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Long-term nitrous oxide monitoring at the Duffin Creek Water Pollution Control Plant

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CASE STUDY

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Key insights

- Understanding, predicting, and mitigating nitrous oxide emissions is crucial as utilities across Canada strive to reduce their carbon footprint.
- Monitoring and measuring of nitrous oxide at the Duffin Creek Water Pollution Control Plant will inform actions that support safe, cost-effective services that have low emissions.
- Effective aeration controls are important to support the mitigation of nitrous oxide emissions from wastewater treatment processes, as shown through literature and field studies.
- Insights from this work highlight operational conditions that could contribute to nitrous oxide emissions, and the associated opportunities to reduce nitrous oxide emissions through process optimization. Examples include preventing oxygen ingress into the pre-anoxic zone and improving aeration control to reduce control errors.



Winterized controller for N₂O sensors.





Background

The Region of Durham (the Region), which serves approximately 800,000 residents, has long been recognized as an industry leader in delivering safe, reliable, and low-carbon water and wastewater services. Nitrous oxide is a potent greenhouse gas generated during certain wastewater treatment processes. Although extensive research has been conducted on its causes, questions remain about how to best mitigate emissions.

In 2023, the Region began monitoring nitrous oxide emissions from the Duffin Creek Water Pollution Control Plant with support from Jacobs Consultancy Canada Inc. The goal was to understand spatial, temporal, and process-related variability in emissions, particularly in relation to aeration control and other relevant operating parameters.

Challenges

Measuring and monitoring nitrous oxide in wastewater treatment processes presents two main challenges:

1. Variability resulting from the dynamics in incoming wastewater and operating conditions, interactions between liquid-phase gases, and other factors.
2. Data volume, which requires advanced data management and analytics tools, and real-time interpretation to inform operational decisions.

Globally, significant efforts are underway to understand the variability in nitrous oxide emissions from advanced wastewater treatment processes. To further understand this, the Region and Jacobs have planned to conduct two concurrent studies:

1. Enhanced nitrous oxide monitoring and modelling at the Duffin Creek Water Pollution Control Plant (WPCP): over fifteen months of continuous monitoring in Aeration Tank 9 (completed) and eight months in Aeration Tank 13 (ongoing).
2. Validation of electricity savings from ammonia-based aeration control (ABAC) and optimization of air control strategies (ongoing).

The two studies are complementary: ABAC-related changes will be examined for their effects on nitrous oxide emissions, with a goal to identify optimization strategies aimed to improve aeration energy efficiency while minimizing process nitrous oxide emissions.

A key challenge was managing and analyzing the large amounts of data generated to develop mitigation insights and inform operations. Jacobs tackled the challenge by creating a hybrid predictive model for nitrous oxide, integrating on-site data, process expertise, and advanced predictive algorithms to estimate liquid-phase nitrous oxide concentrations based on operating data. Diagnostic tools were used to analyze the results and answer the following questions:

- What caused specific nitrous oxide peaks and which variables were associated with them?
- What operational adjustments could reduce or prevent these peaks?
- Is there a model that describes the correlation between measured variables that can explain nitrous oxide behavior?

Approach

Jacobs developed an approach that integrates data-driven models with treatment process knowledge. The approach predicts liquid phase nitrous oxide concentrations and analyzes the results using diagnostic tools.

With some initial trial and error during the first few weeks of the field measurements, appropriate locations for the placement of the liquid-phase nitrous oxide sensors (Unisense/

Aquafy) were identified. These were installed in aeration tank nine, as shown in Figure 1.

Impact

The nitrous oxide emissions at the plant varied both spatially and temporally. Emissions were affected by plant operations, dissolved oxygen controls, and outside factors such as temperature. Figure 2 presents the estimated N₂O emissions by cell in aeration tank nine from January 2024 to March 2025.

The hybrid predictive model, which combines field monitoring and advanced data analytics, successfully tracked the observed nitrous oxide profile at the Duffin Creek WPCP (Figure 3). This demonstrates the model's potential to help utilities predict nitrous oxide emissions and contributing factors. This hybrid model uses diagnostic tools to identify the operational parameters that most influence nitrous oxide levels. By combining these insights with process knowledge, it turns complex data into actionable strategies for reducing nitrous oxide emissions.

As shown in Figure 4, specific nitrous oxide emission factors (EF) for aeration tank 9 were calculated, averaging at 0.90 percent.

Ongoing monitoring of liquid-phase nitrous oxide continues, with sensors relocated to aeration tank 13 in July 2025. This tank mirrors the configuration of aeration tank 9. The research undertaken by the Region and Jacobs contributes to [Water Research Foundation Project 5251](#), with ongoing efforts to expand the offline predictive model to enhance forecasting capabilities and an online mitigation tool to inform operations staff.

