Waikato Regional Council Technical Report 2023/06

Organic Soil greenhouse gas emissions accounting for the Waikato Region

www.waikatoregion.govt.nz
ISSN 2230-4363 (Online)

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February 2024

Document #: 25919648

Peer reviewed by:
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Acknowledgements

We would like to thank;

- Jordan Goodrich (MfE), Jack Pronger (Manaaki Whenua), Deb Burgess (MfE), and Gerald Rhys (MPI) for technical advice on calculations and insight into national inventory methods for Organic Soils emissions.
- The team at EnviroStrat (Ross Abercrombie and Cerasela Stancu) for constructive input and ensuring consistency alongside the regional inventory.
- Haydon Jones, Blair Dickie, Rebecca Finnerty, and Mike Scarsbrook (WRC) for providing in-house discussion, advice, and technical support throughout the project.
- Dave Campbell (the University of Waikato) for his thorough and constructive review of the report.

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Background

The Waikato Region has about 84,000 ha of Organic Soils (OS) or peat, of which 65,000 ha have been drained, mostly for pastoral agriculture. Drainage and disturbance of OS causes loss of organic material to the atmosphere as greenhouse gas (GHG) emissions such as carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). Through these emissions, OS contribute to the region's GHG footprint. Despite this, OS emissions are not currently accounted for in the regional GHG inventory and therefore total regional GHG emissions are underestimated.

Waikato Regional Council (WRC) seeks to understand GHG losses from drained OS, with the intention that these emissions could be included in a future regional GHG inventory. In preparation, this report identifies and recommends accounting methodologies, presents key calculations and limitations, and provides recommendations for reporting OS emissions at the regional scale. Results will benchmark Waikato against national and international inventories and provide information for reducing and offsetting emissions where required.

For this study, OS were identified as those soils that met the classification of Organic Soils in the New Zealand Soil Classification (NZSC), and area was determined using a Waikato Region specific hybridised spatial layer of S-Map, and where this was not available, the Fundamental Soils Layer (FSL).

Methods

Emissions from drained OS were calculated using Tier 1 default emission factors (EFs) from the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines and the 2013 Wetland Supplement (WS). Both methods were compared for their suitability for regional scale drained OS emissions accounting. The 2006 IPCC Guidelines account for CO_2 and N_2O emissions from drained OS and is currently used by the national Aotearoa-New Zealand GHG inventory. The 2013 WS extends the 2006 IPCC Guidelines, with additional calculations for dissolved organic carbon (DOC) in drainage water and CH_4 emissions from land surface and drainage ditches. EFs in the 2013 WS are disaggregated by nutrient status and drainage depth, based on more studies, and split into different climatic zones to provide more accurate estimates of emissions. The national GHG inventory is considering adopting the 2013 WS for its OS emissions estimates.

Activity data was compiled for OS in the Waikato Region. Activity data describes the characteristics and practices taking place on an area that result in GHG emissions or removals (e.g., land use, climate zone, nutrient status, drainage depth) and therefore determines the appropriate EF to use. Table A presents an overview of key activity data sources.

Table A: Source of activity data for OS emissions calculated using the 2006 IPCC Guidelines and 2013 WS.

Activity	Source	Method used by 2006 IPCC	Method used by 2013 WS
Land Use	Land Use and Carbon Analysis System (LUCAS) NZ Land Use Map (LUM) v011.	Yes	Yes
Climate	Temperature data layer of Land Environments New Zealand (LENZ).	Yes	Yes
Nutrient Status	Historical wetlands layer in Freshwater Ecosystems of New Zealand (FENZ).	Yes	Yes
Peat volume mined	Local consultancy report.	Yes	Yes
Drainage depth	Preliminary local data from water table monitoring study.	No	Yes
Drainage ditch area	Default value from method.	No	Yes
Peat fire area	Not included, but sensitivity analysis completed.	No	Yes

Emissions

Using Tier 1 default EFs, the 2006 IPCC and 2013 WS Tier 1 methods produced emissions totals of 0.87 and 1.71 Mt CO_2e yr^{-1}, respectively (Tables B and C). The greatest emissions came from OS under grassland and although not shown in the Tables B and C, emissions were dominated by CO_2.

Table B: OS GHG emissions summary calculated following 2006 IPCC Guidelines including both Tier 1 and local draft Tier 2 EFs. NC means that no suitable draft Tier 2 EF was available, and the Tier 1 EF is still used in the final emissions calculation.

Activity		**Area (ha)**	**Tier 1 Emissions (t CO_2e yr^{-1})**	**Draft Tier 2 Emissions (t CO_2e yr^{-1})**
Forest Land	*Temperate*	634	1,582	NC
Cropland	*Warm Temperate*	1,414	57,186	NC
Grassland	*Warm Temperate*	61,932	800,031	1,188,698
Peat extraction	*Nutrient Poor, Onsite emissions*	69	51	NC
	Nutrient Poor, Offsite emissions	NA	3,527	NC
Settlements[A]	*Warm Temperate*	610	7,879	11,708
Other land[A]	*Warm Temperate*	9	113	172
			870,368	1,262,924

[A] Grassland EF used for emissions calculations.

Table C: OS GHG emissions summary calculated following 2013 WS including both Tier 1 and local draft Tier 2 EFs. NC means that no suitable draft Tier 2 EF was available, and the Tier 1 EF is still used in the final emissions calculation. NR means not reported due to insufficient data.

Activity		**Area (ha)**	**Tier 1 Emissions (t CO_2e yr^{-1})**	**Draft Tier 2 Emissions (t CO_2e yr^{-1})**
Forest Land	*Temperate*	634	7,770	NC
Cropland	*Temperate*	1,414	54,023	NC
Grassland	*Temperate, Nutrient Poor, drained*	43,063	1,061,159	888,900
	Temperate Nutrient rich, deep drained	18,869	563,927	NC
Peat extraction	*Onsite emissions*	69	871	NC
	Offsite emissions	NA	3,527	NC
Settlements[A]	*Temperate, Nutrient Poor*	197	4,851	4,066
	Temperate, Nutrient rich, deep drained	413	12,343	NC
Other land[A]	*Temperate, Nutrient Poor*	9	214	184
Fires		NR	NR	NR
			1,708,685	1,535,611

[A] Grassland EF used for emissions calculations.

Default Tier 1 EFs in the 2006 IPCC Guidance are based on international data and not the peatlands of Aotearoa-New Zealand. However, the Tier 1 EF for CO_2 in the 2013 WS includes one local study by Nieveen et al., (2005). Although on reanalysis by Campbell et al., (2015) the study by Nieveen et al., (2005) was found to have been impacted by inadequate data correction. Aside from Nieveen et al. (2005) other local studies have been completed that investigated CO_2 and N_2O emissions from OS under grassland in the Waikato Region. These studies are presented in Table D and were assessed for inclusion as Tier 2 EFs.

Table D: Draft local Tier 2 EFs for CO_2 and N_2O derived from local data.

Source	t CO_2-C ha^{-1} yr^{-1}	Comments
Schipper & McLeod (2002)	3.7	Comparing soil C between two sites – total carbon loss.
Campbell et al (2015)	2.94	Eddy covariance method – total carbon loss (NECB).[A]
Campbell et al (2021)	1.96	Eddy covariance method – total carbon loss (NECB).
Campbell et al (2021)	8.25	Eddy covariance method – total carbon loss (NECB).
Mean	4.21 (1.8 – 6.6)	95% confidence limit in parenthesis.
Source	**kg N ha^{-1} yr^{-1}**	**Comments**
Kelliher et al (2016)	1.57[B] (0.2 – 10.6)	Chamber measurements. 95% confidence limit in parenthesis.

[A] NECB = net ecosystem carbon balance.

[B] In Kelliher et al. (2016) the original value is reported as 4.3 g N ha^{-1} d^{-1}, this value and the corresponding 95% confidence limits have been converted to kg N ha^{-1} yr^{-1}.

The draft local Tier 2 grassland CO_2 EF of 4.21 t CO_2-C ha^{-1} yr^{-1} was within the range of uncertainty for the Tier 1 EF for the 2006 IPCC Guidelines of 2.5 (0.25 – 4.75) t CO_2-C ha^{-1} yr^{-1} and for nutrient poor grasslands in the 2013 WS, with an EF of 5.3 (3.7 – 6.9) t CO_2-C ha^{-1} yr^{-1}. The four local measurements presented in Table D were from drained and modified raised ombrotrophic (low nutrient) peat bogs in Moanatuatua and Rukuhia, with allied shorter-term mobile measurements at Rukuhia, Komakorau, and Moanatuatua. Because the draft local Tier 2 CO_2 EF for grassland likely provides a better estimate of CO_2 emissions from local low nutrient OS under grassland than the Tier 1 EF, and because about 70% of OS under grassland are low nutrient, it was considered suitable to use for all grassland emissions estimates for the 2006 IPCC Guidelines. The draft local Tier 2 EF was also considered appropriate for use for all low nutrient OS under grassland for emissions based on the 2013 WS calculations.

The draft local Tier 2 EF for N_2O from grassland of 1.57 kg N ha^{-1} yr^{-1} was outside the range of uncertainty for the Tier 1 EFs in the 2006 IPCC Guidelines of 8 (2 – 24) kg N_2O-N ha^{-1} yr^{-1} and the 2013 WS EF of 4.3 (1.9 – 6.8) kg N_2O-N ha^{-1} yr^{-1}, although its own range of uncertainty overlapped with those of the Tier 1 EFs (Table D). The draft local Tier 2 N_2O EF was much lower than Tier 1 EFs, but the draft local Tier 2 EF was only derived from one study. Based on the limited local data it was considered inappropriate to use the draft local Tier 2 N_2O EF for regional OS emissions calculations.

Including the EF for CO_2 from nutrient poor grassland under drained OS changed the overall emissions totals for the 2006 IPCC Guidance and 2013 WS to 1.26 and 1.54 Mt CO_2e yr^{-1}, respectively (Tables B & C).

The 2013 WS includes EFs for fire, but because fires are infrequent, no area data was available, and therefore these emissions where not included in our study (Table C). However, to understand the impact of fire on overall OS emissions, a sensitivity analysis was completed for areas between 0.1 – 1000 ha on drained and undrained OS. From the sensitivity analysis potential GHG emissions from fire ranged from 15 to 146,337 t CO_2e for undrained OS and 61 to 608,446 t CO_2e for drained OS.

Limitations

The methods and results highlighted some of the limitations to reporting emissions. These included:

- The accuracy of OS extent is limited by the quality of available regional-scale soil maps.
- OS soil area is reducing due to subsidence, but the soil maps only capture the extent at the time of mapping.

- The most up-to-date LUCAS information was from 2016, this is now 7 years old. This was not consistent with the current regional GHG inventory year, which was 2021/2022.
- Some land use on OS was incorrectly mapped, for example forestry.
- Drainage ditch area on OS is unknown and a default value of 2.5% of land area for forest land and 5% everywhere else had to be used.
- There is limited local data on mean annual water table depth (drainage depth) especially for nutrient rich OS.

Recommendations

The 2013 WS should be used in favour of the outdated 2006 IPCC Guidelines for the final accounting method because the WS expands on information covered in the 2006 Guidelines and provides updated and more refined EFs. Although one study in the 2013 WS was NZ-based, this is not representative of all NZ conditions and systems.

The 2013 WS method should be implemented on a regional basis using a Tier 1 approach, except for using the draft local Tier 2 EF for CO_2 for nutrient poor, drained OS in the Waikato Region. Using this approach, total emissions are 1.54 Mt CO_2e yr^{-1}. Using the recommended approach, estimated OS emissions would be responsible for 11% of the region's total gross emissions (13% net emissions) for the current regional inventory for the 2021/22 emissions year.

WRC should have a long-term goal of undertaking more measurements suitable for developing and refining local Tier 2 EFs, particularly for CO_2 and N_2O from grassland. The decision for further development of EFs should be supported by a key category analysis.

Improving the understanding of OS extent and activity data is recommended. Improvements could include:

- using existing data or new techniques to better understand OS area and change over time,
- ground truthing of drainage area estimates,
- more monitoring of water table depth on nutrient rich OS,
- understand fire frequency and extent, and
- advocating for the update and improvement of regional scale land use information.

Although outside of the scope of this project WRC should also consider whether emissions from rewetted OS, unmodified OS, and mineral soil wetlands and land use change on mineral soils should be included in regional scale GHG accounting.

1 Introduction

The Waikato Region has about 84,000 ha of Organic Soils (OS) that formed from the slow accumulation of peat (about 1 mm per year) in wetlands over the past 10,000 – 14,000 years, resulting in organic material more than 10 m deep in some cases. Drainage of OS in local wetlands began in the early 1900s and now about 65,000 ha have been drained, mostly for pastoral agriculture. Some shallow OS that existed in wetlands prior to colonisation have been lost due to drainage and burning and are now represented by other soil orders (e.g., Gley Soils).

While intact peat wetlands are a greenhouse gas (GHG) sink (Goodrich et al. 2017), disturbance and drainage of OS causes loss of organic material to the atmosphere as GHG emissions, thereby contributing to the region's GHG footprint (Pronger et al. 2021). Emissions are dominated by carbon dioxide (CO_2) from organic matter oxidation, but more potent GHGs, nitrous oxide (N_2O) and methane (CH_4) (298 and 34 times the GWP of CO_2, respectively)[1] are also released to a lesser extent (Langeveld et al. 1997; Pachauri and Reisinger 2007; Pachauri et al. 2014; Masson-Delmotte et al. 2021). Although OS cover approximately 3% of the Waikato Region's surface area, they contribute disproportionately to emissions from soil (Schipper et al. 2017). Despite this, OS emissions are not currently accounted for in the regional GHG inventory.

Waikato Regional Council (WRC) seeks to account for GHG losses from drained OS, with the intention that these emissions could be included in a future regional inventory (2024/25). This approach recognises their significant contribution to GHG emissions and aligns with the national inventory (Ministry for the Environment 2023a). This technical report supports the commentary presented in the latest regional GHG inventory (Waikato Regional Council and EnviroStrat Limited 2023) about eventually including OS, by identifying and recommending accounting methodologies, presenting key calculations and considerations, and providing a pathway for reporting OS emissions at the regional scale. Results from this report will enable OS emissions comparisons across districts and sectors, and benchmark Waikato against national and international inventories.

While previous Waikato Regional inventories have not accounted for GHG emissions from OS, the national GHG inventory currently uses default emission factors (EFs) from the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines to estimate CO_2 and N_2O emissions from drained OS in the land use, land use change and forestry (LULUCF) and agriculture sectors, respectively, while CH_4 is excluded (Eggleston et al. 2006). However, recognising advances in scientific knowledge of OS emissions since the 2006 IPCC Guidelines were published, the IPCC released a specific set of accounting guidance for estimating GHG emissions from wetlands and drained OS: the 2013 Wetlands Supplement (WS) (Hiraishi et al. 2014). The WS extends the coverage of the 2006 IPCC Guidelines and includes new and refined EFs to reduce uncertainties, including the disaggregation of EFs by nutrient status and drainage depth. Countries with significant OS emissions have been updating their inventories to remain consistent with this new methodology (e.g., United Kingdom, Germany) (Evans et al. 2017;

[1] The GWP metric values applied in this study are 100-year GWP values with the inclusion of climate-carbon feedbacks, sourced from the IPCC Climate Change Fifth Assessment Report (AR5) (2014) (Table 8.7, Chapter 8). Currently, the New Zealand National Inventory uses the IPCC Fourth Assessment Report (AR4) (2007) GWP values. It should be noted that GWP values vary as knowledge increases, with differences in GWP values across AR4, AR5, and the most recent IPCC Sixth Assessment Report (AR6) (2021).

Tiemeyer et al. 2020). The New Zealand national inventory is also considering a transition to the 2013 WS (Ministry for the Environment 2023a). Noting EFs are mostly based on Northern Hemisphere data and only one NZ study is included in the 2013 WS, this technical report will review both the IPCC 2006 Guidelines and the 2013 WS to compare and determine their applicability for use as a method to account for GHG emissions from drained OS in the Waikato Region.

