Local Government Operations Protocol

For the quantification and reporting of greenhouse gas emissions inventories

Version 1.1

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Developed in partnership and adopted by:

California Air Resources Board

California Climate Action Registry

ICLEI - Local Governments for Sustainability

The Climate Registry

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Abbreviations and Acronyms

AB 32	Assembly Bill 32, California State
APHA	American Public Health Association
ASTM	American Society for Testing and Materials
AWWA	American Water Works Association
Btu	British thermal unit(s)
ARB	California Air Resources Board
CARROT	Climate Action Registry Reporting Online Tool
CCAR	California Climate Action Registry
CEMS	Continuous Emissions Monitoring System
CFC	chlorofluorocarbon
CFR	Code of Federal Regulations
CH_4	methane
CHP	combined heat and power
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
COP	coefficient of performance
CWCCG	California Wastewater Climate Change Group
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
EU ETS	European Union Emission Trading Scheme
FOD	first-order decay
FTE	full time employee
g	gram(s)
GHG	greenhouse gas
GRP	General Reporting Protocol
GWP	Global Warming Potential
HCFC	hydrochlorofluorocarbon
HFC	hydrofluorocarbon
HHV	higher heating value
HSE	health, safety, and environment
HV/AC	heating, ventilating, and air conditioning
IAPWS	International Association for the Properties of Water and Steam

IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
J	joule
JPA	Joint Powers Authority
kg	kilogram(s)
kWh	kilowatt-hour(s)
lb(s)	pound(s)
LFG	landfill gas
LHV	lower heating value
LPG	liquefied petroleum gas
MMBtu	one million British thermal units
mpg	miles per gallon
MSW	municipal solid waste
mt	metric ton(s)
MWh	megawatt-hour(s)
NF_3	nitrogen trifluoride
N_2O	nitrous oxide
NMVOC	non-methane volatile organic compound(s)
NO_x	oxides of nitrogen
NSPS	new source performance standards
ODS	ozone depleting substances
PFC	perfluorocarbon
REC	renewable energy certificates
SF_6	sulfur hexafluoride
T&D	transmission and distribution
UNFCCC	United Nations Framework Convention on Climate Change
WBCSD	World Business Council for Sustainable Development
WEF	Water Environment Federation
WERF	Water and Environment Research Foundation
WRI	World Resources Institute
WWTP	wastewater treatment plant

Chapter 10 Wastewater Treatment Facilities

Local governments are often responsible for providing wastewater services to their communities. This may include activities like wastewater collection, managing septic systems, primary and secondary treatment, solids handling and effluent discharge.

Wastewater treatment processes can encompass many different sources of GHG emissions. This chapter focuses solely on calculating the CH_4 and N_2O emissions created by septic systems and centralized wastewater treatment. For guidance on calculating the GHG emissions from other activities related to wastewater treatment, you should refer to other chapters in the Protocol. Table 10.1 provides references to the appropriate chapter and section for common GHG sources related to wastewater.

Local governments from Canada and Mexico who are Members of The Climate Registry should refer to the country specific information provided in Appendix D. Where available, The Climate Registry provides country specific default values that can be used in equations throughout this chapter.

California Local Governments and AB 32

Note: If your local government operates a wastewater facility that includes co-generation or power generation operations with a nameplate capacity of 1 MW or higher and emits over 2,500 metric tons of CO_2 per year, or a stationary combustion source that emits at least 25,000 metric tons of CO_2 per year, you will be subject to ARB's mandatory reporting regulation under AB 32. The regulation has additional reporting requirements beyond what is described in this Protocol.

To download the mandatory reporting requirements visit: www.arb.ca.gov/cc/reporting/ghg-rep/ghg-rep.htm.

Please note that if you are generating power or heat at your wastewater facility and the electricity and/or heat are consumed entirely within the facility, you should report the Scope 1 stationary combustion emissions from generating that power in the Wastewater Treatment Facility sector, not in the Power Generation Facilities sector of your Standard Inventory Report. See Chapter 13 for more information.