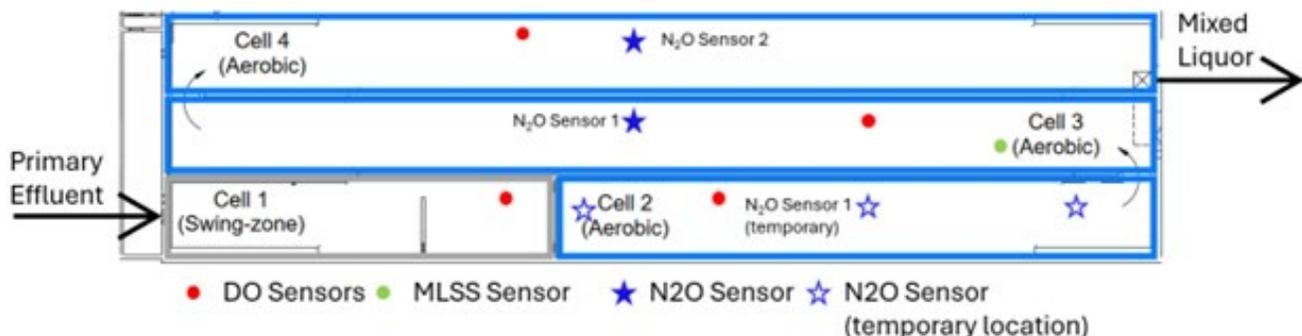


Figure 1. Placement of liquid-phase nitrous oxide sensors in aeration tank 9.

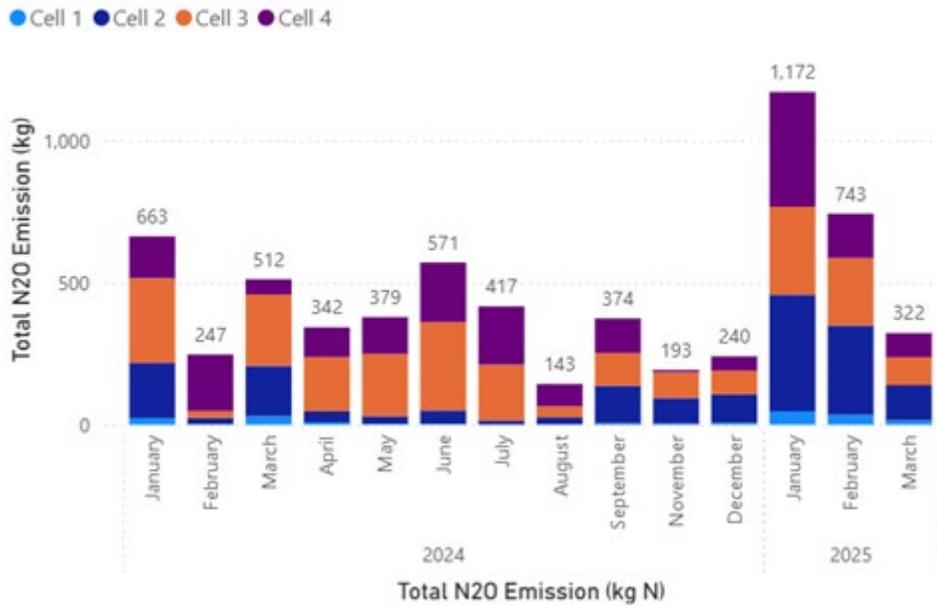


Figure 2. Estimated total nitrous oxide emissions for aeration tank 9 (excluding October 2024 due to incomplete data).

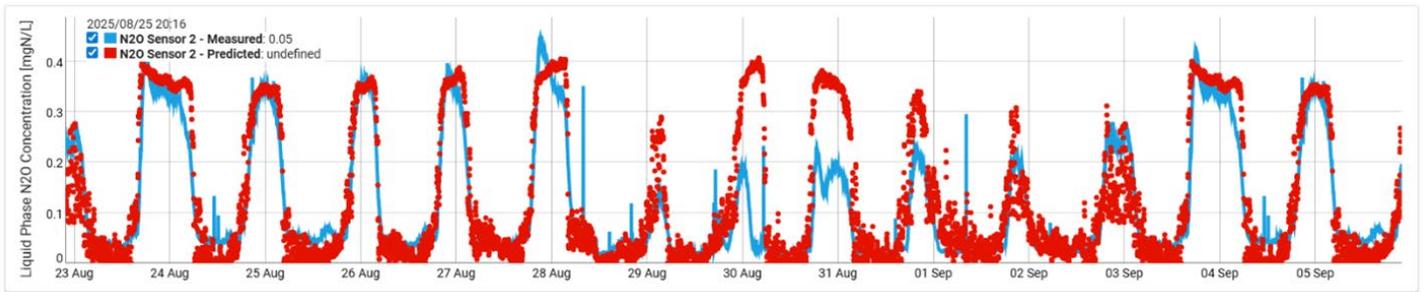


Figure 3. Duffin Creek WPCP predictive N₂O model.

