Evaluation of Microbiological Risks Associated with Direct Potable Reuse (DPR)

STAR Grant Kickoff Meeting
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Outline

- Objectives
- QMRA Methods
- Results
  - Base Analyses
  - Sensitivity Analyses
- Conclusions

Objectives

Conduct a microbial risk evaluation to understand the potential public health implications of various DPR options

- conduct a literature review of ranges of reference pathogens in raw sewage and of their removal in various unit treatment processes
- develop a risk assessment approach that can be used by managers to assess the risk associated with a proposed DPR treatment project

Background

- Currently there are no federal recommendations for direct potable reuse
- DPR treated (or "finished") water could be:
  - introduced directly into a potable water supply distribution system *OR*
  - circulated into a conventional drinking water treatment facility before entering distribution system
- Pathogen control critically important due to immediate health effects

Overview of Analysis

Evaluate four DPR treatment trains (consistent with WaterReuse Research, 2015)

- with and without reverse osmosis
- with and without circulation through drinking water treatment
- with high and low UV dose applications (illustrative of operational/design choices)

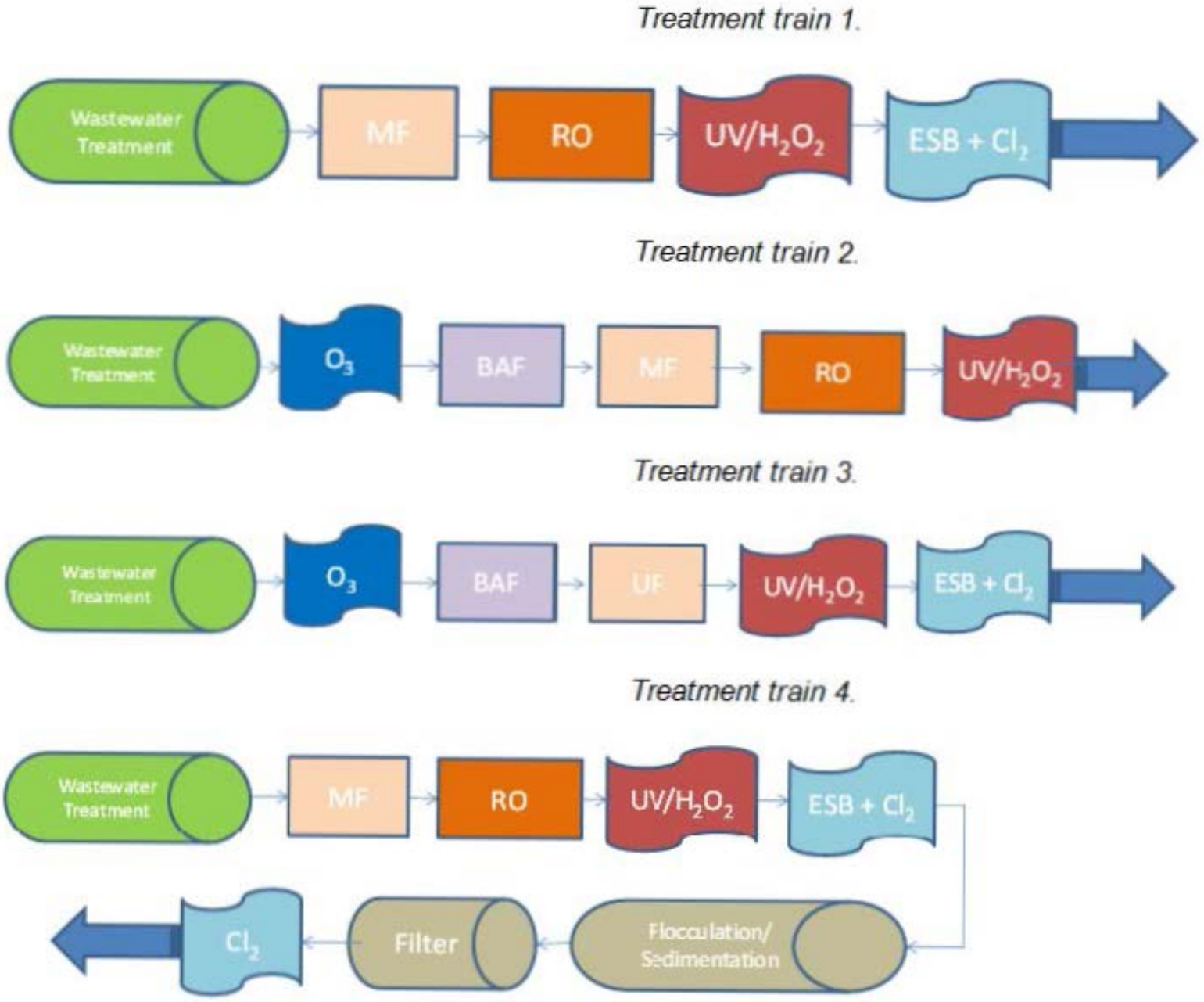


Figure 1. DPR Treatment Trains Evaluated

Methods (1)

- Use previously published statistical methods coupled with QMRA to estimate infection via ingestion of water from DPR treatment trains
- Assume ingestion of “finished” water for each scenario
- Reference Pathogens
