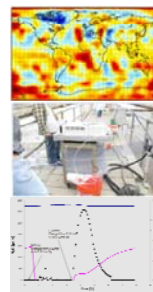


Taking Stock of Nitrogen Greenhouse Gases from BNR Facilities

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ACWA Annual Conference
July 23rd, 2009



Wastewater tmt. derived GHG

Table 8-1: Emissions from Waste (Tg CO₂ Eq.)

Gas/Source	1990	1995	2000	2001	2002	2003	2004	2005	2006
CH₄	172.9	169.1	146.7	143.0	145.5	151.0	148.1	149.0	151.1
Landfills	149.6	144.0	120.8	117.6	120.1	125.6	122.6	123.7	125.7
Wastewater Treatment	23.0	24.3	24.6	24.2	24.1	23.9	24.0	23.8	23.9
Composting	0.3	0.7	1.3	1.3	1.3	1.5	1.6	1.6	1.6
N₂O	6.6	7.7	8.9	9.2	9.0	9.3	9.6	9.7	9.9
Domestic Wastewater Treatment	6.3	6.9	7.6	7.8	7.6	7.7	7.8	8.0	8.1
Composting	0.4	0.8	1.4	1.4	1.4	1.6	1.7	1.7	1.8
Total	179.6	176.8	155.6	152.1	154.5	160.3	157.7	158.7	161.0

Note: Totals may not sum due to independent rounding.

Source: USEPA GHG Sources and Sinks Inventory, 2008



Domestic wastewater N₂O emission estimates

$$N_2O_{TOTAL} = N_2O_{PLANT} + N_2O_{EFFLUENT}$$

$$N_2O_{PLANT} = N_2O_{NIT/DENIT} + N_2O_{WOUT NIT/DENIT}$$

$$N_2O_{NIT/DENIT} = [(US_{POPND}) \times EF_2 \times F_{DID-COM}] \times 1/10^9$$

$$N_2O_{WOUT NIT/DENIT} = \{[(US_{POP} \times WWTP) - US_{POPND} \times F_{DID-COM}] \times EF_1\} \times 1/10^9$$

$$N_2O_{EFFLUENT} = \{[(US_{POP} \times Protein \times F_{NFR} \times F_{NON-COM} \times F_{DID-COM}) - N_{SLUDGE}] \times EF_3 \times 44/28\} \times 1/10^6$$

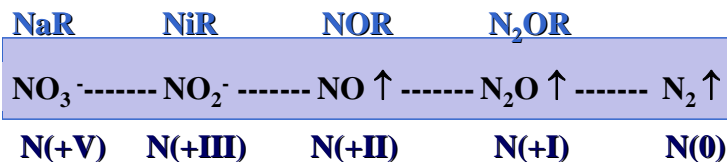
- EF1=3.2 g N₂O/PE/year
- EF2=7.0 g N₂O/PE/year
- EF3= 0.005 kg N₂O -N/kg sewage-N produced

Source: USEPA GHG Sources and Sinks Inventory, 2008



Gaseous N formation during denitrification

- Both N₂O and NO are known intermediates of denitrification

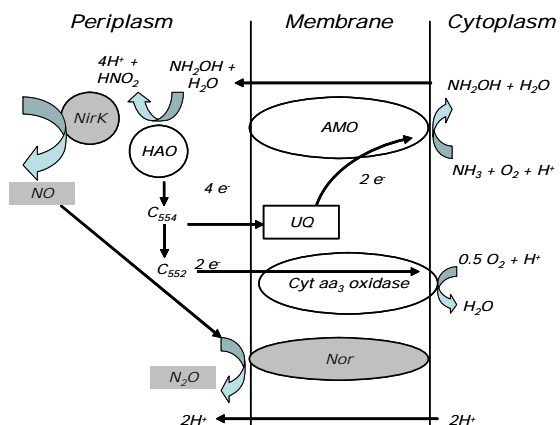


Denitrifying bacteria can both **produce** and **consume** N₂O



Gaseous N formation during nitrification

Revisiting the AOB metabolic pathway



Nitrifying bacteria can **produce** but not **consume** N₂O



Role of nitrification and denitrification in N₂O emissions

N₂O production mainly
High N₂O emission expected

N₂O production and consumption
Low N₂O emission expected



- Based on known mechanisms, significantly higher emissions from aerated zones expected
- How does this influence the way we have been thinking about N₂O emissions from WWTPs?



