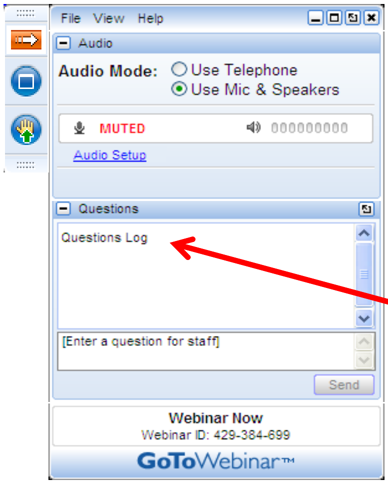
Emerging Trends in Wastewater Disinfection

March 22, 2017

1:00 – 3:00 pm ET

How to Participate Today



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- **Submit your questions using the Questions pane.**
- **A recording will be available for replay shortly after this web seminar.**

Today's Moderator

Gary Hunter, P.E., BCEE, ENV SP

- Senior Wastewater Process Specialist – Black & Veatch Corporation
- Responsible for design, operation, maintenance and troubleshooting of wastewater disinfection projects
- Past Chair of the WEF Disinfection Committee
- Past Chair of WEF Disinfection and Public Health Symposia

Agenda

Topic	Speaker(s)
Analysis of Variability in UV Disinfection Systems: A Stochastic Approach (WE&RF Project ENER16C15)	Ernest "Chip" Blatchley, III, Ph.D., PE, BCEE, F. ASCE *Purdue University*
Emerging Research on Peracetic Acid (PAA) for Disinfection (WE&RF Project LIFT14T16)	Allegra da Silva, Ph.D., PE Joe Jacangelo, Ph.D., REHS *MWH, now a part of Stantec*
How Oklahoma DEQ Evaluates and Implements Emerging Disinfection Technologies	Gregory Carr, PE Rocky Chen, PE *Oklahoma Department of Environmental Quality*
Questions & Answers	All Speakers

This webcast was organized by the Water Environment & Reuse Foundation in cooperation with the WEF Disinfection & Public Health Committee

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Ernest (Chip) Blatchley, Ph.D.

Professor of Civil Engineering and Environmental and Ecological Engineering, Purdue University

Analysis of Variability in UV Disinfection Systems: A Stochastic Approach

Ernest R. Blatchley III Ph.D., P.E., BCEE, F. ASCE[1,2]
[1]Lyles School Civil Engineering
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Purdue University
West Lafayette, IN

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NYC Environmental Protection

Metropolitan Water Reclamation District of Greater Chicago

tra

atg UV Technology

Graduate Students

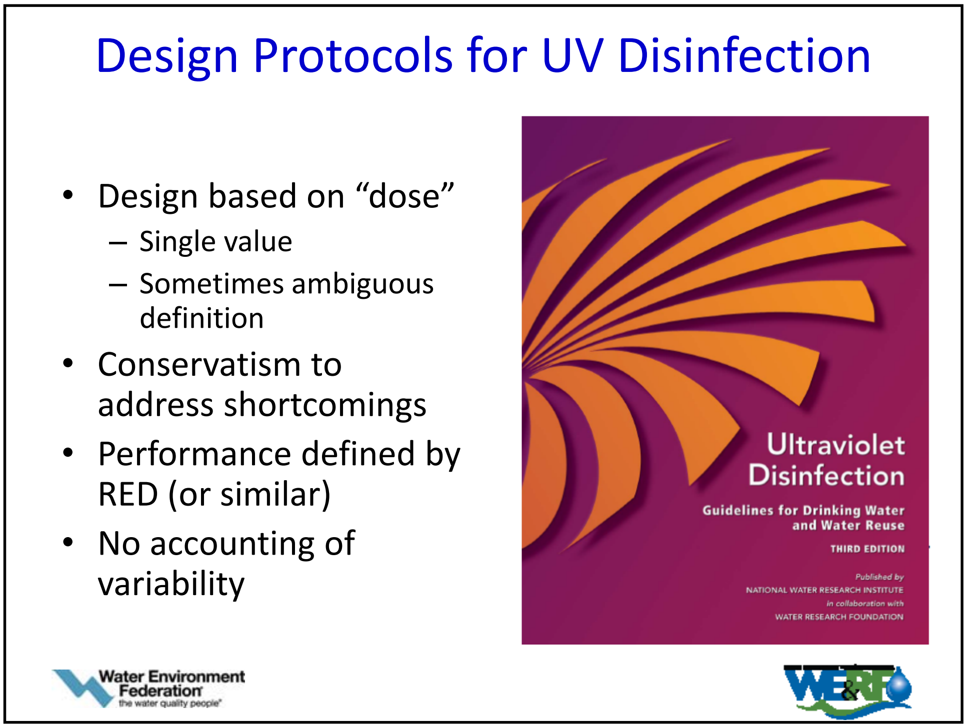
Yousra Ahmed
Ph.D. Student
Numerical Modeling

Angela Ortiz
M.S. Graduate
Laboratory
Experiments

Xing Li
M.S. Student
Laboratory
Experiments

Outline

- Current design and validation protocols
- Basis of stochastic approach
- Belmont WWTP (Indianapolis)
  - Dose-response behavior
  - Effects of variability
  - Monte Carlo simulations
- Other microbial endpoints
  - Chicago (O'Brien WWTP)
    - *E. coli*
    - Fecal coliforms
  - New York (26th Ward WWTP)
    - Fecal coliforms
    - *Enterococcus*
  - Phage
- Future work



Design Protocols for UV Disinfection

- Design based on “dose”
  - Single value
  - Sometimes ambiguous definition
- Conservatism to address shortcomings
- Performance defined by RED (or similar)
- No accounting of variability

Ultraviolet Disinfection

Guidelines for Drinking Water and Water Reuse

THIRD EDITION

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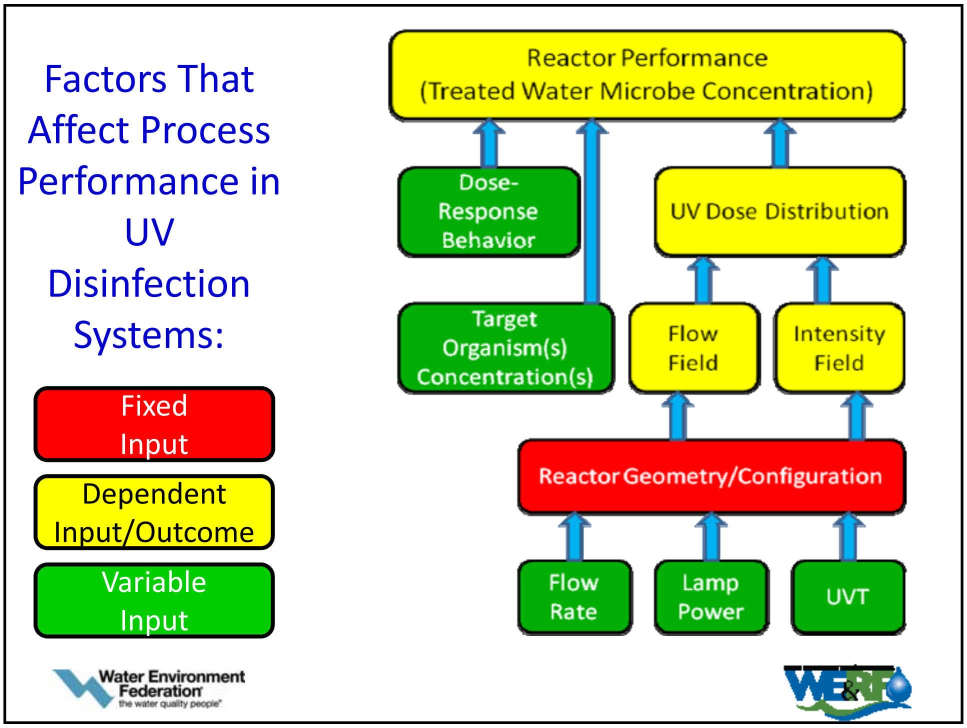

Factors That Affect Process Performance in UV Disinfection Systems:

🟥 Fixed Input

🟨 Dependent Input/Outcome

🟩 Variable Input

Hypotheses

- Variability in process performance of UV disinfection systems is attributable to variability in input parameters.
- A stochastic CFD-I modeling approach can be used to accurately simulate variability in process performance of UV disinfection systems.
- Design approaches that account for variability can yield reactor designs that are more efficient and reliable than those that are generated using traditional methods.

Participants/Microbes

Participating Utility	Organism(s)	Analytical Method(s)
Belmont AWT Indianapolis, Indiana	*E. coli*	USEPA 1103.1
HDR Technology Validation Center, Johnstown, New York	Coliphage MS2	Double Layer Plaque Assay
Metropolitan Water Reclamation District of Greater Chicago (O'Brien WWTP)	*E. coli* Fecal Coliforms Bacteriophage	*Standard Methods* 9222G *Standard Methods* 9222D USEPA 1602
New York Department of Environmental Protection (26th Ward WWTP)	*Enterococcus* Fecal Coliforms Bacteriophage	USEPA 1600 *Standard Methods* 9222D USEPA 1602

Variability and Uncertainty Analysis

1) CFD-I Model Uncertainty:

- Selection of turbulence model, boundary conditions, particle trajectories (*i.e.,* number of simulated particles), and fluence rate model parameters (*i.e*., number of rays used in photopia, material optical properties)

2) Input parameter variability:

- Target organism(s) concentration(s), N_0
- UV dose-response behavior of target(s)
- Lamp power
- UVT
- Flow rate

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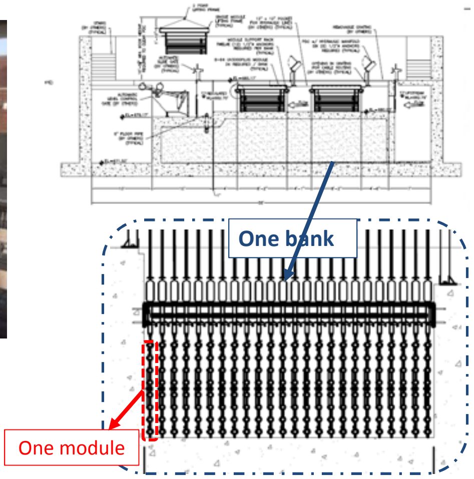
Application of Stochastic Modeling Approach: Belmont AWT, Citizens Energy, Indianapolis, IN

Trojan UV3000Plus



- 7 Channels
- 2 Banks per channel
- 24 modules x 8 lamps (LPHO)

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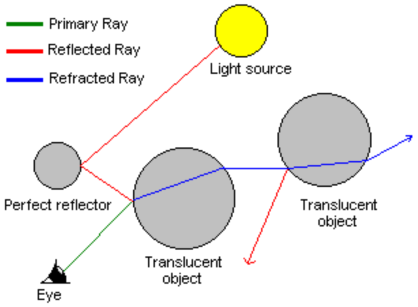
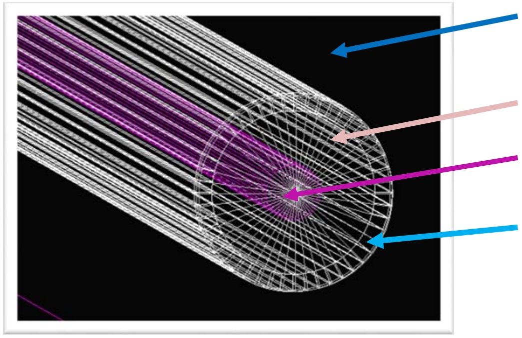
Fluence Rate Field Simulation: Ray Tracing

- Probabilistic ray tracing
- System geometry defined
- Assignments
  - Lamp power
  - Absorbance (UVT)
  - Reflectance
  - Refractive index
- Simulate large number of rays
- Illuminance estimated by power/area