  - Adenovirus
  - Norovirus
  - Cryptosporidium
  - Giardia
  - *Salmonella enterica*
  - *Campylobacter spp.*
  - representative of other pathogens potentially of concern from the waterborne exposure route
  - represent major portion of illnesses from known pathogens in the US
  - published dose-response relationships

Methods (2)

- Conduct literature review to characterize:
  - distribution of each reference pathogen in raw sewage
  - reduction of each reference pathogen across each of the individual unit treatment processes
- Use Monte Carlo numerical simulation
  - cumulative daily risk estimates based on daily risk estimates for each of the reference pathogens for each treatment train
  - distribution of estimated annual risks for each treatment train
- Conduct sensitivity analysis to evaluate impact of alternative dose-response models and treatment approaches

Risk Calculations (1)

- Pathogen specific daily risks computed through QRMA using:
  - estimated daily density of each pathogen in DPR finished water
    - wastewater pathogen densities (randomly selected)
    - pathogen removal values (randomly selected) across each unit process:

$$RP_{Product_i} = RP_{Influent_i} \times 10^{-WWTP\_RP_i} \times \prod_{1}^{n} 10^{-DPRUnitProcess\_RP_i}$$

  - volume of water ingested; and
  - published dose response relationships

Risk Calculations (2)

- Cumulative daily risks from all of the evaluated pathogens were then computed as

$$CumDailyRisk = 1 - \prod_{1}^{i}(1 - RPrisk_i)$$

- Daily risks are combined to generate a cumulative annual risk estimate
- Repeat all of the above 1000 times to get a distribution of annual risks