1.1 Project aim and objectives

The aim of this project is to identify a methodology for calculating OS emissions for regional scale GHG accounting in the Waikato. The objectives to achieve this aim are:

1) Compare the 2006 IPCC Guidelines to the 2013 Wetland Supplement approach for calculating regional scale OS emissions.
2) Review the limitations of current approaches and available spatial information used to estimate total emissions e.g., OS soil extent, land use categories, nutrient status, drainage depth, 1990 baseline.
3) Provide recommendations toward a pathway that enables Waikato Regional Council to implement the 2013 WS for drained OS using Tier 1 EFs and determine the ability to implement region-specific draft (Tier 2) EFs.
4) Provide recommendations for future research to support the implementation and development of emissions estimates for drained OS as well as refining and reducing uncertainties.

2 Methodology

For this study, emissions from drained OS in the Waikato Region were calculated using both the 2006 IPCC Guidelines and 2013 Wetland Supplement. OS emissions were calculated using Tier 1 EFs, and then repeated using local data where appropriate. An overview of the methods used for both approaches are described in the following section.

2.1 2006 IPCC Guidelines

The 2006 IPCC Guidelines Volume 4 provides guidance for preparing annual GHG inventories in the Agriculture, Forestry, and Other Land Use (AFOLU) Sector. Accounting methods for CO_2 emissions from OS are presented in chapters 4 to 9 in the 2006 IPCC Guidelines, and N_2O emissions are in chapter 11. Methane (CH_4) emissions from drained OS, were not included in the 2006 Guidelines because of a lack of data (Eggleston et al. 2006).

The 2006 IPCC Guidelines are currently used by the New Zealand (NZ) national GHG inventory to account for national emissions from drained OS (Ministry for the Environment 2023a). However, the NZ national GHG inventory adheres to the United Nations Framework Convention on Climate Change (UNFCCC) reporting guidelines and the international methodology guidelines set out by the Intergovernmental Panel on Climate Change (IPCC). Therefore, in the NZ national GHG inventory OS N_2O emissions are accounted for in the Agriculture Sector and CO_2 emissions in the Land Use, Land Use Change, and Forestry (LULUCF) Sector. The Waikato Regional GHG inventory, which is where emissions from OS in the

Waikato Region are intended to be accounted for in the future[2], uses the Global Protocol for Community-Scale Greenhouse Gas Inventories (GPC) for its reporting format (Fong et al. 2021). The GPC format refers to Volume 4 of the 2006 IPCC Guidelines when accounting for soil N_2O emissions from managed agricultural soils and CO_2 emissions from soil carbon stock changes due to land use change, and places both in the AFOLU sector.

The method for accounting for GHG emissions from OS in the 2006 Guidelines is generally to multiply a known area of OS (activity data) by an appropriate default emission factor, determined by land use category and climate zone. The OS emission factors (EF) in the 2006 Guidelines were based on data gathered from a small number of international studies, which limits their applicability to NZ conditions. Appendix A presents a summary of CO_2 and N_2O emissions from OS in the Waikato Region in 1990, 2008, 2012, and 2016 calculated using the 2006 IPCC Guidelines.

2.2 2013 Wetland Supplement

The 2013 Wetlands Supplement (WS) (Hiraishi et al. 2014) updates and extends the 2006 IPCC Guidelines, with calculations for off-site CO_2 emissions from dissolved organic carbon (DOC) in drainage water and CH_4 emissions calculated from both OS land surface and drainage ditches. EFs are disaggregated by nutrient status and drainage depth, based on more studies, and split into different climatic zones to provide more accurate estimates of emissions. One of 18 studies that were used to derive the Tier 1 CO_2 EF was based on a deep-drained, nutrient rich, grassland bog in NZ (Nieveen et al. 2005)[3].

While coverage of the 2006 IPCC Guidelines on wetlands is restricted to drained peatlands, peatlands managed for peat extraction, and peatlands converted to flooded lands, the WS has five chapters addressing different types of wetland and OS systems. These include Drained Inland Organic Soils (Chapter 2), Rewetted Organic Soils (Chapter 3), Coastal Wetlands (Chapter 4), Inland Wetland Mineral Soils (Chapter 5), and Constructed Wetlands for Wastewater Treatment (Chapter 6). In this report, the focus will be on calculations for Drained Inland OS (Chapter 2) using the 2013 WS method. Appendix B presents a summary of CO_2, DOC, CH_4, and N_2O emissions from OS in the Waikato Region in 1990, 2008, 2012, and 2016 calculated using the 2013 WS.

2.3 Organic Soils

2.3.1 Definitions

2.3.1.1 IPCC

The 2006 IPCC Guidelines (Annex 3A.5, Chapter 3, Volume 4) identifies OS "*on the basis of criteria 1 and 2, or 1 and 3 listed below (FAO 1998[4]):*

1. Thickness of organic horizon greater than or equal to 10 cm. A horizon of less than 20 cm must have 12 percent or more organic carbon when mixed to a depth of 20 cm.

[2] While the regional GHG inventory (Waikato Regional Council & EnviroStrat, 2023) includes a category for emissions from Agriculture Soils, these are N_2O emissions from applied fertiliser and crop residues applied to soil and do not represent background N_2O emissions from managed Agricultural soils or CO_2 emissions due to land use change.

[3] Nieveen et al. (2005), based at Rukuhia in the Waikato region, was one of 18 studies that were used to derive the Tier 1 "Grassland, deep-drained, nutrient-rich" EF despite being from a nutrient-poor bog.

[4] Referred to in text as '(FAO 1998)' in the 2006 IPCC Guidelines Annex 3A.5, but full reference not found in bibliography. Instead, an updated version of this reference (World Resource Base 1998) has been referenced in this report.

2. Soils that are never saturated with water for more than a few days must contain more than 20 percent organic carbon by weight (i.e., about 35 percent organic matter).
3. Soils are subject to water saturation episodes and has either:
   a) At least 12 percent organic carbon by weight (i.e., about 20 percent organic matter) if the soil has no clay; or
   b) At least 18 percent organic carbon by weight (i.e., about 30 percent organic matter) if the soil has 60% or more clay; or
   c) An intermediate proportional amount of organic carbon for intermediate amounts of clay."

The IPCC follows the Food and Agriculture Organisation (FAO) definition for Histosols, although the criteria for thickness is omitted to accommodate the use of historically used country-specific definitions.

The IPCC definition used in the 2013 WS follows the definition (see above) used in the 2006 IPCC Guidelines (Annex 3A.5, Chapter 3 in Volume 4).

2.3.1.2 National and Regional

Regional scale soil mapping (S-Map and the Fundamental Soils Layer) uses the OS definition from the New Zealand Soil Classification (Hewitt 2010), which is:

> *"17% organic matter content (includes slightly peaty (17 - 30%), peaty (30 - 50%), and peat soils (>50%)) in horizons at least 30 cm thick within 60 cm of the soil surface."*

The New Zealand Soil Classification (NZSC) definition of OS is consistent with the IPCC definition for the 2006 IPCC Guidelines and 2013 WS, therefore it was used for this study.

The national GHG inventory uses the NZSC definition of OS as well. However, the national inventory historically included mineral soils with a peaty layer for N_2O emissions in the agriculture sector, these are defined as (Hewitt 2010):

> *"17 per cent organic matter content (includes slightly peaty, peaty and peat soils of 17 - 30 per cent, 30 - 50 per cent and greater than 50 per cent organic matter content). 0.1 metres of this depth occurring within 0.3 metres of the surface".*

The inclusion was based on a study by Kelliher et al. (2002) who found that mineral soils with a peaty layer emitted similar levels of N_2O as OS. But mineral soils with a peaty layer have now been omitted from the national GHG inventory (*Pers. Comm.,* Charlie Clark - MfE).

In the 2013 WS there is a separate section (Chapter 5 Inland Wetland Mineral Soils) for calculating emissions from wet mineral soils. For this study mineral soils with a peaty layer were excluded, and only emissions from OS were accounted for when using the 2006 IPCC Guidelines and 2013 WS. This was to maintain consistency with the existing national inventory, and between methods.

2.3.1.3 Peatlands

There are no IPCC definitions for peatland, but it is generally accepted that peatlands are areas of wetland (or former wetland) which are characterised by deposits of peat, where a high-water table has prevented dead organic material from fully decomposing and allowing it to accumulate and peat to form. All mapped OS in the Waikato Region were formed from organic soil material in wetlands and are therefore from peat. Collectively these areas of OS are called peatlands. In the 2013 WS, the concept of peatland is included in '(land with) organic soil' (Hiraishi et al. 2014).

2.3.2 Extent

For both the 2006 IPCC Guidelines and 2013 WS approaches, OS extent was determined using a hybridised spatial layer of S-Map, and where this was not available, the Fundamental Soils Layer (FSL) (Figure 1). The older FSL was mapped between 1940 and 1980 with complete coverage at 1:50,000 scale. The FSL is being replaced by the newer S-Map, which uses up-to-date soil mapping approaches (e.g., digital soil mapping) and is considered better overall quality. Being newer, S-Map does not include areas of drained OS soil which have been lost due to oxidation since the FSL mapping was completed.

S-Map soil units can sometimes contain more than one soil order (e.g., Organic and Gley). S-Map approximates the proportion that each soil order covers within the soil unit. To estimate soil area, we weighted each soil unit by the proportion of OS in each soil unit e.g., if a polygon was 100 ha, and the soil order was Organic, Organic, Gley and the proportion was 70%, 15%, 15%, then OS area was (100 ha x 0.70) + (100 ha x 0.15) = 85 ha.

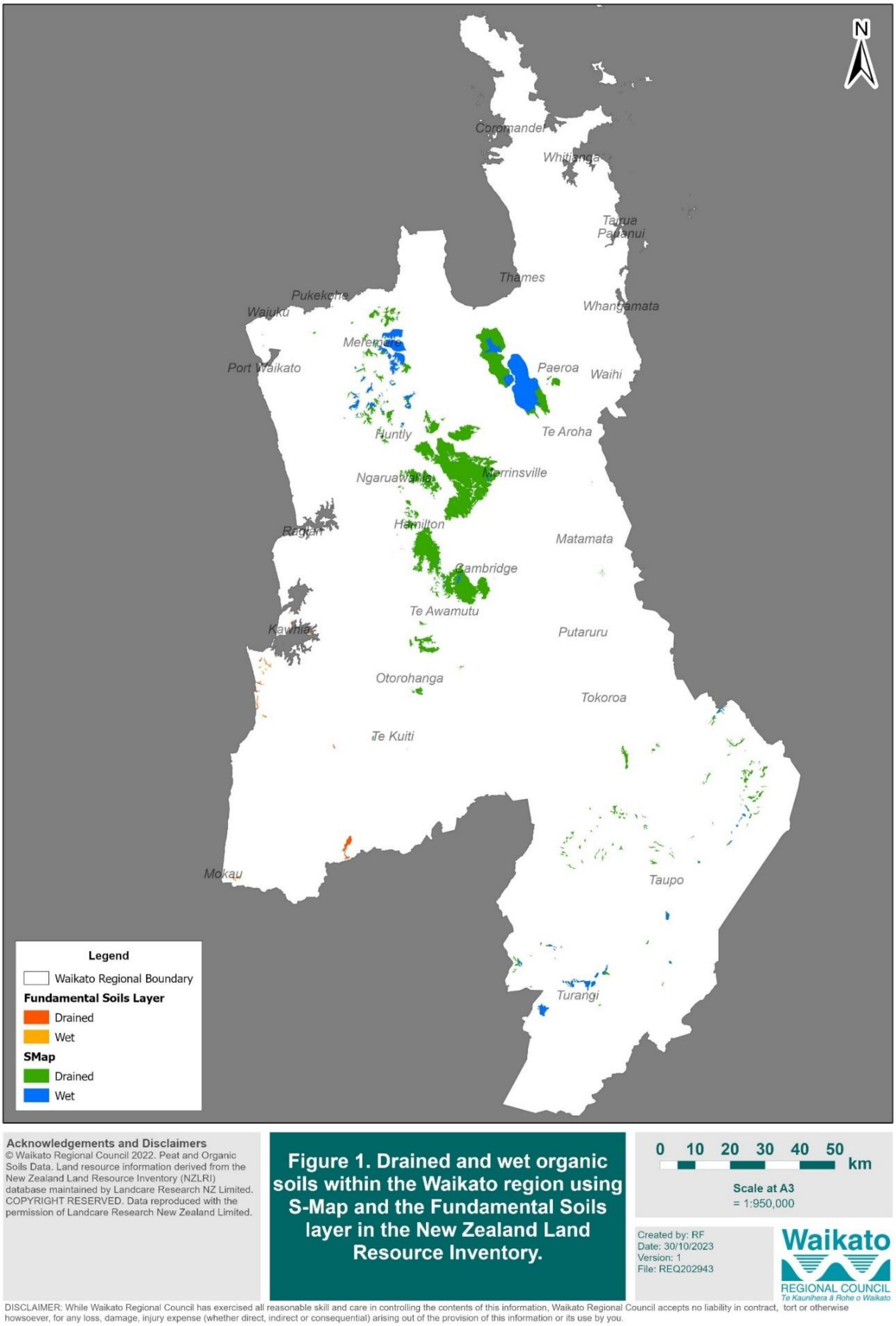


Figure 1: Extent of drained and wet OS as mapped by S-Map and the Fundamental Soils Layer.

2.4 Activity data

Activity data describes the characteristics and practices taking place on an area, that result in GHG emissions or removals (e.g., land use, climate zone, nutrient status, drainage depth). The IPCC (both 2006 IPCC Guidelines and 2013 WS) provides specific guidance on assembling the necessary activity data for implementation of default (Tier 1) methodology as well as general guidance for higher tiers where local or modelled data are used (Tier 2 and 3).

The default methodology in the 2006 IPCC Guidelines assumes that a country has data on the area of Organic Soils, broken down by climate zone, land use, and (to a limited extent) nutrient status. The 2013 WS uses activity data requirements of the 2006 IPCC Guidelines (land use, climate, and limited nutrient status classifications), and further delineates peatlands by drainage depth and nutrient status (nutrient poor or nutrient rich).

2.4.1 Land use

For both the IPCC 2006 approach and the 2013 WS, land use area and land cover information were estimated using 2016 data from the Land Use and Carbon Analysis System (LUCAS) NZ Land Use Map (LUM) v011 (Ministry for the Environment 2016), this approach is consistent with the national GHG inventory. The LUCAS LUM is divided into 12 land use classes and captures changes between 1990, 2008, 2012, and 2016 using a range of approaches (see Appendix C for area totals) (Manaaki Whenua - Landcare Research 2021). The 2016 LUCAS LUM is the most recent, although an update is expected in the near future.

2.4.2 Climate

Consistent with the national GHG inventory, the temperature data layer of Land Environments New Zealand (LENZ) was used to estimate climate region for both the 2006 IPCC Guidelines and 2013 WS approaches in this study. All OS in the Waikato Region are in the temperate climatic region (>10 °C). This aligns with the default climate classification provided in the 2006 IPCC Guidelines (2006 IPCC Guidelines Volume 4, Chapter 3, Figure 3A.5.1)[5] and can be derived using the Climate Zones classification scheme (2006 IPCC Guidelines Figure 3A.5.2), which suggest the North Island of NZ is Warm Temperate Moist.

2.4.3 Nutrient status

In the 2006 IPCC Guidelines, there are two temperate climatic zone EFs for on-site and off-site emissions from peat mines and these are stratified by nutrient status. Mined OS in the Waikato Region are nutrient poor given that they were originally in raised ombrotrophic peat bog wetlands.

The 2013 WS expands nutrient status to grassland[6] and provides default nutrient status assumptions. Based on European examples, only boreal-zone peatlands are formed under ombrotrophic (rain-fed, nutrient-poor) conditions, and therefore the default nutrient status for peatlands in temperate climate zones, like the Waikato, is nutrient-rich. However, a range of wetland types of different nutrient status exist in the Waikato, often formed as raised peat bogs under rain-fed conditions, and these nutrient poor drained bogs represent our deepest-drained OS (Newnham et al. 1995). For this study, nutrient status was derived from the

[5] IPCC Climate Zones (Figure 3A.5.1) include Tropical Montane, Tropical Wet, Tropical Moist, Tropical Dry, Warm Temperate Moist, Warm Temperate Dry, Cool Temperate Moist, Cool Temperate Dry, Boreal Moist, Boreal Dry, Polar Moist, Polar Dry. For New Zealand, EFs are stratified into warm and cool temperate, with the Waikato being Warm Temperate Moist.

