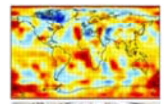
Taking Stock of Nitrogen Greenhouse Gases from BNR Facilities



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ACWA Annual Conference
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Wastewater tmt. derived GHG

Table 8-1: Emissions from Waste (Tg CO_2 Eq.)

Gas/Source	1990	1995	2000	2001	2002	2003	2004	2005	2006
CH_4	**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
N_2O	**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 N_2O emission estimates

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

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

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

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

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

- EF1=3.2 g N_2O/PE/year
- EF2=7.0 g N_2O/PE/year
- EF3= 0.005 kg N_2O -N/kg sewage-N produced

Source: USEPA GHG Sources and Sinks Inventory, 2008

Gaseous N formation during denitrification

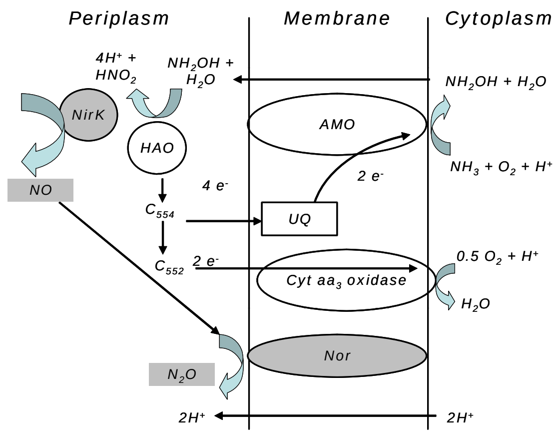
- Both N_2O and NO are known intermediates of denitrification

NaR	NiR	NOR	N_2OR	
NO_3^- -------	NO_2^- -------	NO ↑ -------	N_2O ↑ -------	N_2 ↑
N(+V)	N(+III)	N(+II)	N(+I)	N(0)

Denitrifying bacteria can both produce and consume N_2O

Gaseous N formation during nitrification

Revisiting the AOB metabolic pathway



Nitrifying bacteria can produce but not consume N_2O

Role of nitrification and denitrification in N_2O emissions

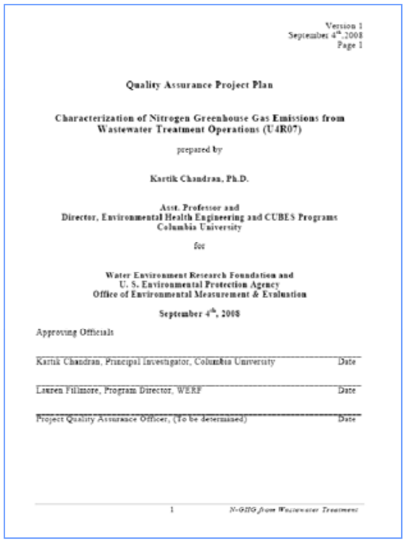
N_2O production mainly
High N_2O emission expected

N_2O production and consumption
Low N_2O emission expected

Aerobic	Anoxic	← RAS + PE

- Based on known mechanisms, significantly higher emissions from aerated zones expected
- How does this influence the way we have been thinking about N_2O emissions from WWTPs?

Development of a standardized protocol for measurement



Version 1
September 4th, 2008
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Quality Assurance Project Plan

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

prepared by

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Office of Environmental Measurement & Evaluation

September 4th, 2008

Approving Officials

Kartik Chandran, Principal Investigator, Columbia University Date

Lauren Fillmore, Program Director, WERF Date

Project Quality Assurance Officer, (To be determined) Date

1 *N-GHG from Wastewater Treatment*

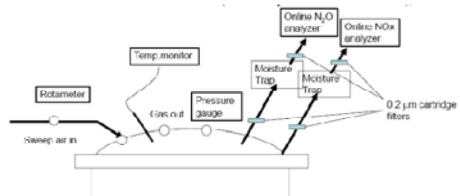


Figure P3: Schematic of flux-chamber set-up for N_2 and NOx flux measurements

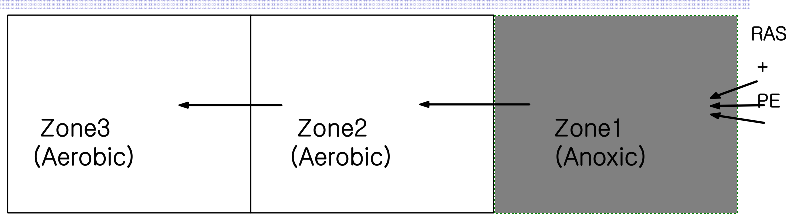
- Protocol has been reviewed by US EPA and is now being implemented nationwide
- Shared with other teams around the globe via GWRC

