MEASUREMENT TOWARDS MITIGATION - GHG EMISSIONS FROM NELSON WWTP

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ABSTRACT

Greenhouse gas (GHG) emissions from wastewater treatment plants (WWTPs) are a growing concern for local authorities in Aotearoa/New Zealand. Significant quantities of climate warming gas are emitted from WWTPs, and these emissions make up a substantial proportion of each operating authority's carbon footprint. Authorities are therefore grappling with how to better quantify emissions of nitrous oxide (N_2O) and methane (CH_4) from WWTPs.

While Water NZ has provided helpful guidelines to inform desktop estimates of GHG emissions, there remains a degree of uncertainty with these approaches. This uncertainty led Nelson City Council (NCC) to develop an innovative measurement approach to estimate the GHG emissions for their Nelson WWTP as part of their wastewater emissions reduction programme.

Supported by Three Waters Stimulus funding, NCC, Tonkin & Taylor (T+T) and Land and Water Science (LWS) embarked on a campaign of physical measurements across the WWTP. Flux measurements and gas samples are being taken over a year in each of the spring, summer, autumn and winter seasons. Key plant processes including the biofilter, facultative and maturation ponds and wetlands are being sampled. Measurements are being carried out using an accumulation chamber, including from a boat for the ponds and wetland. Gas samples at each flux measurement are analysed for CO_2, CH_4 and N_2O by gas chromatography undertaken at Lincoln University.

From this data, a refined estimate of the GHG emissions was calculated. Initial results from spring, summer and winter show measured emissions are significantly higher compared with desktop estimated methods, with CH_4 from the facultative pond the largest source of emissions for this WWTP.

Based on these findings NCC will install methane sensors to reduce temporal uncertainty and further refine emissions estimates. Ultimately this work aims to improve GHG estimates allowing for climate informed operational and investment and decisions to be made.

KEYWORDS

Wastewater, emissions, climate change, greenhouse gas, measurement

PRESENTER PROFILE

Ollie is an engineer who has worked in the water sector for 14 years. Building on experience gained in the rebuild of Christchurch following the 2011 earthquake sequence, he pivoted to international development for the World Bank where climate adaptation was a necessity. His experience has extended to climate change mitigation in his current role with Tonkin & Taylor.

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INTRODUCTION

Greenhouse gas (GHG) emissions from wastewater treatment plants (WWTPs) are a growing concern for local authorities in Aotearoa/New Zealand. Significant quantities of climate warming gas are emitted from WWTPs, and these emissions make up a substantial proportion of each operating authority's carbon footprint.

As an example of the potential financial impact, if the estimated emissions[1] from Nelson City Council's (NCC's) Nelson Wastewater treatment plant (NWWTP) were to be offset through the New Zealand emissions trading scheme (ETS), based on current value[2] this could cost up to $400k per year, a significant additional cost to NCC.

Given the impact and significant financial cost, authorities are seeking to better understand how to quantify emissions of carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) from WWTPs.

Building on emissions factor-based approaches pioneered by the Intergovernmental Panel on Climate Change (IPCC), Water NZ provided the industry with helpful direction. Their 2021 guidelines serve as a basis for estimating emissions based on a desktop assessment (Water NZ 2021), but there remains a degree of uncertainty with this approach.

The alternative approach adopted by NCC was direct measurement of emissions, and a case study of how this was undertaken is presented. This paper does not claim to be an example of best practice, but rather an example of a pragmatic approach developed from the ground up using available resources and equipment. The purpose of this paper is to share knowledge with the industry in the area of GHG measurement where there is currently a dearth of knowledge. Ultimately it is hoped that other authorities can learn from this experience to help them on their own path towards climate change mitigation for their WWTPs.

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[1] Based on measurement results documented in Section 5.1.1, emissions are estimated at 5,759 tCO_2-e/yr

[2] On 23 June 2022 the carbon price is approximately $70 per NZU which is equivalent to tCO_2-e

1 PROJECT OBJECTIVES

In 2019 NCC declared a climate emergency. Given that current emissions factor based approaches for estimating GHG emissions from WWTPs have very high levels of uncertainty and are subjective, NCC sought to proactively understand the emissions for their NWWTP. The key objectives of this project are to reduce the uncertainty in GHG estimates and to determine the major sources of emissions within the WWTP process train.

Armed with a better understanding of the sources of emissions from the plant, NCC would be able to make climate informed operational and investment decisions including long-term planning for upgrade and renewal of the plant.