Development of a standardized protocol for measurement

Version 1
September 4th, 2008
Page 1

Quality Assurance Project Plan

Characterization of Nitrogen Greenhouse Gas Emissions from Wastewater Treatment Operations (U4R07)

prepared by
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for
**Water Environment Research Foundation and
U. S. Environmental Protection Agency,
Office of Environmental Measurement & Evaluation**
September 4th, 2008

Approving Officials

Kavith Chandra, Principal Investigator, Columbia University	Date
Lauren Filmore, Program Director, WERF	Date
Project Quality Assurance Officer, (To be determined)	Date

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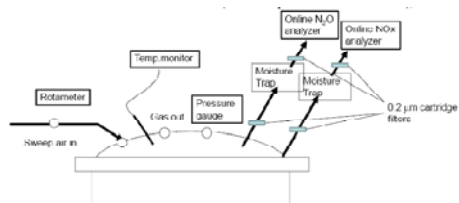


Figure P3: Schematic of flux-chamber set-up for N₂ and NO_x flux measurements

- Protocol has been reviewed by US EPA and is now being implemented nationwide
- Shared with other teams around the globe via GWRC



Summary of protocol

- Adaptation of USEPA surface emission isolation flux chamber approach
- Differentiating between “generation” and “emission”
 - **Generation: liquid-phase N₂O conc.**
 - **Emission: gas-phase N₂O conc.**
- Advective gas flow rate (ASTM 1946)
 - **He tracer method- field GC-TCD method**
- Spatial and temporal characterization



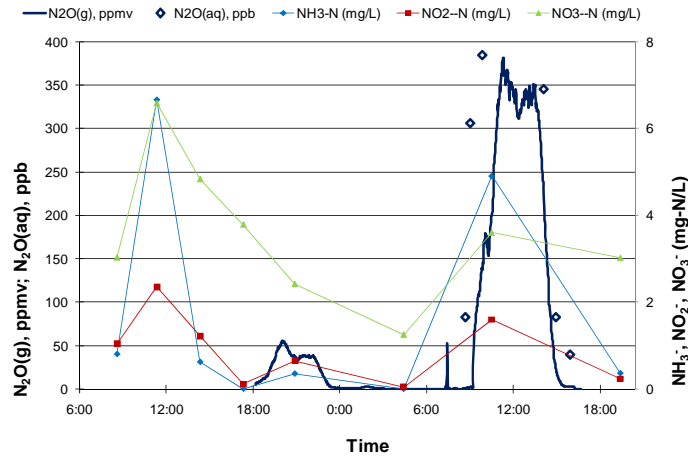


Application of protocol at test facilities

Spatial variability in N₂O emissions

Ammonia(ppm-N)	1.5 ±0.71	11.5 ±4.95	14
Nitrite (ppm-N)	0	0.003 ±0.001	0.002 ±0.003
Nitrate (ppm-N)	10.15 ±0.21	2.65 ±0.35	0.85 ±0.07
DO (mg-O ₂ /L)	4.2	2.3	0.1
ORP (mV)	55.9	-10	-172
pH	7.1	7.12	7.02
Temp (°C)	29.5	29.3	29.1
Aqueous N ₂ O (ppb-N ₂ O)	572.55	192.16	54.9
Gaseous N ₂ O (ppm-N ₂ O)	22.8 ±0.67	16.47 ±0.27	1.46 ±0.14

Diurnal variability in N₂O emissions



- Significant diurnal variability in N₂O(g) and N₂O (l) conc. **in aerobic zones**
- Near perfect correlation with diurnal NH₃, NO₂⁻ and NO₃⁻ conc.



Summary of N₂O inventories

Plant configuration	Water temperature (°C)	% influent TKN emitted as N ₂ O
Separate stage nitrification	14.7	0.05*
Four-stage Bardenpho	13.6	0.18
Step-feed BNR	29.4	3.2
Step-feed	17.4	0.26
Plug flow	11.0	0.10
Plug flow	11.4	0.6

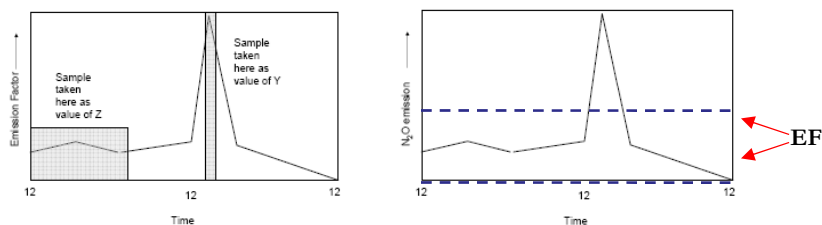
Represents aerobic N₂O hotspots- overestimate

Represents two points- influent (min) and effluent (max)

Obviously a problem with this simplistic approach



Implications of variability in N₂O emissions

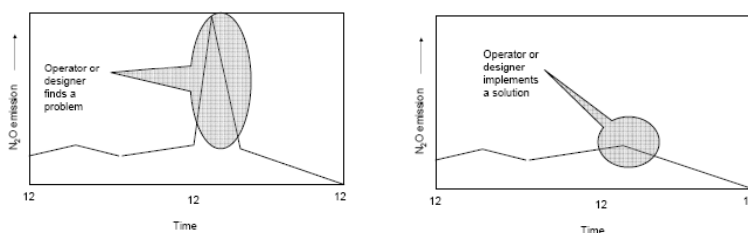


- EF and % 'assign' a single value to describe the behavior of highly dynamic biological reactions
- Some plants obviously much better than others- not credited
- Loading based criteria similar to those employed for liquid phase N species might be better
 - weekly, monthly, annual

