You Have Gas!
Sewer Methane GHG Accounting

Wednesday, November 7, 2018

3:00-5:00 pm ET

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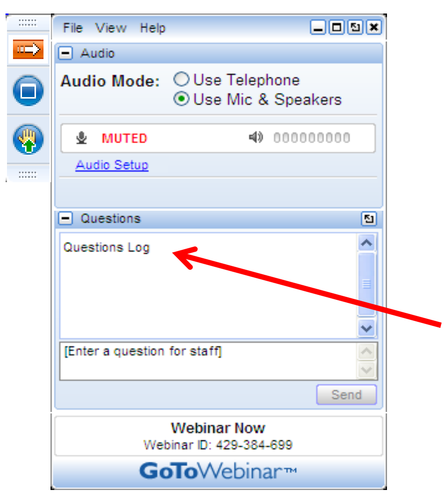
How to Participate Today



- **Audio Modes**
  - Listen using Mic & Speakers
  - Or, select “Use Telephone” and dial the conference (please remember long distance phone charges apply).
- **Submit your questions using the Questions pane.**
- **A recording will be available for replay shortly after this web seminar.**

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Today's Moderator

Christine Radke, PMP
The Water Research Foundation

Speakers

John Willis, Ph.D., PE, BCEE
Brown & Caldwell

Keshab Sharma, Ph.D.
University of Queensland (Australia)

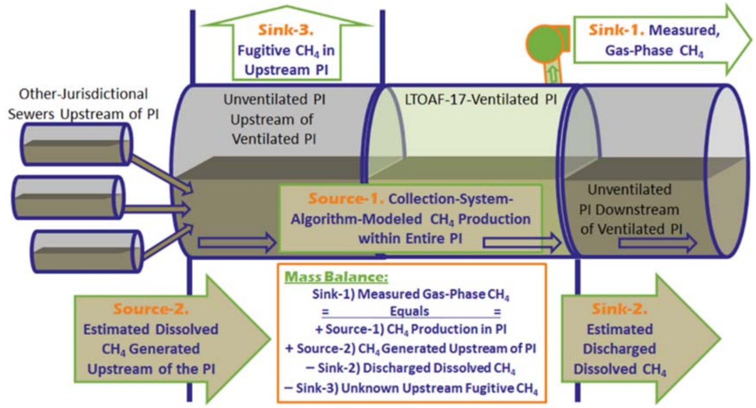
Asbjorn Haaning-Nielsen, Ph.D.
Aalborg University (Denmark)

Wendy Barrott, Ph.D, PE
Great Lakes Water Authority (Michigan)

WEF Webinar

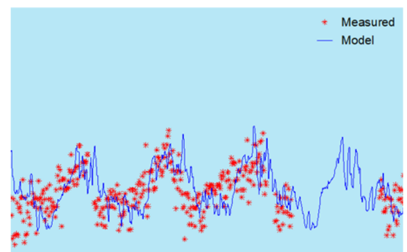
November 7, 2018

New GHG Methodology to Estimate/ Quantify Sewer Methane



John Willis, Ph.D., P.E., BC
Keshab Sharma, Ph.D., UQ-AWMC
Asbjørn Haaning Nielsen, Ph.D., Aalborg U.
Wendy Barrott, Ph.D., P.E., GLWA

With contributions by:
B. Brower, C. Peot, S. Murthy (DC Water);
P. Regmi (BC); W. Graf (WRF); and
Z. Yuan (UQ-AWMC)



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Presentation Overview

• Introduction, GHG Context, and Sewer-CH_4 Concepts	Willis
• Sewer-CH_4 Methodology Details	Willis
• Method Development	Sharma
• Gravity-Sewer-Method Verification	Willis
• Forcemain-Method Verification	Sharma
• Assessment of Method and Related Research	Haaning Nielsen
• Utility Perspective and Use of Methodology	Barrott
• Conclusions	Willis

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Introduction, GHG Context, and Sewer-CH_4 Concepts

John Willis, Ph.D., P.E., BCEE,
Brown and Caldwell

Brown AND Caldwell

Conflict exists between GHG Protocols and Scientific Research on Sewer-CH_4

IPCC and other GHG protocols assume there is **No CH_4 from sewers** in the developed world

VS.

Our research suggests that **over half** of the US Centralized **Wastewater Industry's Scope-1 GHG** emissions are from **sewer CH_4**

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Our Research Suggests Sewer CH_4 is over 50% of Centralized Scope-1 GHG

Plant Classification		% of US Flow in Category	Estimated US National Flow, m^3/s	GHG Emissions Factor, MT CO_2e/mo per m^3/s treated: Sewer CH_4	GHG Emissions Factor: CH_3OH CO_2	GHG Emissions Factor: Other Scope-1	US National GHG Emissions, 1,000 MT CO_2e/yr: Sewer CH_4	US National GHG Emissions: CH_3OH CO_2	US National GHG Emissions: Other Scope-1	Sewer CH_4 as % of Scope-1
ENR	w/o Digestion	4.3%	47	79.4	38.6	49.7	45	22	28	47.3%
	w/ Digestion	7.7%	84	79.4	94.6	49.7	80	95	50	35.5%
	ENR Totals:	12.0%	131				125	117	78	39.0%
BNR	w/o Digestion	17.7%	193	79.4	0.0	49.7	184	0	115	61.5%
	w/ Digestion	31.3%	343	79.4	25.2	49.7	327	104	205	51.4%
	BNR Totals:	49.0%	536				511	104	320	54.7%
Secondary	w/o Digestion	14.1%	154	79.4	0.0	49.7	146	0	92	61.5%
	w/ Digestion	24.9%	273	79.4	0.0	49.7	260	0	163	61.5%
	Secondary Totals:	39.0%	426				406	0	254	61.5%
	US National Totals:	100.0%	1,094				1,042	221	653	54.4%

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Our Research Suggests Sewer CH_4 is over 50% of Centralized Scope-1 GHG

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ENR	w/o Digestion	4.3%	47	79.4	38.6	49.7	45	22	28	47.3%
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	Secondary Totals:	39.0%	426				406	0	254	61.5%
	US National Totals:	100.0%	1,094				1,042	221	653	54.4%

How can this be reconciled with IPCC's determination that sewer CH_4 can be ignored in the developed world???

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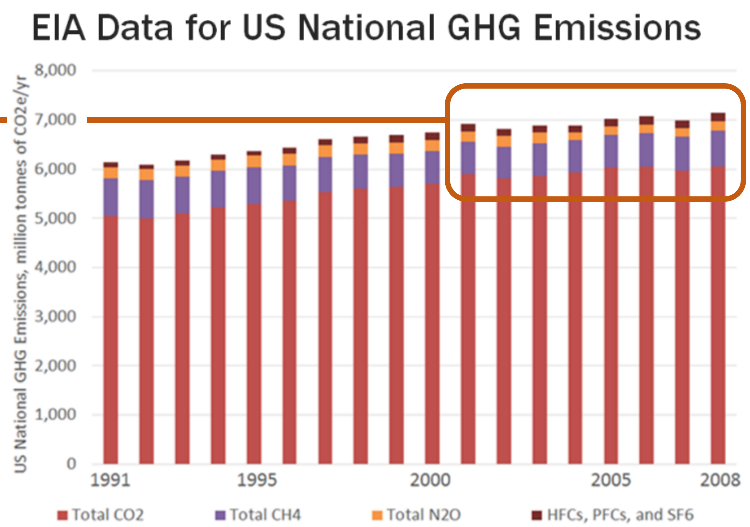
It is Due to Sewer-CH_4's Relative Insignificance on a National Scale

The USA's total GHG emissions are nominally 7.0 B-MT CO_2e/yr



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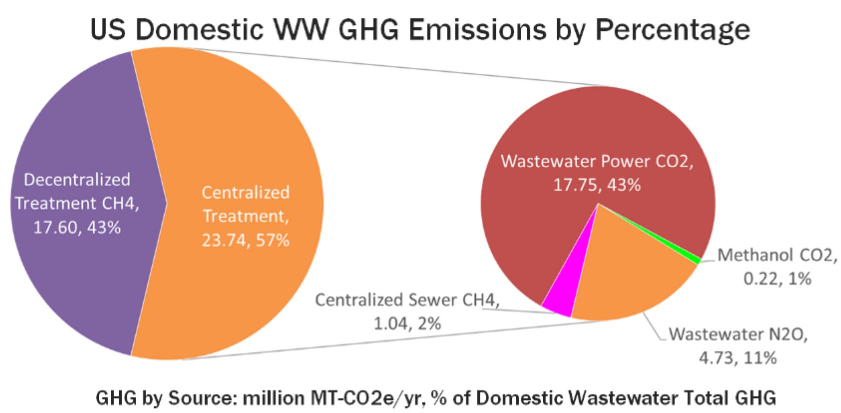
It is Due to Sewer-CH_4's Relative Insignificance on a National Scale

- **The USA's total GHG emissions are 7.0 B-MT CO_2e/yr**
- **All WW is 41 M-MT CO_2e/yr (0.59%)**
- **Centralized WW is 24 M-MT CO_2e/yr (0.34%)**
- **Sewer-CH_4 is 1 M-MT CO_2e/yr (0.015%)**



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Inconsistency between Protocols and Research

IPCC and other GHG methodologies assume **ZERO CH_4 from sewers** in the developed world… VS. Our research suggest that sewer CH_4 is **over half** of the **US Wastewater Industry's Scope-1 GHG** emissions…

- The method discussed is relatively straightforward and yet data intensive and dependent on fairly robust collection-system hydraulic models.
- We are looking for interested to utilities to either:

1) **Employ the method**, OR

2) **Have us Employ the Method** (you get a system-specific emissions equation as ***f(flow, temperature)***; that can be used to estimate daily-to-annual GHG

AND

Share your results so we can **develop a further simplified methodology**, likely as ***f(size, temperature, %gravity/surcharged)*** that "anyone" can use

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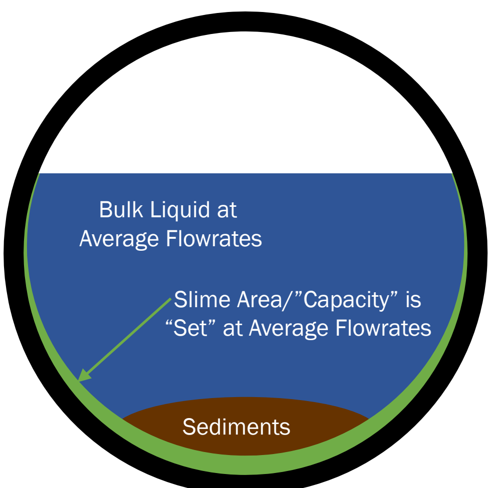
Sewer CH_4 Production



- Slime (biofilm) layers provide long residence time to support methanogens in deeper layers
- Sulfide reducers and hydrolyzers are more prominent in outer layers
- Some flow/velocity is needed to infuse carbon and sulfate into biofilm
- Sediments do not normally contribute to CH_4

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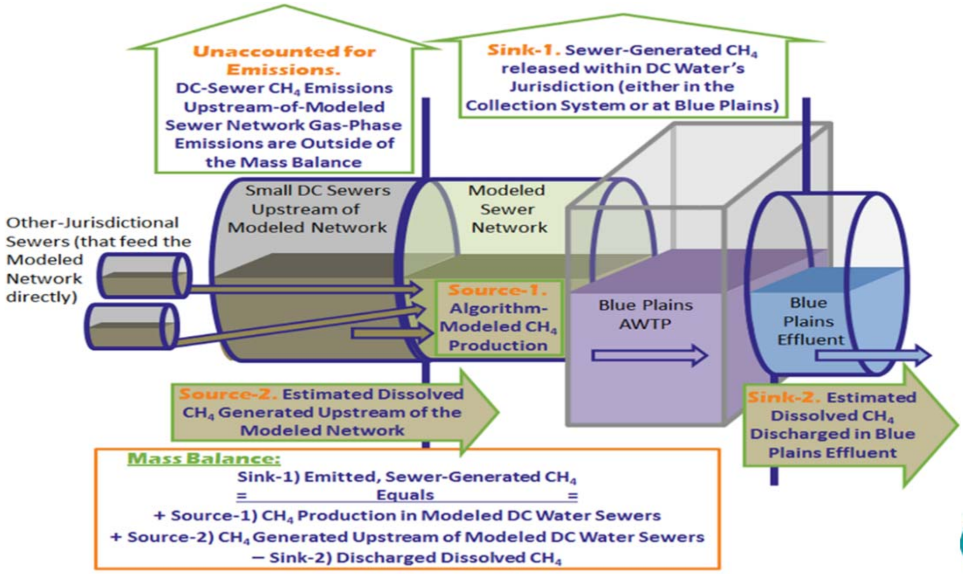
Overall CH_4 Mass Balance