Table 10.1 Protocol References for Wastewater- Related Emission Sources

GHG type/source	Protocol Reference
CO_2, CH_4 and N_2O from fuel-combusting equipment	Chapter 6, Section 6.1
CO_2, CH_4 and N_2O from purchased electricity	Chapter 6, Section 6.2
CO_2, CH_4 and N_2O from power generated and consumed at wastewater facility	Chapter 8

10.1 Organizational Boundary Issues

To determine what emissions from wastewater treatment your local government is responsible for calculating and reporting under the Protocol, you will need to examine your wastewater treatment activities according to the organizational boundary guidance in Chapter 3. It is the same process you used to determine what other facilities your local government is responsible for.

Remember you should consistently apply your organizational consolidation approach across all sources of emissions within your local government. Thus, if the rest of your local government's inventory is based on operational control, use the operational control conditions to determine if the wastewater treatment facility that serves your local government falls under your control.

Local Governments Served by Regional Wastewater Treatment Plants

Many local governments are served by regionally-serving wastewater treatment plants. Only the local government that has operational and/or financial control over the facility itself should report fugitive emissions from that facility as Scope 1 emissions. If you do not have financial or operational control over the treatment facility, you should not report the fugitive emissions from that facility as Scope 1 emissions. You are encouraged, however, to optionally report these emissions as Scope 3.

10.2 Emissions Unique to Wastewater Treatment

Wastewater treatment processes can create a unique set of process and fugitive greenhouse gas emissions. Wastewater from domestic and industrial sources is treated to remove soluble organic matter, suspended solids, pathogenic organisms, and chemical contaminants.

Soluble organic matter is generally removed using biological processes in which microorganisms consume the organic matter for cell maintenance and growth. The resulting biosolids (sludge) are removed from the effluent prior to discharge to the receiving water.

Production of CH_4 Emissions

Microorganisms can biodegrade soluble organic material in wastewater under aerobic or anaerobic conditions - it is anaerobic conditions that lead to the production of CH_4. During collection and treatment, wastewater may be accidentally or deliberately managed under anaerobic conditions. In addition, the resulting biosolids may be further biodegraded under aerobic or anaerobic conditions.[24]

Production of N_2O Emissions

The generation of N_2O may also result from the treatment of domestic wastewater during both nitrification and denitrification of the nitrogen 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 dinitrogen gas (N_2). N_2O can be an intermediate product of both processes, but is more often associated with denitrification.[25]

Sources of Emissions

Table 10.2 summarizes the sources of fugitive and process CH_4 and N_2O emissions discussed in this chapter. For most sources, two methodologies are provided - a source-specific method that requires source-specific data and a general method that requires only population served by the facility. For each applicable source, you will choose a method and associated equation based on data available.

[24] EPA *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2006*, Chapter 8.
[25] Ibid.

Table 10.2 Summary of Wastewater Treatment Process and Fugitive Emission Sources

GHG type	GHG source	Data Available	Equation
Stationary CH_4 emissions	Incomplete combustion of digester gas at a centralized WWTP with anaerobic digestion of biosolids	• Digester gas (ft^3/day) • Fraction of CH_4 in biogas	Equation 10.1
		Population served	Equation 10.2
Process CH_4 emissions	Anaerobic and facultative treatment lagoons	• BOD_5 load ($kg\ BOD_5$/day) • Fraction of overall BOD_5 removal performance	Equation 10.3
		Population served	Equation 10.4
Fugitive CH_4 emissions	Septic systems	BOD_5 load ($kg\ BOD_5$/person/day)	Equation 10.5
		Population served	Equation 10.6
Process N_2O emissions	Centralized WWTP with nitrification/denitrification	Population served	Equation 10.7
Process N_2O emissions	Centralized WWTP without nitrification/denitrification	Population served	Equation 10.8
Process N_2O emissions	Effluent discharge to receiving aquatic environments	N load (kg N/day)	Equation 10.9
		Population served	Equation 10.10

Box 10.3 at the end of this chapter provides an example of how to calculate emissions from a wastewater treatment plan.

10.3 Ongoing Research and Development

While IPCC, EPA and others have worked to estimate GHG emissions from wastewater on a gross basis, there are not widely-accepted, standardized guidelines to estimate emissions from wastewater treatment at a facility level.