$$CumAnnualRisk = 1 - \prod_{j=1}^{365}(1 - CumDailyRisk_j)$$

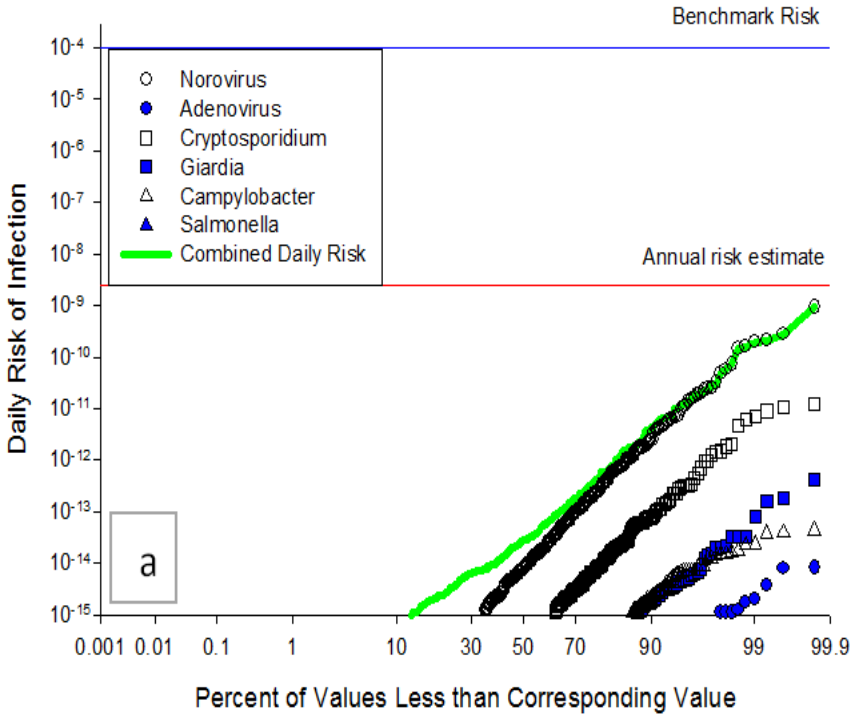
Results – Literature Review

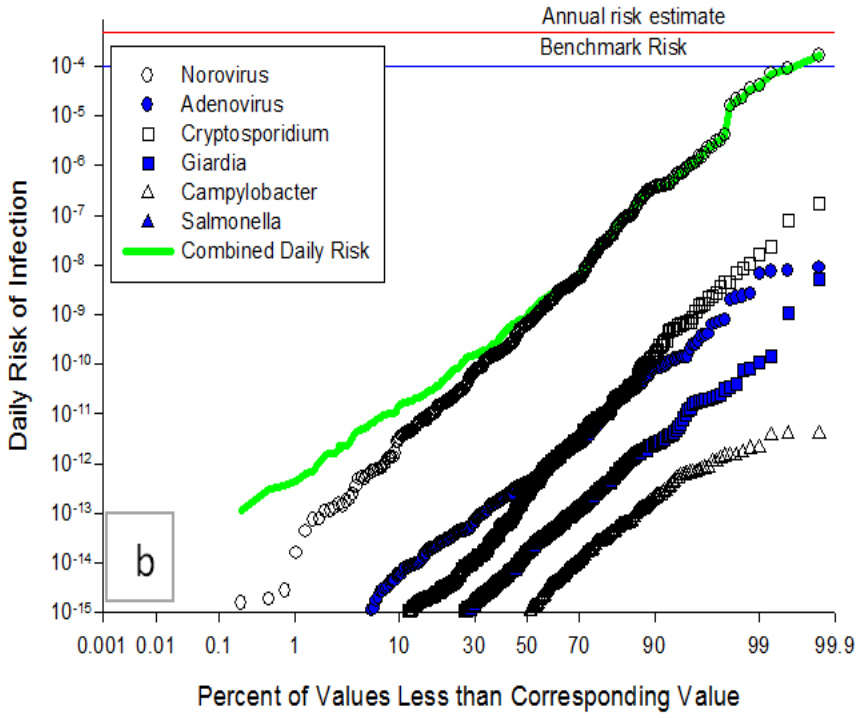
	Adenovirus		Campylobacter		Cryptosporidium		Giardia		Norovirus[2]		Salmonella	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Raw Wastewater[1]	56	6.9E+03	900	4.0E+04	0.3	5.0E+04	3.2	1.0E+04	3.76	0.93	3	1.1E+03
Conventional Secondary Wastewater Treatment	0.9	3.2	0.6	2.0	0.7	1.5	0.5	3.3	0.8	3.7	1.3	1.7
Ozonation	4.0		4.0		1.0		3.0		5.4		4.0	
Biologically Active Filtration	0	0.6	0.5	2	0	0.85	0	3.9	0	1	0.5	2
Microfiltration	2.4	4.9	3.0	9.0	4.0	7.0	4.0	7.0	1.5	3.3	3.0	9.0
Reverse Osmosis	2.7	6.5	4.0		2.7	6.5	2.7	6.5	2.7	6.5	4.0	
Ultrafiltration	4.9		5.6	9.0	4.4	6.0	4.7	7.4	4.5		5.6	9.0
Ultraviolet Disinfection with Advanced Oxidation (800mJ/cm2)	6.0		6.0		6.0		6.0		6.0		6.0	
Ultraviolet Disinfection with Peroxide (12 mJ/cm2)	0.0	0.5	4.0		2.0	3.5	2.0	3.5	0.5	1.5	4.0	
Conventional Drimking Water Treatment	1.5	2.0	3.0	4.0	1.4	3.9	0.3	4.0	1.5	2.0	2.0	3.0
Disinfection with Free Chlorine	4.0	5.0	4.0		0.0		0.0	0.5	1.0	4.0	4.0	