This project was funded by NCCs long term plan (LTP) 2021 – 2031 programme and has been supported by three waters stimulus funding.

As direct measurement of GHG emissions from WWTPs is a new and rapidly evolving field, the project team adopted an adaptive approach to ensure best value from funding and to meet these project objectives.

1 NELSON WWTP DESCRIPTION

NWWTP treats the wastewater from approximately half of Nelson with a catchment population estimated at approximately 25,000. Located 9 km north of the Nelson city center, incoming flows are on average 7,900 m^3/day on a dry day. The plant uses a pond-based treatment system similar to many other WWTPs in New Zealand (refer Photograph 1). It takes flows from a gravity and pressure wastewater network serving a predominately residential catchment with some industrial discharges also captured.

Photograph 1: Oblique view of NWWTP with land-based plant in foreground and facultative pond in background. (Source Nelson City Council).

1.1 PLANT OPERATIONS

The typical flow path through the plant is shown in Figure 1 with detail of additional treatment facilities provided in Figure 2. Under normal operating conditions, flow enters the plant at the inlet screen where grit and screenings are removed from the effluent. Once screened, flow passes through a network of pipes to the aerated facultative pond which serves an oxidation function. Next, effluent flows through the baffled maturation pond and onwards to the wetland before being discharged to Tasman Bay via a 350 m long ocean outfall pipe.

Figure 1: Overall plan of NWWTP with typical flow path shown in blue (Source: Top of the South Maps (TOTSM)).

Typically, the plant is operated with the pond treatment system sufficient to provide the treatment required to meet resource consent conditions. In the event of increased loading and/or seasonal fluctuations, the trickling filter, clarifier and sludge thickening systems are also operated (refer Figure 2).

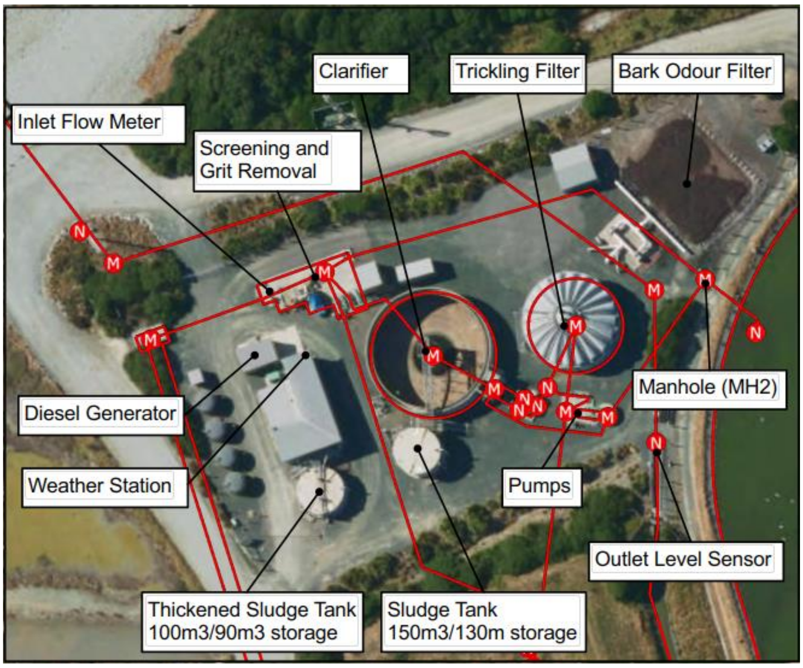

Figure 2: Detail plan of land based plant at NWWTP (Source: TOTSM)

A vacuum odour system extracts foul air from the inlet screen and other land-based plant and discharges them via a bark odour filter.

Going into this project, the contributions of each of these parts of the plant (ponds, wetland and land-based plant) to GHG emissions was unknown, and hence NCC's desire to better understand them.

1.2 SOURCES OF UNCERTAINTY IN GHG EMISSIONS ESTIMATES

Given the project objective to reduce uncertainty in GHG emissions estimates, it is worth defining the three types of uncertainty considered:

1.2.1 Temporal uncertainty

Temporal uncertainty captures how emissions vary over time. Methods which have a high measurement frequency will have lower temporal uncertainty and vice versa. Temporal uncertainty can be reduced with continuous measurement of emissions.

1.2.2 Spatial uncertainty

Spatial uncertainty captures how emissions vary across an area. Methods which involve more sampling across an area will reduce spatial uncertainty. For example, by conducting more measurements at different locations across a pond.