Sewer-CH_4 Methodology

John Willis, Ph.D., P.E., BCEE,
Brown and Caldwell

Methodology uses Two Equations

- Gravity-Sewer Model:

$$r_{CH4\text{-}GS} = 0.419 \times 1.06^{(T-20)} \times Q^{0.26} \times D^{0.28} \times S^{-0.135}$$

r_{CH4}, = CH_4 emission rate in kg CH_4/(km*day)

T = Temperature in ^{O}C

Q = Flow in m^3/s

D = Pipe diameter in m

S = Slope in m/m

- Forcemain/Surcharged-Sewer Model:

$$r_{CH4\text{-}FM} = 3.452 \times D \times 1.06^{(T-20)}$$

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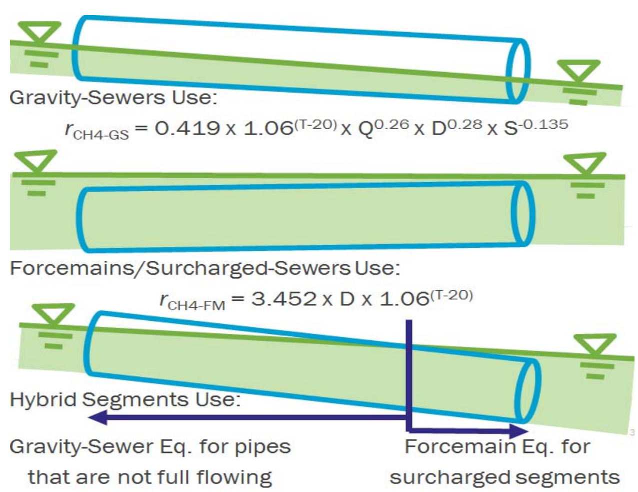
Equations are used for each Segment/Partial Segments

- Hydraulic model at average flow provided "shape file" (we've used Excel)
  - **If the hydraulic grade is below the pipe crown at both ends:**
    Gravity
  - **If the hydraulic grade is above the pipe crown at both ends:**
    Surcharged
  - **If the hydraulic grade is above the pipe crown at one and below the crown at the other:**
    Gravity and Surcharged

Can assume linear changes in hydraulic and crown grade



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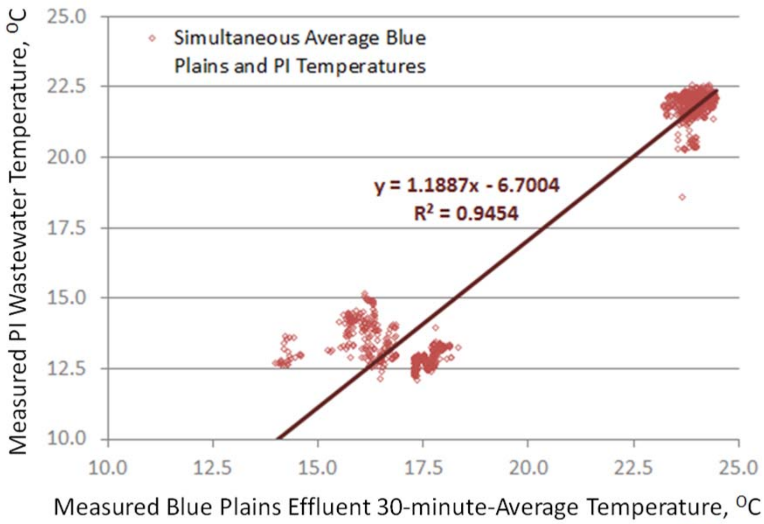
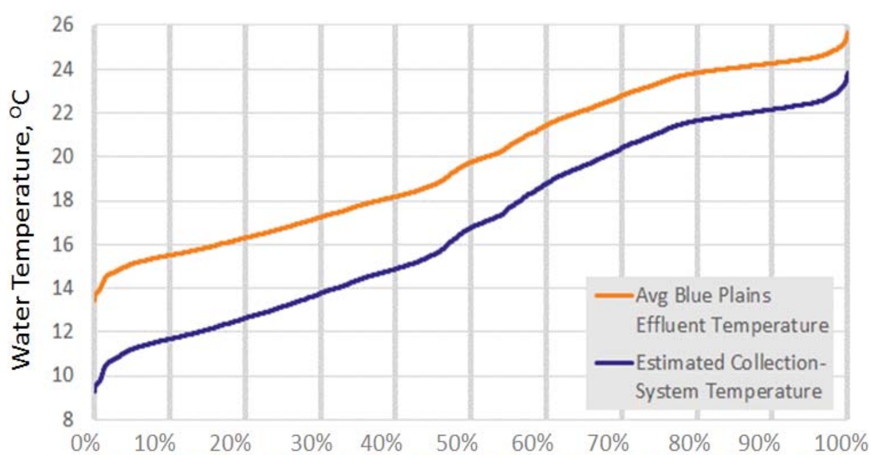
How to Estimate Collection System Temperatures?

- If you measure raw sewage temperatures, they can be used.
- If not:
  - A correlation to commonly measured temperatures can provide a “surrogate”
  - Or, as a fallback, this DC Water correlation could also be used as a less-accurate translation



Temperatures remapped across 2014 Effluent Data



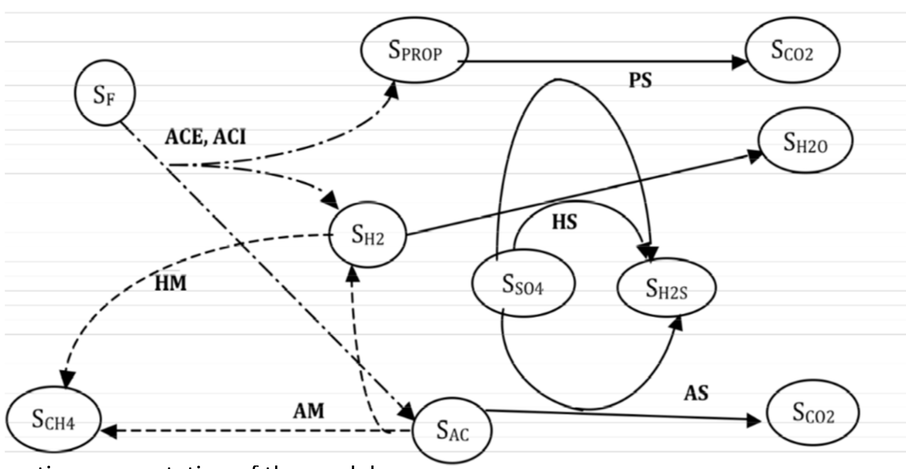
Blue Plains Temperature: 15.0 15.9 16.7 17.7 18.8 20.5 22.1 23.4 24.1 24.6

Sewer Temperature: 11.1 12.2 13.2 14.4 15.7 17.7 19.6 21.1 21.9 22.6

Method Development

Keshab Sharma, Ph.D.
The University of Queensland - Advanced Water Management Centre

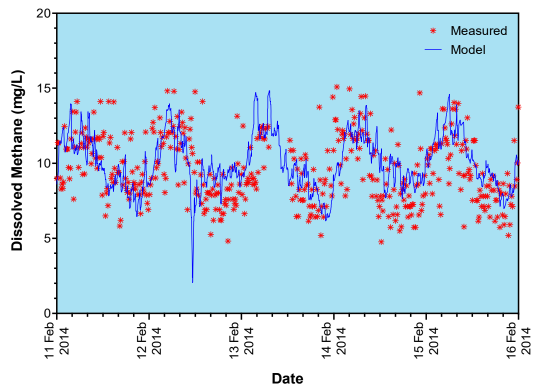
SeweX Model Development

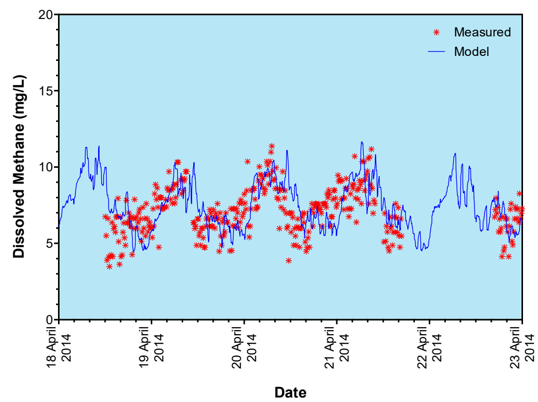


Schematic representation of the model:
SRB processes (solid lines), FB processes (dash-dotted lines), and MA processes (dashed lines)

SeweX has been Widely Used over Last 10 years

- Over 30 sewer catchments have been modeled with SeweX with full scale data collected to calibrate/verify approximately 30% of these





Gold Coast (Australia) Measurements vs. SeweX-Predictions for Summer (Feb. 2014) and Fall (April 2014)

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Empirical GS-Model Development and Application

Sewer Properties
Length = 1000 m (constant)
Pipe Diameter = D mm
Pump run time = P (min/day)
Average daily flow = Q (m3/s) with diurnal variation
Temperature = T°C
A range of the parameters/sets of sewer conditions to be applied

Network Data
Pipe length
Pipe diameter
Average daily flow
Pump run time (hours/day)
Temperature

Calibrated Sewer Model

Simulations to estimate methane production under each set of sewer conditions

Non-linear regression of the simulation results data to develop a correlation between the sewer parameters and the methane production

Methane production in each pipe section to obtain total methane production in the entire sewer network

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GS-Model Development for Gravity Sewer (GS)

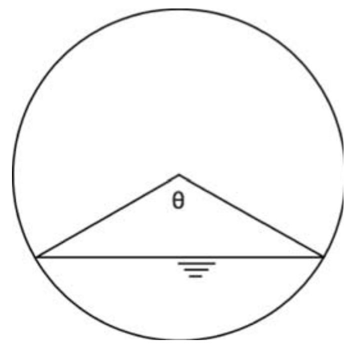
$$\theta = \frac{3\pi}{2}\sqrt{1-\sqrt{1-\sqrt{\frac{\pi Q n}{D^{\frac{8}{3}} S^{\frac{1}{2}}}}}}$$

$$\theta = k \cdot Q^{\alpha} \cdot D^{\beta} \cdot S^{\gamma}$$

$$A_{bf} = \theta \cdot \frac{D}{2} \cdot L = k \cdot Q^{\alpha} \cdot D^{\beta} \cdot S^{\gamma} \cdot \frac{D}{2} \cdot L$$

$$r_{CH_4} = k' \cdot A_{bf} = k \cdot Q^{\alpha} \cdot D^{\beta} \cdot S^{\gamma} \cdot L$$

$$r_{CH_4,20} = k \cdot Q^{\alpha} \cdot D^{\beta} \cdot S^{\gamma}$$



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GS-Model Methodology

- Diurnal variation of sewer flow was assumed. A typical flow profile was used and the same profile was employed to all the pipes irrespective of their size and flow.
- Water depth and flow velocity in sewer pipes were estimated as a function of pipe size, flow and slope using Hazen-Williams equation.
- Typical domestic sewage characteristics were used.
- Parameters calibrated for methane production in a sewer system in Australia were employed.
- Same parameters were used for all the sewer pipes irrespective of their size, flow, flow velocity, and water depths.

