Final Report

Discussion Paper for a Wastewater Treatment Plant Sector Greenhouse Gas Emissions Reporting Protocol

Prepared for

California Wastewater Climate Change Group

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Executive Summary

The California Global Warming Solutions Act of 2006 (Assembly Bill 32 [AB-32]) mandates that the California Air Resources Board (CARB) adopt rules and regulations to reduce greenhouse gas (GHG) emissions to 1990 levels by the year 2020. As defined in AB 32, GHGs include: carbon monoxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. To meet this goal, CARB must adopt regulations on mandatory emission reporting and verification beginning in January 2008, and must identify emissions reduction measures beginning in 2011. These regulations will become enforceable beginning in 2009 and 2012, respectively.

In a proactive approach to meeting future regulatory requirements, California wastewater agencies have formed the California Wastewater Climate Change Group (CWCCG), whose purpose is to respond to climate change and forthcoming regulations and to provide a unified voice for the California wastewater industry. This paper summarizes the CWCCG's efforts to identify the existing methodologies for estimating GHG emissions from municipal wastewater treatment plant (WWTP) processes, which include both domestic and industrial wastewater that is treated by a municipal WWTP. The CWCCG is focusing on developing estimation methods for CH_4 and N_2O emissions from WWTP treatment processes. This paper also makes recommendations, which build on the existing methodologies, for developing a more accurate and appropriate protocol for estimating both facility and statewide WWTP GHG emissions.

The CWCCG conducted a thorough review of all existing GHG emission estimation protocols. Most current protocols originate from the GHG Protocol Initiative and are internationally recognized as the most widely-used accounting tools for GHG emissions inventories. However, the GHG Protocol Initiative does not have a protocol for estimating GHG emissions from WWTP processes. The Intergovernmental Panel on Climate Change (IPCC) has developed a methodology for estimating emissions from wastewater treatment. The U.S. Environmental Protection Agency (USEPA) and the California Energy Commission (CEC) have conducted national- and state-level estimates of wastewater treatment-related GHG emissions using the IPCC as a basis with some modifications. The USEPA Climate Leaders Program is also in the process of developing a WWTP protocol, which will also follow the IPCC methodology.

The IPCC protocol represents the only available methodology to estimate facility-level wastewater treatment GHG emissions. This protocol was developed to estimate national-level emissions from wastewater treatment and has been modified by both the USEPA and CEC in developing their national- and state-level estimates. The IPCC approach is a top-down approach that does not use facility-specific information; rather, it uses general assumptions such as the amount of protein consumed per capita per year and the amount of BOD generated per capita per year. Although the IPCC approach may provide a good starting point for facilities to estimate their emissions, for several reasons, the IPCC approach may not be the best possible approach for individual facility estimates.

To better estimate the facility-specific GHG emissions for all WWTPs in California, it is recommended that the CWCCG develop a protocol with a variety of methodologies to estimate CH_4 and N_2O process emissions, which will allow for flexibility in the level of detail and accuracy. The protocol should provide guidance to WWTP operators as to what method is best suited for a particular plant.

Expected GHG emissions from WWTPs in California are as follows:

- CO_2 from combustion sources (to be estimated using existing protocols, as appropriate, such as the California Climate Action Registry [CCAR] General Reporting Protocol or the CCAR Power/Utility Reporting Protocol).
- CO_2 from indirect sources, such as purchased electricity (to be estimated using existing protocols, as appropriate, such as the CCAR General Reporting Protocol).
- CH_4 emissions that are uncollected or controlled from anaerobic secondary wastewater treatment processes.
- CH_4 fugitive emissions from solids handling processes (e.g., anaerobic digestion of sludge and sludge dewatering).
- CH_4 emissions from the incomplete combustion of digester gas.
- N_2O emissions from nitrification and denitrification processes.
- N_2O emissions from wastewater effluent in receiving aquatic environments.

This study identified four primary recommended GHG emissions estimating options with each providing advantages for specific circumstances. The emissions estimating methods for California WWTPs are as follows:

- Option 1: USEPA Approach/IPCC Approach
- Option 2: USEPA Approach with Updated Default Values
- Option 3: Complete Emissions Inventory/Sampling-based Approach
- Option 4: Model and Source Test

The next phase of the protocol will involve development of GHG emissions estimation.

Contents

Page

Executive Summary iii

Acronyms and Abbreviations vii

1.0 Introduction 1-1
- 1.1 Background 1-1
- 1.2 Project Description 1-1
- 1.3 Objectives 1-2

2.0 WWTP Emissions 2-1
- 2.1 Types of Emissions at a WWTP 2-1
  - 2.1.1 Direct Emissions 2-1
  - 2.1.2 Indirect Emissions 2-1
  - 2.1.3 Fugitive Emissions 2-2
  - 2.1.4 *De Minimus* Emissions 2-2
- 2.2 WWTP Industry in California 2-2
- 2.3 CO_2 Emissions 2-2
- 2.4 CH_4 Emissions 2-3
- 2.5 N_2O Emissions 2-3
- 2.6 Summary of WWTP Process Emissions 2-3

3.0 Review of Existing Protocols 3-1
- 3.1 IPCC Methodology 3-1
  - 3.1.1 CH_4 Emissions 3-1
  - 3.1.2 N_2O Emissions 3-3
- 3.2 USEPA Methodology 3-4
  - 3.2.1 CH_4 Emissions 3-4
  - 3.2.2 N_2O Emissions 3-6
- 3.3 CEC Methodology 3-7
  - 3.3.1 CH_4 Emissions 3-7
  - 3.3.2 N_2O Emissions 3-8
- 3.4 Applicability of Protocols 3-8
  - 3.4.1 Facility-level Protocols 3-8
  - 3.4.2 State-level Protocols 3-9

4.0 Recommendations 4-1
- 4.1 Accounting Boundaries 4-1
- 4.2 Characterizing Facility Baseline Emissions 4-2
  - 4.2.1 CH_4 4-2
  - 4.2.2 N_2O 4-3
- 4.3 Characterizing Statewide Aggregate Emissions 4-4

5.0 Summary 5-1

Contents, Continued

Page

6.0 References 6-1

Appendices

A IPCC Wastewater Treatment Methodology
B USEPA Wastewater Treatment Methodology
C National Wastewater Treatment Emission Calculations
D NACWA Comment Letter on USEPA Wastewater Treatment Emissions Estimates

Tables

2-1 GHG Emission Sources for WWTP Processes........ 2-4

3-1 IPCC 2006 Inventory Methodology to Estimate CH_4 Emissions from Domestic Wastewater Treatment 3-2

3-2 IPCC 2006 Inventory Methodology to Estimate N_2O Emissions from Domestic Wastewater Treatment 3-3

3-3 Factors Used by IPCC to Estimate N_2O Emissions from NDN Processes 3-3

3-4 Factors Used by USEPA to Estimate CH_4 Emissions from Domestic Wastewater Treatment 3-4