Ray Tracing: Photopia



Water

Air

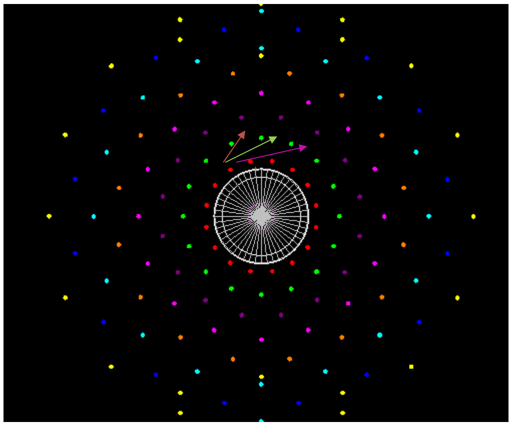
LP UV Lamp

Quartz Sleeve

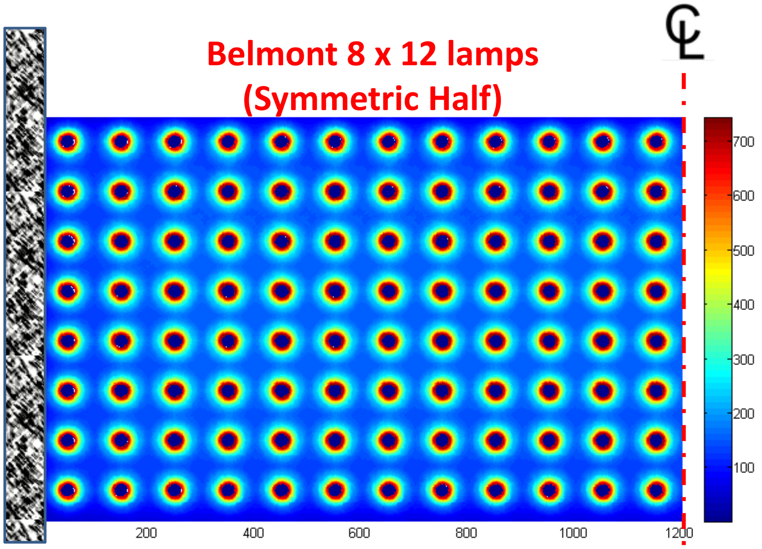
Lamp Dimensions:
UV Lamp (7mm diameter), OD of the quartz sleeve =25 mm, Length=156 cm

Simulation of UV Fluence Rate Field

- Goal: Mimic **fluence rate** definition
- Array of small receiving spheres at increasing radial distances from source
- Linear interpolation used for fluence rate at intermediate locations

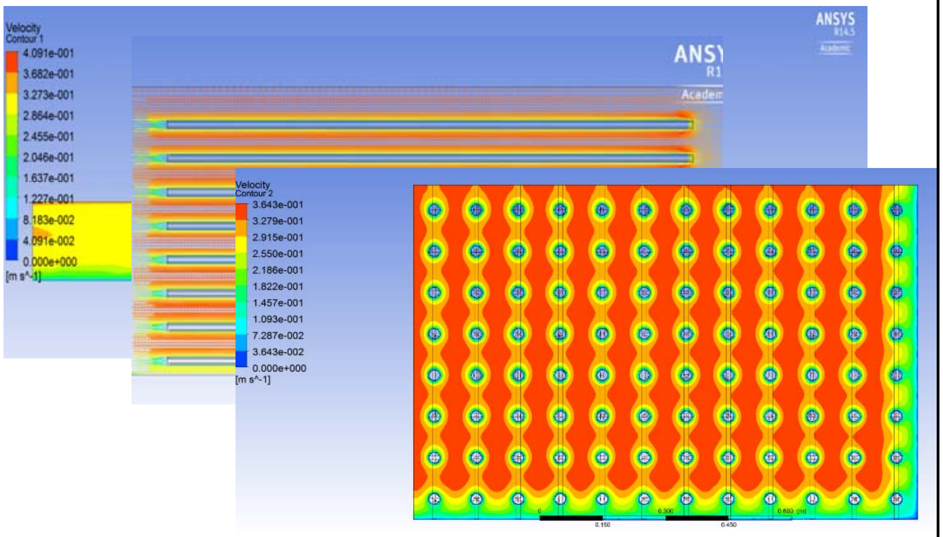


Simulated Fluence Rate Field

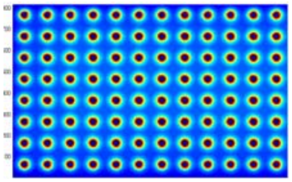


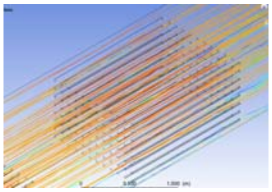
Belmont 8 x 12 lamps (Symmetric Half)

Velocity Field Results-CFD



UV Dose Distribution



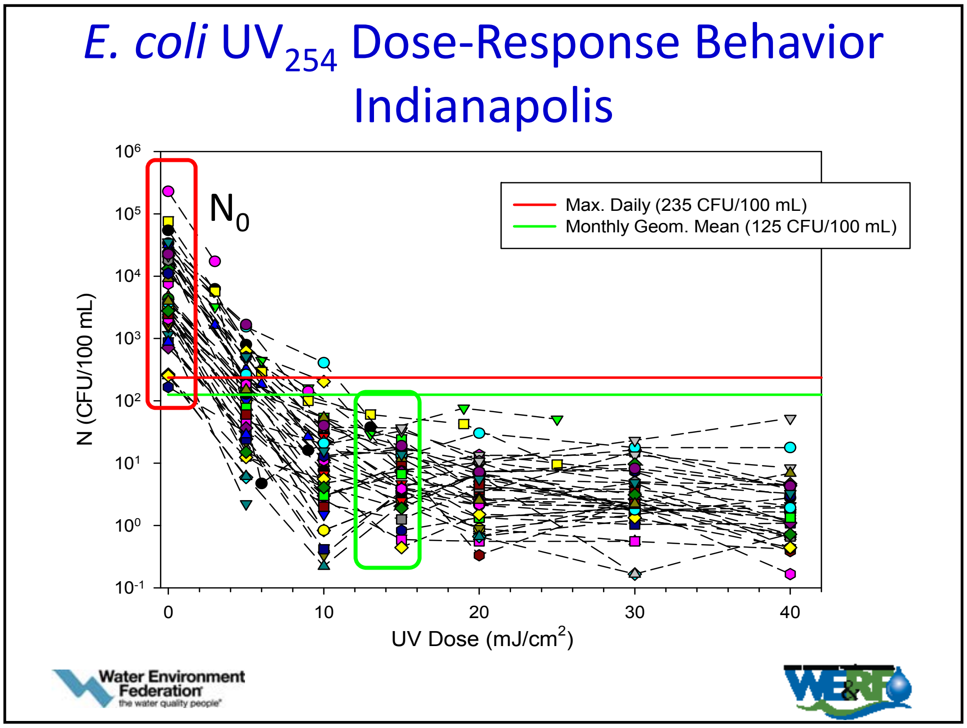


Fluence Rate Field + **Particle Tracking**

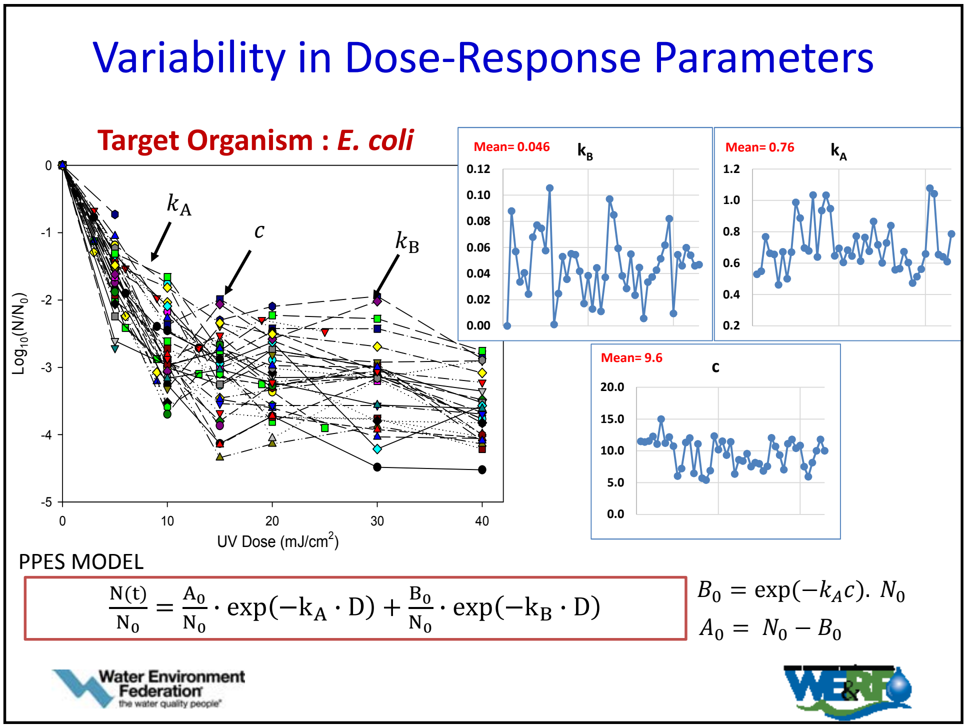
↓

$$D_{trajectory} = \sum_{i=1}^{n} I_i(R,z)\Delta t_i$$

Dose Distribution



E. coli UV_{254} Dose-Response Behavior Indianapolis



Variability in Dose-Response Parameters

Target Organism : *E. coli*

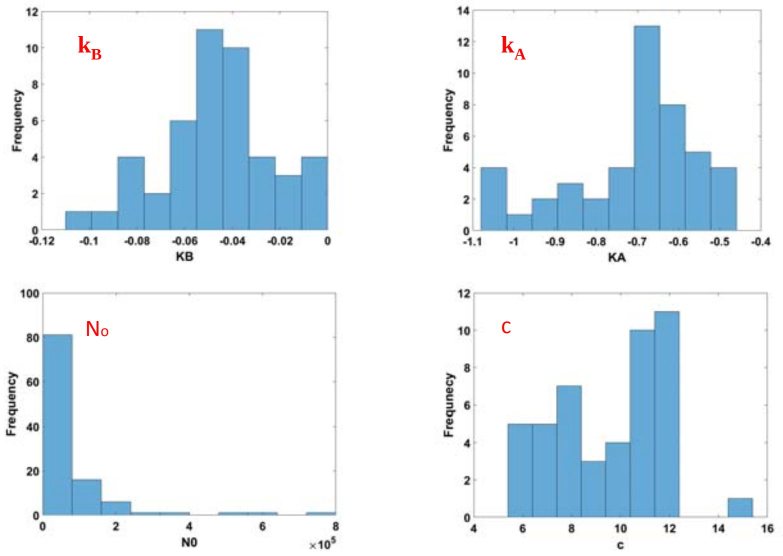
PPES MODEL

$$\frac{N(t)}{N_0} = \frac{A_0}{N_0} \cdot \exp(-k_A \cdot D) + \frac{B_0}{N_0} \cdot \exp(-k_B \cdot D)$$