[1] Adenovirus IU/L, Campylobacter MPN/L, Cryptosporidium oocysts/L, Giardia cysts/L, Norovirus log 10 copies/L, Salmonella PFU/L

[2] Values shown for raw wastewater are mean and standard deviation of normal distribution in log10 copies

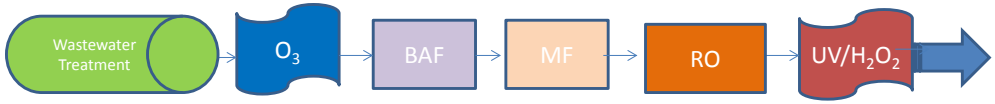
Results – Estimated Daily Risks (TT1)

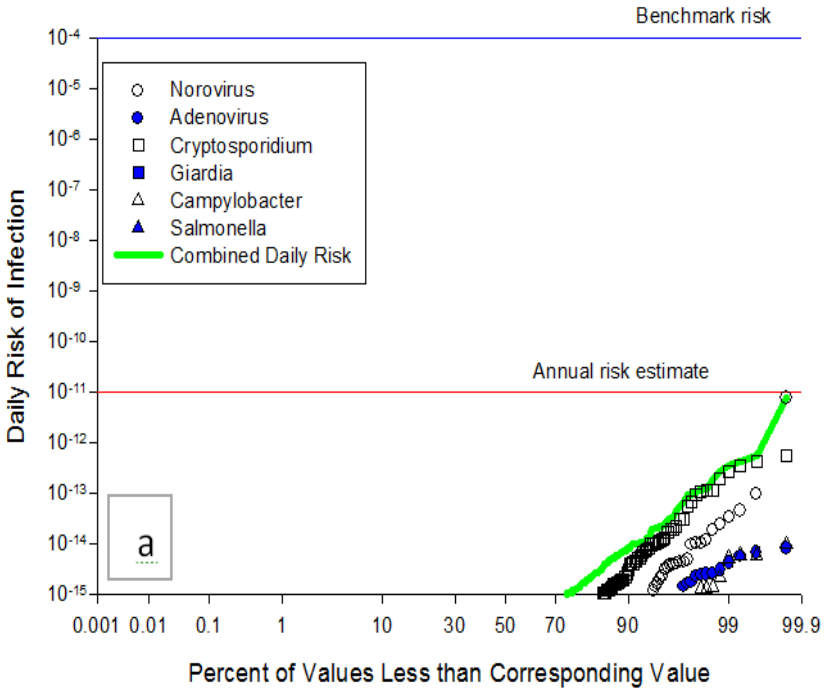


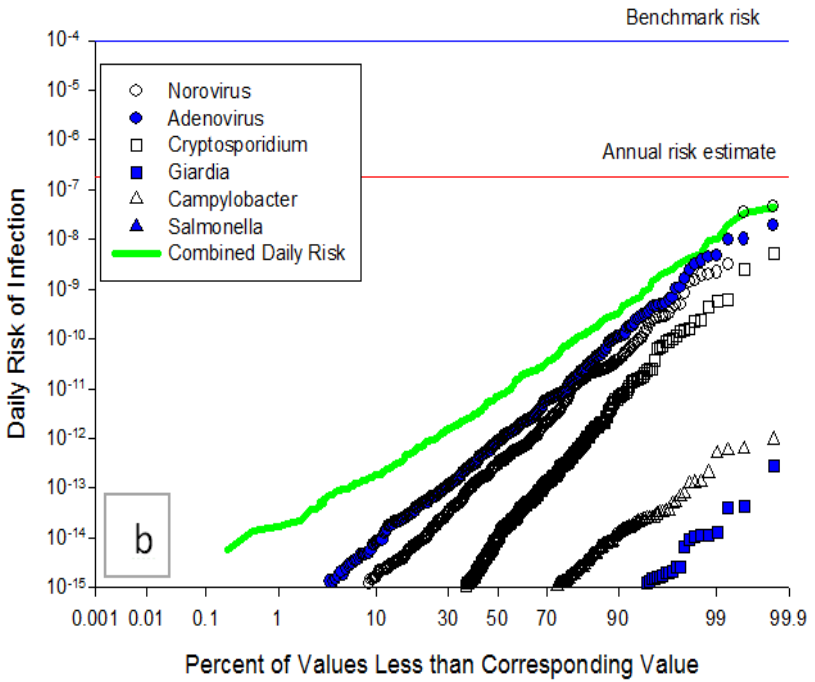


(a) Simulation using UV dose of 800 mJ/cm^2 with H_2O_2; (b) Simulation using UV dose of 12 mJ/cm^2

Results – Estimated Daily Risks (TT2)

