

Customer case

Mitigation of N₂O emissions and performance and efficiency improvement at industrial

v1 2025CC001

Case highlights

- 3 main N₂O production hotspots and root causes identified
- Models matched sensor and liquid-phase N₂O data
- Carbon limitation identified as the dominant N₂O root cause
- Expected impact: 87% reduction of N₂O emissions; 10% external carbon saving; 10-15% reduction of effluent TN

Introduction and problem statement

The Dutch water company Evides Industriewater operates multiple wastewater treatment plants in the Netherlands. At one of their industrial wastewater treatment sites (Figure 1), they were investigating opportunities for simultaneous plant optimisation and greenhouse gas emission reduction. Nitrous oxide (N_2O) measurements from a temporary campaign revealed highly dynamic process emissions with significant peaks. The true sources of N_2O were hard to identify, as multiple factors, or a combination of them, could have caused the emissions. As root causes were unclear, it was difficult for Evides Industriewater to identify and rank mitigation actions that would positively affect both carbon footprint and plant performance.



Figure 1: Layout and configuration of the industrial wastewater treatment plant under investigation. The wastewater has municipal characteristics but is highly dynamic and has a rather high ammonia load.

Project Goals

The primary goal of this project is to identify and mitigate the root causes of nitrous oxide (N_2O) emissions in Evides Industriewater's industrial wastewater treatment plant while simultaneously improving overall plant performance.

Plant characteristics

- Industrial WWTP with municipal characteristics
- Reactor type: conventional activated sludge system with pre-denitrification
- More concentrated in NH_4 and less COD; complex influent dynamics
- Liquid-phase onsite N_2O monitoring performed
- EF estimated at 0.16% ($0.016 \text{ N}_2\text{O N} / \text{incoming NH}_4 \text{ N}$) (high/low)

Solution and Objectives

Evides Industriewater worked with AM-Team to identify the root causes of N₂O and identify the best mitigation strategies. Such model-based assessment, based on real plant data, reveals key insights that are impossible to extract from onsite data only.

The objectives were to:

- Screen general plant performance
- Identify the N₂O root causes
- Rank those root causes according to their contribution
- Virtually test mitigation strategies that would simultaneously benefit plant performance and carbon footprint
- Rank those strategies in terms of impact and feasibility

“The multitude of strategies tested by the model were impossible to evaluate onsite at the real plant. Based on a scientifically sound methodology, we were able to test and rank mitigation measures and identified the most promising ones to implement.”

- Ioanna Gkoutzamani, Process Engineer |
Evides Industriewater



Approach

AM-Team's 3D CFD- N₂O model and dynamic N₂O model were used for 3D and dynamic assessment. Both models serve different purposes: the 3D model reveals spatial patterns and local N₂O hotspots, while the dynamic model reveals the dynamic plant response as function of time, based on influent dynamics. Both models were calibrated and validated against actual plant data.

3 types of input data (a mixture of online and offline data) were used:

- Available influent data (flows, COD, ammonia, ...)
- Operational data (eg air flows, carbon dosing, ...)
- Plant design data (sizing, layout)

Simulations were run under different operational conditions, reflecting the real situation. ‘What-if’ mitigation scenarios included operational modifications beyond the current operation.

Results and findings

Root cause analysis

The 3D dissolved oxygen (DO) profile in Figure 2 reveals that most of the aerobic zones were very low in dissolved oxygen. Only in the second part of aerobic zone 2, DO levels started to increase to levels around 2 mg/L. Low levels of DO stimulated local N_2O production in the aerobic zones (Figure 2, right). However, also the recycling of DO back to the anoxic zone locally caused an N_2O hotspot due to the high ammonia levels in that spot. Next to the impact of DO, also a carbon limitation in anoxic zone 1 caused an N_2O hotspot. As such, 3 main root causes could be identified. The root cause related to carbon limitation was expected to be the dominant pathway with an estimated relative contribution of >90%.

“The 3D root cause analysis by our CFD - N_2O model is comparable to an x-ray scan in the hospital: it provides a heat map of hot spots of N_2O production (red) and consumption (blue). These visuals not only provide immediate understanding of what drives the N_2O emissions, but can also be easily understood by everyone.”

