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METHODS FOR ESTIMATING GREENHOUSE GAS EMISSIONS FROM WASTEWATER

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INTRODUCTION

The EIIP guidelines are designed to describe emission estimation techniques for greenhouse gas sources in a clear and unambiguous manner and to facilitate preparation of inventories at the state level. This chapter presents the methodology for estimating methane and nitrous oxide emissions from wastewater. The methodology presented in this chapter has been revised to reflect new activity data, emission factors, and methods pertaining to this source category. Where possible, the methodology has been updated to be consistent with the *Inventory of United States Greenhouse Gas Emissions and Sinks: 1990-2002*.

Section 2 of this chapter contains a general description of this source category. Section 3 provides a listing of the steps involved in estimating methane and nitrous oxide emissions from wastewater. Section 4 presents the preferred estimation method. Section 5 is a placeholder for alternative estimation techniques that may be added in the future. A summary of uncertainty for this source category is provided in Section 6. References used in developing this chapter are identified in Section 7.

In addition to these guidelines, there are a series of user friendly spreadsheet tools available to assist in the development of emission inventories at the state level. Please consult the Wastewater Module of the State Inventory Tool[1] to calculate emissions from this source category using the preferred emission estimation method.

[1] Note: The spreadsheet tool may have a different order of calculations, and may not show all calculations to the user.

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SOURCE CATEGORY DESCRIPTION

2.1 EMISSION SOURCES

Disposal and treatment of industrial and municipal wastewater often result in methane emissions. Wastewater may be treated using aerobic and/or anaerobic technologies, or if untreated, may degrade under either aerobic or anaerobic conditions. Methane is produced when organic material in treated and untreated wastewater degrades anaerobically, i.e., in the absence of oxygen.

Municipal wastewater is treated primarily through either septic tank systems or sewage treatment plants. Septic tanks, common in low population density areas, collect wastewater onsite in an underground tank; since the tank's contents are not exposed to the air, the waste is decomposed anaerobically. In more populated areas, domestic wastewater is treated at a large central facility. Such treatment plants service approximately 75 percent of American households (U.S. EPA 2001). At these facilities, the wastewater undergoes a multi-step treatment process in which waste may be decomposed both aerobically and anaerobically.

In highly organic wastewater streams, e.g., streams from food processing plants or pulp and paper plants, the available oxygen in the water is rapidly depleted as the organic matter decomposes. The organic content (sometimes known as "loading") of these wastewater streams is expressed in terms of biochemical oxygen demand, or BOD. BOD represents the amount of oxygen taken up by the organic matter in the wastewater during decomposition. Alternatively, the chemical oxygen demand (COD) is often used to characterize industrial wastewater. COD refers to the amount of oxygen consumed during the oxidation of both organic matter and oxidizable *in*organic matter. Under the same conditions, wastewater with a higher BOD or COD will produce more methane than wastewater with a lower BOD/COD.

Nitrous oxide is emitted from both domestic and industrial wastewater containing nitrogen-rich organic matter. Nitrous oxide is produced through the natural processes of nitrification and denitrification. Nitrification occurs aerobically and converts ammonia into nitrate, whereas denitrification occurs anaerobically, and converts nitrate to nitrous oxide. Human sewage is believed to constitute a significant portion of the material responsible for nitrous oxide emissions from wastewater (Spector 1997). There is not sufficient information available at this time to accurately estimate nitrous oxide emissions from industrial wastewater and other components of domestic wastewater.

2.2 FACTORS INFLUENCING EMISSIONS

Methane production in wastewater systems is influenced primarily by BOD loading and also by temperature, retention time, lagoon maintenance, lagoon depth, and the percent of wastewater treated anaerobically. Nitrous oxide generation is affected by temperature, pH, BOD loading, and nitrogen concentration.