1.2.3 Measurement uncertainty

Measurement uncertainty captures how well a method quantifies actual emissions. An accurate and precise method or instrument (such a laboratory testing) will typically result in lower uncertainty compared with a field-based measurement.

2 GREENHOUSE GAS MEASUREMENT OPTIONS

Given the context of the NWWTP and the project objectives, NCC approached Tonkin & Taylor for support with better estimating GHG emissions. Prior to starting work the project team took a step back and considered a range of available options with initial analysis of cost, risk and residual uncertainty. These were presented in an options report (Tonkin & Taylor, 2021) which is summarised in Table 1.

The options are generally ordered based on level of complexity, effort to implement and indicative cost, or conversely by reduced uncertainty.

Table 1: Summary of options considered for developing an improved GHG emission estimate

Option		**Indicative annual cost**[3]		**Complexity level/risks**	**Certainty GHG emissions estimate**
		Initial	**Ongoin g**		
1	Desktop estimate using IPCC standard	$	$	Low	High uncertainty in the order of ±100%.
2	Refined desktop estimate based on IPCC standard	$$	SS	Low	Slightly reduced levels of uncertainty.
3	Accumulation chamber measurement campaign	$$$	$$$	Medium –significant H&S management.	Spatial certainty high. Temporal certainty low.
4	Gas sensor installation and measurement	$$$$$	$$	High –specialised instrumentation required.	Temporal certainty high Spatial certainty low.
5	Unmanned aerial vehicle measurement	$$	$$	High – experimental technology.	Spatial certainty high. Temporal certainty low.
6	Data-driven modelling *Use existing data plus Option 3.*	$$$$	$$	Medium – sophisticated data science required.	Lower uncertainty.
7	Advanced fully integrated model. *Use existing data plus Options 3,4.*	$$$$$	$$$	High – requires specialised instruments and data science.	Lowest uncertainty estimated less than ±10%.

[3] For the purposes of comparing options estimated annual costs are presented as follows: $ <$5,000, $$ between $5,000-$25,000, $$$ between $25,000-$50,000, $$$$ between $50,000-$100,000 and $$$$ >$100,000

Given the costs, advantages, disadvantages and risks of each option, a multicriteria analysis approach was applied with the following decision criteria:

- Risk.
- Residual uncertainty.
- Capital cost.
- Operational cost.
- Suitability for independent use by NCC.
- Ability to model operational changes.

Based on discussions and scoring in a workshop, Option 6 was selected by NCC. This option involved a campaign of accumulation chamber measurement of GHG emissions over 4 seasonal surveys (spring, summer, autumn and winter). Once surveys were completed, statistical regression analysis is planned to be undertaken to determine which (if any) variables are good predictors of GHG emissions. If these are identified, they will be used to develop a data driven model to refine emissions estimates and potentially predict future emissions based on operational data. The proposed approach is detailed in Section 3.

2.1 GREENHOUSE GASES TO BE MEASURED

The GHG emissions which this work sought to measure were nitrous oxide (N_2O) and methane (CH_4). N_2O is a potent GHG, with a global warming potential (GWP) estimated between 256 and 298 times that of carbon dioxide (CO_2), while CH_4 has a much lower GWP of between 25 and 34 (Water NZ 2021). CH_4 is removed from the atmosphere by a chemical reaction, hence has a relatively short life of 12 years. By contrast, N_2O persists for 114 years and is much slower to be removed from the atmosphere (Forster et al, 2007). The measurement approach sought to capture fluxes of these gases, or the magnitude and direction of flow in units of grams CO_2 equivalent per square metre per day (gCO_2-e/m^2/day). Once fluxes were determined they are multiplied through by area and duration to estimate total emissions.

While CO_2 is itself a GHG, as per IPCC's 2006 and 2019 guidance, and current New Zealand industry practice (Water NZ 2021), CO_2 emissions from wastewater are considered to be wholly biogenic, that is they are produced by living organisms. This is because emissions are generally derived from modern organic matter in human excreta or food waste. These CO_2 emissions would therefore occur naturally irrespective of the treatment approach taken and hence the IPCC guidelines suggest excluding them from national emission inventories. This project followed this industry standard approach.