3-5 CEC Inventory Methodology to Estimate CH_4 Emissions from Wastewater Treatment 3-7

3-6 EC Inventory Methodology to Estimate N_2O Emissions from Domestic Wastewater Treatment 3-8

Figures

3-1 National Wastewater Treatment CH_4 Emission Sources........ 3-5

3-2 National Wastewater Treatment N_2O Emission Sources 3-6

4-1 California WWTP and Discharge Pathways and Emission Sources........ 4-1

Acronyms and Abbreviations

AB	Assembly Bill
ASMN	Activated Sludge Model-Nitrogen
BOD	biochemical oxygen demand
CARB	California Air Resources Board
CCAR	California Climate Action Registry
CEC	California Energy Commission
CH_4	methane
CO_2	carbon dioxide
CWCCG	California Wastewater Climate Change Group
CWNS	Clean Watershed Needs Survey
EIIP	Emission Inventory Improvement Program
GHG	greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
kg	kilogram
LACSD	Los Angeles County Sanitation Districts
N	nitrogen
N_2O	nitrous oxide
NACWA	National Association of Clean Water Agencies
NDN	nitrification/denitrification
USEPA	United States Environmental Protection Agency
WWTP	wastewater treatment plant

1.0 Introduction

1.1 Background

In 2006, the California Legislature established, and the Governor signed, the California Global Warming Solutions Act of 2006 (Assembly Bill 32 [AB 32]). AB 32 mandates that the California Air Resources Board (CARB) adopt rules and regulations to reduce greenhouse gas (GHG) emissions to 1990 levels by the year 2020. As defined in AB 32, GHGs include: carbon monoxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. These are the gases listed as GHGs in the Kyoto Protocol. To meet this goal, CARB must adopt regulations on mandatory emission reporting and verification beginning in January 2008 and must identify emissions reduction measures beginning in 2011. These regulations will become enforceable beginning in 2009 and 2012, respectively.

Based on CARB's initial regulatory concepts, the largest emitters of GHG emissions, such as the cement manufacturing, landfill, power/utility, refiner, and transportation sectors, will be required to report emissions beginning in 2009. Wastewater treatment plants (WWTPs) have not been initially identified as one of the largest emitting sectors. However, many WWTPs generate their power and may be included in the power/utility sector. In addition, California WWTP utilities anticipate that once CARB regulates the largest sources of emissions, it will then create additional regulations for the next-largest sources of emissions, which will likely include WWTPs. Previous national and state GHG emissions estimates have focused mainly on emissions of CH_4 and N_2O from wastewater treatment and have identified wastewater treatment as one of the top 10 CH_4 and N_2O emitters in the nation and in the state of California.

1.2 Project Description

In a proactive approach to meeting future regulatory requirements, California wastewater agencies have formed the California Wastewater Climate Change Group (CWCCG), whose purpose is to respond to climate change and forthcoming regulations and to provide a unified voice for the California wastewater industry. The group, formed in May 2007, currently comprises 40 wastewater agencies and three wastewater organizations (the Bay Area Clean Water Agencies, the Southern California Alliance of Publicly Owned Treatment Works, and the Central Valley Clean Water Agencies). Together, this group represents the majority of wastewater treated in the state of California.

The initial goals for this group are to identify the existing methodologies for estimating emissions from municipal WWTP processes and to develop a WWTP-sector GHG emissions reporting protocol. This paper summarizes CWCCG's efforts to identify the existing methodologies for estimating emissions from municipal WWTP processes, which include both domestic and industrial wastewater that is treated by a municipal WWTP. This paper also makes recommendations, which build on the existing methodologies, to develop more accurate and appropriate methods to estimate both facility and statewide WWTP GHG emissions.

1.3 Objectives

Wastewater treatment is already recognized as a source of air pollutants and, therefore, is heavily regulated. The Intergovernmental Panel on Climate Change (IPCC) and others have developed protocols to estimate GHG emissions from wastewater on a gross basis. However, there is no existing protocol to estimate GHG emissions specifically from WWTPs at a facility level. The goals of this discussion paper are to identify the needs for a specific WWTP GHG emissions reporting protocol through the understanding of where California WWTP emissions come from, estimation methods that currently exist, and gaps in existing methods. Initial research conducted by CWCCG members identified both CH_4 and N_2O as the main GHG emissions from wastewater treatment. Therefore, this paper focuses mainly on CH_4 and N_2O emissions.

Section 2.0 of this discussion paper describes the types of WWTP processes common to California and the expected GHG emissions. Section 3.0 provides an assessment of the existing methodologies to estimate WWTP emissions and where improvements can be made. Section 4.0 presents recommendations on which emissions should be covered in a WWTP protocol for California and methods to characterize facility- and statewide-level GHG emissions. WWTPs will eventually be able to use a WWTP-specific emission reporting protocol to characterize facility baseline emissions, which will aid in developing reduction strategies. A WWTP-specific protocol also can be used to characterize the statewide baseline emissions from WWTPs and help the CWCCG determine if WWTPs should be a regulated source of GHG emissions.

Using the findings and recommendations of this paper, the CWCCG intends to work cooperatively with both the California Climate Action Registry (CCAR) and CARB to develop an acceptable WWTP-sector GHG emissions reporting protocol that will be recognized as the standard method for estimating WWTP process emissions.

2.0 WWTP Emissions

2.1 Types of Emissions at a WWTP

There are multiple sources of GHG emissions at a WWTP. CCAR, a non-profit voluntary registry for GHG emissions, categorizes emissions types as direct, indirect, fugitive, and *de minimus* (CCAR, 2006).

2.1.1 Direct Emissions

CCAR defines direct emissions as emissions from sources that are owned or controlled by the reporting organization. Direct emissions result from stationary combustion, mobile combustion, and industrial processes. Stationary sources at WWTPs include boilers, emergency generators, and pumps that emit GHGs such as CO_2, N_2O, and CH_4 as a result of combustion processes. Mobile sources such as automobiles, trucks, off-road vehicles, and construction equipment also release the same types of GHG emissions from combustion processes. Internationally accepted protocols have been established previously to estimate emissions from stationary and mobile combustion sources. The CCAR outlines methods to estimate direct GHG emissions from mobile and stationary combustion sources in their General Reporting Protocol (CCAR, 2006). Because methodologies for estimating emissions from mobile and stationary combustion sources already exist, these are not further discussed in this paper. However, references to applicable methodologies for estimating these emissions should be included in a WWTP-sector GHG emissions reporting protocol.

Emissions from industrial processes are another subcategory of direct emissions. Emissions protocols for specific industrial processes such as the production of iron and steel, cement manufacturing, and the production of semiconductor wafers are internationally recognized and are available through resources such as the GHG Protocol Initiative, UK Guidelines for the UK Emissions Trading Scheme, and CCAR. However, a protocol for WWTP process emissions has not yet been properly developed.