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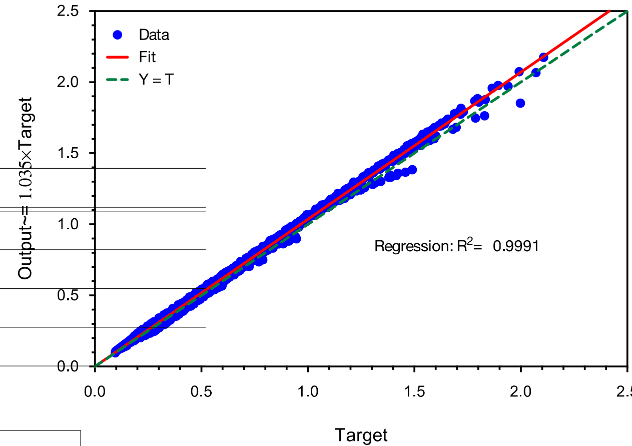
GS-Model Validation

Estimated Values for Parameters

Parameter	Estimated value	SE
k	0.419	0.00251
α	0.260	0.00076
β	0.280	0.00258
γ	-0.138	0.00099



Correlation Coefficients of Estimated Parameters

	k	α	β	γ
k	1.000	0.430	0.714	0.825
α	0.430	1.000	-0.938	-0.156
β	0.714	-0.938	1.000	-0.193
γ	0.825	-0.156	-0.193	1.000

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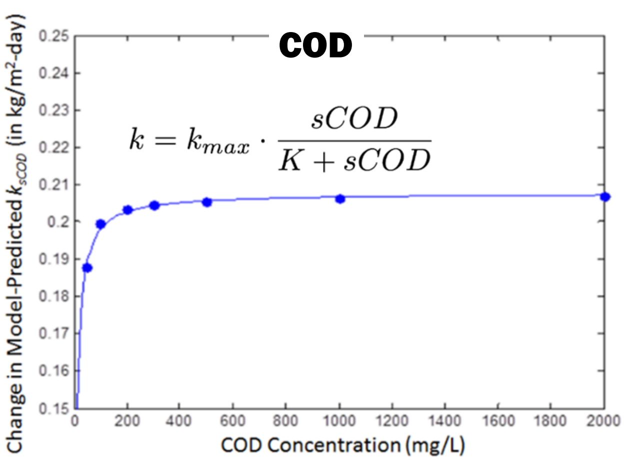
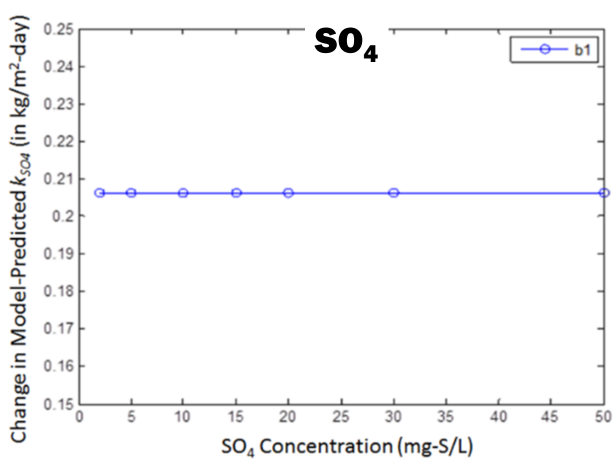
Effects of COD and SO_4 Concentration





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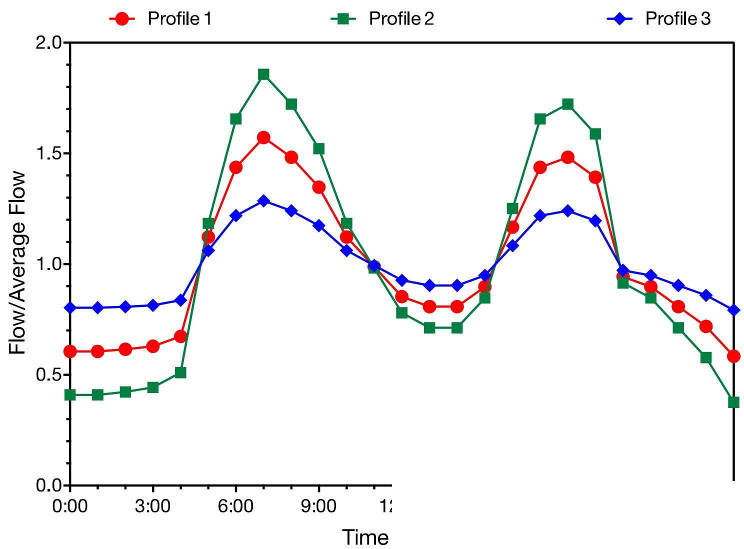
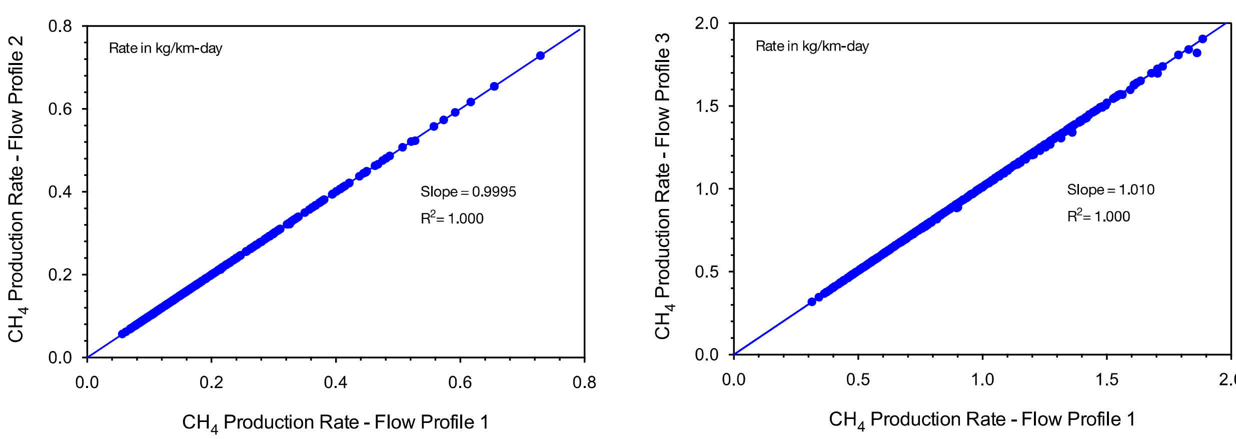
Simulated Wastewater Flow Profiles



Comparison of Methane
Tested Flow Profiles



Methane Generation in Gravity Sewer

$$r_{CH_4} = 0.419 \times 1.06^{(T-20)} \times Q^{0.26} \times D^{0.28} \times S^{-0.138}$$

Where,
r_{CH_4}= Methane production rate (kg/km-day)
Q = Average flow over a day (m^3/s)
D = Pipe diameter (m)
S = Pipe slope (m/m)

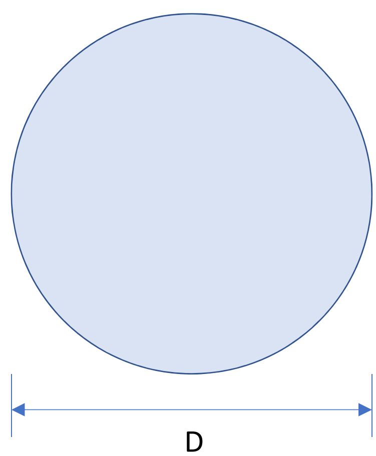
FM-Model Development for Force Main

$$A_{bf} = \pi DL$$

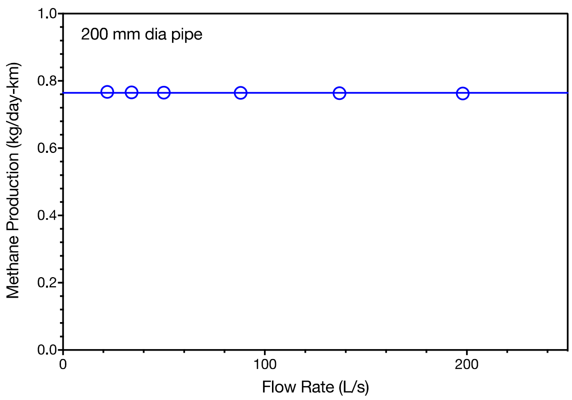
$$r_{CH_4} = k' \cdot A_{bf} = k \cdot D \cdot L$$

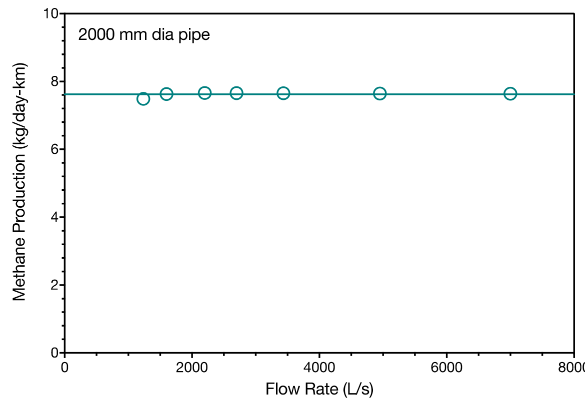
$$r_{CH_4,20} = k \cdot D$$

$$k = k_{20} \cdot 1.06^{T-20}$$



Effect of Flow on Methane Production





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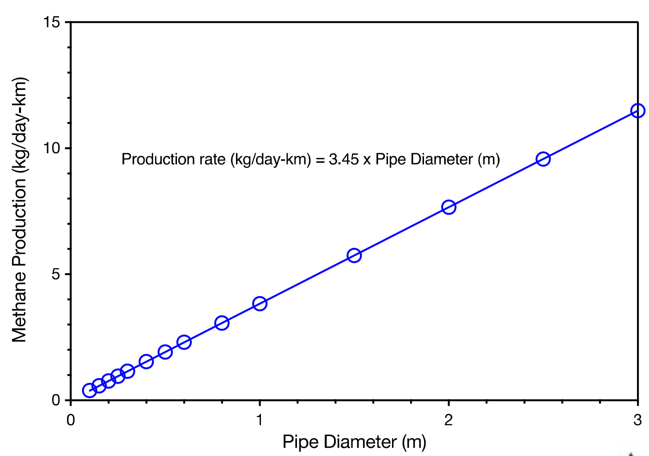
Effect of Pipe Size on Methane Production

$$r_{CH_4,20} = 3.45 \cdot D$$



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FM-Model Methodology

- Pipe diameters ranging from 100 mm to 1500 mm
- Flow varied between 1 L/s and 3000 L/s depending upon the pipe size
- Constant sewer flow
- Typical domestic sewage characteristics
- Parameters calibrated for methane production in a sewer system in Australia
- Same parameters were used for all the sewer pipes

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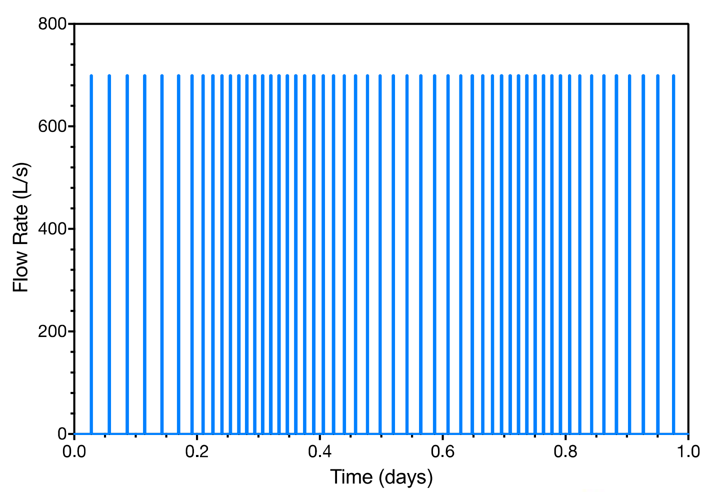
Typical Flow Profile Used

- A pump station model to generate hydraulic profile
- A number of different parameters considered
  - incoming flow rates
  - pump capacities
  - wet-well dimensions duty levels were



