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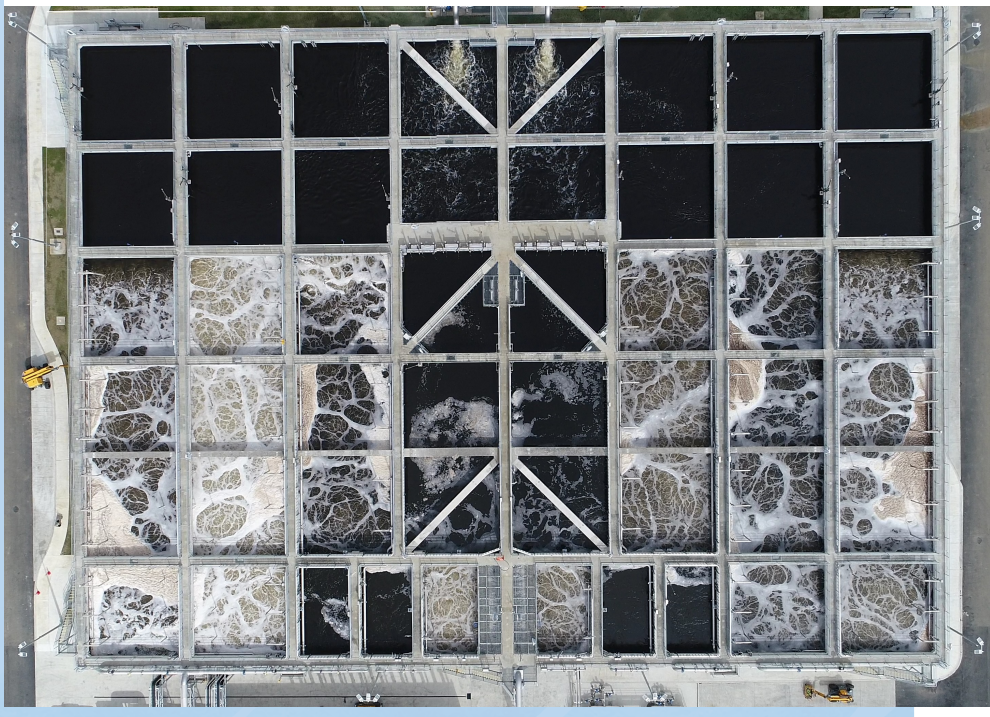
The New Zealand Water & Wastes Association Wai ora Aotearoa

WATER NEW ZEALAND
Standard Methods

Carbon accounting guidelines for wastewater treatment: CH_4 and N_2O



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Version 1.1

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REVISIONS

Version	Date	Revision
Version 1	August 2021	Issued
Version 1.1	September 2021	Pg 45 and 48: CH4 from land application revised. Calculations assumed 40% VS destruction changed to 45% VS destruction Pg 24: CH4 from ponds revised. Calculations assumed some BOD removal in sludge, changed to '0' removals in sludge

CONTENTS

EXECUTIVE SUMMARY

This document provides guidelines for accounting for methane (CH_4) and nitrous oxide (N_2O) emissions from municipal wastewater treatment, discharge and sludge processing in New Zealand. Emissions from on-site septic tanks are also covered. The guidelines were designed with certain objectives in mind:

- To help wastewater treatment providers to prepare a greenhouse gas (GHG) inventory through the use of standardized approaches and principles;
- To provide guidance on the scope and boundaries to be considered for activities in the wastewater industry;
- To provide more detailed guidance on GHG accounting for treatment processes used widely in New Zealand;
- To consider the current state of knowledge for wastewater GHG emissions and applicability of the methodology updates published by the Intergovernmental Panel on Climate Change (IPCC, 2019); and
- To increase consistency and transparency in GHG accounting and reporting among wastewater treatment providers.

The guidelines describe different levels of assessment depending upon the quality and extent of plant data available. They provide some default values that can be used in the absence of good data. The document provides details for improving data quality over time.

There is high uncertainty in many of the emission factors described in these guidelines. Emissions of CH_4 and N_2O will vary in wastewater processes temporally and spatially. The choice of treatment process can affect emissions, but equally how a process is operated and the wastewater characteristics will also have a bearing on the GHG flux. To improve estimates of key emissions, a national monitoring plan is needed to look at developing more process specific emission factors.

This document identified a number of areas requiring further study (Section 11).

GLOSSARY & ABBREVIATIONS

Term	Description
AD	Anaerobic digestion
AR4	IPCC fourth assessment report
AR5	IPCC fifth assessment report
BOD (also BOD_5)	Biochemical oxygen demand (5 day test)
B_0	Maximum methane potential
ccfb	Climate carbon feedbacks
CH_4	Methane
CO_2	Carbon dioxide
COD	Chemical oxygen demand
DOC	Fraction of degradable organic carbon (as defined in IPCC, 2019)
DOC_f	Fraction of DOC that can decompose (as defined in IPCC, 2019)
$DDOC_m$	Mass of degradable organic carbon (DOC) deposited (as defined in IPCC, 2019)
DS	Dry solids content (%)
EF	Emission factor
F	Fraction of CH_4 (by volume) in generated landfill gas
F_{NPR}	Fraction of nitrogen in protein
$F_{IND-COM}$	Factor for industrial/commercial discharge
$F_{NON-CON}$	Fraction of non-consumed protein, based on consumed protein
$FRAC_{GASM}$	Fraction of nitrogen volatilised
$FRAC_{LEACH}$	Fraction of nitrogen that is leached
GWP_{100}	Global warming potential over a 100-year time period
HSSF	Horizontal subsurface flow wetland
IPCC	Intergovernmental Panel on Climate Change
K_{REM}	Sludge removal factor, kgBOD/kg sludge
MCF	Methane correction factor
MfE	Ministry for the Environment
NIR	New Zealand National Inventory Report
N_{HH}	Additional nitrogen household products
N_{REM}	Nitrogen removed
N_2O	Nitrous oxide
Ox	Oxidation fraction
R	Amount of CH_4 recovered or flared
SF	Surface flow wetland
S_{mass}	Organics removed as sludge (BOD)
TKN	Total Kjeldahl nitrogen
TN	Total nitrogen
TOW	Total organics in wastewater
TS	Total dry solids
TSS	Total suspended solids
VS	Volatile solids

Term	Description
VSS	Volatile suspended solids
VSSF	Vertical subsurface flow wetland
WWTP	Wastewater treatment plant

FIGURES

TABLES

1. INTRODUCTION

1.1. Background

The transmission and treatment of wastewater will produce carbon dioxide, methane (CH_4) and nitrous oxide (N_2O) that will contribute to global emissions of greenhouse gases (GHGs). Carbon dioxide and CH_4 are produced as by-products of organic breakdown and N_2O can be formed as an intermediate step in the processes of nitrification and denitrification, widely used in the removal of ammonia and total nitrogen. This document focuses on the methodology for calculation of the contribution from CH_4 and N_2O as GHGs from our wastewater plants in New Zealand. Together these gases may form a substantial contribution to a council's total emissions.

The Zero Carbon Act (2019) introduced a framework for New Zealand for managing GHG emissions. This included targets to reduce net emissions of all GHGs (except biogenic CH_4) to zero by 2050 and to reduce biogenic CH_4 to 24-47 per cent below 2017 levels by 2050. The Climate Change Commission recently introduced a series of interim targets and reduction plan needed to achieve the 2050 goal (He Pou a Rangi, 2021). In New Zealand's 2021 NIR, wastewater treatment and discharge were estimated to contribute only 0.4% of national emissions. However, for councils and council-controlled organisations operating wastewater treatment plants the GHG emissions associated with wastewater and sludge treatment can be a substantial part of their carbon footprint.

In 2006, the Intergovernmental Panel on Climate Change (IPCC) produced guidelines for calculating national GHG inventories (IPCC, 2006). The methodologies were revised in 2019 resulting in a substantial increase of the default emission factor for N_2O from aerobic wastewater treatment plants (IPCC, 2019). It is also noted that the nature of national level GHG methodologies lack a level of detail required to plan assets.

In addition, the National Inventory Report (NIR) (MfE, 2021) states:

> *Most wastewater treatment in New Zealand is aerobic, including domestic, commercial and industrial wastewater. Methane (CH_4) emissions from domestic wastewater are mainly from rural septic tank usage. Wastewater emissions are also from some municipal treatment plants, which use semi-aerobic processes, and from industries in New Zealand, in particular, the meat and the pulp and paper industries.*

These guidelines provide a standardised approach to assess GHG emissions generated by municipal and domestic wastewater treatment, discharge and sludge processing in New Zealand. The goal is to provide consistency for wastewater asset owners/operators in New Zealand, as well as a greater level of detail to assist with asset planning and benchmarking. Relevant sections of these guidelines will be referenced in the water sector's low carbon pathway document (currently under development by Water New Zealand's Climate Change Special Interest Group) and made available to the Ministry for the Environment (MfE) who collate national greenhouse gas inventories and provides guidance to the industry sectors for developing voluntary emissions inventories.

1.2. Scope of guidelines document

These guidelines only cover direct, operational emissions of CH_4 and N_2O. They include emission estimates for municipal and domestic wastewater treatment, effluent discharge, sludge treatment and disposal.

Some of the other GHG emission sources explicitly excluded from these guidelines include:

- Water treatment and supply;
- GHGs from combustion of fuels or use of electricity onsite;
- GHGs from materials used onsite (e.g., precipitants, polyelectrolytes or pH correction chemicals);
- Embodied GHGs within capital infrastructure or materials (including equipment replacement);
- Use of green tariffs, carbon credits or related market-based reporting;
- Avoided GHGs (e.g., through the displacement of mineral fertilisers by land application of biosolids);
- Anthropogenic biogenic CO_2 emissions from wastewater treatment (see below).

Other environmental impacts are not covered in this guide.

BIOGENIC GHG EMISSIONS

Biogenic carbon is that derived from biomass (i.e., organic material). It is part of the Earth's 'short' carbon cycle whereby atmospheric CO_2 is incorporated into living cells, consumed, respired or combusted to be released back into the atmosphere to start the cycle again. This is as opposed to carbon in fossil fuels that forms part of a 'long' carbon cycle, where carbon has been trapped in geologic formations for millennia. Biogenic CO_2 emissions have typically been excluded from carbon accounting methodologies. However, the ISO 14064-1:2018 standard has provided revised guidance for reporting.

'Anthropogenic biogenic GHG' emissions (e.g., CO_2, CH_4 and N_2O) can result from biomass combustion or aerobic and anaerobic decomposition of biomass. The ISO 14064-1:2018 standard requires that 'anthropogenic biogenic CO_2' emissions and removals be quantified and reported separately from other anthropogenic emissions.

For wastewater, the majority of the organic carbon content (whether in dissolved or particulate form) is of biogenic origin (i.e. associated with feedstocks that stem from biomass, such as human food production, consumption, and disposal of those wastes to sewer). However, it is known that a minor proportion of the organic carbon content of wastewater is of non-biogenic origin (e.g. soap feedstocks derived from fossil fuels).

These guidelines do not cover the reporting of anthropogenic CO_2 emissions from wastewater treatment plants, whether of biogenic or non-biogenic origin. The other 'anthropogenic biogenic GHG emissions' (CH_4 and N_2O) are covered in these guidelines.

INDUSTRIAL WASTEWATER

Treatment of industrial wastewaters can deviate significantly from municipal wastewater, depending on the industry. In New Zealand, there is a prevalence for primary industries, such as dairy, abattoir, pulp and paper, and food and drink production wastewaters. These will often have much higher organic and nutrient loads. However, more complex and inorganic industrial discharges from textile, tanning, electroplating and pharmaceutical industries are also present.

The New Zealand NIR applies the IPCC (2006) methodology for industrial wastewater, which uses lower N_2O emission factors than are in the IPCC (2019) update. This means these guidelines and the NIR approach are currently misaligned. The NIR also expresses GHG emission factors on a production basis (e.g. tonnes of kills for meat industry). This is a higher level assessment than is covered in these guidelines for municipal wastewater.

It is important to note that industrial wastewaters have many other parameters that can influence treatment, and therefore also potentially impact emissions, including:

- Biodegradability and treatability of the wastewater in biological processes;
- Biodegradability of organic matter, which can be very low in some wastewaters with high inorganic or un-biodegradable wastewater;
- Ratio of biodegradable organic material to nutrients (N and P). This is typically well balanced in domestic sewage, but can vary significantly for industrial wastewater;
- Toxicity. Presence of toxic or inhibitory effects which impact biological activity.

For industrial wastewater treatment and municipal wastewater that has a high proportion of industrial contributions (i.e. disposed of to sewer with little or no pre-treatment), this guidance material should be used with discretion. If the parameters listed above can be seen as not impacting treatment at any given treatment plant, then a case can be made to apply these guidelines. Table 3 provides typical BOD:COD ratio's for municipal wastewater treatment, the measurement approach may need to be adopted based on industrial wastewater deviations from these ratios. For example, a BOD:COD ratio of ~ <0.3 would favour a CH_4 estimate using either i) a BOD-based MCF (Section 4.2) or ii) a 'sequential stage' approach based on COD removed (Section 4.2). For wastewater influent where the total nitrogen has a significant oxidised nitrogen (NO_2^- / NO_3^-) component then subsequent N_2O emissions maybe expected to be lower (excluding inhibitory effects) than are described in these guidelines. Toxicity effects are dependent on plant-specific wastewater composition and processes, so site-specific determination of inhibition or emission measurement is necessary to eliminate this being problematic.

Further research is required into the implications of the significant deviations from municipal sewage parameters that are found in industrial wastewaters, and how these impact emission factors in various treatment processes.

2. RELEVANT DOCUMENTS, REPORTING BOUNDARIES & METHODOLOGIES

The following sections outline the relevant and interconnecting documents used for estimating GHG emissions associated with wastewater treatment in New Zealand.

2.1. ISO 14064-1:2018 standard

The ISO 14064-1:2018 standard is an internationally recognised standard against which governments, businesses and other organisations can quantify, monitor, report and verify their GHG emissions. It includes requirements and guidance for determining GHG emission and removal boundaries, quantifying an organisation's GHG emissions and removals, and identifying specific company actions or activities aimed at improving GHG management. Adherence to the ISO 14064-1:2018 standard, or GHG Protocol, is recommended for NZ organisations undertaking municipal wastewater treatment.

Aspects of the ISO 14064-1:2018 standard relevant to the quantification of wastewater and sludge process emissions of CH_4 and N_2O are discussed in these guidelines.

2.2. Reporting boundaries

Organisations need to establish reporting boundaries, including direct and indirect GHG emissions and removals associated with their operations. The ISO 14064-1:2018 standard provides guidelines on establishing which indirect emissions to include, with the basis being the consideration of significance and the intended use of the GHG inventory.

For consistency and comparability across wastewater treatment providers, the reporting boundaries shown in Figure 1 should be included. This methodology covers all the emissions shown but with a particular focus on wastewater treatment emissions. This methodology will refer to other guidelines (e.g., IPCC) for guidance on calculation of sludge treatment and discharge emissions. Appendix B provides an example of boundaries applied to Melbourne Water wastewater activities.

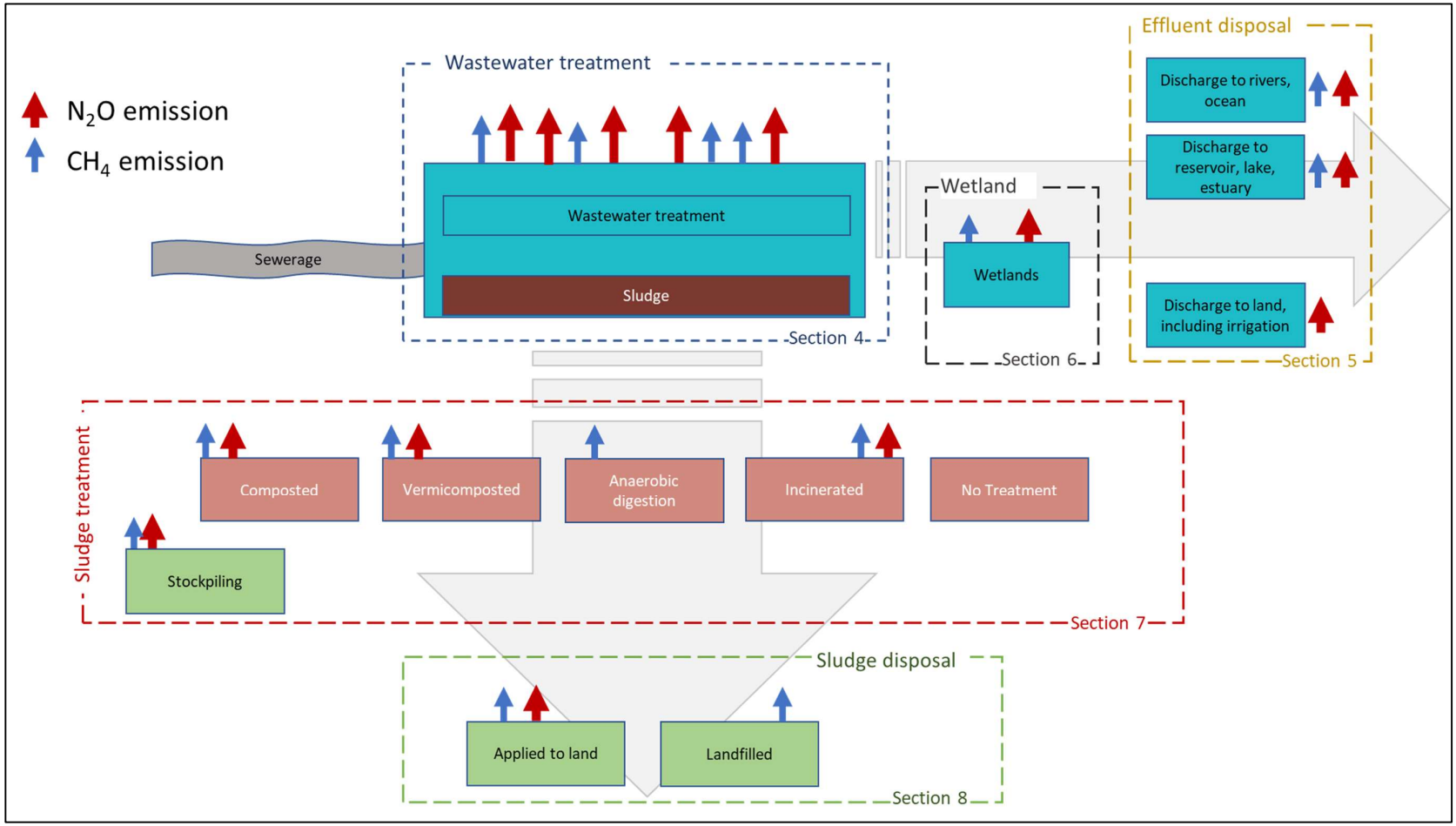

Figure 1: Sources of N_2O and CH_4 emissions from wastewater and sludge treatment and disposal

Note 1: The dashed boundaries above encompass the emission boundaries covered within these guidelines.
Note 2: Biogenic CO_2 emissions are excluded from Figure 1 (see '*Biogenic GHG emissions'* section below for more detail).
Note 3: Anaerobic digestion (AD) is considered to include all AD-related technologies, includes pre-treatments (e.g., mesophilic, thermophilic, temperature-phased, acid-phased, thermal hydrolysis).
Note 4: Emissions from sewerage (collection) system(s) are excluded.

EMISSION SOURCE EXCLUSIONS

Fossil carbon

A fraction of the wastewater influent carbon to a plant may be of fossil carbon origin, which is likely derived from petroleum based household products such as detergents and pharmaceuticals. The fossil carbon component would count towards emission estimates. Without better data, fossil carbon in New Zealand municipal wastewater is assumed to be small[1], and its relative degradability is unknown. These assumptions could change as the research improves.

Sewer networks

It is recognised that sewer networks can be a source of CH_4. However, the best practice guidance currently is that there is insufficient data to ascertain a positive default emission factor and, for closed underground sewers, the EF should be '0' (IPCC, 2019). It is recognised that this is likely to be a source of under-estimation of wastewater-related emissions. However, for NZ, with a cooler climate and generally short, flowing sewer systems, the direct CH_4 emissions are likely to be lower than in warmer climates. For further information refer to IPCC (2019) and literature sources (Liu, 2015).