Schematics courtesy of Dr. Denny Parker



Where we want to go

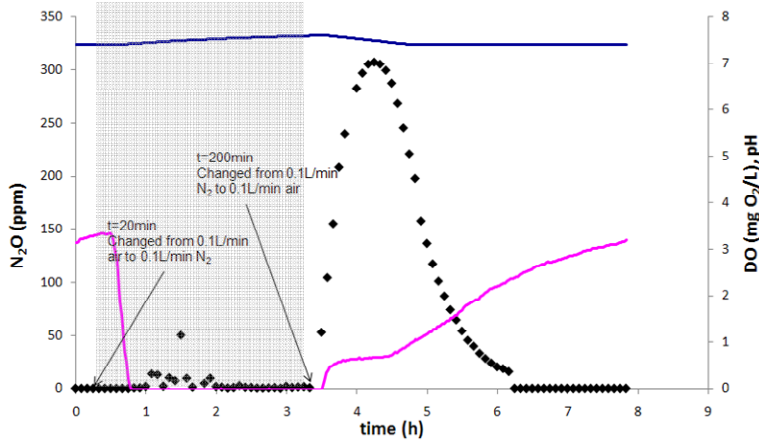
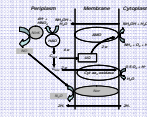


- How do we get there? – dynamic inventories and process modeling
 - being done as part of this project
 - need to reconcile observations with mechanisms

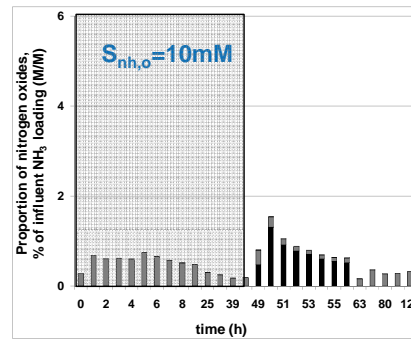
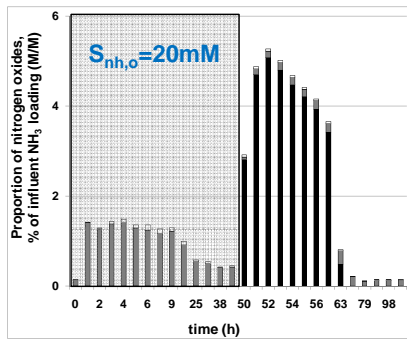
Schematics courtesy of Dr. Denny Parker