Since local governments are often responsible for providing wastewater treatment services for their communities, the Protocol provides guidance on estimating the process and fugitive emissions from wastewater treatment. These estimation methodologies are based largely on the existing "top-down" methodologies used by ARB, US EPA and others to estimate emissions for an entire state or country.

Box 10.1 The California Wastewater Climate Change Group
In a proactive approach to meet potential future GHG regulatory requirements, over forty California wastewater agencies have formed the California Wastewater Climate Change Group (CWCCG). CWCCG participated in the development of this chapter but is also working to develop an emissions quantification protocol for wastewater treatment plants in California that will allow an operator to estimate its GHG profile of all six major GHGs.

For the more conventional GHG pollutants like CO_2 from combustion and power importation, the document will reference and steer the operator toward a variety of existing general reporting protocols for most of the GHG pollutants. For other pollutants, like N_2O, the CWCCG intends to use Water Environment Research Foundation (WERF) research on N_2O from activated sludge plants, currently under way. The WERF research, which is focusing on a combination of direct measurements and refinement of mathematical modeling, should provide quantification tools for the industry. Other pollutants such as CH_4 and other potential fugitive emissions release points will also be incorporated as part of later WERF study programs or other study programs, so that a complete wastewater industry emission profile can be obtained.

For more information, refer to the *Discussion Paper for a Wastewater Treatment Plant Sector Greenhouse Gas Emissions Reporting Protocol* (April 2008), prepared for CWCCG by CH2MHILL available for download at:
http://www.scap1.org/Air%20Reference%20Library/Forms/Indx_CWCCG_GHG_EM.aspx

10.3.1 CH_4 Emissions Estimation Methodologies

Within the wastewater treatment systems owned and/or operated by local governments, CH_4 emissions can arise from septic systems, aerobic systems that are not well managed, anaerobic treatment and facultative treatment lagoons, and from anaerobic digesters when the captured biogas is not completely combusted.

Box 10.2 CH_4 Emissions from Aerobic Systems
The IPCC inventory guidance includes a methodology for estimating CH_4 emissions from poorly-operated aerobic wastewater treatment systems. Such poorly-operated facilities will inherently produce poor-quality effluents, which are not in compliance with modern discharge standard requirements. The US EPA inventory methodology includes the equations to calculate CH_4 emissions from this source, but US EPA assumes these are negligible. Thus, CH_4 emissions from centralized aerobic treatment are not included in the US inventory. This assumption is based on the acknowledgement that the regulatory system in the US ensures that wastewater treatment plants are routinely in compliance with their discharge requirements, which requires that they are well-operated. This same regulatory system is in place in California, which ensures that plants are in reliable compliance with their discharge requirements and are consistently well-operated. Therefore, the equations for calculating CH_4 emissions from poorly-operated aerobic wastewater treatment systems are omitted from this protocol.

This section provides equations for calculating CH_4 emissions from these sources based on the population served by the wastewater treatment system, or based on site-specific data. These methodologies are adapted for use by local governments from Section 6.2.2 of the 1996 *IPCC Guidelines* and Section 8.2 of the *US EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks* (1990-2006). For each term in the equations, this section provides a description and an appropriate default value, as applicable.

10.3.1.1 Stationary Emissions from Incomplete Combustion of Digester Gas

Many local governments operate anaerobic digesters to treat excess biosolids produced by the wastewater treatment process. Anaerobic digestion creates CH_4, which is then combusted. Due to small, but inherent inefficiencies, these treatment processes are a source of CH_4 emissions.

Equation 10.1 should be used by local governments that collect measurements of the volume of digester gas (biogas) produced and the fraction of CH_4 in their biogas in accordance with local, state and/or federal regulations or permits, or published industry standardized sampling and testing methodologies (e.g., 40 CFR 136, NSPS, APHA, AWWA, WEF, ASTM, EPA, etc.)[26].

If these site-specific data are not available, you should use Equation 10.2 to estimate this source of emissions.

Please note if significant industrial contributions of BOD_5 are discharged to your municipal treatment system, the Protocol recommends using Equation 10.1 instead of Equation 10.2 to more accurately account for the increase in BOD_5 from industrial discharges.