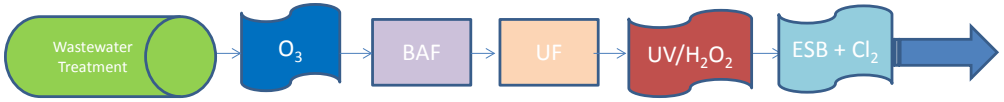


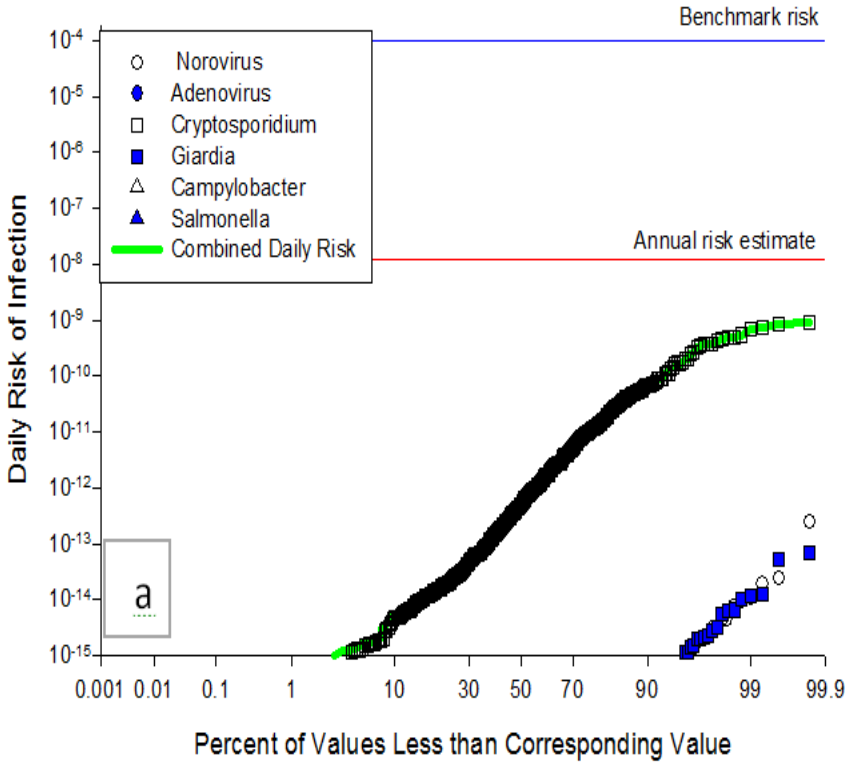


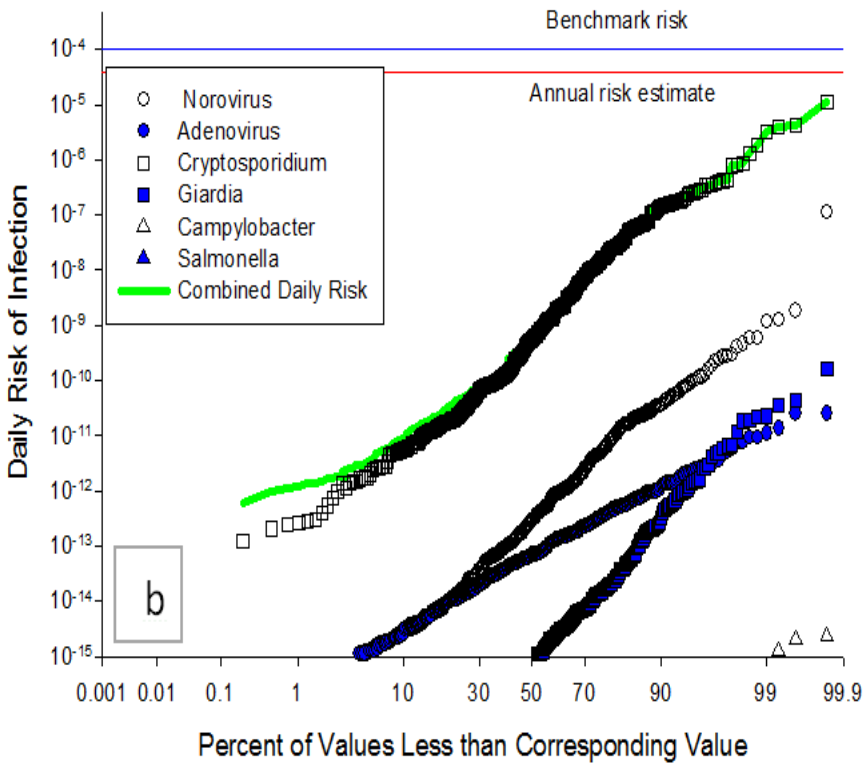


(a) Simulation using UV dose of 800 mJ/cm^2 with H_2O_2; (b) Simulation using UV dose of 12 mJ/cm^2

Results – Estimated Daily Risks (TT3)