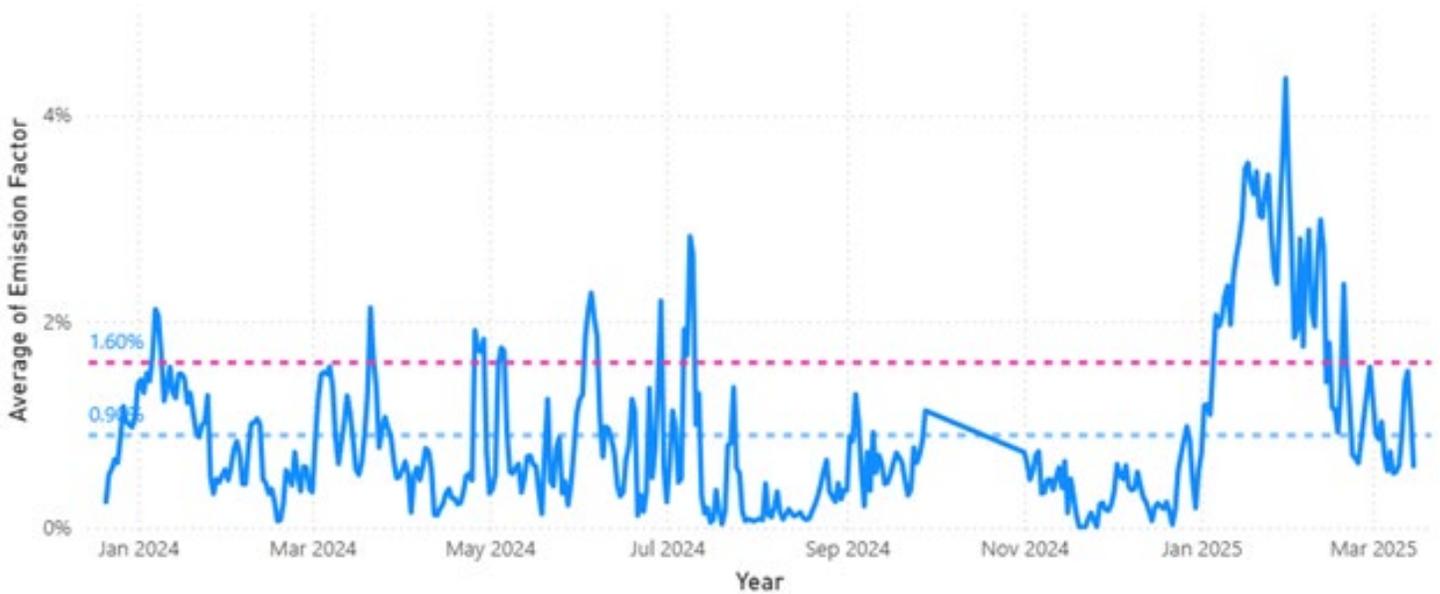


Figure 4. Nitrous oxide total emissions factors for aeration tank 9.

Jacobs will continue to support the Region with data collection and analysis to further understand nitrous oxide emissions. Improvements to the aeration control system will be implemented in spring 2026 together with the planned ABAC, which will provide the opportunity to optimize aeration energy efficiency while minimizing process nitrous oxide emissions.

Other planned future work to be carried out at Duffin Creek includes:

- Installing additional nitrous oxide sensors to better profile nitrous oxide emissions along the plug-flow aeration tanks and improve the tank-level quantification
- Expanding the nitrous oxide monitoring to Stage 1 and 2 aeration tanks, which have different configurations, to determine the specific emission factors for that secondary treatment portion and ultimately determine a whole-plant emission factor for Duffin Creek WPCP.

This hybrid model approach has been successfully applied to long-term nitrous oxide monitoring data at the Duffin Creek WPCP as well as the Region of Waterloo's Elmira Wastewater Treatment Plant (Shen et al., 2025). This work received the 2024 Water Environment Association of Ontario Intelligent Water Solutions award.

Lessons learned

Over 15 months of monitoring, nitrous oxide emissions varied significantly across time and locations due to operational factors such as dissolved oxygen control, ammonia loading peaks, and external conditions like temperature. Specific emission factors for aeration tank 9 averaged 0.90 percent of the influent total nitrogen load.

The hybrid predictive model accurately reflected observed nitrous oxide profiles and identified key operational parameters, demonstrating its potential to help utilities forecast emissions and develop mitigation strategies. Continuous monitoring, sensor optimization, and expanded data collection will further improve emission profiling

and support future efforts to implement advanced aeration control systems, enhance energy efficiency, and minimize nitrous oxide emissions across the plant.

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