Equation 10.1	Stationary CH_4 from Incomplete Combustion of Digester Gas (site-specific digester gas data)
Annual CH_4 emissions (metric tons CO_2e) =	
(Digester Gas x F_{CH4} x $\rho(CH_4)$ x (1-DE) x 0.0283 x 365.25 x 10^{-6}) x GWP	

Where:

Term		**Description**	**Value**
Digester Gas	=	measured standard cubic feet of digester gas produced per day [ft^3/day]	user input
F CH_4	=	measured fraction of CH_4 in biogas	user input
p(CH_4)	=	density of methane at standard conditions [g/m^3]	662.00
DE	=	CH_4 Destruction Efficiency	.99
0.0283	=	conversion from ft^3 to m^3 [m^3/ft^3]	0.0283
365.25	=	conversion factor [day/year]	365.25
10^{-6}	=	conversion from g to metric ton [metric ton/g]	10^{-6}
GWP	=	Global Warming Potential	21

Source: EPA *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2007*, Chapter 8, 8-7 (2009).

[26] Acronym definitions: CFR-Code of Federal Regulations; NSPS-National Source Performance Standard; APHA-American Public Health Association; AWWA-American Water Works Association; WEF-Water Environment Federation; ASTM-American Society for Testing and Materials.

Equation 10.2	Stationary CH_4 from Incomplete Combustion of Digester Gas (default)
Annual CH_4 emissions (metric tons CO_2e) = (P x Digester Gas x F_{CH4} x $\rho(CH_4)$ x (1-DE) x 0.0283 x 365.25 x 10^{-6}) x GWP	

Where:

Term		Description	Value
P	=	population served by the WWTP with anaerobic digesters	user input
Digester Gas	=	cubic feet of digester gas produced per person per day [ft^3/person/day]	1.0
F_{CH4}	=	fraction of CH_4 in biogas	0.65
$\rho(CH_4)$	=	density of methane [g/m^3]	662.00
DE	=	CH_4 Destruction Efficiency	.99
0.0283	=	conversion from ft^3 to m^3 [m^3/ft^3]	0.0283
365.25	=	conversion factor [day/year]	365.25
10^{-6}	=	conversion from g to metric ton [metric ton/g]	10^{-6}
GWP	=	Global Warming Potential	21

Source: EPA *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2007*, Chapter 8, 8-7 (2009).

10.3.1.2 Process Emissions from Wastewater Treatment Lagoons

Equation 10.3 should be used by local governments with wastewater treatment lagoons that collect measurements of the average BOD_5 load, BOD_5 removal in primary treatment upstream of the lagoon (if primary treatment is present), and the fraction of overall lagoon removal performance in accordance with local, state and/or federal regulations or permits, or published industry standardized sampling and testing methodologies (e.g., 40 CFR 136, NSPS, APHA, AWWA, WEF, ASTM, EPA, etc.).

If these site-specific data are not available, you should use Equation 10.4 to estimate this source of emissions.

If significant industrial contributions of BOD_5 are discharged to your municipal treatment lagoons, you should use Equation 10.3. Alternatively, you can adjust the population served in Equation 10.4 to account for the industrial contribution. This is done using a factor that accounts for industrial and commercial wastewater discharge ($F_{ind-com}$). The $F_{ind-com}$ factor is 1.25. If your facility does not treat wastewater from industrial or commercial sources, ignore this term in equation 10.4.

Equation 10.3	Process CH_4 from Anaerobic and Facultative Wastewater Treatment Lagoons (site-specific BOD_5 load, F removed values)

Annual CH_4 emissions (metric tons CO_2e) =

$$(BOD_5 \text{ load} \times (1-F_P) \times Bo \times MCF_{anaerobic} \times 365.25 \times 10^{-3}) \times GWP$$

Where:

Term		Description	Value
BOD_5 load	=	amount of BOD_5 produced per day (influent to wastewater treatment process) [kg BOD_5/day]	user input
F_P	=	fraction of BOD_5 removed in primary treatment, if present	user input
Bo	=	maximum CH_4-producing capacity for domestic wastewater [kg CH_4/kg BOD_5 removed]	0.6
$MCF_{anaerobic}$	=	CH_4 correction factor for anaerobic systems	0.8
365.25	=	conversion factor [day/year]	365.25
10^{-3}	=	conversion from kg to metric ton [metric ton/kg]	10^{-3}
GWP	=	Global Warming Potential	21

Source: EPA *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2007*, Chapter 8, 8-7 (2009).

