THE Water Research FOUNDATION

Climate Mitigation & Greenhouse Gases

THE CHALLENGE

A collective body of scientific research has shown that greenhouse gas (GHG) emissions trap heat in the Earth's atmosphere leading to a warming effect that is the primary driver for a changing climate. Extreme events and variabilities from a changing climate pose unique challenges for the water and wastewater utility sector to provide sustainable, reliable, and affordable services to their communities. Further, water utilities are tasked with reducing GHG emissions from their own operations.

An often-quoted number reveals that global water use, storage, and distribution account for roughly 10% of GHG emissions (Kerres et al. 2020), which includes activities outside the water utilities' control. GHG emissions from wastewater operations are estimated to be 1.3% of global emissions (Climate Watch 2021). Numerous water utilities have goals to reduce their GHG emissions, for example, by reducing emissions by about 50% from 2005 levels by 2030 and to be net zero by 2050.

Many other sectors beyond waste have quickly identified the source of their GHG emissions and have harnessed these emissions using operational waste-to-energy methods. However, sectors that process organic matter—like landfills and wastewater treatment—have an added challenge. Wastewater treatment processes can generate GHG emissions throughout the life cycle of wastewater treatment processes, yet knowledge is limited by what can be measured.

To help solve this challenge, the water sector is working to develop and update methods to better understand, measure, and mitigate GHG emissions from each step in the wastewater treatment life cycle. Of utmost concern are wastewater emissions like nitrous oxide (N_2O) and methane (CH_4), due to their significant global warming potential (GWP). These compounds have GWPs approximately 270 times and 80 times higher than carbon dioxide (CO_2) for a 20-year timescale, respectively (IPCC 2021). Another concern is utility worker health and safety when high levels of these gases are in abundance at treatment facilities.

Defining Emission Types Using the GHG Protocol

The Greenhouse Gas Protocol (2025) is the world's most widely used GHG accounting standard. It measures an organization's GHGs using three scope levels (Figure 1).

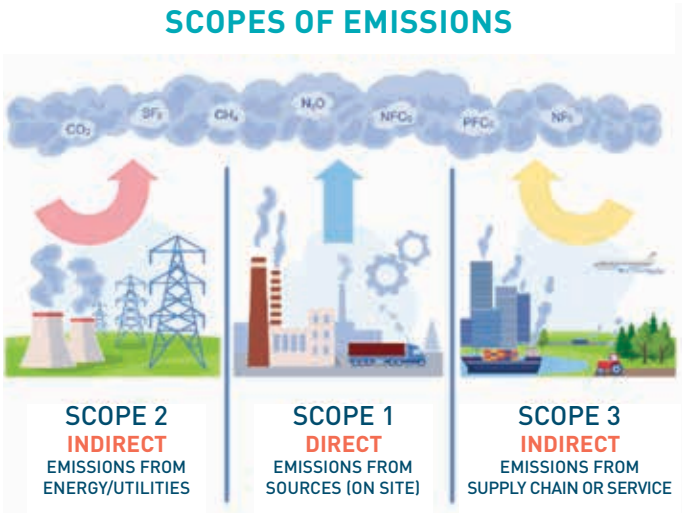

Figure 1. The Greenhouse Gas Protocol provides a global accounting standard categorizing emission scope levels to assist an organization with GHG emission measurements.

The current understanding of Scope 1 emissions from water utility-owned facilities is based on limited studies but continues to evolve with more monitoring and analyses. For example, Moore et al. 2023 and Song et al. 2023 suggest that the U.S. wastewater sector might emit twice as much CH_4 as estimated previously by the U.S. Environmental Protection Agency. Complicating utility efforts to achieve net-zero goals by reducing Scope 1 emissions are more stringent water quality-based regulations that require more energy-intensive treatment methods or resource recovery goals.

THE RESEARCH

The Water Research Foundation (WRF) has been studying the impact of utility GHG emissions since the early 2000s. The 2006 report, *Climate Change and Water Resources: A Primer for Municipal Water Providers* (2973) included a summary of climate science relating to GHGs. WRF's subsequent work on GHG emissions covered topics such as GHG inventory and management (4156, 4224), emissions from lagoons and ponds (1778) and septic systems (1362), N_2O emissions from wastewater treatment (1791, 1792), and flare efficiency (1779). More recently WRF published work focused on emissions from sewers (4885) and biofilm (4873).