- Dr. Giacomo Bellandi, Technology Lead | AM-Team



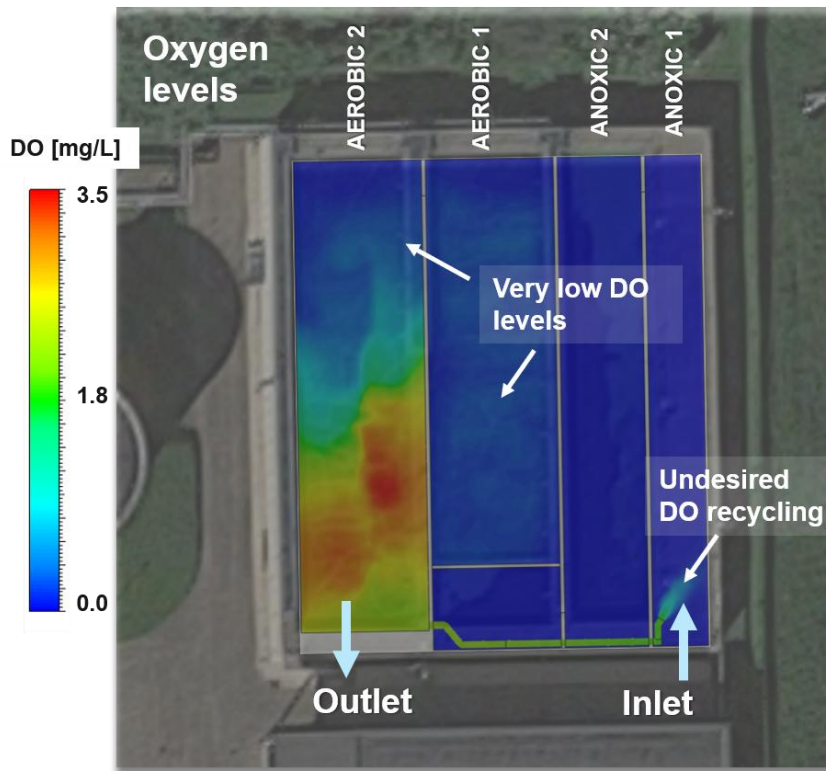


Figure 2(a)

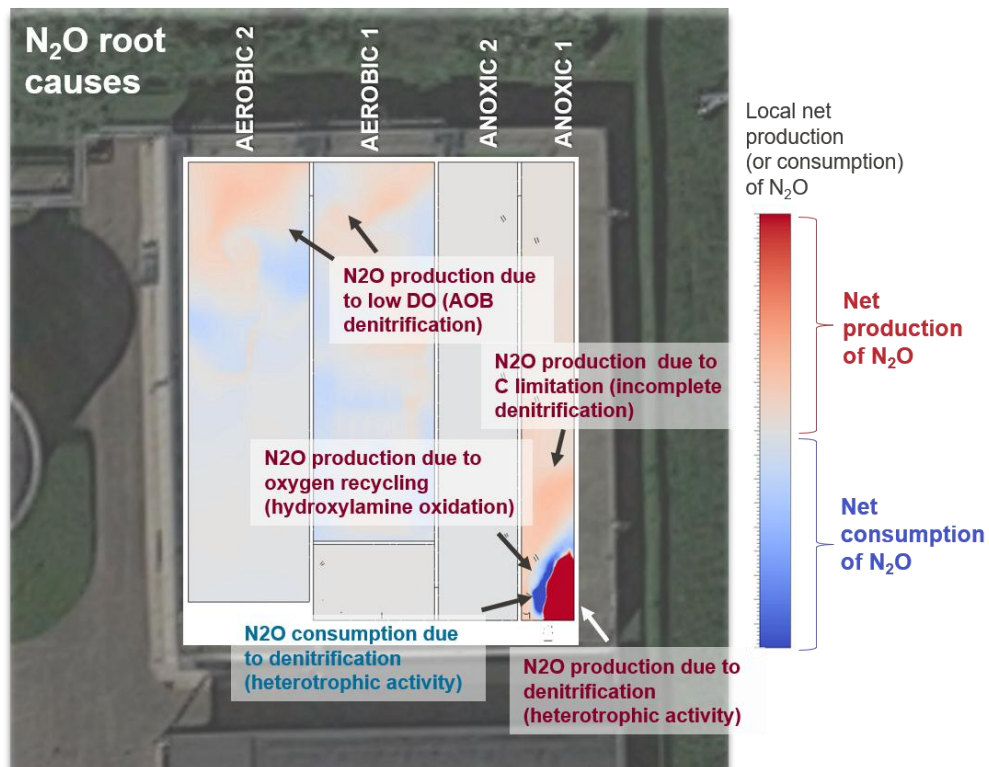


Figure 2(b)

Figure 2 (a) & (b): 3D DO levels (left) and local production / consumption of N_2O (right). Different N_2O hotspots were identified in various parts of the bioreactor.

N₂O hotspots were identified in various parts of the bioreactor.