2.1.2 Indirect Emissions

CCAR defines indirect emissions as emissions that are a consequence of the actions of a reporting entity but are produced by sources owned or controlled by another entity. Indirect emissions result from the purchase of electricity, imported steam, district heating or cooling, and production of electricity from a cogeneration plant. Internationally accepted protocols have been established previously to estimate emissions associated with the identified indirect emission sources. For example, the CCAR outlines methods to estimate indirect emissions in its General Reporting Protocol (CCAR, 2006). Because methodologies for estimating emissions from indirect sources have already been developed for indirect emissions related to electricity, steam, heating, and cooling, these methodologies are not further discussed in this paper. However, references to applicable methodologies for estimating these emissions should be included in a WWTP-sector GHG emissions reporting protocol.

2.1.3 Fugitive Emissions

CCAR defines fugitive emissions as "intentional and unintentional releases of GHG emissions from joints, seals, gaskets, etc." Fugitive emissions result from specific industrial processes and can result from WWTP operations. Examples of GHG fugitive emission from WWTP processes are CH_4 leaks from digesters and associated equipment for solids handling (e.g., dewatering of anaerobically digested sludge).

2.1.4 *De Minimus* Emissions

CCAR defines *de minimus* emissions as a quantity of GHG emissions from a combination of sources and/or gases which, when summed, are considered insignificant (e.g., equal to less than 5 percent of an organization's total emissions). The category of *de minimus* emissions was defined to prevent overly burdensome emissions reporting. *De minimus* emissions are not further discussed in this report as these emissions are defined in detail in the CCAR General Reporting Protocol (CCAR, 2006).

2.2 WWTP Industry in California

The United States Environmental Protection Agency's (USEPA's) Office of Wastewater Management conducts the Clean Watershed Needs Survey (CWNS) every 4 years. Based on the most recently available data, in 2000, there were 577 wastewater treatment facilities in California treating approximately 6,600 million gallons per day. Based on the CWNS data, the majority of municipal WWTPs in California have primary sedimentation, followed by an aerobic secondary treatment process (e.g., activated sludge). The resulting primary and secondary sludge at an aerobic WWTP typically is sent to an anaerobic digester, dewatered, and the resulting biosolids are then sent offsite to a landfill or for reuse. Anaerobic treatment of wastewater at a WWTP (e.g., anaerobic lagoons) is also practiced by smaller communities and a few larger facilities. The types of GHG emissions that are expected from these typical wastewater process schemes are discussed in Sections 2.3 through 2.5.

2.3 CO_2 Emissions

WWTP CO_2 emissions, other than those from stationary and mobile combustion sources (discussed in Section 2.1.1), result from the combustion of sludge (i.e., incineration) or digester gas (i.e., flares, turbines, boilers). Both sludge and digester gas are types of biofuels or renewable energy fuel sources, and their resulting CO_2 emissions are generally accepted as "biogenic" carbon-neutral emissions or non-fossil fuel emissions. The general international practice for CO_2 emissions from the combustion of wastewater products such as sludge or digester gas is that these emissions should not be reported as GHG emissions and should be kept in a category separate from fossil fuel emissions, which are considered anthropogenic emissions. Based on this general practice, CO_2 emissions from WWTPs are not further discussed.

2.4 CH_4 Emissions

Existing international practice (IPCC, 2006) and CCAR practice recognize CH_4 and N_2O as the only GHG emissions from WWTP processes. According to IPCC, CH_4 emissions from aerobic processes are expected to be limited and depend on the design and management of a system. A poorly managed aerobic system may emit more CH_4 emissions than a well managed system. The majority of wastewater within California is treated centrally through aerobic processes at treatment plants that are well managed and regulated; therefore, CH_4 emissions from aerobic treatment are expected to be very minimal. The larger source of CH_4 emissions occurs from open anaerobic wastewater treatment processes, when the CH_4 produced is released directly to the atmosphere uncollected, uncontrolled, and without treatment, such as anaerobic lagoons, anaerobic reactors (e.g., digesters), or septic tanks. While CH_4 emissions from septic tanks can be significant, these emissions are not considered in this paper for inclusion in a WWTP protocol because septic tanks are not part of municipal WWTP operations.

CH_4 emissions also result from fugitive releases from solids handling processes, such as sludge digestion. Typical solids handling processes in California consist of anaerobic digestion of sludge with the capture of CH_4 emissions generated during digestion. These emissions are then treated or controlled through flaring or some other combustion process to produce heat or power. Digested sludge is then dewatered before trucking offsite to a landfill or for reuse. Fugitive CH_4 emissions are expected to be minor and may be considered *de minimus* by CARB and CCAR. Small amounts of direct CH_4 emissions may also be released as a result of incomplete combustion of digester gas.

2.5 N_2O Emissions

N_2O emissions result from nitrification/denitrification (NDN) processes at a WWTP. N_2O, as well as nitric oxide, are normal intermediate byproducts of denitrification, which is a process by which nitrite and nitrate are converted to nitrogen gas. N_2O can also be produced under some nitrifying conditions via nitrifying microorganisms. In addition to the NDN process, N_2O emissions can also result from natural denitrification of nitrogen-containing compounds in treated wastewater discharged to a receiving stream. As wastewater enters a river or other body of water, the remaining nitrogen species in the effluent can naturally be converted and released as N_2O. Small amounts of N_2O emissions may also come from the combustion of digester gas.

2.6 Summary of WWTP Process Emissions

Based on the typical WWTP processes identified in Section 2.1.4 for California and the discussion above, the expected GHG emissions are CO_2, CH_4, and N_2O. Of these three GHGs, accepted methods already exist to estimate CO_2 emissions from direct stationary combustion and indirect sources. In addition, process CO_2 emissions from most WWTP processes typically are considered biogenic and are either not reported or are kept separate from other GHG emissions, although an industry-specific WWTP protocol should include specific calculation methodologies for biogenic CO_2 emissions. Therefore, the CWCCG is focusing on developing estimation methods for CH_4 and N_2O emissions to be included in a

WWTP-sector GHG emissions reporting protocol. In the WWTP protocol, CH_4 and N_2O emissions from combustion should be categorized as direct emissions from stationary combustion.

When comparing the GHGs emitted at a WWTP, CH_4 and N_2O have 100-year global warming potentials of 21 and 310, respectively (IPCC, 2001). The 100-year global warming potential is a measurement of the heat-trapping capacity of a GHG when compared to that of CO_2. Therefore, CH_4 and N_2O are more potent GHGs. The sources of CH_4 and N_2O emissions at a WWTP are summarized in Table 2-1.