Although emissions released direct from the upstream sewer network are excluded, the IPCC guidelines make allowance for dissolved CH_4 generated in sewer that is released at the plant. This is incorporated in the emission factors presented in Section 4.

Grit and screenings

Grit and screenings are generated at the head of the works, and are typically landfilled. Organic matter entrained in these residues can generate CH_4 once in landfill. However, these are considered insignificant (typically at least one to two orders of magnitude less than sludge biosolids generated at a wastewater treatment plant), and are currently excluded. For some organisations, emissions from landfill of this waste might be reported under their solid waste management accounting.

2.3.Organisational boundaries (scope or categories)

The term 'Scopes' has been replaced by six 'Categories' under the ISO 14064-1:2018 standard, although the term 'Scopes' is still used under the GHG Protocol (WRI/WBCSD, 2015). Compared with the previous ISO standard, the six categories under the current ISO standard provide a more granular breakdown of activities, particularly for indirect emissions. Examples for a municipal wastewater treatment provider are shown in Table 1. Any particular organisation might have these processes in different categories depending upon where operational control or equity share occurs.

[1] There is high variability in literature, for example, a 2013 study estimated 4-14% of influent TOC to be of fossil origin: (Law et.al. 2013)

Table 1: Typical emission sources for wastewater treatment providers

Scope (GHG Protocol)	**Category** (ISO 14064-1:2018)	**Subcategory** (ISO 14064-1:2018)	**Examples**
Scope 1 - Emissions from operations that are owned or controlled by the reporting company	**Cat 1:** Direct GHG emissions and removals	**1.4** Direct fugitive emissions from the release of GHG in anthropogenic systems	N_2O & CH_4 from wastewater treatment
			N_2O & CH_4 from wetlands owned by the organisation
			Fugitive emission from onsite flaring, anaerobic digestion or composting
			N_2O & CH_4 from effluent disposal or sludge disposal to land owned by the organisation
			CH_4 from disposal of sludge in landfill owned by the organisation
			N_2O & CH_4 from effluent disposal to water bodies
Scope 2 - Emissions from the generation of purchased or acquired electricity, steam, heating, or cooling consumed by the reporting company	**Cat 2:** Indirect GHG emissions from imported energy	*Not applicable for this guide*	
Scope 3 – All other indirect emissions that arise as a consequence of an organisation's activities, but generated outside its boundaries, from sources that it does not own or control	**Cat 3:** Indirect GHG emissions from transportation	*Not applicable for this guide*	
	Cat 4: Indirect GHG emissions from products an organisation uses	**4.3** Emissions from the disposal of solid and liquid waste	N_2O & CH_4 from effluent disposal to land not owned by the organisation
			N_2O & CH_4 from third party composting
			N_2O & CH_4 from treatment of desludged septic tank waste
			GHG emissions for third party disposal of sludge to land / landfill
	Cat 5: Indirect GHG emissions (use of products from the organisation)	**5.2** Emissions from downstream leased assets	N_2O & CH_4 from any leased assets. Methodologies in these guidelines are relevant for estimating emissions from leased assets
	Cat 6: Indirect GHG emissions (other sources)	*Not applicable for this guide*	

2.4.Global warming potentials (GWP)

For an organisational footprint aligned to ISO 14064-1:2018, the latest 100-year global warming potential (GWP) should be used. The standard does not explicitly state whether GWPs with carbon feedbacks[2] should be used; therefore, this is optional or can be reported additionally. The quantification of emissions of CH_4 and N_2O are sensitive to the GWP chosen, so for transparency, the GWP used should be disclosed alongside the reported GHG inventory measurement.

The latest IPCC report lists the most recent assessment report (AR5) GWPs, as of 2021 these a shown inTable 2 (Myhre et.al., 2013). Note that as of 2021, MfE are still using the AR4 values, so utilities might wish to continue to use GWP_{100} values that align with their overall organisational inventories.

Table 2: Global warming potentials from IPCC

GHG	**AR4 GWP_{100}**	**AR5 GWP_{100}**	**AR5 GWP_{100} with climate carbon feedbacks**
CH_4	25	28	34
N_2O	298	265	298

Emission factors in these guidelines are expressed as the individual gases. However, a conversion to 'CO_2 equivalents' (CO_2e) has been made in each summary section.

2.5.IPCC methodology

The Intergovernmental Panel on Climate Change (IPCC) develops and refines internationally agreed methodologies that provide guidelines for the preparation of national GHG inventories. These methodologies include the formulation of emission factors across sectors of the economy. Wastewater Treatment and Discharge (Volume 5, Chapter 6) was updated as part of the 2019 refinement (IPCC, 2019). The updated IPCC (2019) methodology aims to improve the national-level reporting process by ensuring that the methodology used to determine inventories is based on the latest science. Under the IPCC guidelines, CO_2 emission factors for wastewater are not considered since these are biogenic and not included in national total emissions.

This guide aligns with the IPCC (2019) methodology. Some methodologies were not updated in IPCC (2019) and so the suggested methodologies revert back to IPCC (2006) guidance. With the objective of meeting national level reporting requirements, national-scale data inventories result in a lack of detail and guidance necessary for site-level reporting. The IPCC approach therefore requires some additional guidance to make it appropriately detailed for New Zealand wastewater treatment providers.

The methodology recommended in these guidelines generally aligns with and refers to the IPCC (2019) refinement guidelines. However, a number of changes and additions are included in the guidelines offered in this document, to reflect the needs of New Zealand utilities when estimating wastewater emissions. These changes reflect the views and knowledge of the authors of these guidelines, and it is anticipated that the guidelines will be updated in future years, as the science and understanding around wastewater emissions evolves.

2.6.New Zealand National Inventory Report (1990 - 2019)

The New Zealand National Inventory Report (NIR) represents the national GHG reporting requirements under the United Nations Framework Convention on Climate Change. It largely applies the IPCC conversion and emission factors to sectoral activities. Note, for the wastewater sector, it uses the 2006 IPCC guidelines (rather than the 2019 refinement). However, some factors have been derived to be

[2] Climate carbon feedbacks account for feedback processes which may amplify or reduce radiative forcing or temperature.

specific to New Zealand or reviewed as suitable for use in New Zealand. Where this has occurred then the New Zealand specific or reviewed factors should be used in preference to the default (or latest) IPCC factors. See Table 18 (land-based discharge section) for an example of this.

2.7.MfE Measuring Emissions: A Guide for Organisations

The Ministry for the Environment regularly prepares a guidance document (e.g., MfE, 2020) to assist organisations to measure and report their GHG emissions. These guidelines include average emission factors for wastewater treatment plants; however, the scope of these emission factors is significantly different to that included in this methodology. For example, MfE (2020) does not include N_2O emissions associated with the treatment process itself. Therefore, the wastewater factors are not recommended for use by municipal wastewater treatment providers.

2.8.Benchmarking

Organisations should report absolute emissions of GHGs covering the scope identified in these guidelines as well as all other relevant non-biogenic emission sources e.g. electricity, fuels, in accordance with an appropriate standard. Reporting on an equivalent basis enables meaningful emissions benchmarking.

For benchmarking purposes, reporting of emissions using the following intensity metrics is recommended:

i) m^3 wastewater treated
ii) per capita
iii) kg BOD

The basis for the population (per capita) estimates should be stated (e.g., census data, or from actual wastewater mass load data and assumptions around mass loads per capita). Reporting emissions at a site-level 'per kg BOD' enables those discharging trade waste to better estimate their organisations indirect emissions.

3. DECISION TREES AND DATA QUALITY

Section Summary

Loading rates for plant influent		
Component	**Assessment type**	**kg / person / year**
BOD	Level 1	37
	Level 2 (preferred)	Site specific
COD	Level 1	52
	Level 2 (preferred)	Site specific
Total nitrogen	Level 1	5.5
	Level 2 (preferred)	Site specific

3.1. BOD or COD basis

The IPCC (2019) methodology provides an estimation methodology for CH_4 from wastewater treatment and discharge using biochemical oxygen demand (BOD) or chemical oxygen demand (COD) as the basis. Either approach can be taken for calculating the CH_4 emissions. Some considerations when making the choice would be:

- If only BOD influent and effluent data is collected this might be the preferred method.
- The BOD of sludge is difficult to determine, whereas the COD of sludge can be measured or can be estimated theoretically. In this case, the COD basis might be more accurate.
- If COD influent and effluent data is collected, this is recommended as the preferred method.
- If there is a mixture of COD and BOD data collected, then conversion factors between COD and BOD are provided which can be used as defaults. In many cases, COD of sludge will not be measured, whereas volatile solids (VS) might be measured. In such cases, conversion factors from VS to COD (default values provided) can be applied.

The equations used in these guidelines apply to both a BOD- and COD-based assessment, although BOD is shown as the default. Where the COD factors differ, these are provided in the guidelines. Measured data should be used where possible. However, the factors in Table 3 can be used to help convert between characteristics.

Table 3: Comparison of conversion ratios based on treatment stage[a]

Type of wastewater	BOD/COD	BOD/TOC
Raw influent	0.5 (0.3 – 0.8)	1.2 – 2.0
After primary settlement	0.5 (0.4 – 0.6)	0.8 – 1.2
Final effluent	0.2 (0.1 – 0.3)	0.2 – 0.5

[a] data source: Metcalf & Eddy (2003)

3.2.Decision tree

Organisations should look to obtain the best quality data possible. Generally, quantitative data on the following is needed as a minimum:

- Influent:
  - BOD or COD load (kg/yr); and
  - Total nitrogen (TN) or Total Kjeldahl Nitrogen[3] (TKN) load (kg/yr as N).
- Effluent:
  - BOD or COD load (kg/yr); and
  - Total nitrogen (TN) load (kg/yr as N).
- Sludge:
  - Dry tonnage (kg total dry solids/yr) and/or volatile solids (VS) dry tonnage (kg VS/yr).

However, flow and population data can be used for a high-level assessment if influent and effluent loads are not known.

There are different 'Levels' of data accuracy with which to make emission estimates. These levels refer to the IPCC Tiered Methodology but they are not directly aligned.

The decision trees in Figure 2 (treatment) and Figure 3 (discharge) provide advice for organisations looking to understand which approach to adopt. The levels are:

- Level 1: Population based or default average data;
- Level 2: Plant specific data; and
- Level 3: Direct measurement.

[3]TKN and TN are equivalent when oxidised N (nitrate plus nitrite) is zero or negligible, which is typically the case for raw wastewater, except where the raw wastewater has been aerated significantly (e.g. in catchments with steep gravity sewers and cold wastewater).

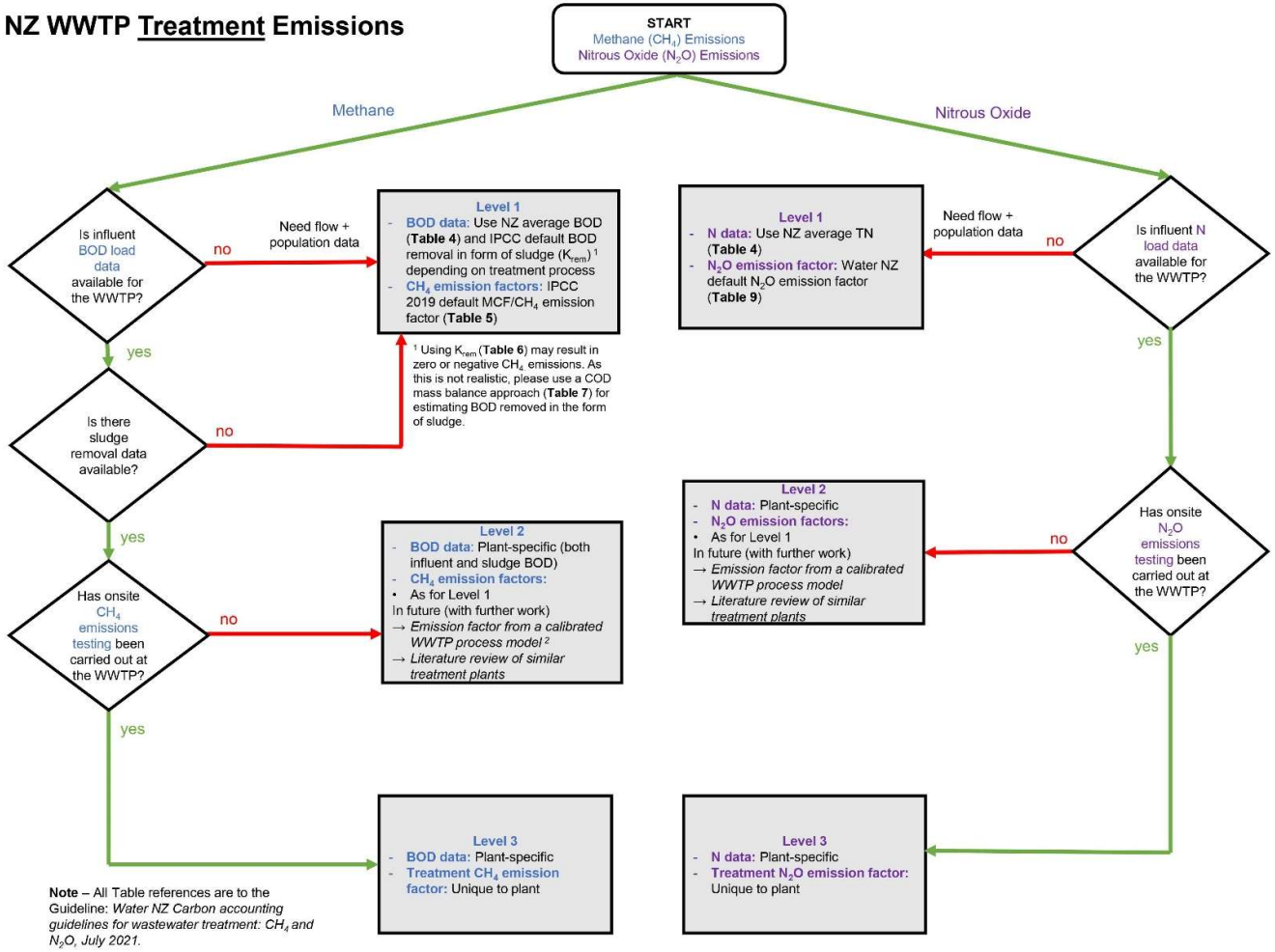

Figure 2: Decision tree for WWTP GHG emission estimates

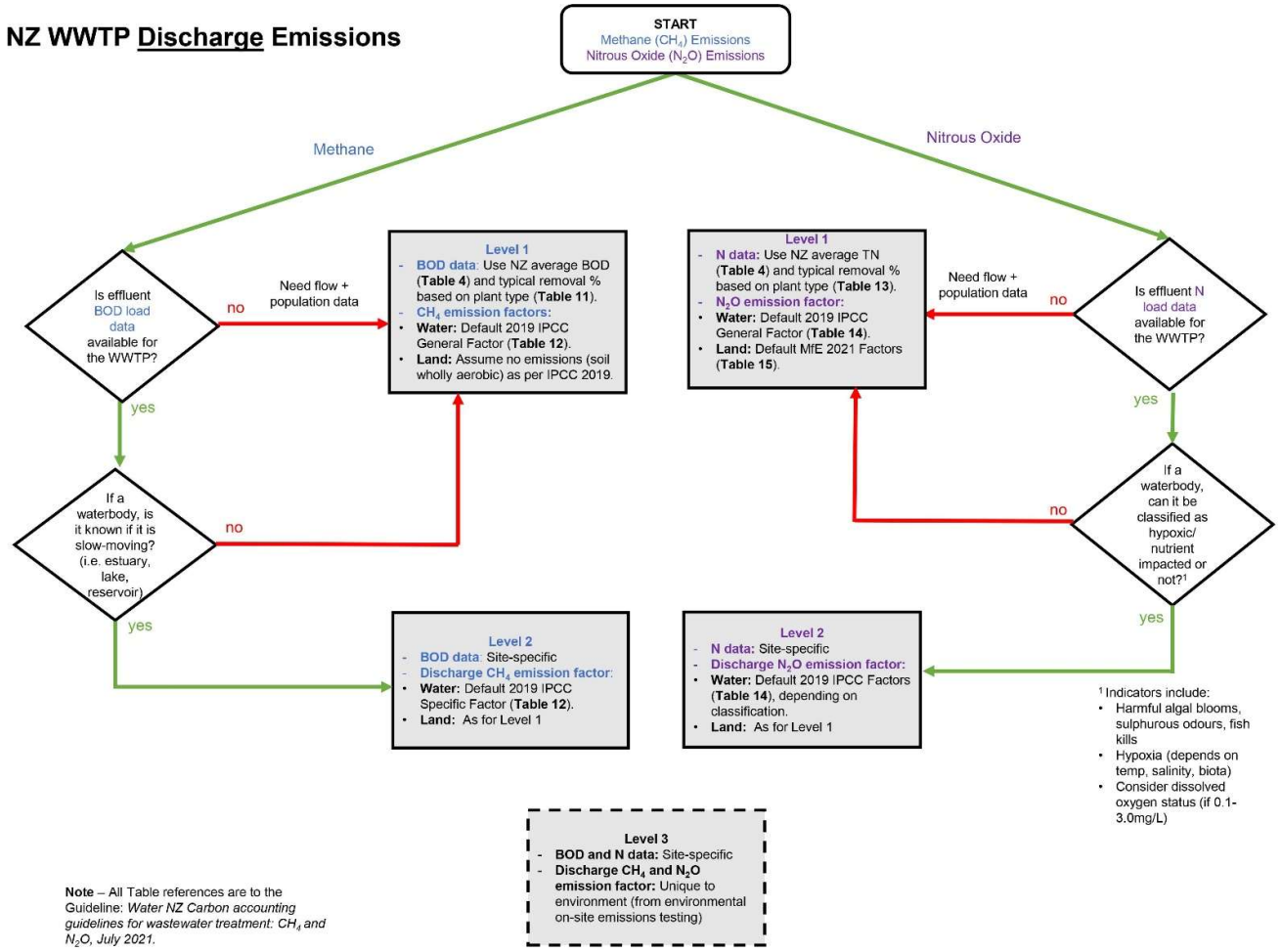

Figure 3: Decision tree for downstream GHG emissions from WWTPs (discharges to water bodies and land)

3.3.Level 1 – Population based

The IPCC and New Zealand national inventory report (NIR) (MfE, 2021) use a population-based approach to estimate the BOD and total nitrogen loads. IPCC (2019) estimation of nitrogen requires the application of multiplier factors to the population[4]. This default method (MfE, 2021) potentially overestimates the likely loadings when compared to literature values (**Table 4**).

Table 4: Parameters comparison of data sources for BOD and TN in raw wastewater

Reference	BOD (kg/person/year)	TN (kg/person/year)
MfE (2021)	26 (18 - 26)	5.8 - 11.1[a]
Metcalf & Eddy 5th T3-13	34 (18 – 44)	5.1 (3.3 – 6.6)
Hauber (1995)[b]	37 (18 – 48)	5.5 (3.3 – 9.5)
Beca data[c] - NZ Plant 1 (2020/21 summer)	23	4.7
Beca data[c] - NZ Plant 2 (2006/07 summer)	29	5.5

[a] This range represents with and without multipliers N_{HH}, $F_{Non\text{-}COM}$, $F_{IND\text{-}COM}$ applied (see MfE, 2021; Table 7.5.7); the true uncertainty range will be greater than this.
[b] Based on 17 NZ towns and cities including trade waste; (BOD average excluding trade waste = 27 kg/person/year).
[c] Based on measured influent load and population data.

Population estimates can be problematic for communities with seasonal changes in population, such as tourist centres. In this case, the population used in the Level 1 assessment should consider the annual average population, not just the resident population. For a Level 1 assessment, we recommend the following population-based values be used to estimate loadings in New Zealand:

- **BOD**: 37 kg/person/year;
- **Total nitrogen**: 5.5 kg/person/year.

However, we would recommend moving to a Level 2 approach to get more catchment specific values for BOD and nitrogen. This is particularly true if there are significant trade waste discharges to your plant, or significant tourism.

3.4.Level 2 – Plant specific

Level 2 assessments require plant influent and effluent load data as well as sludge removal information. Default emission factors are still used.

The minimum sampling requirements for a Level 2 assessment are recommended as follows.