Equation 10.4	Process CH_4 from Wastewater Treatment Lagoons (default values)

Annual CH_4 emissions (metric tons CO_2e) =

$$((P \times F_{ind\text{-}com}) \times BOD_5 \text{ load} \times (1-F_P) \times Bo \times MCF_{anaerobic} \times 365.25 \times 10^{-3}) \times GWP$$

Where:

Term		Description	Value
P	=	population served by lagoons adjusted for industrial discharge, if applicable [person]	user input
$F_{ind\text{-}com}$	=	factor for industrial and commercial co-discharge waste into the sewer system	1.25
BOD_5 load	=	amount of BOD_5 produced per person per day [kg BOD_5/person/day]	0.090
F_P	=	fraction of BOD_5 removed in primary treatment, if present	0.325*
Bo	=	maximum CH_4-producing capacity for domestic wastewater [kg CH_4/kg BOD_5 removed]	0.6
$MCF_{anaerobic}$	=	CH_4 correction factor for anaerobic systems	0.8
365.25	=	conversion factor [day/year]	365.25
10^{-3}	=	conversion from kg to metric ton [metric ton/kg]	10^{-3}
GWP	=	Global Warming Potential	21

Source: EPA *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2007*, Chapter 8, 8-9 (2009) except: *$F_{p:}$ Tchobanoglous, G., F.L. Burton, and H.D. Stensel, *Wastewater Engineering: Treatment and Reuse*, p. 396, 4th Edition (2003).

10.3.1.3 Fugitive Emissions from Septic Systems

In some jurisdictions, the local government may own or operate a network of septic systems. If your local government owns or operates septic systems, use the appropriate equation below to estimate the fugitive CH_4 from this emission source.

Equation 10.5 should be used when measurements of the average BOD_5 load are collected in accordance with local, state and/or federal regulations or permits, or published industry standardized sampling and testing methodologies (e.g., 40 CFR 136, NSPS, APHA, AWWA, WEF, ASTM, EPA, etc.).

If this site-specific data is not available, you should use Equation 10.6 to estimate this source of emissions.

Equation 10.5	Fugitive CH_4 from Septic Systems (site-specific BOD_5 load data)
Annual CH_4 emissions (metric tons CO_2e) = (BOD_5 load x Bo x MCF_{septic} x 365.25 x 10^{-3}) x GWP	

Where:

Term		**Description**	**Value**
BOD_5 load	=	amount of BOD_5 produced per day [kg BOD_5/day]	user input
Bo	=	maximum CH_4-producing capacity for domestic wastewater [kg CH_4/kg BOD_5 removed]	0.6
MCF_{septic}	=	CH_4 correction factor for septic systems	0.5
365.25	=	conversion factor [day/year]	365.25
10^{-3}	=	conversion from kg to metric ton [metric ton/kg]	10^{-3}
GWP	=	Global Warming Potential	21

Source: EPA *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2007*, Chapter 8, 8-8 (2009).

Equation 10.6	Fugitive CH_4 from Septic Systems (default BOD_5 load)
Annual CH_4 emissions (metric tons CO_2e) = $(P \times BOD_5 \text{ load} \times Bo \times MCF_{septic} \times 365.25 \times 10^{-3}) \times GWP$	

Where:

Term		Description	Value
P	=	population served by septic systems [person]	user input
BOD_5 load	=	amount of BOD_5 produced per person per day [kg BOD_5/person/day]	0.090
Bo	=	maximum CH_4-producing capacity for domestic wastewater [kg CH_4/kg BOD_5 removed]	0.6
MCF_{septic}	=	CH_4 correction factor for septic systems	0.5
365.25	=	conversion factor [day/year]	365.25
10^{-3}	=	conversion from kg to metric ton [metric ton/kg]	10^{-3}
GWP	=	Global Warming Potential	21

Source: EPA *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2006*, Chapter 8, 8-9 (2008).