[6] Nutrient status also expanded to those land uses that are assigned the grassland EFs e.g., other land and settlements.

historical wetlands layer in Freshwater Ecosystems of New Zealand (FENZ) (see Appendix D for land use area totals stratified by nutrient status (determined by wetland type) and see Appendix E for the GIS layers used in this study).

2.4.4 Drainage depth

The 2013 WS disaggregates OS by drainage depth[7]. The IPCC define deep-drained OS as having a mean annual water table depth (WTD) > 30 cm, while shallow-drained OS have mean annual WTD < 30 cm. Under the 2013 WS Tier 1 classifications, only EFs for nutrient-rich OS are stratified by drainage depth, all nutrient-poor OS are classed as 'drained'. WRC's peat surface oscillation (PSO) network suggests that all peatlands are deeply drained (Glover-Clark 2021; Pronger et al. 2021; Layton 2022), and other studies that report drainage depth of OS in the Waikato also indicate that these systems would be classified as deep-drained (Kelliher et al. 2016; Campbell et al. 2021).

2.4.5 Drainage ditch area

In the 2013 WS, drainage ditch area was required for the calculation of CH_4 emissions from drains for all land uses. According to the 2013 WS, the total area of drained OS occupied by ditches is any area of manmade channel in the peatland. Ditch area may be calculated as the width of ditches multiplied by the total ditch length. Ditch width can be calculated as the average distance from bank to bank.

Local values for ditch area were unknown, so default values from the 2013 WS were used to provide indicative ditch areas. Default ditch values are available for different land use classes and climate zones. For temperate forest land, 2.5% of the total land area was used, while all remaining land uses within a temperate climate zone were 5%, based on methods outlined in the 2013 WS[8].

2.4.6 Peat fires

The 2013 WS includes a method for calculating emissions from peat fires. While peat fires do occur occasionally on local peatlands (Rolleston 2022), information on the extent and date of these fires is not easily available. To understand the potential impact of peat fires on the OS inventory, a sensitivity analysis of emissions for areas between 0.1 – 1000 ha, regardless of the land use, was completed. Fire data is excluded from current totals but results from the sensitivity analysis can be found in the results (section 3.3) and calculations can be found in the 2013 WS spreadsheet in Appendix B.

2.4.7 1990 baseline

The national GHG inventory compares emissions to a 1990 benchmark, however the Waikato Regional inventory does not and is not required to do so. Regional councils in NZ must have regard to the emissions reduction plan (Ministry for the Environment 2022a) and national adaptation plan (Ministry for the Environment 2022b), but they do not have a legal mandate for carbon mitigation. The regional inventory follows GPC methodology and only includes calculations for the year of the regional inventory and change since the first inventory (2015/16). Therefore, for this study, OS emissions were not compared to a 1990 benchmark.

There is no method for estimating the area of OS in 1990 due to soils being mapped at different times, and not in 1990. This is also complicated by a limited understanding of how

[7] Drainage depth is determined by multi-year averages. This is to prevent a particular peatland from changing from one drainage class to another, e.g., in a particularly wet or dry year.

[8] In the 2013 WS, fractional ditch areas recorded in published studies are given for individual sites in Table 2A.1 and these data have been used to provide indicative ditch area values by land use class in Table 2.4.

subsidence has changed the area of OS since the soils were mapped, between each available LUCAS year, and how it will change area in the future. The current area of drained OS is expected to be less than in 1990 due to ongoing subsidence and oxidation of organic matter. Eventually subsidence and oxidation results in OS becoming mineral soils, most likely Gley Soils. While there is no requirement for WRC to compare to a 1990 baseline, it is important for the area of OS to be known for each GHG inventory reporting year, however this requires further research.

2.5 Emission factors

2.5.1 Tier 1

Separate OS emission estimates were calculated using Tier 1 default EFs from the 2006 IPCC guidance and 2013 WS. These EFs are presented in Table 1.

The 2006 IPCC Guidelines only provided default EFs for estimating emissions of CO_2 and N_2O from OS. These EFs were stratified by climate zone (e.g., boreal/cold temperate, warm temperate, and tropical/sub-tropical) and by land use (e.g., forest, cropland, grassland, settlements, other land). All OS in the Waikato Region were classed as temperate (see section 2.4.2). Emissions from peat extraction included on-site emissions from the mining site and off-site emissions from the volume of mined material. Volume mined was estimated from data presented in Clarkson (2016) and a IPCC 2006 Tier 1 carbon fraction conversion factor of 0.07 t C m^{-3} air-dry peat was used to estimate the emissions from the volume of mined peat.

The 2013 WS provided updated default EFs for estimating emissions of CO_2 and N_2O, but it also included EFs for DOC export and CH_4 from land and drainage ditches from drained inland OS (Chapter 2). EFs for other wetland and OS types (e.g., rewetted OS, coastal wetlands, inland wetland mineral soils, constructed wetlands) are also included in the 2013 WS but only EFs from inland OS were included in this inventory (discussed further in section 5.5). In the 2013 WS, peat extraction only included on-site emissions from the drained peat and suggests using the 2006 IPCC Guidelines for calculating CO_2 emissions for off-site emissions[9]. The 2013 WS EFs are stratified by climate zone, land use, drainage depth, and nutrient status. All OS in the Waikato Region are warm temperate moist (section 2.4.2), either nutrient rich or nutrient poor (section 2.4.3) and assumed to be deeply drained (section 2.4.4).

For both the 2006 IPCC Guidelines and the 2013 WS, no explicit EF was presented for settlements. The IPCC guidance recommends using the cropland EFs, because the peat is drained and not removed. However, because settlements are not cultivated it was decided that it was more appropriate to use the grassland EFs.

Other land has no EF in the 2006 IPCC Guidelines or 2013 WS. Areas mapped as other land were reviewed using aerial photography (Appendix F) and reclassified as either grassland or not OS and were assigned an EF based on that reclassification.

[9] Table 2.1 of the 2013 WS – see note i.

Table 1: Tier 1 emission factors from the 2006 IPCC Guidelines and 2013 WS approaches for temperate systems alongside draft Tier 2 emission factors from local studies.

Land use	Gas	Emission Factors		
		2006 IPCC Tier 1	**2013 WS Tier 1[B]**	**Local Tier 2**
Forest land (drained)	CO_2 (t CO_2-C ha^{-1} yr^{-1})	0.68 (0.41–1.91)[A]	2.6 (2–3.3)	-
	DOC (t CO_2-C ha^{-1} yr^{-1})	-	0.31 (0.19–0.46)	-
	CH_4 (land) (kg CH_4 ha^{-1} yr^{-1})	-	2.5 (-0.6–5.7)	-
	CH_4 (ditch) (kg CH_4 ha^{-1} yr^{-1})	-	217 (41–393)	-
	N_2O (kg N_2O-N ha^{-1} yr^{-1})	-	2.8 (-0.57–6.1)	-
Cropland	CO_2 (t CO_2-C ha^{-1} yr^{-1})	10[C]	7.9 (6.5–9.4)	-
	DOC (t CO_2-C ha^{-1} yr^{-1})	-	0.31 (0.19–0.46)	-
	CH_4 (land) (kg CH_4 ha^{-1} yr^{-1})	-	0 (-2.8–2.8)	-
	CH_4 (ditch) (kg CH_4 ha^{-1} yr^{-1})	-	1,165 (335–1,995)	-
	N_2O (kg N_2O-N ha^{-1} yr^{-1})	8 (2–24)[A]	13 (8.2–18)	-
Grassland	CO_2 (t CO_2-C ha^{-1} yr^{-1})	2.5 (0.25–4.75)[C] (warm temperate)	5.3 (3.7–6.9) (nutrient poor) 6.1 (5–7.3) (nutrient rich)	4.21 (1.8–6.6)
	DOC (t CO_2-C ha^{-1} yr^{-1})	NA	0.31 (0.19–0.46)	-
	CH_4 (land) (kg CH_4 ha^{-1} yr^{-1})	NA	1.8 (0.72–2.9) (nutrient poor) 16 (2.4–29) (nutrient rich)	-
	CH_4 (ditch) (kg CH_4 ha^{-1} yr^{-1})	NA	1,165 (335–1,995)	-
	N_2O (kg N_2O-N ha^{-1} yr^{-1})	8 (2–24)[A]	4.3 (1.9–6.8) (nutrient poor) 8.2 (4.9–11) (nutrient rich)	1.57 (0.2–10.6)
Peat extraction (on-site emissions)	CO_2 (t CO_2-C ha^{-1} yr^{-1})	0.2 (0–0.63)[A] (nutrient poor) 1.1 (0.03–2.9)[A] (nutrient rich)	2.8 (1.1–4.2)	-
	DOC (t CO_2-C ha^{-1} yr^{-1})	NA	0.31 (0.19–0.46)	-
	CH_4 (land) (kg CH_4 ha^{-1} yr^{-1})	NA	6.1 (1.6–11)	-
	CH_4 (ditch) (kg CH_4 ha^{-1} yr^{-1})	NA	542 (102–981)	-
	N_2O (kg N_2O-N ha^{-1} yr^{-1})	0	0.3 (-0.03–0.64)	-
(off-site emissions)	CO_2 (t CO_2-C ha^{-1} yr^{-1})	0.07 (nutrient poor, tonnes C m^{-3} air-dry peat)	See 2006 IPCC Tier 1	-
Settlements	See Grassland	See Grassland	See Grassland	-
Other land	See Grassland	See Grassland	See Grassland	-

[A] Error in brackets as 'range', 'range of underlying data', 'uncertainty', or 'uncertainty range'
[B] 95% confidence interval in brackets for all 2013 WS EFs and local Tier 2 EFs.
[C] ±90% error in brackets, represents a nominal estimate of error, equivalent to two times standard deviation as a percentage of the mean.

2.5.2 Draft Tier 2

A draft Tier 2 EF of 4.21 t C ha^{-1} yr^{-1} was calculated for CO_2 emissions from grasslands. This value is a mean of CO_2 emissions measured or estimated at four managed OS studies (Schipper and McLeod 2002; Campbell et al. 2015; Campbell et al. 2021) under rotationally grazed dairy pasture in the Waikato Region (Table 2). The Campbell et al., (2015) study was a reanalysis of data and results presented by Nieveen et al., (2005) who reported that net ecosystem exchange (NEE) was indistinguishable from zero. However, the findings of Nieveen et al., (2005) were impacted by inadequate data correction leading to underestimates of both daytime and night-time NEE but biased towards net CO_2 uptake. The Campbell et al., (2015) re-analysis accounted for very large grazing-induced changes in pasture biomass using phytomass index, which refined their gap-filling procedure.

A draft Tier 2 EF of 1.57 t N ha^{-1} yr^{-1} was calculated for N_2O emissions from grasslands, this value is from a single study by Kelliher et al. (2016) of a managed OS under rotationally grazed dairy pasture in the Waikato Region.

Table 2: Draft Tier 2 EFs for CO_2 and N_2O derived from local data.

Source	t CO_2-C ha^{-1} yr^{-1}	Comments
Schipper & McLeod (2002)	3.7	Comparing soil C between two sites – total carbon loss
Campbell et al (2015)	2.94	Eddy covariance method – total carbon loss (NECB)[A]
Campbell et al (2021)	1.96	Eddy covariance method – total carbon loss (NECB)
Campbell et al (2021)	8.25	Eddy covariance method – total carbon loss (NECB)
Mean	4.21 (1.8 – 6.6)	95% confidence limit in parenthesis.
Source	**kg N ha^{-1} yr^{-1}**	**Comments**
Kelliher et al (2016)	1.57[B] (0.2 – 10.6)	Chamber measurements. 95% confidence limit in parenthesis.

[A] NECB = net ecosystem carbon balance.

[B] In Kelliher et al (2016) the original value is reported as 4.3 g N ha^{-1} d^{-1}, this value and the corresponding 95% confidence limits have been converted to kg N ha^{-1} yr^{-1}.

While developing a method to report on emissions from peatlands in the UK, Evans et al., (2017) stated that local data that came from less than four sites was too unreliable to replace Tier 1 values. However, local data that were calculated from at least four primary sites and that fell outside of the 95% confidence interval of the Tier 1 EF were considered demonstrably robust enough to replace Tier 1 values. However, after expert advice, Evans et al., (2017) also used local data when it fell within the 95% confidence interval of the Tier 1 EF and was considered to provide a more realistic estimate of emissions.

The draft Tier 2 grassland CO_2 EF of 4.21 t CO_2-C ha^{-1} yr^{-1} was within the range of uncertainty for the Tier 1 EF for the 2006 IPCC Guidelines and for nutrient poor grasslands in the 2013 WS. The draft Tier 2 CO_2 EF was broadly similar to the 2013 WS Tier 1 EF (Table 1). The four local measurements were from drained and modified raised ombrotrophic (low nutrient) peat bogs in Moanatuatua (Schipper & McLeod 2002, Campbell et al 2021) and Rukuhia (Campbell et al 2015). Campbell et al., (2015) also included allied shorter-term mobile measurements at Rukuhia, Komakorau, and Moanatuatua. These bogs displayed similar NEE when water tables were at a similar depth, suggesting that values from that study could be extrapolated to other similar peats farms in the Waikato. Because the draft Tier 2 CO_2 EF for grassland likely provides a better estimate of CO_2 emissions from local low nutrient OS under grassland than the Tier 1 EF, it was considered suitable to use for all grassland emissions estimates for the 2006 IPCC Guidelines because about 70% of OS under grassland are low nutrient. The draft Tier 2 EF was also considered appropriate for use for all low nutrient OS under grassland for emissions based on the 2013 WS calculations.

The draft Tier 2 EF for N_2O from grassland of 1.57 kg N ha^{-1} yr^{-1} was outside the range of uncertainty for the Tier 1 EFs in the 2006 IPCC Guidelines and the 2013 WS, although its own range of uncertainty overlapped with those of the Tier 1 EFs (Table 1). The draft Tier 2 N_2O EF was much lower than Tier 1 EFs, but the draft Tier 2 EF was only derived from one local study. Based on the limited local data it was considered inappropriate to use the draft Tier 2 N_2O EF for regional OS emissions calculations.

2.6 Calculations

Emissions were calculated in a Microsoft Excel spreadsheet, and were generally Area × EF (Equation 1),

$$Emissions = A \times EF \qquad \text{Equation 1}$$

Where:

Emissions = emissions of a particular gas (e.g., CO_2, CH_4, N_2O).
A = land area of drained OS in a particular climate zone and nutrient status.
EF = emission factor for a particular climate zone, drainage depth, and nutrient status.

Using the 2006 IPCC Guidelines, on-site N_2O emissions were calculated for grassland and cropland. CO_2 emissions were calculated for grassland, cropland, wetlands, settlements, and other land. Using the 2013 WS, on-site CO_2, CH_4 (from both land and drains), and N_2O emissions, as well as off-site DOC, were calculated for grassland, cropland, forested land, settlements, other land, and extracted peat. CO_2, CO, and CH_4 emissions were calculated for peat fires, but not included in the overall estimate of emissions.

For extracted peat, the IPCC 2006 Guidelines calculations also included off-site emissions of CO_2-C from the volume mined (Equation 2),

$$CO_2 - C_{ww_{peat_{off-site}}} = \frac{(Vol_{dry\_peat} \times Cfraction_{vol\_peat})}{1000} \qquad \text{Equation 2}$$

Where:

$CO_2 - C_{ww\ peat\ off\text{-}site}$ = off-site $CO_2 - C$ emissions from peat removed for horticultural use.
Vol_{dry_peat} = volume of air-dry peat extracted, $m^3\ yr^{-1}$.
Cfraction = carbon fraction of air-dry peat by volume, tonnes C, m^{-3} of air-dry peat.

For off-site emissions from extracted peat, production volumes were sourced from Clarkson (2016), and this was multiplied by a carbon conversion factor of 0.07 t C m^{-3} air-dry peat, presented in Section 7.2.1.1 of the IPCC 2006 Guidelines.

Each GHG was summed into tonnes of emissions per year and then converted to carbon dioxide equivalent (CO_2e) emissions estimated using the global warming potentials for each gas sourced from the Climate Change Fifth Synthesis Report (AR5) (Eggleston et al. 2006; Hiraishi et al. 2014; Pachauri et al. 2014)[10]. See Appendix A and B for detailed calculations for both 2006 IPCC Guidelines and 2013 WS approaches.