Summary of protocol

- Adaptation of USEPA surface emission isolation flux chamber approach
- Differentiating between "generation" and "emission"
  - Generation: liquid-phase N_2O conc.
  - Emission: gas-phase N_2O conc.
- Advective gas flow rate (ASTM 1946)
  - He tracer method- field GC-TCD method
- Spatial and temporal characterization

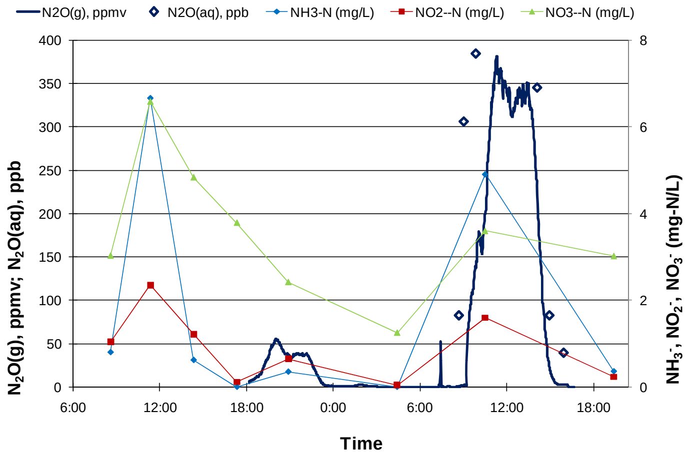
Application of protocol at test facilities

Spatial variability in N_2O 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-O2/L)	4.2	2.3	0.1
ORP (mV)	55.9	-10	-172
pH	7.1	7.12	7.02
Temp (℃)	29.5	29.3	29.1
Aqueous N_2O (ppb-N_2O)	572.55	192.16	54.9
Gaseous N_2O (ppm-N_2O)	22.8 ±0.67	16.47 ±0.27	1.46 ±0.14

Diurnal variability in N_2O emissions



- Significant diurnal variability in $N_2O(g)$ and N_2O (l) conc. in aerobic zones
- Near perfect correlation with diurnal NH_3, NO_2^- and NO_3^- conc.

Summary of N_2O inventories

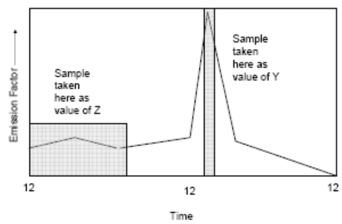
Plant configuration	Water temperature (°C)	% influent TKN emitted as N_2O
Separate stage nitrification	14.7	0.05*
Four-stage Bardenpho	13.6	0.18
Step-feed BNR	29.4	3.2
Step-feed	17.4	0.26
Plug flow	11.0	0.10
Plug flow	11.4	0.6

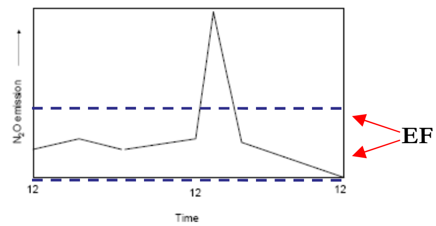
Represents aerobic N_2O hotspots- overestimate

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

Obviously a problem with this simplistic approach

Implications of variability in N_2O emissions

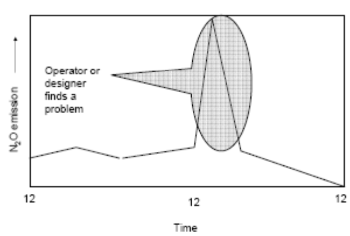


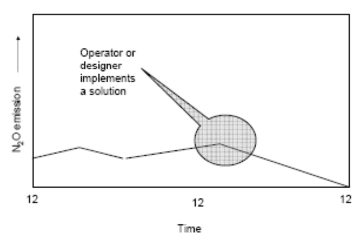


- EF and % 'assign' a single value to describe the behavior of highly dynamic biological reactions
- Some plants obviously much better than others- not credited
- Loading based criteria similar to those employed for liquid phase N species might be better
  - weekly, monthly, annual