Many treatment plants use facultative anaerobic lagoons for storage and treatment. The methane potential from these lagoons is not well understood and little field data are available. Industrial and commercial wastewater processes also use lagoons for treatment and storage. Facultative lagoons, the most common type, treat wastewater by both anaerobic fermentation and aerobic processes. At the bottom of the lagoon, where an anaerobic environment exists, organic matter is digested to methane and carbon dioxide. As these gases bubble to the surface, much of the carbon dioxide is absorbed and used by algae, along with nutrients liberated during digestion. Aerobic conditions, which support algal growth, are maintained near the surface. Most facultative lagoons are aerated to help promote aerobic decomposition, but anaerobic decomposition still occurs. As BOD loading increases and natural surface aeration diminishes, facultative lagoons proceed to a more anaerobic state. This results in higher methane production, providing that the temperature is higher than 59°F; below this temperature the lagoons serve principally as a sedimentation tank.

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OVERVIEW OF AVAILABLE METHODS

The data required to estimate methane emissions from municipal wastewater are not easily obtained; data for industrial wastewater are even more difficult to obtain.

To estimate methane emissions from municipal wastewater, the following steps are required: (1) obtain required data; (2) estimate total biochemical oxygen demand (BOD_5)[2] produced; (3) estimate annual quantity of BOD_5 treated anaerobically; (4) estimate gross annual methane emissions from wastewater treatment; and (5) convert annual methane emissions from wastewater to metric tons of carbon equivalent (MTCE).

To estimate nitrous oxide emissions from wastewater, the following steps are required: (1) obtain required data; (2) estimate annual per capita consumption of nitrogen in protein; (3) estimate the state's annual consumption of nitrogen in protein; (4) factor in the state's annual non-consumption nitrogen; (5) adjust total nitrogen in wastewater estimate to account for land application of sewage sludge; (6) estimate the state's annual nitrous oxide emissions from wastewater treatment; and (7) convert annual nitrous oxide emissions to metric tons of carbon equivalent.

To estimate methane emissions from industrial wastewater, the following steps are required: (1) determine which industries should be included in industrial wastewater estimates, (2) obtain required data; (3) determine industries for estimating emissions; (4) calculate annual wastewater production for each industry; (5) calculate methane emissions for each industry; (6) calculate total methane emissions; and (7) convert methane emissions to metric tons of carbon equivalent.

The methods described here are taken from the report by the Intergovernmental Panel on Climate Change (IPCC) entitled *IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997). They are presented as used in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (U.S. EPA 2004).

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[2] BOD represents the amount of oxygen that would be required to completely consume the organic matter contained in the wastewater through aerobic decomposition processes (U.S. EPA 2002). A standardized measurement of BOD is the "5-day test" denoted as BOD_5.

4

PREFERRED METHOD FOR ESTIMATING EMISSIONS

4.1 METHANE EMISSIONS FROM MUNICIPAL WASTEWATER TREATMENT

This section provides the method for estimating methane (CH_4) emissions from municipal wastewater treatment. The method requires the following steps: (1) obtain required data; (2) estimate biochemical oxygen demand; (3) estimate annual quantity of BOD_5 treated anaerobically; (4) estimate gross annual CH_4 emissions from wastewater treatment; and (5) convert annual CH_4 emissions to metric tons of carbon equivalent (MTCE).

Step (1): Obtain Required Data

- *Required Data.* The information needed to calculate CH_4 emissions from municipal wastewater are (1) state population; (2) kilograms (kg) BOD_5 per capita per day; and (3) the fraction of total wastewater that is treated anaerobically.

- *Data Sources.* Population data may be obtained from state agencies responsible for handling demographic or census information. Information on BOD_5 and wastewater characteristics may be obtained from state and local public works agencies. Default values are provided in this section if state-specific information on wastewater characteristics are not available.

  Published data on the fraction of wastewater treated anaerobically are scarce. If state-specific data are not available, this section contains default values for the fraction of wastewater treated anaerobically.

Step (2): Estimate Biochemical Oxygen Demand

- Multiply the total state population (number of people) by the wastewater BOD_5 generation rate (kg per capita per day) to obtain BOD generated per day. A default wastewater BOD_5 generation rate of 0.065[3] may be used if state-specific data are not available.