3 GREENHOUSE GAS MEASUREMENT

3.1 PHYSICAL DATA COLLECTION

With the decision made to proceed with a direct measurement approach using an accumulation chamber, Tonkin & Taylor worked with subconsultant Land and Water Science (LWS) to develop an approach which would allow accurate measurement of emissions. In the absence of a publicly available standard measurement protocol, the project developed its own which was tailored to the NWWTP requirements. This was documented in the measurement methodology (LWS 2021) and revised sampling approach (LWS 2022) which are summarised below. The measurement approach had the key components detailed below:

3.1.1 Accumulation chamber

At the heart of the approach was the accumulation chamber which has previously been used for WWTP GHG measurement in international studies (Chandran et al. 2016; Grubver et al. 2019; Tumendelger et al. 2019). In this case, a West Systems portable diffuse flux meter (refer Photograph 2) was used, which makes use of non-consumptive laser and infra-red spectroscopy to measure the gaseous fluxes of interest. The measurement capabilities of this device included parts per billion (ppb) of CH_4 which was the most important parameter of interest. Parts per million (ppm) of CO_2 was also reported by the accumulation chamber, but not N_2O. Therefore, a separate process of sample capture and laboratory analysis with gas spectrometry equipment was required to measure N_2O (refer Section 4.1).

Photograph 2: West System accumulation chamber in place to capture emissions measurements at NWWTP. A silver float surrounds the accumulation chamber. (Source Di Elliot).

Captured flux data was logged for later retrieval and analysis, together with a range of other measurements which were taken to be considered as potential predicting variables in subsequent regression analysis and modelling. These parameters included the following:

- Weather conditions.
- Wind direction.
- Wind strength.
- Air temperature.
- Relative humidity.

- Barometric pressure.
- Water depth.
- Global position system (GPS) coordinates (easting and northing).

In addition, the following parameters were measured at 100 mm below the pond surface level, and also at 200 mm above the bottom of the ponds:

- Water temperature.
- Conductivity.
- Dissolved oxygen.
- pH.
- Oxygen reduction potential.
- Salinity.
- Total dissolved solids.
- Conductivity.
- Turbidity.

3.1.2 Sample capture

In Survey 1, issues were experienced with capturing samples as a vacuum could not be maintained in the 5 mL vials (exetainers) being used. For Survey 2 onwards a vacuum pump system was developed to capture larger samples in 1000 mL Tedlar foil bags to enable laboratory analysis.

A schematic of the sampling setup is provided in Figure 3 and was used as follows:

- An electric diaphragm pump was used to draw a sample from the accumulation chamber. A variable rate speed controller was used to control the vacuum from the pump. The pump speed was set at zero during flux measurement, and then opened to 10 ml/sec for Tedlar bag sampling.
- The dead-volume of the pump, and tubing was flushed prior to opening the valve on the Tedlar bag. The gas in the chamber is mixed by both a manifold and by recirculation of the gases.

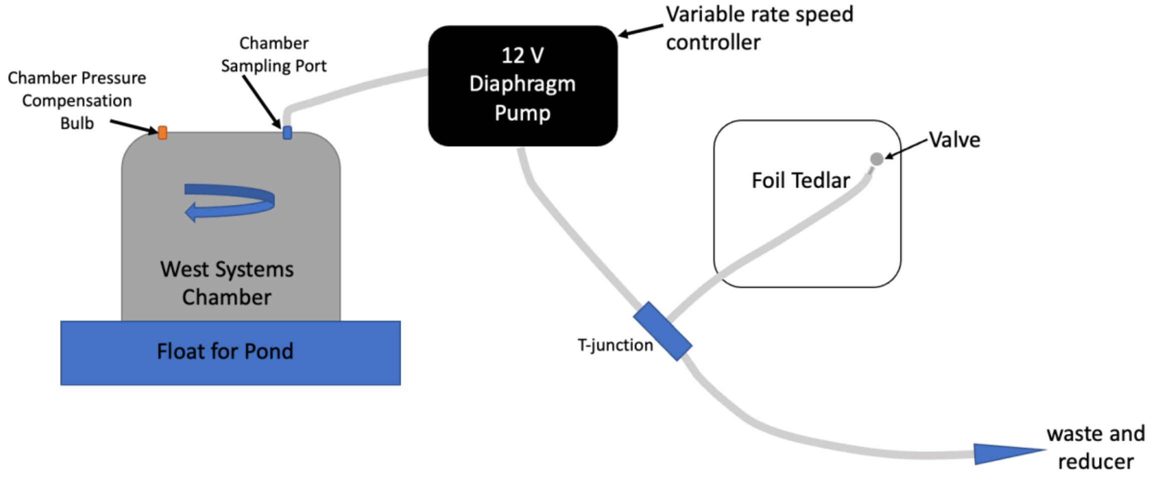

Figure 3: Schematic of accumulation chamber used for GHG measurement at NWWTP (Source: LWS 2022).