TABLE 2-1
GHG Emission Sources for WWTP Processes
Discussion Paper for a Wastewater Treatment Plant Sector Greenhouse Gas Emissions Reporting Protocol

Process Step	Expected GHG Emissions
Primary Treatment	None expected
Secondary Treatment	None expected from well managed aerobic processes
	CH_4 from uncollected or uncontrolled anaerobic wastewater treatment processes (e.g., anaerobic lagoons)
Advanced Treatment	N_2O emissions from NDN process
Solids Handling	Fugitive CH_4 emissions from sludge handling processes such as digestion (these emissions may be considered *de minimus*)
	CH_4 emissions resulting from incomplete combustion of digester gas
Effluent Discharge	N_2O emissions from denitrification of nitrogen species originating from wastewater effluent in receiving water

3.0 Review of Existing Protocols

A thorough review of all existing protocols was conducted as part of this effort to identify resources for estimating GHG emissions from WWTP processes. Most current protocols originate from the GHG Protocol Initiative. The GHG Protocol Initiative is a partnership between the World Resources Institute and the World Business Council for Sustainable Development and is internationally recognized as the most widely used accounting tool for GHG emissions inventories. Some of the protocols used by the CCAR, the California Energy Commission (CEC), and the USEPA originate from the GHG Protocol Initiative. However, the GHG Protocol Initiative does not have a protocol for estimating GHG emissions from WWTP processes.

Other sources of GHG protocols are as follows:

- The Intergovernmental Panel for Climate Change: *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006)
- U.K. Department of Environment, Food, and Rural Affairs: The U.K. Emissions Trading Scheme
- Emission Inventory Improvement Program (EIIP): *Technical Report Series Volume 8: Estimating* Greenhouse *Gas Emissions* (EIIP, 1999)
- CCAR: *General Reporting Protocol* (CCAR, 2006)
- USEPA: *Inventory of U.S. Greenhouse Gas Emissions and Sinks (1990-2005)* (USEPA, 2007)
- CEC: *Inventory of California Greenhouse Gas Emissions and Sinks (1990-2004)* (CEC, 2006)

The IPCC has developed a methodology for estimating emissions from wastewater treatment. EIIP presents a modified version of the IPCC methodology in their report. The USEPA and CEC have estimated national- and state-level wastewater treatment-related GHG emissions using the IPCC and EIIP as a basis with some modifications. The USEPA Climate Leaders Program is also in the process of developing a WWTP protocol, which will also be based on the IPCC methodology. More detailed descriptions of the IPCC, USEPA, and CEC methodologies are provided below.

3.1 IPCC Methodology

3.1.1 CH_4 Emissions

The current IPCC methodology (2006) presents a general, top-down approach to estimating CH_4 emissions from domestic wastewater that is generally based on the factors summarized in Table 3-1. The full IPCC methodology is provided in Appendix A.

TABLE 3-1
IPCC 2006 Inventory Methodology to Estimate CH_4 Emissions from Domestic Wastewater Treatment
Discussion Paper for a Wastewater Treatment Plant Sector Greenhouse Gas Emissions Reporting Protocol

Factor	Value	Units
Fraction of population based on type	Location-specific: (i.e., rural, urban)	Fraction
Degree of utilization of a specific treatment/discharge pathway	Location-specific: (i.e., septic tank, latrine, sewer, other, or none)	Fraction
Emission factor for CH_4 from BOD	Calculated, or default: 0.6 kg CH_4/kg BOD, 0.25 kg CH_4/kg COD	kg CH_4 per kg BOD or COD
Maximum CH_4 producing capacity	Country-specific	kg CH_4/kg BOD
CH_4 correction factor	Based on treatment system processes (i.e., centralized aerobic treatment, anaerobic digestion, septic system, etc.)	Fraction
Total Organically Degradable Material	Calculated	kg BOD/yr
Population	Country-specific[a]	No. people
Per capita BOD	Country-specific: 85 g BOD/person-day for the United States	g BOD/person-day
Correction factor for industrial BOD discharged to sewers	Location-specific: 1.25 for industrial waste-water collection, 1.00 if uncollected[a]	Fraction
Removal of organics as sludge	Location-specific[a]	kg BOD/yr
Amount of CH_4 recovered	Location-specific[a]	kg CH_4/yr

Notes:

BOD = biochemical oxygen demand

CH_4 = methane

COD = chemical oxygen demand

kg = kilograms

[a]More research will be needed to develop these values, including facility uncertainty determinations.

The IPCC method can be used to estimate all of the wastewater emissions from a country by summing the emissions associated with specific populations and the specific types of treatment employed. For instance, in the United States, 78 percent of the population is considered "high urban" and, of that population, 95 percent is served by sewer system. Furthermore, the wastewater that flows through a sewer system can be treated by a variety of treatment processes (e.g., a centralized aerobic treatment plant followed by anaerobic digestion, lagoon, etc.). The emissions that result from different subsets of the population and the different subsets of treatment processes are then summed to form an aggregate nationwide estimate of CH_4 emissions from ALL wastewater treated, not just wastewater treated at a WWTP.

This method does not account for CH_4 emissions resulting from incomplete combustion of digester gas, nor does it account for CH_4 fugitive emissions (e.g., from digestion or dewatering), which are expected to be minor. More research investigations are needed; these sources require facility-level reporting protocol quantification methodologies. The emissions from biosolids sent offsite to landfills or incinerators or from biosolids used in agriculture are also not accounted for. However, emissions from biosolids sent offsite are estimated at the downstream point of emission and are included in other protocols (e.g., landfill and agriculture emissions protocols).

This method is a top-down approach that is based on population and assumed contributions of biochemical oxygen demand (BOD) per capita. Influent wastewater BOD concentrations on a plant-by-plant basis are not taken into consideration.

3.1.2 N_2O Emissions

The current IPCC methodology (2006) for N_2O also represents a top-down approach. N_2O is estimated from two pathways: emissions from treated wastewater effluent discharged to a receiving water body and emissions from NDN processes. The factors used in estimating N_2O emissions from these two sources are summarized in Tables 3-2 and 3-3.

TABLE 3-2
IPCC 2006 Inventory Methodology to Estimate N_2O Emissions from Domestic Wastewater Treatment
Discussion Paper for a Wastewater Treatment Plant Sector Greenhouse Gas Emissions Reporting Protocol

Factor	Value	Units
Nitrogen in the effluent discharged to the aquatic environment	Calculate[a]	kg N/yr
Population	Country-specific[a]	No. people
Protein consumption	Country-specific: 42.1 kg/person-yr for U.S.	kg/person-yr
Fraction of nitrogen in protein	Default: 0.16 kg N/kg protein	kg N/kg protein
Factor for non-consumed protein added to wastewater	Country-specific: 1.4 for developed countries	Fraction
Factor for industrial and commercial co-discharge of protein into the sewer system	Default: 1.25[a]	Fraction
Nitrogen removed with sludge	Default: 0 kg N/yr[a]	kg N/yr
Emission factor for N_2O from discharged wastewater	Default: 0.005 kg N_2O-N/kg N[b]	kg N_2O-N/kg N

[a]More research will be needed to develop these values, including facility uncertainty determinations.

[b]Regional factors may be addressed in reporting protocol.