Influent composition

- 24-hour composite sampling (ideally flow weighted), either:

[4] $TN = Pop \times Protein \times F_{NPR} \times N_{HH} \times F_{Non-con} \times F_{ind-}$ (MfE, 2021; IPCC, 2019; Vol 5, Eq. 6.10)

Where: TN = total nitrogen (kgN/yr); Pop = population equivalents (person/yr); Protein = typical protein consumption per person (kg/person/yr); F_{NPR} = fraction of nitrogen in protein (kgN/kgProtein); $F_{NON\text{-}CON}$ = factor for non-consumed protein (kgN/kgN); $F_{IND\text{-}COM}$ = factor for industrial/commercial discharge (kgN/kgN); N_{HH} = factor for additional nitrogen household products (kgN/yr)

- 1 year's worth of sampling, once per fortnight [26 samples total];
- 2 months' worth of sampling, 2 x per week, one peak month and one off-peak month [16 samples total].

Note, samples should not be taken on the same day every week (i.e., for the fortnightly sampling, this should be done on 13 day rolling intervals). Where temporal variability is high (e.g., seasonal changes from tourism or trade waste), then one year of monitoring, once per fortnight [26 samples total] is needed.

Values should be averaged over the year for the annual estimate of influent BOD and TN loads. TKN can be assumed equal to TN for influent.

Effluent composition

Effluent samples should be taken once per fortnight for the year of the estimate [26 samples total]. Note that nitrogen measurements must be total nitrogen; TKN is not suitable. Effluent and influent composition sampling should be undertaken during corresponding periods and preferably confined to the reporting period for emission calculations.

Flow

Plant flows should preferably be derived from influent flow meters, where the accuracy of the flow meters is known from calibration and is preferably within 5% of the known (true) value. Totalised daily flows (from real-time totalisers integral to the flow meter instrument in preference to computer-based estimates derived from flow meter signals) should be used where possible. Corresponding data periods for flow and composition sampling should be used. If influent and effluent composition sampling deliberately excluded specific periods (e.g., wet weather), then the flow dataset applied should similarly exclude those periods.

Unless there are known sources of effluent disposal to different routes (e.g., water recycling), the influent flow and effluent flow for a wastewater treatment plant can be assumed to be equal with only minor losses (e.g., for service water use within the plant not directed back to process) for most applications. For most pond and wetland systems, evaporative losses and rainfall make this approach unviable. In this case, effluent flow meter records will need to be applied in the calculations.

Loads

Wastewater (influent and effluent) loads are calculated from the product of flow and concentration (e.g., flow in ML/d multiplied by concentration in mg/L yields load in kg/d units). Multiplication of average flow and average concentration should be avoided as far as possible. Annual loads should be calculated from the sum of the products of flow and concentration at the shortest feasible time interval (e.g., daily flow x daily flow-weighted composite average concentration). Interpolation of concentrations from days sampled to days not sampled is permissible.

3.5.Level 3 – Direct measurement

Level 3 assessments include the sampling requirements as for Level 2, but also involve on-site testing of treatment plant emissions, to generate a plant-specific emission factor.

Direct measurement provides the highest quality data which is plant-specific, although it can be costly and time consuming to undertake. At the time of issue of these guidelines, direct measurement from wastewater treatment plants have not yet been carried out in New Zealand.

An emission factor derived from direct measurement should be derived ensuring that all spatial and temporal variation of CH_4 or N_2O emissions from a process are included. The recommended minimum time for on-site monitoring of emissions to develop plant-specific emission factors is 6 months (capturing both peak and off peak seasons). Ideally monitoring should be for 12 months.

Direct measurements of N_2O flux from New Zealand waterbodies have been made (Clough et.al., 2006; 2007; 2009; 2011; 2013). However, specific measurements looking at the influence, if any, of wastewater discharge on GHG emissions from waterbodies have not been carried out to date.

4. MUNICIPAL WASTEWATER TREATMENT

Section Summary

			EF	AR4 GWP_{100}	AR5 GWP_{100}	AR5 GWP_{100} with ccfb
Source	**Gas**	**Unit**	**kgGas / unit**	**$kgCO_2e$ / unit**	**$kgCO_2e$ / unit**	**$kgCO_2e$ / unit**
Anaerobic pond	CH_4	kgBOD	0.5	12.5	14.0	17.0
Facultative / aerated pond	CH_4	kgBOD	0.125	3.125	3.5	4.25
Aerobic plant	CH_4	kgBOD	Depends on S_{mass}	Depends on S_{mass}	Depends on S_{mass}	Depends on S_{mass}
Wastewater treatment	N_2O	$kgN_{influent}$	0.015714	4.683	4.164	4.683

Emissions of GHGs (CH_4 and N_2O) are the sum of those from wastewater treatment (Section 4), discharge to waterways (Section 5) and sludge treatment and disposal (Sections 7 and 8). This is summarised in Equation 1 (in kg CO_2e/yr units).

$$GHG_{Emissions} = GHG_{WWTP} + GHG_{Discharge} + GHG_{Sludge} \quad [1]$$

4.1. Processes with no GHG emissions

Many processes within a WWTP will not generate CH_4 or N_2O themselves. There may be areas where GHG emissions arise but which are not considered to be a source of GHG within this guidance. These include:

- UV disinfection;
- Tertiary sand filtration;
- Waste activated sludge dewatering;
- Ultrafiltration;
- Odour control;
- Chemical phosphorus removal.

Some processes may act as areas of release of GHG (e.g., due to turbulence, or being uncontained) such as dewatering of digested sludge, or the aeration basin of secondary treatment.

Ozonation is a source of N_2O, however this is not used in New Zealand and is not reviewed in this guidance.

4.2. Methane

SOURCES ONSITE

Dissolved CH_4 may be present in the influent to a treatment plant, which can become emitted during various stages of treatment in a WWTP. The CH_4 emission factor for a given type of centralised aerobic plant in IPCC (2019) is derived from literature that includes various sources of CH_4 on-site. It includes emissions detected from grit chambers, screens, Imhoff tanks, primary settlement tanks, aeration

basins, clarifiers, centrifuge exhaust (Bellucci, 2010). Other literature sources used gas dispersion modelling to derive an MCF for a whole plant treatment (Delre, 2017). The methodology described in this section applies to combined emissions of CH_4 from wastewater treatment. Emissions from sludge treatment occurring onsite (e.g., anaerobic digestion) are described separately in Section 7.

EMISSION FACTOR

The emission factor for CH_4 from wastewater treatment is determined using Equation 2 (IPCC, 2019; Vol 5, Ch 6, Equation 6.2)

$$EF = B_0 \times \mathrm{MCF} \quad [2]$$

Where:

> B_0 is the maximum CH_4 producing capacity and MCF is the methane correction factor. The B_0 is 0.625 $kgCH_4/kgBOD$ (or 0.25 $kgCH_4/kgCOD$) for municipal wastewater (MfE, 2021). The B_0 and MCF must be used together, and differ based on treatment type and discharge pathway.

In IPCC (2019), a single MCF of 0.03 was recommended for all aerobic wastewater treatment systems (activated sludge, biological nutrient removal, sequencing batch reactor, Bardenpho, A2O process). A review of CH_4 emissions from wastewater processes acknowledged that it varied by treatment; however more exhaustive on-site monitoring data are required to develop different MCFs for different treatment processes (IPCC, 2019; Annex 6A.3). Recommended MCFs are shown in Table 5 (IPCC, 2019; Vol5, Table 6.3).

Table 5: Methane correction factors for wastewater treatment processes

Wastewater treatment system	IPCC (2019) Classification	MCF
Oxidation pond	Anaerobic shallow / facultative	0.2
Aerated pond (partial aeration)[1]	Anaerobic shallow / facultative	0.2
Aerated pond (high aeration)[1]	Aerobic	0.03
Maturation pond	Aerobic shallow	0
Anaerobic pond	Anaerobic deep	0.8
Secondary (non-BNR)[2]	Aerobic	0.03
Secondary (BNR)[3]	Aerobic	0.03

[1] Partial aeration can be assumed when mixing energy is $<5W/m^3$, a highly aerated system would have $>10W/m^3$ mixing energy (expert judgement). Aeration intermediate to this could apply an averaged MCF.

[2] For example, trickling filters or rotating biological contactors and high-rate activated sludge processes (short sludge age, approximately <2 days) not designed for biological nutrient removal (BNR).

[3] Suspended growth BNR activated sludge processes (e.g., SBRs, MLE, Bardenpho, A2O, MBBR, IFAS).

MULTI-PROCESS ACCOUNTING

For each WWTP, the dominant onsite processes should be categorised as best as possible as primary, secondary and tertiary (if relevant). Wetlands would constitute a further treatment step.

CH_4 emission estimates from wastewater across a WWTP can then be determined by one of two approaches:

1. **Single factor** – apply this where a single dominant process is present and/or a single MCF value applies (**Table 6**);
2. **Sequential stages** – apply this where multiple processes are present with different MCF values (**Table 6**). If a polishing wetland is present, use this approach.

These approaches apply different methodologies (as described below). The 'single factor' approach aligns to IPCC (2019), but is flawed when describing more complex combinations of sequential processes. The 'sequential stages' method proposed here ensures a mass balance is achieved but requires more details of inter-stage performance and BOD removal in sludge. There is also greater uncertainty in the MCF values for the 'sequential stages' method.

For parallel processes of different type (with different MCF values), the emissions can be calculated in the same manner as for sequential stages described below, except that the influent will be split between streams.

SINGLE FACTOR

The emissions from wastewater treatment applying a single factor are calculated as in Equation 3 (adapted from IPCC, 2019; Vol 5, Equation 6.1):

$$CH_{4\,WWTP} = \left[\left(TOW_{influent} \times (1 - F_{TOWsludge}\right) \times EF\right] - R \quad [3]$$

Where:

$CH_{4\,WWTP}$ =emissions per year (kg CH_4/ yr);
$TOW_{influent}$ = influent organic component load, measured as biochemical oxygen demand (kgBOD/yr);
$F_{TOWsludge}$ = fraction of organics (BOD load) physically removed from the system as sludge (kgBOD/kgBOD);
EF = emissions factor for the wastewater treatment system under consideration (kgCH_4/kgBOD);
R = mass of CH_4 recovered or flared (kg CH_4/ yr).

The value 'R' in Equation 2 is most typically '0' in New Zealand for the wastewater component. Recovery and beneficial use of biogas during anaerobic digestion of sludge solids should not be accounted for here– this is accounted for separately in Section 7. A value for 'R' should be applied, for example where there is a covered anaerobic pond (or upflow anaerobic sludge reactor treating the mainstream flow) and CH_4 is recovered or flared. In this case, the CH_4 not recovered can be estimated by applying a fugitive release factor (see Table 17).

The fraction of organics removed as sludge is calculated using Equation 4:

$$F_{TOWsludge} = \frac{S_{removed}}{TOW_{influent}} \quad [4]$$

Where:

$S_{removed}$ = sludge physically removed from the system during the reporting period (kgBOD/yr) estimated from total (suspended) solids (TSS) using an appropriate conversion factor (for calculation method see Equation 7);
$TOW_{influent}$ = influent organic component load (kgBOD/yr).

SEQUENTIAL STAGES

The emissions from wastewater treatment applying a sequential stage approach are calculated as in Equation 5:

$$CH_{4\,WWTP} = \left[\left(TOW_{influent} \times \left(F_{TOWrem} - F_{TOWsludge}\right) \times EF\right]\right] - R \quad [5]$$

Where:

$CH_{4\ WWTP}$ = emissions per year (kg CH_4/ yr);
$TOW_{influent}$ = influent organic component load for the *relevant treatment stage in sequence under consideration* (kgBOD/yr);
F_{TOWREM} = fraction of organics removed (kgBOD/kgBOD) *from* the *relevant treatment stage in sequence under consideration (i.e., combined removal as sludge and/or biological decomposition;*
$F_{TOWsludge}$ = fraction of organics physically removed as sludge (kgBOD/kgBOD) *during the reporting period from* the *relevant treatment stage in sequence under* consideration;
EF = emissions factor for wastewater treatment ($kgCH_4$/kgBOD) *from the relevant treatment stage in sequence under consideration*;
R = amount of CH_4 recovered or flared ($kgCH_4$/yr) from that system.

The fraction of organics removed (F_{TOWREM}) is calculated using Equation 6:

$$F_{TOW\ REM} = \frac{TOW_{influent} - TOW_{effluent}}{TOW_{influent}} \quad [6]$$

Where:

F_{TOWrem} = fraction of organics removed (kgBOD/kgBOD) *from* the *relevant treatment stage in sequence under consideration (i.e., combined removal as sludge and/or biological decomposition;*
$TOW_{influent}$ = influent organic component load for the *relevant treatment stage in sequence under consideration* (kgBOD/yr);
$TOW_{effluent}$ = effluent organic component load for the *relevant treatment stage in sequence under consideration* (kgBOD/yr);

Organics removed as sludge (S) – secondary aerobic plants

The organic component removed as sludge ($S_{removed}$) is a function of sludge produced from wastewater treatment (S_{mass}) and a sludge factor (K_{rem}) which is a conversion factor to estimate how much organic matter (expressed as BOD) is physically removed from the treatment process as sludge per kilogram of sludge produced (IPCC, 2019). This is expressed in Equation 7 (equation 6.3B in IPCC, 2019):

$$S_{removed} = (S_{mass} \times K_{rem} \times 1000) \quad [7]$$

Where:

$S_{removed}$ = organic component removed from wastewater (in the form of sludge) in aerobic plants (kg BOD/yr);
S_{mass} = amount of sludge physically removed from the wastewater treatment system under consideration as dry mass (t/yr);
K_{rem} = sludge factor (kgBOD/kg sludge).

The conversion factor for BOD from sludge (K_{rem}) can be estimated based on the values in Table 6 (Table 6.6A; IPCC, 2019).

Table 6: K_{rem} according to treatment type

Treatment type	K_{rem} (kgBOD/kg dry sludge mass)	Range
Mechanical treatment plants (primary sedimentation sludge)	0.5	0.4 – 0.6
Aerobic treatment plants with primary treatment (mixed primary and secondary sludge, untreated or treated aerobically)	0.8	0.65 – 0.95
Aerobic treatment plants with primary treatment and anaerobic sludge digestion (mixed primary and secondary sludge, treated anaerobically)	1.0	0.8 – 1.2
Aerobic wastewater treatment plants without separate primary treatment	1.16	1.0 – 1.5

Using the K_{rem} method to estimate BOD removed in the form of sludge can sometimes provide negative or very low numbers of estimated $CH_{4\ WWTW}$, which is unrealistic. A better estimate can be made using a COD-based approach. Default factors to convert tonnes of dry solids, or TSS, to COD can be found in **Table 7**. If COD-based sludge conversions are used, all organic loads (influent, removal and sludge) must also be expressed in COD terms, for consistency and B_0 in Equation 2 must also be expressed in COD terms.

Table 7: Typical ratios for COD and TSS by sludge type

Treatment type	Default sludge values	Source
Mechanical treatment plants (primary sedimentation sludge)	COD/VSS: 1.8 VSS/TSS: 0.83	NZ plant data
Aerobic treatment plants with primary treatment	COD/VSS: 1.7 VSS/TSS: Short SRT 0.85, Long SRT 0.80	NZ plant data
Aerobic wastewater treatment plants without separate primary treatment	COD/VSS: 1.6 VSS/TSS: Short SRT 0.9, Long SRT 0.75	NZ plant data
Lagoon / pond sludge	COD/VSS: 1.57 VSS/TSS: <50%	Davies-Colley (1995) Von Sperling (2007)

Short SRT assumed to be < 10 days.

Organics removed as sludge (S) – ponds or lagoon systems

Pond (lagoon) systems are desludged infrequently (Table 8). For ponds, the $S_{removed}$ factor in Equation 3 should be '0' in any reporting year in which no physical removal of sludge (desludging) took place. Even when the ponds are desludged, the $S_{removed}$ factor for that reporting period, may be reasonably set to '0' as solids are likely heavily degraded and BOD potential greatly diminished.

Should estimates be required for quantifying pond sludge (e.g., for waste disposal calculations), or where the organics load (BOD or COD) removal via the sludge is considered to be significant in mass terms, then in the absence of measured data provided, Table 8 may be used as a guide.

Table 8: Sludge accumulation and characteristics for stabilisation ponds

Item	Anaerobic ponds	Primary facultative ponds	Secondary facultative ponds	Maturation ponds	Comments
Sludge accumulation rate (m^3/person/year)[1]	0.02 – 0.10	0.03 - 0.09	0.03 – 0.05	-	von Sperling (2007)
Removal interval (years)	10-15	10-20	20-30	20-30	Expert judgment
VS/TS ratio	<50%	<50%	<50%	-	von Sperling (2007)
%TS (sludge removed by pumping)	5 – 7%	5 – 7%	5 – 7%	-	von Sperling (2007)
Sludge accumulation kgCOD/person/year	2.8 (0.7- 5.5)	2.8 (1.0- 5.0)	1.9 (1.0- 2.8)	-	Calculated assuming density of 1.0, 5-7% TS, 50% VS and 1.57 COD/VSS ratio

[1] Assumed to incorporate a decay rate of VS over time.

4.3.Nitrous oxide

A direct emission factor for N_2O from WWTPs was introduced in the original IPCC guidelines (2006 and earlier) and updated in the latest Refinement Guidelines (IPCC, 2019). The updated emission factor was significantly higher than that in the older IPCC (2006) publication. To some extent, this reflected the greater number of measurements which had been undertaken between these publication dates. Details of the review can be found in Appendix A.

Equation 8 provides an estimation method for N_2O from wastewater treatment plants:

$$N_2O_{WWTP} = TN_{influent} \times EF_{plant} \times \frac{44}{28} \quad [8]$$

Where:

N_2O_{WWTP} = N_2O emissions (kgN_2O/yr);
$TN_{influent}$ = total nitrogen in influent (kgN/yr);
EF_{plant} = emission factor for WWTP (kgN_2O-N/kgN);
44/28 = conversion from N_2O-N to N_2O.

N_2O is generated both as a by-product in the oxidation of ammonium to nitrite (partial nitrification) and as an intermediate in denitrification of nitrate to nitrogen gas (Valkova, 2020). For this reason, it is only considered to be generated in aerobic treatment processes designed for intensive nitrification/denitrification, such as in activated sludge or similar systems, including both suspended growth and biofilm systems. The provisional recommendation is for a fixed emission factor of 0.010

$kgN_2O\text{-}N/kgN_{influent}$ from aerobic wastewater treatment in New Zealand (Table 9). For further commentary on the emission factor for N_2O from WWTPs, refer to de Haas and Ye (2021).

Table 9: Emission factors (EF_{plant}) for N_2O from municipal wastewater treatment plants

Wastewater treatment system	**IPCC (2019) classification**	**EF_{plant}** (kgN_2O-N/kgN)	**Range** (kgN_2O-N/kgN)
Aerated pond	Anaerobic shallow / facultative	0	0 – 0.001
Aerated lagoon	Anaerobic shallow / facultative	0	0 – 0.001
Anaerobic pond	Anaerobic deep	0	0 – 0.001
Oxidation pond	Anaerobic shallow / facultative	0	0 – 0.001
Maturation pond	Aerobic shallow	0	0 – 0.001
Treatment pond (with submerged media, rock-piles with circulation, floating reed beds, etc.)	Facultative	0.010	0.00002 – 0.044
Secondary (partial or intermittent nitrification e.g., high rate activated sludge or trickling filters and similar suspended or fixed growth processes)	Aerobic (not listed by IPCC, 2019)	0.010	≥0 (no data)
Secondary (non-BNR)	Aerobic	0.010	0.00002 – 0.044
Secondary (BNR)	Aerobic	0.010	0.00002 – 0.044

WWTPs that are designed for BOD removal only and do not nitrify or denitrify can be expected to have a '0', or very low, N_2O emission factor. However, these processes must be actively managed to maintain a low sludge age, or have the potential for partial/intermittent nitrification, depending on seasonal factors (e.g., loading, temperature). The default factor listed in Table 10 is currently recommended for such systems, but recognising that further work is necessary to evaluate nitrogen removal in real systems.

