provides a tabulation of results from 6 separate research papers. |
| Assumed conventional activated sludge-based WWTP with primary gravity sedimentation, Japan | Fresh domestic sewage, primary-treated and secondary-treated wastewater sampled | $\Delta^{14}C$ values (‰) of sewage DOC was more negative ($^{14}C$ ages in the order of ≈1000–5000 years) than nearby lake and river water; no fossil C fraction given. | Nara et al. (2010) | No information on relative fossil C fraction given. |

| | | | | |
|---|---|---|---|---|
| $A_2O$ WWTP, Japan | 13 wastewater samples collected along the treatment train during March, 2008 | $\delta^{13}C$ signature of −50.7‰ (depleted with respect to background air) | Toyoda et al. (2011) | WWTP received municipal wastewater |

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