10.3.2 N_2O Emissions Methodologies

This section provides equations for calculating N_2O emissions from a centralized WWTP with nitrification/denitrification, centralized WWTP without nitrification/denitrification, and effluent discharge to receiving aquatic environments. They are adapted for use by local governments from Section 6.3 of the 2006 *IPCC Guidelines* and Section 8.2 of the *US EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks (1990-2006).* For each term in the equations, this section provides a description and an appropriate value.

The $F_{ind\text{-}com}$ term accounts for industrial and commercial discharges into a municipal wastewater treatment facility in Equations 10.7, 10.8, and 10.10. If your facility does not have these types of wastewater inputs, please ignore the $F_{ind\text{-}com}$ term in these equations.

10.3.2.1 Process Emissions from WWTP with Nitrification/Denitrification

Equation 10.7	Process N_2O Emissions from WWTP with Nitrification/Denitrification
Annual N_2O emissions (metric tons CO_2e) = $((P_{total} \times F_{ind-com}) \times EF\ nit/denit \times 10^{-6}) \times GWP$	

Where:

Term		Description	Value
P_{total}	=	total population that is served by the centralized WWTP adjusted for industrial discharge, if applicable [person]	user input
$F_{ind-com}$	=	factor for industrial and commercial co-discharge waste into the sewer system	1.25
EF nit/denit	=	emission factor for a WWTP with nitrification/denitrification [g N_2O/person/year]	7
10^{-6}	=	conversion from g to metric ton [metric ton/g]	10^{-6}
GWP	=	N_2O Global Warming Potential	310

Source: EPA *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2007*, Chapter 8, 8-13 (2009).

10.3.2.2 Process Emissions from WWTP without Nitrification/Denitrification

Equation 10.8	Process N_2O Emissions from WWTP without Nitrification/Denitrification
Annual N_2O emissions (metric tons CO_2e) = $((P_{total} \times F_{ind-com}) \times EF\ w/o\ nit/denit \times 10^{-6}) \times GWP$	

Where:

Term		Description	Value
P_{total}	=	population that is served by the centralized WWTP adjusted for industrial discharge, if applicable [person]	user input
$F_{ind-com}$	=	factor for industrial and commercial co-discharge waste into the sewer system	1.25
EF w/o nit/denit	=	emission factor for a WWTP without nitrification/denitrification [g N_2O/person/year]	3.2
10^{-6}	=	conversion from g to metric ton [metric ton/g]	10^{-6}
GWP	=	Global Warming Potential	310

Source: EPA *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2007*, Chapter 8, 8-13 (2009).

10.3.2.3 Process Emissions from Effluent Discharge to Rivers and Estuaries

Equation 10.9 should be used by local governments that collect measurements of the average total nitrogen discharged in accordance with local, state and/or federal regulations or permits, or published industry standardized sampling and testing methodologies (e.g., 40 CFR 136, NSPS, APHA, AWWA, WEF, ASTM, EPA, etc.).

If this site-specific data is not available, you should use Equation 10.10 to estimate this source of emissions.

If significant industrial contributions of nitrogen are discharged to your municipal treatment system, you should use Equation 10.9. Alternatively, you can adjust the population served in Equation 10.10 to account for the industrial contribution. The industrial-equivalent population is calculated based on the total nitrogen discharged by industry to the municipal treatment system, expressed in kg of total nitrogen per day divided by the nitrogen population equivalent of 0.026 kg N/person/day.

The industrial-equivalent population is added to the domestic populations served by the centralized wastewater treatment system, and the total population (domestic plus industrial-equivalent) is the value you should use in Equation 10.10, as appropriate.

Equation 10.9	Process N_2O Emissions from Effluent Discharge (site-specific N load data)
Annual N_2O emissions (metric tons CO_2e) = (N Load x EF effluent x 365.25 x 10^{-3} x 44/28) x GWP	

Where:

Term		**Description**	**Value**
N Load	=	measured average total nitrogen discharged [kg N/day]	user input
EF effluent	=	emission factor [kg N_2O-N/kg sewage-N produced]	0.005
365.25	=	conversion factor [day/year]	365.25
10^{-3}	=	conversion from kg to metric ton [metric ton/kg]	10^{-3}
44/28	=	molecular weight ratio of N_2O to N_2	1.57
GWP	=	Global Warming Potential	310
Source: EPA *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2007*, Chapter 8, 8-13 (2009).			