2.7 Uncertainties

Uncertainty represents the extent to which the value of a variable is unknown. In emissions inventories, uncertainty arises from quantifiable errors and variations in methods and data including field measurement errors, discrepancies in geographic and land cover mapping, incomplete data, misreporting or misclassification, unrepresentative sampling, and model inaccuracies. The quantification of uncertainty in inventories enables agencies to determine

[10] Non-CO_2 emissions were converted to carbon dioxide equivalents (CO_2e) using GWP values of 34 for CH_4 and 298 for N_2O (Pachauri et al. 2014).

whether estimated changes in emissions over multiple years exceed the uncertainty associated with estimates for an individual year (Hiraishi et al. 2014)[11].

Uncertainty analysis serves to provide total uncertainty estimates for emissions or removals in a land-use category and highlight areas for potential enhancement of inventory methods to mitigate uncertainties. The 95% confidence interval (CI) is the measure of uncertainty for national GHG inventories. It is considered best practice to report 95% CI for activity data, EFs, and other parameters, as well as for total GHG emissions within any key category or land use category for a geographic area (Eggleston et al. 2006).

Uncertainties associated with drained inland Organic Soils include high spatial variability of soil organic carbon, variations in surface areas and EFs based on drainage class, and substantial spatial and temporal variability in N_2O emissions. This leads to significant errors relative to mean fluxes. Another notable source of uncertainty is estimates of fire emissions due to variations in fire behaviour among vegetation types, differences in the fraction of fuel combusted across ecosystems, land management practices, the distribution of smoke among GHGs (Hiraishi et al. 2014).

Ideally, uncertainties are reduced as far as practicable. In general, more sampling to estimate values for land-use categories will increase precision and reduce confidence intervals, while implementation of higher tier methods that incorporate country-specific information is likely to increase accuracy. In this report, uncertainties in EFs were reported (95% CI) where possible and used to determine the adequacy of draft Tier 2 EFs.

3 Results

3.1 Activity

In the Waikato Region, there are 83,945 ha of OS. Of this, 82,678 ha are in the area mapped by S-Map and 1,267 in the area mapped solely by the FSL (Figure 1). Additionally, mineral soils with a peaty layer cover about 6,000 ha of the Waikato Region, but these were not included in emissions calculations to be consistent with the NZ national inventory. N_2O emissions from mineral soils with a peaty layer were previously included in the NZ national GHG inventory, but are currently not included (*Pers. Comm.,* Charlie Clark - MfE).

Of the total OS area, 64,610 ha were assessed for emissions in the Waikato Region for 2016 under both the 2006 IPCC Guidelines and 2013 WS approaches. There was 19,335 ha which were not assessed for emissions, as these were classified as wetlands (vegetated non-forest and open water) and pre-1990 natural forest by LUCAS. Of the area assessed for emissions, there were 15 ha of 'Other land' not classified in a particular LUCAS land use class. An assessment of the mapped polygons revealed the areas were generally either nutrient poor grassland or incorrectly mapped (e.g., sand dune, roadside). Polygons dominated by grassland were re-classified as 'Grassland' (8.7 ha) and assigned the nutrient poor grassland EF, while incorrectly mapped OS polygons remained 'Other land' (6.5 ha) and retained the EF of 0. The assessment methodology can be found in Appendix F.

[11] Section 7.3 of the 2013 WS outlines uncertainties and refers to Chapter 3 in Volume 1 of the 2006 IPCC Guidelines for further information.

In 2016, grassland dominated the OS area assessed for emissions, covering 61,932 ha. In the 2013 WS, grassland was further divided into 43,063 ha of nutrient poor and 18,869 ha of nutrient rich OS[12]. Cropland comprised 1,414 ha, this will have likely been maize for silage or grain. Settlements occupied 610 ha and were mostly part of Hamilton City. To apply the 2013 WS, settlements were further divided by nutrient rich and nutrient poor OS, these covered 413 and 197 ha respectively. Forestry coverage identified was 634 ha, including emissions from land under managed (planted) forest and excluding natural forest. Peat mines covered 69 ha of OS; this was represented by a single peat mine on the Hauraki Plains. The volume of peat extracted in 2016, as required by the 2006 IPCC approach, was estimated to be 13,728 m^3.

The 2013 WS includes a category for peat fires, but as outlined in section 2.4.5 there were insufficient data to estimate the annual area of the peat fires for the region. The potential impact of this on emissions is described in section 3.3.

3.2 Emissions

3.2.1 Tier 1

Total GHG emissions from drained OS in the Waikato Region were 0.87 Mt CO_2e in 2016 when calculated using the Tier 1 EFs provided in the 2006 IPCC Guidelines (Table 3). Due to its extensive area, grassland dominated emissions from OS soils for both CO_2 and N_2O. There was a large change in N_2O emissions between the amount emitted as N_2O and CO_2e due to the high GWP of N_2O. CO_2 emissions from cropland were about 7% of total emissions, but only occupy around 2% of OS area, this is due to a high Tier 1 CO_2 EF relative to other land uses. Collectively settlements, peat extraction, and forest land represent about 1% of emissions from OS, due to covering only a small area. Across all land uses, emissions of CO_2, including off-site emissions from mined peat, were about 73% of total emissions, and N_2O emissions were 27% (Table 3).

Using the approach and Tier 1 EFs provided in the 2013 WS, CO_2e emissions for drained OS in the Waikato Region in 2016 were 1.71 Mt CO_2e (Table 4). Grasslands on OS dominated emissions, and within the grassland land use, nutrient poor OS emitted almost twice as much as nutrient rich OS. The large emissions from grassland were due to their extensive area on OS in the Waikato Region. Relative to grassland, cropland emissions were small, about 3% of total emissions, even though cropland had the highest EFs across most gases. Collectively forest and plantation land, settlements, and peat extraction comprised about 1.7% of total emissions (Table 4). Across all land uses CO_2 emissions, including CO_2 exported off-site as DOC, were about 82% of total emissions. CH_4 emissions were about 8% of total emissions, most of this was from the up to 5% of land area associated with drainage ditches. N_2O emissions accounted for 10% of total emissions (Table 4).

The Tier 1 CO_2 EFs in the 2013 WS for both rich and poor nutrient grassland were more than double the 2006 IPCC Guidelines grassland EFs. Because grassland was the dominant activity on drained OS in the Waikato Region, this difference had a large impact on total emissions. Additionally, the 2013 WS included EFs for DOC and CH_4 from paddocks and drainage ditches. While not included in the final calculation, guidance for estimating emissions from peat fires were also included in the 2013 WS (see section 3.3). The 2006 IPCC Guidelines had a higher N_2O EF for grassland than the 2013 WS, resulting in higher overall N_2O emissions, even though the 2013 WS included N_2O EFs for more activities. The 2013 WS refers to the 2006 Guidelines

[12] Nutrient status was determined by historical wetland types outlined using FENZ data e.g., nutrient poor OS were classed as 'bog' and nutrient rich OS were classed as all other wetland types (fen, gumland, marsh, swamp). See Appendix D for more details.

for off-site extracted peat emissions, so both 2006 and 2013 calculations include off-site CO_2 emissions using the 2006 Guidelines. However, it is unclear how much of the off-site emissions from mined peat once used as its end-product (e.g., garden compost) remain in the Waikato Region.

Table 3: CO_2 and N_2O emissions from Organic Soils in the Waikato Region during the 2016 annual period, estimated using IPCC (2006) Guidelines and Tier 1 EFs.

		CO_2			Mined Peat				N_2O			
			Emissions				Emissions			Emissions		
Activity	**Area (ha)**	***EF (t CO_2-C ha^{-1} yr^{-1})***	**(t CO_2-C yr^{-1})**	**(t CO_2 yr^{-1})**	***Conversion factor (t C m^{-3} dry peat)***	**Volume mined (m^3)**	**(t CO_2-C yr^{-1})**	**(t CO_2e yr^{-1})**	***EF (kg N_2O-N ha^{-1} yr^{-1})***	**(t N_2O-N yr^{-1})**	**(t CO_2e yr^{-1})**	**Total Emissions by Activity (t CO_2e yr^{-1})**
Forest Land (Temperate)	634	*0.68*	431	**1,582**	-	-	-	-	-	-	**-**	**1,582**
Cropland (Warm Temperate)	1,414	*10*	14,140	**51,894**	-	-	-	-	*8*	11	**5,292**	**57,186**
Grassland (Warm Temperate)	61,932	*2.5*	154,830	**568,226**	-	-	-	-	*8*	495	**231,805**	**800,031**
Peat Extraction (Nutrient Poor)	69	*0.2*	14	**51**	*0.07*	13,728	961	**3,527**	-	-	**-**	**3,577**
Settlements (Warm Temperate)	610	*2.5*	1,524	**5,596**	-	-	-	-	8	5	**2,283**	**7,879**
Other land [A] (Grassland, warm temperate)	9	*2.5*	22	**80**	-	-	-	-	*8*	0.1	**33**	**113**
Other land (Not OS)	7	*0*	0	**0**	-	-	-	-	*0*	0	**0**	**0**
Total Emissions by GHG Gas (t CO_2e yr^{-1})				**627,428**				**3,527**			**239,413**	**870,368**
									Grand Total of Emissions (Mt CO_2e yr^{-1})			**0.87**

Table 4: GHG emissions from Organic Soils in the Waikato Region during the 2016 annual period, estimated using Guidelines from the 2013 Wetland Supplement and Tier 1 Efs.

		CO_2			CO		Mined peat			DOC			CH_4			CH_{4_DITCH} [D]			N_2O			Total Emissions by Activity
		EF	Emissions		*EF*	Emissions	*C.F.* [C]	*Emissions*		*EF*	Emissions		*EF*	Emissions		*EF*	Emissions		*EF*	Emissions		
Activity (Temperate)	**Area (ha)**	*(t CO_2-C ha^{-1} yr^{-1})*	(t CO_2-C yr^{-1})	(t CO_2 yr^{-1})	*(g kg^{-1} d.m.b CO-C yr^{-1})*	(t CO_2e yr^{-1})	*(t C m^{-3} dry peat)*	(t C yr^{-1})	(t CO_2 yr^{-1})	*(t C ha^{-1} yr^{-1})*	(t C yr^{-1})	(t CO_2 yr^{-1})	*(kg CH_4 ha^{-1} yr^{-1})*	(t CH_4 yr^{-1})	(t CO_2e yr^{-1})	*(kg CH_4 ha^{-1} yr^{-1})*	(t CH_4 yr^{-1})	(t CO_2e yr^{-1})	*(kg N_2O-N ha^{-1} yr^{-1})*	(t N_2O-N yr^{-1})	(t CO_2e yr^{-1})	(t CO_2e yr^{-1})
Forest and Plantation	634	*2.6*	1,648	**6,048**	-	-	-	-	-	*0.3*	196	**721**	*2.5*	1.6	**54**	*217*	3.4	**117**	*2.8*	1.8	**830**	**7,770**
Cropland	1,414	*7.9*	11,174	**41,010**	-	-	-	-	-	*0.3*	438	**1,609**	*0*	0	**0**	*1,165*	82.4	**2,801**	*13*	18.4	**8,603**	**54,023**
Grassland (Nut. poor, drained)	43,063	*5.3*	228,232	**837,612**	-	-	-	-	-	*0.3*	13,349	**48,992**	*1.8*	77.5	**2,635**	*1,165*	2508	**85,286**	*4.3*	185	**86,633**	**1,061,159**
Grassland (Nut. rich, deep drained)	18,869	*6.1*	115,104	**422,431**	-	-	-	-	-	*0.3*	5,850	**21,468**	*16*	302	**10,265**	*1,165*	1099	**37,371**	*8.2*	155	**72,392**	**563,927**
Peat Extraction (on-site)	69	*2.8*	193	**707**	-	-	-	-	-	*0.3*	21.3	**78**	*6.1*	0.4	**14**	*542*	1.9	**63**	*0.3*	0.02	**9.7**	**871**
(offsite)	13,728 [A]	-	-	**-**	-	-	*0.07*	961	3,527	-	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**	**3,527**
Settlements (See nut. poor grassland)[B]	197	*5.3*	1,043	**3,829**	-	-	-	-	-	*0.3*	61	**224**	*1.8*	0.4	**12**	*1,165*	11.5	**390**	*4.3*	0.8	**396**	**4,851**
Settlements (See nut. rich grassland)[B]	413	*6.1*	2,519	**9,246**	-	-	-	-	-	*0.3*	128	**470**	*16*	6.6	**225**	*1,165*	24.1	**818**	*8.2*	3.4	**1584**	**12,343**
Other land (See nut. poor grassland) [B]	9	*5.3*	46	**169**	-	-	-	-	-	*0.3*	3	**10**	*1.8*	0	**0**	*1,165*	0.5	**17**	*4.3*	0.04	**18**	**214**
Other land (Not OS)	7	*0*	0	**0**	-	-	-	-	-	*0*	0	**0**	*0*	0	**0**	*0*	0	**0**	*0*	0	**0**	**0**
Fires	NR	*362*	NR	**NR**	*207*	NR	-	-	-	-	-	**NR**	*9*	NR	NR	-	-	-	-	-	**-**	**NR**
Total Emissions by GHG Gas (t CO_2e yr^{-1})				**1,321,052**		**NR**			**3,527**			**73,572**			**13,205**			**126,864**			**170,466**	**1,708,685**
Grand Total of Emissions (Mt CO_2e yr^{-1})																						**1.71**

A) Volume mined (m^3)

B) EFs for settlements and other land re-classed as grassland are the same as grasslands

C) Conversion factor

D) CH_{4_DITCH} emissions calculated for 2.5% of total land area for forests and 5% for all other land categories.

3.2.2 Draft Tier 2

To assess the impact of local data on OS emissions, the Tier 1 grassland CO_2 EF of 2.5 t CO_2-C ha^{-1} yr^{-1} in the 2006 IPCC Guidelines and the low nutrient grassland EF of 5.3 t CO_2-C ha^{-1} yr^{-1} in the 2013 WS were substituted with the locally derived draft Tier 2 EF of 4.21 t CO_2-C ha^{-1} yr^{-1} (see section 2.5.2).

Using the 2006 IPCC guidelines and the draft Tier 2 CO_2 EF, OS emissions from grasslands in the Waikato Region increased from 800,031 to 1,188,698 t CO_2e yr^{-1} and total OS emissions increased from 0.87 to 1.26 Mt CO_2e yr^{-1} (Table 5).

For the 2013 WS and using the draft Tier 2 CO_2 EF for low nutrient OS under grassland emissions decreased from 1,061,159 t CO_2e yr^{-1} to 888,900 t CO_2e yr^{-1} and total OS emissions decreased from 1.71 to 1.54 Mt CO_2e (Table 6).

OS GHG emissions were not calculated using the draft Tier 2 grassland EF for N_2O (see section 2.5.2 for more detail).

Table 5: 2016 GHG emissions from Organic Soils, in the Waikato Region, estimated using the 2006 IPCC Guidelines EFs and Tier 2 EFs where applicable.

		CO_2			Mined Peat				N_2O			
			Emissions				Emissions		*EF*	Emissions		
Activity[A]	Area (ha)	*EF (t CO_2-C ha^{-1} yr^{-1})*	(t CO_2-C yr^{-1})	(t CO_2 yr^{-1})	*Conversion factor (t C m^{-3} dry peat)*	Volume mined (m^3)	(t CO_2-C yr^{-1})	(t CO_2e yr^{-1})	*(kg N_2O-N ha^{-1} yr^{-1})*	(t N_2O-N yr^{-1})	(t CO_2e yr^{-1})	Total Emissions by Activity (t CO_2e yr^{-1})
Forest Land (Temperate)	634	*0.68*	431	**1582**	-	-	-	-	-	-	-	**1,582**
Cropland (Warm Temperate)	1,414	*10*	14,140	**51,894**	-	-	-	-	*8*	11.3	**5,292**	**57,186**
Grassland (drained, Temperate)	61,932	***4.21***	260,734	**956,893**	-	-	-	-	*8*	495	**231,805**	**1,188,698**
Peat Extraction (Nutrient Poor)	69	*0.2*	14	**51**	*0.07*	13,728	961	**3,527**	-	-	-	**3,578**
Settlements (drained)	610	***4.21***	2,568	**9,425**	-	-	-	-	*8*	5	**2,283**	**11,708**
Other land	9	***4.21***	38	**139**	-	-	-	-	*8*	0.1	**33**	**172**
Total Emissions by GHG Gas (t CO_2e yr^{-1})				**1,019,983**				**3,527**			**239,413**	**1,262,924**
									Grand Total of Emissions (Mt CO_2e yr^{-1})			**1.26**

Table 6: 2016 GHG emissions from Organic Soils, in the Waikato Region, estimated using the 2013 WS EFs and Tier 2 EFs where applicable.