Contributors to WRF's current research topic, **Climate Mitigation & Greenhouse Gases**, include numerous water sector professionals from the American Water Works Association, Water Environment Federation, US Water Alliance, Canadian Water Network, International Water Association, Global Water Research Coalition, utilities, universities, consulting firms, and federal agencies. This research topic area will help utilities:

- Increase the level and practice of GHG emissions accounting and monitoring.
- Improve available information on GHG emissions.
- Enhance knowledge of N_2O emissions.

GHG Inventory and Library

To help utilities enhance workplace safety through identification and mitigation of CH_4 emissions and meet net-zero emission goals, a climate action plan is recommended. The first step in a climate action plan is to conduct an inventory of Scope 1, 2, and 3 GHG emissions to gain a baseline and inform mitigation goals. To estimate GHG emissions, a utility needs an inventory of GHG emission sources, amount of energy used, and GHG emissions factors (based on actual GHG measurements when possible).

Figure 2. A wastewater treatment aeration tank is a source of N_2O emissions, a potent GHG.

WRF's research aims to improve state-of-the-practice and develop utility-facing guidance for GHG accounting in *Establishing Industry-Wide Guidance for Water Utility Life Cycle Greenhouse Gas Emission Inventories* (5188). During project origination, there was both a lack of consistency in GHG accounting specific to the water utility sector and understanding around the water sector's GHG emissions.

The creation of a user-friendly tool and guidance can help water utilities determine GHG emissions from all three scopes. The tool will include information from the Intergovernmental Panel on Climate Change's (IPCC) 2019 refinement report and other current data. Many questions will be discussed, such as where to find the best available emission factors and how to deal with areas of uncertainty like process N_2O and sewer CH_4. Ultimately, this project should help water utilities increase their level of GHG accounting practices and start to make progress toward their climate action plan goals to reduce GHG emissions.

Currently, GHG emissions factors for wastewater process units are based on very small datasets from limited publications of measured GHG emissions. More GHG emission measurements will help the sector improve its knowledge. For example, Song et al. (2024) points out that in 2006, the IPCC Emission Factor for N_2O was based on a single monitoring campaign. In 2019, it was based on 30 campaigns which found the emission factor to be 50 times higher.

In *Developing a GHG Emissions Library for Unit Processes by Water Utilities and Decentralized Systems* (5255), the research addresses the dataset challenge by creating a space for people to share their measurements of Scope 1 GHG emissions. This project will collect measured GHG emissions and energy-use data (such as operating data, experimental plan, synthesis/reporting, recommendations, and contact info) and will accept anonymous utility data submissions. Data sharing efforts will help establish the foundation for more

accurate emission factors and consensus on methods with potential for adoption by The Climate Registry and ICLEI–Local Government for Sustainability guidance documents.

GHG Monitoring and Method Comparison

The two significant knowledge gaps in water sector GHG emissions are N_2O emissions from wastewater treatment processes (Figure 2) and methane emissions from sewer collection systems. There is great interest in N_2O emissions because of its high GWP but knowledge is limited. N_2O production and consumption in wastewater treatment processes is an active area of study, and the water sector has observed variability in N_2O emission measurements.

Of interest is new research that explores how nitrous oxide could be an indicator demonstrating how well wastewater treatment plant processes perform. (Pharand et al. 2025). WRF's *Advancing the Understanding of Nitrous Oxide Emissions Through Enhanced Whole-Plant Monitoring and Quantification* (5251) is a project that will collect N_2O emissions data from water resource recovery facilities (WRRFs) and utility participants. This project will collect new utility data from one year of continuous online monitoring and monitoring by primarily liquid-phase, site-wide measurements, as well as using previously collected utility data. Besides creating an N_2O emissions database, this project will produce a standard method for conducting on-site N_2O monitoring, guidance about selecting the most appropriate emission factor, best practices in mitigating N_2O, and minimizing the risk of N_2O in new builds and country-level N_2O estimates from the wastewater sector.