3.1.3 Land emissions measurement

Where samples were captured on land (particularly for bark odour filter measurements), the accumulation chamber was simply placed in the required location and measurements taken (refer Photograph 3).

Photograph 3: Accumulation chamber in place sampling biofilter emissions. Source: Di Elliot.

3.1.4

3.1.5 Ducted emissions measurement

Given the land-based plant is served by a foul air duct system, this provided a convenient opportunity to capture emissions from the plant operations. In order to undertake these measurements, existing tapping points on the odour duct network were used (refer Photograph 4).

Photograph 4: Direct sampling of gaseous concentration from foul air duct. Source: Di Elliot.

3.1.6 Water emissions measurement

For measurements on water, a boat was used. Working on a wastewater pond has some significant safety hazards and hence a detailed safety plan was prepared including seeking permissions form the Nelson harbourmaster (Southern Waterways 2021). The boat used was a small aluminium dingy (approximately 3m long) mounted with a crane for lifting and lowering the accumulation chamber (refer Photograph 5). The boat was manned by two technicians with one operating sample equipment and logging and the other controlling the boat and accumulation chamber positioning.

Photograph 5: Photo of boat setup prior to sampling. Note accumulation chamber lifted clear of water with crane. Source: Di Elliot.

A guide rope was used to ensure repeatable positioning of the boat for sample capture. Anchored to the top of pond embankments with waratah posts, the rope was tensioned along a predetermined grid and the motor used to position along the rope for each sample (refer Photograph 6). This attachment to the guide rope reduced the risk of drift during sampling. The rope was repositioned along the next grid and the process repeated until all the samples were captured. It took approximately four days to capture 66 samples across the ponds and wetlands in good weather conditions. As wind speed was a key limiting factor for safety and accuracy of measurement, work was suspended if it exceeded a pre-determined threshold.

Photograph 6: Photo of guide rope setup to ensure consistent positioning for sampling. Source Di Elliot.

4 ANALYSIS

4.1 LABORATORY TESTING

Given the accumulation chamber did not measure N_2O flux directly, Tedlar bag samples were shipped to Lincoln University for measurement of the concentration of CO_2, CH_4, and N_2O by gas chromatography. The main purpose of this analysis was to determine the mass ratio of CH_4 to N_2O.

The estimated N_2O flux for each sample was then calculated using the mass flow rate of CH_4 from the accumulation chamber and the mass ratio of CH_4 to N_2O from laboratory testing using the Equation 1:

$$\text{Flux } N_2O = \text{Flux } CH_4/\text{Mass ratio } CH_4{:}N_2O \quad (1)$$

This approach for estimating N_2O emissions has been used in other environmental studies (Fridriksson et al., 2006; Gebert et al., 2011).

4.2 ANALYSIS APPROACH

With the combination of accumulation chamber and laboratory testing data, estimation of emissions could proceed. This was initially done as a spreadsheet-based approach, multiplying average emissions across each location by the area of each location for the biofilter, facultative pond, maturation pond and wetland. The calculation approach made the following key assumptions which are limitations that will be the subject of further refinement (refer Section 6.1):

- Spatially, it was assumed that emissions were uniform across the location and equal to the average of the measurements for each location. This did not account for any spatial patterns such as lower emissions at the edge of the pond where it was shallower.
- Temporally, samples (taken at a particular point in time) were representative of emissions at all times for the period considered. This approach did not account for variation over time due to diurnal patterns in flow or pond temperature changes over a day.

After the completion of Survey 3, the quantity of data made spreadsheet analysis difficult and cumbersome. A decision was taken to present results in Microsoft Power BI, a visualisation tool which allowed better interaction and analysis of the data.

The dashboard which was created (refer Figure 7) has interactive filters for survey number and location which users can select. Measured fluxes were plotted visually in addition to box and whisker plots which show the distribution of data. Estimated total annual emissions are also reported based on the filter selected noting the limitations described above.