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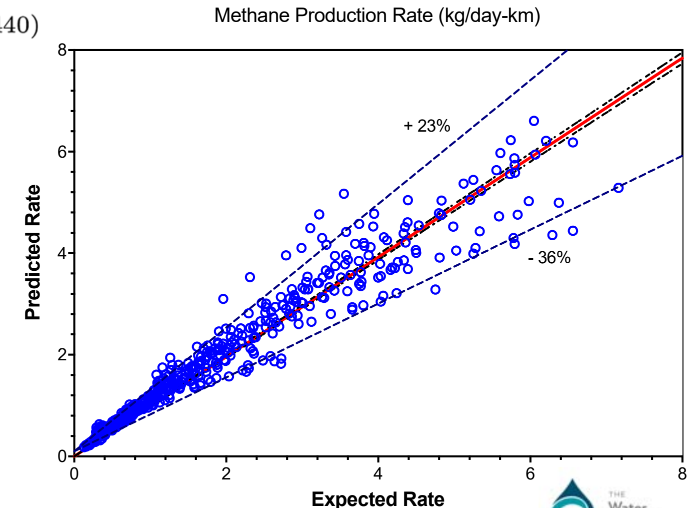
Comparison of Results

$$r_{CH_4,20} = 3.45 \cdot D.N_P^{\alpha}.\beta^{(1-N_P \times P_I/1440)}$$

Estimated Values for Parameters

Parameter	Estimated value	SE
α	0.202	0.0054
β	0.396	0.0087



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Methane Generation in Force Main

$$r_{CH_4} = 3.45 \cdot 1.06^{T-20} D.N_P^{0.202}.0.396^{(1-N_P \times P_I/1440)}$$

Where,
r_{CH_4} = Methane production rate (kg/km-day)
T = Temperature(°C)
D = Pipe diameter (m)
N_P= Number of pumping events per day
P_I= Average pumping interval (min)

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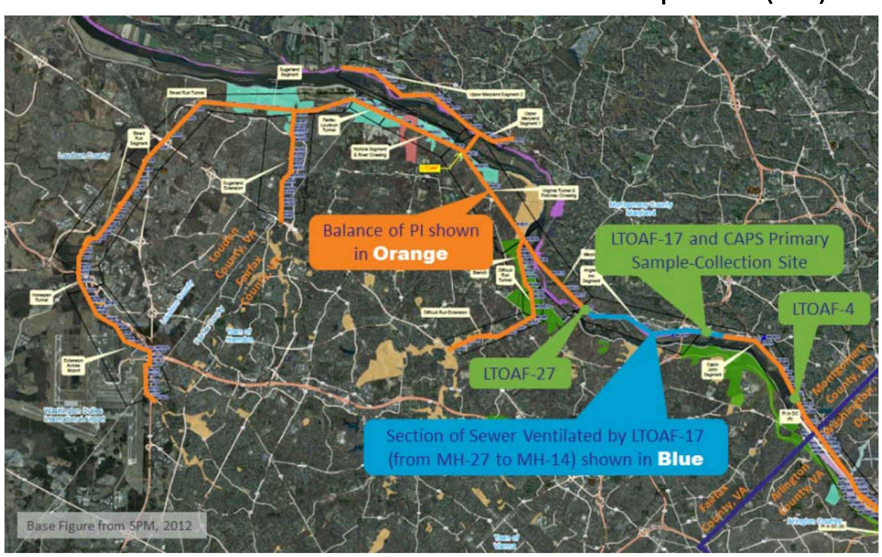
Gravity-Sewer-Method Verification

John Willis, Ph.D., P.E., BCEE
Brown and Caldwell

Overview of the Potomac Interceptor (PI) Test



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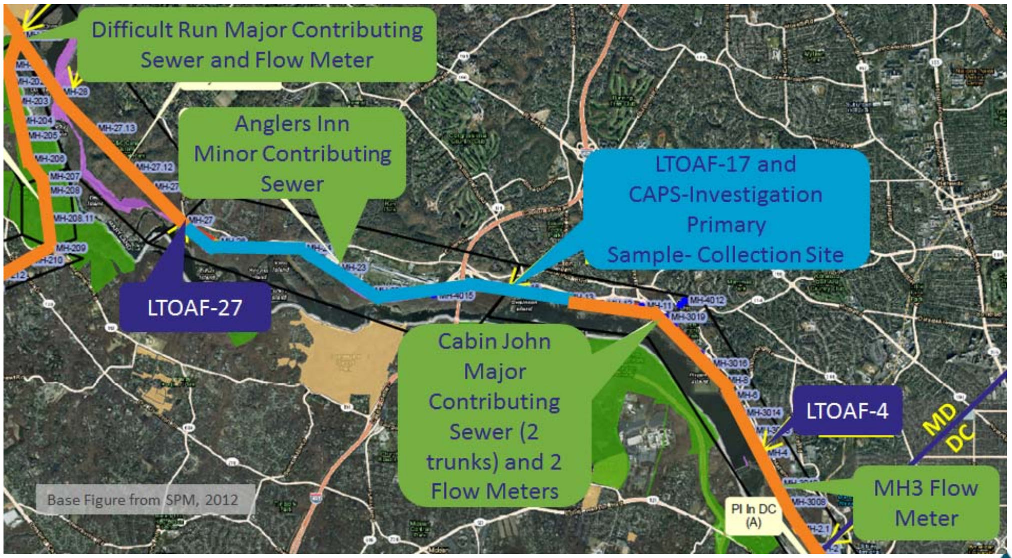
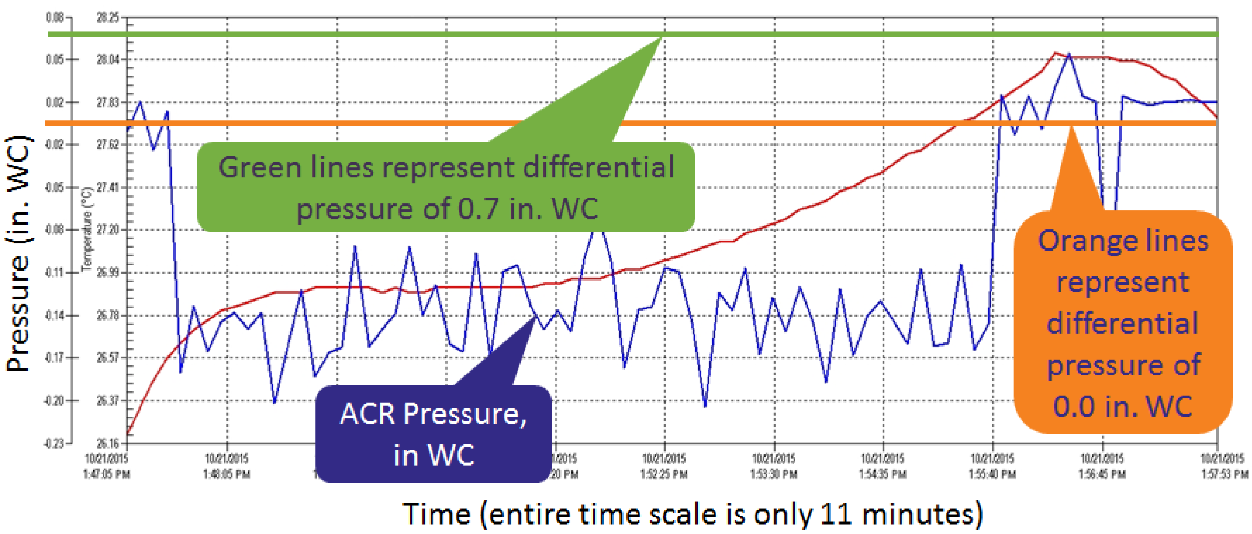
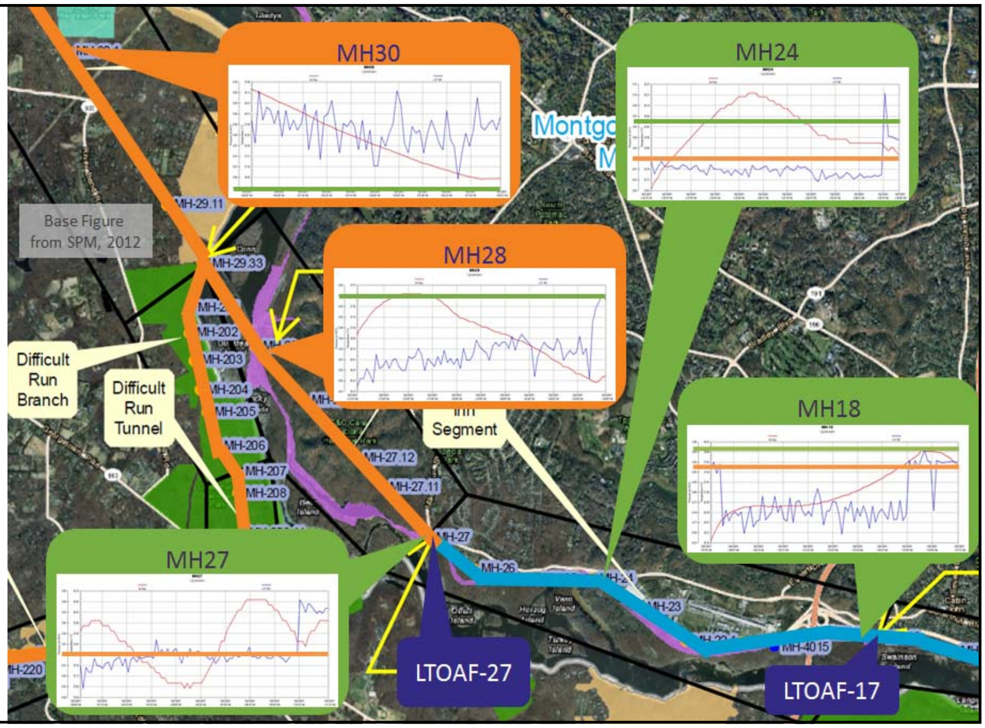
Determination of Extent Ventilated



Sample ACR Output File/Figure



Upstream Manhole Pressures



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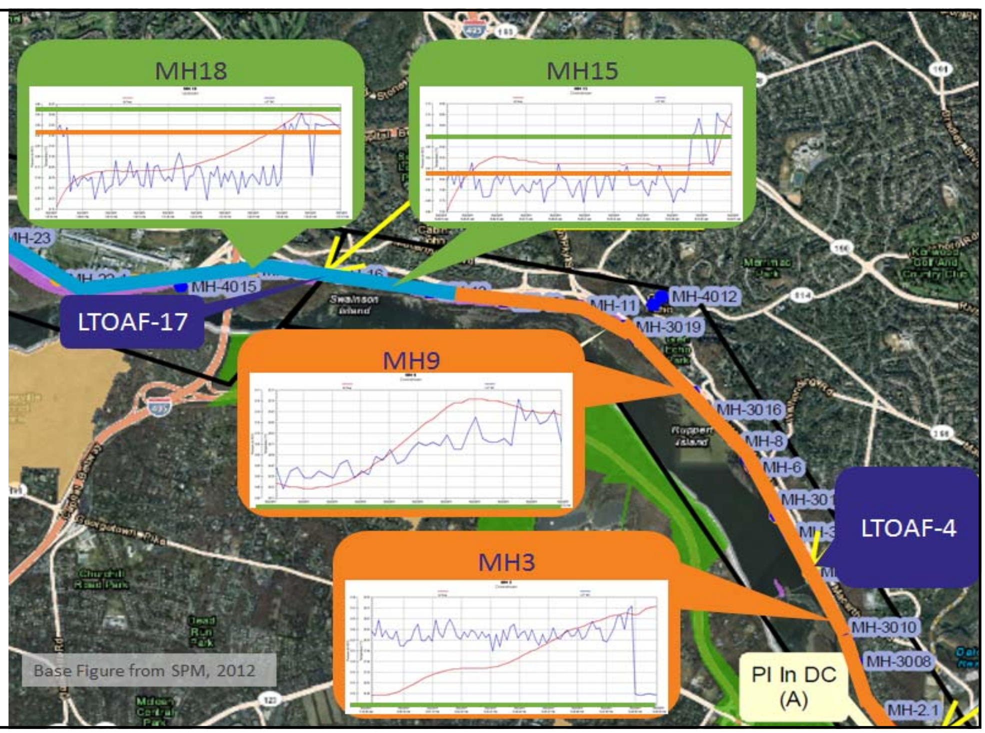
Downstream Manhole Pressures