Note:

N = nitrogen

TABLE 3-3
Factors Used by IPCC to Estimate N_2O Emissions from NDN Processes
Discussion Paper for a Wastewater Treatment Plant Sector Greenhouse Gas Emissions Reporting Protocol

Factor	Value	Units
Population	Country-specific	No. people
Degree of utilization of modern centralized WWTP	Location-specific	Percent
Fraction of industrial and commercial co-discharged protein	Default: 1.25	Fraction
Emission Factor	Default: 3.2 g N_2O/person-year[a]	g N_2O/person-yr

Source: IPCC, 2006.

[a]More research will be needed to develop these values.

This method assumes that the majority of N_2O emissions at a WWTP are emissions from treated wastewater discharged to a receiving body, based on a factor of 0.005 kg N_2O-N/kg nitrogen in the effluent. The IPCC states that direct emissions from NDN processes at WWTPs may be considered a minor source and that these emissions are typically much lower than those from the effluent. Furthermore, direct emissions of N_2O from wastewater processes are predominantly associated with advanced centralized WWTPs. Despite IPCC's conclusion that process N_2O emissions are minor, N_2O emissions from WWTP processes have not been studied extensively to date and may be influenced by process conditions.

If a country is including N_2O from NDN processes in its estimate, then the amount of nitrogen associated with these emissions must be back-calculated and subtracted from the amount of nitrogen in the effluent.

3.2 USEPA Methodology

The USEPA has estimated emissions for the entire United States. The most recent estimate was published in April 2007 for emissions from 1990 to 2005 (USEPA, 2007). As estimated, wastewater treatment is the seventh highest contributing sector to national CH_4 emissions and the sixth highest contributing sector to national N_2O emissions. The method used in the USEPA's inventory is based on the IPCC approach and is provided in Appendix B.

3.2.1 CH_4 Emissions

The estimate of total national CH_4 emissions from domestic wastewater treatment completed by the USEPA accounts for emissions from septic systems, centrally treated aerobic systems, centrally treated anaerobic systems, and anaerobic digesters. The population served and the percent of wastewater treated by each of these treatment system types was determined from data from the United States Census Bureau and the USEPA CWNS. Some of the location-specific factors used by the USEPA are included in Table 3-4.

TABLE 3-4
Factors Used by USEPA to Estimate CH_4 Emissions from Domestic Wastewater Treatment
Discussion Paper for a Wastewater Treatment Plant Sector Greenhouse Gas Emissions Reporting Protocol

Factor	Value
Degree of utilization of a specific treatment/discharge pathway:	
Percent of wastewater treated in septic systems	21 percent
Percent of wastewater treated centrally aerobically	74 percent
Percent of wastewater treated centrally anaerobically	5 percent
Emission Factor for CH_4 from BOD:	Calculated
Maximum CH_4 producing capacity	0.6 kg CH_4/kg BOD
CH_4 correction factor[a]:	--
Septic systems	0.5
Central aerobic treatment	0.0 or 0.3
Central anaerobic treatment	0.8

Source: USEPA, 2007 (see Appendix B).

[a]More research will be needed to develop these values, including maintenance practices.

Based on estimates of national GHG emissions from wastewater treatment and using the data and methodology outlined by the USEPA (2007), there are no expected emissions from centralized aerobic treatment processes (Figure 3-1). The majority of CH_4 emissions from wastewater treatment in the United States come from septic tanks (76 percent), which, as previously discussed, are not part of a municipal WWTP. Uncontrolled CH_4 emissions from anaerobic wastewater treatment systems, such as anaerobic lagoons, account for 23 percent of the wastewater treatment-sector emissions. CH_4 emissions from controlled anaerobic sludge digesters via incomplete combustion of digester gas accounts for only 1 percent, which includes fugitive emissions. The calculations completed by Los Angeles County Sanitation Districts (LACSD) are included in Appendix C.

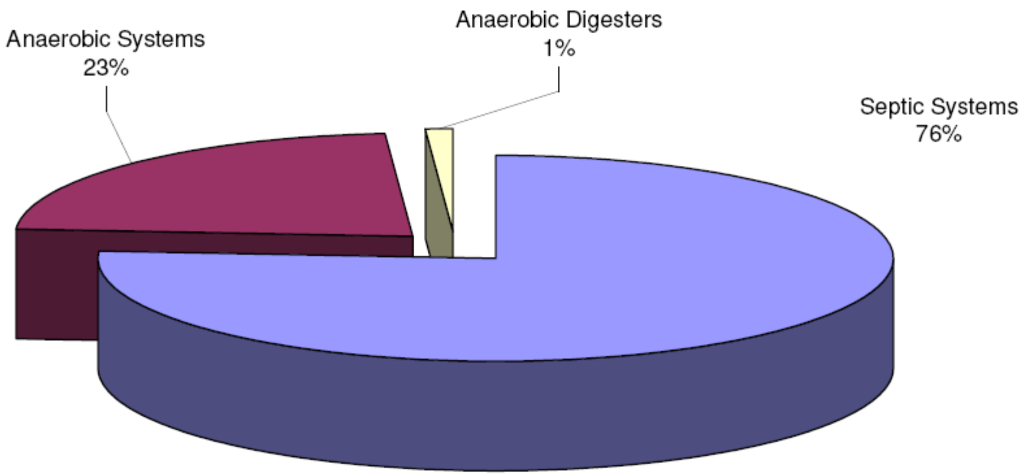

FIGURE 3-1
NATIONAL WASTEWATER TREATMENT CH_4 EMISSION SOURCES[1]

Several factors used by the USEPA may be considered overly conservative, resulting in an inflated estimate of CH_4 emissions. In January 2007, the National Association of Clean Water Agencies (NACWA) submitted a comment letter to the USEPA with suggestions for improving the emissions estimate (attached as Appendix D). NACWA's major comments included the following:

- The USEPA estimated that 5 percent of centrally treated systems are anaerobic systems. NACWA argued that true anaerobic systems are seldom, if ever, used, and a more reasonable estimate of 0.5 percent should be used.
- The maximum CH_4-producing capacity of 0.6 kg CH_4/kg BOD removed is overly conservative and is more accurately calculated to be 0.4 kg CH_4/kg BOD removed.
- The calculations assume 100 percent complete removal of all influent BOD. Treatment plants are not 100 percent efficient. A more reasonable 90 percent estimate of overall performance should be used.

[1]Source: U.S. EPA, Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-2005 (2007) and LACSD analysis of sector coverage.

The proposed changes outlined by NACWA result in a more appropriate estimate of national wastewater CH_4 emissions and would significantly reduce USEPA's national estimate.

3.2.2 N_2O Emissions

The USEPA estimated the total national N_2O emissions from domestic wastewater using the IPCC 2006 methodology described above, also taking into account the nitrogen content in biosolids, which is not available for conversion to N_2O. Estimates for N_2O emissions from effluent conversion, NDN processes, and conventional treatment without NDN processes were all conducted.

Based on estimates of national GHG emissions from wastewater treatment conducted by USEPA, and using the data and methodology outlined by the USEPA (2007), approximately 97.2 percent of N_2O emissions result from the conversion of nitrogen compounds from treated wastewater effluent in a receiving water body (Figure 3-2). Roughly 2.8 percent of emissions come from conventional activated sludge treatment processes, and less than 0.1 percent come from NDN processes. The calculations completed by LACSD are included in Appendix C.