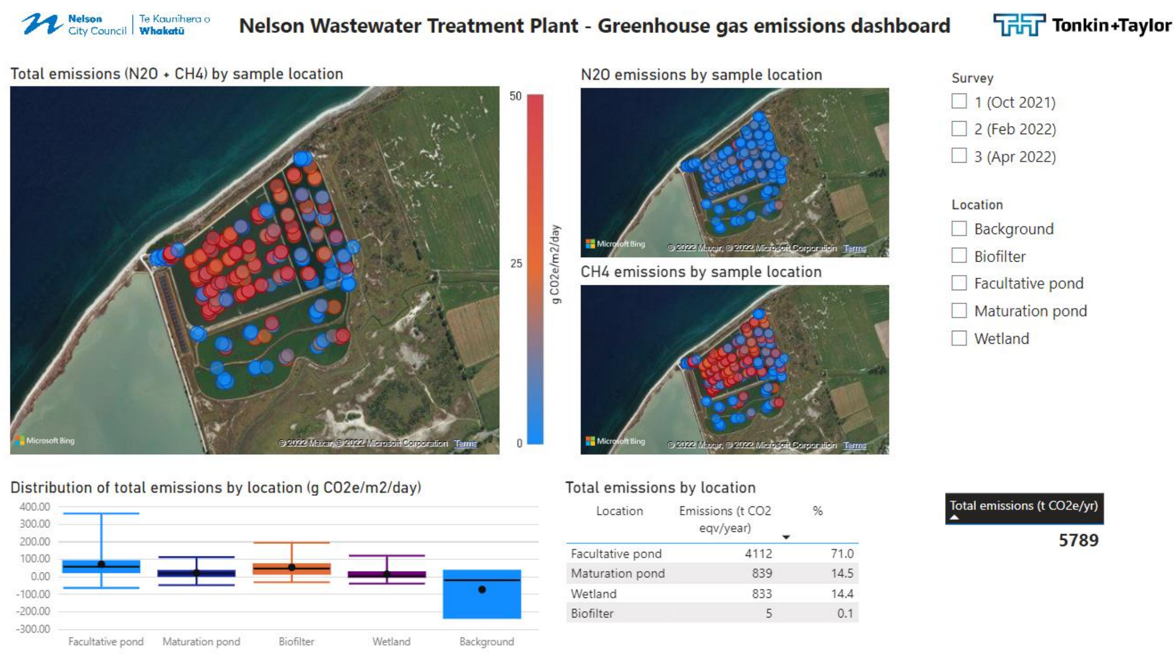

Figure 7: Power BI dashboard used to visualise emissions measurements.

4.3 FUTURE ANALYSIS

Once a full year of data has been collected (survey 4 is outstanding at the time of preparing this paper), the measured emissions (as the dependent variable or outcome) will be compared with a range of potential independent variables (predictors) which were measured as part of everyday plant operations. Relevant independent variables could include:

- Plant operational parameters
    - Inlet flow
    - Pond pH
    - Biological/chemical oxygen demand
    - Dissolved oxygen
- Environmental conditions
    - Temperature (air and water)
    - Depth to base of pond
    - Humidity
    - Wind speed
    - Rainfall

A regression analysis could identify which (if any) independent variables were good predictors of GHG emissions and help to reduce temporal and spatial uncertainty which is significant given that only four surveys are planned over a year.

5 RESULTS AND DISCUSSION

5.1 SUMMARY OF GHG EMISSIONS

As measurements are ongoing, estimates will be refined, but data at the current point in time is still useful to show the trends observed which are described and discussed below.

5.1.1 Temporal emissions

A summary of emissions estimates is presented in Table 2 below.

Table 2: Summary of estimated annual emissions

Emissions estimate	Estimated annual emissions (tCO_2-e/yr)	Comparison to baseline
IPCC desktop method (By Toitū Envirocare, 2020)	2,573	+91%
Baseline - IPCC desktop method (By LWS in Tonkin & Taylor 2021)	1,345	-
Survey 1 (Oct 2021)	6,575	+388%
Survey 2 (Feb 2021)	8,286	+516%
Survey 3 (Apr 2021)	2,568	+91%
Time weighted (Surveys 1-3)	5,769	+330%

The total emissions estimated based on survey measurements were between 91% and 516% higher than the baseline estimated using the IPCC desktop method. This suggests that standard emissions factors used in the desktop method may underestimate actual emissions for NWWTP. It also suggests that temporal variation is significant and hence more effort is required to better capture this and reduce the resulting uncertainty.

5.1.2 Spatial patterns

As apparent in Figure 8, there is a clear pattern of higher emissions from the facultative pond, which decrease as flows pass through the maturation pond and wetland. The distribution of emissions across locations is shown in Table 3.