Short term change in DO- Nitrification

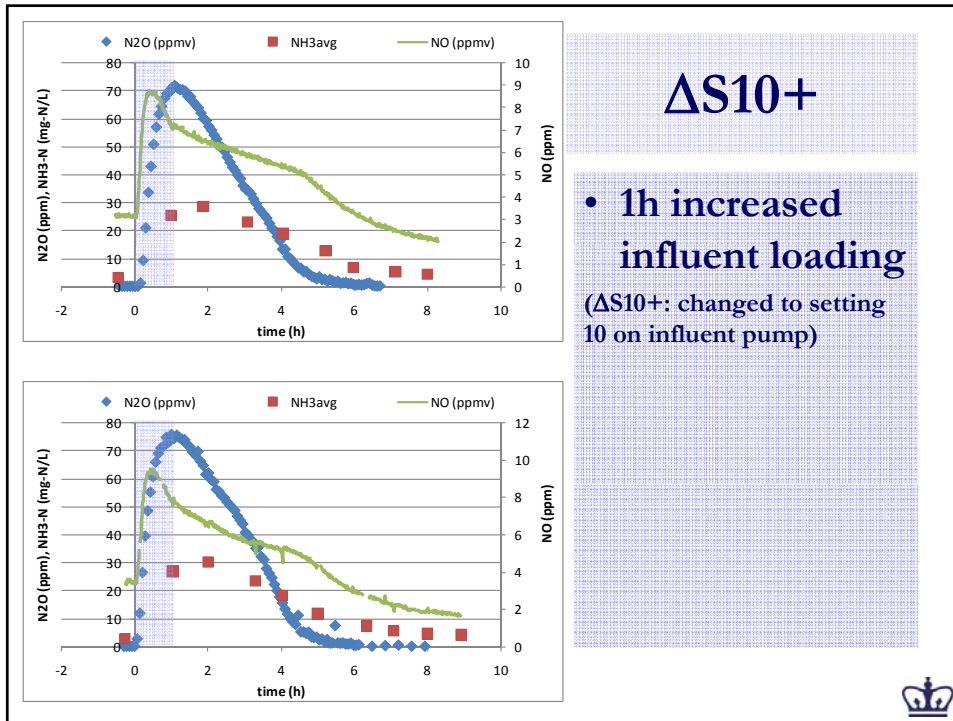


- N_2O production is directional
 - Manifestation of recovery response



- N_2O (black bars) is caused by **recovery** from low DO and not due to low DO itself
 - N_2O not observed during low DO- rather NO (grey bars) observed
 - N_2O production by nitrifiers needs O_2 !
 - Extent of N_2O and NO generation and emission depends on S_{nh} accumulation



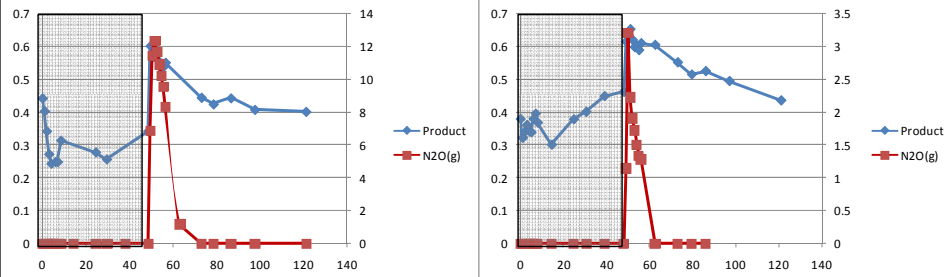


Factors for N₂O from nitrification



- How do we capture multiple phenomena that eventually result in N₂O generation?

N_{N_2O} : Dimensionless number for predicting local N_2O generation potential



- Dimensionless number for N_2O formation potential

- Online measure of $\mu/\mu_{max} \sim S_{nh} * S_{O_2} / K_{S,O_2} * K_{S,nh}$
- BNR designs that minimize N_{N_2O} can minimize N_2O hotspots



Summary of observations

- Significantly higher generation and emissions from aerated zones
- N_2O emissions related to **recovery from** stress response of nitrifying bacteria
 - Similar patterns observed when pure nitrifying cultures subjected to dynamic patterns observed at full-scale
 - Attributed to an imbalance between the expression of specific pathways in AOB
- In general, emissions significantly higher than those from USEPA and IPCC approaches
- Next: Based on mechanisms, develop BNR strategies to minimize both *aqueous* and *gaseous* N discharges



Interim guidance- what we know now

Symptom	Potential Solution
Emission due to N-overload	Minimize N-loading 1. Re-distribute flow in SF 2. Flow equalize PE
Emission due to low DO nitrification	Ensure NH₃ levels and DO levels 1. Keep $\mu \ll \mu_{\max}$ (Recovery leads to N ₂ O)

Minimize N_{N2O}





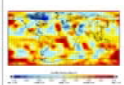

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 Kartik Chandran Laboratory Earth and Environmental Engineering		CLIMATE CHANGE RESEARCH
Home Research Publications Contact Us	<p>Wastewater Treatment and Climate Change Program</p> <p>Waste discharge and wastewater treatment are sources of greenhouse gas emissions. Although carbon dioxide (CO₂) and methane (CH₄) have been the main focus in climate change calculations and discussions, the potential impact of nitrous oxide (N₂O), which is also generated from wastewater treatment plants (WWTPs) is now getting increased prominence. It is 1 one of the relatively important gases considered by the Intergovernmental Panel on Climate Change (IPCC) for its greenhouse gas emission scenario. This is understandable given that the greenhouse impact of N₂O is about three hundred times that of CO₂.</p> <p>There are three outstanding and related issues that we address as part of our research program:</p>	
<p>Inventory, fluxes and mechanisms of N₂O release from WWTPs</p>  <p>Despite the acknowledgment of N₂O release from WWTPs, a quantitative picture of its emission rate has not been established. We have developed a protocol, which after being approved by the EPA, is being implemented at all WWTPs nationwide to reduce the total amount of N₂O being released into the atmosphere. We are also conducting the fluxes and mechanisms of N₂O release.</p>	<p>Global climate impact of wastewater treatment operations</p>  <p>Understanding the regional impact of wastewater treatment operations is essential to estimate the global climate impact of wastewater treatment operations. We are currently working to understand the global climate impact of wastewater treatment operations.</p>	<p>Process optimization for minimizing N₂O release from WWTPs</p>  <p>Based on our work with pilot-scale studies, we have identified technological routes that minimize N₂O release from biological processes, ranging from the process level to the treatment plant level. We are integrating these routes with full-scale and pilot-scale system performance, measures to identify existing challenges and opportunities, and energy efficiency and quality metrics.</p>