BOD_5 Generated (kg/day) = Population x BOD_5 Generation Rate (kg/capita/day)

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[3] The IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000) uses this value for daily wastewater BOD_5 production, as estimated in U.S. EPA 1997.

Example:	A state that has a current population of 2 million people would calculate its BOD_5 generated as follows:
	2,000,000 persons x 0.065 kg/capita/day **= 130,000 kg BOD_5/day**

Step (3): Estimate Annual Quantity of BOD_5 Treated Anaerobically

- Multiply the BOD_5 generated (kg/day) by the fraction of wastewater BOD_5 treated anaerobically and by 365 days per year to obtain annual BOD_5 treated anaerobically. A default value of 16.25 percent[4] may be used if state-specific information on the fraction of wastewater treated anaerobically is not available.

Annual BOD_5 Treated Anaerobically (kg/yr) = BOD_5 Generated (kg/day) x Fraction of Wastewater BOD_5 Treated Anaerobically (%) x 365 (days/year)

Step (4): Estimate Gross Annual Methane Emissions from Wastewater Treatment

- Multiply the quantity of BOD_5 treated anaerobically by the CH_4 emission factor, in kg CH_4/kg BOD_5, to obtain the total CH_4 emissions (in kg). The recommended emission factor is 0.6 kg CH_4/kg BOD_5.

CH_4 Emissions (kg CH_4) = BOD_5 Treated Anaerobically (kg BOD_5/yr) x CH_4 Emissions Factor (kg CH_4/kg BOD_5)

Example:	Annual CH_4 emissions from wastewater treatment in the state are calculated as follows:
	130,000 kg BOD_5/day x 16.25% x 365 days/yr = 7,710,625 kg BOD_5 treated anaerobically/yr
	7,710,625 kg BOD_5/yr x 0.6 kg CH_4/kg BOD_5 = **4,626,375 kg CH_4/yr**

Step (5): Convert Annual Methane Emissions from Wastewater to Metric Tons of Carbon Equivalent

- In order to convert the emissions in units of kg of CH_4 to units of metric tons of carbon equivalent (MTCE) multiply the result of Step 3 by 0.001 metric tons per kg, by the mass ratio of carbon to carbon dioxide (12/44), and by the Global Warming Potential (GWP) for CH_4 (21).

CH_4 Emissions (MTCE) = CH_4 Emissions (kg CH_4) x 0.001 metric tons/kg x (12/44) x 21

Example:	The following equation can be used to convert kg CH_4 to MTCE:
	4,626,375 kg CH_4/yr x 0.001 metric tons/kg x (12/44) x 21 = **26,497 MTCE/yr**

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[4] This number is the percentage of wastewater BOD_5 the U.S. EPA assumes is anaerobically digested in the *Inventory of Greenhouse Gas Emissions and Sinks: 1990-2002.*

4.2 Nitrous Oxide Emissions from Municipal Wastewater Treatment

This section provides the method for estimating nitrous oxide (N_2O) emissions from municipal wastewater. To estimate emissions from this source, five steps must be performed: (1) obtain required data; (2) estimate annual per capita consumption of nitrogen (N) in protein; (3) estimate the state's annual consumption of N in protein; (4) factor in the state's annual non-consumption N; (5) adjust total nitrogen in wastewater estimate to account for land application of sewage sludge; (6) estimate the state's annual N_2O emissions from wastewater treatment; and (7) convert annual N_2O emissions to MTCE.

Step (1): Obtain Required Data

- *Required Data.* The data needed to calculate N_2O emissions from municipal wastewater are (1) annual per capita protein consumption, (2) the fraction of N in protein, (3) the non-consumption N factor, (4) state population, and (5) an emission factor.