$$B_0 = \exp(-k_A c).\ N_0$$

$$A_0 = N_0 - B_0$$

Input Parameters: Data Sets

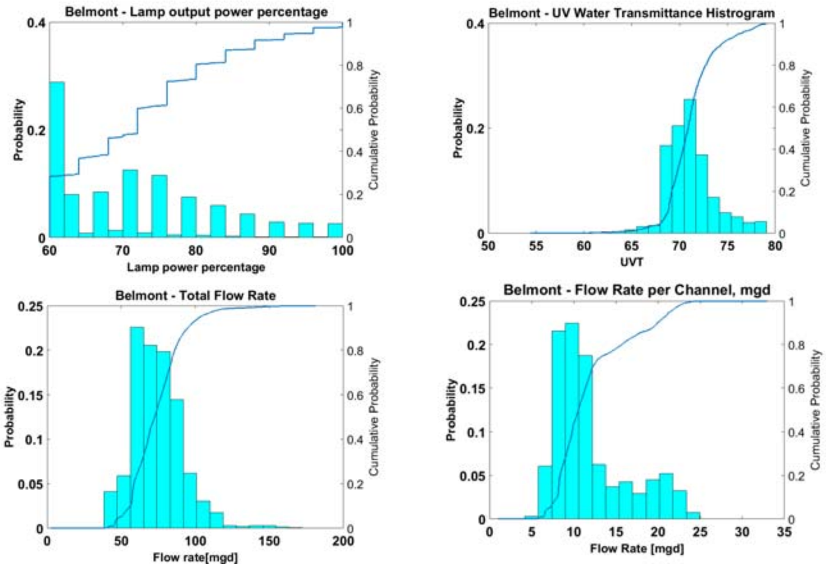


Pearson's Correlation Coefficients

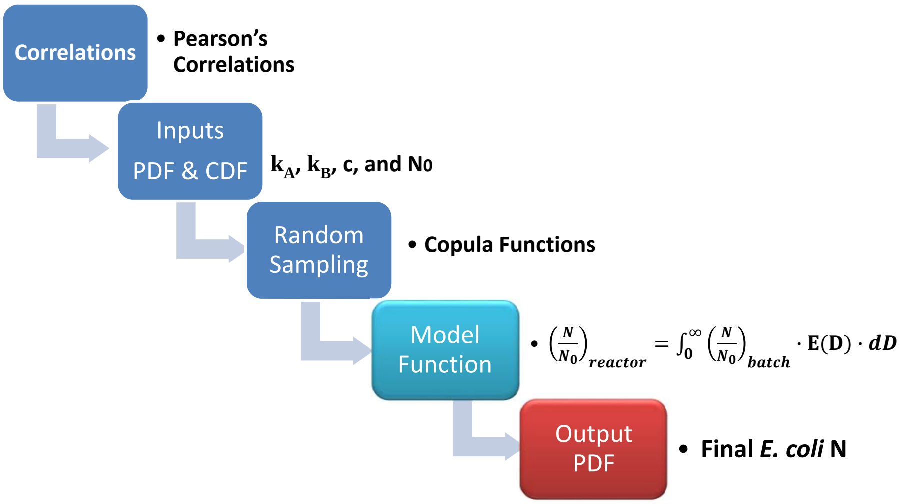
Pearson's correlation coefficients for PPES model parameters (k_A, k_B, A_0, B_0, c) and measured collimated beam experiment parameters (N_o, UVT). Number of observations was 46 (highlighted cells are the ones with strong correlation).

	K_A	K_B	c	A_0	B_0	N_o	UVT
K_A	1	0.144	0.773	-0.094	0.094	0.120	-0.029
K_B		1	0.279	0.128	-0.128	-0.230	0.152
c			1	0.471	-0.471	0.322	-0.143
A_0				1	-1	0.317	-0.08
B_0					1	-0.317	0.08
N_o						1	-0.349
UVT							1

Operating Conditions (2013)



Monte Carlo Simulations



Correlations

- **Pearson's Correlations**

Inputs PDF & CDF

k_A, k_B, c, and No

Random Sampling

- **Copula Functions**

Model Function

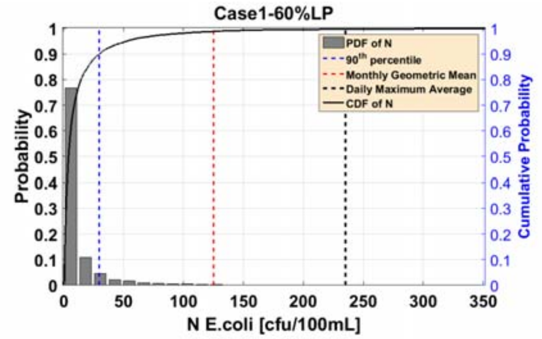
- $\left(\frac{N}{N_0}\right)_{reactor} = \int_0^\infty \left(\frac{N}{N_0}\right)_{batch} \cdot \mathbf{E(D)} \cdot dD$

Output PDF

- **Final *E. coli* N**

MC Simulations: Results

Belmont Case#	Flow (mgd)	NCh	NB/channel	Flow/Channel (mgd)	Velocity m/s	UVT %	LP* %
1	50	7	1	7.14	0.15	60	60
2	150	7	1	21.4	0.47	60	60
3	50	7	2	7.14	0.15	60	60
4	150	7	2	21.4	0.47	60	60



Values Randomly Selected From 46 Measurements:

- N_0
- Kinetic Parameters

Dose Distribution (Fixed) Based on Operating Conditions

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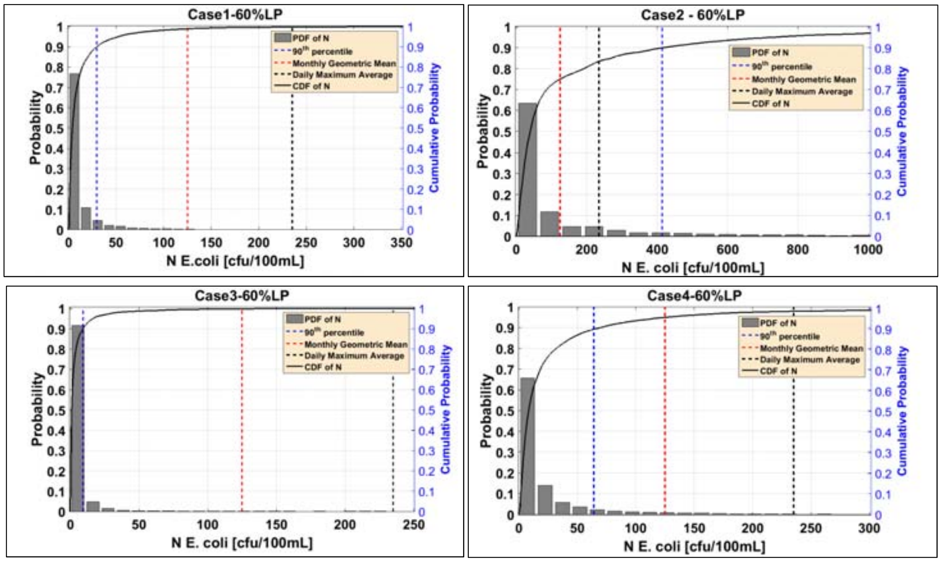
Monte Carlo Simulations: Results



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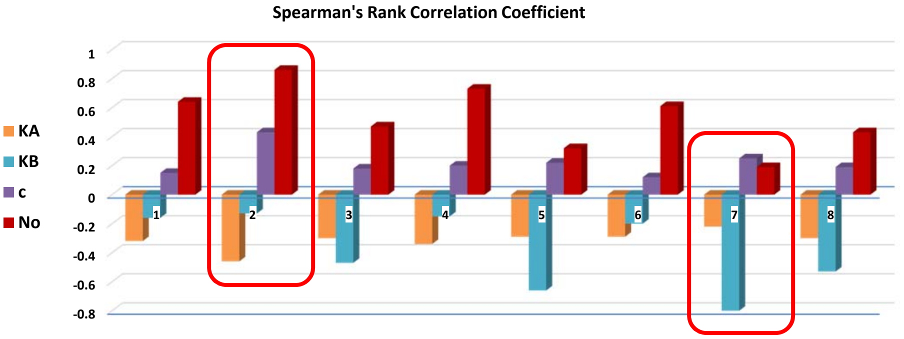
Sensitivity Analysis

Spearman’s rank correlation coefficients between output N, and the input dose-response parameters and N_o

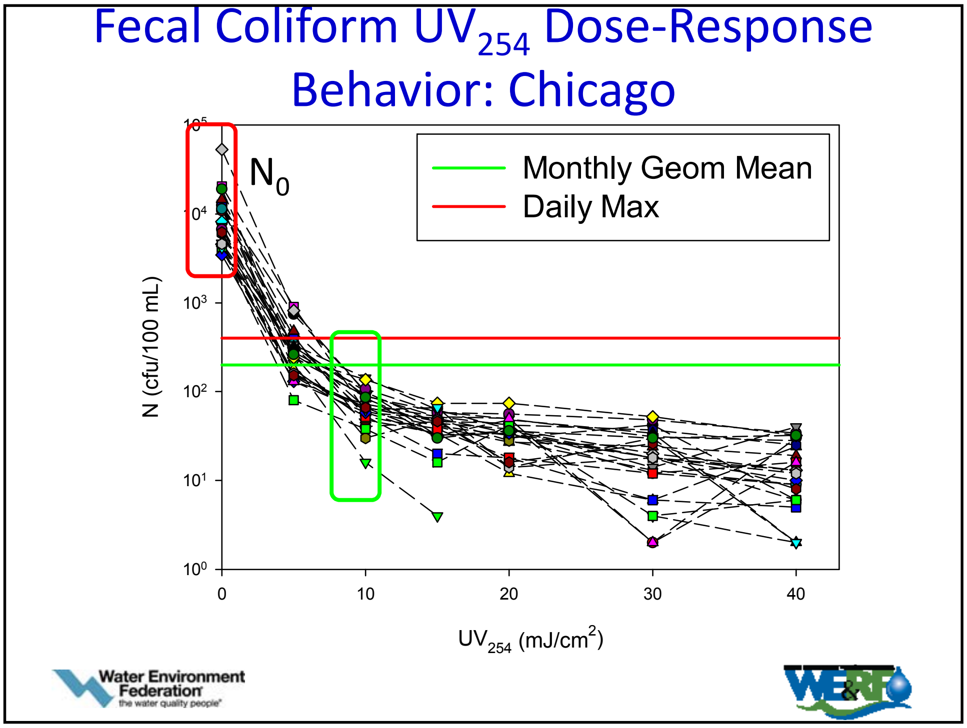
	N –case1	N-case2	N-case3	N-case4	N-case5	N-case6	N-case7	N-case8
Flow, mgd	50	150	50	150	50	150	50	150
UVT %	60	60	60	60	73	73	73	73
NB	1	1	2	2	1	1	2	2
Mean RED, mJ/cm^2	35	10.9	63	24	96	40	151	72



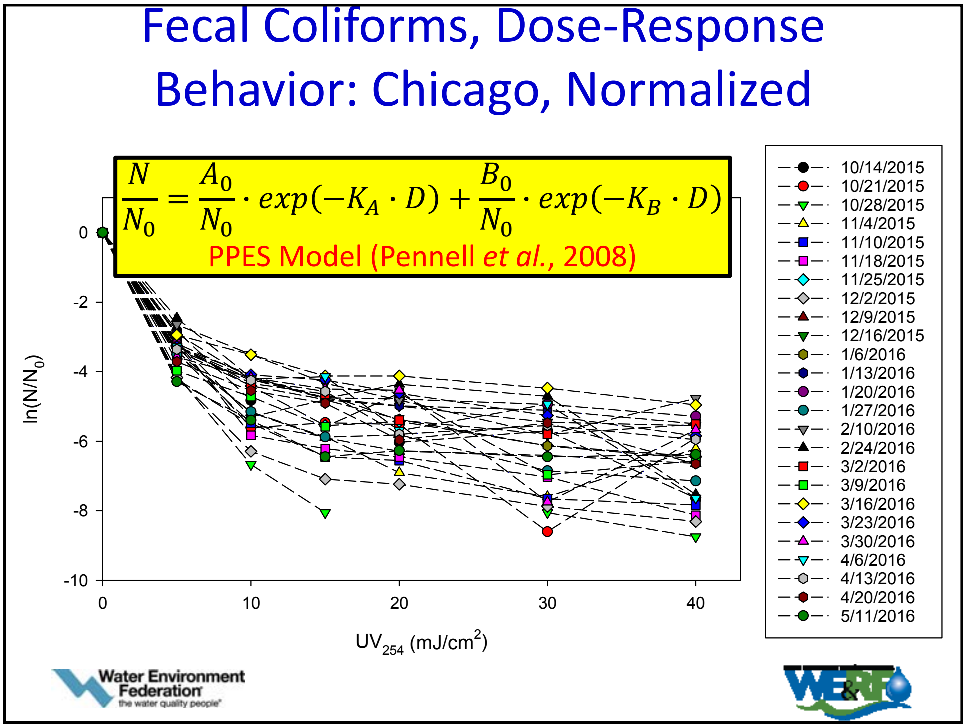
Application to Other Facilities

- Chicago (O’Brien WWTP)
  - Fecal coliforms
  - *E. coli*
  - Bacteriophage
- New York (26th Ward WWTP)
  - Fecal coliforms
  - *Enterococcus*
  - Bacteriophage