		CO_2			CO		Mined peat			DOC			CH_4			CH_{4_DITCH}[B]			N_2O			Total Emissions by Activity
		EF	Emissions		*EF*	Emissions	*C.F.*[C]	Emissions		*EF*	Emissions		*EF*	Emissions		*EF*	Emissions		*EF*	Emissions		
Activity (Temperate)	**Area (ha)**	*(t CO_2-C ha^{-1} yr^{-1})*	(t CO_2-C yr^{-1})	(t CO_2 yr^{-1})	*(g kg^{-1} d.m.b CO-C yr^{-1})*	(t CO_2e yr^{-1})	*(t C m^{-3} dry peat)*	(t C yr^{-1})	(t CO_2 yr^{-1})	*(t C ha^{-1} yr^{-1}*	(t C yr^{-1})	(t CO_2 yr^{-1})	*(kg CH_4 ha^{-1} yr^{-1})*	(t CH_4 yr^{-1})	(t CO_2e yr^{-1})	*(kg CH_4 ha^{-1} yr^{-1})*	(t CH_4 yr^{-1})	(t CO_2e yr^{-1})	*(kg N_2O-N ha^{-1} yr^{-1})*	(t N_2O-N yr^{-1})	(t CO_2e yr^{-1})	(t CO_2e yr^{-1})
Forest and Plantation	634	*2.6*	1,648	6,048	-	-	-	-	-	*0.3*	196	721	*2.5*	1.6	54	*217*	3.4	117	*2.8*	1.8	830	7,770
Cropland	1,414	*7.9*	11,174	41,010	-	-	-	-	-	*0.3*	438	1,609	*0*	0	0	*1,165*	82.4	2,801	*13*	18.4	8,603	54,023
Grassland (Nut. poor, drained)	43,063	***4.21***	**181,295**	**665,354**	-	-	-	-	-	*0.3*	13.349	48,992	*1.8*	77.5	2,635	*1,165*	2508	85,286	*4.3*	185	86,633	**888,900**
Grassland (Nut. rich, deep drained)	18,869	*6.1*	115,104	422,431	-	-	-	-	-	*0.3*	5,850	21,468	*16*	302	10,265	*1,165*	1099	37,371	*8.2*	155	72,392	563,927
Peat Extraction (on-site)	69	*2.8*	193	707	-	-	-	-	-	*0.3*	21.3	78	*6.1*	0.4	14	*542*	1.9	63	*0.3*	0.02	9.7	871
(off-site)	13,728 A	-	-	-	-	-	*0.07*	961	3,527	-	-	-	-	-	-	-	-	-	-	-	-	3,527
Settlements (See nut. poor grassland)	197	***4.21***	**829**	**3,044**	-	-	-	-	-	*0.3*	61	224	*1.8*	0.4	12	*1,165*	11.5	390	*4.3*	0.8	396	**4,066**
Settlements (See nut. rich, grassland)	413	*6.1*	2,519	9,246	-	-	-	-	-	*0.3*	128	470	*16*	6.6	225	*1,165*	24.1	818	*8.2*	3.4	1,584	12,343
Other land (See nut. poor grassland)	9	***4.21***	**37**	**139**	-	-	-	-	-	*0.3*	3	10	*1.8*	0	0	*1,165*	0.5	17	*4.3*	0.04	18	**184**
Other land (Not OS)	7	0	0	0	-	-	-	-	-	*0*	0	0	*0*	0	0	*0*	0	0	*0*	0	0	**0**
Fires	NR	*362*	NR	**NR**	*207*	NR	-	-	**-**	-	-	**NR**	*9*	NR	NR	-	-	-	-	-	**-**	**NR**
Total Emissions by GHG Gas (t CO_2e yr^{-1})				**1,147,979**		NR			3,527			73,572			13,205			126,864			170,466	**1,535,611**
																					Grand Total of Emissions (Mt CO_2e yr^{-1})	**1.54**

A) Volume mined (m^3)
B) Dry matter burnt
C) Conversion factor

3.3 Fire sensitivity analysis

There was insufficient information on the frequency and extent of peat fires in the Waikato Region to confidently include them in the OS emissions inventory. An area-based sensitivity analysis based on Tier 1 EFs from the 2013 WS was used to understand the impact peat fires might have on total OS emissions (Table 7).

The analysis indicated that fires of 100 ha or less on undrained OS would contribute < 1% to total emissions and a fire of 1000 ha would contribute about 8%. For drained OS, fires on 10 ha or less would contribute < 0.5% to total emissions, fires on 100 ha would contribute around 4% and fires on 1000 ha would contribute 27%.

Table 7: Fire sensitivity analysis using Tier 1 EFs from 2013 WS for drained and undrained OS. Emissions from fire were added to total emissions presented in Table 3 to calculate contribution %.

	Area (ha)				
	0.1	1	10	100	1000
Undrained OS (t CO_2e yr^{-1})	15	146	1,464	14,638	146,377
Contribution to total emissions (%)	0.0001	0.009	0.09	0.9	8
Drained OS (t CO_2e yr^{-1})	61	609	6,085	60,845	608,446
Contribution to total emissions (%)	0.004	0.04	0.4	4	27

Fires on undrained OS do occur, for example Clarkson (1997) reported fires of about 150 ha and 2000 ha in 1984 and 1989 at Whangamarino wetland in the lower Waikato catchment. Also reported by Clarkson (1996) was a fire in 1972 at Moanatuatua wetland south of Hamilton City, this fire covered about 80 ha. Although Kopuatai has not had any large-scale fires since the 1970s, lighting-initiated fires have more recently occurred in 2005, 2017, and 2020, but were extinguished promptly so had limited spatial extents (Wilson et al. 2022). Historically fires on drained OS were likely more common than now, due to fire being used for land clearance and triggered by sparks from steam engines (Clarkson 1997). However, fires on drained OS do occur from time to time. A recent example was a fire in May 2022 that burned drained OS on grassland near Whatawhata, west of Hamilton City. The fire size was not reported, but it was large enough to require a fire and emergency response and smoke was observed in western suburbs of Hamilton City (Stuff News 2022). Fire on drained OS can burn underground for years, further adding to the complexity of accounting for peat fires (Wilson et al., 2022). However, because these fires are irregular, and the area and duration are not well reported it is difficult to include them in an annual emissions inventory.

4 Limitations

Many limitations were identified when compiling the Waikato Region OS GHG inventory, these are outlined below.

4.1 Organic Soils extent

The accuracy of OS extent is limited by the quality of available regional-scale soil maps. For this study, OS area was estimated using a hybridised soil map, the better-quality S-Map was used where it was available and the FSL was used where S-Map wasn't available. The 1,267 ha of OS mapped by the FSL will change as more of the region is mapped by S-Map, therefore changing the overall OS area.

Drained OS extent is reducing due to ongoing peat subsidence; however, soil maps only capture the extent of OS at the time of mapping. Mapping normally occurs over many years and new mapping is not carried out regularly. Most of the OS in the Waikato Region has been recently re-mapped in the last 10 years through the S-Map project, but still not representative of a single year. Also, the uncertainty of OS extent will increase as the time since the last survey increases, particularly for FSL maps, and without a method to capture change in OS through time, future changes in emissions through loss of OS due to peat subsidence will not be captured.

4.2 Activity data

4.2.1 Land use

In terms of land use and land cover, the most up-to-date LUCAS information was from 2016. This was not consistent with the current regional GHG inventory year, which was 2021/2022. WRC does not have the capability to estimate land use for years when LUCAS data are not available. However, large changes in activity data on OS, and therefore OS emissions, are unlikely in the years between LUCAS updates. This is confirmed by small changes in land activity on OS, and therefore total emissions, in the years LUCAS data was updated (2002, 2008, 2012, 2016), as seen in Appendix A and B.

Some land use on OS will be incorrectly mapped. For example, 1,232 ha was identified as forestry on drained OS, this was unexpected. To investigate this further, 10% of the polygons that contained forestry on OS were randomly selected and aerial photography was used to determine the land use. From this analysis it was identified that half the polygons were forestry, but the other half were not (Appendix F). For those areas identified as not forestry the land use code was not changed, because if a change from forestry to non-forestry was made then a similar investigation should be completed looking for forestry on non-forestry land. This was outside the capacity of the current project.

Similarly, 15 ha of OS was not classified by a LUCAS land use class (classed as 'Other land'). To investigate this further, the mapped areas were assessed and re-classified into a more appropriate land use class based on observation of the polygon (Appendix F).

4.2.2 Drainage ditch area

A default value of 2.5% (forestry) and 5% (all other land uses) of total OS area was used to estimate drainage ditch area for CH_4 emissions from drains. It is unknown how close this is to the true drainage ditch area.

4.2.3 Drainage depth

Drainage depth was estimated based on average water table depths in existing Waikato studies (Kelliher et al. 2016; Campbell et al. 2021). WRC's peat surface oscillation (PSO) network[13] suggests that all peatlands are deeply drained (mean annual WTD > 30 cm), however these are all nutrient poor sites except one, therefore, they are not representative of all Waikato OS (Glover-Clark 2021). Also, in the 2013 WS, separate EFs based on shallow and

[13] Waikato Regional Council, in collaboration with the University of Waikato, installed 11 PSO sites across the Waikato on dairy farms, dry-stock farms, and blueberry orchards.

deep drainage are only presented for nutrient rich OS, and there is only a single drainage class for nutrient-poor systems.

4.3 Emission factors

As the 2013 WS expands upon data in the 2006 Guidelines, Tier 1 EFs from the WS should be used in favour of those in the 2006 Guidelines. No NZ studies were used to calculate the Tier 1 EFs in the 2006 IPCC guidance and aside from one study in the 2013 WS that originated from an NZ source, the referenced studies for EF calculation pertain to peatland sites that are not representative of those in New Zealand or occur in different climatic regions. In the absence of other data, these default EFs might be suitable, but developing regionally specific EFs for NZ conditions is needed.

Draft Tier 2 EFs for N_2O and CO_2 for grassland are from gravity-drained ombrotrophic managed OS in the Hamilton Basin, which are likely to generate different emissions compared to managed OS on the Hauraki Plains and the Lower Waikato, especially if water table depths are markedly different. Furthermore, the draft Tier 2 N_2O EF is only from 1 study and was omitted from this inventory.

To address the paucity of available local data, it is advisable to develop more Tier 2 and 3 EFs for the region (and in NZ more broadly) to account for the spatial variability in peat types and land and drainage management of OS in the Waikato. In the interim it is worth considering exploring the option of developing local EFs from international sites with comparable conditions (Artz et al. 2014).

5 Recommendations

5.1 Accounting method

The 2013 WS includes refined EFs and better represents the known range of GHG emissions from drained OS and should therefore be used as the underlying method for regional OS GHG accounting. In contrast, the 2006 Guidelines are known to be outdated. This is supported by the national inventory considering a transition from the 2006 Guidelines to the 2013 WS (Ministry for the Environment 2023a), if implemented this will mean that the Waikato Region OS GHG inventory will be consistent with the future national approach.

5.2 Tier 2 EFs and local data

The 2006 Guidelines and 2013 WS recommend that where possible, local data should be used in place of default EFs.

The local grassland EF for CO_2 of 4.21 t CO_2-C ha^{-1} yr^{-1} (Table 2) was from published research on rotationally grazed nutrient poor, gravity drained OS under dairy pasture in the Hamilton Basin. The draft Tier 2 EF was a mean from studies where C loss was estimated using either soil sampling data comparing carbon loss in a drained grazed OS system to an adjacent peat wetland (Schipper and McLeod 2002) or from paddock scale NECB data collected during eddy covariance-based studies (Campbell et al. 2015; Campbell et al. 2021). The local EF falls within the 95% confidence interval of 2013 WS low nutrient drained grassland Tier 1 EF (5.3 (3.7–6.9) t CO_2-C ha^{-1} yr^{-1}). It is not known how well these local CO_2 EFs represent managed OS on the Hauraki Plains and the Lower Waikato where drainage management is different, and in the case of the Lower Waikato where peat type is likely to be different as well. Although the Tier 2

CO_2 EF falls within the 95% confidence interval of the 2013 WS EFs, because it was collected from local paddock-scale measurements averaged from more than one study, it should be substituted into emissions calculations for nutrient poor, drained OS in the Waikato Region.

The local grassland N_2O draft Tier 2 EF of 1.57 kg N_2O-N ha^{-1} yr^{-1} (Table 2) was from one local study of a managed low nutrient drained OS under rotationally grazed dairy pasture in the Hamilton Basin (Kelliher et al. 2016). The N_2O Tier 2 EF was from chamber measurement data, so not paddock scale. The value is much lower than the 2006 Guidelines Tier 1 EF of 8 kg N_2O-N ha yr^{-1} and the 2013 WS nutrient poor drained Tier 1 EF of 4.3 kg N_2O-N ha^{-1} yr^{-1}. Therefore, regardless of method the Tier 2 EF will result in lower N_2O emissions being accounted for in the regional inventory. While, the Tier 2 EF is from local data, it does not represent a paddock scale measurement and it is much lower than the Tier 1 EF. Therefore, following a conservative approach the regional inventory should use a Tier 1 EF for N_2O from grassland until other measurements are available.

Considering the scale of OS GHG emissions in the Waikato there should be a focus on refining and incorporating Tier 2 EFs (and eventually Tier 3 EFs) for CO_2, N_2O, DOC, and CH_4 using local data. Better understanding emissions from all gases and activities is important, but CO_2 emissions from grasslands on OS represent the greatest portion of GHGs in the inventory and these should receive priority for developing Tier 2 EFs.

The final recommended method for accounting for OS emissions in the Waikato Region is to use the 2013 WS methods and default Tier 1 EFs with the Tier 2 CO_2 EF for nutrient poor grassland (as recommended in Table 8). Total emissions calculated using this method are 1.5 Mt CO_2e yr^{-1} (full workings in Table 6). An example of OS calculated using the approach recommended here is compared to emissions from other sectors in the regional GHG inventory in section 5.3.

Table 8: Recommended EFs for accounting for Waikato-based OS derived from the 2013 WS approach for temperate systems and the CO_2 Tier 2 EF from local studies from nutrient poor grassland.

Land use	Gas	2013 WS Tier 1	Local Tier 2
Forest land (drained)	CO_2 (t CO_2-C ha^{-1} yr^{-1})	2.6 (2–3.3)	-
	DOC (t CO_2-C ha^{-1} yr^{-1})	0.31 (0.19-0.46)	-
	CH_4 (land) (kg CH_4 ha^{-1} yr^{-1})	2.5 (-0.6–5.7)	-
	CH_4 (ditch) (kg CH_4 ha^{-1} yr^{-1})	217 (41–393)	-
	N_2O (kg N_2O-N ha^{-1} yr^{-1})	2.8 (-0.57–6.1)	-
Cropland	CO_2 (t CO_2-C ha^{-1} yr^{-1})	7.9 (6.5–9.4)	-
	DOC (t CO_2-C ha^{-1} yr^{-1})	0.31 (0.19-0.46)	-
	CH_4 (land) (kg CH_4 ha^{-1} yr^{-1})	0	-
	CH_4 (ditch) (kg CH_4 ha^{-1} yr^{-1})	1,165 (335–1,995)	-
	N_2O (kg N_2O-N ha^{-1} yr^{-1})	13 (8.2–18)	-
Grassland	CO_2 (t CO_2-C ha^{-1} yr^{-1})	- 6.1 (5–7.3) (nutrient rich)	4.21 (1.8–6.6) (nutrient poor)
	DOC (t CO_2-C ha^{-1} yr^{-1})	0.31 (0.19-0.46)	-
	CH_4 (land) (kg CH_4 ha^{-1} yr^{-1})	1.8 (0.72–2.9) (nutrient poor) 16 (2.4–29) (nutrient rich)	-
	CH_4 (ditch) (kg CH_4 ha^{-1} yr^{-1})	1165 (335–1,995)	-
	N_2O (kg N_2O-N ha^{-1} yr^{-1})	4.3 (1.9–6.8) (nutrient poor) 8.2 (4.9–11) (nutrient rich)	-
Peat extraction (on-site emissions)	CO_2 (t CO_2-C ha^{-1} yr^{-1})	2.8 (1.1–4.2)	-
	DOC (t CO_2-C ha^{-1} yr^{-1})	0.31 (0.19-0.46)	-
	CH_4 (land) (kg CH_4 ha^{-1} yr^{-1})	6.1 (1.6–11)	-
	CH_4 (ditch) (kg CH_4 ha^{-1} yr^{-1})	542 (102–981)	-
	N_2O (kg N_2O-N ha^{-1} yr^{-1})	0.3 (-0.03–0.64)	-
(off-site emissions)	CO_2 (t CO_2-C ha^{-1} yr^{-1})	0.07 (2006 IPCC Tier 1, nutrient poor, tonnes C m^{-3} air-dry peat)	See 2006 IPCC Tier 1
Settlements	See Grassland	See Grassland	See Grassland
Other land	See Grassland	See Grassland	See Grassland
Grand Total of Emissions (Mt CO_2e) using the final recommended approach for OS in the Waikato			**1.5**

- See Table 6 for full workings on the grand total of emissions.