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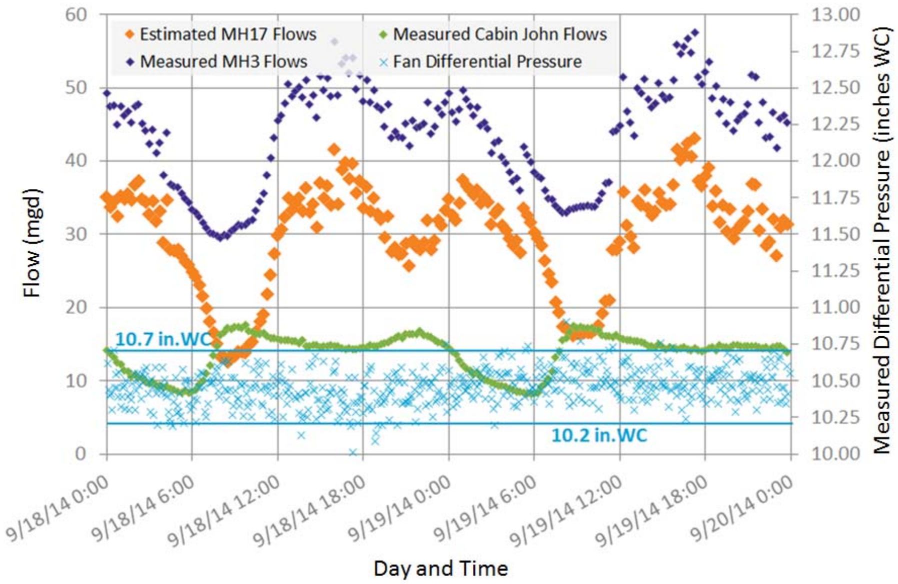
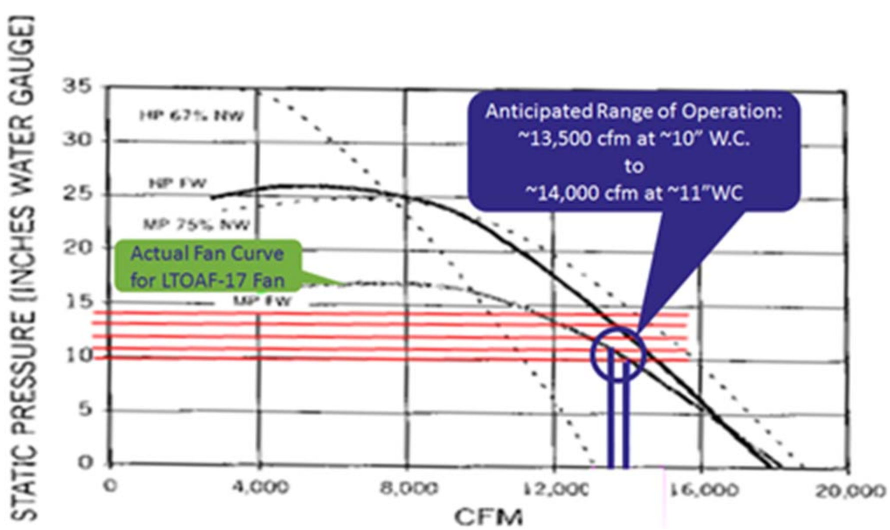
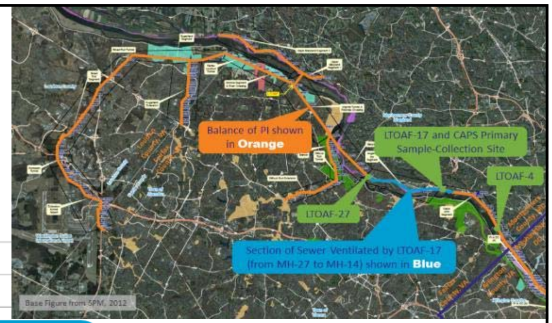
Foul-Air Fan ΔP Pressure is "Stable" over Range of Flows

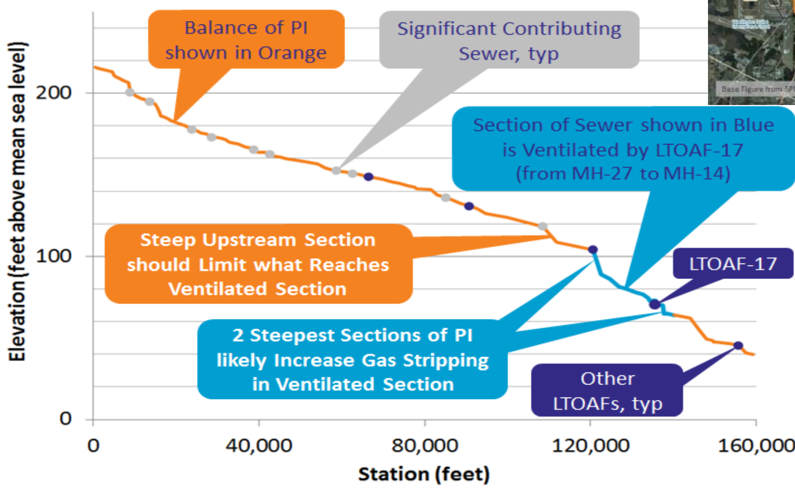


Ventilation Flow Rate: Consistently assumed 13,750cfm

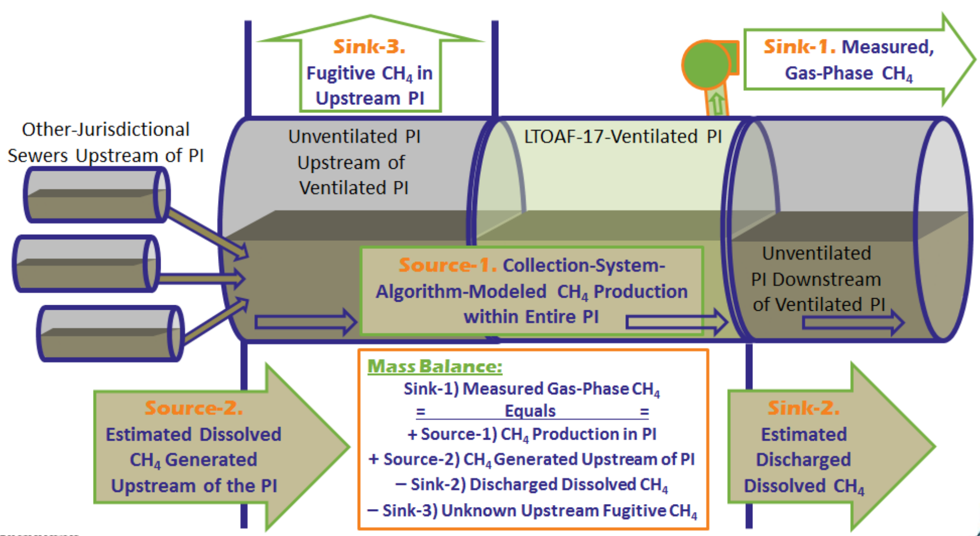


Grade in Potomac Interceptor is Assumed Relevant

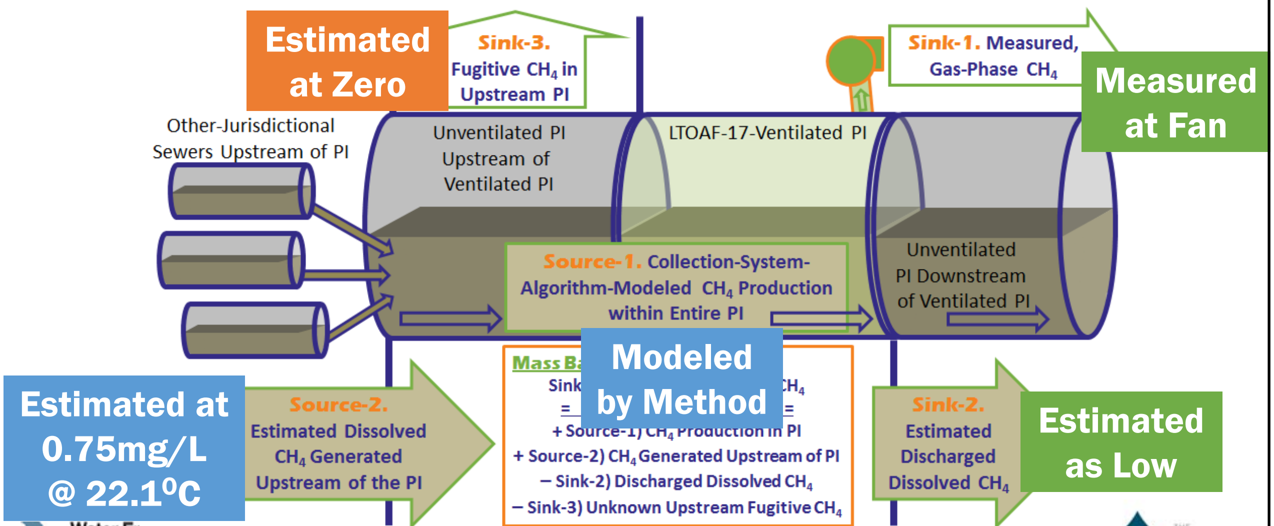




Methane Sources and Sinks for the Potomac Interceptor



Methane Sources and Sinks for the Potomac Interceptor



Two Sampling Campaigns

- Summer
  - September 16, 17 and 18, 2014
  - Measured Daily-Average Potomac-Interceptor Sewage Temperatures of 21.5 to 22.1°C
- Winter
  - April 7, 8, and 9, 2015
  - Measured Daily-Average Potomac-Interceptor Sewage Temperatures of 12.1 to 12.7°C

Results showed Good Correlation with Temperature

Monitoring Day Designation:	Summer Day 1	Summer Day 2	Summer Day 3	Winter Day 1	Winter Day 2	Winter Day 3
Source-1) Simple-Algorithm-Predicted CH_4 Production within the Modelled PI						
Modelled Gravity Sewer CH_4, kg CH_4/D	63	62	60	38	37	38
Modelled Surcharged Sewer CH_4, kg CH_4/D	2.0	1.9	1.9	1.1	1.1	1.1
Modelled CH_4 Production in PI, kg CH_4/D	64.9	64.3	62.2	38.7	38.4	39.4
Modelled as % of Measured	49.7%	49.0%	47.0%	46.4%	55.6%	58.9%
Source-2) Estimated Transport of CH_4 into the PI from Other-Jurisdictional Sewers						
Average Dissolved CH_4 Feed Sewers to the PI, mg/L[a]	0.75	0.74	0.75	0.40	0.36	0.38
Estimated CH_4,Transport into the PI from Feed Sewers, kg CH_4/D	84.7	85.8	81.1	50.6	50.2	51.5
Transported CH_4 as % of Measured	64.9%	65.4%	61.3%	60.6%	72.7%	77.0%
Sink-2) Estimated Dissolved CH_4 Discharged from the LTOAF-17-Ventilated Reach						
Dissolved CH_4 Concentration Leaving LTOAF-17-Ventilated Section, mg/L	0.111	0.110	0.109	0.085	0.083	0.084
Dissolved CH_4 Discharged from LTOAF-17-Ventilated Section, kg CH_4/D	12.6	12.8	11.8	10.7	11.6	11.6
Transported CH_4 as % of Measured	9.6%	9.8%	8.9%	12.8%	16.8%	17.3%
Sink-1) Measured Data for each Day of Sampling						
Average PI Sewage Temperature, ^oC	22.1	21.8	21.5	12.7	12.1	12.6
Average Measured Flow at LTOAB-17, mgd	29.9	30.8	28.7	33.3	36.9	36.2
Measured CH_4 Emissions, kg CH_4/D	131	131	132	83	69	67
Total Accounted for CH_4 to be Emitted at LTOAF-17						
Total Modelled + Estimated - Discharged (Predicted) CH_4, kg CH_4/D	137	137	131	79	77	79
Total Predicted CH_4 as % of Measured	105.0%	104.6%	99.3%	94.2%	111.5%	118.6%
Average Seasonal Predicted CH_4 as % of Measured	103.0%			107.1%		

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Results showed Good Correlation with Temperature

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Average Seasonal Predicted CH_4 as % of Measured	103.0%			107.1%		