From: http://www.hazenandsawyer.com/news/innovative-glycerol-facility-named-acec-national-recognition-award-winner/



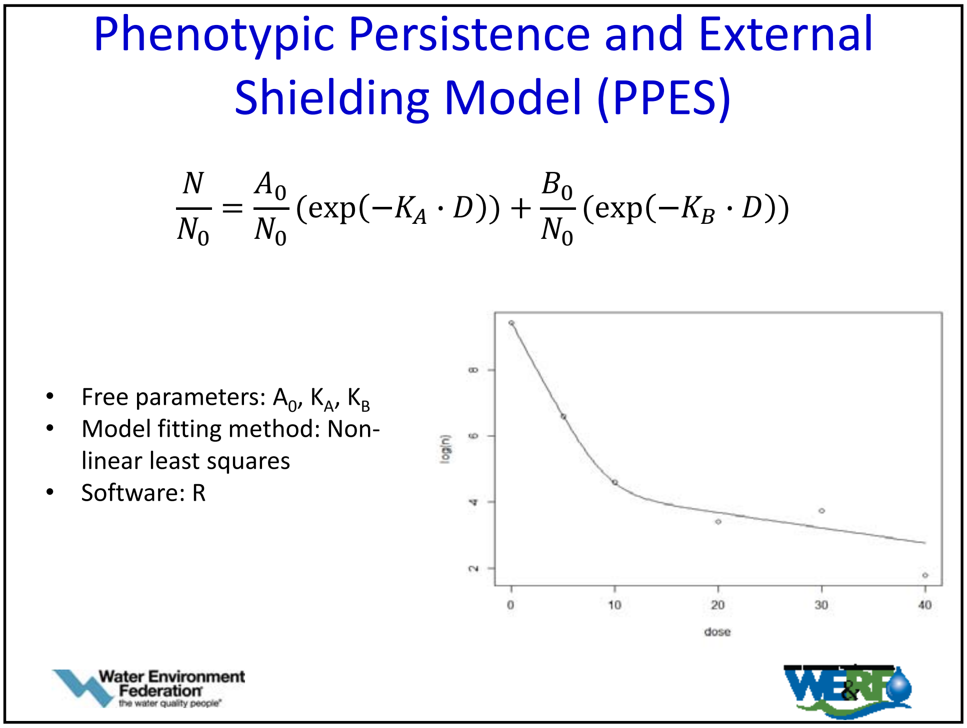
Fecal Coliform UV$_{254}$ Dose-Response Behavior: Chicago



Fecal Coliforms, Dose-Response Behavior: Chicago, Normalized

$$\frac{N}{N_0} = \frac{A_0}{N_0} \cdot exp(-K_A \cdot D) + \frac{B_0}{N_0} \cdot exp(-K_B \cdot D)$$

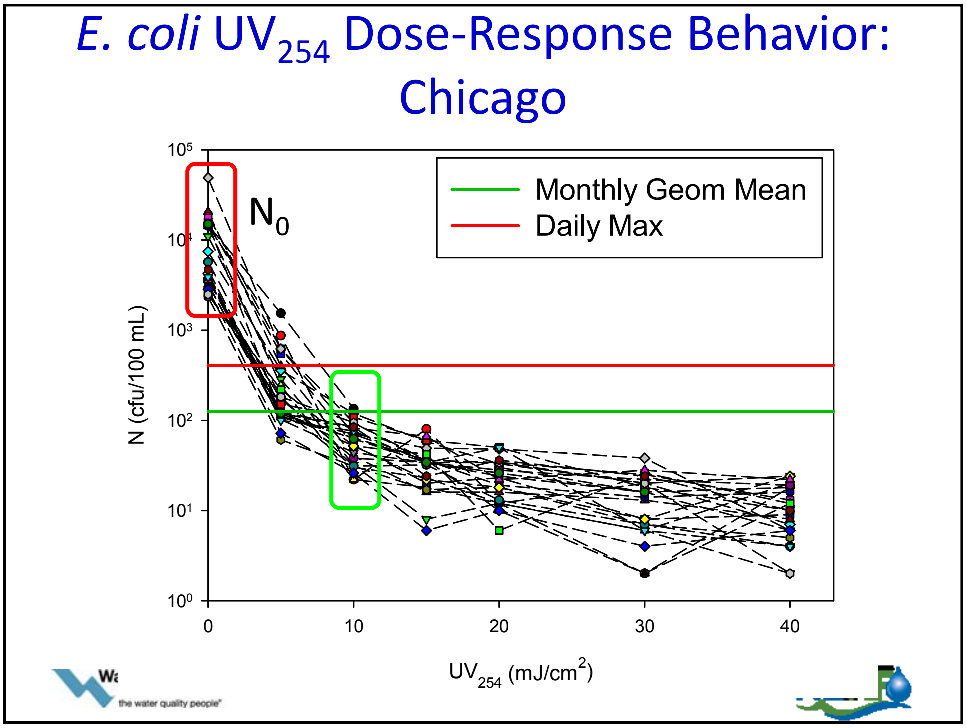
PPES Model (Pennell *et al.*, 2008)



Phenotypic Persistence and External Shielding Model (PPES)

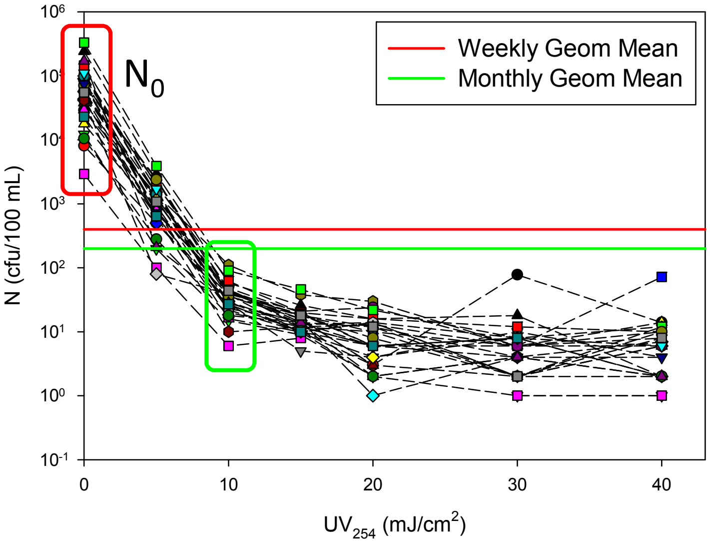
$$\frac{N}{N_0} = \frac{A_0}{N_0}(\exp(-K_A \cdot D)) + \frac{B_0}{N_0}(\exp(-K_B \cdot D))$$

- Free parameters: A_0, K_A, K_B
- Model fitting method: Non-linear least squares
- Software: R

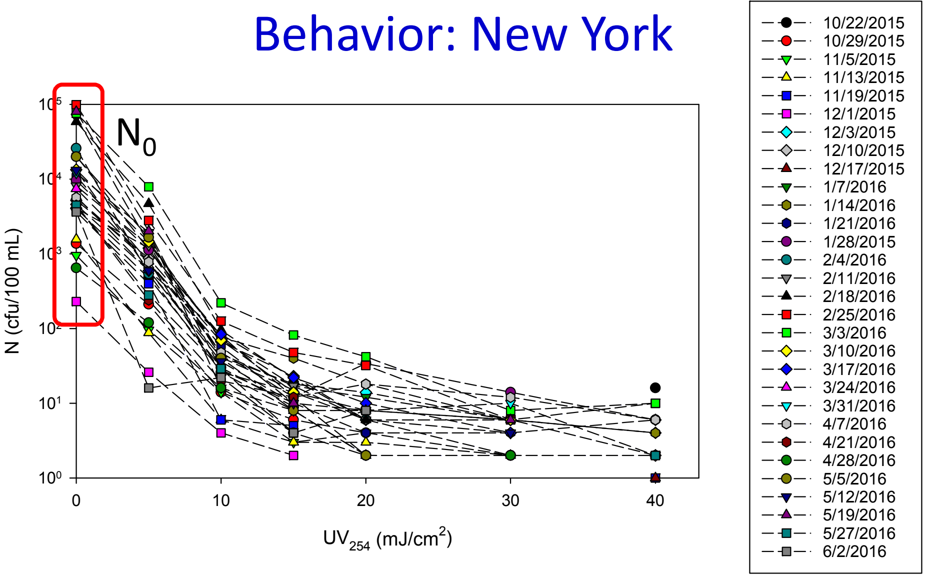


E. coli UV_{254} Dose-Response Behavior: Chicago

Fecal Coliforms UV$_{254}$ Dose-Response Behavior: New York

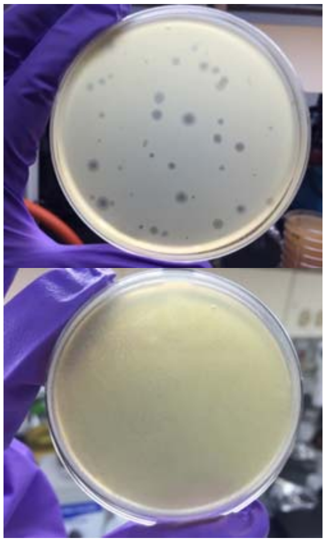


Enterococcus UV$_{254}$ Dose-Response Behavior: New York

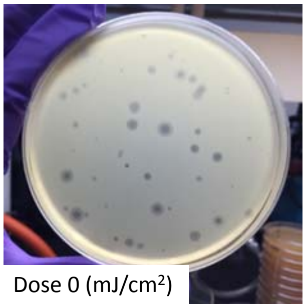


Phage Infectivity Assay – EPA 1602

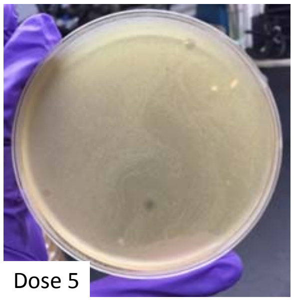
- Single-layer assay
- 100 mL water sample (0.22 µm filtered)
- Add $MgCl_2$, log-phase host, 100 mL 2X TSA
- Mix
- Pour into ten 10-cm diameter plates
- Incubate at 36±1℃ for 16-24 hr
- Host bacteria: *E. coli* (ATCC 15597)
- Detects sum of somatic and F-specific coliphages (Sobsey *et al*., 2004)

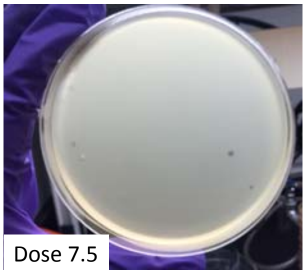


Phage UV_{254} Dose-Response Behavior


Dose 0 (mJ/cm^2)