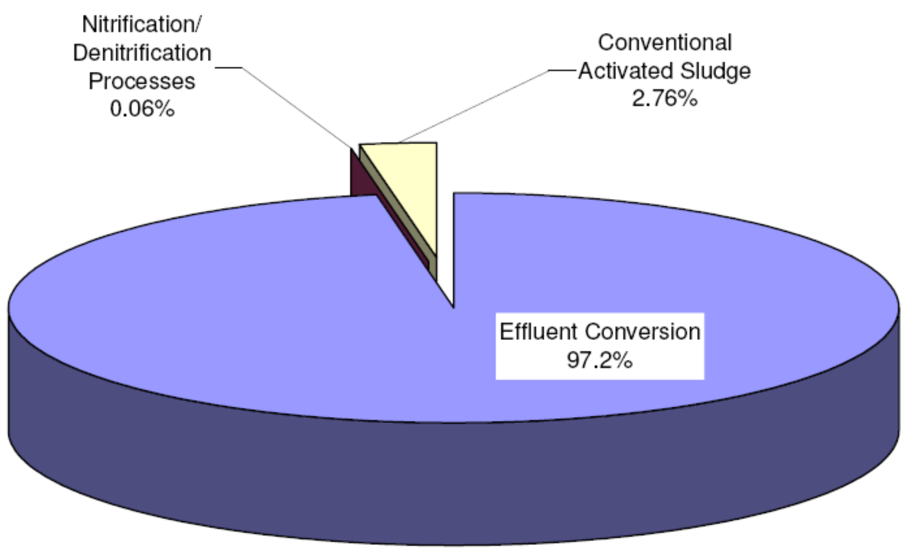

FIGURE 3-2
NATIONAL WASTEWATER TREATMENT N2O EMISSION SOURCES2

NACWA also reviewed the USEPA's estimation of N_2O methods and concluded that the following overly conservative factors were resulting in overestimation of N_2O emissions:

- In the method used by the USEPA, nitrogen content in wastewater is calculated according to annual protein consumption. This method results in a per capita nitrogen load of 9.43 kg N/person-year. This method is at odds with the per capita nitrogen discharge rate to wastewater from the Metcalf & Eddy standard reference of 5.48 kg N/ person-year.

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[2]Source: U.S. EPA, Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-2005 (2007) and LACSD analysis of sector coverage.

- The USEPA calculations also include a factor of 1.25 (from the IPCC methodology) to account for industrial discharges. NACWA argues that industrial discharges are inherently accounted for in both the protein consumption approach and in the per capita nitrogen load approach.

The emissions factor used by USEPA to estimate N_2O from effluent conversion should also be further reviewed. The proposed changes outlined by NACWA would result in a significantly lower estimate of N_2O wastewater treatment emissions (roughly 50 percent).

3.3 CEC Methodology

The CEC has previously estimated GHG emissions on a statewide level. The CEC statewide estimate includes emissions from wastewater treatment based on the method outlined by EIIP (1999), which is a simplified version of the IPCC approach. The latest CEC estimate for 2004 (published in 2006) ranks wastewater treatment as the fourth-largest contributing sector to CH_4 emissions and the third-largest contribution sector to N_2O emissions in the state of California.

3.3.1 CH_4 Emissions

CH_4 emissions were calculated from the factors shown in Table 3-5.

TABLE 3-5
CEC Inventory Methodology to Estimate CH_4 Emissions from Wastewater Treatment
Discussion Paper for a Wastewater Treatment Plant Sector Greenhouse Gas Emissions Reporting Protocol

Factor	Value
State Population	No. People
Per capita BOD	65 g BOD/person/day
Fraction of BOD that degrades anaerobically	Default: 16.25%
Emission Factor	Default: 0.6 kg CH_4/kg BOD

Source: CEC, 2006.

This method does not take into account the varying amounts of emissions that result from different treatment processes (i.e., low to no emission from centralized aerobic treatment plants). Further, the CEC method assumes that 16.25 percent of all BOD degrades anaerobically. This default factor accounts for the anaerobic degradation that takes place in septic systems. The emission factor of 0.6 kg CH_4/kg BOD also does not take into account any correction factors for various treatment methods. For instance, in the USEPA estimate, the emission factor included a 0.0 to 0.3 correction factor for aerobic treatment.

Considering these findings, it is likely that the CEC method overestimates the amount of CH_4 emissions from WWTPs in the state of California.

3.3.2 N_2O Emissions

The method used by CEC to estimate N_2O emissions is also a more simplified version than that used by USEPA (2007). N_2O emissions were calculated using the factors shown in Table 3-6.

This method assumes that all N_2O emissions result from discharged wastewater and does not account for N_2O emissions from NDN processes or conventional activated sludge plants. It is unclear whether this estimate includes factors to account for industrial/ commercial and non-consumed protein contributors, such as those included in the USEPA estimate. Finally, the effluent conversion factor of 0.01 kg N_2O-N/kg N is an order of magnitude larger than the emission factor used by IPCC and the USEPA (0.005 kg N_2O-N/kg N). Considering these findings, it is likely that the CEC estimate of N_2O emissions from wastewater in the state of California is overestimated.

TABLE 3-6
CEC Inventory Methodology to Estimate N_2O Emissions from Domestic Wastewater Treatment
Discussion Paper for a Wastewater Treatment Plant Sector Greenhouse Gas Emissions Reporting Protocol

Factor	Value
Population	No. people
Protein Consumption	42.1 kg/person-yr
Fraction of nitrogen in protein	0.16 kg N/kg protein
Emission factor for N_2O from discharged wastewater	0.01 kg N_2O-N/kg N

Source: CEC, 2006.

3.4 Applicability of Protocols

3.4.1 Facility-level Protocols

The IPCC protocol reviewed in Section 3.1 represents the only available methodology to estimate facility-level wastewater treatment GHG emissions. This protocol was developed to estimate national-level emissions from wastewater treatment and has been modified by both the USEPA and CEC in developing their national- and state-level estimates. Although the IPCC approach may provide a good starting point for facilities to estimate their emissions, for several reasons, the IPCC approach may not be the best possible approach for individual facility estimates.

The IPCC approach is a top-down approach that does not use facility-specific information; rather, it uses general assumptions such as the amount of protein consumed per capita per year and the amount of BOD generated per capita per year. This approach on a facility level will not be as accurate as an approach based on facility-specific data, such as influent nitrogen or BOD concentrations. The IPCC approach was also developed to estimate emissions from a variety of treatment processes. For example, a correction factor is applied in estimating CH_4 emissions according to whether the process is a septic tank, a centralized aerobic plant, a centralized anaerobic plant, or other type. This approach may not be ideal for a single facility using one type of treatment process (e.g., centralized aerobic treatment).