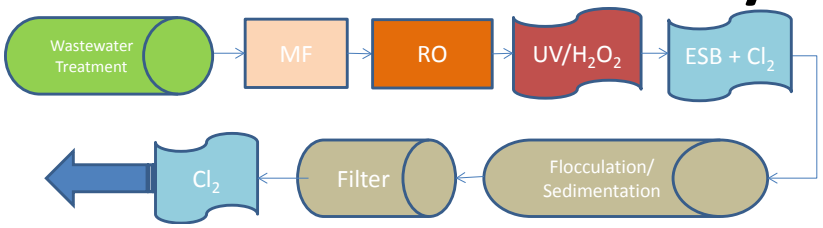


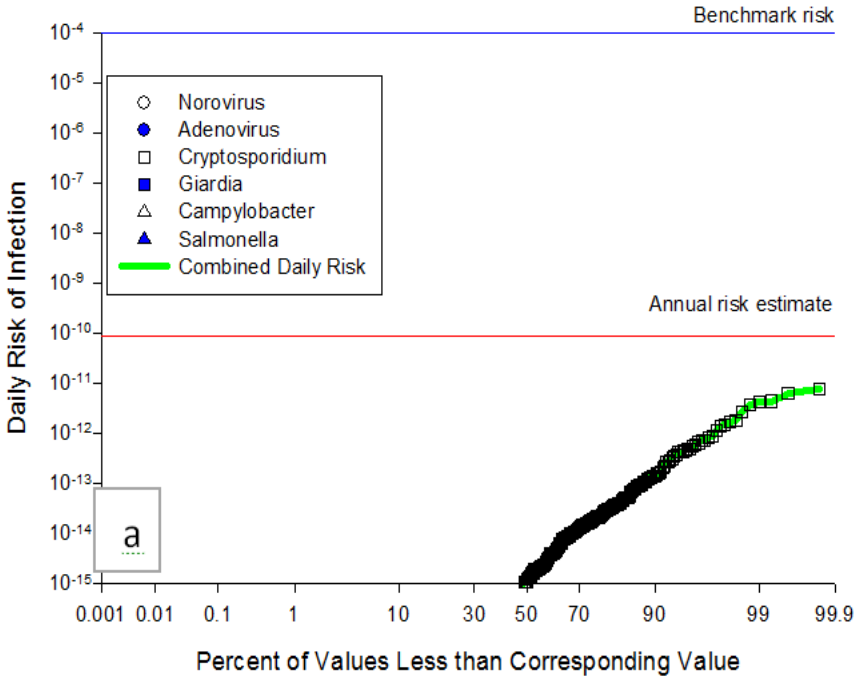


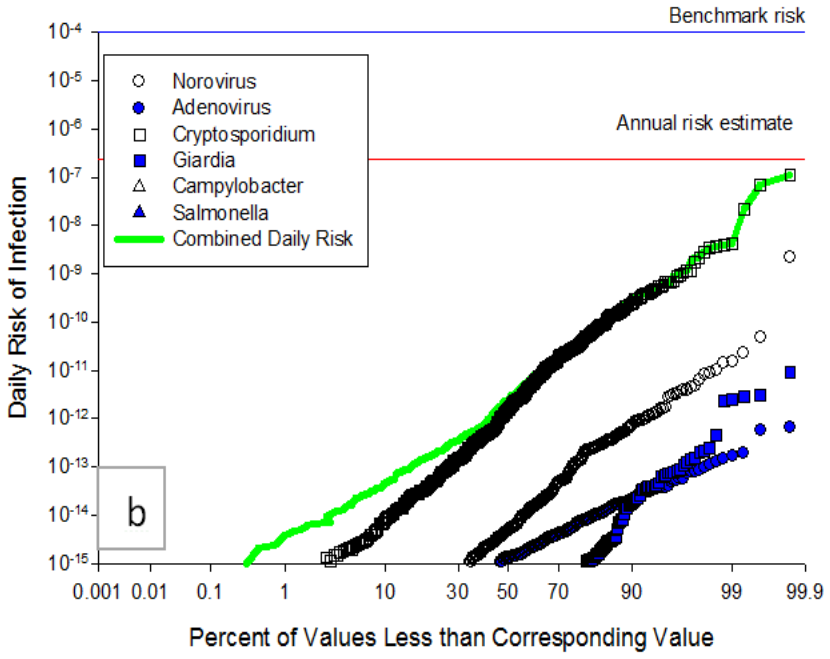


(a) Simulation using UV dose of 800 mJ/cm^2 with H_2O_2; (b) Simulation using UV dose of 12 mJ/cm^2