"Backed in" to **0.75mg/L** dissolved methane in imported sewage **at 22.1^oC**

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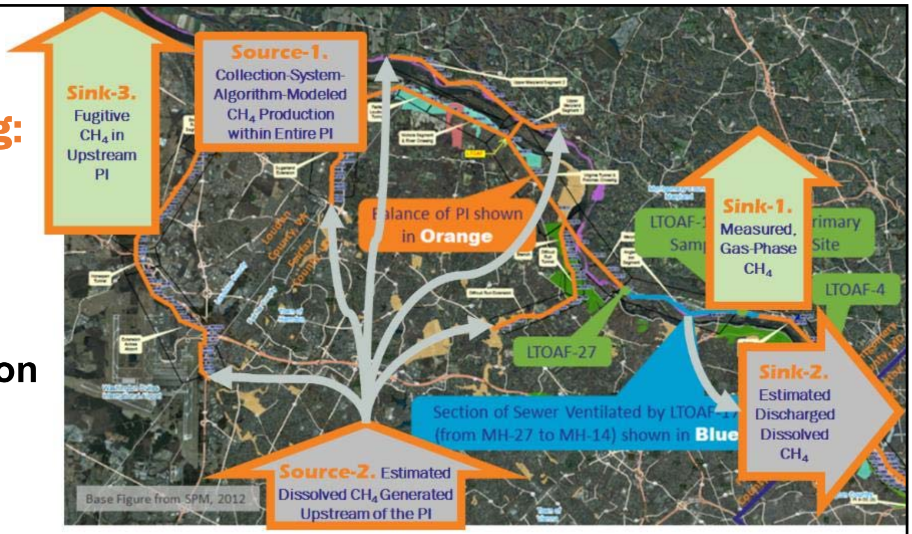
Sources of **Under-Reporting:**



1. **Assumption of Zero Gas-Phase Emissions Upstream of Ventilated Section**
2. **Likely-Low Assumed Imported CH_4 Concentration**
3. **Lack of Consideration for Partially-Surcharged Sewers**

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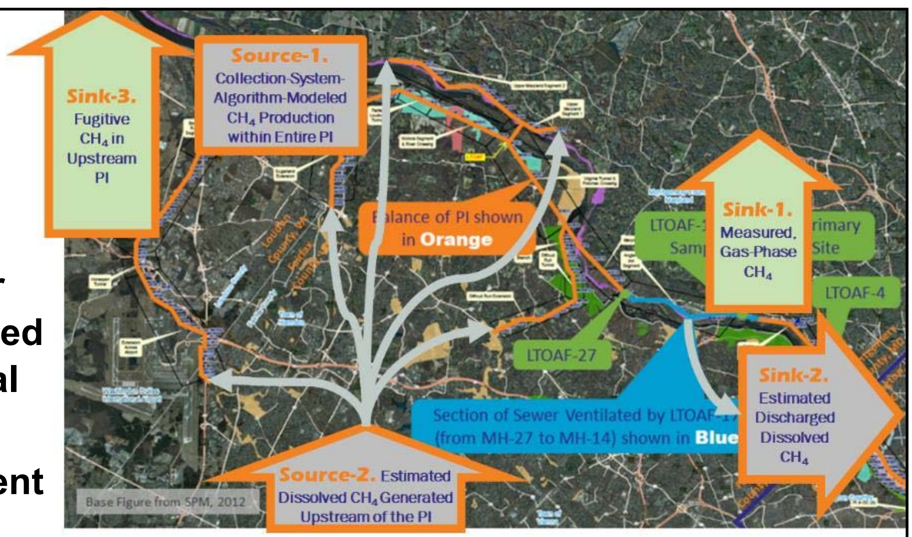
Sources of **Over-Reporting:**



1. **Likely-Low Assumed CH_4 Concentration for Sewage Discharged from Experimental Boundary**
2. **Higher than Current Flows in Design-Average, Hydraulic-Model Shape File**
3. **Assumption that all measured flow at MH17 is Imported as Sewage**

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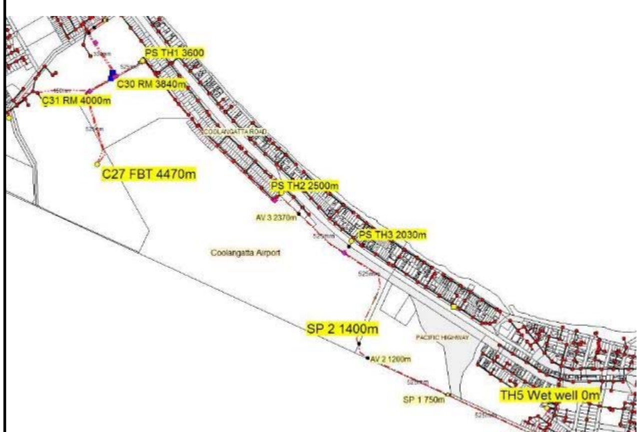
Forcemain-Method Verification

Keshab Sharma, The University of Queensland

The University of Queensland Australia

Sewer Network



Sewer Network

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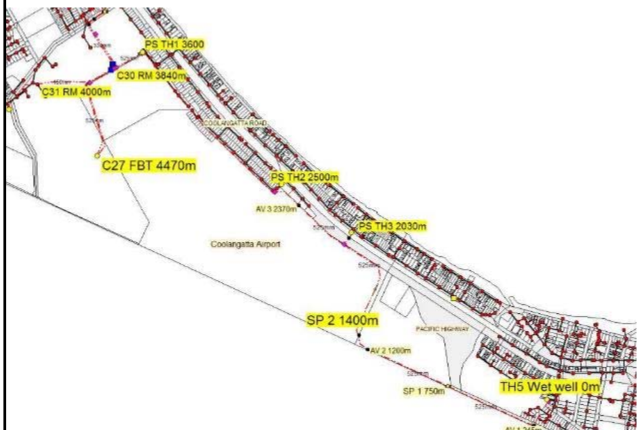
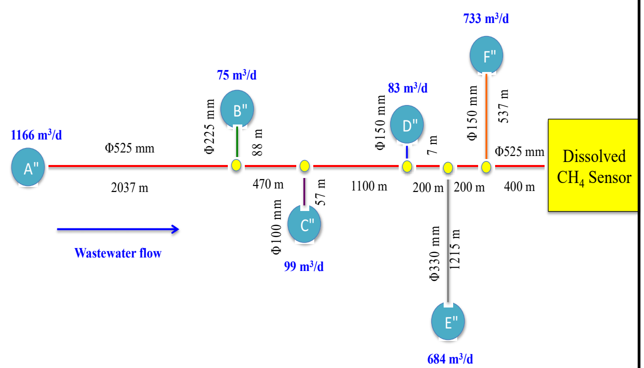
Sewer Network



Sewer Network



Schematic of the Network

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Measured Summer Data

Pipe No.	Pipe Length (km)	Pipe Diameter (m)	Temperature (°C)	No of pumping events/day	Average Pumping Interval (min)	Methane Production (kg/day)
1	2.037	0.525	28	43	6.37	5.94
2	0.088	0.225	28	19	6.76	0.08
3	0.47	0.525	28	62	5.90	1.56
4	0.057	0.1	28	16	3.92	0.02
5	1.1	0.525	28	75	5.45	3.91
6	0.007	0.15	28	21	2.07	0.00
7	0.2	0.525	28	94	4.61	0.76
8	1.215	0.33	28	41	2.17	1.96
9	0.2	0.525	28	126	3.91	0.83
10	0.537	0.15	28	43	15.44	0.57
11	0.4	0.525	28	164	5.55	2.30
					Total:	**17.95**

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Measured Winter Data

Pipe No.	Pipe Length (km)	Pipe Diameter (m)	Temperature (°C)	No of pumping events/day	Average Pumping Interval (min)	Methane Production (kg/day)
1	2.037	0.525	25	43	6.37	4.98
2	0.088	0.225	25	19	6.76	0.07
3	0.47	0.525	25	62	5.90	1.31
4	0.057	0.1	25	16	3.92	0.02
5	1.1	0.525	25	75	5.45	3.28
6	0.007	0.15	25	21	2.07	0.00
7	0.2	0.525	25	94	4.61	0.64
8	1.215	0.33	25	41	2.17	1.64
9	0.2	0.525	25	126	3.91	0.70
10	0.537	0.15	25	43	15.44	0.48
11	0.4	0.525	25	164	5.55	1.93
					Total:	**15.18**

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Comparison of Measured and Modeled CH_4 Emission Rates

Data Series	No of days of measurement	Total measured methane (kg)	Total methane predicted by the model (kg)	Difference
Summer	27	23.46	17.95	-23.49%
Winter	26	15.18	15.07	-0.73%

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Assessment of Method and Related Research

Asbjørn Haaning-Nielsen, Ph.D.,
Aalborg University

AALBORG UNIVERSITY

Related research from Denmark

- At Aalborg University, DK, we have studied chemical and biological *in-sewer* processes for the past 30 years*
- Since the mid-1980's, the wastewater infrastructure in DK has become increasingly centralized
- Today, more than 90% of the wastewater is treated by less than 200 WWTP (all employing C, N and P removal)
- Centralized treatment
  - → extensive pumping of wastewater

** Nielsen, PH & Hvitved-Jacobsen, T (1988). Effect of Sulfate and Organic Matter on the Hydrogen Sulfide Formation in Biofilms of Filled Sanitary Sewers. Journal Water Pollution Control Federation, 60(5), 627-634.*

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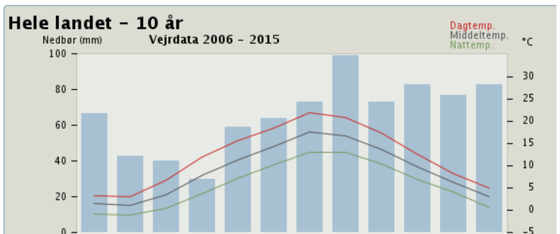
A few facts about Denmark

- Temperate climate
  - Summer high 21.8°C (71.2°F)
  - Winter low -1.2°C (29.4°F)



	JAN	FEB	MAR	APR	MAJ	JUN	JUL	AUG	SEP	OKT	NOV	DEC	ÅR
Nedbør (mm)	67	43	40	30	59	64	73	99	73	83	77	83	792
Nedbørdage	19	15	13	12	14	13	15	19	17	19	21	22	200
Dagtemp.	3.2	3.1	6.6	11.9	15.5	18.4	21.8	20.8	17.3	12.6	8.2	4.9	12.0
Middeltemp.	1.4	1.1	3.5	7.7	11.3	14.3	17.4	16.7	13.7	9.8	6.3	3.0	8.9
Nattemp.	-0.9	-1.2	0.4	3.7	7.2	10.1	13.0	12.9	10.3	6.8	4.0	0.7	5.6
Solskinstimer	50	61	146	211	237	240	242	187	151	102	52	44	1722

- Sewer infrastructure

Type	Area (ha)
Combined sewer	99,674
Separate sewer	150,552

- Per capita water consumption in households
  - 2015: 106 L/PE/d
  - 1989: 174 L/PE/d
  - → increased HRT in recent years

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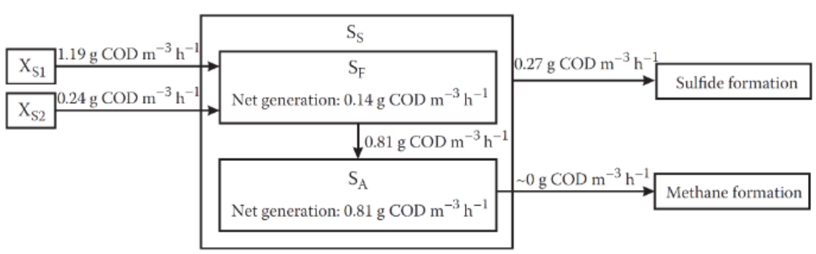
Methane production in sewers

- Generally, we have not considered methane production in sewers a significant process in terms of the overall carbon mass balance



Example showing average values of wastewater organic matter transformations under anaerobic conditions.

From Tanaka, N., Hvitved-Jacobsen, T. (1999), in: I.B. Joliffe, J. E. Ball (eds.), Proceedings of the 8th International Conference on Urban Storm Drainage, Sydney, Australia, 30.8–3.9, 1999, pp. 288–296.