The IPCC approach also does not include all sources of fugitive CH_4 emissions on a plant-by-plant basis.

The IPCC estimation method for N_2O emissions from NDN processes may not be accurate. The IPCC states that process N_2O emissions may be considered a minor source and that the emission factor used is uncertain because it is based on the results of only one field test. In addition, the IPCC approach and the modified approach used by the USEPA and CEC use overly conservative factors that result in inflated estimates of N_2O emissions. N_2O emissions are influenced by process conditions and are highly variable. Therefore, an emission factor that considers potential N_2O emissions specific to process conditions or a plant-specific emission factor based on site-specific testing would provide a better estimate. In future protocol development, facility level issues should be investigated including uncertainty levels.

3.4.2 State-level Protocols

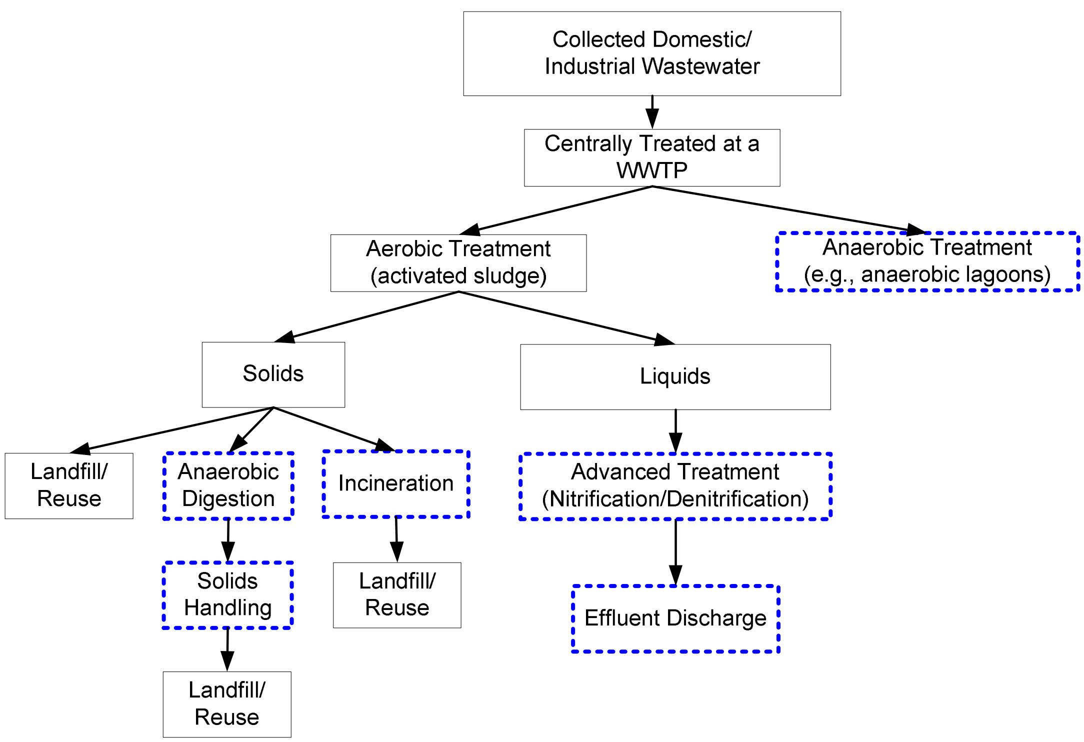
Because facility-level data are not known for every WWTP in California, a top-down approach is more appropriate to estimate the state-level aggregate wastewater treatment GHG emissions. The CEC approach is a top-down approach; however, inconsistencies with the current IPCC approach and the use of overly conservative factors result in the overestimation of wastewater treatment emissions. The CEC approach does not differentiate between types of treatment facilities and processes, as would be appropriate for a state-level estimate. Therefore, the modified approach used by the USEPA may be a more appropriate method to use for the state of California.

4.0 Recommendations

4.1 Accounting Boundaries

Figure 4-1 identifies WWTP and discharge pathways for typical California WWTPs and the expected sources of emissions that are recommended to be included in a WWTP protocol. CH_4 and N_2O emissions are expected from anaerobic treatment processes, sludge handling processes (anaerobic digestion and incineration), NDN processes, and from the effluent discharged to an aquatic environment (receiving waters).

The protocol boundaries for a WWTP should not include emissions from offsite anaerobic treatment, such as a septic tank, because these systems are not included in municipal WWTP operations. The protocol boundaries also should not include emissions from landfill or use of biosolids. As previously discussed, the emissions from landfill or use of biosolids are accounted for in protocols used by other sectors (e.g., landfill and agriculture). Special precautions against double-counting emissions from any source category need to be included in a WWTP-sector GHG emissions reporting protocol. Emissions from collection systems are not included in the IPCC protocol or in the USEPA or CEC estimates. Considering this precedent, collection system emissions should not be included in a WWTP-sector reporting protocol.



Note: Dashed blue boxes indicate sources of CH_4 and N_2O emissions recommended to be included in a WWTP sector GHG emissions reporting protocol.

FIGURE 4-1
CALIFORNIA WWTP AND DISCHARGE PATHWAYS AND EMISSION SOURCES

4.2 Characterizing Facility Baseline Emissions

To better estimate the facility-specific emissions for all WWTPs in California, it is recommended that the CWCCG develop a protocol with a variety of methodologies to estimate CH_4 and N_2O process emissions, which will allow for flexibility in the level of detail and accuracy. Smaller WWTPs with fewer emissions may not need to do a very detailed site-specific evaluation. However, larger WWTPs may want a higher level of detail and accuracy. The protocol should also provide flexibility to account for type of treatment process. For example, WWTPs that have a denitrification process may want to use a more site-specific approach. The protocol should provide guidance to WWTPs as to what method is best suited for a particular plant.

4.2.1 CH_4

Considering the national inventory conducted by the USEPA (2007) and the typical WWTP processes used in California (aerobic treatment and anaerobic digestion), CH_4 emissions are expected to be very low and may be considered *de minimus* by CCAR and CARB. The majority of CH_4 emissions identified in the USEPA inventory come from anaerobic treatment such as lagoons and septic tanks. Septic tanks are not part of a municipal WWTP and should not be included in a WWTP-specific emissions reporting protocol. However, emissions from lagoons should be included. Fugitive emissions from digester leaks, dewatering activities, and emissions from incomplete combustion of digester gas should be considered for inclusion in a WWTP protocol.