Limited studies suggest that sewer methane might contribute up to 35% of Scope 1 emissions, yet it is not considered in GHG protocols due to its difficulty to measure. *Sewer Methane Methods for Everyone* (5220) will increase knowledge by collecting more sewer methane data and developing estimation methods for utilities. The project will measure sewer methane in six full-scale campaigns and methods to estimate methane emissions from gravity sewers will be developed. Project goals are to create a "detailed method" requiring multiple user inputs that will be beta tested with 40–50 sewersheds and a "simple method" that will require limited user inputs. This work will develop products utilities can use to better understand sewer methane emissions and include in their GHG inventories.

Decision Making for Climate Mitigation

A crucial step in a climate action plan is to reduce emissions toward net-zero goals. Initial actions are relatively easy to identify—reduce energy consumption and increase renewable energy production. However, complications originate around wastewater treatment and resource recovery. Utilities will need to install more advanced treatment technologies like biological nutrient removal, anaerobic digestion, or per- and polyfluoroalkyl substances (PFAS) destruction to achieve more stringent treatment goals yet these technologies typically result in more energy use. Another complication arises when utility programs capture methane to generate biogas. This process generates a renewable fuel but it is also a source of GHG emissions. WRF has funded three projects to explore the considerations needed when developing various utility programs to achieve net-zero emission goals.

***Head-to-Head GHG Measurement Comparisons: Evaluating Plant-Wide and Process-Specific Quantification Methods* (5310) will compare the pros and cons of ways to measure GHG emissions for both CH_4 and N_2O using multiple techniques, like infrared cameras, at the same time at multiple WRRFs to inform industry of each technique's advantages and disadvantages.**

The project *Beyond Net Zero: Advancing Interdependencies Between Utility Greenhouse Gas Emission Reductions and Water-Energy-Food Nexus* (5187) is developing a strategic framework and operational guidelines to support WRRFs in making GHG-related decisions to achieve net-zero carbon emissions and beyond. The project includes a literature review synthesis and utility case studies highlighting innovative solutions and approaches for GHG emissions reduction with a focus on cross-sector collaboration and external partnerships.

The objective of WRF project *Tradeoffs Between Process Optimization, GHG Mitigation, and Energy Efficiency* (5288) is to create a framework for integrated evaluation of the benefits and costs that wastewater and water utilities can apply at a unit operations and systems level, consider current and future regulatory frameworks, and offer recommendation for reducing GHG emissions through the utilization of energy-efficient technologies, process optimization, and/or implementation of new treatment processes.

Biological nutrient removal (BNR) issues are being explored in *Balancing Carbon Management, Energy Management, Energy Production, Nutrient Removal, and Densification* (5271). This research will focus on the activated sludge process with systematic testing over 24 months of several BNR configurations to quantify impacts of influent carbon use and diversion on energy production, nutrient removal, and densification.

WHAT'S NEXT?

Due to the involvement of numerous water utilities, consulting firms, universities, and partner organizations, the reduction of wastewater treatment GHG emissions to achieve net-zero goals is a key topic of interest in the water sector.

The results of WRF's research and the significant collaboration amongst the water sector will help utilities create an informed baseline of GHG emissions and identify actions to reduce GHG emissions. Utilities will be better poised to understand what methods to implement, measure, and monitor GHG emissions. And lastly, this research enhances the best available information on GHG emissions and can be adopted into guidance issued by national and global organizations like IPCC and ICLEI–Local Governments for Sustainability.

LEARN MORE WITH WRF'S GHG WEBCAST SERIES

WRF hosted six GHG webcasts in 2023 and 2024 covering a range of GHG topics from basic GHG accounting to GHG emissions detection. These webcasts are a great educational resource and averaged about 600 attendees per webcast.

- Greenhouse Gas Emissions in the Water Sector: Let's Uncover the Basics **(Feb. 16, 2023)**
- Advances in Estimating Greenhouse Gas Emissions and Implementing Mitigation Strategies **(April 11, 2023)**
- Fundamentals of Wastewater Process Greenhouse Gas Emissions **(July 18, 2024)**
- Methane Emissions from Wastewater Treatment **(Sept. 19, 2024)**
- Nitrous Oxide Emissions from Wastewater Treatment **(Oct. 31, 2024)**
- Opportunities for Process Emissions Reductions **(Dec. 12, 2024)**

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