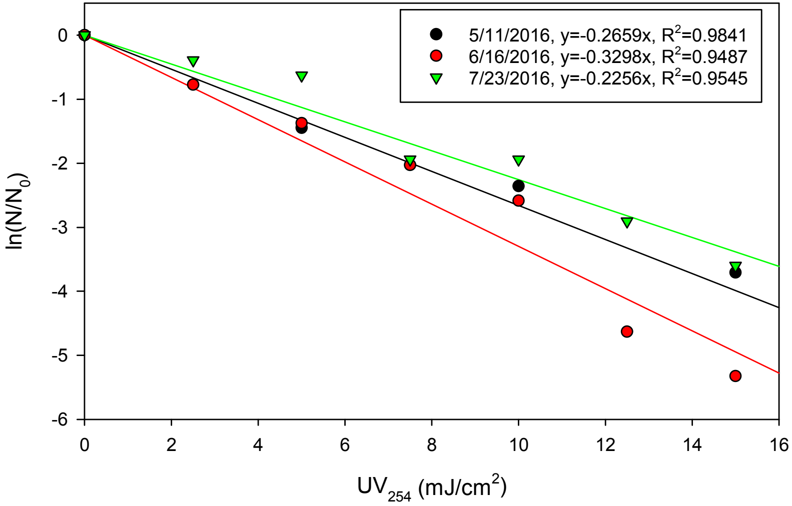

Dose 2.5


Dose 5

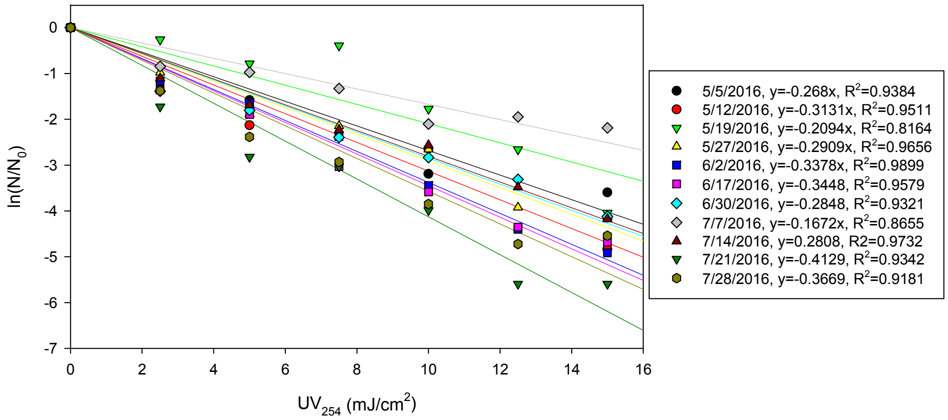

Dose 7.5


Dose 10

Phage UV_{254} Dose-Response Behavior Chicago



Phage UV_{254} Dose-Response Behavior New York



Summary/Conclusions

- Current design and validation approaches may lead to UV disinfection systems that are overdesigned
  - Doses required to achieve reliable compliance with bacterial discharge standards are modest
- Variability in dose-response parameters and N_o plays an important role in the variability in UV reactor performance
- Predictions of variability in process performance can be accounted for through numerical modeling (CFD-I)
- Stochastic modeling approach has potential to yield substantial process improvements in terms of the operating costs and reliability
- Method is applicable to any photochemical endpoint (*e.g.*, other microbial indicators, pathogens)

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Future Work

- Explore the influence of other variables in the system (TSS, precipitation, seasonal variations)
- Define an algorithm for selecting optimum operating conditions
- Extend analysis to other facilities
  - 26th Ward WWTP in New York
  - O'Brien WWTP in Chicago
  - HDR Technology Validation Center
  - Lagrangian Actinometry (Dose distribution)
- Application to other treatment systems, endpoints
  - Reuse
  - Alternative microbial targets (phage, viruses)

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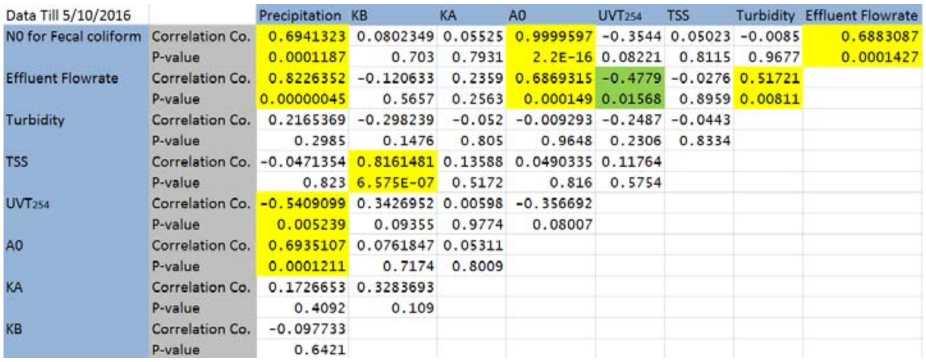
Correlation Analysis



Data Till 5/10/2016		Precipitation	KB	KA	A0	UVT$_{254}$	TSS	Turbidity	Effluent Flowrate
N0 for Fecal coliform	Correlation Co.	0.6941323	0.0802349	0.05525	0.9999597	-0.3544	0.05023	-0.0085	0.6883087
	P-value	0.0001187	0.703	0.7931	2.2E-16	0.08221	0.8115	0.9677	0.0001427
Effluent Flowrate	Correlation Co.	0.8226352	-0.120633	0.2359	0.6869315	-0.4779	-0.0276	0.51721	
	P-value	0.00000045	0.5657	0.2563	0.000149	0.01568	0.8959	0.00811	
Turbidity	Correlation Co.	0.2165369	-0.298239	-0.052	-0.009293	-0.2487	-0.0443		
	P-value	0.2985	0.1476	0.805	0.9648	0.2306	0.8334		
TSS	Correlation Co.	-0.0471354	0.8161481	0.13588	0.0490335	0.11764			
	P-value	0.823	6.575E-07	0.5172	0.816	0.5754			
UVT$_{254}$	Correlation Co.	-0.5409099	0.3426952	0.00598	-0.356692				
	P-value	0.005239	0.09355	0.9774	0.08007				
A0	Correlation Co.	0.6935107	0.0761847	0.05311					
	P-value	0.0001211	0.7174	0.8009					
KA	Correlation Co.	0.1726653	0.3283693						
	P-value	0.4092	0.109						
KB	Correlation Co.	-0.097733							
	P-value	0.6421							

Pearson Correlation Coefficients and *p*-values for Chicago Fecal coliform. PPES model parameters (K_A, K_B, A_0) and measured parameters including Q, N_0, UVT, TSS and precipitation. When *p*-value < 0.01, correlation between two parameters is defined as “strong” (in yellow), *p*-value between 0.05~0.01 as “moderate” (in green) (Stigler, 2008). Number of observations was 25.

Joe Jacangelo, Ph.D.,
Director of Research
MWH, now part of Stantec

Allegra da Silva, Ph.D.,
Supervising Engineer
MWH, now part of Stantec

Emerging Research on Peracetic Acid (PAA) for Disinfection

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303-291-2145

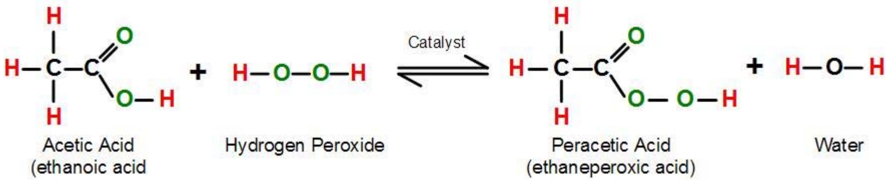
MWH now part of Stantec

Outline

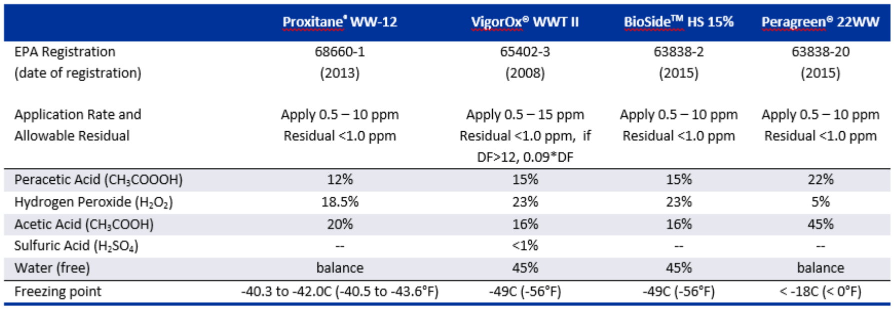
- Benefits of PAA
- Barriers to implementation of PAA
- Overview of WE&RF LIFT14T16 project
- EPA document on PAA
- EPA viral indicator criteria process
- Virus disinfection results – Joe

What is PAA

- Antimicrobial agent/biocide
- EPA-registered & FDA-approved
  - Beverage packaging sterilant
  - Red meat, poultry, fruit, vegetable wash – reduce pathogenic bacteria
  - Oil & gas applications
  - Commercial disinfectant, laundry applications
  - Wastewater disinfectant



EPA OPP registered product information



	Proxitane® WW-12	VigorOx® WWT II	BioSide™ HS 15%	Peragreen® 22WW
EPA Registration (date of registration)	68660-1 (2013)	65402-3 (2008)	63838-2 (2015)	63838-20 (2015)
Application Rate and Allowable Residual	Apply 0.5 – 10 ppm Residual <1.0 ppm	Apply 0.5 – 15 ppm Residual <1.0 ppm, if DF>12, 0.09*DF	Apply 0.5 – 10 ppm Residual <1.0 ppm	Apply 0.5 – 10 ppm Residual <1.0 ppm
Peracetic Acid (CH_3COOOH)	12%	15%	15%	22%
Hydrogen Peroxide (H_2O_2)	18.5%	23%	23%	5%
Acetic Acid (CH_3COOH)	20%	16%	16%	45%
Sulfuric Acid (H_2SO_4)	--	<1%	--	--
Water (free)	balance	45%	45%	balance
Freezing point	-40.3 to -42.0C (-40.5 to -43.6°F)	-49C (-56°F)	-49C (-56°F)	< -18C (< 0°F)

Benefits of PAA

- Strong oxidizer and may eliminate some constituents of emerging concern
- Does not produce halogenated disinfection by-products
- Low aquatic toxicity, relative to chlorine
- Quenching is generally not required
- No Risk Management Plan (RMP)
- Long shelf-life
- Low capital cost for chlorine retrofit

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WE&RF LIFT14T16 PAA research project

Research

- Document current state of knowledge and identify knowledge gaps
- Conduct testing and fill knowledge gaps
  - Bench, pilot, full-scale testing
  - *Peer-reviewed publications*
- Clarify regulatory barriers

PAA guidance document (the WEF book on PAA)

- WEF Disinfection and Public Health Committee approved a special publication
- WERF LIFT14T16 will inform the process

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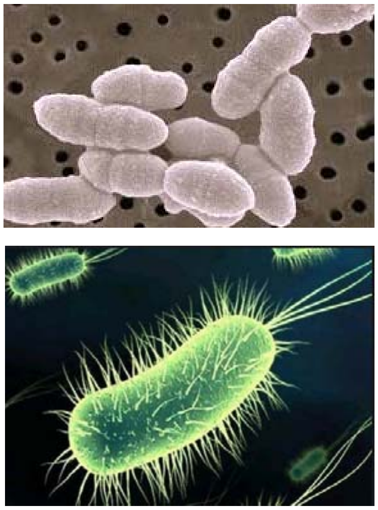
Compile the evidence

- PAA disinfection efficacy for:
  - Fecal and total coliforms
  - *E. coli* and Enterococcus
  - Bacteriophage or other viruses
- How WQ impacts PAA efficacy
- Impacts of PAA on disinfected effluent WQ
- Effect on aquatic life
- Ancillary benefits in wastewater treatment (i.e., controlling algae)
- What is needed to reduce regulatory ambiguity to permit facilities for PAA?



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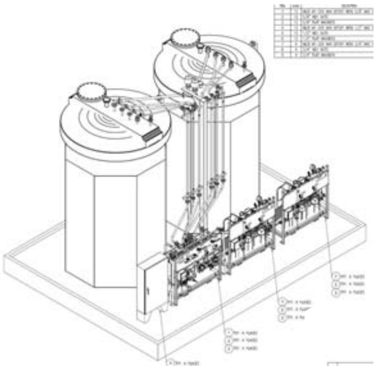
Value of the WERF study to utility partners

The WERF study will answer implementation, application and operations questions

- Will PAA work for us?
- Should we switch to PAA?
- How much will it cost?
- Can we reuse existing assets?
- Will we remain in compliance, at all times, and under all flow scenarios?
- What are the design requirements?
- Can PAA serve as a peak shaving tool?
- Can PAA provide process redundancy?