Table 3: Summary of estimated annual emissions by location (Surveys 1-3)

Location	Estimated annual emissions (t CO_2-e/yr)	Percentage of total
Facultative pond	4,112	71.0%
Maturation pond	839	14.5%
Wetland	833	14.4%
Biofilter	5	0.1%
Total	**5,789**	

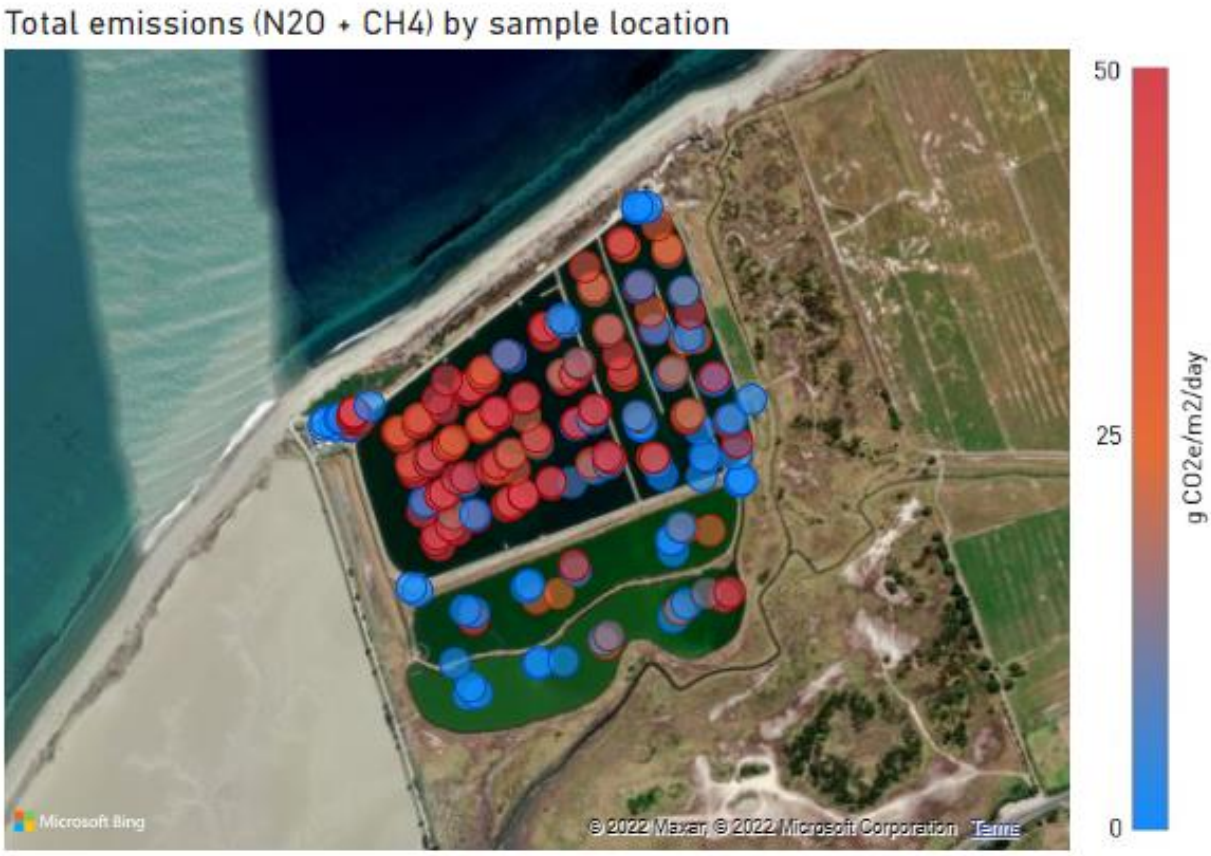

Figure 8: Spatial pattern of total emissions across NWWTP (including all data from Surveys 1-3). Blue indicates low emissions, red indicates high.

5.1.3 CH_4 major source of emissions

Despite N_2O being a much more potent GHG, at NWWTP CH_4 makes a larger contribution to total emissions across all surveys and locations – refer Figure 9.