Equation 10.10	Process N_2O Emissions from Effluent Discharge (default N load data)

Annual N_2O emissions (metric tons CO_2e) =

$$((P_{total} \times F_{ind\text{-}com}) \times (\text{Total N Load} - \text{N uptake} \times BOD_5 \text{ load}) \times \text{EF effluent} \times 44/28 \times (1 - \text{F plant nit/denit}) \times 365.25 \times 10^{-3}) \times GWP$$

Where:

Term		**Description**	**Value**
P_{total}	=	population served [person]	user input
$F_{ind\text{-}com}$	=	factor for industrial and commercial co-discharge waste into the sewer system	1.25
Total N Load[27]	=	total nitrogen load [kg N/person/day]	0.026
N uptake[28]	=	nitrogen uptake for cell growth in aerobic system (kg N/kg BOD_5)	0.05[1]
	=	nitrogen uptake for cell growth in anaerobic system (e.g., lagoon) (kg N/kg BOD_5)	0.005[1]
BOD_5 load	=	amount of BOD_5 produced per person per day [kg BOD_5/person/day]	0.090
EF effluent	=	emission factor [kg N_2O-N/kg sewage-N produced]	0.005
44/28	=	molecular weight ratio of N_2O to N_2	1.57
F plant nit/denit	=	fraction of nitrogen removed for the centralized WWTP with nitrification/denitrification	0.7[1]
	=	fraction of nitrogen removed for the centralized WWTP w/o nitrification/denitrification	0.0[1]
365.25	=	conversion factor [day/year]	365.25
10^{-3}	=	conversion from kg to metric ton [metric ton/kg]	10^{-3}
GWP	=	Global Warming Potential	310

Source: EPA *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2007*, Chapter 8, 8-13 (2009), except:
[1] Grady, C. P. L., Jr., G. T. Daigger, and H. C. Lim, *Biological Wastewater Treatment*, p. 108-109, 644 2nd Edition (1999).

Box 10.3 gives an example of how to calculate greenhouse gas emissions from a wastewater treatment plant.

[27] The default total nitrogen load value is derived based on the following default values from US EPA *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2006*, Chapter 8, 8-14 and Table 8.11: Average US protein intake (41.9 kg/person-year) x default fraction of N in protein (0.16 kg N/kg protein) x factor for non-consumed protein added to water (1.4) / days per year (365.25) = 0.026 kg N/person/day.

[28] Some of the influent nitrogen is required for microbial growth inherent in aerobic or anaerobic treatment processes. Nitrogen is assimilated by bacteria, which grow and are further managed as biosolids. This assimilation results in lower nitrogen levels in the discharged effluent.

Box 10.3 Example Calculation for GHG Emissions Associated with Wastewater Treatment

A centralized wastewater treatment plant serves 90% of a city while the rest of the city uses septic systems, but does not have a method to measure biogas concentrations. On an average day, 35,000 ft^3 of biogas that contains 50% CH_4 is produced. The treatment plant employs nitrification. To calculate the total emissions from wastewater in the city should use equations 10.1, 10.6, 10.7, and 10.10 as shown below.

Eq. 10.1: Stationary CH_4 from incomplete combustion of digester gas

Annual CH_4 emissions ($MTCO_2e$) = digester gas x F_{CH4} x $\rho_{(CH4)}$ x (1 – DE) x 0.0283 x 365.25 x 10^{-6} x GWP

Where:

digester gas	= measured standard cubic feet of digester gas produced per day = 35,000 ft^3/day
F_{CH4}	= measured fraction of CH_4 in biogas = 0.50
$\rho_{(CH4)}$	= density of methane at standard conditions = 662.00 g/m^3
DE	= CH_4 destruction efficiency = 0.99
0.0283 m^3/ft^3	= conversion factor from ft^3 to m^3
365.25 day/year	= conversion factor from day to year
10^{-6} MT/g	= conversion from gram to metric ton
GWP	= Global Warming Potential = 21

= 35,000 ft^3/day x 0.50 x 662.00 g/m^3 x 0.99 x 0.0283 m^3/ft^3 x 365.25 day/year x 10^{-6} MT/g x21