An emission factor of '0' is recommended for N_2O from the majority of pond types. The main mechanism for nitrogen removal in the wastewater pond system is assimilation of nitrogen through algal growth and physical stripping to the air. These removal mechanisms do not generate nitrite or nitrate and, therefore, should not be considered a source of N_2O. Nitrification mechanisms can occur in ponds, more likely in maturation stages; however, the extent of this effect is likely minor. In New Zealand ponds, surface aeration is usually applied for improving BOD removal in the primary facultative pond, reducing odour risk and managing circulation. It is rarely applied in maturation ponds as natural dissolved oxygen levels from the algae exceed the mechanical input. This aeration will not be sufficient for significant nitrification to occur, so N_2O production will be minor. As stated in von Sperling (2007), *"Nitrification is not very representative in facultative and aerated ponds. There is naturally no ammonia oxidation reaction in anaerobic ponds, due to the absence of oxygen".*

The exceptions are where nitrification is encouraged in design of pond treatment systems (e.g., through the addition of submerged media, rock piles with circulation or similar, floating reed beds). In these cases, secondary or tertiary nitrification processes are being created, in the form of fixed film systems. Some processes, due to specific operating conditions and configurations will produce significantly different levels of N_2O emission. This methodology uses default values. For best possible understanding of emissions from a specific plant, direct monitoring is recommended.

4.4.Treatment performance

A Level 2 assessment, using site-specific data, is the preferred approach. Where performance data is absent, literature estimates of typical performance can be used as the basis of the assessment. Characteristics of main pond systems are shown in Table 10 and can be used as a guide in the absence of site-specific data (von Sperling, 2007).

Table 10: Characteristics of main pond systems, showing percent removals

	Facultative	Anaerobic → facultative	Facultative aerated	Complete mix aerated → sedimentation	Anaerobic → facultative → maturation
BOD (%)	75-85	75-85[a]	75-85	75-85	80-85
COD (%)	65-80	65-80	65-80	65-80	70-83
TN (%)	<60	<60	<30	<30	50-65
Area (m^2/person)	2.0-4.0	1.2-3.0	0.25-0.5	0.2-0.4	3.0-5.0

[a] Approx. 50-70% of the BOD is removed in the anaerobic pond, the remainder in the facultative pond.

4.5.Worked examples

Worked examples for different wastewater process configurations (primary, secondary and tertiary) are provided in Appendix C.

5. EFFLUENT DISCHARGE

Section Summary

			EF	AR4 GWP_{100}	AR5 GWP_{100}	AR5 GWP_{100} with ccfb
Source	**Gas**	**Unit**	**kgGas / unit**	**$kgCO_2e$ / unit**	**$kgCO_2e$ / unit**	**$kgCO_2e$ / unit**
Discharge to aquatic environments (general)	CH_4	kgBOD	0.06875	1.7188	1.9250	2.3375
Discharge to aquatic environments other than reservoirs, lakes, and estuaries (more specific)	CH_4	kgBOD	0.021875	0.5469	0.6125	0.7438
Discharge to reservoirs, lakes and estuaries (more specific)	CH_4	kgBOD	0.11875	2.9688	3.3250	4.0375
Freshwater, estuarine, and marine discharge	N_2O	kgN	7.857 x 10-3	2.341	2.082	2.341
Nutrient-impacted and/or hypoxic freshwater, estuarine, and marine	N_2O	kgN	0.029857	8.897	7.912	8.897
Discharge to land	CH_4	kgBOD	0	0	0	0
	N_2O	kgN	0.011811	5.397	4.799	5.397

5.1. Discharge to waterways

METHANE

CH_4 generation can occur from residual organics in the wastewater effluent when discharged into freshwater, estuarine or marine environments. This is modulated by oxygen status of the receiving body (IPCC, 2019). Where wastewater is discharged to aquatic environments with nutrient-impacted/eutrophic conditions (i.e., water bodies that are rich in nutrients and very productive in terms of aquatic animal and plant life), the additional organic matter in the discharged wastewater is expected to increase CH_4 emissions as oxygen is depleted (IPCC, 2019). Most aquatic environments including rivers are supersaturated in CH_4. Nutrient oversupply will increase CH_4 emissions as eutrophication leads to low oxygen conditions. Environments where carbon accumulates in sediments have higher potential for CH_4 generation (IPCC, 2019).

For treated wastewater discharged to the environment, the following equation can be used to estimate CH_4 emissions (IPCC, 2019; Vol 5, Equation 6.1):

$$CH_{4\ discharge\ to\ environment} = TOW_{effluent} \times EF \quad [9]$$

Where:

$TOW_{effluent}$ = total organics in discharged effluent (kgBOD/yr); and
EF = emission factor for discharge ($kgCH_4$/kgBOD) (see Equation 3).

Some of the organic carbon associated with influent BOD to a plant is removed as sludge, whilst most of the BOD remainder is converted to CO_2, which is released to the atmosphere. Typically, a minor portion of the influent BOD remains as residual organics discharged in the effluent. The factor for total organics discharged in treated wastewater effluent is calculated (Equation 10, from IPCC, 2019; Vol 5 Eq.6.3D):

$$TOW_{effluent} = TOW \times (1 - TOW_{REM}) \quad [10]$$

Where:

$TOW_{effluent}$ = total organics in discharged effluent (kgBOD/yr);
TOW = total organically degradable material in municipal wastewater (kgBOD/yr);
TOW_{REM} = fraction of organics removed ($kgBOD_{removed}/kgBOD_{influent}$).

Default TOW_{REM} values are provided in Table 11 (IPCC, 2019; Vol 5; Table 6.6B).

Table 11: Fraction of organics removed (TOW_{REM}) by treatment plant type

Treatment type	**Default** ($kgBOD_{removed}/kgBOD_{influent}$)	**Range** ($kgBOD_{removed}/kgBOD_{influent}$)
Untreated system	0	0 – 0.1
Primary (mechanical)	0.40	0.25 – 0.50
Primary & secondary (biological treatment plants)	0.85	0.80 – 0.90
Primary & secondary & tertiary	0.90	0.80 – 0.98

The emission factor in Equation 9 is derived using an MCF, default factors for which are provided in Table 12.

Table 12: Emission factors from effluent discharge to water bodies

Type of treatment and discharge pathway or system	**MCF**	**EF ($kgCH_4/kgBOD$)**	**EF ($kgCH_4/kgCOD$)**
Discharge to aquatic environments (general)	0.11 (0.004 – 0.27)	0.0688	0.0275
Discharge to aquatic environments other than reservoirs, lakes, and estuaries (more specific)	0.035 (0.004 – 0.06)	0.0219	0.0088
Discharge to reservoirs, lakes and estuaries (more specific)	0.19 (0.08 – 0.27)	0.1188	0.0475

NITROUS OXIDE

The discharge of treated (or untreated) wastewater into the aquatic receiving environment leads to further N_2O emissions. These can be estimated using Equation 11:

$$N_2O_{Effluent} = N_{Effluent} \times EF_{Effluent} \times 44/28 \quad [11]$$

Where:

$N_2O_{effluent}$ = N_2O emissions (kgN_2O/yr);
$N_{effluent}$ = nitrogen in effluent discharged to environment (kgN/yr);
$EF_{effluent}$ = emission factor (kgN_2O-N/kgN).

The $N_{effluent}$ is the nitrogen concentration after treatment through a WWTP. Therefore a number of factors must be applied if an organisation only has influent nitrogen data, or population data. According to IPCC (2019), nitrogen removal by different treatment facilities can range from 10-85%. The default values include transfer to sludge and losses via nitrification-denitrification. The $N_{effluent}$ value is estimated according in Equation 12.

$$N_{Effluent} = TN_{Influent} \times (1 - N_{rem}) \quad [12]$$

Where:

$TN_{influent}$ = influent total nitrogen load (kgN/yr);
N_{REM} = fraction of nitrogen removed ($kgN/kgN_{influent}$).

Table 13 below can be used to estimate the $N_{effluent}$ for Level 1 assessments (based on IPCC 2019 Table 6.10c[5]; range applies expert judgement). Where an organisation has better data for the degree of nitrogen removal from wastewater treatment (via sludge, ammonia volatilization, nitrification/denitrification), then that should be used preferentially (Level 2).

These N_{REM} factors should be applied across the whole plant (i.e. one factor selected). They do not apply cumulatively. For example, the removal across a plant with an aeration basin followed by oxidation ponds, is estimated to be 0.4 in total.

Table 13: Wastewater treatment nitrogen removal fractions (N_{REM})[6] according to treatment type

Treatment type	**Default** ($kgN/kgN_{influent}$)	**Range** ($kgN/kgN_{influent}$)
No treatment	0	0
Primary (mechanical)[1]	0.10	0.05 – 0.20
Secondary (partial or intermittent nitrification)[2]	0.10	0 – 0.25
Secondary (non-BNR)[3]	0.40	0.35 – 0.55
Secondary (BNR)[4]	0.80	0.55 – 0.95

[1] For example, settlement and Imhoff tanks.
[2] For example, high rate activated sludge or trickling filters and similar suspended or fixed growth processes.
[3] For example, aerated ponds, oxidation ponds, trickling filters or rotating biological contactors.
[4] For example, suspended growth activated sludge, e.g. SBRs, MLE, Bardenpho, A2O, or hybrid processes MBBR, IFAS etc.

[5] The IPCC definitions from Table 6.10c have been taken as follows: i) Secondary biological = non-BNR secondary treatment and ii) Tertiary biological = BNR secondary treatment.
[6] Hauber (1995) for a range of NZ plants had an average N_{REM} of 30% (max of 77%). These are in the range of the IPCC factors so the IPCC are recommended for a Level 1 assessment.

The emission factor for effluent discharge from municipal wastewater treatment (Table 14) was updated in the recent IPCC methodology report (IPCC, 2019; Vol 5, Table 6.8A).

Table 14: Emission factors from discharged effluent

Type of treatment and discharge pathway or system	**Comments**	**EF[7]** **(kgN_2O-N/kgN)**	**Range** **(kgN_2O-N/kgN)**
Freshwater, estuarine, and marine discharge	Based on limited field data and on specific assumptions regarding the occurrence of nitrification and denitrification in rivers and estuaries	0.005	0.0005 – 0.075
Nutrient-impacted and/or hypoxic freshwater, estuarine, and marine environments	Higher emissions are associated with nutrient impacted/hypoxic water such as eutrophic lakes, estuaries and rivers, or locations where stagnant conditions occur	0.019	0.0041 – 0.091

For further guidance on the quality status of rivers and lakes in New Zealand, the LAWA website can be used (www.lawa.org.nz). The health of New Zealand lakes are assigned a Trophic Level Index (TLI), with '>4-5' (poor) being eutrophic and '>5' (very poor) being supertrophic. The status of river quality is also provided, assigned a State from A-D for different indicators (MfE, 2020b)(Appendix D).

5.2.Effluent discharge to land

Land disposal of effluent is commonplace in New Zealand (e.g. discharge to soil via soakaway trenches or similar; and irrigation). Land disposal is largely an aerobic process, but local conditions such as waterlogging, build up of organic matter, surface clogging, compaction of soils and presence of inhibitory substances can cause significant changes to the emission profile.

METHANE

When referencing the land disposal of septic tank effluent, the IPCC (2019) document states 'negligible [CH_4] emissions come from land disposal field'. The IPCC (2019) does not specifically mention release of CH_4 from treated wastewater applied to soils, and therefore it is not included in the calculation methodology[8].

If anaerobic storage occurs in ponds, prior to land disposal, CH_4 emissions may occur. If there is evidence of CH_4 generation then the methodology for sewage sludge storage (manure management) can be applied.

In contrast, there is specific guidance on the emissions of N_2O from wastewater disposed to soil (below).

[7] There is a large range in emission estimates reflecting diversity of catchment, water flows and chemistry affecting the EF. Clough (2013) estimated emissions from the Waikato river equal to 0.0005 kgN_2O-N/$kgN_{leached}$, and recommended a river factor of 0.0025 kgN_2O-N/$kgN_{leached}$ being appropriate for New Zealand. Combined with the emissions from estuaries, these emission factors align with those in the IPCC (2019). A literature review by Foley and Lant (2007) found a range of 0.0001 to 0.0014 kgN_2O-N/kgN discharged, with a median of 0.0003 kgN_2O-N/kgN discharged (n = 12 data points). For nutrient impacted waterbodies, this publication gave a range of 0.0003 to 0.0186 kgN_2O-N/kgN discharged, with a median of 0.0012 kgN_2O-N/kgN discharged (n = 15 data points).

[8] Table 6.8 of IPCC (2019; Vol 5), for industrial wastewater discharge to soil, recognises that wastewater might be a source of CH_4.

NITROUS OXIDE

In most soils, an increase in available N enhances nitrification and denitrification rates, which then increase the production of N_2O (IPCC, 2019). Residual organic nitrogen in wastewater can be a source of N_2O emissions when applied to land. This methodology is largely identical to the disposal of sewage sludge to land described later.

The IPCC methodology accounts for direct and indirect emissions of N_2O emissions from land application. Direct emissions occur at the point of application and indirect emissions occur by leaching / runoff or ammonia volatilisation. Country specific NZ factors are available for many of the factors, although these have not been derived specifically for sewage sludge. For the purposes of these guidelines, the effluent nitrogen applied is considered equivalent to a manure, assuming that the nitrogen applied can either be volatilised (as ammonia), leached from the soil or nitrified/ denitrified with a fraction released as N_2O.

Direct N_2O emissions are calculated using:

$$N_2O_{direct} = EF_1 . \times N_{app} . \times \frac{44}{28} \quad [13]$$

Where:

N_2O_{direct} = the direct N_2O emissions (kg/ yr);
EF_1 = emission factor for manure application (in kg N_2O-N/kg N applied);
N_{app} = nitrogen applied (kg TN/ yr);
44/28 = molar mass based conversion factor from N_2 to N_2O.

Indirect N_2O emissions are calculated as:

$$N_2O_{indirect} = (EF_4 . FRAC_{GASM} + EF_5 . FRAC_{LEACH} .) \times N_{app} \times \frac{44}{28} \quad [14]$$

Where:

$N_2O_{indirect}$ = indirect N_2O emissions (kg/yr);
EF_4 = emission factor for N_2O from volatilised N (in kg N_2O-N/kg $N_{volatilised}$)[9];
$FRAC_{GASM}$ = fraction of N in applied manure that volatilises (in kg $N_{volatilised}$/ kg$N_{applied}$);
EF_5 = emission factor for N_2O from leached N (in kg N_2O-N/kg $N_{leached}$);
$FRAC_{LEACH}$ = fraction of applied N that leaches (in kg $N_{leached}$/ kg$N_{applied}$).

Table 15 shows the recommended values to calculate N_2O emissions from land application (MfE, 2021).

Table 15: Parameter values used to estimate N_2O emissions from land application of treated effluent

Parameter	Value	Unit
EF_1	0.01	kg N_2O-N/kg $N_{applied}$
EF_4	0.010	kg N_2O-N/kg $N_{volatilised}$
EF_5	0.0075	kg N_2O-N/kg $N_{leached}$
$FRAC_{GASM}$	0.1	kg $N_{volatilised}$/ kg$N_{applied}$
$FRAC_{LEACH}$	0.07	kg $N_{leached}$/ kg$N_{applied}$
$EF_{combined}$ ($EF_1 + EF_4 * FRAC_{GASM} + EF_5 * FRAC_{LEACH}$)	0.011525	kg N_2O-N/kg $N_{applied}$

[9] EF_4 and EF_5 are terminology used in IPCC (2019) and have been retained, rather than numbering sequentially.

6. CONSTRUCTED WETLANDS

Section Summary

			EF	AR4 GWP_{100}	AR5 GWP_{100}	AR5 GWP_{100} with ccfb
Source	**Gas**	**Unit**	**kgGas / unit**	**$kgCO_2e$ / unit**	**$kgCO_2e$ / unit**	**$kgCO_2e$ / unit**
Surface flow (SF) wetland	CH_4	kgBOD	0.250	6.250	7.000	8.500
	N_2O	kgN	2.043×10^{-3}	0.609	0.541	0.609
Horizontal subsurface flow (HSSF) wetland	CH_4	kgBOD	0.0625	1.563	1.750	2.125
	N_2O	kgN	0.01241	3.700	3.290	3.700
Vertical subsurface flow (VSSF) wetland	CH_4	kgBOD	6.25×10^{-3}	0.156	0.175	0.213
	N_2O	kgN	3.61×10^{-4}	0.1077	0.0958	0.1077

INTRODUCTION

Constructed wetlands (alternatively known as 'man-made', 'engineered' or 'artificial' reedbeds) utilise natural processes within vegetation, soils and microbial activity to improve effluent quality. Both CH_4 and N_2O are considered by-products of wetlands. There are many environmental factors controlling GHG emissions from Wetlands, such as availability of carbon and nutrients (especially nitrogen), depending on loading, temperature, hydrological regime, groundwater depth, moisture of the filter material and presence and type of plant (IPCC, 2013).

Rates of biological activity in wetlands will be affected by seasonal temperature changes leading to decreasing performance in winter and by latitude. Emission estimates discussed in this section are annual average emissions.

METHANE

The emissions of CH_4 from wetlands are calculated as (adapted from IPCC, 2013; Ch.6, Equation 6.1):

$$CH_{4\,wetland} = (1 - R) \times TOW \times EF \quad [15]$$

Where:

$CH_{4\,wetland}$ = methane emissions from the wetland ($kgCH_4$/yr);
TOW = total BOD load in the WWTP raw influent (kgBOD/yr) – refer to Section 5.2.3;
R = BOD removal (fraction) in the treatment processes upstream of the wetlands (e.g. R = 0.9 for 90% removal upstream of a wetland used for tertiary treatment), based on BOD measurements or estimates;
EF = emission factor ($kgCH_4$/kgBOD) for CH_4 from wetland, relative to BOD load applied to the wetland.

The emission factor for wastewater treatment can then be determined using the following equation (IPCC, 2013; Ch 6, Equation 6.2):

$$EF = B_0 \times \mathrm{MCF} \quad [16]$$

Where:

B_0 = 0.625 $kgCH_4$/kgBOD (same as for domestic and municipal wastewater);
MCF = methane correction factor for wetland.

The MCF differs based on the type of constructed wetland used (Table 16).

Table 16: Methane correction factor for constructed wetlands

Wetland type	MCF	Range
Surface flow (SF)	0.4	0.08 – 0.7
Horizontal subsurface flow (HSSF)	0.1	0.07 – 0.13
Vertical subsurface flow (VSSF)	0.01	0.004 – 0.016

NITROUS OXIDE

The N_2O emissions from types of wetland can be estimated using Equation 17 and applying the factors in Table 17 (IPCC, 2013; Chapter 6; Table 6.7):

$$N_2O_{wetland} = N_{effluent} \times EF_{wetland} \times 44/28 \quad [17]$$

Where:

$N_2O_{wetland}$ = N_2O emissions from wetlands (kgN_2O/yr);
$N_{effluent}$ = nitrogen in effluent discharged to wetland (kgN/yr) (see Equation 9);
$EF_{wetland}$ = emission factor from wetland (kgN_2O-N/kgN).

Table 17: N_2O emission factors from constructed wetlands

Wetland type	$EF_{wetland}$ (kgN_2O-N/kgN)	Range (kgN_2O-N/kgN)
Surface flow (SF)	0.0013	0.00013 – 0.0025
Horizontal subsurface flow (HSSF)	0.0079	0.0017 - 0.0141
Vertical subsurface flow (VSSF)	0.00023	0.00007 – 0.00039

WETLAND TREATMENT PERFORMANCE

The removal of BOD and nitrogen by wetlands will influence any subsequent emissions from receiving waters after the wetlands. However, a typical removal performance is not provided in the IPCC documentation for wetlands. The type of wetland, its feed quality, size and loading are all significant features influencing performance, so generalisation on published data is not necessarily appropriate.

Surface flow wetlands will accumulate solids and due to the organic breakdown can denitrify, but will not nitrify if insufficient aerobic conditions exist. Accumulated sludge can produce CH_4. Horizontal subsurface beds will remove ammonia and can remove nitrates. These may eventually block and lead to high CH_4 production from the organic residues. Likewise, sludge buildup can occur over time in vertical flow wetlands. If they are managed to down flow at all times aerobic conditions can occur.

A New Zealand study on seven Waikato wetland sites saw a 59-84% BOD removal (72% average) and 17-33% TKN removal (22% average) (Environment Waikato, 2004). Finnemore et.al (2011) observed a 46% BOD removal and 40% total nitrogen removal in a wetland system. Primary data from a wetland should be used in preference.

Emissions of CH_4 and N_2O from the water bodies or land after wetlands should also be accounted for.