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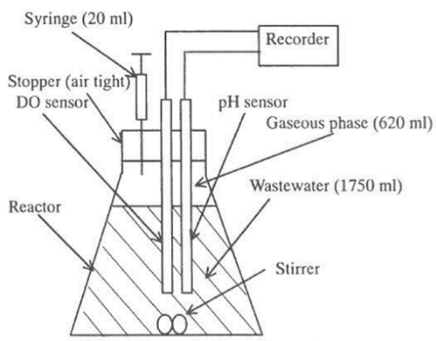
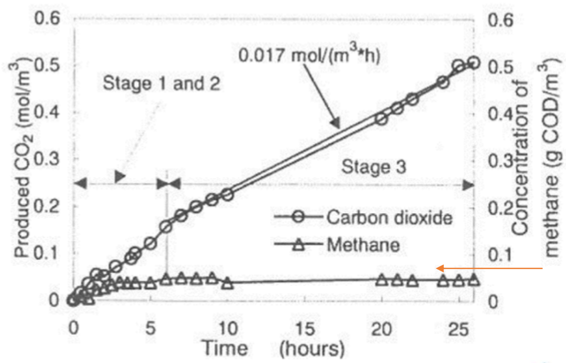
Methane production in wastewater

- Tanaka & Hvitved-Jacobsen (1998) investigated anaerobic organic matter transformations in wastewater from sewers in DK
- During 24 hours of anaerobic incubation, methane concentration increased slightly:





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…i.e., the wastewater itself is not a significant source of methane

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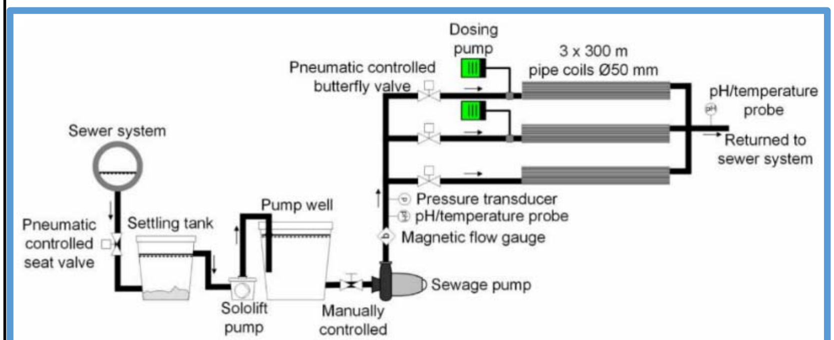
Recent investigations

- Pilot scale study of activities of sewer biofilms + effects of ferrous and ferric iron dosing for sulfide control



Pilot scale experimental setup

Kiilerich, B., Kiilerich, P., Nielsen, A. H., & Vollertsen, J. (2018). Variations in activities of sewer biofilms due to ferrous and ferric iron dosing. In press for Water Science and Technology.

Methane was measured by GC-FID. VFA and sulfate was measured using ion chromatography

Number of force mains	3
Length per force main	300 m
Inside diameter	40.8 mm
Hydraulic retention time	7.7 h
# pump cycles per day	7
Pumping time	6 min/pump cycle
Velocity during pumping	0.6 m/s

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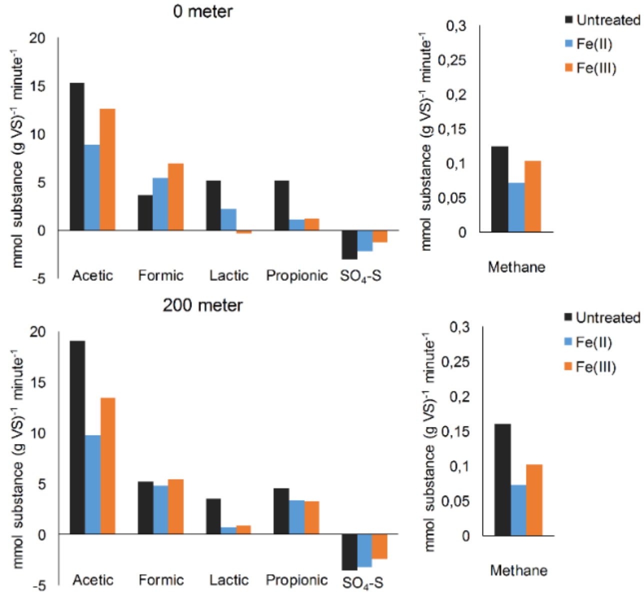
The effect of sulfide control

- Example data: Activity of suspended biofilm from inlet and 200m inside the force mains:
  - Sulfate reduction >> methane formation
  - Reduced sulfate reduction and methane formation as result of sulfide precipitation
  - Slightly increased reaction rates @ 200 m compared to the inlet (0 m)



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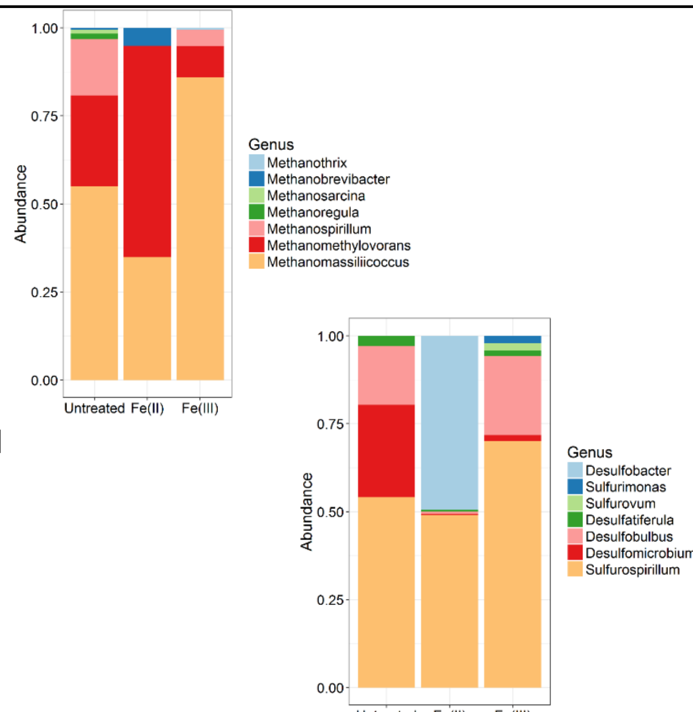
Impact of sulfide control

- As shown, the addition of ferrous and ferric iron for sulfide control was found to impact the methane (and sulfide) formation rates
- Microbiome analysis showed that the distribution of microbes related to sulfide production and methane production was significantly affected as well



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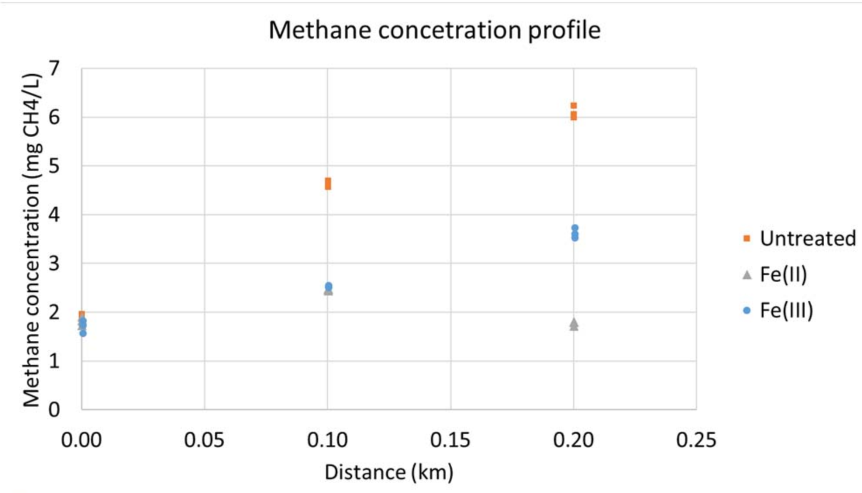
Concentration profile



Samples collected @ 100 m intervals from the pilot scale force main

Methane production over 200 m:
Untreated = 4.23 mg CH_4/L
Fe(II) ≈ 0 mg CH_4/L
Fe(III) = 1.91 mg CH_4/L

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Comparison with proposed method

- For the experimental conditions, the proposed Forcemain/Surcharged-Sewer Method/Equations predicts:

$$rCH_4\text{-}FM = 0.0533 \text{ kg } CH_4/(\text{km}\cdot\text{d})$$

- For the first 200 m, this corresponds to an increase of the methane concentration of 5.4 mg CH_4/L; i.e., in good agreement with the untreated line (4.2 mg CH_4/L)

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Summary

- The proposed model fits well with observed data from an pilot scale experimental sewer
- Sulfide control in terms of ferrous or ferric dosing lowers the methane formation significantly

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Utility Perspective and Use of Methodology

Wendy Barrott, Ph.D., P.E., Manager of Research & Innovation,
Great Lakes Water Authority (GLWA)

GLWA Great Lakes Water Authority

Single WRRF for Region

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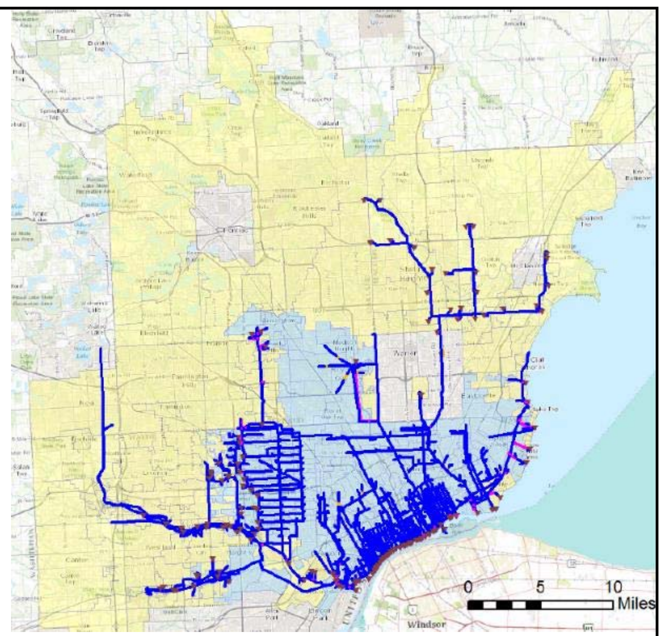
Great Lakes Water Authority

Service Area Summary:

- Population: 3.5 million
- Service Area: 946 mi.^{2}
- Approx. Length: 585 miles
- Average Flows: 645 MGD
- Peak Flows: 1.7 BGD
- ~% Forcemains: 1 %
- Min/Max Sewage Temperatures:
  - March 50 ^{O}F
  - August 72 ^{O}F



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Why GLWA estimated Sewer-CH_4 Emissions

- State of our GHG Accounting:
  - Early
  - On-site gas burning to date
  - Gross estimates using emission factors
  - No measurements to date
- Rationale for Developing our Sewer CH_4 Emissions:
  - GLWA recognizes that managing GHG will be the challenge of the next 30 years
  - Sewer CH_4 is an emerging area of concern
  - Why not?