- *Data Sources*. Where state data are available, they should be used. Otherwise, data on annual per capita protein consumption for the United States have been published by the United Nations Food and Agriculture Organization (FAO 2000). Default values are provided in Table 14.4-1. The fraction of N in protein has been calculated at 16 percent (IPCC/UNEP/OECD/IEA 1997). The fraction of non-consumption N in wastewater is estimated to be 75 percent of the protein consumption value (FAO 2000). Population data may be obtained from state agencies responsible for handling demographic or census information and/or from the U.S. Census. An emission factor has not been estimated for the United States; thus, the default value, as provided by the Intergovernmental Panel on Climate Change (IPCC), 0.01 kg N_2O-N/kg sewage-N, should be used (IPCC/UNEP/OECD/IEA 1997).

Step (2): Estimate Annual Per Capita Consumption of Nitrogen in Protein

- Multiply the annual per capita consumption of protein by the percentage of N in protein to obtain the annual per capita consumption of N in protein. Default values for per capita protein consumption are provided in Table 14.4-1.

Per Capita Consumption of N in Protein (kg) = Per Capita Protein Consumption (kg) x N in Protein (%)

Example:	Annual consumption of N in protein for people living in the United States in 2000 can be calculated as follows: 41.9 kg protein x 16% N in protein = **6.70 kg N per capita per year**

Table 14.4-1: U.S. Per Capita Protein Consumption (kg) 1990-2002

1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
39.2	39.8	40.0	40.2	41.2	40.5	40.7	40.9	41.2	42.0	41.9	41.8	41.8

Source: U.S. EPA 2004.

Step (3): Estimate the State's Annual Consumption of Nitrogen in Protein

- Multiply the annual per capita consumption of N in protein by the state population to obtain the state's annual consumption of N in protein.

Annual Consumption of N in Protein (kg N) = Consumption of N in Protein (kg/capita/year) x Population

Example:	For a state with a population of 3 million, the calculation would be:
	6.71 kg N/capita x 3,000,000 people = **20,130,000 kg N**

Step (4): Factor in the State's Annual Non-consumption of Nitrogen

- Multiply the annual per capita consumption of N in protein by a non-consumption factor (1.75) to obtain the state's annual total N in wastewater.

Annual Total N in Wastewater (kg N) = Annual Consumption of N in Protein (kg N) x 1.75

Example:	The calculation to estimate the annual total N in wastewater would be:
	20,130,000 kg N x 1.75 = **35,227,500 kg N**

Step (5): Adjust Total Nitrogen in Wastewater Estimate to Account for Land Application of Sewage Sludge. (Optional)

The preferred methodology does not include a detailed step-by-step approach to estimating emissions from land application of sewage sludge. There are three central reasons for considering this to be an optional step. First, the data necessary to estimate emissions are not likely to be available at the state level. Second, there is considerable uncertainty surrounding the method used to estimate these emissions at the national level. Third, emissions from sewage sludge would then need to be included in the methodology for estimating emissions from agriculture soils in Chapter 10. However, if states have data on land applied sewage sludge, they can calculate emissions by applying the general guidance provided below.

States with data on sewage sludge applied to soils can calculate emissions by multiplying (1) the dry weight of sewage sludge produced in the state by (2) the fraction of sewage sludge applied to soil and by (3) 3.3 percent to estimate the amount of N applied to soils in the form of sewage sludge.[5] This value should then be subtracted from the total N in wastewater value noted above.

[5] States choosing to estimate N_2O emissions from land application of sewage sludge should recalculate emissions from commercial organic fertilizer application to ensure that sewage sludge emissions are not being counted twice.

Step (6): Estimate the State's Annual Nitrous Oxide Emissions from Wastewater Treatment

- Multiply the state's annual total N in wastewater by the emission factor (0.01 kg N_2O-N/kg N in protein) to obtain the state's annual emissions of N_2O in terms of N.
- Multiply emissions in kg N_2O-N by the ratio of the molecular weight of N_2O to the atomic weight of the N contained in N_2O (44/28) to yield emissions in kg N_2O.