Schematics courtesy of Dr. Denny Parker

Where we want to go

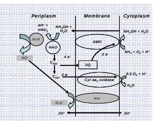


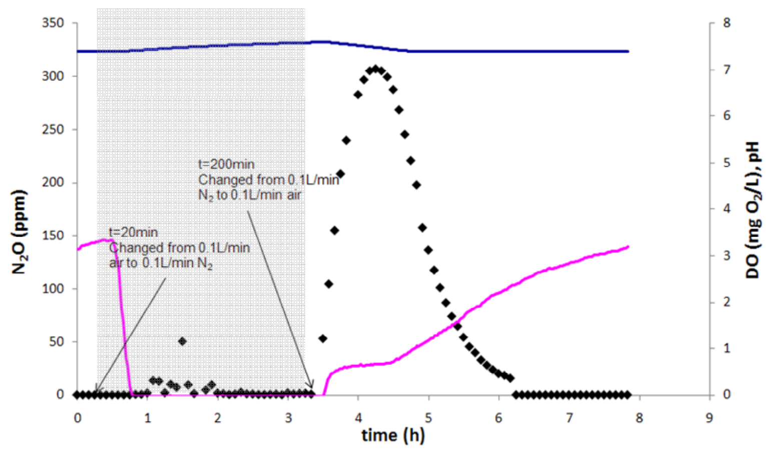


- How do we get there? – dynamic inventories and process modeling
  - being done as part of this project
  - need to reconcile observations with mechanisms

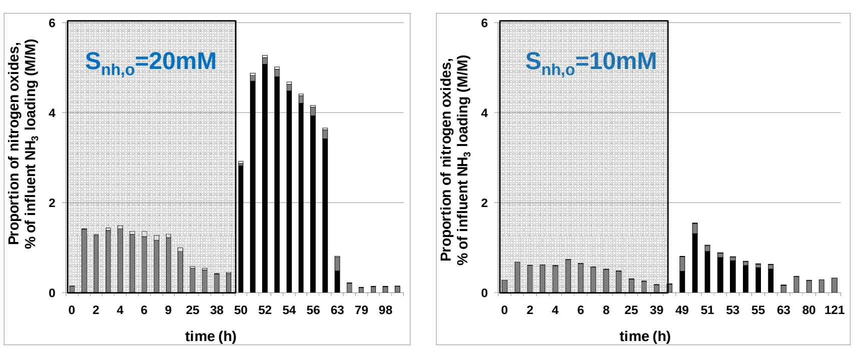
Schematics courtesy of Dr. Denny Parker

Short term change in DO- Nitrification

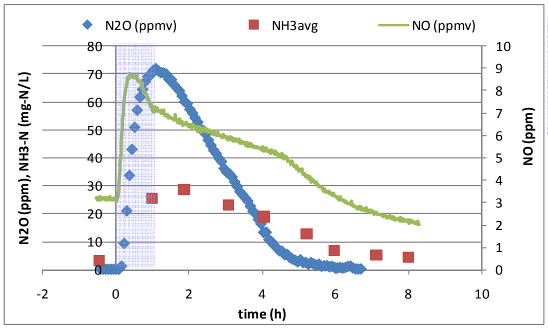


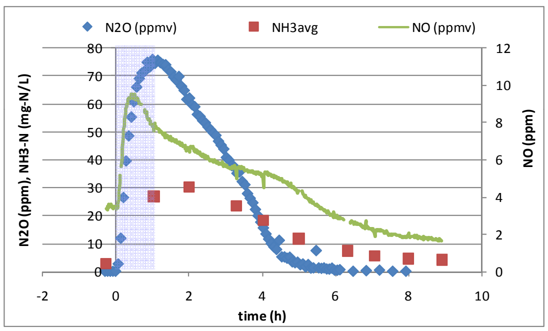


- N_2O production is directional
  - Manifestation of recovery response



- 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





ΔS10+

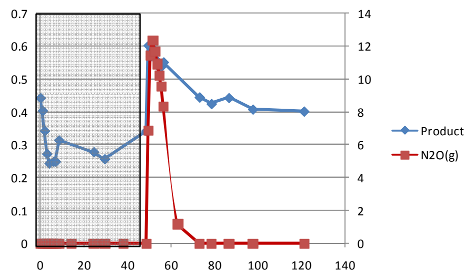
- 1h increased influent loading

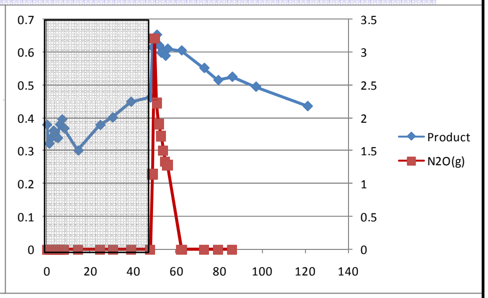
(ΔS10+: changed to setting 10 on influent pump)

Factors for N_2O from nitrification

- How do we capture multiple phenomena that eventually result in N_2O generation?

N_{N2O}: Dimensionless number for predicting local N_2O generation potential





- Dimensionless number for N_2O formation potential
  - Online measure of μ/μ_{max} ~ $S_{nh}*S_{O2}/K_{S,O2}*K_{S,nh}$
  - BNR designs that minimize N_{N2O} 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 NH_3 levels and DO levels 1. Keep $\mu << \mu_{max}$ (Recovery leads to N_2O)

Minimize N_{N2O}

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