The temporary N₂O monitoring campaign conducted by Evides Industriewater revealed significant dynamics and peaks, causing a dynamic emission profile (Figure 3) with 2 peaks per day. Calibrated based on the available onsite plant data, the dynamic model captured DO, ammonia and ultimately the N₂O dynamics. Worth noticing is that reasonable fits could be obtained despite a reasonable scarcity of influent information. While additional influent information, specifically influent carbon, could further improve model accuracy, the model was found sufficiently adequate to start virtual mitigation strategy testing.

The dynamic model further confirmed that C limitation (limiting Heterotrophic denitrification) was the dominant root cause of the peaks and hence virtual mitigation strategy testing could start.

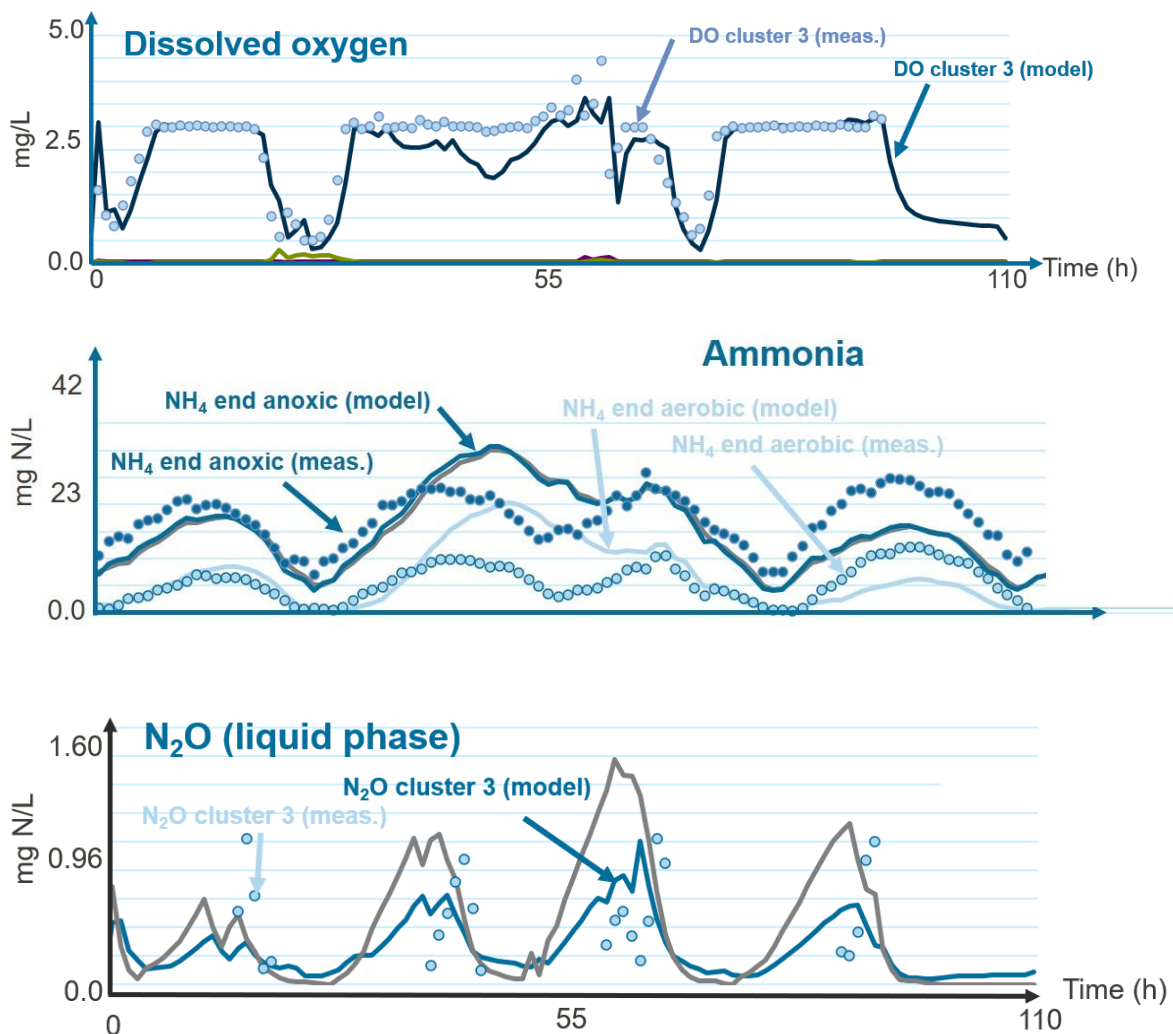


Figure 3: Dynamic profiles of measured (dots) and predicted (lines) of DO, ammonia and liquid-phase N₂O levels. The significant N₂O dynamics could be captured by the dynamic model.