- 95% confidence interval in brackets for all EFs.

5.3 Impact on regional inventory

If OS emissions were to be included using the recommended approach (nutrient poor grassland CO_2 Tier 2 EF alongside 2013 WS methods and remaining Tier 1 EFs) in the regional inventory for the latest emissions year (2021/22), emissions would be responsible for 13% of the region's total net emissions (11% gross emissions) (Figure 2)[14]. Looking at previous inventory years, OS would be responsible for 16% (2015/16) and 18% (2018/19) of regional net emissions (Appendix G) (Stancu & Marquart 2017; EnviroStrat Limited & AECOM 2020). OS are a relatively high emitter compared to other sectors (exceeds industry, stationary energy, and waste emissions) and it is recommended they be accounted for and addressed in the Waikato Regional inventory and that methods outlined in this report serve as guidance for the WRC approach to accounting. Using the GPC methods, OS would be accounted for within the AFOLU sector within the regional inventory.

[14] Gross emissions include emissions from energy, industrial processes, agriculture, and waste. Net emissions also include emissions and removals from land-use change and forestry.

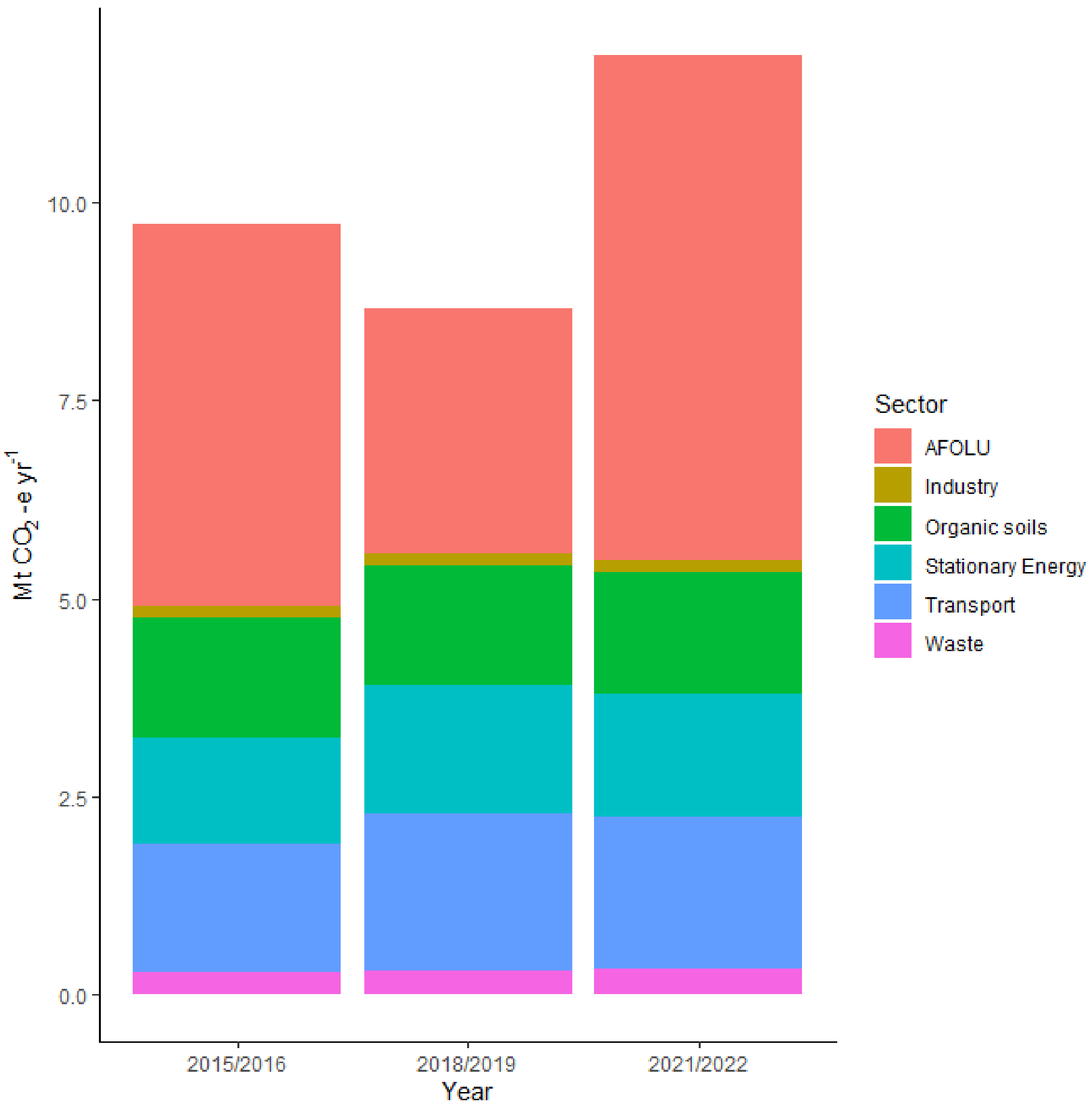


Figure 2: Total net emissions (including forestry) for current and past two regional inventories by sector using the recommended approach of nutrient poor grassland CO_2 EF alongside 2013 WS methods and remaining Tier 1 EFs. Note: the AFOLU category includes agriculture and forestry.

5.4 Key categories

A key category is a category that is prioritized within the national inventory system because its estimate has a significant influence on a country's total inventory of GHGs[15]. By identifying the key categories in the national inventory, inventory compilers can prioritize and improve overall estimates.

If considered a key category, the IPCC recommends the collection of Tier 2 or 3 data. This is because uncertainty is generally lower when using higher-tier methods to estimate emissions and removals. However, higher-tier methods generally require extensive resources for data collection, so it may not be feasible to collect this data or use these methods for every category. It is best practice to identify categories that contribute significantly to the total magnitude of inventory emissions, removals, and/or uncertainty, to ensure efficient use of resources.

Identifying key categories using Approach 1 (as per the 2006 Guidelines), involves summing cumulative emissions in descending order until reaching 95% of the total emissions. In cases

[15] The purpose, general rules, and approaches for the key category analysis of the whole greenhouse gas inventory are presented in Chapter 4 in Volume 1 of the 2006 IPCC Guidelines.

where inventory estimates span multiple years, assessing a category's contribution to both the level and trend of the national inventory is recommended. For single-year inventories, a level assessment should be performed.

If future regional and national inventories include emissions from other sources (e.g., OS), a key category analysis is recommended. For instance, grassland may be classed as a key category, given it comprises 95% of total OS emissions using the recommended methodology[16] and if included in the regional inventory, total OS emissions would comprise 11% of gross emissions. These numbers are significant relative to the rest of the inventory and while there is high uncertainty around EFs and limited local data, this justifies increasing effort around refining EF to ensure these numbers are more robust. Changes in EFs could have a big impact on emissions totals, as evidenced when comparing the difference in grassland emissions calculated using default Tier 1 EFs in the 2006 Guidelines and 2013 WS methods, and local Tier 2 EFs.

5.5 Organic Soils extent and activity data

Improved geospatial mapping techniques could improve estimates for OS area, nutrient status data, land use area, and drainage ditches. In future, area estimates can be improved as S-Map coverage spreads and the use of geophysical mapping techniques are explored. Data sources such as the wetlands database (holds nutrient data for remnant wetlands often adjacent to current drained peatland areas) and Davoren (1978) (contains information on peat composition and classifies wetlands based on trophic status) could be used to improve activity data.

Drainage depth may require ground truthing and local data on drainage information and systems. Research and ongoing monitoring by the University of Waikato, Manaaki Whenua Landcare Research (MWLR), and WRC investigates WTD at the farm scale using the regional PSO network. Currently these sites are all located on nutrient-poor sites and installing more sites on nutrient-rich OS are recommended. Drain parameters could also be estimated using in-field, desktop surveys, or other mapping techniques such as LiDAR (Glover-Clark 2021).

Peat fires have currently been excluded from emissions totals, but the sensitivity analysis revealed emissions are potentially significant and reinforces the need to include OS fires in calculations in future. As well as highlighting the potential risk of emissions from OS fires and the need to avoid/manage this. Potential emissions from peat fires ranged from 15 – 146,337 t CO_2e (undrained) and 61 – 608,446 t CO_2e (drained) across the given range (0.1 – 1000 ha), suggesting fires of any scale would cause large emissions relative to land area. For inclusion in the following inventory, more accurate information (e.g., fire depth and extent, carbon content of burnt peat in both undrained and drained peatlands) should be gathered for OS areas subjected to fire as this area is currently unknown and is a knowledge gap. Ideally, this information should be captured as fires occur to then determine an annual average.

Alongside inland drained OS, the 2013 WS includes additional chapters for accounting for rewetted OS and other mineral wetland emissions. Although this was outside of scope for this project, these emissions could be accounted for in future. To undertake this, more data is needed including more developed mapping techniques and a method for accounting for emissions removals from intact systems (e.g., Kopuatai). A discussion of the feasibility of accounting for these other chapters in future is given in Appendix H.

5.6 Emissions from inorganic soils

The aim of this project was to identify a methodology for calculating OS emissions for regional scale GHG accounting in the Waikato, with the view that these emissions could eventually be

[16] CO_2 emissions from grassland alone (including DOC emissions) comprise 75% of total OS emissions.

included in the regional GHG inventory. However, within the AFOLU sector of the GPC approach, soil carbon stock and biomass changes in inorganic soils due to land use changes are included (Fong et al. 2021). If emissions from OS are included in the Waikato Regional GHG inventory, then emission from inorganic soils should be considered for inclusion to maintain consistency.

6 Conclusions

Understanding GHG emissions from OS is important for accurately accounting for total emissions and for identifying GHG source categories for targeting to reduce and offset emissions. While both the 2006 and 2013 methods provide OS emissions estimates, the 2013 WS builds on the 2006 Guidelines by providing more detailed and comprehensive calculation methods. Sections 4 and 5 of this report recommend steps towards implementing and improving data sources for the 2013 WS methods and eventually shifting to the use of appropriate local (Tier 2) EFs as these become available. Using the 2013 WS methods and default Tier 1 EFs with the Tier 2 CO_2 EF for nutrient-poor OS is the recommended method for accounting for OS emissions in the Waikato Region.

7 References

Artz R, Saunders M, Yeluripati J, Potts J, Elston D, Chapman S 2014. An assessment of the proposed IPCC "2013 Supplement to the 2006 guidelines: Wetlands" for use in GHG accounting of Scottish peatland restoration. CXC briefing, Scottish Government Revised Version February.

Campbell DI, Glover-Clark GL, Goodrich JP, Morcom CP, Schipper LA, Wall AM 2021. Large differences in CO2 emissions from two dairy farms on a drained peatland driven by contrasting respiration rates during seasonal dry conditions. Science of the Total Environment. 760:143410.

Campbell DI, Wall AM, Nieveen JP, Schipper LA 2015. Variations in CO2 exchange for dairy farms with year-round rotational grazing on drained peatlands. Agriculture, Ecosystems & Environment. 202:68–78.

Clarkson BR 1997. Vegetation recovery following fire in two Waikato peatlands at Whangamarino and Moanatuatua, New Zealand. New Zealand Journal of Botany. 35(2):167–179.

Clarkson BR 2016. Peat extraction in New Zealand wetlands. Wellington, Ministry for the Environment. https://data.mfe.govt.nz/document/12844-peat-extraction-in-new-zealand-wetlands-report/view/ [accessed 01/12/2023].

Davoren A 1978. Survey of New Zealand peat resources. University of Waikato for the National Water and Soil Conservation Organisation. https://docs.niwa.co.nz/library/public/wstp14.pdf [accessed 01/12/2023].

Eggleston H, Buendia L, Miwa K, Ngara T, Tanabe K 2006. 2006 IPCC guidelines for national greenhouse gas inventories. Intergovernmental Panel on Climate Change. https://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html [accessed 01/12/2023].

EnviroStrat Limited, AECOM 2020. Waikato Region Greenhouse Gas Emissions Inventory for the period July 2018 to June 2019. Hamilton, Waikato Regional Council. https://www.waikatoregion.govt.nz/assets/WRC/WRC-2019/Waikato-Region-GHG-Inventory-18-19.pdf

Evans C, Artz R, Moxley J, Smyth M-A, Taylor E, Archer N, Burden A, Williams J, Donnelly D, Thomson A, Buys G, Malcolm H, Wilson D, Renou-Wilson F, Potts J 2017. Implementation of an emissions inventory for UK peatlands. Report to the Department for Business, Energy and Industrial Strategy, Centre for Ecology and Hydrology, Bangor. TRN860/07/2014(1). https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1904111135_UK_peatland_GHG_emissions.pdf

Fong WK, Sotos M, Doust M, Schultz S, Marques A, Deng-Beck C. 2021. Global protocol for community-scale greenhouse gas inventories : an accounting and reporting standards for cities. Washington DC, World Resources Institute. https://cdn.locomotive.works/sites/5ab410c8a2f42204838f797e/content_entry5ab410fb74c4833febe6c81a/5ab4110fa2f42204838f79ba/files/GPC_Standard.pdf?1541698648 [accessed 01/12/2023].

Glover-Clark G 2021. Drained peat soil subsidence - Contrasting land-use monitoring in the Waikato Region. Hamilton, University of Waikato.

Goodrich JP, Campbell DI, Schipper LA 2017. Southern Hemisphere bog persists as a strong carbon sink during droughts. Biogeosciences. 14(20):4563–4576.

Hewitt AE 2010. New Zealand soil classification. 3rd ed. Landcare Research science series no. 1. Lincoln, Landcare Research New Zealand.

Hiraishi T, Krug T, Tanabe K, Srivastava N, Baasansuren J, Fukuda M, Troxler T 2014. 2013 supplement to the 2006 IPCC guidelines for national greenhouse gas inventories: Wetlands. Geneva, Intergovernmental Panel on Climate Change.

International Soil Reference and Information Centre 1998. World reference base for soil resources. Rome: Food and Agriculture Organization of the United Nations. https://wrb.isric.org/files/WRB_1998_FAO_Report_84.pdf

Kelliher F, van Koten C, Lindsey S, Wise B, Rys G 2016. Nitrous oxide emissions from drained peat soil beneath pasture. New Zealand Journal of Agricultural Research. 59(4):363–376.

Langeveld C, Segers R, Dirks B, Van den Pol-van Dasselaar A, Velthof G, Hensen A 1997. Emissions of CO2, CH4 and N2O from pasture on drained peat soils in the Netherlands. European Journal of Agronomy. 7(1–3):35–42.

Layton H 2022. Peat soil properties and seasonal surface elevation changes of drained Waikato peatlands. A thesis submitted in partial fulfilment of the requirements for the degree of Masters of Science (Research). Hamilton, University of Waikato. https://researchcommons.waikato.ac.nz/bitstream/handle/10289/15391/thesis.pdf?sequence=4&isAllowed=y

Manaaki Whenua - Landcare Research 2021. LCDB v5.0 – Land cover database version 5.0, Mainland, New Zealand. https://lris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/ [accessed 01/12/2023].