Annual Emissions of N_2O from Wastewater (kg N_2O) = Annual Total N in Wastewater (kg N) x Emission Factor (kg N_2O-N/kg N) x 44/28

Example:	For a state with a population of 3 million, the calculation would be:
	35,227,500 kg N x 0.01 kg N_2O-N/kg N in protein x 44/28 = **553,575 kg N_2O**

Step (7): Convert Annual Nitrous Oxide Emissions to Metric Tons of Carbon Equivalent

- To convert emissions in kilograms of N_2O to units of MTCE, multiply the result of Step 4 by 0.001 metric tons per kg, by the ratio of carbon to carbon dioxide (12/44), and by the GWP of N_2O (310).

Example:	Emissions in kg N_2O can be converted to MTCE using the following equation:
	553,575 kg N_2O x 0.001 x (12/44) x 310 = **46,802 MTCE**

4.3 Direct Nitrous Oxide Emissions From Municipal Wastewater Treatment

To estimate direct N_2O emissions from municipal wastewater treatment, several steps must be performed. The total state population is factored by the percentage not on septic (75 percent national average) and then by 0.4 g N_2O/person/year emission factor (IPCC 1997). The direct N_2O emissions estimate is then converted to MTCE through the process described in Step 6 of Section 4.2. It is important to note that direct N_2O emissions are included in the total N_2O emissions estimate described in Section 4.2. In order to report direct and "indirect" emissions, the direct emissions estimate must be netted-out of the total N_2O emissions estimate.

4.4 Methane Emissions from Industrial Wastewater Treatment

To estimate CH_4 emissions from industrial wastewater treatment, six steps must be performed: (1) obtain required data; (2) determine industries for estimating emissions; (3) calculate annual wastewater production for each industry; (4) calculate methane emissions for each industry; (5) calculate total CH_4 emission; and (6) convert CH_4 emissions to MTCE.

Step (1): Obtain Required Data

- *Required Data.* The information needed to calculate CH_4 emissions from industrial wastewater are (1) an understanding of industrial wastewater streams in the state, particularly for those industries listed in the IPCC guidance; (2) amount of wastewater produced by each industry (could be the product of annual production and wastewater outflow per metric tons of product produced); (3) oxygen demand from organic or inorganic material in the wastewater (expressed as Chemical Oxygen Demand, or COD); and (4) the fraction of wastewater treated anaerobically.

- *Data Sources.* Published data on annual production, wastewater outflow, industry-specific COD, and the fraction of industrial wastewater that is anaerobically treated are not readily available. Default data used to estimate emissions from industrial wastewater in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (U.S. EPA 2004) are provided in Table 14.4-2. If the relevant data (as described in Step 2) are available for other industrial sources in your state, the methodology may be applied to those industries as well. IPCC's *Guidelines for National Greenhouse Gas Inventories: Reference Manual* may provide default values for other industries. After the industry-specific data have been obtained, each industry's CH_4 emissions from wastewater treatment are estimated in much the same manner as described in Section 4.2 for estimating CH_4 emissions from the treatment of municipal wastewater.

  If wastewater outflow data are available, they should be provided in liters. If not, production data should be provided in metric tons per year, and wastewater outflow in cubic meters (m^3) per metric ton of product produced. COD should be reported in grams per liter (l), and the fraction of wastewater anaerobically digested should be provided as a percentage.

Step (2): Determine Industries for Estimating Emissions

- The IPCC *Good Practice Guidelines* (IPCC 2000) suggest estimating emissions only from the three or four industries with the highest potential for CH_4 production. These industries will produce large quantities of wastewater with a high organic COD load. The three industries with the greatest CH_4 production potential in the United States (and the industries represented in the Wastewater Module of the State Inventory Tool) are: (1) Fruits and Vegetables; (2) Red Meat and Poultry; and (3) Pulp and Paper. These industries are not necessarily representative of the top methane-producing industries in each individual state; the estimation process should be modified to reflect the industrial characteristics in each state.