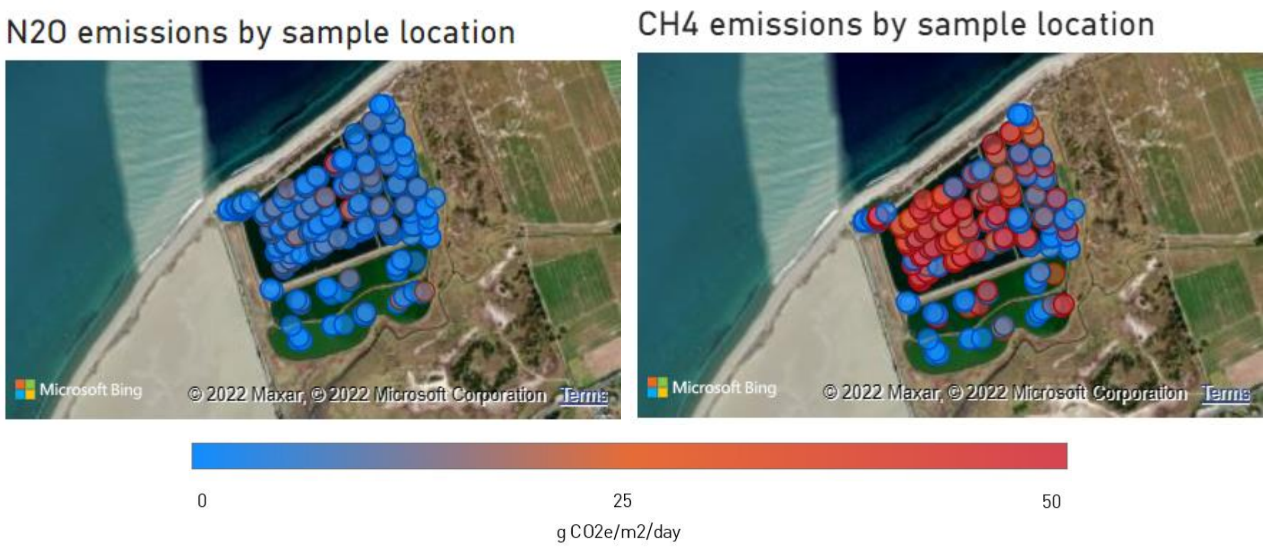

Figure 9: Contribution of N_2O and CH_4 to total emissions for NWWTP (including all data from Surveys 1-3).

6 CONCLUSIONS AND NEXT STEPS

While this measurement work is still in progress, the interim findings are nevertheless useful given the project objectives to reduce uncertainty in estimating GHG emissions from the NWWTP.

6.1 INSTALLATION OF METHANE SENSORS

Given the temporal variation apparent across surveys, NCC has decided to take action to reduce this through the installation of aqueous phase methane sensors as originally considered at the options stage. Aqueous concentrations will be converted to gas emissions using proven bulk flux equations (Pengfei et al., 2019; Wanninkhof, 2014; Solomon et al., 2009).

The findings of the surveys undertaken allowed the highest emissions source (CH_4 from the facultative pond) to be prioritised for sensor installation. Once data starts to flow, the spatial patterns identified can be used to extrapolate to other locations. NCC will also procure a second portable sensor to capture measurements, with a year-long sample period at the maturation pond initially proposed. This portable sensor may also be used to verify spatial patterns.

6.2 ADAPTED ANALYIS APPROACH

While it was originally intended that regression analysis would be conducted based on the four surveys alone (refer Section 4.3), the decision to install methane sensors will allow for significant reductions in uncertainty, and potentially real time estimates of emissions based on identified trends in the data. It is yet to be decided if the data-driven model will be developed, but if it is the additional sensor data will help resolve temporal correlations. The model will be continuously updated and improved as a longer history of measurement data becomes available.

6.3 CALIBRATION OF EMISSIONS FACTORS

Once there is a sound understanding of emissions with reduced spatial, temporal and measurement uncertainty, the data can be used to calibrate the emissions factors used in desktop-based approaches suggested by Water NZ (2021). These revised factors may be useful for other similar pond-based plants in New Zealand and indeed internationally. This will be useful as not all authorities may be in the position to fund the type of pioneering work that NCC has conducted for this project.

Clearly the refined estimates presented show emissions to be greater than estimated with desktop methods. Having identified the major sources, NCC is already on the path to making climate informed operational and investment decisions for the NWWTP.

ACKNOWLEDGEMENTS

Nelson City Council as a visionary client who backed up their climate emergency with funding to better understand emissions from NWWTP.

Three Water stimulus funding which allowed this work to be undertaken.

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Andrew Boyce (LWS) – tireless champion and always open to adjust scope to the demands of the project.

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