7. SLUDGE TREATMENT

Section Summary

			EF	AR4 GWP_{100}	AR5 GWP_{100}	AR5 GWP_{100} with ccfb
Source	**Gas**	**Unit**	**kgGas / unit**	**$kgCO_2e$ / unit**	**$kgCO_2e$ / unit**	**$kgCO_2e$ / unit**
Anaerobic digestion in high quality digester (1%MCF)	CH_4	tDS_{raw}	0.95	23.8	26.6	32.4
Anaerobic digestion in low quality digester (10%MCF)	CH_4	tDS_{raw}	9.5	238	266	324
Combustion of biogas	CH_4	m^3	1.99×10^{-5}	4.97×10^{-4}	5.57×10^{-4}	6.76×10^{-4}
Combustion of biogas	N_2O	m^3	1.99×10^{-6}	5.93×10^{-4}	5.27×10^{-4}	5.93×10^{-4}
Composting & vermicomposting	CH_4	tDS_{raw}	10	250	280	340
Composting & vermicomposting	N_2O	kgN	0.029857	8.90	7.91	8.90
Incineration	CH_4	tDS_{raw}	0.0097	0.243	0.272	0.330
Incineration	N_2O	tDS_{raw}	0.99	295	262	295

7.1.Background

SLUDGE TREATMENT IN NEW ZEALAND

Sludge treatment processes commonly used in New Zealand are listed below and may be used in combination with final disposal to landfill or land application:

- Anaerobic digestion;
- Composting;
- Vermicomposting;
- Incineration.

Incineration is generally not permitted in New Zealand for most wastes, but is used on a small scale for disposal of medical, quarantined, hazardous waste or sewage sludge (MfE, 2021). Aerobic digestion is used in New Zealand, however there is sparse data on GHG emissions from this process, it is currently a knowledge gap. Alternative technologies such as pyrolysis, gasification, plasma gasification, wet oxidation or hydrothermal carbonisation do not currently operate in New Zealand.

DATA REQUIREMENTS

The emissions calculation for sludge disposal, detailed in this section, is based upon the dry tonnes of the raw sludge (i.e., before sludge treatment). However, the data measured by organisations might be as wet tonnes, and either 'pre' or 'post' treatment. A conversion factor between raw and treated may be required to account for mass loss, which is dependent on the treatment applied.

The wet tonnes should be converted to dry tonnes using measured %TS content of sludge at each individual site. The %TS content can change depending on the composition and dewatering techniques used.

Default conversion factors from *treated sludge* TS to *raw sludge* TS are shown in Table 18. Site-specific conversion factors can be used instead, if performance characteristics are known for the sludge treatment system under consideration.

Table 18: Mass conversion factors for sludge

Parameter	Mass conversion factor from treated sludge TS to raw TS[2]	Assumptions
Raw sludge	n/a	Assumes 75% VS (UKWIR, 2016; Ogilvie, 1998; Andreoli, 2007)
Anaerobically Digested sludge	1.50943	Assumes 45% VS removal (UKWIR, 2016)
Thermally hydrolysed sludge	1.81818	Assumes 60% VS removal (UKWIR, 2016)
Composted sludge[3]	1.70213	Assumes 55% VS removal (UKWIR, 2016),
Vermicomposted sludge	1.70213	As for composted sludge
Septic tank sludge	1.66806	Assumes 89% VS (Rose, 2015) and 45% VS removal[1] (assumed same as digestion)

[1] May be highly variable depending on storage time and temperature.
[2] Raw sludge TS = treated sludge TS x mass conversion factor.
[3] Values do not comply to co-composted sludge i.e. mixed with green waste or other filler materials.

MAXIMUM METHANE POTENTIAL

The estimate of emissions from sludge treatment processes is based upon the maximum methane potential of sewage sludge ($B_{0\ sludge}$). This is similar to the approach undertaken for CH_4 emissions from wastewater. However, the IPCC documentation does not provide an explicit $B_{0\ sludge}$ value for sewage sludge. The advantage of using the 'B_0 approach' is that an estimation of the destruction of CH_4 potential through different sludge treatment processes can be made. This allows more flexibility in determining emissions. The estimate for $B_{0\ sludge}$ has been adapted from the UKWIR model[10] (UKWIR, 2016), the only difference using a value of 65% v/v CH_4 in biogas. This gives a $B_{0\ sludge}$ of 0.212 $kgCH_4/kgTS_{feed}$ or 0.282 $kgCH_4/kgVS_{feed}$, where TS is total (dry) solids and VS is volatile (dry) solids.

7.2.Anaerobic digestion

Anaerobic digestion (AD) is used to generate CH_4 from sewage sludge, which is combusted for heat or power generation. Fugitive, or unintended, emissions of CH_4 which escape from the process must be accounted for.

[10] The UKWIR $B_{0\ sludge}$ number is a derived value based on 75% VS, 65% VS destruction, 60% CH_4 in biogas, 0.668 $kgCH_4/m^3$ and 1.0$m^3_{biogas}/kgVS_{destroyed}$.

METHANE

Fugitive emissions can occur from leaks in the anaerobic digester (e.g. pressure relief valves, hydraulic seals, overflow pipes, annular space), inefficiencies in biogas capture and flaring systems, from the dewatering step or via return liquors. A range of estimates for the fugitive emissions can be found in the literature. However, the 2019 refinement to the IPCC guidance (IPCC, 2019) provided more detailed guidance on the likely emissions from anaerobic digesters than was available previously. The IPCC (2019) guidance distinguishes between digester type (Vol 4; Table 10.14), defined as follows:

- High quality biogas digesters – digesters are designed, constructed and operated according to industrial technology standard for waste stabilization. Biogas is captured and used as a fuel.
- Low quality biogas digesters – digesters used for waste stabilization, includes digestion in a covered anaerobic lagoon. Biogas is captured and flared or used as a fuel.

The MCF in Table 19 relate to both i) leakages from the digester and ii) emissions from the digestate during storage after digestion. The IPCC (2019) guidance distinguishes between 'high quality gastight storage of the digestate' and 'low quality gastight storage of the digestate', with different factors being applicable. Estimates of leakage rates, expressed as MCF, are provided in Table 19 (IPCC, 2019; Vol 4; Table 10A.11).

Table 19: MCFs for biogas digester and digestate storage

Biogas digester quality	**Conditions for digestate storage**	**Climate zone**	
		Cool Temperate	**Warm Temperate**
High quality biogas digester	High quality 'gastight' storage	0.0100	0.0100
	Low quality gas storage	0.0141	0.0141
	Open storage	0.0355	0.0438
	Average	0.0199	0.0227
Low quality biogas digester	High quality 'gastight' storage	0.0959	0.0959
	Low quality gas storage	0.1000	0.1000
	Open storage	0.1214	0.1297
	Average	0.1058	0.1085
The value of MCF for digestate storage is based on the MCF value of anaerobic lagoons.			

a. Under IPCC the climate zone for 'warm temperate' is when the mean annual temperature (MAT) >10°C. For 'cool temperate' region the MAT is 0°C – 10°C.

The method used to estimate fugitive CH_4 emissions applies a calculation as a function of the VS of waste material, $B_{0\,sludge}$, MCF and leakage rates. The average MCF is multiplied by the VS and the $B_{0\,sludge}$ of the waste material.

The CH_4 emissions from anaerobic digestion are calculated based on a percentage (MCF) of the overall biogas production. Where the biogas volume is metered and CH_4 concentration is known then Equation 18 applies.

$$CH_{4\,ad} = AD_{metha} \times MCF \quad [18]$$

Where:

$CH_{4\,ad}$ = fugitive CH_4 emissions from anaerobic digestor and digestate storage ($kgCH_4$/year);
$AD_{methane}$ = CH_4 in biogas generated during anaerobic digestion ($kgCH_4$/year);
MCF = methane conversion factor for anaerobic digestion (fraction).

If the volume of biogas is unknown then an estimate of the CH_4 production can be made using Equation 19:

$$AD_{methane} = VS \times B_{0\,sludge} \times VS_{destroyed} \times MCF \quad [19]$$

Where:

$AD_{methane}$ = fugitive CH_4 emissions from anaerobic digestor and digestate storage ($kgCH_4$/year);
VS = volatile solids (kgVS/year);
$B_{0\,sludge}$ = maximum methane potential of sewage sludge ($kgCH_4$/kgVS);
$VS_{destroyed}$ = 45% VS destroyed is default for conventional anaerobic digestion.

The default emissions factor for CH_4 from an anaerobic digester equates to 0.95 $kgCH_4/tDS_{raw}$ relative to the raw sludge total DS in the feed to the digester.. For the same assumptions but an MCF of 10% (for a low quality biogas digester), the emissions equate to 9.5 $kgCH_4/tDS_{raw}$ relative to the raw sludge TS in the feed to the digester.

The anaerobic digesters found on larger WWTPs in NZ are typically well-designed, contained systems. Where floating roofs are used instead of fixed roofs, these may have a higher leakage rate over time (e.g., through the annular space). However, leakage can occur from other parts of the digester.

NITROUS OXIDE

The 2019 IPCC update provides an emission factor for N_2O from anaerobic digestion of 0.0006 kgN_2O-N/kgN) (Vol 4, Chapter 10, Table 10.21). Previously the IPCC had judged the N_2O emission factor for sludge to be zero. A footnote in the 2019 guidelines states that the emissions mainly occur from the storage of the digestate. The waste section of the IPCC (2006) report assumes N_2O emissions from anaerobic digestion at biogas facilities to be negligible (IPCC 2006; Vol 5, Chapter 4, Table 4.1). In these guidelines, N_2O emissions from storage of digestate are accounted for under the land application section. The current recommendation is that N_2O emissions directly from anaerobic digestion on WWTP sites in New Zealand be considered negligible.

PRE-TREATMENT TO ANAEROBIC DIGESTION

Anaerobic digestion may incorporate a pre-treatment stage to increase CH_4 production. For example, thermal hydrolysis or acid phase digestion converts a greater percentage of volatile solids into CH_4, so gas yields are generally greater. Assuming the same MCF for biogas digester and digestate storage (see **Table 17**), this will equate to a greater quantity of fugitive CH_4 emissions from AD with pre-treatment, when applying a method using a percentage loss of total gas volume.

BIOGAS COMBUSTION & FLARING

Biogas production can be determined by several approaches, either measured data in m^3 determined at standard temperature and pressure (preferred) or estimated using 338 m^3_{biogas}/$tonneTS_{feed}$[11] (in lieu of better data).

Emission factors for the stationary combustion of biogas were derived from energy sector annual emission factors (MBIE, 2021). Calorific values (MJ/m^3) were sourced from the New Zealand Energy Information Handbook (CAENZ, 2008). These are shown in Table 20.

[11] Estimate based on 75% VS in raw sludge (typical 70-80%), 45% VS destroyed (typical 40-55%) and 1.0m^3/kg $VS_{destroyed}$ (typical 0.8-1.1 m^3/kg $VS_{destroyed}$) (Andreoli, 2007).

Table 20: GHG emissions from biogas combustion

Fuel combusted	kgCH_4 / m^3	kg N_2O / m^3	Comments
Combustion of biogas	1.99 x 10^{-5}	1.99 x 10^{-6}	Based on 0.9 tCH_4/PJ and 0.09 tN_2O/PJ (MBIE, 2021)

When biogas is flared, emissions of uncombusted CH_4 need to be estimated. The efficiency of the flare should be taken into account, where possible, to estimate the fugitive emissions from flaring. Equation 20 can be applied to calculate flaring emissions (Government of Alberta, 2020).

$$CH_{4\,flaring} = Vol.biogas_{flared} \times F_{CH4} \times \rho_{CH4} \times (1 - D_{CH}) \quad [20]$$

Where:

$CH_{4\,flaring}$ = fugitive CH_4 emissions from flaring (kgCH_4/year);
$Vol.biogas_{flared}$ = volume of biogas flared (m^3/year);
F_{CH4} = fraction of CH_4 in biogas (m^3_{CH4}/m^3_{biogas});
ρ_{CH4} = = density of CH_4 (kg/m^3);
D_{CH4} = destruction efficiency of combustion device (%) (obtained from vendor).

7.3.Composting

New Zealand has seen an increase in commercial-scale composting of solid waste in recent years (MfE, 2021). Many factors affect GHG emissions during traditional composting treatment, including moisture content, additives, bulking agent, temperature, pile scale, C/N ratio and aeration conditions (Czepiel, 1996; Szanto, 2007; Lv, 2018). Typically, 0.1 – 9.9% of nitrogen in compost can be released as N_2O, and 0.8–14% of the initial carbon can be converted to CH_4 (Jiang, 2018).

Maulini-Duran (2013) showed higher emissions of CH_4 and N_2O from in-vessel composting of digested sewage sludge, compared to in-vessel composting of raw sewage sludge. However, further studies are needed to determine whether a different emission factor is warranted for composting digested sludge.

There is no clear consensus on whether vermicomposting leads to higher or lower GHG emissions. A recent study with sewage sludge and rice straw showed higher N_2O emissions in vermicomposting compared to a control compost (Lv, 2018). Conversely, Wang (2014) showed lower N_2O and CH_4 emissions in vermicomposting of duck manure compared to composting. There is a knowledge gap on GHG emissions from vermicomposting as practiced in New Zealand.

Composting emission factors from 'waste' were not updated in IPCC (2019), so these revert to the IPCC (2006; Vol 5 Ch4) factors. Composting factors for 'animal manure' were updated in IPCC (2019; Vol 4, Ch10), however these are inconsistent with those reported under the 'waste' category. The IPCC chapter on wastewater clearly indicates that the 'waste' compost method be used; for consistency these are applied[12].

[12] IPCC, 2019; Vol 4, Ch10 uses a maximum methane potential (B_0) value for manure and applies a methane correction factor (0.5% to 2% depending on composting method and climate). The N_2O emission factor is split between composting treatment system types (e.g. static pile, in-vessel, windrow). Applying the 'manure composting' emission factors for CH_4 and N_2O (Vol 4, Ch10) would lead to lower emissions than those using the 'waste composting' factors (Vol 5, Ch4).

METHANE

The choice of emission factor for CH_4 from composting of waste is 0.01 $kgCH_4/kgTS_{feed}$ (IPCC, 2006; Vol 5 Ch4).

NITROUS OXIDE

The choice of emission factor for N_2O from composting of waste is 0.019 kgN_2O/kgN_{feed}.[13] Table 21 provides the factor in alternative units (IPCC, 2006; Vol 5 Ch4). They are considered appropriate for organic wastes such as food waste, garden (yard) and park waste and sludge.

Table 21: N_2O emission factors for composting of waste materials

	gN_2O / kg waste (wet wt)	**gN_2O / kgTS (dry wt)**	**kg N_2O-N / kg waste N**
Emission factor	0.24	0.6	0.019

7.4.Incineration

No incineration of wastewater sludge occurs in New Zealand (MfE, 2021). However, some industrial processes co-incinerate wastewater sludge.

METHANE & NITROUS OXIDE

Small quantities of CH_4 can be produced when the hydrocarbons in fuels are not completely combusted. N_2O is produced during fossil fuel combustion when nitrogen in the air or fuel is oxidized in the high temperature environment of the engine or incinerator.

CH_4 and N_2O factors are published for incineration of sewage sludge. The NIR (MfE, 2021) applies default emission factors from IPCC (2006). The emission factors for combustion of sewage sludge (MfE, 2021) are:

- CH_4 = 9.7 gCH_4/TSfeed;
- N_2O = 990 gN_2O/ TSfeed.

[13] This assumed 2% of N in total solids and a moisture content of 60%.

8. SLUDGE DISPOSAL

Section Summary

			EF	AR4 GWP_{100}	AR5 GWP_{100}	AR5 GWP_{100} with ccfb
Source	**Gas**	**Unit**	**kgGas / unit**	**$kgCO_2e$ / unit**	**$kgCO_2e$ / unit**	**$kgCO_2e$ / unit**
Landfill disposal raw sludge	CH_4	tDS_{raw}	45.42	1135.44	1271.69	1544.20
Landfill disposal treated sludge	CH_4	$tDS_{treated}$	27.25	681.26	763.02	926.52
Land application	N_2O	kg N	0.01811	5.397	4.799	5.397
Land application digested sludge (temperate, daily spread)	CH_4	tDS_{raw}	0.582	14.55	16.3	19.79
Land application digested sludge (temperate, stored)	CH_4	tDS_{raw}	4.66	116	130	158
Land application digested sludge	N_2O	tDS_{raw}	0.445	133	118	133
Land application composted sludge (temperate, daily spread)	CH_4	tDS_{raw}	0.47626	11.91	13.34	16.19
Land application composted sludge (temperate, stored)	CH_4	tDS_{raw}	3.8101	95.25	106.7	129.54
Land application composted sludge	N_2O	tDS_{raw}	0.216863	64.63	57.47	64.63

* EFs based on default nitrogen content

Emissions from disposal of treated sludge (e.g. composted or anaerobically digested) may occur as a Scope 1 emission (on owned land) or Scope 3 emission (on non-owned land). Sludge disposal in New Zealand is typically by landfill or land application.

8.1.Landfill disposal

The majority of sewage sludge in New Zealand is disposed to landfill (MfE, 2021). For a council operation, these will typically be captured under its solid waste reporting. Where a dedicated private landfill is used, GHG emissions from the landfill need to be reported.

METHANE

The IPCC and NZ Inventory use a first-order decay model[14] to calculate emissions of CH_4 from landfill. Emissions will occur from multiple years as the organic matter decays. This approach can be taken, although an alternative is to estimate CH_4 emissions assuming that the total CH_4 potential is achieved in a single year (MfE, 2020; MfE, 2021) (Equation 21).

[14]An excel calculator is available on the IPCC website www.ipcc-nggip.iges.or.jp/public/2019rf/vol5.html

$$CH_{4\,landfill} = DOC \times DOC_f \times F \times MCF \times \frac{16}{12} \times (1 - R) \times (1 - Ox) \quad [21]$$

Where:

$CH_{4\,landfill}$ = CH_4 emissions from landfill ($kgCH_4/kgTS$);
DOC = degradable organic carbon (kgDOC/kgTS);
DOC_f = fraction of DOC that can decompose;
F = fraction of CH_4 (by volume) in generated landfill gas;
16/12 = molecular weight ratio of CH_4/C;
MCF = CH_4 correction factor for aerobic decomposition (=1 for managed landfills);
R = recovery efficiency (fraction);
Ox = oxidation fraction.

The annual emissions from landfill can then be calculated according to Equation 22.

$$CH_{4\,landfill} = kg\,TS \times EF_{landfill} \quad [22]$$

Where:

$CH_{4\,landfill}$ = CH_4 emissions from landfill ($kgCH_4$/year);
kgTS = kg total dry solids.

The composition of sludge residue will depend on the treatment processes employed onsite. In the IPCC (2019) refinement, the DOC was estimated as a multiplication of the carbon content and volatile suspended solids (VSS) [15] fraction of the sludge. As a sense-check, applying the VS destruction values for the sludge treatment processes (composting, vermicomposting, anaerobic digestion, thermal hydrolysis), and assuming 50% of the TS is carbon, the DOC of treated sludge is estimated to range from 0.28 to 0.35. This is consistent with the DOC values for treated sludge from IPCC (2019). For landfill disposal the default IPCC values for DOC are recommended. However, site specific determination of DOC is recommended where possible.

Default parameters for estimation of CH_4 emissions from landfill are provided in Table 22.

[15] *"In this refinement, the DOC in sludge was estimated as multiplication of carbon content and volatile suspended solids fraction of sludge. It is assumed, that volatile suspended solids fraction is equivalent to degradable organics in sludge. This approach is applicable to sludge mainly from industrial activities, where carbon is evenly distributed in the sludge. In case of sludge from wastewater treatment, which consists from inorganic and organic fraction, majority of carbon is concentrated in organic fraction and therefore DOC of sewage sludge is equivalent to total carbon content" (IPCC, 2019).* Total carbon content of treated sludge is given as 31% of TS (± 27%) (IPCC, 2019). The total carbon value is blank for untreated sludge. Volatile suspended solids (VSS) measurement of biosolids can be problematic, so for simplicity the VSS can be estimated using the proxy of a volatile solids (VS) measurement.