Step (3): Calculate Annual Wastewater Production for Each Industry

- If data on annual wastewater production are available for each industry in the state, move on to Step 4. However, if data on wastewater production are not available, use production data to estimate wastewater production. To do this, multiply annual production by the default value in the second column of Table 14.4-2 and by 1,000 liters/m^3 to convert to liters.

Wastewater Production (l) = Production (metric tons/yr) x Wastewater Produced per Metric Ton of Product (m^3/metric ton) x 1,000 (l/m^3)

Example:	For a state with annual production of 10,000 metric tons of fruits and vegetables, 5,000 metric tons of red meat and poultry, and 20,000 metric tons of pulp paper, the calculations would be as follows: *Fruits and Vegetables*

10,000 metric tons/yr x 5.6 m^3/metric ton x 1,000 (liters/m^3) = **56,000,000 liters**

Red Meat and Poultry

5,000 metric tons/yr x 13 m^3/metric ton x 1,000 (liters/m^3) = **65,000,000 liters**

Pulp and Paper

20,000 metric tons/yr x 85 m^3/metric ton x 1,000 (liters/m^3) = **1,700,000,000 liters**

Step (4): Calculate Methane Emissions for Each Industry

- To calculate CH_4 emissions for each industry, multiply annual wastewater production by the industry-specific COD, fraction of COD treated anaerobically, and the industry-specific emission factor. Default values for these three components are included in columns 3, 4, and 5 of Table 14.4-2.

CH_4 Emissions (g CH_4) = Wastewater Production (l) x COD (g COD/l) x Fraction of COD Anaerobically Treated (%) x Emission Factor (g CH_4/g COD)

Example: Annual CH_4 emissions for the state from industrial wastewater production would be calculated as follows:

Fruits and Vegetables

56,000,000 liters x 5 g COD/liter x 0.05 x 0.25 g CH_4/g COD = **3,500,000 g CH_4**

Red Meat and Poultry

65,000,000 liters x 4.1 g COD/liter x 0.77 x 0.25 g CH_4/g COD = **51,301,250 g CH_4**

Pulp and Paper

1,700,000,000 liters x 0.4 g BOD/liter x 0.10 x 0.6 g CH_4/g BOD = **40,800,000 g CH_4**

* The default values for the Pulp and Paper industry use BOD instead of COD because more accurate BOD data were available.

Table 14.4-2: Default Data Elements for Selected Industries

Process	Wastewater Produced (m^3/ metric ton of product)	COD (g COD/l wastewater)	Fraction of COD Anaerobically Treated	Emission Factor (g CH_4 / g COD)
Fruits and Vegetables	5.6	5	5%	0.25
Red Meat and Poultry	13	4.1	77%	0.25
Pulp and Paper	85	0.4*	10%*	0.6*

Source: U.S. EPA 2004.

*For the Pulp and Paper industry, default values use BOD instead of COD because more accurate BOD data were available.

Step (5): Calculate Total Methane Emissions

- To calculate total CH_4 emissions from this source category, sum emissions for all industries.

Example:	The total CH_4 emissions from industrial wastewater production for the state would be as follows: 3,500,000 g CH_4 + 51,301,250 g CH_4 + 40,800,000 g CH_4 = **95,601,250 g CH_4**

Step (6): Convert Methane Emissions to Metric Tons of Carbon Equivalent

- In order to convert the emissions in units of grams of CH_4 to units of MTCE, multiply the result of Step 5 by 0.000001 metric tons per gram, by the ratio of the atomic weight of carbon to the molecular weight of carbon dioxide (12/44), and by the GWP of CH_4 (21).

CH_4 Emissions (MTCE) = CH_4 Emissions (g CH_4) x 0.000001 metric tons/kg x (12/44) x 21

Example:	The total emissions from industrial wastewater production for the state (in MTCE) would be as follows: 95,601,250 g CH_4 x 0.000001 metric tons/kg x 12/44 x 21 = **547.5 MTCE**

5

ALTERNATIVE METHODS FOR ESTIMATING EMISSIONS

There are no alternative methods for estimating emissions from wastewater available at this time.