The following methods are recommended to further develop a WWTP protocol to estimate CH_4 emissions:

- **Option 1: USEPA Approach/IPCC Approach**. Smaller wastewater treatment facilities that are not expecting to be required to submit an inventory to CARB may be able to use the existing top-down approach outlined by the USEPA (2007). In such a case, no plant-specific sampling and analysis would be required. It should be noted, however, that this option will result in conservative emissions estimates. Guidance should be provided in the protocol to help determine whether this option is appropriate for a given situation.
- **Option 2**: **USEPA Approach with Updated Default Values**. Recognizing that the approach in Option 1 will lead to conservative emissions estimates, this option would allow a treatment plant to make a more accurate emissions estimate by using more accurate factors. The updates to the USEPA approach should incorporate the NACWA findings. This approach may be more appropriate for large wastewater facilities that use aerobic processes and that want a more accurate estimate.
- **Option 3**: **Complete Emissions Inventory/Sampling-based Approach**. For anaerobic plants, or those with potentially high CH_4 emissions, a more site-specific emissions inventory program may be required. This program may consist of source testing and modeling anaerobic sources and fugitive sources. This approach is a source-specific, bottom-up approach.

4.2.2 N_2O

Similar to the recommendations for estimating CH_4 emissions, a variety of methods should be developed for estimating N_2O emissions. The IPCC method (2006) states that the majority of N_2O emissions are expected to be from treatment plant effluent and that NDN process emissions should be low. However, as discussed, N_2O process emissions are heavily influenced by process conditions and have not been studied extensively. The top-down approach of estimating N_2O emissions based on protein consumption may not provide an accurate estimate.

Modeling is a potential approach to establishing better N_2O emissions estimates. There is a new modeling tool for estimating N_2O emissions from NDN processes called Activated Sludge Model-Nitrogen (ASMN) developed by Hiatt, et al. (2007a,b). This new model is the only comprehensive model available to calculate N_2O emissions and was built upon previous activated sludge models developed by Grady and Gujer (Grady et al., 1986; Gujer et al., 1999). The input to the model is influent nitrogen concentration. N_2O emissions are estimated based on process kinetics. Combined with a computer solution, this new model can provide a tool to evaluate plant-specific N_2O emissions. Thus far, only lab-scale testing of this model has been performed. The emissions estimated by this model should be calibrated and verified with facility-level, in-field testing.

Considering the availability of this model, the following methods for estimating N_2O WWTP emissions are recommended for further development in a protocol:

- **Option 1: USEPA Approach/IPCC Approach**. Smaller wastewater treatment facilities that are not expecting to be required to submit an inventory to CARB may be able to use the existing top-down approach outlined by the USEPA (2007). This estimate will use existing knowledge and will not require plant-specific sampling or further detailed analysis. Guidance should be provided in the protocol to help determine whether this option is appropriate for a given situation.

- **Option 2**: **USEPA Approach with Updated Default Values**. Recognizing that the approach in Option 1 will lead to conservative emissions estimates, this option would provide a treatment plant with a more accurate emissions estimate by using more factors that are not overly conservative. The updates to the existing USEPA approach should incorporate the NACWA findings.

- **Option 3: Mass Balance Approach with New Emission Factors**. The new model described above can be used to develop general emissions factors for different classes of WWTPs characterized by size and treatment schemes. A WWTP utility could then estimate its emissions using the general emission factor that most closely represents its operations. This approach will require in-field testing at a range of WWTPs to calibrate the model.

- **Option 4: Model and Source Test**. This approach will provide a WWTP with the most site-specific emissions estimate. Using this approach, operators will conduct source testing at their WWTP and input those results into the model to develop a more accurate estimate of N_2O emissions from their facility.

This proposed approach for protocol development will allow flexibility for plant operators to develop a more general emissions estimate down to a site-specific estimate depending on their preference.

4.3 Characterizing Statewide Aggregate Emissions

As discussed in Section 3.4.2, a more accurate statewide aggregate emissions estimate can be calculated using a top-down approach with refined factors used in the USEPA approach (2007) rather than the existing CEC approach. The CEC approach is a simplified approach, which may result in overestimation of WWTP emissions.

5.0 Summary

GHG emissions from WWTPs in California are expected to include the following:

- CO_2 from combustion sources (to be estimated using existing protocols, as appropriate, such as the CCAR General Reporting Protocol or the CCAR Power/Utility Reporting Protocol).
- CO_2 from indirect sources, such as purchased electricity (to be estimated using existing protocols, as appropriate such as the CCAR General Reporting Protocol).
- CH_4 emissions that are uncollected or controlled from anaerobic secondary wastewater treatment processes.
- CH_4 fugitive emissions from solids handling processes (e.g., anaerobic digestion of sludge and sludge dewatering).
- CH_4 emissions from the incomplete combustion of digester gas.
- N_2O emissions from NDN processes.
- N_2O emissions from wastewater effluent in receiving aquatic environments.

The IPCC has developed a method for estimating wastewater treatment emissions on a national scale but, as discussed in this paper, this method is not the most appropriate for estimating emissions from an individual facility. In addition, as discussed in Section 3.0, the IPCC method uses overly conservative values that can lead to overestimation of N_2O emissions and does not account for all fugitive sources of CH_4 emissions. In light of coming regulations on emissions inventories, WWTPs need an approach appropriate for individual facilities so that they can better assess their GHG emissions footprint and identify where there is potential to reduce emissions.

The proposed approach for developing CH_4 and N_2O estimating methods for WWTPs is to identify multiple methodologies from which a WWTP operator can choose according to the size of the plant, its treatment processes, and its expected emissions. The most conservative estimate can be calculated using the existing top-down approach provided by IPCC and used by USEPA and CEC. Increased accuracy can be achieved by using emission factors that are more specific to individual plant operations.

CH_4 emissions are expected to be very minor at most plants in California if a plant is using aerobic secondary treatment processes. If this is the case, emissions can most conservatively be estimated using the first recommended option (Option 1: USEPA Approach/IPCC Approach), which is to estimate emissions using the USEPA method. The second option (Option 2: USEPA Approach with Updated Default Values) is the USEPA method with refined factors, incorporating the findings of NACWA. The final option, which will result in the most accurate estimate of CH_4 emissions, would be to conduct site-specific source testing and modeling (Option 3: Complete Emissions Inventory/Sampling-based Approach). This option might be preferred for treatment plants using anaerobic processes with uncollected and uncontrolled methane emissions that expect their CH_4 emissions to be significant.

The first two recommended options for estimating N_2O emissions are the same as for CH_4 emissions using the USEPA approach. These methods are the most conservative. The development of a new model by Hiatt et al. (2007a,b) for estimating N_2O emissions provides a method for more accurate site-specific estimates. As proposed, Option 3: Mass Balance Approach with New Emission Factors for N_2O emissions estimates would use the new ASMN model to develop general emission factors for different classes of WWTPs. WWTP facilities could then estimate their emissions using the emission factor that most closely represents their operations. The final recommended option for estimating N_2O emissions (Option 4: Model and Source Test) is to develop a site-specific emissions estimate. This option would require a facility to conduct site-specific source testing, followed by modeling to evaluate site-specific emissions.

6.0 References

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Appendix A
IPCC Wastewater Treatment Methodology

Appendix B
USEPA Wastewater Treatment Methodology

Appendix C
National Wastewater Treatment Emission Calculations

Appendix D
NACWA Comment Letter on USEPA Wastewater Treatment Emissions Estimates