Masson-Delmotte V, Zhai P, Pirani S, Connors C, Péan S, Berger N, Caud Y, Chen L, Goldfarb M, Scheel Monteiro PM 2021. IPCC, 2021: Summary for policymakers. In: Climate change 2021: The physical science basis. Contribution of working group I to the Sixth Assessment Report of the Intergovernmental Panel On Climate Change. Cambridge, Cambridge University Press.

Ministry for the Environment 2016. LUCAS NZ Land Use Map 1990 2008 2012 2016 v011. https://data.mfe.govt.nz/layer/52375-lucas-nz-land-use-map-1990-2008-2012-2016-v011/ [accessed 01/12/2023].

Ministry for the Environment 2021. Defining 'natural wetlands' and 'natural inland wetlands' : Guidance to support the interpretation of the National Policy Statement for Freshwater Management 2020 and the Resource Management (National Environmental Standards for Freshwater) Regulations 2020. Wellington, Ministry for the Environment. https://environment.govt.nz/assets/publications/Defining-natural-wetlands-and-natural-inland-wetlands.pdf

Ministry for the Environment 2022a. Towards a productive, sustainable and inclusive economy : Aotearoa New Zealand's first emissions reduction plan. Wellington, Ministry for the Environment. https://environment.govt.nz/assets/publications/Aotearoa-New-Zealands-first-emissions-reduction-plan.pdf

Ministry for the Environment 2022b. Adapt and thrive: building a climate-resilient New Zealand : Aotearoa New Zealand's First National Adaptation Plan. Wellington, Ministry for the Environment. https://environment.govt.nz/assets/publications/climate-change/MFE-AoG-20664-GF-National-Adaptation-Plan-2022-WEB.pdf

Ministry for the Environment 2023a. New Zealand's Greenhouse Gas Inventory 1990–2021. Volume 1, Chapters 1–15. Wellington: Ministry for the Environment. https://environment.govt.nz/assets/publications/climate-change/New-Zealands-Greenhouse-Gas-Inventory-1990-2021-Chapters-1-15.pdf

Ministry for the Environment 2023b. National Policy Statement for Freshwater Management 2020: February 2023. Wellington, Ministry for the Environment.

Needham H, Townsend M, Hewitt JE, Hailes SF 2013. Intertidal habitat mapping for ecosystem goods and services: Waikato estuaries. Waikato Regional Council Technical Report 2013/52. Hamilton, Waikato Regional Council. https://www.waikatoregion.govt.nz/assets/WRC/WRC-2019/TR201352.pdf

Needham HR, Townsend M, Hewitt JE, Hailes S 2014. Intertidal habitat mapping for ecosystem goods and services: Tairua harbour. Waikato Regional Council Technical Report 2014/39. Hamilton, Waikato Regional Council. https://www.waikatoregion.govt.nz/services/publications/tr201439/

Newnham R, De Lange P, Lowe D 1995. Holocene vegetation, climate and history of a raised bog complex, northern New Zealand based on palynology, plant macrofossils and tephrochronology. The Holocene. 5(3):267–282.

Nieveen JP, Campbell DI, Schipper LA, Blair IJ 2005. Carbon exchange of grazed pasture on a drained peat soil. Global Change Biology. 11(4):607–618.

Pachauri RK, Allen MR, Barros VR, Broome J, Cramer W, Christ R, Church JA, Clarke L, Dahe Q, Dasgupta P 2014. Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change. [Geneva], IPCC.

Pachauri RK, Reisinger A 2007. Climate change 2007: synthesis report. Contribution of Working Groups I, II and III to the fourth assessment report of the Intergovernmental Panel on Climate Change. [Geneva], IPCC.

Pronger J, Wyatt J, Glover-Clark GL 2021. Review of potential management interventions to reduce peat subsidence and CO2 emissions in the Waikato. Waikato Regional Council Technical Report 2021/10. Hamilton, Waikato Regional Council. https://www.waikatoregion.govt.nz/services/publications/tr202110/

Resource Management (National Environmental Standards for Freshwater) Regulations 2020 (LI 2020/174). https://www.legislation.govt.nz/regulation/public/2020/0174/latest/LMS364099.html [accessed 01/12/2023].

Rolleston TA 2022. Peat fire in Waikato blankets township in dense fog. https://www.stuff.co.nz/national/300578015/peat-fire-in-waikato-blankets-township-in-dense-fog

Schipper L, McLeod M 2002. Subsidence rates and carbon loss in peat soils following conversion to pasture in the Waikato Region, New Zealand. Soil Use and Management. 18(2):91–93.

Schipper LA, Mudge PL, Kirschbaum MU, Hedley CB, Golubiewski NE, Smaill SJ, Kelliher FM 2017. A review of soil carbon change in New Zealand's grazed grasslands. New Zealand Journal of Agricultural Research. 60(2):93–118.

Stancu S, Marquart M 2017. Waikato Region Greenhouse Gas Emissions Inventory 2015/16. Waikato Regional Council Technical Report 2017/31. Hamilton, Waikato Regional Council. https://www.waikatoregion.govt.nz/assets/WRC/WRC-2019/TR201731.pdf

Tiemeyer B, Freibauer A, Borraz EA, Augustin J, Bechtold M, Beetz S, Beyer C, Ebli M, Eickenscheidt T, Fiedler S 2020. A new methodology for organic soils in national greenhouse gas inventories: Data synthesis, derivation and application. Ecological Indicators. 109:105838.

Vymazal J 2007. Removal of nutrients in various types of constructed wetlands. Science of the Total Environment. 380(1–3):48–65.

Waikato Regional Council, EnviroStrat Limited 2023. Waikato Region Greenhouse Gas Emissions Inventory 2021/2022. Hamilton, Waikato Regional Council. https://www.waikatoregion.govt.nz/environment/climate-change/waikato-regional-greenhouse-gas-inventory/

Wilson CR, Lusk CH, Campbell DI 2022. The role of the peat seed bank in plant community dynamics of a fire-prone New Zealand restiad bog. Austral Ecology. 47(7):1515–1527.

8 Appendix A – 2006 IPCC Guidelines calculation spreadsheet

See supplementary spreadsheet for further calculation details – **AppendixA_2006_OS_GHG_accountingWRC.xlsx**.

Table 9: Summary of OS emissions using 2006 IPCC Guidelines and Tier 1 EFs found in the Agriculture & Summary tab of the 2006_OS_GHG_accountingWRC spreadsheet.

Summary (CO_2 emissions)

	1990	**2008**	**2012**	**2016**		**Worksheet**
Forest land (Temperate)	451	415	451	431	t C yr^{-1}	Forest (chapter 4A)
Cropland (Warm Temperate)	12,341	14,160	14,140	14,140	t C yr^{-1}	Cropland (4B)
Grassland (Warm Temperate)	153,258	154,835	154,780	154,830	t C yr^{-1}	Grassland (4C)
Peat Mines	NR	661	644	975	t C yr^{-1}	Wetland (4D)
Settlements	1,256	1,517	1,525	1,525	t C yr^{-1}	Settlements (4E)
Other land	22	22	22	22		Other land (4F)
	167,327	171,610	171,561	171,922	t C yr^{-1}	
	614,091	629,808	629,629	630,955	t CO_2 yr^{-1}	
	0.61	0.63	0.63	0.63	Mt CO_2 yr^{-1}	

Summary (N_2O emissions)

	1990	**2008**	**2012**	**2016**		
Grassland	490.4	495.5	495.3	495.5	t N yr^{-1}	Grass&Cropland (3D)
Cropland	9.9	11.3	11.3	11.3	t N yr^{-1}	
Settlements	4.0	4.9	4.9	4.9	t N yr^{-1}	
Other land	0.1	0.1	0.1	0.1	t N yr^{-1}	
	792.0	803.4	803.1	803.4	t N_2O yr^{-1}	
	0.24	0.24	0.24	0.24	Mt CO_2e yr^{-1}	

Final Summary of emissions

	0.85	**0.87**	**0.87**	**0.87**	**Mt CO_2e yr^{-1}**

9 Appendix B – 2013 Wetland Supplement calculation spreadsheet

See supplementary spreadsheet for further calculation details – **AppendixB_WS_OS_Ch2_GHG_accountingWRC.xlsx**.

Table 10: Summary of OS emissions using 2013 WS methods and Tier 1 EFs found in the Summary_By_Gas tab of the WS_OS_Ch2_GHG_accountingWRC spreadsheet.

Summary (CO_2 emissions)	**1990**	**2008**	**2012**	**2016**		**Worksheet**
Cropland (Temperate)	9,750	11,187	11,174	11,174	t CO_2-C yr^{-1}	WS Cropland (Ch.2)
Grassland (Temperate) All	340,048	343,381	343,226	343,336	t CO_2-C yr^{-1}	WS Grassland (Ch.2)
Forest and Plantation (Temperate)	1,724	1,588	1,724	1,648	t CO_2-C yr^{-1}	WS Forest & Plantation (Ch.2)
Settlements All	2,954	3,546	3,563	3,563	t CO_2-C yr^{-1}	WS Settlements (Ch.2)
Extracted peat	2,506	744	823	1,154	t CO_2-C yr^{-1}	WS Extraction (Ch.2)
Other land	46	46	46	46	t CO_2-C yr^{-1}	WS Other land (Ch.2)
Fires	NR	NR	NR	NR	t CO_2-C yr^{-1}	WS Fires (Ch. 2)
	357,027	360,493	360,556	360,921	t CO_2-C yr^{-1}	
	1,310,290	1,323,008	1,323,241	1,324,579	t CO_2e yr^{-1}	
	1.31	1.32	1.32	1.32	Mt CO_2e yr^{-1}	

Summary (DOC emissions)	**1990**	**2008**	**2012**	**2016**		**Worksheet**
Cropland (Temperate)	383	439	428	438	t C yr^{-1}	WS Cropland (Ch.2)
Grassland (Temperate)	19,004	19,200	19,193	19,199	t C yr^{-1}	WS Grassland (Ch.2)
Forest and Plantation (Temperate)	206	189	206	196	t C yr^{-1}	WS Forest & Plantation (Ch.2)
Settlements	156	188	189	189	t C yr^{-1}	WS Settlements (Ch.2)
Other land	3	3	3	3	t C yr^{-1}	WS Other land (Ch.2)
Extracted peat	NR	10	21	21	t C yr^{-1}	WS Extraction (Ch.2)
Fires	NR	NR	NR	NR	t C yr^{-1}	WS Fires (Ch. 2)
	19,751	20,029	20,050	20,047	t C yr^{-1}	
	72,485	73,505	73,583	73,573	t CO_2e yr^{-1}	
	0.07	0.07	0.07	0.07	Mt CO_2e yr^{-1}	

Summary (CH_4 emissions)	**1990**	**2008**	**2012**	**2016**		**Worksheet**

Cropland (Temperate)	0	0	0	0	t CH_4 yr^{-1}	WS Cropland (Ch.2)
Grassland (Temperate)	379	380	379	379	t CH_4 yr^{-1}	WS Grassland (Ch.2)
Forest and Plantation (Temperate)	2	2	2	2	t CH_4 yr^{-1}	WS Forest & Plantation (Ch.2)
Settlements	6	7	7	7	t CH_4 yr^{-1}	WS Settlements (Ch.2)
Other land	0	0	0	0	t CH_4 yr^{-1}	WS Other land (Ch.2)
Extracted peat	NR	0	0	0	t CH_4 yr^{-1}	WS Extraction (Ch.2)
Fires	NR	NR	NR	NR	t CH_4 yr^{-1}	WS Fires (Ch. 2)
	387	389	388	388	t CH_4 yr^{-1}	
	13,152	13,217	13,205	13,206	t CO_2e yr^{-1}	
	0.0132	0.0132	0.0132	0.0132	Mt CO_2e yr^{-1}	

Summary (CH_{4DITCH} emissions)	**1990**	**2008**	**2012**	**2016**		**Worksheet**
Cropland (Temperate)	72	82	82	82	t CH_4 yr^{-1}	WS Cropland (Ch.2)
Grassland (Temperate)	3,571	3,608	3,606	3,608	t CH_4 yr^{-1}	WS Grassland (Ch.2)
Forest and Plantation (Temperate)	4	3	4	3	t CH_4 yr^{-1}	WS Forest & Plantation (Ch.2)
Settlements	29	35	36	36	t CH_4 yr^{-1}	WS Settlements (Ch.2)
Other land	1	1	1	1	t CH_4 yr^{-1}	WS Other land (Ch.2)
Extracted peat	NR	1	2	2	t CH_4 yr^{-1}	WS Extraction (Ch.2)
Fires	NR	NR	NR	NR	t CH_4 yr^{-1}	WS Fires (Ch. 2)
	3,676	3,730	3,730	3,731	t CH_4 yr^{-1}	
	124,990	126,826	126,829	126,863	t CO_2e yr^{-1}	
	0.125	0.127	0.127	0.127	Mt CO_2e yr^{-1}	

Summary (N_2O emissions)	**1990**	**2008**	**2012**	**2016**	t N_2O-N yr^{-1}	**Worksheet**
Cropland (Temperate)	16	18	18	18	t N_2O-N yr^{-1}	WS Cropland (Ch.2)
Grassland (Temperate)	337	340	340	340	t N_2O-N yr^{-1}	WS Grassland (Ch.2)
Forest and Plantation (Temperate)	2	2	2	2	t N_2O-N yr^{-1}	WS Forest & Plantation (Ch.2)
Settlements	4	4	4	4	t N_2O-N yr^{-1}	WS Settlements (Ch.2)
Other land	0	0	0	0	t N_2O-N yr^{-1}	WS Other land (Ch.2)
Extracted peat	NR	0.01	0.02	0.02	t N_2O-N yr^{-1}	WS Extraction (Ch.2)
Fires	NR	NR	NR	NR	t N_2O-N yr^{-1}	WS Fires (Ch. 2)
	359	364	364	364		
	167,928	170,519	170,458	170,466	t CO_2e yr^{-1}	
	0.17	0.17	0.17	0.17	Mt CO_2e yr^{-1}	

Final Summary of emissions	**1.69**	**1.71**	**1.71**	**1.71**	**Mt CO_2e yr^{-1}**

10 Appendix C – Organic Soil stratified by land use

See supplementary spreadsheet for further calculation details
– **AppendixC_LUCAS_Organic_Soils_Areas.xls**.

Table 11: Area totals for OS stratified by land use for the latest LUCAS year (2016).

Sum of Area_weighted_by_O		
LUCNA_2016	SUBNA_2016	Total (ha)
Cropland - Annual	Unknown	1,125
Cropland - Annual Total		1,125
Cropland - Perennial	Unknown	289
Cropland - Perennial Total		289
Grassland - High producing	Grazed - dairy	50,304
	Grazed - non-dairy	10,202
Grassland - High producing Total		60,506
Grassland - Low producing	Grazed - dairy	22
	Grazed - non-dairy	528
	Ungrazed	460
Grassland - Low producing Total		1,011
Grassland - With woody biomass	Unknown	415
Grassland - With woody biomass Total		415
Natural Forest	Unknown	593
Natural Forest Total		593
Other	Unknown	15
Other Total		15
Planted Forest - Pre-1990	Unknown	431
	Unspecified exotic species	1
Planted Forest - Pre-1990 Total		432
Post 1989 Forest	Pinus radiata	101
	Regenerated natural species	5
	Unspecified exotic species	100
Post 1989 Forest Total		207
Settlements	Unknown	610
Settlements Total		610
Wetland - Open water	Human induced	9
	Unknown	171
Wetland - Open water Total		181
Wetland - Vegetated non forest	Peat mine	69
	Unknown	18,492
Wetland - Vegetated non forest Total		18,561
(blank)	(blank)	
(blank) Total		
Grand Total		83,945

11 Appendix D – Organic Soil stratified by land use and nutrient status

See supplementary spreadsheet for further calculation details – **AppendixD_OS_LUCAS_historic_wetland.xls**.

Table 12: Area totals for Organic Soils stratified by land use for the latest LUCAS year (2016) and nutrient status (wetland type from FENZ data).