Table 22: Parameter values used to estimate CH_4 emissions from sludge deposited in landfill

Parameter	Value	Units	Reference
DOC (Raw sludge)	0.5 (0.37 – 0.64)	kgDOC/kgTS	IPCC (2019; Vol 5, Table 2.4A)
DOC (Treated sludge)	0.3 (0.12 – 0.48)	kgDOC/kgTS	IPCC (2019; Vol 5, Table 2.4A)
DOC_f	0.5 (0.40 – 0.60)	$kgDOC_f$/kgDOC	IPCC (2019; Vol 5, Table 3.0)
F	0.57 (0.54 – 0.60)	fraction	MfE (2021; Table 7.2.7)
R	0.7344 (0.66 – 0.81)	fraction gas	MfE (2020)
Ox	0.1	fraction	IPCC (2019; Vol 5, Table 3.2)

Note: the 'R' value may change annually and the latest MfE value should be used when this occurs.

To express the CH_4 emissions from treated landfill sludge on a raw sludge basis then the factors in Table 18 can be applied.

8.2.Land application

Emissions of N_2O and CH_4 can occur from the disposal of residual solids to land. Emission estimates of N_2O from land are based on the nitrogen concentration of the treated sludge. Default values are derived from literature (Table 23). These values should be substituted if better data is available.

Table 23: Sludge nitrogen concentrations

Sludge type	Default nitrogen content (kgN/kgDS)	Source
Primary sludge	0.023[₮] (0.016 – 0.027) 0.025 (0.014 – 0.040)	Ogilvie (1998) Metcalf & Eddy (2003)
Waste activated sludge	0.07 (0.06 to 0.08)	WRC (1984)
Digested sludge[b]	0.042 (0.018 - 0.066) 0.031[₮] (0.017 – 0.040) 0.030[a] (0.016-0.030)	IPCC (2019), Vol 5, Tbl 2.4A Ogilvie (1998) Metcalf & Eddy (2003)
Thermally hydrolysed sludge	As for digested sludge	As for digested sludge
Composted sludge	0.018[₮]	UKWIR (2016)
Vermicomposted sludge	As for composting	As for composting
Pond sediment (removed)	0.022[₮] (0.003 – 0.054) 0.020	Ogilvie (1998) Von Sperling (2007)
Dried sludge	0.059 (0.027 – 0.081)	ECN (2021)

[₮] Preferred default; [a] Digested primary sludge; [b] co-digested sludge (primary & secondary) may have higher TN values.

METHANE

Emissions of CH_4 can occur from the organic residues when spread on land. This is dependent on the residual volatile solids present after treatment. The CH_4 emissions from land application are calculated as:

$$CH_4 = VS \times B_{0\ sludge} \times MCF \quad [23]$$

Where:

CH_4 = methane emitted ($kgCH_4/yr$);
VS = volatile solids applied to land (kgVS/yr);
$B_{0\ sludge}$ = maximum methane production potential (kg CH_4/kg VS) of sewage sludge; (Section 7.2) MCF = methane conversion factor (as a fraction).

IPCC (2019, vol. 4, Table 10.17) gives an MCF for daily spreading of 0.001 (0.1%) and 0.005 (0.5%) in cool and temperate climate respectively. This assumes spreading within 24 hours, so where there is extended storage an MCF of 0.02 (2%) or 0.04 (4%) should be used, in cool and temperate climates respectively. This refers to storage of solids, the IPCC guidance should be sourced if emissions from liquid storage is required.

CH_4 emissions from the land application of sludge for the different scenarios are provided in Table 24.

Table 24: CH_4 emissions from land application of treated sludge ($kgCH_4$ / tDS_{feed})

Parameter	Daily spread / cool climate	Daily spread / temperate climate	Stored / cool climate	Stored / temperate climate
Raw sludge	-	-	-	-
Digested sludge	0.11642	0.58210	2.32840	4.65680
Thermally hydrolysed sludge	0.08467	0.42335	1.69338	3.38676
Composted sludge	0.09525	0.47626	1.90505	3.81011
Vermi-composted sludge	0.09525	0.47626	1.90505	3.81011

Note: Table value relate to default assumptions of 75% VS in raw sludge. 45% $VS_{destroyed}$ in AD, 60% $VS_{destroyed}$ in THP, 55% $VS_{destroyed}$ in composting, 55% $VS_{destroyed}$ in vermicomposting.

NITROUS OXIDE

The IPCC methodology accounts for direct and indirect emissions of N_2O emissions from land application. Direct emissions occur at the point of application and indirect emissions occur by leaching / runoff or ammonia volatilisation. Country specific NZ factors are available for some of the factors.

Direct N_2O emissions are calculated using:

$$N_2O_{direct} = EF_1 . \times N_{app} . \times 44/28 \quad [24]$$

Where:

N_2O_{direct} = direct N_2O emissions for sludge application to land (kg/yr as N_2O);
EF_1 = emission factor for fertiliser application (in kg N_2O-N/kg N applied);
44/28 = molar mass based conversion factor from N to N_2O.
N_{app} = nitrogen component of the sludge applied to land (kgN/yr) derived from the dry solids of sludge applied (kgTS/yr), multiplied by the appropriate nitrogen content (kgN/kgTS) from Table 23.

Indirect N_2O emissions are calculated as:

$$N_2O_{indirect} = (EF_4.FRAC_{GASM} + EF_5.FRAC_{LEACH}.) \times N_{app} \times \frac{44}{28} \quad [25]$$

Where:

$N_2O_{indirect}$ = indirect N_2O emissions for sludge application to land (kg/yr as N_2O);
EF_4 = emission factor for N_2O from volatilised N (in kg N_2O-N/kg $N_{volatilised}$);
$FRAC_{GASM}$ = fraction of N in applied manure that volatilises;
EF_5 =emission factor for N_2O from leached N (in kg N_2O-N/kg $N_{volatilised}$);
$FRAC_{LEACH}$ = fraction of applied N that leaches.
N_{app} = nitrogen component of the sludge applied to land (kgN/yr) derived from the dry solids of sludge applied (kgTS/yr), multiplied by the appropriate nitrogen content (kgN/kgTS) from Table 23.

The New Zealand factors in Table 15 apply to N_2O emissions from land application (MfE, 2021). Therefore the overall combined emission factor for N_2O from land application of sludge is 0.01811 kg N_2O/kg $N_{applied}$.

9. ONSITE TREATMENT

Section Summary

			EF	AR4 GWP_{100}	AR5 GWP_{100}	AR5 GWP_{100} with ccfb
Source	**Gas**	**Unit**	**kgGas / unit**	**$kgCO_2e$ / unit**	**$kgCO_2e$ / unit**	**$kgCO_2e$ / unit**
Onsite containment tank	CH_4	Person /year	0.320	8.00	8.96	10.88
Onsite containment tank	N_2O	Person /year	0.115	34.27	30.48	34.27
Onsite septic tank & land dispersal	CH_4	Person /year	5.995	149.9	167.9	203.8
Onsite septic tank & land dispersal	N_2O	Person /year	0.085	25.30	22.50	25.30

*Values are summary for all stages of treatment of septic tank waste.

The use of septic tanks is still widespread in New Zealand, being used by many organisations and households. About 270,000 on-site domestic wastewater systems are in use in New Zealand (MfE, 2008), which with typical occupancy of 2.5 people per property, is a population of 675,000 people. Using AR5 GWP_{100} combined total this is an emission of over 115,222 tCO_2e per year.

This section provides guidance to organisations which own or operate septic tanks or containment tanks, to calculate GHG emissions from these systems. This provides additional guidance over that given in previous sections which focussed on centralised municipal wastewater treatment. For providers of centralised wastewater treatment facilities the septic tank sludge should be included in the load calculations, and the calculations outlined in the previous Sections should be applied.

IPCC (2019) provides guidance for emissions of CH_4 and N_2O from septic tanks.

9.1. Population served

The population using the septic tank is used as the basis for estimating emissions. For a static population, this is usually straightforward. For sites with a transitory population, such as those associated with tourism, the population might need to be estimated in a different way. In this case, the average users per day, rather than the total individuals over the year, can be used as a proxy for the population served.

9.2. Sludge removed

The mass of sludge removed from a septic tank can sometimes be provided by the organisation contracted to remove the sludge. This might be the only data available with which to estimate the usage of a septic tank. Since population numbers form the basis of the septic tank emission estimates, a conversion factor from tonnage removed to population served is required.

Equation 26 provides an approach to estimate the population served from tonnage. Septic tank sludge typically has a dry solids content of 3-6% (Andreoli et.al. 2007).

$$Pop_{septic} = S_{wet}.\times 0.045 \times 1.66806 \times \frac{1}{0.020} \quad [26]$$

Where:

Pop_{septic} = population served by septic tank;
S_{wet} = wet tonnes (or m^3) of septic sludge removed per year;
0.045 = dry solids content of septic tank sludge, average 4.5% TS (w/v) from Andreoli et.al. (2007);
1.66806 = Conversion from treated dry weight to raw dry weight (Table 18);
0.020 = tonnes of total suspended solids per person per year - based on 55gTSS/person/day the mid-range (35-75 g/person/day) from USEPA (2002).

9.3.Septic & containment tanks

Septic tanks have GHG emissions from three sources:

1. Onsite (CH_4 from anaerobic activity);
2. Land disposal if used (N_2O from effluent nitrogen);
3. Third party treatment of effluent / sludge.

Containment tanks do not use an onsite land dispersion field; all the volume is contained within the tank and periodically removed for treatment.

ONSITE EMISSIONS

In these guidelines, onsite CH_4 emissions are assumed to not occur in containment tanks, which may be emptied regularly. Emissions of CH_4 from onsite treatment such as septic tanks are estimated using Equation 27 (derived from the IPCC 2019; Vol 5; Eq.6.1):

$$CH_4 = TOW_{septic} \times Pop_{septic} \times (1 - 0.5) \times B_0 \times MCF_{septic} \quad [27]$$

Where:

CH_4 = emissions of CH_4 from septic tank (kg CH_4/yr);
TOW_{septic} = total organics disposed to septic system inlet (37 kg BOD/person/yr) (Section 3.3);
Pop_{septic} = population served by septic tank;
0.5 = fraction of organics in wastewater removed in sludge when septic tank is managed in accordance with sludge removal instructions;
B_0 = maximum CH_4 producing capacity for wastewater (0.625 kgCH_4/kgBOD – MfE, 2021);
MCF_{septic} = methane correction factor for septic tank (0.5 – IPCC, 2019 Vol 5; Table 6.3).

LAND DISPOSAL

N_2O emissions from land disposal of septic tank effluent are considered. As an approximation, a fraction of all TN load to the septic tank is assumed to be emitted as N_2O. A minor portion of the total nitrogen might be incorporated in the sludge removed periodically for separate disposal from the effluent, however this is ignored as an approximation in Equation 28.

The N_2O emissions from effluent land disposal from septic tanks can be calculated according to Equation 28 (derived from the IPCC 2019; Vol 5; Eq.6.9):

$$N_2O_{septic} = TN_{septic} \times Pop_{septic} \times EF_{N2O} \times \frac{44}{28} \quad [28]$$

Where:

N_2O_{septic} = N_2O emissions from septic tank and land disposal of effluent, kg N_2O/yr;
TN_{septic} = total nitrogen in septic system (5.5 kg N/person/yr) (Section 3.3);
Pop_{septic} = population served by septic tank;
EF_{N2O} = emission factor for septic tanks and land disposal of effluent (0.0045 kgN_2O-N/kg N);
44/28 = conversion factor N_2O-N to N_2O.

THIRD PARTY SLUDGE TREATMENT

Following desludging, the sludge might be treated at a local WWTP. It is assumed that the septic tank sludge is added to the inlet works and becomes part of the wastewater stream. The subsequent GHG emissions from septic tank sludge processing through wastewater treatment should be included. The emissions from transportation can be optionally included in the assessment, but are outside the scope of these guidelines (refer to Section 2.1). Likewise, energy used to process the sludge at the WWTP is excluded here (see Section 2.1).

If the WWTP is known and can provide a GHG emission factor (on a per capita basis) for the plant then this can be applied. If the WWTP destination is unknown, or the plant-specific GHG emission factor, is unknown then generic factors in Table 25 for third party treatment of septic tank sludge can be used.

Table 25: Generic emission factors for treatment scenarios applicable to third party treatment of septic tank sludge

WWTP Scenario	**Septic tank sludge[1] ($kgCH_4$ / cap / year)**	**Septic tank sludge (kgN_2O / cap / year**	**Containment tank sludge[2] ($kgCH_4$ / cap / year)**	**Containment tank sludge (kgN_2O / cap / year)**
Primary settlement – trickling filter – landfill - river	0.335	0.046	0.562	0.115
Screened -> extended aeration -> landfill -> river	0.335	0.046	0.562	0.115
Primary settlement – activated sludge – anaerobic digestion – landfill -river	0.214	0.046	0.320	0.115
Anaerobic pond (uncovered, no biogas collection/combustion) – facultative pond - river	3.65	0.042	7.19	0.042
Facultative pond – aerated lagoon - river	0.316	0.042	0.525	0.042

1 Estimated to have equivalent of 0.265 kgN/person/year and 7.086 kgBOD/person/year.

2 Estimated to have equivalent of 4.675 kgN/person/year (assumes 15% loss of N as ammonia) and 14.17 kgBOD/person/year (assumed twice the septic tank load).

OVERALL EMISSIONS

Based on the different emission sources the per capita GHG emissions are summarised in Table 26. The default third party treatment of an activated sludge plant with anaerobic digestion is used.

Table 26: Per capita emissions per year from onsite treatment

Emission source	**Onsite ($kgCH_4$ /cap/yr)**	**Land effluent disposal (kgN_2O / cap/yr)**	**3rd party sludge disposal ($kgCH_4$ / cap/ yr)**	**3rd party sludge disposal (kgN_2O / cap/ yr)**	**Total CH_4 ($kgCH_4$ / cap/yr)**	**Total N_2O (kgN_2O / cap/ yr)**
Containment tank	0	0	0.320	0.115	0.320	0.115
Septic tank & land disposal of effluent	5.781 ok	0.0389	0.214	0.046	5.995	0.085

There is no distinction in the IPCC guidelines for GHG emissions dependent upon climate region or season. All emissions from septic tanks across all regions are therefore treated equally.

9.4.Advanced onsite treatment

Other than septic tanks, more advanced systems for onsite wastewater treatment might be used by communities that don't have access to centralised sewerage collection and treatment systems. This could include systems that incorporate an aeration stage or membranes, potentially alongside or following a septic tank compartment.

The IPCC (2019) provides no guidance on emissions from these types of systems. There will likely be additional release of N_2O on-site with an aerated system. For operators of these systems, a GHG emission estimate can be made using a combination of the factors in the sections on 'onsite treatment' and 'municipal wastewater treatment', as appropriate to the system.

10. UNCERTAINTY ASSESSMENT

There are many sources of uncertainty, which can be particularly high for the wastewater sector. Both activity data and emission factors have uncertainty associated with them. The more generic data is used in the calculations the higher is the uncertainty in the results. Uncertainty should be able to be reduced by using primary data in the methods.

Many estimates of uncertainty, for individual factors, are provided in the IPCC methodology documents. The IPCC recommends, and reports, a 95% confidence interval as a definition of the range (IPCC, 2000):

> "This statement indicates that the confidence interval is specified by the confidence limits defined by the 2.5 percentile and 97.5 percentile of the cumulative distribution function of the estimated quantity. Put another way, the range of an uncertain quantity within an inventory should be expressed such that: (i) there is a 95% probability that the actual value of the quantity estimated is within the interval defined by the confidence limits, and (ii) it is equally likely that the actual value, should it be outside the range quoted, lies above or below it."

The uncertainties for individual components are provided in Table *27*.

Table 27: Uncertainty range for individual factors

Component	Value	Units	Range	Uncertainty range (±)	Uncertainty reference
Human population	-		-	5%	IPCC (2019) Table 6.7
BOD (default)	37	kg/p/yr	-	30%	IPCC (2019) Table 6.7
COD (default)	52	kg/p/yr		30%	IPCC (2019) Table 6.7
Total nitrogen (default)	5.5	kg/p/yr	3.3 - 9.5	72%	Ogilvie (1998)
Maximum CH_4 capacity (Bo) WWTP	0.625	kg/kg	-	30%	IPCC (2019) Table 6.7
MCF WWTP lagoons	0.2	kg/kg	0 – 0.3	30%	IPCC (2019) Table 6.7
MCF WWTP centralised plant	0.03	kg/kg	0.003 – 0.09	10%	IPCC (2019) Table 6.7
MCF facultative lagoon	0.2	kg/kg	0 – 0.3	30%	IPCC (2019) Table 6.7
MCF anaerobic lagoon	0.8	kg/kg	0.8 – 1.0	25%	IPCC (2019) Table 6.3
EF_{plant} N_2O BNR/non-BNR	0.01	kg/kg	0.00002 – 0.044	90%	MfE (2021),Table 7.5.16
EF_{plant} N_2O treatment pond	0.01	kg/kg	0.00002 – 0.044	90%	MfE (2021),Table 7.5.16
EF_{plant} N_2O pond	0	kg/kg	0 – 0.001	-	IPCC (2019) Table 6A.4
MCF discharge rivers	0.035	kg/kg	0.004 – 0.06	89%	IPCC (2019) Table 6.8
MCF discharge lakes	0.19	kg/kg	0.08 – 0.27	58%	IPCC (2019) Table 6.8
EF N_2O aqueous discharge	0.005	kg/kg	0.0005-0.075	90%	MfE (2021),Table 7.5.16
EF N_2O aqueous nutrient ltd	0.019	kg/kg	0.0041-0.091	90%	MfE (2021),Table 7.5.16
Krem primary	0.5	kg/kg	0.4-0.6	25%	IPCC (2019) Table 6.7
Krem aerobic	0.8	kg/kg	0.65-0.95	25%	IPCC (2019) Table 6.7
Krem aerobic & AD	1	kg/kg	0.8-1.2	25%	IPCC (2019) Table 6.7
Krem no primary	1.16	kg/kg	1.0-1.5	25%	IPCC (2019) Table 6.7

Component	Value	Units	Range	Uncertainty range (±)	Uncertainty reference
Amount sludge removed (Smass)	-	kg	-	30%	IPCC (2019) Table 6.7
TOW_{REM} untreated	0	kg/kg	0-0.1		IPCC (2019) Table 6.6B
TOW_{REM} primary	0.4	kg/kg	0.25-0.50	38%	IPCC (2019) Table 6.6B
TOW primary & secondary	0.85	kg/kg	0.80-0.90	6%	IPCC (2019) Table 6.6B
TOW_{REM} primary, secondary, tertiary	0.9	kg/kg	0.80-0.95	11%	IPCC (2019) Table 6.6B
N_{REM} primary	0.1	kg/kg	0.05-0.20	100%	IPCC (2019) Table 6.10c
N_{REM} secondary	0.4	kg/kg	0.35-0.55	38%	IPCC (2019) Table 6.10c
N_{REM} tertiary	0.8	kg/kg	0.55-0.95	30%	expert judgement
EF N_2O from land	0.0115	kg/kg	-	55%	MfE (2021)
MCF wetland SF	0.4	kg/kg	0.08-0.7	79%	IPPC (2013) Table 6.5
MCF wetland HSSF	0.1	kg/kg	0.07-0.13	31%	IPPC (2013) Table 6.5
MCF wetland VSSF	0.01	kg/kg	0.004-0.016	56%	IPPC (2013) Table 6.5
EF N_2O wetland SF	0.0013	kg/kg		90%	IPPC (2013) Table 6.7
EF N_2O wetland HSSF	0.0079	kg/kg		79%	IPPC (2013) Table 6.7
EF N_2O wetland VSSF	0.00023	kg/kg		70%	IPPC (2013) Table 6.7
BOD removal wetlands	72%	%	46-84	40%	Environment Waikato, 2004
N removal wetlands	22%	%	17-40	60%	Environment Waikato 2004
B_0 sludge	0.212	kg/kgTS	-	15%	IPCC (2019) v4, Table 10.16
B_0 sludge	0.282	kg/kgVS		15%	IPCC (2019) v4, Table 10.16
CH_4 composting	10	kg/tDS	-	100%	MfE (2021), s7.3.3
N_2O composting	0.6	kg/tDS	-	150%	MfE (2021), s7.3.3
CH_4 anaerobic digestion	2	kg/tDS	0-20	900%	IPCC (2019) Table 4.1
CH_4 incineration	9.7	kg/t	-	100%	MfE (2021) Table 7.4.6
N_2O incineration	0.9	kg/t	-	100%	MfE (2021) Table 7.4.6
CH_4 EF treated sludge to land (MCF x B_0)	Table 24	kg/tDS		34%	IPCC (2019) v4, s10.4.4 & Table 10.16
EF landfill raw	45.4176	kg/tDS	-	40%	MfE (2021), s7.2.3
EF landfill treated	27.25056	kg/tDS	-	40%	MfE (2021), s7.2.3
N content raw sludge	0.023	t/tDS		53%	Ogilvie (1998)
N content AD sludge	0.031	t/tDS		86%	Ogilvie (1998)
N content THP sludge	0.031	t/tDS		86%	as for AD sludge
N content compost sludge	0.018	t/tDS		100%	UKWIR 2016
N content vermisludge	0.018	t/tDS		100%	UKWIR 2016
CH_4 containment tank	0.32	cap/yr		40%	MfE (2021),Table 7.5.16
N_2O containment tank	0.115	cap/yr		90%	MfE (2021),Table 7.5.16
CH_4 Onsite septic tank	5.995	cap/yr		40%	MfE (2021),Table 7.5.16
N_2O Onsite septic tank	0.086	cap/yr		90%	MfE (2021),Table 7.5.16

11. KNOWLEDGE GAPS

Through the development of these guidelines, knowledge gaps were identified which could not be addressed immediately. These are areas that need further research or evidence to refine the measurement methodology or emission factors. These are identified for consideration by the wider industry in the future.