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Project Steering Committee

Upper Trinity Basin Water Quality Compact Project
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Technical Partners
CHEMetrics
Bio-Aquatic
UIUC
Xylem/ Wedeco
EnviroTech

Participating Utilities and Agencies
- Trinity River Authority, TX
- Fort Worth Water Dept., TX
- North Texas Municipal Water District, TX
- Dallas Water Utilities, TX
- Austin Water Utility, TX
- El Paso Water Utilities, TX
- City of Garland, TX
- Gulf Coast WDA, TX
- Metro Vancouver, BC, Canada
- Metro Wastewater Reclamation District, CO
- Village of Mundelein, IL
- City of Memphis, TN
- Water Environment Services, OR
- Gwinnett County DWR, GA
- North Hudson Sewerage Authority, NJ
- NYC DEP, NY
- Metro Water Services, TN
- Tullahoma Utilities Board, TN
- City of Danville, VA
- San Francisco PUC, CA
- East Bay MUD, CA
- East Bay Discharger Authority, CA
- Napa Sanitation District, CA
- Utilities Commission Greenville, KY

Project status and accomplishments to date

- Task 1 – Literature review (ongoing)
  - Manuscript submittal May 12
- Task 2 – Participating utility survey (ongoing)
- Task 3 – Regulatory coordination (ongoing)
- Task 4 – Demonstration testing (ongoing)
- Task 5 – Preparation of a guidance document (initiated)
- Task 6 – Project management (ongoing)

Demonstration testing

Participating Utility	Task 4 – Demonstration Testing		
	Bench Test	**Pilot -test**	**Full-scale test**
PAA Efficacy, Kinetics and Water Quality Impacts			
Denver MWRD	Norovirus/MS2	--	--
Dallas Water Utilities	--	Pilot reactor for E. coli/WET	--
North Texas MWD	E. coli inactivation	Pilot reactor for E. coli/WET	--
El Paso Water Utilities	E. coli inactivation	Pilot reactor for E. coli/WET	--
Austin Water Utilities	E. coli inactivation	Pilot reactor for E. coli/WET	--
Metro Vancouver Langley WWTP	--	UV+PAA for FC and E. coli	Cold weather; toxicity
City of Memphis Maxson and Stiles WWTPs	E. coli inactivation	E. coli inactivation & DBPs	E. coli at Stiles
NYCDEP, Hunts Point WWTP	--	FC, Enterococcus, CN	--
GCWDA, Washburn Tunnel	Bromide spiking study	Enterococcus	Enterococcus, DBPs
East Bay MUD	Bromide spiking study	--	--
San Francisco PUC	FC and Enterococcus inactivation	Pilot reactor for FC and Enterococcus/WET	--
Napa Sanitation District	FC and Enterococcus inactivation	Pilot reactor for FC and Enterococcus/WET	--
East Bay Dischargers Authority	FC inactivation	FC inactivation	FC inactivation
Metro Nashville Dry Creek WWTP	--	--	E. coli inactivation
Ft. Worth Village Creek WWTP	--	E. coli inactivation	--
Secondary Uses of PAA at WWTPs			
Gwinnett County FWH WRC	PPCP/EDC removal	UV+PAA	UV+PAA for FC/WET
TRA CRWS WWTP	--	E. coli/WET	Tertiary filter trial

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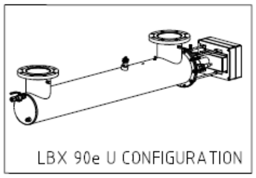
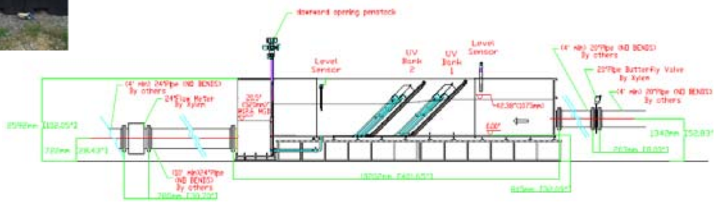
UV + PAA





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Task 5 – Preparation of a guidance document

WEF PAA special publication outline
Publication – by WEFTEC 2018

Chapter	Title	Pages	Tables	Figures	Lead Author
1	Introduction	15	2	1	Bob Bastian
2	Fundamentals	20	2	2	Philip Block
3	Mechanisms and Kinetics of Disinfection	30	3	4	Joe Jacangelo
4	PAA Monitoring (residuals, microbial indicators)	20	3	4	Janelle Amador
5	Toxicity and Calculation of Allowable Residuals	25	2	2	Joe Jacangelo
6	Contaminants of Concern (DBPS and CECs)	20	3	3	Philip Block
7	PAA Performance Testing	30	3	3	Denise Funk
8	Regulatory Coordination	20	2	2	Kati Bell
9	Design and Process Control	30	2	6	Alberto Garbini
10	Construction, Installation, Commissioning	30	2	4	Sarah Stewart
11	Operations and Compliance	20	2	5	Eric Kreuger
12	Economics of PAA	25	3	5	Cody Charnas
13	Innovations in PAA Applications	20	3	4	Varsha Wylie
14	Case Studies	40	17	20	Allegra da Silva
A	Appendix - PAA Implementation Roadmap	5	3	5	Kati Bell

EPA Coliphage process

- EPA is developing water quality criteria for viruses (coliphages), because:

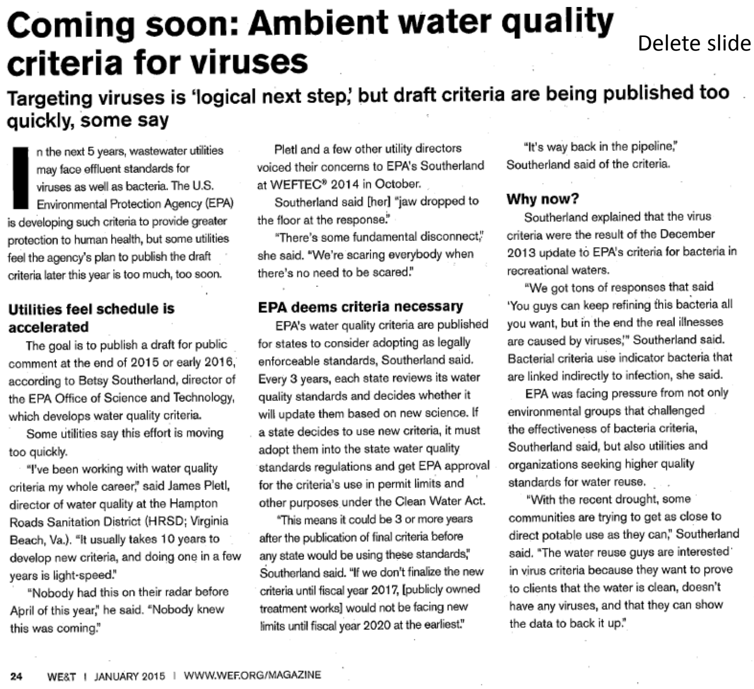
1. **Viruses** predominately cause the **illnesses** associated with primary contact in recreational waters impacted by human sources.
2. **Viruses** (noroviruses) are the most common cause of epidemic **gastroenteritis** following consumption of bivalve **shellfish** contaminated with fecal matter.
3. Interest in **potable reuse** – need to establish virus data in wastewater. Harmonize SDWA and CWA.

WHO/SEARO/Karen Reidy

http://carolinafishmarket.com/oysters-in-charlotte-specials/

EPA Timeline

Date	Milestone
April 2015	Review of *Coliphages as Possible Viral Indicators of Fecal Contamination for Ambient Water Quality*
March 2016	Coliphage Expert Workshop
2016	Listening sessions/webinars • Conferences (New Orleans/Chapel Hill) • States • Other stakeholders (industry/environmental groups) • Webinars
Summer 2016	Analytical method multi-laboratory validation; data collection
Late 2017	Draft Criteria released for public review



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Coming soon: Ambient water quality criteria for viruses

Targeting viruses is 'logical next step,' but draft criteria are being published too quickly, some say

In the next 5 years, wastewater utilities may face effluent standards for viruses as well as bacteria. The U.S. Environmental Protection Agency (EPA) is developing such criteria to provide greater protection to human health, but some utilities feel the agency's plan to publish the draft criteria later this year is too much, too soon.

Utilities feel schedule is accelerated

The goal is to publish a draft for public comment at the end of 2015 or early 2016, according to Betsy Southerland, director of the EPA Office of Science and Technology, which develops water quality criteria.

Some utilities say this effort is moving too quickly.

"I've been working with water quality criteria my whole career," said James Pletl, director of water quality at the Hampton Roads Sanitation District (HRSD; Virginia Beach, Va.). "It usually takes 10 years to develop new criteria, and doing one in a few years is light-speed."

"Nobody had this on their radar before April of this year," he said. "Nobody knew this was coming."

Pletl and a few other utility directors voiced their concerns to EPA's Southerland at WEFTEC® 2014 in October.

Southerland said [her] "jaw dropped to the floor at the response."

"There's some fundamental disconnect," she said. "We're scaring everybody when there's no need to be scared."

EPA deems criteria necessary

EPA's water quality criteria are published for states to consider adopting as legally enforceable standards, Southerland said. Every 3 years, each state reviews its water quality standards and decides whether it will update them based on new science. If a state decides to use new criteria, it must adopt them into the state water quality standards regulations and get EPA approval for the criteria's use in permit limits and other purposes under the Clean Water Act.

"This means it could be 3 or more years after the publication of final criteria before any state would be using these standards," Southerland said. "If we don't finalize the new criteria until fiscal year 2017, [publicly owned treatment works] would not be facing new limits until fiscal year 2020 at the earliest."

"It's way back in the pipeline," Southerland said of the criteria.

Why now?

Southerland explained that the virus criteria were the result of the December 2013 update to EPA's criteria for bacteria in recreational waters.

"We got tons of responses that said 'You guys can keep refining this bacteria all you want, but in the end the real illnesses are caused by viruses,'" Southerland said. Bacterial criteria use indicator bacteria that are linked indirectly to infection, she said.

EPA was facing pressure from not only environmental groups that challenged the effectiveness of bacteria criteria, Southerland said, but also utilities and organizations seeking higher quality standards for water reuse.

"With the recent drought, some communities are trying to get as close to direct potable use as they can," Southerland said. "The water reuse guys are interested in virus criteria because they want to prove to clients that the water is clean, doesn't have any viruses, and that they can show the data to back it up."

24 WE&T | JANUARY 2015 | WWW.WEF.ORG/MAGAZINE

Permit pipeline

Date	Milestone
Late 2017	Draft Criteria released for public review
2017 + **x** years	Final Criteria published
2017 + **x** + **y** years	Potential for NPDES permits with viral limits

MS2 and MNV Infectivity Reduction in in Secondary Effluent: Efficacy of PAA, NH_2Cl, UV, and PAA-UV Combined Treatment

Team:

Nate Dunkin, Doctoral Candidate

Shih-Chi Weng, JHU/MWH-Stantec Alliance Post-Doctoral Fellow

Kellogg Schwab, Director, Johns Hopkins University Water Institute

Joseph G. Jacangelo, Director of Research, MWH/Stantec; Johns Hopkins University

Jim McQuarrie, Metro Wastewater Reclamation District, Denver CO

Kati Bell, MWH, now part of Stantec

Allegra da Silva, MWH, now part of Stantec

The Importance of Norovirus

- Acute gastroenteritis is 2nd greatest global health burden of all infectious diseases
  - 89.5 million DALYs & 1.45 million deaths per year [1]
- Norovirus (NoV) is the number one global cause of gastroenteritis across all age groups
  - Causative agent in 60% of all foodborne illnesses in U.S. & 95% of all non-bacterial foodborne illnesses [2]

The disability-adjusted life year (**DALY**) is a measure of overall disease burden, expressed as the number of years lost due to ill-health, disability or early death.

[1] Murray, C.J., et al. (2012) Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. Lancet 380(9859), 2197-2223.

[2] Dicaprio, E., Ma, Y., Purgianto, A., Hughes, J. and Li, J. (2012) Internalization and dissemination of human norovirus and animal caliciviruses in hydroponically grown romaine lettuce. Appl Environ Microbiol 78(17), 6143-6152.