6

UNCERTAINTY

This chapter presents methodology for estimating methane (CH_4) and nitrous oxide (N_2O) emissions from municipal and industrial wastewater treatment. Uncertainty surrounds both the emission factors and activity data used in these calculations.

The quantity of CH_4 emissions from wastewater treatment is based on several factors with varying degrees of uncertainty. For domestic wastewater, there is some degree of uncertainty associated with the factor used to estimate the occurrence of anaerobic conditions in treatment systems based on septic tank usage data. The national default estimate of the fraction of the wastewater stream not on septic is 75 percent, but this fraction varies from state to state. There can also be variation in the per-capita BOD production associated with food consumption, food waste, and disposal characteristics for organic matter. Additionally, there is variation in these factors that can be attributed to specific characteristics of wastewater treatment regimes.

N_2O emissions are dependant on nitrogen (N) inputs into the wastewater and the characteristics of wastewater treatment methods. Estimates of U.S. population, per capita protein consumption data, and fraction of nitrogen in protein are believed to be fairly accurate. However, the fraction that is used to represent the ratio of non-consumption nitrogen also contributes to the overall uncertainty of these calculations. The emission factor for effluent is the default emission factor from IPCC (1997) where it is expressed as 0.01 based on a range of 0.002 to 0.02 kg N_2O per kg N-sewage, and consequently presents a significant level of uncertainty when calculating N_2O emissions. Methods of sludge disposal also present a level of complexity to estimating N_2O emissions from wastewater treatment. Disposal methods for sewage sludge, or biosolids, include incineration, landfilling, or land-application as fertilizer.

There are large uncertainties associated with the industrial wastewater emission estimates. Wastewater outflows and organics loadings vary considerably for different plants and different sub-sectors (e.g., office paper vs. newsprint, or fish vs. beef). Again, there can also be variation in the per-capita BOD production associated with industrial processes, and disposal characteristics for organic matter. Furthermore, there is variation in these factors that can be attributed to characteristics of industrial pretreatment treatment systems as well as eventual treatment at municipal facilities.

7

REFERENCES

IPCC. 2000. *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, Intergovernmental Panel on Climate Change, National Greenhouse Gas Inventories Program. Internet address: http://www.ipcc-nggip.iges.or.jp/public/gp/gpgaum.htm.

IPCC/UNEP/OECD/IEA. 1997. *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, 3 volumes. Intergovernmental Panel on Climate Change, United Nations Environment Programme, Organization for Economic Co-Operation and Development, International Energy Agency. Paris, France.

Spector, M. 1997. "Production and Decomposition of Nitrous Oxide During Biological Denitrification." Unpublished, Lehigh University. Bethlehem, PA.

FAO. 2000. *FAOSTAT Statistical Database*. Food and Agriculture Organization of the United Nations. Internet address: http://apps.fao.org/lim500/nph-wrap.pl?FoodBalanceSheet&Domain=FoodBalanceSheet.

U.S. EPA. 1997. *Estimate of Global Greenhouse Gas Emissions from Industrial and Domestic Wastewater Treatment*. United States Environmental Protection Agency. EPA-600/R-97-091.

U.S. EPA. 2004. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002*. Office of Atmospheric Programs, U.S. Environmental Protection Agency. EPA-430-R-04-003. Internet address: http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2004.html.

U.S. EPA. 2002. *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2000*. U.S. Environmental Protection Agency. EPA 236-R-02-003. Internet address: http://www.epa.gov/globalwarming/publications/emissions/index.html.

U.S. EPA 2001. "Source Water Protection Practices Bulletin: Managing Septic Systems to Prevent Contamination of Drinking Water." U.S. Environmental Protection Agency. EPA 816-F-01-021. Internet address: http://www.epa.gov/safewater/dwa/electronic/swp/septic.pdf.

U.S. EPA. 1999. Clean Water Needs Survey Database. U.S. Environmental Protection Agency. Internet address: http://www.epa.gov/owm/foi.htm.