Table 28: Identified knowledge gaps

Item	Subject	Description of knowledge gap
Calculator		
1	Calculation tool	A calculator was not developed as part of this study, but would be beneficial for the sector to have a calculator that links with these guidelines. It would provide a common implementation.
Unquantified GHG sources		
2	Fraction of influent which is fossil carbon	Currently this is assumed to be '0', but is unknown in NZ. Fossil carbon in the influent would count towards the carbon footprint when converted to CO_2. Further work is recommended to better ascertain the fraction and its relative biodegradability.
3	Sewer CH_4	IPCC refers to this, but it is excluded. Some allowance is made in the WWTP EF. It is likely to be quite significant according to an Australian Research Council project seeking funding. Further research is recommended to measure, quantify or model in NZ sewer networks.
N_2O emission factors		
4	N_2O from WWTPs	Recent research indicates that a variable EF for N_2O from WWTP aligns with data. Selecting a single EF (as in these guidelines) is not ideal. Further evidence of this proposed relationship could allow a more accurate, process specific EF to be adopted. It may also help influence future capital expenditure decisions. Further research and data collection is recommended.
5	N_2O from WWTPs	N_2O plant emissions are influenced by operational conditions and parameters. Guidance describing operational influences and mitigation could influence process control options.
6	N_2O from non-BNR plants (i.e. BOD only removal plants)	For plants which remove BOD only, the emission factor for N_2O could be lower. However, pathways for N_2O production are still likely present in non-BNR plants. More research is required to develop individual factors for different plant types.
7	N_2O EF from process models	A detailed review of the suitability, applicability and limitations is needed. For instance, are the process models available (e.g. Biowin)? Are they sufficiently predictive? For different plant types? For the complexity of how plants are operated?
8	Receiving environments EFs	Specific emission factors for NZ receiving environments. Some research is underway for NZ rivers, but more is needed.
Treatment systems relevant to NZ		
9	Onsite treatment systems	GHG emissions from small onsite treatment systems are uncertain and there are a range of systems used in NZ, not covered by the IPCC guidance. Given the number of onsite systems in NZ, more work is necessary. Further work to quantify emissions from these systems is recommended.
10	Wetlands	It is unclear whether the IPCC EFs for CH_4 and N_2O are meant to be used for wetlands that are used as tertiary systems (which is common in NZ). Further research into the emission factors is needed. There are some differences to Foley's (2010) review e.g. VSSF looks low forN_2O. Processes in wetlands are potentially complex to model.Additional

Item	Subject	Description of knowledge gap
		BOD inputs occur which makes it difficult to determine how much of the CH_4 release is attributable to wastewater-derived BOD.
11	Ponds - Fixation of CO_2 by algae in ponds	Measurement of BOD in effluent where significant algal growth has occurred will also include the carbon assimilated by algae, and therefore not reflect the influent BOD removed through typical pond treatment processes. The same could apply where significant algal content is removed in the solids stream. More research is needed to better understand the complexity here.
Composition data		
12	Maximum methane potential (B_0) of wastewater	B_0 of wastewater heavily influences the CH_4 emissions. This could be better established experimentally in NZ, and would provide a more refined measurement.
13	Maximum methane potential (B_0) of sewage sludge	B_0 of sewage sludge influences the CH_4 emissions from all the sludge treatment and disposal processes in the guidelines. Refining this value through experimental data.
14	Degradable component of sludges and screenings	Opportunity to improve knowledge in this space. Could link up with Rob Tinholt and Cass in this space.
15	BOD degradability	Data on how the degradability of BOD and CH_4 potential changes through wastewater treatment processes.
16	Landfill emissions	Questions around IPCC values for sludge to landfill. DOC and DOCf values for different sludge types are not well described in the default methods available. It is not obvious how these are derived experimentally. Further work with waste industry to determine better values.
IPCC methodology		
17	CH_4 emissions for combined process plants	In lieu of interstage BOD and sludge data, whole of plant EFs for CH_4 are required. Research into what this should be for various combinations of processes would aid in this.
18	K_{rem} (sludge removal)	The guidelines proposes using the IPCC K_{rem} method at this stage (despite its challenges). Knowledge of BOD removal in the sludge mass is highly uncertain and highly unlikely to be measured. A COD mass balance approach is an alternative (particularly for plants without AD, as it makes the COD mass balance easier). Future area of interrogation or research could be to back calculate values from COD based models to verify or otherwise the suitability of K_{rem} for NZ example treatment processes.
19	CH_4 emissions	Methane correction factors (MCF) based on BOD removal would align with the 'sequential stages' method adopted in these guidelines. The potential for an alternative approach to more accurately account for CH_4 emissions from aerobic plants (whole plant EFs used currently, where is methanogensis occurring), as well as anaerobic and facultative ponds should be considered.
Anaerobic digestion		
20	Leakage rates from anaerobic digesters	IPCC defaults may not be representative of the actual leakage rates from anaerobic digesters in New Zealand.
21	CH_4supersaturation	Supersaturation in digesters, and then fugitive emissions from centrates etc. How do these apply? Is it well reflected in the IPCC values? Further investigation
Other sludge treatment processes		
22	Aerobic digestion	No data on GHG emissions from this process. This is an omission as these plants exist in NZ.
23	Sludge treatment	Vermicomposting - Several of the large NZ vermiculture plants are more of pile it up and add a few worms rather than a dedicated plant

Item	Subject	Description of knowledge gap
		with controlled worm conditions. Two styles of vermiculture, so probably widely differing values. . The result from these is a leachate entering the ground which will be high in N. there should be low CH_4 as worms are intolerant of anaerobic conditions, but N_2O can be significant. I am concerned that this is a BIG gap in knowledge.
24	Sludge treatment	Composting - data is currently highly variable. Difficult to recommend the process based on GHG estimate. More data needed.
25	Sludge liming	Consideration of pH when storing and landfilling sludge - what about the effect of liming. How long does the inhibitory impact of high pH last, and is the ultimate CH_4 potential eventually realised in landfill?
Benchmarking		
26	International EF benchmarking	Literature assessment of identified global EFs, and how these were derived. IPCC or field measurements? Review the most recent literature and studies overseas. Incorporate latest data into future iterations of these guidelines.
Standards alignment		
27	Anthropogenic biogenic CO_2 emissions	ISO 14064:2018 requires that 'anthropogenic biogenic CO_2' emissions and removals shall be quantified and reported separately from other anthropogenic emissions. Recommend that further guidance be developed to help account for biogenic CO_2 emissions.
Outside of scope for these guidelines		
28	Potable water	Sludge landfilled from WTPs. From reservoirs and polymer. Is this covered anywhere? Further guidance required.
29	Trade / Industrial Wastes	There is little understanding about how industrial wastewaters with characteristics significantly different to municipal wastewaters will emit when compared to the IPCC and proposed NZ guidelines. Measurement of GHG from industrial processes is recommended.
30	Direct measurement protocols	Protocols to undertake direct measurement of CH_4 and N_2O are not available for New Zealand. If this activity becomes more routine a set of measurement protocols would ensure consistency and robustness of the measurements.

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APPENDIX A – N_2O WWTP EF

The IPCC (2019) derived an emission factor based on an observed correlation between N_2O emissions (expressed as a fraction of influent total nitrogen load) and influent nitrogen mass load, using 30 data sources (published date range 1998 to 2018). The Figure 6A.1 from IPCC (2019) is recreated in Figure 4 below, from which the emission factors were derived.

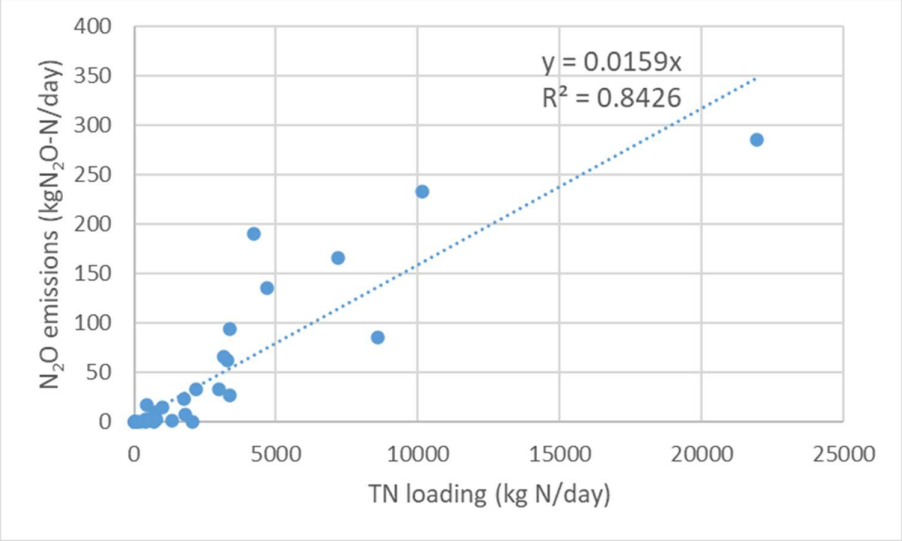


Figure 4: Correlation between influent total nitrogen (TN) loading and N_2O emissions

The literature cited in the IPCC (2019) Refinement Guidelines was reviewed for this project. Some errors were identified in Table 6A.5 of the IPCC (2019) guidance, and recalculation of the emission factor was made. Alongside this was an estimation of the emission factor, using the same dataset, based on total nitrogen (TN) removed across the wastewater treatment plant (i.e. influent minus effluent loads), which has been the method adopted in Australia under the NGER Determination since 2007 (Australian Govt., 2020). A comparison of these calculations is shown in Table 29.

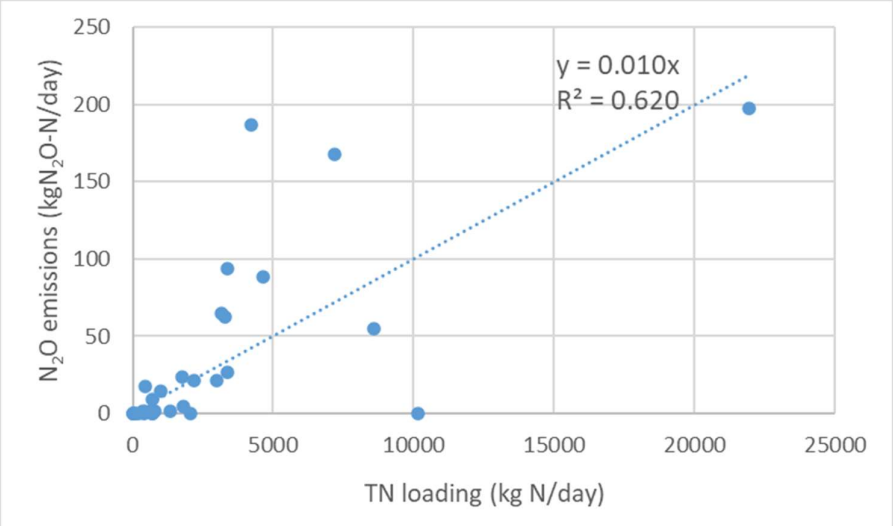


Figure 5: Correlation between influent total nitrogen (TN) loading and N_2O emissions (using revised emission factors correcting for errors in IPCC, 2019)

Table 29: N_2O emission factors in full-scale municipal wastewater treatment plants

Type of treatment process	Categories	References	Reported in IPCC (2019) ($kg\ N_2O\text{-}N/kg\ N_{influent}$)	Revised N_2O emission factor ($kg\ N_2O\text{-}N/kg\ N_{influent}$)	Alternative N_2O emission factor ($kg\ N_2O\text{-}N/kg\ N_{REM}$)
AO	BNR	Daelman et.al. (2015)	0.028	0.028	0.035
AO (MLE)	BNR	Foley et.al. (2010)	0.021	0.0205	0.0270
AO (MLE)	BNR	Foley et.al. (2010)	0.045	**0.0443**	0.0508
A2O	BNR	Foley et.al. (2010)	0.013	0.0134	0.0140
SBR	BNR	Foley et.al. (2010)	0.023	0.0233	0.0327
OD	BNR	Foley et.al. (2010)	0.008	0.0080	0.0083
JHB	BNR	Foley et.al. (2010)	0.015	0.0146	0.0153
		Foley et.al. (2010)		**0.0066**	0.0080
IA	BNR	*Kimochi et.al. (1998)*	*0.0008*	0.0008	0.0011
IA	BNR	*Kimochi et.al. (1998)*	*0.0005*	0.0005	0.0006
IA	BNR	*Kimochi et.al. (1998)*	*0.0001*	0.0001	0.0003
A2O	BNR	Wang et.al. (2016)	0.013	0.013	No data
CAS	BNR	Aboobakar et.al. (2013)	0.00036	0.00036	0.00071
AO	BNR	Rodriguez-Caballero et.al. (2014)	0.12	**0.0012**	No TN data
OD	BNR	Masuda et.al. (2018)	0.00016	**0.00014**	0.00016
AO	BNR	Masuda et.al. (2018)	0.0013	**0.0012**	0.00128
AO	BNR	Masuda et.al. (2018)	0.0049	**0.0037**	0.00493
Sep.stage BNR	BNR	Ahn et.al. (2010)	0.00019	**0.000120**	0.000119
Bardenpho	BNR	Ahn et.al. (2010)	0.0036	**0.002313**	0.002676
Step-feed BNR	BNR	Ahn et.al. (2010)	0.011	**0.007168**	0.011639
step feed bnr3	*BNR*	*Ahn et.al. (2010)*		***0.000318***	*0.000382*
MLE	BNR	Ahn et.al. (2010)	0.0007	**0.000445**	0.000573
MLE	BNR	Ahn et.al. (2010)	0.0006	**0.000382**	0.000445
OD	BNR	Ahn et.al. (2010)	0.0003	**0.000191**	0.000191
Step-feed BNR	BNR	Ahn et.al. (2010)	0.015	**0.009545**	0.010818
Step feed, plug flow	BNR	Ni et.al. (2015); Pan et.al. (2016)	0.019	0.019	0.025333333
SBR	BNR	Bao et.al. (2016)	0.029	**0.019**	<0.037
SBR	BNR	Rodriguez-Cabellero et.al. (2015)	0.038	0.038	0.043
Plug flow	Non-BNR	Ahn et.al. (2010)	0.004	**0.002577273**	0.005053476
Plug flow	Non-BNR	Ahn et.al. (2010)	0.0062	**0.002219873**	0.005820779
Step-feed non-BNR	Non-BNR	Ahn et.al. (2010)	0.0018	**0.006388364**	0.012201021
Plug flow	Non-BNR	Masuda et.al. (2015)	0.023	**0.00002299**	0.00008909
AO	Non-BNR	Bao et.al. (2016)	0.013	**0.009**	<0.017
IA	Non-BNR	De Mello et.al. (2013)	0.0016	0.0016	No data
Mean			0.014	0.009	0.011
Min			0.0001	0.00002	0.00009
Max			0.12	0.044	0.051

Note: values in bold have changed.

More recently, the case for a variable emission factor has been made. Under this method the emission factor (expressed either a fraction of influent TN load or a fraction of TN load removed) changes according to an inverse correlation with the fraction (or percentage) of TN *removal* occurring across the plant (Parravicini, 2016; Valkova, 2021; de Haas and Ye, 2021).

Figure 6 provides a comparison of alternative emission factor approaches on the tonnes of N_2O released, based on a 200,000 m^3/day plant with 60 mg/L total nitrogen in influent. The four approaches are:

- IPCC (2019): 0.016 $kgN_2O\text{-}N/kgN_{influent}$
- Revised IPCC: 0.010 $kgN_2O\text{-}N/kgN_{influent}$
- Based on TN removal: 0.011 $kgN_2O\text{-}N/kgN_{REM}$
- Valkova (2021): [4.362-(0.047*%TN removed)] $kgN_2O\text{-}N/kgN_{influent}$

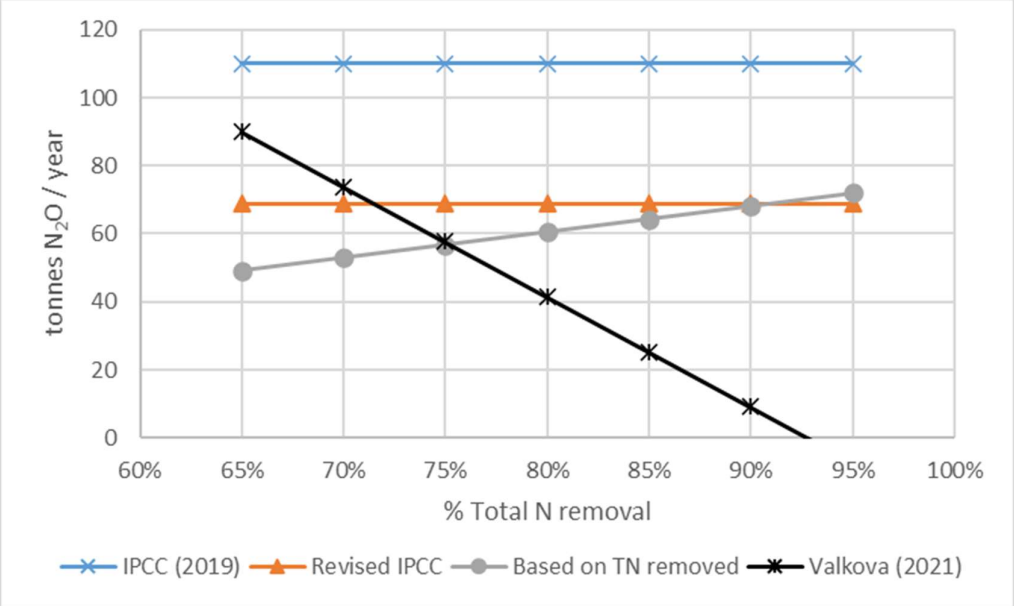


Figure 6: N_2O emission estimates using alternative calculation methods

The recommendation for the N_2O emission factor is 0.001 $kgN_2O\text{-}N/kgN_{influent}$. Some of the considerations include:

- From a review of the literature used in IPCC (2019) a lower emission factor is warranted based on errors in the original data interpretation.
- A fixed emission factor based on N-removed might be more intuitive than one based on N-influent since emissions arise largely from nitrification and denitrification biological processes. However, inter-conversion between fixed emission factors (i.e. expressed as a fraction of influent TN vs. TN removed) can be problematic. For example, a fixed factor based on TN *removal* results in a *variable* factor based on influent TN that *increases* with % TN removed, which is the opposite to the trend described by Valkova et.al. (2021) and de Haas and Ye (2021) (Figure A3), based on measured N_2O emissions from actual plant data.
- A variable emission factor (e.g. based on extent of TN removal across a plant or process step) might be more appropriate in future. Further work is required to validate the findings from recent studies (e.g. de Haas and Ye, 2021).