Sum of Area_weighted_by_O			Npoor	Nrich
LUCNA_2016	SUBNA_2016	TYPENAME	Total (ha)	Total (ha)
Cropland - Annual	Unknown	Bog	563	
		Fen	95	
		Gumland	0	
		Marsh	2	
		Swamp	411	
		(blank)	55	563
	Unknown Total		1,125	1,125
Cropland - Annual Total			1,125	
Cropland - Perennial	Unknown	Bog	284	
		Fen	2	
		Marsh	0	
		Swamp	1	
		(blank)	2	5
	Unknown Total		289	289
Cropland - Perennial Total			289	
Grassland - High producing	Grazed - dairy	Bog	36,129	
		Fen	6,779	
		Gumland	12	
		Marsh	156	
		Swamp	4,892	
		(blank)	2,337	14,176
	Grazed - dairy Total		50,304	50,304
	Grazed - non-dairy	Bog	6,385	
		Fen	1,550	
		Gumland	6	
		Marsh	64	
		Swamp	987	
		(blank)	1,211	3,817
	Grazed - non-dairy Total		10,202	10,202
Grassland - High producing Total			60,506	
Grassland - Low producing	Grazed - dairy	Bog	2	
		Swamp	0	
		(blank)	20	20
	Grazed - dairy Total		22	22
	Grazed - non-dairy	Bog	157	
		Fen	81	
		Marsh	8	
		Swamp	100	
		(blank)	182	371
	Grazed - non-dairy Total		528	528
	Ungrazed	Bog	268	
		Fen	32	
		Marsh	6	

		Swamp	84	
		(blank)	70	192
	Ungrazed Total		460	460
Grassland - Low producing Total			1,011	
Grassland - With woody biomass	Unknown	Bog	122	
		Fen	43	
		Gumland	1	
		Marsh	28	
		Swamp	65	
		(blank)	156	293
	Unknown Total		415	415
Grassland - With woody biomass Total			415	
Natural Forest	Unknown	Bog	219	
		Fen	96	
		Gumland	3	
		Marsh	16	
		Swamp	74	
		(blank)	184	374
	Unknown Total		593	593
Natural Forest Total			593	
Other	Unknown	Bog	7	
		Fen	6	
		Gumland	0	
		(blank)	2	8
	Unknown Total		15	15
Other Total			15	
Planted Forest - Pre-1990	Unknown	Bog	36	
		Fen	24	
		Marsh	41	
		Swamp	49	
		(blank)	281	395
	Unknown Total		431	431
	Unspecified exotic species	Bog	0	
		Marsh	1	
		Swamp	0	
		(blank)	0	1
	Unspecified exotic species Total		1	1
Planted Forest - Pre-1990 Total			432	
Post 1989 Forest	Pinus radiata	Bog	2	
		Fen	5	
		Gumland	2	
		Marsh	4	
		Swamp	6	
		(blank)	83	100
	Pinus radiata Total		101	101
	Regenerated natural species	Bog	0	
		Marsh	1	
		Swamp	1	
		(blank)	2	5
	Regenerated natural species Total		5	5
	Unspecified exotic species	Bog	8	
		Fen	11	
		Marsh	15	

		Swamp	4	
		(blank)	63	92
	Unspecified exotic species Total		100	100
Post 1989 Forest Total			207	
Settlements	Unknown	Bog	197	
		Fen	30	
		Marsh	7	
		Swamp	25	
		(blank)	350	413
	Unknown Total		610	610
Settlements Total			610	
Wetland - Open water	Human induced	Bog	2	
		Marsh	5	
		Swamp	1	
		(blank)	1	7
	Human induced Total		9	9
	Unknown	Bog	66	
		Fen	7	
		Marsh	8	
		Swamp	50	
		(blank)	40	105
	Unknown Total		171	171
Wetland - Open water Total			181	
Wetland - Vegetated non forest	Peat mine	Bog	69	
	Peat mine Total		69	69
	Unknown	Bog	13,285	
		Fen	1,221	
		Gumland	9	
		Marsh	528	
		Swamp	3,270	
		(blank)	180	
	Unknown Total		18,492	
Wetland - Vegetated non forest Total			18,561	
Grand Total			83,945	

12 Appendix E – GIS layers

Soil layers
S-Map (SMAP - SMAP_SOIL_PROP_BASIC_2020)
https://lris.scinfo.org.nz/layer/111207-smap-soil-classification-soil-order-dec-2022/
https://smap.landcareresearch.co.nz/
Fundamental Soils Layer (FSL) (FSL NZLRI - LAND_RESOURCE_INVENTORY_FSL_EW)
https://lris.scinfo.org.nz/layer/48136-fsl-north-island-v10-all-attributes/
Peat and Organic soils
https://data.waikatoregion.govt.nz:8443/ords/f?p=140:12:0::NO::P12_METADATA_ID:8197

Land use layers
Land Use and Carbon Analysis System (LUCAS) Land Use Map (LUM) 1990 2008 2012 2016 v008
https://data.mfe.govt.nz/layer/52375-lucas-nz-land-use-map-1990-2008-2012-2016-v008/
Freshwater Ecosystems New Zealand (FENZ) historic wetlands
https://data.mfe.govt.nz/document/22287-fenz-user-guide/

Temperature layer
Land Environments of New Zealand (LENZ) 2010 (updated 2020)
https://lris.scinfo.org.nz/layer/48094-lenz-mean-annual-temperature/

13 Appendix F – Mapping issues and assessments

Forestry index

The coding of some land uses has caused some discrepancies when it comes to unexpected land uses on OS. During the compilation of the activity data, organic soil area under planted and natural forestry was higher than expected (e.g., hundreds of ha) based on existing observations of OS in the Waikato. To understand the extent of this, we intersected the OS layer and forestry polygons in the LUCAS layer and observed 10% of polygons (randomly selected) to understand how widespread the issue was, and where appropriate, determine what the correct land cover. Index categories listed below and example images in Table 13:

1. Forest polygon located in pasture paddock. No evidence of present or past forestry.
2. Polygon is not forestry but is nearby forest.
3. Forestry is coastal/lakeside native vegetation.
4. Shelterbelt/road or driveway verging.
5. Gully, riparian.
6. Polygon is pine forestry.
7. Kahikatea stand or wetland vegetation.
8. Other.

Table 13: Example aerial images of forestry mapped as OS labelled with assigned forestry index number (1 – 8) and forestry type.

		
Pre-1990 natural forest – 1.	Post-1989 forest – 2.	Pre-1990 planted forest – 3.
		
Pre-1990 natural forest – 4.	Pre-1990 planted forest – 5.	Post-1989 forest – 6.
		
Pre-1990 natural forest	Pre-1990 natural forest – 8.	

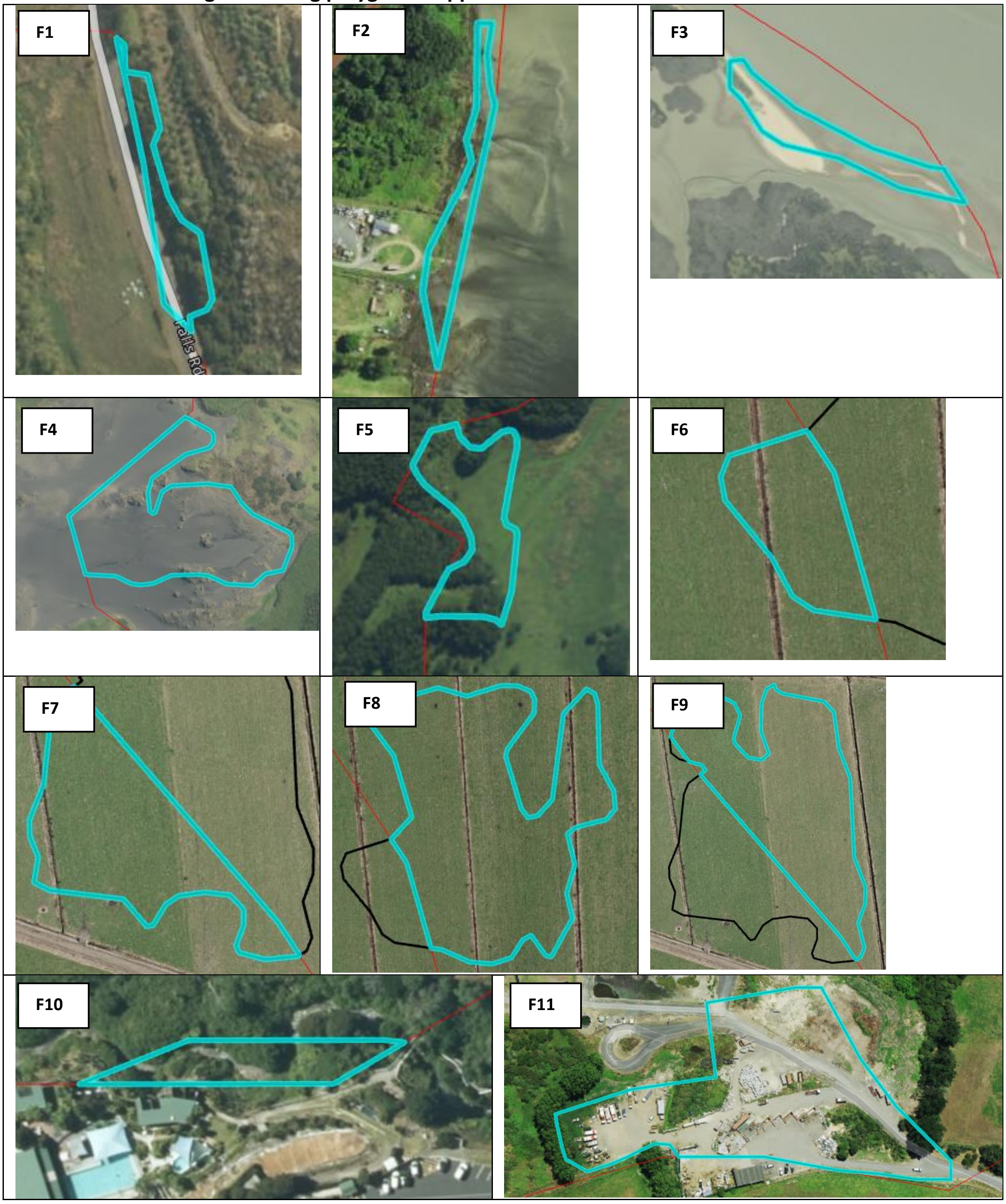
Other land assessment

15 ha of OS were classified as other land (e.g., not classified by a particular LUCAS LUM land use class). An assessment of the OS mapped as 'Other land' revealed the land was a mixture of different land uses often at the edge of OS polygons (examples given in Table 14 and associated photos in Table 15). Each of the 11 mapped polygons were investigated to re-classify the land use based on what was observed on aerial imagery. Areas were dominated by nutrient poor (all classed as bog based on historical FENZ data) grassland or were not OS (e.g., dunes, roadsides, etc). Classification was based on personal judgement.

Table 14: Observations made from polygons mapped as 'Other Land' to determine re-classification and EF.

Polygon	Area (ha)	Aerial description	Comments	Classification	EF	Figure
1	0.10	Roadside forestry, included part of road	Should not include road or roadside. Wetland on one side of road, quarry on other side (where polygon is mapped) does not look like OS	Not OS	NA	F1
2	0.45	Vegetated coastline	Coastal wetland	Not OS	NA	F2
3	0.67	Sandspit	Or water depending on tide, coastal wetland	Not OS	NA	F3
4	3.60	Beach, sand dune	Includes some coastal wetland, mostly sand	Not OS	NA	F4
5	2.27	Mostly grassland, some forestry, near coast	Polygon mostly grassland and includes some forestry, includes tributary heading to sea	Grassland		F5
6	0.30	Pasture paddock with drains	Drains and darkness of visible soil suggests soil is organic	Grassland		F6
7	1.30	Pasture paddock with drains	Drains and darkness of visible soil suggests soil is organic	Grassland		F7
8	2.42	Pasture paddock with drains	Drains and darkness of visible soil suggests soil is organic	Grassland		F8
9	2.39	Pasture paddock with drains	Drains and darkness of visible soil suggests soil is organic	Grassland		F9
10	0.07	Stream next to geothermal pool complex	Likely not OS given proximity to stream - soil likely influenced by stream material	Not OS	NA	F10
11	1.58	Mine carpark	Developed and tar sealed - some areas of vegetation - soil does not look organic	Not OS	NA	F11
Total	15.16	All largely mapping errors, most found on the edge of a polygon				NA

Table 15: Aerial images showing polygons mapped as 'Other Land'.



14 Appendix G – Organic Soil emissions comparison to the regional inventory

See below tables for calculations associated with Figure 2 in Section 5.3. Table 16 lists total emissions from each sector for the 2015/16, 2018/19, and 2021/22 inventory years, compared to OS emissions. Table 17 shows sector emissions as a percentage of total net emissions (including forestry) and Table 18 shows sector emissions as a percentage of total gross emissions (excluding forestry).

Table 16: Emissions by sector for each inventory year (net emissions

	Inventory year emissions (Mt CO_2e)		
Sector	2015/16	2018/19	2021/22
Organic soils	1.5	1.5	1.5
AFOLU (incl. Forestry)	4.8	3.1	6.4
Transport	1.6	2.0	1.9
Stationary Energy	1.3	1.6	1.6
Waste	0.3	0.3	0.3
Industry	0.1	0.1	0.1
Total emissions	9.7	8.6	11.9
Total emissions (excl. OS)	8.2	7.1	10.3

*AFOLU = Agriculture, Forestry, and Other Land Use

Table 17: Sector emissions as a percentage of total net emissions (includes forestry)

	Inventory year emissions (%)		
Sector	2015/16	2018/19	2021/22
Organic soils	16	18	13
AFOLU (incl. Forestry)	50	36	54
Transport	17	23	16
Stationary Energy	14	19	13
Waste	3	3	3
Industry	1	2	1

Table 18: Sector emissions as a percentage of total gross emissions (excludes forestry)

	Inventory year emissions (%)		
Sector	2015/16	2018/19	2021/22
Organic soils	11	11	11
AFOLU (excl. Forestry)	65	60	60
Transport	12	15	14
Stationary Energy	10	12	12
Waste	2	2	2
Industry	1	1	1

15 Appendix H – Discussion: accounting for emissions from all chapters of the 2013 WS

The 2013 WS supplement includes additional chapters. Although outside the scope of this report (this study focussed on inland drained OS), these chapters could be assessed for suitability for inclusion. Additionally, estimating the extent of these areas using accurate spatial data and maps are needed to support these inclusions, as outlined below:

- **Rewetted Organic Soils (Chapter 3)** – to further understand the potential emissions profile of areas retired from their current drained land use. Rewetted OS would use the soil and LUCAS layers as described in this report given there are no current examples of rewetting of peat in the Waikato. A method for detecting rewetted systems would be needed.

- **Coastal Wetlands (Chapter 4)** – open the discussion towards opportunities in Blue Carbon. Coastal wetlands (seagrass and mangroves) were mapped using rapid field assessments in a number of estuaries and harbours within the Waikato region in 2013 based on methodology trialled in the Tairua harbour (Needham et al. 2013; Needham et al. 2014). This information was repeated in summer 2023 and likely to be delivered as a technical report. Other options for mapping in future include desktop assessments of aerial imagery or (Light Detection and Ranging) LiDAR, although there may difficulty in differentiating vegetation in environments using these methods (*Pers. Comm., Michael Townsend* – WRC).

- **Inland Wetland Mineral (Chapter 5)** – including mineral soils with a peaty layer and gley soils. Mineral soils with a peaty layer are no longer accounted for in the national inventory (and were not measured in this study) but should be considered in this chapter in future. Inland mineral wetlands are currently being mapped within the Waikato region under the National Policy Statement for Freshwater Management (NPS-FM) 2020 (Ministry for the Environment 2023b) and the National Environmental Standards for Freshwater 2020 (Reddy 2020), which requires councils to *"identify and map wetlands 0.05 ha or greater"* based on methods outlined in Ministry for the Environment (2021). Methods include in-field assessment, but this is likely a desktop mapping task using available information (e.g., intersection of LUCAS with a soil map). Given the size of the Waikato combined with the minimum wetland size requirement, this is a large undertaking and delivery is likely constrained by time.

- **Constructed Wetlands for Wastewater Treatment (Chapter 6)** – man-made wetlands are man-made engineered systems designed and constructed to use wetland vegetation, soils, and associated microbial assemblages to aid in the treatment of wastewater (Vymazal 2007). Semi-natural treatment wetlands[17] are also included in this chapter (Hiraishi et al. 2014). These wetlands may provide future opportunities around offsetting emissions and avoiding nutrient loss for businesses, but a method for detecting constructed wetland systems would be needed.

[17] Natural wetlands modified for the purpose of wastewater treatment.