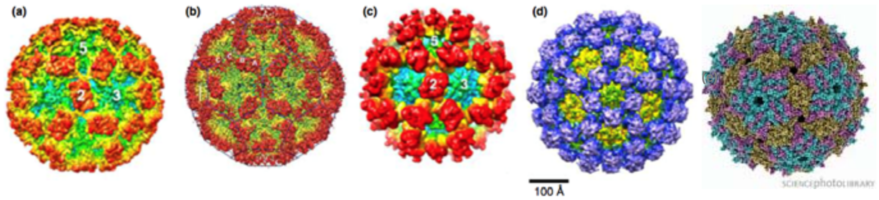
Pathogens Causing Highest Level of Illness Annually in the United States

Rank	Pathogen	Type	Episodes
1	Norovirus	Virus	20,796,079
2	*Giardia intestinalis*	Protozoan parasite	1,121,864
3	*Salmonella* species	Bacterium	1,095079
4	*Campylobacter* species	Bacterium	1,058387
5	*Clostridium perfringens*	Bacterium	966,120
6	*Cryptosporidium* species	Protozoan parasite	678,828
7	*Shigella* species	Bacterium	421,048
8	*Staphylococcus auereus*	Bacterium	241,188

Adapted from Texas Water Development Board Final Report on Direct Potable Reuse

Human Norovirus Surrogates

- No readily available cell culture model exists for human NoV
  - Thus, surrogate organisms are used for field and laboratory studies
- MS2 is a widely used bacteriophage
- Murine NoV (MNV-1)



(a) NoV G.II [3] (b) Tulane Virus [4] (c) MNV-1 [3] NoV VLP [5] (e) MS2

Experimental and Data Analysis Overview

- Organisms and Disinfectants
  - MNV, MS2
  - PAA, NH2Cl, UV, PAA+UV treatment
- Waters
  - Secondary Municipal WW Effluent and phosphate buffer
- Data Analysis
  - Modeling
  - CT Values

Wastewater quality characteristics

Metro Water Reclamation District, Denver, CO

Water quality parameters for secondary wastewater effluent

	Parameter	Unit	Measurement
	pH	-	7.1
	Conductivity	μS/cm	924
	Turbidity	NTU	4.07
	UV_{254} absorbance	Abs	0.17
	COD	mg/L	80.7
	TOC	mg/L	10.6
	Alkalinity	mg/L as $CaCO_3$	118
Anions	Chloride	mg/L	117
	Nitrate	mg/L	18.2
	Sulfate	mg/L	125
	Phosphate	mg/L	1.67

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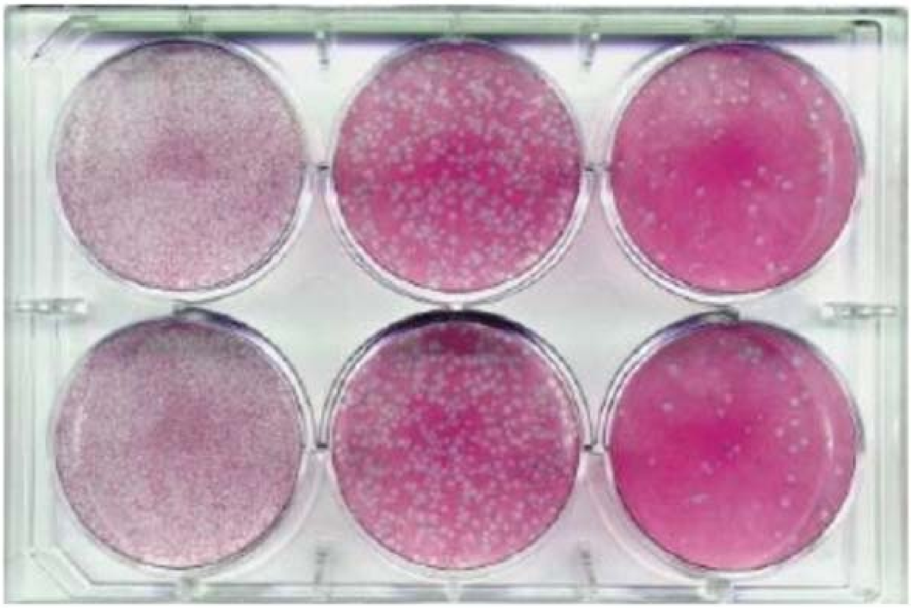
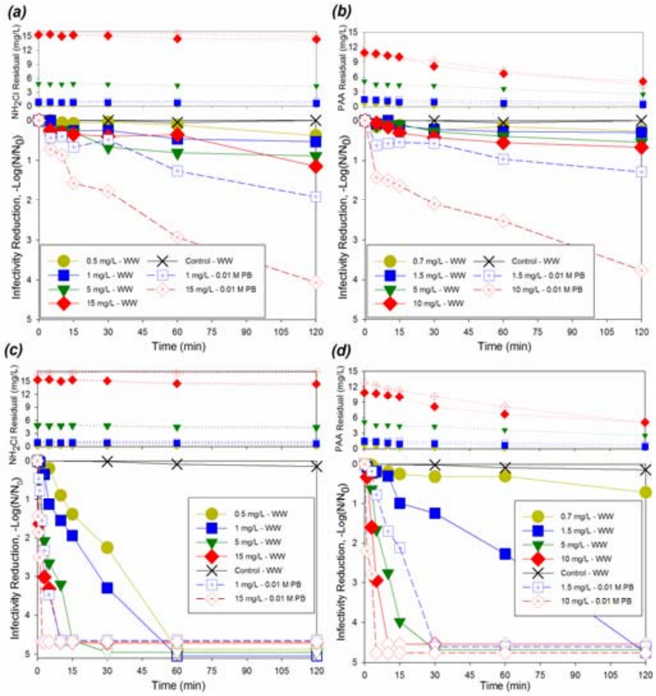


Infectivity Reduction by Monochloramine and PAA



Temporal profiles for reduction of viral infectivity in secondary effluent wastewater (WW) and 0.01 M phosphate buffer (PB) for *(a)* MS2 by NH_2Cl, *(b)* MS2 by PAA, *(c)* MNV by NH_2Cl, and *(d)* MNV by PAA. Hollow symbols with no shading or crosses represent viral concentrations below the sensitivity limit of the assay.

Dunkin et al., *Environ. Sci Technol.* 2017, 51, 2972-2981.

Summary of Kinetic Inactivation Models Considering Disinfectant Demand.

Model	Log(N/ N$_0$) =
Chick-Watson[54] (n = 1)	$-\frac{k}{\mathrm{k}'}(C_0 - C_t)$
Chick-Watson[54]	$-\frac{k}{\mathrm{k}'n}(C_0^n - C_t^n)$
IGF Hom[55]	$-\frac{kmC_0^n}{(\mathrm{k}'n)^m} \cdot \gamma(m, nk't)$
Power Law[56]	$-\frac{\log\left[1 + (x-1) \cdot \frac{k}{\mathrm{k}'n}(C_0^n - C_t^n) \cdot N_0^{x-1}\right]}{(x-1)}$
Hom-Power Law[57]	$-\frac{\log\left[1 + (x-1) \cdot \frac{-kmC_0^n}{(\mathrm{k}'n)^m} \cdot \gamma(m, nk't) \cdot N_0^{x-1}\right]}{(x-1)}$

IGF: Incomplete gamma function, $\gamma(\alpha,x)$

***Table 1*. Summary of Best Fit Model Parameters for MS2 and MNV Infectivity Reduction by PAA and NH_2Cl in Municipal Wastewater (WW) and 0.01 M Phosphate Buffer (PB).**

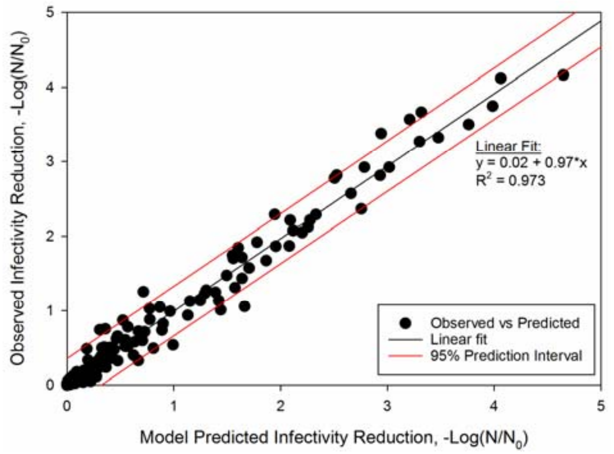
Virus	Matrix	Disinfectant	Best Model	k'	k	n	m	x	σ	SSE
MS2	WW	NH_2Cl	IGF Hom	0.0006	0.024	0.371	0.592	-	0.162	0.717
MS2	WW	PAA	IGF Hom	0.0071	0.018	0.442	0.578	-	0.061	0.099
MNV	WW	NH_2Cl	Hom-Power Law	0.0006	0.001	1.417	1.786	1.523	0.199	0.913
MNV	WW	PAA	IGF Hom	0.0071	0.012	1.554	1.208	-	0.250	1.638
MS2	0.01 M PB	NH_2Cl	IGF Hom	0.0004	0.128	0.303	0.553	-	0.153	0.304
MS2	0.01 M PB	PAA	IGF Hom	0.0061	0.169	0.550	0.387	-	0.167	0.362
MNV	0.01 M PB	NH_2Cl	IGF Hom	0.0004	0.979	0.370	0.730	-	0.219	0.430
MNV	0.01 M PB	PAA	Power Law	0.0061	0.020	0.620	-	1.363	0.149	0.179

σ: standard deviation of the residual errors

SSE: sum of squares of the errors

Dunkin et al., *Environ. Sci Technol.* 2017, 51, 2972-2981.

Observed virus infectivity reduction versus model predicted virus infectivity reduction for all viral experimental data, excluding non-detects.



Dunkin et al., *Environ. Sci Technol.* 2017, 51, 2972-2981.

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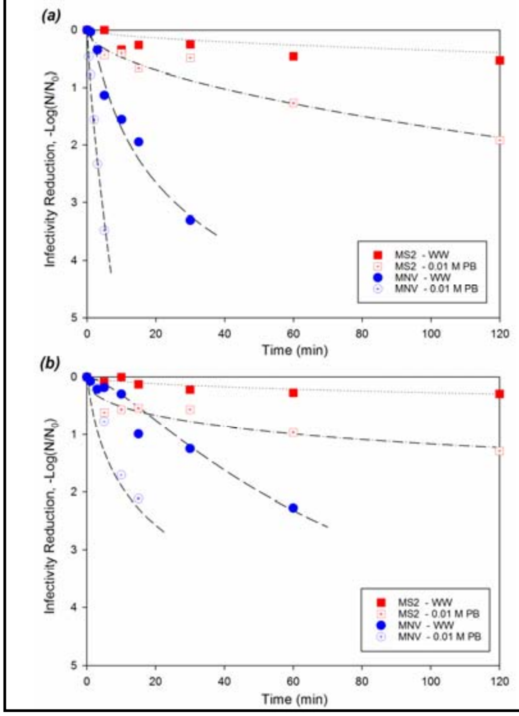
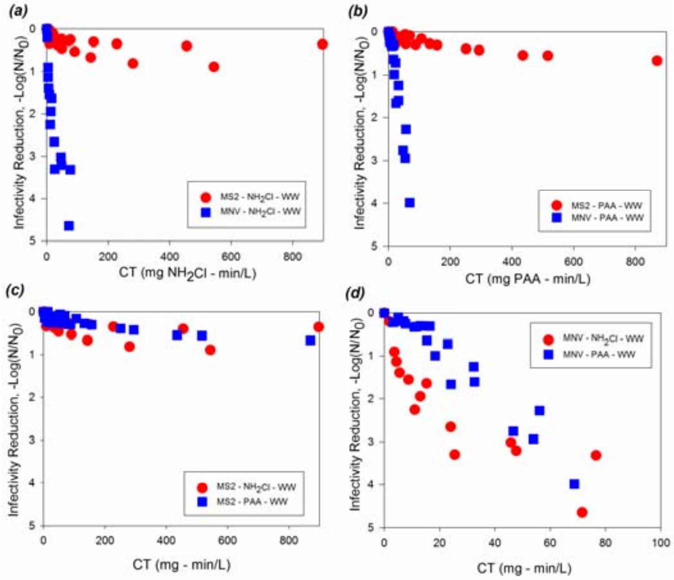


Examples of best model fits shown for MS2 and MNV infectivity reduction in secondary effluent wastewater (WW) and 0.01 M phosphate buffer (PB) *by (a)* 1 mg/L NH_2Cl and *(b)* 1.5 mg/L PAA.