= 2,490 $MTCO_2e$

Eq. 10.6: Fugitive CH_4 from septic systems

Annual CH_4 emissions ($MTCO_2e$) = P x BOD_5 load x Bo x MCF_{septic} x 365.25 x 10^{-3} x GWP

Where:

P	= population served by septic systems = 5,000 people
BOD_5 load	= amount of BOD_5 produced per person per day = 0.090 kg BOD_5/person/day
Bo	= maximum CH_4-producing capacity for domestic wastewater = 0.6 kg CH_4/kg BOD_5
MCF_{septic}	= CH_4 correction factor for septic systems = 0.5
365.25 day/year	= conversion factor from day to year
10^{-3} metric ton/kg	= conversion factor from kg to metric ton
GWP	= Global Warming Potential = 21

= 5,000 people x 0.090 kg BOD_5/person/day x 0.6 kg CH_4/kg BOD_5 x 0.5 x 365.25 day/year x 10^{-3} (MT/kg) x 21

= 1,035 $MTCO_2e$

Box 10.3 cont.

Eq. 10.7: Process N_2O emissions from wastewater treatment plants (WWTP) with nitrification/denitrification

Annual N_2O emissions ($MTCO_2e$) = P_{total} x EF nit/denit x 10^{-6} x GWP

Where:

P_{total} = total population served by the centralized WWTP adjusted for industrial discharge
= 45,000
people x 1.25* = 56,250 people
EF nit/denit = emission for a WWTP with nitrification/denitrification
= 7 g N_2O/person/year
10^{-6} metric ton/g = conversion from gram to metric ton
GWP = Global Warming Potential
= 310
= 56,250 people x 7 g N_2O/person/year x 10^{-6} metric ton/g x 310
= **122 $MTCO_2e$**

* The 1.25 is a factor used to account for co-discharged industrial and commercial protein into the sewer system.

Eq. 10.10: Process N_2O emissions from effluent discharge

Annual N_2O emissions ($MTCO_2e$) = P_{total} x (total N load – N uptake x BOD_5 load) x EF effluent x 44/28 x (1 – F plant nit/denit x 365.25 x 10^{-3} x GWP

Where:

P_{total} = population served adjusted for industrial discharge
= 45,000 x 1.25 = 56,250 persons
Total N load = total nitrogen load
= 0.026 kg N/person/day
N uptake = nitrogen uptake for cell growth in aerobic system
= 0.05 kg N/kg BOD_5
BOD_5 load = amount of BOD_5 produced per person per day
= 0.090 kg BOD_5/person/day
EF effluent = emission factor
= 0.005 kg N_2O-N/kg sewage-N produced
44/28 = molecular weight ratio of N_2O to N_2
F plant nit/denit = fraction of nitrogen removed for the centralized WWTP with nitrification/denitrification
= 0.7 or 0.0 (if no nitrification/denitrification)
365.25 day/year = conversion factor
10^{-3} metric ton/kg = conversion factor from kg to metric ton
GWP = Global Warming Potential
= 310

Annual N_2O emissions ($MTCO_2e$) = 56,250 persons x (0.026 kg N/person/day – 0.05 kg N/kg BOD_5 x 0.09 kg BOD_5/person/day) x 0.005 kg N_2O-N/kg sewage-N produced x 44/28 x (1 – 0.7) x 365.25 day/year x 10^{-3} MT/kg x 310
= *323 $MTCO_2e$* (for 90% of wastewater in population)
+
= 6,250 persons x (0.026 kg N/person/day – 0.05 kg N/kg BOD_5 x 0.09 kg BOD_5/person/day) x 0.005 kg N_2O-N/kg sewage-N produced x 44/28 x (1) x 365.25 day/year x 10^{-3} MT/kg x 310
= *120 $MTCO_2e$* (for 10% of population on septic systems)
= 443 $MTCO_2e$

Box 10.3 Cont.

Total wastewater emissions = Stationary CH_4 + fugitive CH_4 + process $N_2O_{(plant)}$ + process $N_2O_{(effluent)}$

= 2,490 $MTCO_2e$ + 1,035 $MTCO_2e$ + 122 $MTCO_2e$ + 443 $MTCO_2e$

= 4,090 $MTCO_2e$