APPENDIX B – BOUNDARY SETTING

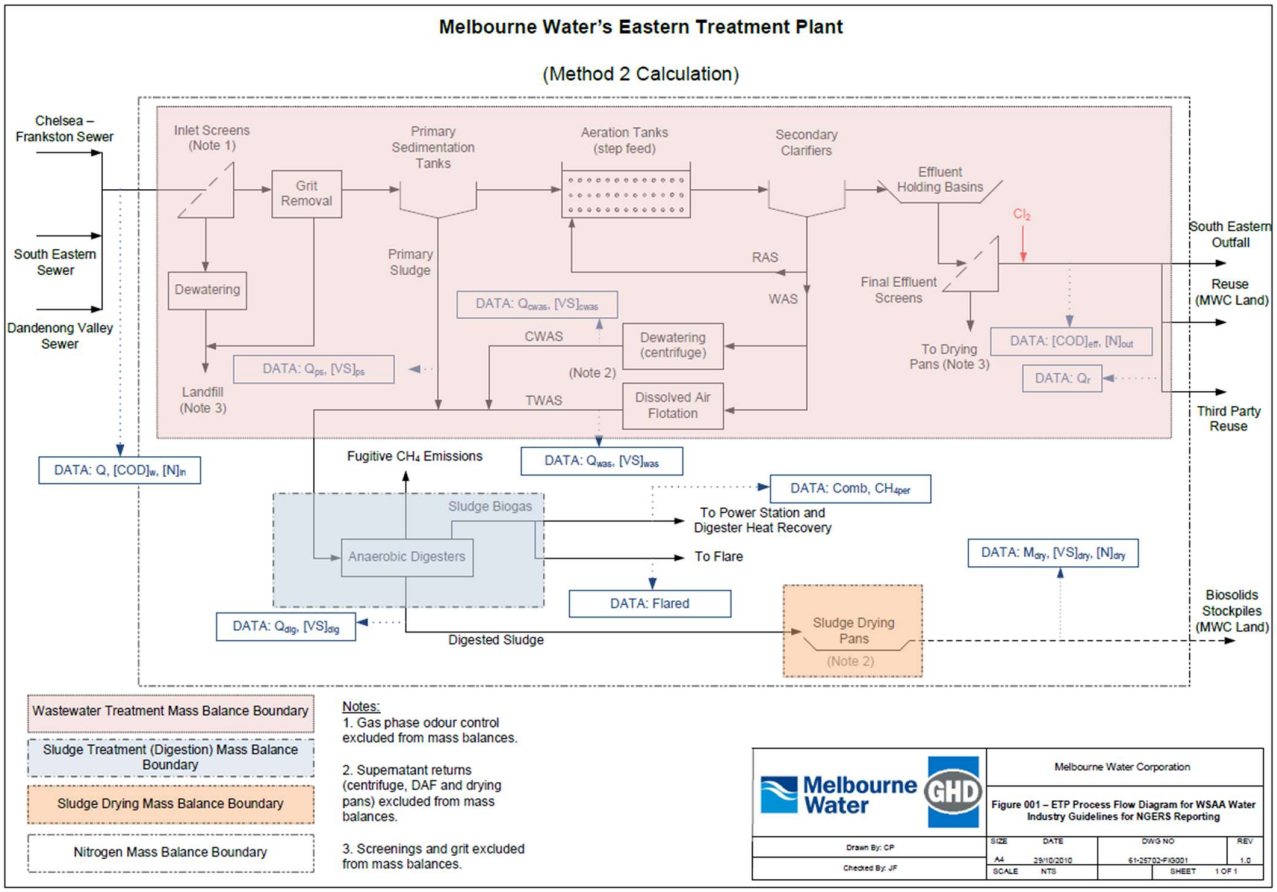
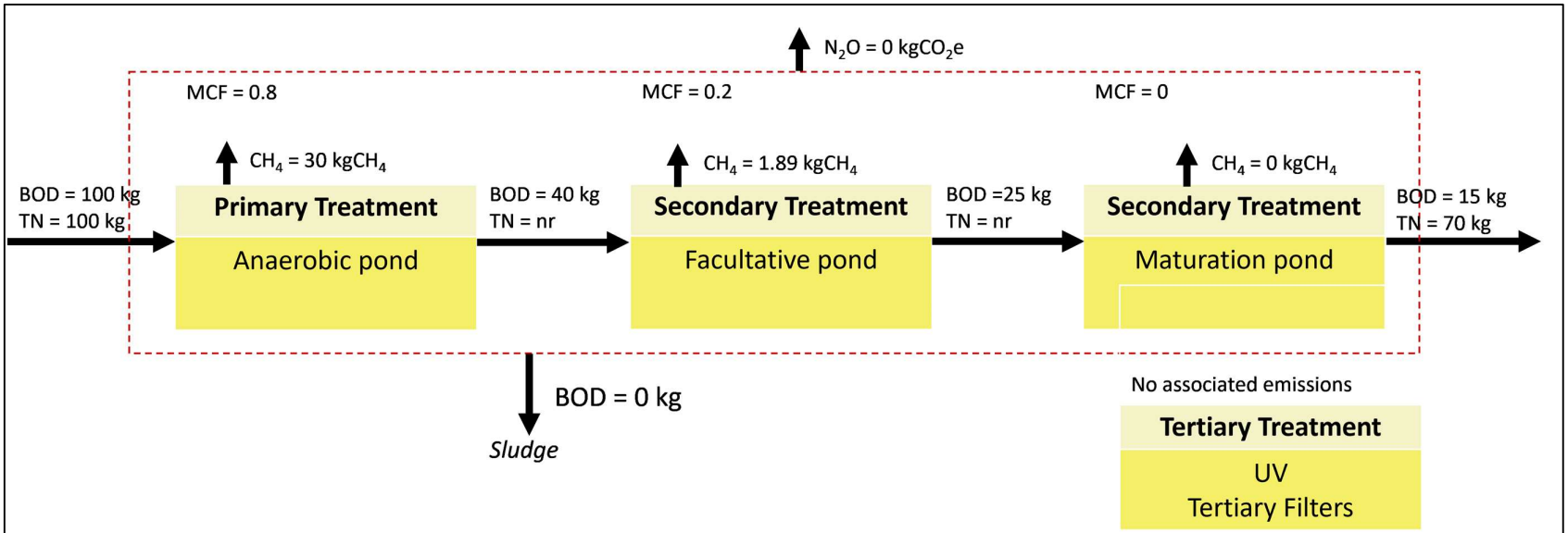


Figure 7: Boundary setting for mass balance across treatment processes (Presented with the permission of Melbourne Water)

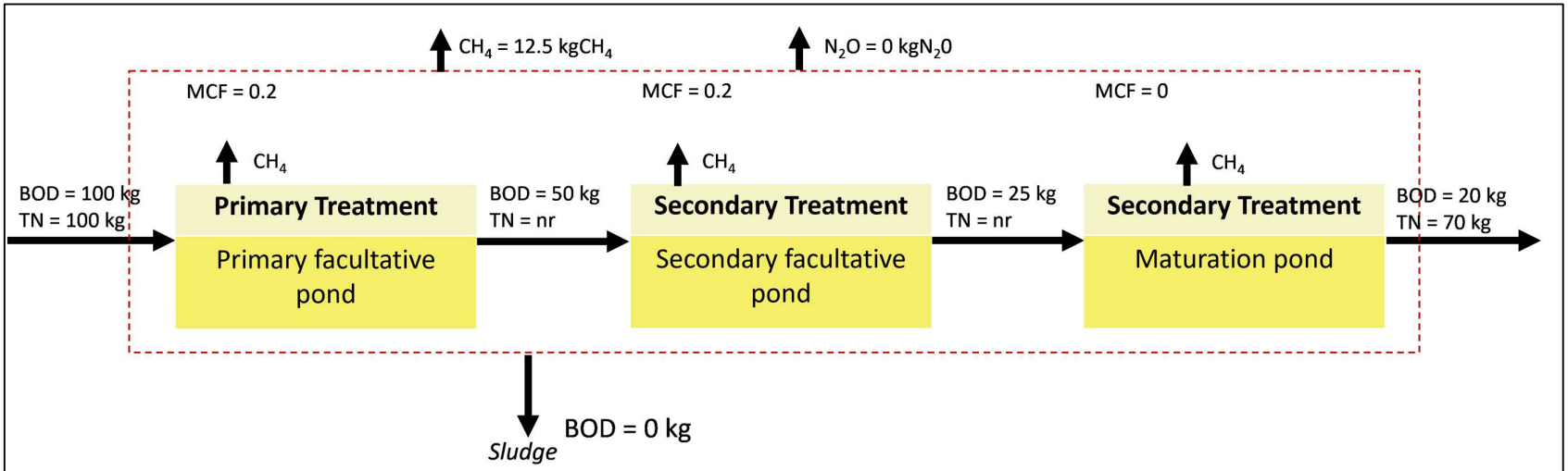
APPENDIX C – EXAMPLE CALCULATIONS

Example calculation of emissions are shown in the Figures below for different wastewater treatment configurations. Wider plant emissions are not included e.g., from sludge treatment and effluent release to waterbodies.



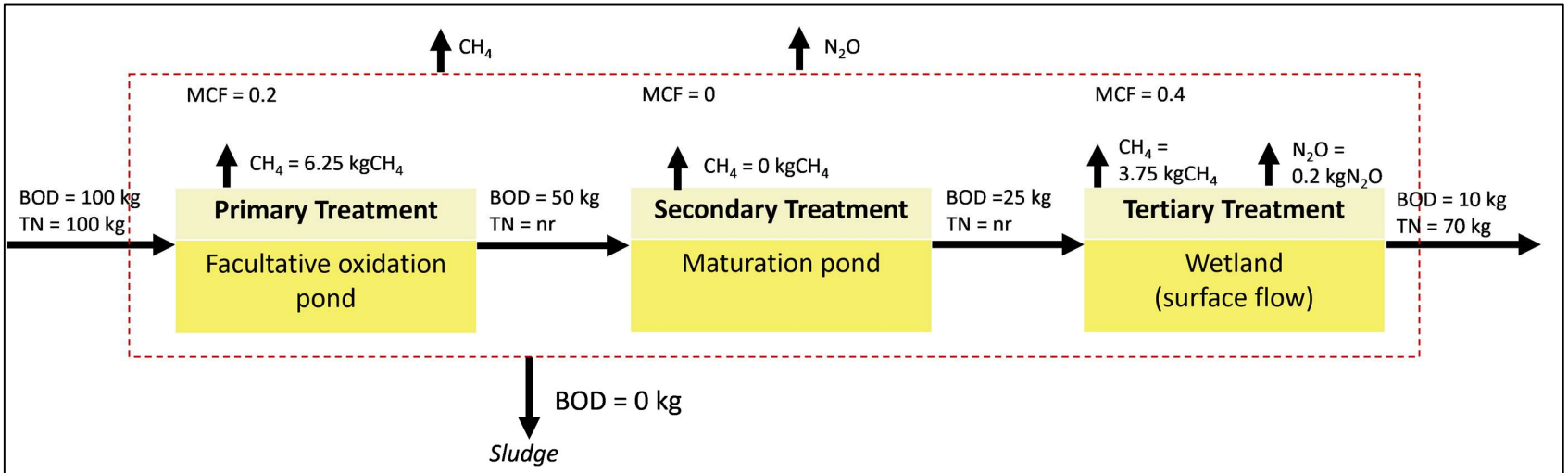
Narrative:

There are no N_2O emissions from this pond system. The ponds are made up of 3 types of ponds each with a different MCF. Therefore the 'sequential stages' method is applied. Typical BOD removals by stage are applied, due to lack of site specific data in this example. The BOD removed in pond sludge is considered to be '0'. In the anaerobic pond emissions are calculated as [100 x (0.6 - 0) x 0.625 x 0.8] as per Equation 3. For the facultative pond emissions are calculated as [40 * (0.375 - 0) * 0.126]. The CH_4 emission factor is '0' from maturation ponds.

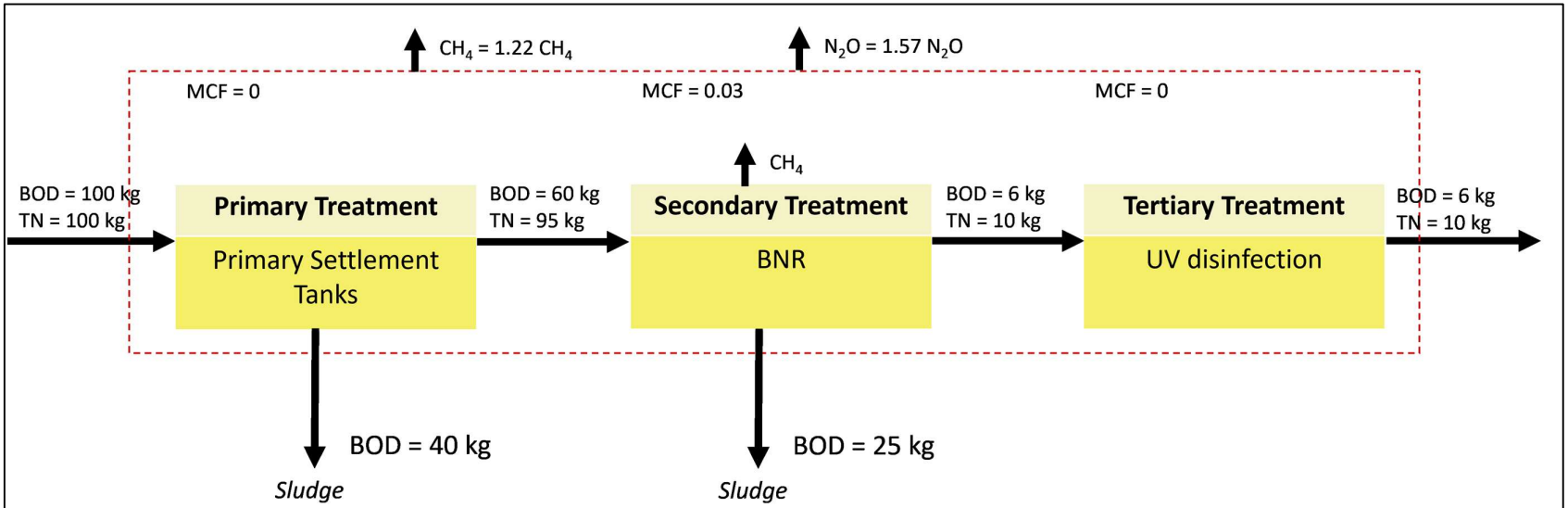


Narrative:

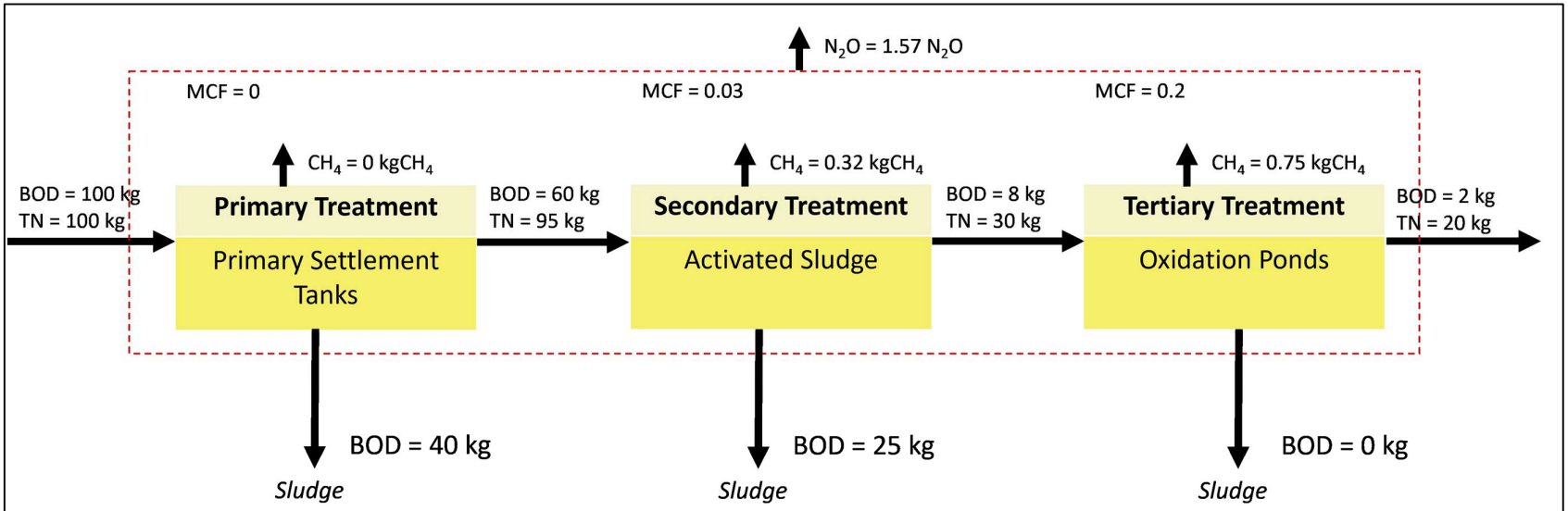
There are no N_2O emissions from this pond system. The series of ponds are dominated by a single type of pond (facultative) which have the same MCF. Therefore the 'single factor' method is applicable. Typical BOD removals by stage are applied, due to lack of site specific data in this example. The BOD removed in pond sludge is considered to be '0'. The CH_4 emissions for this pond system are calculated as [100 x (1 - 0) x 0.625 x 0.2] as per Equation 2.



Narrative:
The treatment includes a mixture of ponds and wetlands with different MCFs, therefore the 'sequential stages' method is applied. There are no N_2O emissions from the ponds, but wetlands do have an emission factor. The N2O from wetlands is calculated as [100*0.0013*(44/28)]. Typical BOD removals by stage are applied, due to lack of site specific data in this example. The BOD removed in pond sludge is considered to be '0'. In the facultative pond emissions are calculated as [100 x (0.5 - 0) x 0.625 x 0.2] as per Equation 3. The CH_4 emission factor is '0' from maturation ponds. For the wetland emissions are calculated as [25 * (0.6 - 0) * 0.625 * 0.4].



Narrative:
The dominant treatment process is BNR and therefore the 'single factor' method is suitable. A single N_2O emission factor applies from the BNR process and is calculated as [100*0.010*(44/28)]. The CH_4 emissions are calculated as a single factor [100 x (1 – 0.35) x 0.625 x 0.03].



Narrative:
The dominant treatment processes are conventional activated sludge and oxidation ponds, which have different MCFs, therefore the 'sequential stages' method is applied. A single N_2O emission factor applies from the activated sludge process and is calculated as [100*0.010*(44/28)]. The BOD removed in pond sludge is considered to be '0'. The activated sludge emissions are calculated as [60 x (0.867 – 0.583) x 0.625 x 0.03] as per Equation 3. The oxidation pond emissions are calculated as [8 x (0.75 – 0) x 0.625 x 0.2]

APPENDIX D – WATER QUALITY STATUS

The LAWA website (www.lawa.org.nz) provides details of water quality in New Zealand. An example output defining the status levels for dissolved reactive phosphorus (DRP) is found below. Further definitions for other water quality components can be found in MfE (2020b).

Dissolved Reactive Phosphorus

Value (and component)	Ecosystem health (Water quality)	
Freshwater body type	Rivers	
Attribute unit	DRP mg/L (milligrams per litre)	
Attribute band and description	**Numeric attribute state**	
	Median	95th percentile
A Ecological communities and ecosystem processes are similar to those of natural reference conditions. No adverse effects attributable to dissolved reactive phosphorus (DRP) enrichment are expected	≤ 0.006	≤ 0.021
B Ecological communities are slightly impacted by minor DRP elevation above natural reference conditions. If other conditions also favour eutrophication, sensitive ecosystems may experience additional algal and plant growth, loss of sensitive macroinvertebrate taxa, and higher respiration and decay rates.	> 0.006 and ≤0.010	> 0.021 and ≤0.030
C Ecological communities are impacted by moderate DRP elevation above natural reference conditions. If other conditions also favour eutrophication, DRP enrichment may cause increased algal and plant growth, loss of sensitive macro-invertebrate and fish taxa, and high rates of respiration and decay.	> 0.010 and ≤ 0.018	> 0.030 and ≤ 0.054
D Ecological communities impacted by substantial DRP elevation above natural reference conditions. In combination with other conditions favouring eutrophication, DRP enrichment drives excessive primary production and significant changes in macroinvertebrate and fish communities, as taxa sensitive to hypoxia are lost.	>0.018	>0.054
Numeric attribute state must be derived from the median of monthly monitoring over 5 years.		