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GLWA's Use of the Proposed Methodology

Started with output Excel file from our collection-system model at average flows:

Base-File Data Needs

	Segment ID; not specifically used			Shape, Size, Length, and Slope				Flow	Upstream and Downstream HGLs	
	A	B	C	D	E	F	G	H	I	J
7	Pipe (model link name)	From MH	To MH	Pipe Shape [1]	Diameter (inches)	Length (feet)	Slope (ft/100 ft)	Static- Model Avg Flow (cfs	Avg Depth Upstream (inches)	Avg Depth Downstream (inches)
8	600	600	2985	CIRCULAR	162	500	0.000	9.12	10.2	4.1
9	605	605	600	CIRCULAR	138	900	0.089	8.04	23.3	10.2
10	620	620	605	CIRCULAR	162	600	0.100	8.04	16.3	23.3
11	621	621	620	CIRCULAR	138	2696	0.060	0.00	0.0	16.3
12	622	622	621	CIRCULAR	138	2154	0.035	0.00	0.0	0.0
13	623	623	622	CIRCULAR	102	682	0.050	0.00	0.0	0.0

GLWA's Use of the Proposed Methodology

Performed unit conversions to metric:

Inputs Used in Both Gravity- and Surcharged-Sewer Calculations

Length in Feet to Kilometers (Segment Length, Gravity Sewer Length)

cfs to m³/s (Static-Model Average Flow)

Inches and Feet to Meters (Diameter, Slope, Avg Depth Upstream, Avg Depth Downstream)

	K: Avg Flow (mgd) [million UK gallons per day]	L: Segment Length (km)	M: Gravity Sewer Length (km)	N: Static-Model Average Flow (m^3/s)	O: Diameter (m)	P: Slope (m/m)	AD: Avg Depth Upstream (m)	AE: Avg Depth Downstream (m)
8	4.926	0.152	0.152	0.2583058	4.1148	0.00000	0.258	0.104
9	4.341	0.274	0.274	0.2276104	3.5052	0.00089	0.591	0.258
10	4.341	0.183	0.183	0.2276104	4.1148	0.00100	0.414	0.591
11	0.000	0.822	0.822	0	3.5052	0.00060	0.000	0.414
12	0.000	0.657	0.657	0	3.5052	0.00035	0.000	0.000
13	0.000	0.208	0.208	0	2.5908	0.00050	0.000	0.000

GLWA's Use of the Proposed Methodology

Classify portions of each segment as "gravity" or "surcharged":

Determination of Gravity and Surcharged Lengths

Diameter and Upstream and Downstream Depths (Diameter, Avg Depth Upstream, Avg Depth Downstream)

% Submergence at each End; % of Length Submerged (Upstream % of Diameter, Downstream % of Diameter, % of Link Surcharged)

Lengths Used for Respective CH_4-Production Calculations (Length Submerged, Length not Submerged)

	O: Diameter (m)	AD: Avg Depth Upstream (m)	AE: Avg Depth Downstream (m)	AF: Upstream % of Diameter	AG: Downstream % of Diameter	AH: % of Link Surcharged	AI: Length Submerged (km)	AJ: Length not Submerged (km)
37	2.7432	0.205	0.208	7.5%	7.6%	0.0%	0.000	0.410
38	2.7432	0.208	0.204	7.6%	7.4%	0.0%	0.000	0.116
40	0.59436	0.079	2.572	13.3%	432.8%	79.3%	0.039	0.010
42	0.4572	0.306	2.444	66.9%	534.5%	92.9%	0.040	0.003
409	1.292352	1.571	1.716	121.6%	132.8%	100.0%	0.073	0.000
689	0.109728	0.725	0.455	660.8%	414.4%	100.0%	0.061	0.000

GLWA's Use of the Proposed Methodology

Each segment can be classified as "Gravity", "Surcharged", or "Hybrid":

Determination of Gravity and Surcharged Lengths

Determination of Segments as Gravity, Surcharged, or Hybrid

Diameter and Upstream and Downstream Depths | % Submergence at each End, % of Length Submerged | Lengths Used for Respective CH_4-Production Calculations

Class	Row	Diameter (m)	Avg Depth Upstream (m)	Avg Depth Downstream (m)	Upstream % of Diameter	Downstream % of Diameter	Length Submerged (km)	Length not Submerged (km)
Gravity	37	2.7432	0.205	0.208	7.5%	7.6%	0.000	0.410
Gravity	38	2.7432	0.208	0.204	7.6%	7.4%	0.000	0.116
Hybrid	40	0.59436	0.079	2.572	13.3%	432.8%	0.039	0.010
Hybrid	42	0.4572	0.306	2.444	66.9%	534.5%	0.040	0.003
Surcharged	409	1.292352	1.571	1.716	121.6%	132.8%	0.073	0.000
Surcharged	689	0.109728	0.725	0.455	660.8%	414.4%	0.061	0.000

GLWA's Use of the Proposed Methodology

GRAVITY-SEWER CH_4 production at monthly-average temperatures:

Gravity-Sewer, Monthly-Average kg-CH_4/D at Monthly Average Temperatures

	January	February	March	April	May	June	July	August	September	October	November	December
Days:	1	1	1	1	1	1	1	1	1	1	1	1
ure, deg C:	11.11	10.39	9.77	11.10	14.11	17.35	20.11	21.91	21.42	18.99	16.64	13.69

Calculated Outputs - Gravity-Sewer Simple Algorithm

CH_4, kg-CH_4/D | Monthly Average Temperatures, °C | Months

	January	February	March	April	May	June	July	August	September	October	November	December
Daily CH4, kg-CH4/D:	437.2	419.3	404.3	437.1	520.9	628.8	738.8	820.6	797.1	692.1	603.3	508.0
	0.202	0.193	0.187	0.202	0.240	0.290	0.341	0.379	0.368	0.319	0.278	0.234
	0.057	0.055	0.053	0.057	0.068	0.082	0.097	0.108	0.104	0.091	0.079	0.067
	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.003	0.003	0.002	0.002	0.002
	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.018	0.017	0.017	0.018	0.021	0.026	0.030	0.034	0.033	0.029	0.025	0.021
	0.089	0.085	0.082	0.089	0.106	0.128	0.150	0.167	0.162	0.141	0.123	0.103
	0.046	0.044	0.043	0.046	0.055	0.066	0.078	0.086	0.084	0.073	0.064	0.054

GLWA's Use of the Proposed Methodology

Specific Use of **GRAVITY SEWER EQUATION**:

$r_{CH4\text{-}GS}$ =

$$L * 0.419 * 1.06^{(T-20)} * S^{-0.135} * D^{0.28} * Q^{0.26}$$

- $r_{CH4\text{-}GS}$ = CH_4 in kg-CH_4/day
- L = Length in km
- T = Temperature in °C
- S = Slope in m/m
- D = Pipe diameter in m
- Q = Flow in m^3/s

Gravity-Sewer Equation Use

Model Input Avg. Daily Temperature, deg C: 11.11

Daily CH4, kg-CH4/D: **437.2**

Row	Gravity Sewer Length (km)	Model Average Flow (m³/s)	Diameter (m)	Slope (m/m)	January
38	0.410	0.0886599	2.7432	0.00049	ormulas!C5
39	0.116	0.0886599	2.7432	0.00045	0.057
41	0.010	0.0164804	0.59436	0.00994	0.001
43	0.003	0.1695044	0.4572	0.01000	0.001
410	0.000	0.5116846	1.292352	0.00208	0.000
690	0.000	0.0138554	0.109728	0.01300	0.000
691	0.173	0.0043296	1.2192	0.02699	0.018
692	0.150	0.3440491	1.524	0.00041	0.089
693	0.083	0.3440491	1.2192	0.00037	0.046
694	0.098	0.3440491	1.524	0.00094	0.053
695	0.078	0.3440491	1.2192	0.00039	0.044
696	1.057	0.3440491	1.524	0.00110	0.564

GLWA's Use of the Proposed Methodology

SURCHARGED SEWER CH_4 production at monthly-average temperatures:

Surcharged-Sewer, Monthly-Average kg-CH_4/D at Monthly Average Temperatures

Days:	1	1	1	1	1	1	1	1	1	1	1	1
ure, deg C:	11.11	10.39	9.77	11.10	14.11	17.35	20.11	21.91	21.42	18.99	16.64	13.69

Calculated Outputs - Forcemain/Surcharged-Sewer Simple Algorithm

CH_4, kg-CH_4/D

Monthly Average Temperatures, °C

Daily CH4, kg-CH4/D:	52.0	49.9	48.1	52.0	62.0	74.9	88.0	97.7	94.9	82.4	71.8	60.5

Slope (m/m)	January	February	March	April	May	June	July	August	September	October	November	December
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.119	0.114	0.110	0.119	0.142	0.172	0.202	0.224	0.218	0.189	0.165	0.139
	0.094	0.090	0.087	0.094	0.112	0.135	0.159	0.177	0.172	0.149	0.130	0.109
	0.491	0.471	0.454	0.490	0.584	0.706	0.829	0.921	0.894	0.777	0.677	0.570
	0.035	0.033	0.032	0.035	0.041	0.050	0.059	0.065	0.063	0.055	0.048	0.040
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

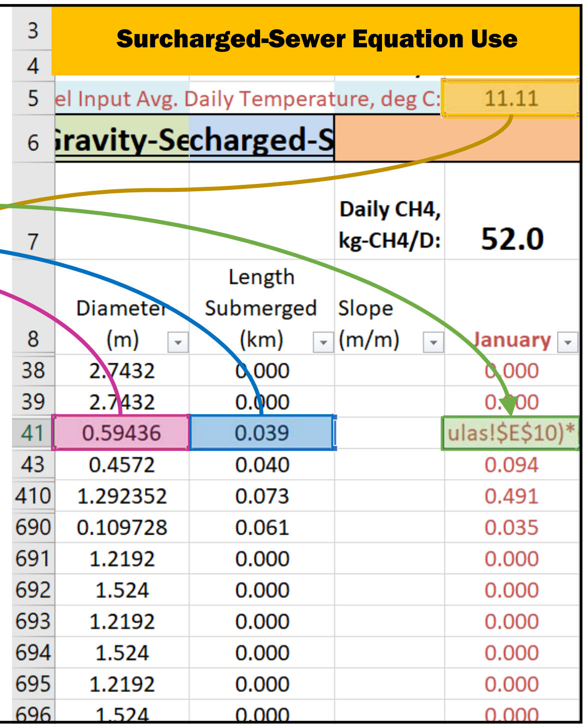
Months

GLWA's Use of the Proposed Methodology

Specific Use of **SURCHARGED SEWER EQUATION**:

$$r_{CH4\text{-}FM} = L * 3.452 * D * 1.06^{(T-20)}$$

r_{CH4}	= CH_4 in kg-CH_4/day
L	= Length in km
T	= Temperature in ^oC
D	= Pipe diameter in m



GLWA's Annual Sewer-CH_4 Emissions

- GLWA's Annual Sewer-CH4 represent 240 MT-CH_4/yr, or
- 5,000 (@ GWP-21) or 6,700 (@GWP-28) MT-CO_2e/yr

Emissions-Estimation Element	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Totals, MT-CH_4/yr	Annual GHG @GWP=21, MT-CO_2e/yr	Annual GHG @GWP=28, MT-CO_2e/yr
Days	31	28	31	30	31	30	31	31	30	31	30	31	365	699	1,370
Average Temperature, Degrees C	11.1	10.4	9.8	11.1	14.1	17.3	20.1	21.9	21.4	19.0	16.6	13.7	15.6	15.8	15.9
Gravity-Sewer CH_4, kg-CH_4/D	440	422	407	440	524	632	743	825	802	696	607	511	215	4,509	6,012
Surcharged-Sewer CH_4, kg CH_4/D	52	50	48	52	62	75	88	98	95	82	72	60	25	534	712
Monthly Totals, MT-CH_4/mo:	15.2	13.2	14.1	14.7	18.2	21.2	25.8	28.6	26.9	24.1	20.4	17.7	240	5,043	6,724

Kudos

Kim Siemens
Water resources engineer with CDM Smith
Arthur Chan
Environmental Engineer with CDM Smith
Jenny Casler
IT Project Manager for GLWA

Conclusions

John Willis, Ph.D., P.E., BCEE
Brown and Caldwell

Conclusions –

- Sewer Methane is significant – and knowledge provides opportunities
- This Method and the supporting data have been peer-reviewed and provide a much closer estimate than currently-employed "no-emissions assumptions"

Water Environment Federation the water quality people

THE Water Research FOUNDATION

Conclusions – How you can Participate

- Sewer Methane is significant – and knowledge provides opportunities
- This Method and the supporting data have been peer-reviewed and provide a much closer estimate than currently-employed "no-emissions assumptions"
- We are looking **for interested utilities to:**
  - **Apply our method or have us apply our method to your system**
  - **Contribute to our database** (anonymously if so preferred)
  - For development of a **further simplified method for broader application**

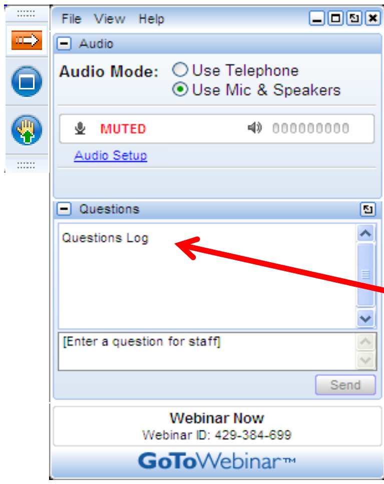
If you are interested in participating call/email me at:

John Willis at JWillis@BrwnCald.com; 770-361-6431

Water Environment Federation the water quality people

THE Water Research FOUNDATION

Questions for Our Speakers?



- **Submit your questions using the Questions Pane.**

Thank You