Dunkin et al., *Environ. Sci Technol.* 2017, 51, 2972-2981.



(a) Comparison of NH_2Cl CT values for infectivity reduction of MS2 bacteriophage and MNV in secondary effluent wastewater (WW), (b) Comparison of PAA CT values for infectivity reduction of MS2 bacteriophage and MNV in WW, (c) Comparison of NH_2Cl and PAA CT values for infectivity reduction of MS2 in WW, and (d) Comparison of NH_2Cl and PAA CT values for infectivity reduction of MNV in WW (note different CT scale).

Dunkin et al., *Environ. Sci Technol.* 2017, 51, 2972-2981.

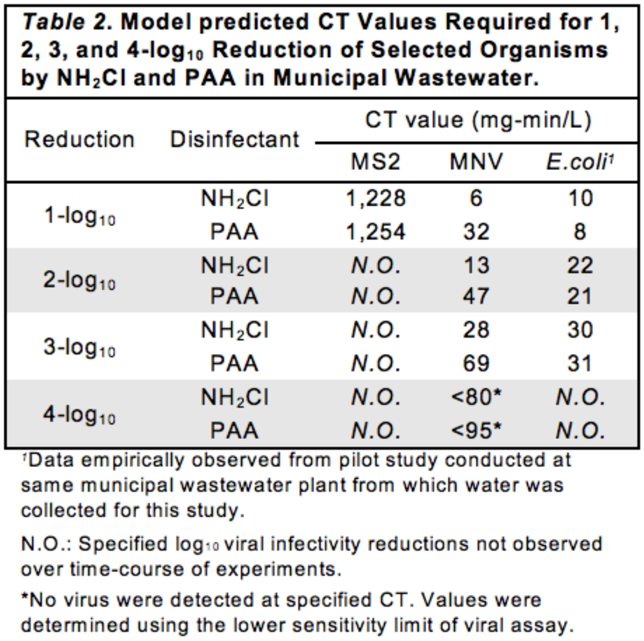


***Table* 2. Model predicted CT Values Required for 1, 2, 3, and 4-log$_{10}$ Reduction of Selected Organisms by NH_2Cl and PAA in Municipal Wastewater.**

Reduction	Disinfectant	CT value (mg-min/L)		
		MS2	MNV	*E.coli*[1]
1-log$_{10}$	NH_2Cl	1,228	6	10
	PAA	1,254	32	8
2-log$_{10}$	NH_2Cl	*N.O.*	13	22
	PAA	*N.O.*	47	21
3-log$_{10}$	NH_2Cl	*N.O.*	28	30
	PAA	*N.O.*	69	31
4-log$_{10}$	NH_2Cl	*N.O.*	<80*	*N.O.*
	PAA	*N.O.*	<95*	*N.O.*

[1] Data empirically observed from pilot study conducted at same municipal wastewater plant from which water was collected for this study.

N.O.: Specified log$_{10}$ viral infectivity reductions not observed over time-course of experiments.

*No virus were detected at specified CT. Values were determined using the lower sensitivity limit of viral assay.

Dunkin et al., *Environ. Sci Technol.* 2017, 51, 2972-2981.

Virus Disinfection Summary

- Wastewater treatment plant disinfection practices using informed by MS2 inactivation data will likely be protective for public health but is also overly conservative if MNV is the target organism.
- When employing NH2Cl or PAA, *E. coli* appears to be a reasonable indicator for norovirus.
- For NH2Cl and PAA, equivalent CT values in phosphate buffer resulted in greater viral reduction which indicate that viral inactivation data in laboratory grade water is not generalizable to municipal wastewater applications.
- There was no synergy observed between PAA and UV at doses commonly employed by wastewater treatment plants. However, for *E. coli* compliance, the capital and operational costs may be reduced by the additive effects of the two disinfection methods.

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Ongoing Work on Human Norovirus

- Impact of murine and human norovirus GI and GII harvesting and preparation methods on disinfection studies.
- Impact of UV on human norovirus GI and GII RNA.

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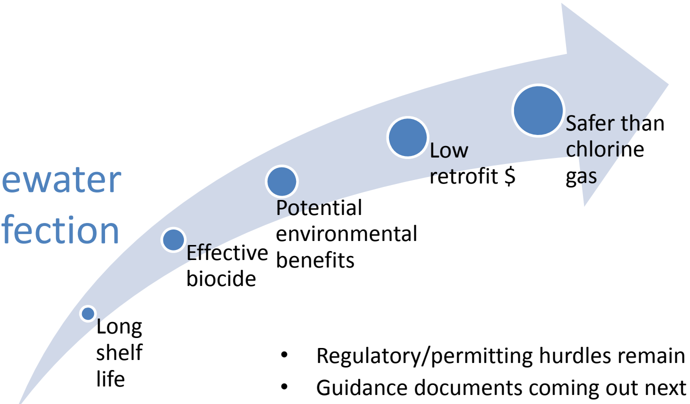
Conclusion: PAA is worthy of careful consideration

For wastewater disinfection



- Regulatory/permitting hurdles remain
- Guidance documents coming out next year (WEF, EPA)

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Chief Engineer
Oklahoma Department of
Environmental Quality

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How Oklahoma DEQ Evaluates and Implements Emerging Disinfection Technologies

Gregory Carr, P.E., WQD Chief Engineer
Rocky Chen, P.E., WQD Engineering Manager

Oklahoma Dept of Environmental Quality WQD's Construction Permitting Section

- Reviews engineering reports for PWS, municipal wastewater, and water reuse infrastructure projects
- Reviews permit applications for construction permits
  - Water treatment & distribution infrastructure
  - Wastewater collection & treatment infrastructure
  - Reclaimed water ("reuse") treatment & distribution
- Staff: Engineering Manager (1), Plan review engineers (7), Administrative Assistant (1)

Oklahoma State Statutes (water)

- Title 27A, “Environment & Natural Resources”
  - Section 2-6-304 - Public Water Supply (Permit Required)

- A. Except as otherwise provided for in this section, **no person shall supply water, or do any construction work** of any nature for supplying water, to the public from or by a **public water supply system by** means of any waterworks **without a written permit to construct issued by the Executive Director of the Department of Environmental Quality.**

Oklahoma State Statutes (sewer)

- Title 27A, “Environment & Natural Resources”
  - Section 2-6-401 – Sewer Systems (Permit Required)

- A. **No person shall construct** or let a contract for any construction work of any nature for a **municipal treatment works**, nonindustrial wastewater treatment system, sanitary sewer system or other sewage treatment works, or for any extension thereof, or make any change in the manner of nonindustrial wastewater treatment or make any change in the treatment, storage, use or disposal of sewage sludge **without a permit issued by the Executive Director**.

Oklahoma Administrative Code

- OAC 252:626
  - PUBLIC WATER SUPPLY CONSTRUCTION STANDARDS
- OAC 252:627
  - OPERATION AND MAINTENANCE OF WATER REUSE SYSTEMS
- OAC 252:656
  - WATER POLLUTION CONTROL FACILITY CONSTRUCTION STANDARDS

Variances from Construction Standards

- 252:656-3-7. Variances from construction standards
  - "A variance from the standards in this Chapter may be allowed, upon request of the applicant, if the DEQ finds the variance will not increase the likelihood of a system failure. No variance will be allowed unless it is noted on the construction permit."

Variances from Construction Standards

- "The consulting engineer shall justify the requested variance by submitting data showing the proposed processes or equipment will equal or exceed the performance of processes or equipment known to perform the same function according to the standards contained in this Chapter."
- "The DEQ may require that pilot studies and appropriate testing be conducted and evaluations be made under the supervision of a competent process engineer other than one employed by the manufacturer or developer"

DEQ Guidance Documents

- To change Oklahoma State Statutes or Oklahoma Administrative Codes, a bill must be submitted to the Oklahoma Legislature which then must be passed into law by a majority vote of the Oklahoma House of Representatives AND the Oklahoma Senate, and then signed by the Governor . (this is the short version)
- DEQ Guidance Documents were created to provide technical guidance for certain types of projects, but aren't State Statute or Agency Rule (for ease of updates/modifications).

DEQ Guidance Documents for Water Reuse Projects

- The following Guidance Documents were created for water reuse projects:
  - Pilot Study for Treatment System Design
  - Peracetic Acid as a Disinfectant for Wastewater
  - Advanced Oxidation Process (AOP) for the Oxidation of Microcontaminants
  - Membrane Bioreactor (MBR)

DEQ Guidance Documents

Pilot Study for Treatment Plant Design

- Clearly state the goal of the pilot study
- Assessed measurables (effluent concentrations, removal efficiencies, O&M indicator parameters)
- Pilot Study Duration (12 months, or provide justification for less than 12 months)
- DEQ notification: the utility or its engineer must notify DEQ at least 60 calendar days prior to the start of the study.
- DEQ approval: the protocol must be approved by DEQ prior to the start of the pilot study
- Pilot Study Report: must be prepared and sealed by a professional engineer licensed in the State of Oklahoma


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DEQ Guidance Documents
PAA as a Disinfectant for Wastewater

(courtesy of Solvay)

- Perform pilot study (see previous slide for guidance info)
- Submit engineering report for DEQ approval
- Submit plans & specification for construction of PAA treatment process, with special emphasis on:
  - Storage containers
  - Space for 30-day supply
  - Secondary containment
  - Acid-proof floor
  - Temperature control of storage area
  - Leak detection
  - Standby equipment
  - Alarm system
  - Protective safety equipment

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DEQ Guidance Documents
AOP for Oxidation of Microcontaminants

- Perform pilot study (see previous slide for guidance info), with special emphasis on:
  - Water quality monitoring parameters (UVT, DOC, etc)
  - Dose-response Process Performance (applied UV, chemical dosage, etc)
  - Economic performance (electricity, consumables, O&M)
- Submit engineering report for DEQ approval
- Submit plans & specification for construction of the AOP treatment process
- Perform full-scale challenge testing (minimum 10 months)

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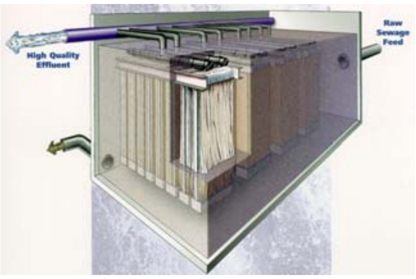
DEQ Guidance Documents

Membrane Bioreactor (MBR)



Courtesy of GE

- Perform pilot study (see previous slide for guidance info) to determine design parameters
- Engineering Reports and Plans & Spec's shall account for the following:
  - Pre-treatment (fine screens; CIP; redundancy)
  - Biological Treatment
  - Sludge Recycling & Wasting
  - Redundancy

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Summary

- Engineering Report approval and Construction Permit approval are required prior to construction of treatment processes
- A pilot study and/or variance request may be required prior to submittal of ER and P&S
- Contact DEQ to discuss the project prior to pilot study, ER, or P&S submittal.

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Questions or Comments?

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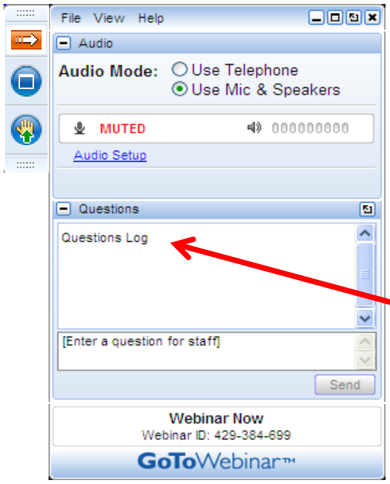

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Thank You

Questions