Virtual mitigation strategy testing

Given that the model could identify the N_2O root causes, it was consequently being used to run ‘what-if’ scenarios with the aim of reducing these emissions and improving general plant performance and efficiency. This ‘virtual mitigation strategy testing’ revealed that adjusting the carbon dosing was a core strategy to mitigate. The impact of different adjusted C dosing strategies on N_2O peaks becomes clearly visible from Figure 4.

Even though C-dosing was already an inherent part of the operations, the key was in adjusting the dosing strategy in terms of timing. According to the simulation outcomes, an ‘optimized C dosing strategy’ (COD proportional) could potentially reduce emissions by 87% and carbon dosing requirements by 10%. In addition, effluent total nitrogen (TN) was expected to reduce with 10-15%. As shown in the dynamic N_2O pattern, peaks are expected to completely disappear with this strategy.

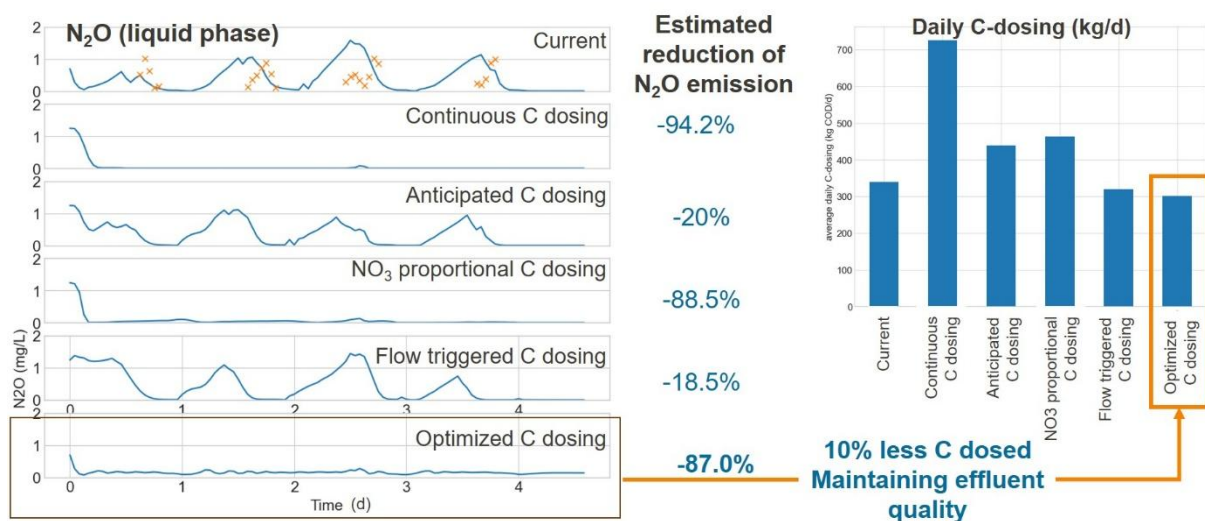


Figure 4: Reduction of N_2O emissions as a result of adjusted C dosing strategies and resulting consumption of C source. The selected scenario is expected to reduce emissions by 87% and C consumption by 10%

As also other root causes were responsible for N_2O emissions (see Figure 2), additional optimisation potential is in further adjusting the aeration controls, specifically avoiding low DO levels (aeration zone 1 and first half of zone 2) and DO recycling (end of zone 2). However, C dosing adjustment was expected to have the highest ROI in terms of 3E optimization (Emissions, Effluent, Efficiency). The model outcomes supported the business case for the onsite works and at the time of this writing, Evides Industriewater is implementing the new dosing strategy.

Conclusion and impact

Evides Industriewater could pinpoint the N₂O root causes and as a result, act upon them. 3 main root causes were identified, leading to local N₂O production hotspots: 1) undesired recycling of oxygen from the aerobic to anoxic zone, 2) very low DO levels in most of the aerobic zones and 3) carbon limitation. The latter was identified to be the dominant pathway of N₂O production.

According to the virtual mitigation strategy testing, optimising the already implemented carbon dosing is expected to reduce N₂O emissions by 87% and would bring an additional OpEx saving of 10% external carbon demand. In addition, effluent quality is expected to improve with 10-15% in terms of TN removal.

Without the model insights, Evides Industriewater could not have tested those scenarios onsite and the outcomes were used to support the business case for onsite works. Implementation of the mitigation measures is currently ongoing.

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About AM-Team:

AM-Team provides globally unique modelling and data services and digital twin solutions to smartly design, optimise and digitalise municipal and industrial water and wastewater treatment plants. The company has worked on over 150 sites on 4 continents. AM-Team directly works with utilities and also partners with engineering firms, software companies and technology vendors.

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