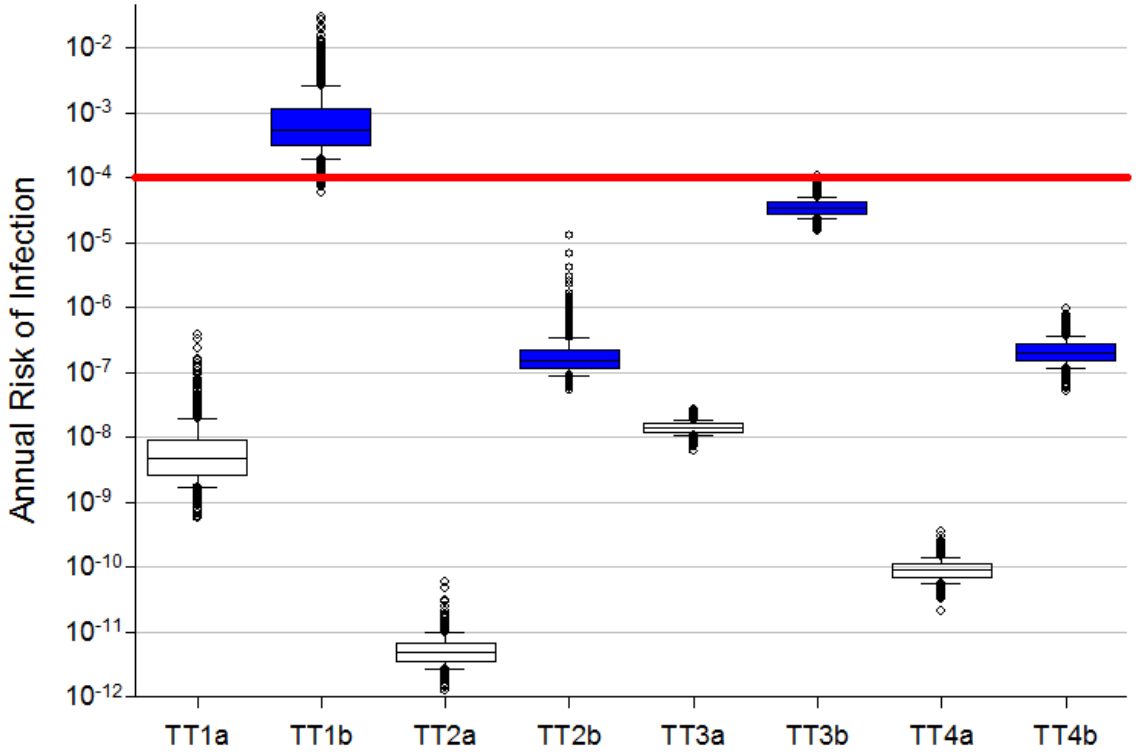
Results – Estimated Daily Risks (TT4)







Results – Annual Risks



Treatment Train 1a :	WWTP - MF-RO-UVAOP-ECBCl
Treatment Train 1b:	WWTP - MF-RO-UV-ECBCl
Treatment Train 2a:	WWTP - O3-BAF-MF-RO-UVAOP
Treatment Train 2b:	WWTP - O3-BAF-MF-RO-UVA
Treatment Train 3a:	WWTP - O3-BAF-UF-UVAOP-ESBCl
Treatment Train 3b:	WWTP - O3-BAF-UF-UV-ESBCl
Treatment Train 4a:	WWTP - O3-BAF-UF-UVAOP-ESBCl-DWT
Treatment Train 4b:	WWTP - O3-BAF-UF-UV-ESBCl-DWT

Overall Conclusions

- Annual risk estimates for any treatment train are driven by the highest daily risks for any of the reference pathogens
- In designing DPR systems, reduction of both *Cryptosporidium* and human enteric viruses are important
  - understanding NoV presence and removal across individual unit treatment processes is important in developing DPR projects
  - treatment trains (TT3) without RO may not achieve the benchmark protection due to risks from *Cryptosporidium* unless upstream of a conventional drinking water treatment facility or using high UV AOP doses
- Clear quantitative risk-based advantages for DPR projects to circulate "finished water" into the drinking water treatment plant
- Findings highlight the need to understand the meaning of "log removal credits" States use to determine the adequacy of a proposed DPR project

Take Away Message

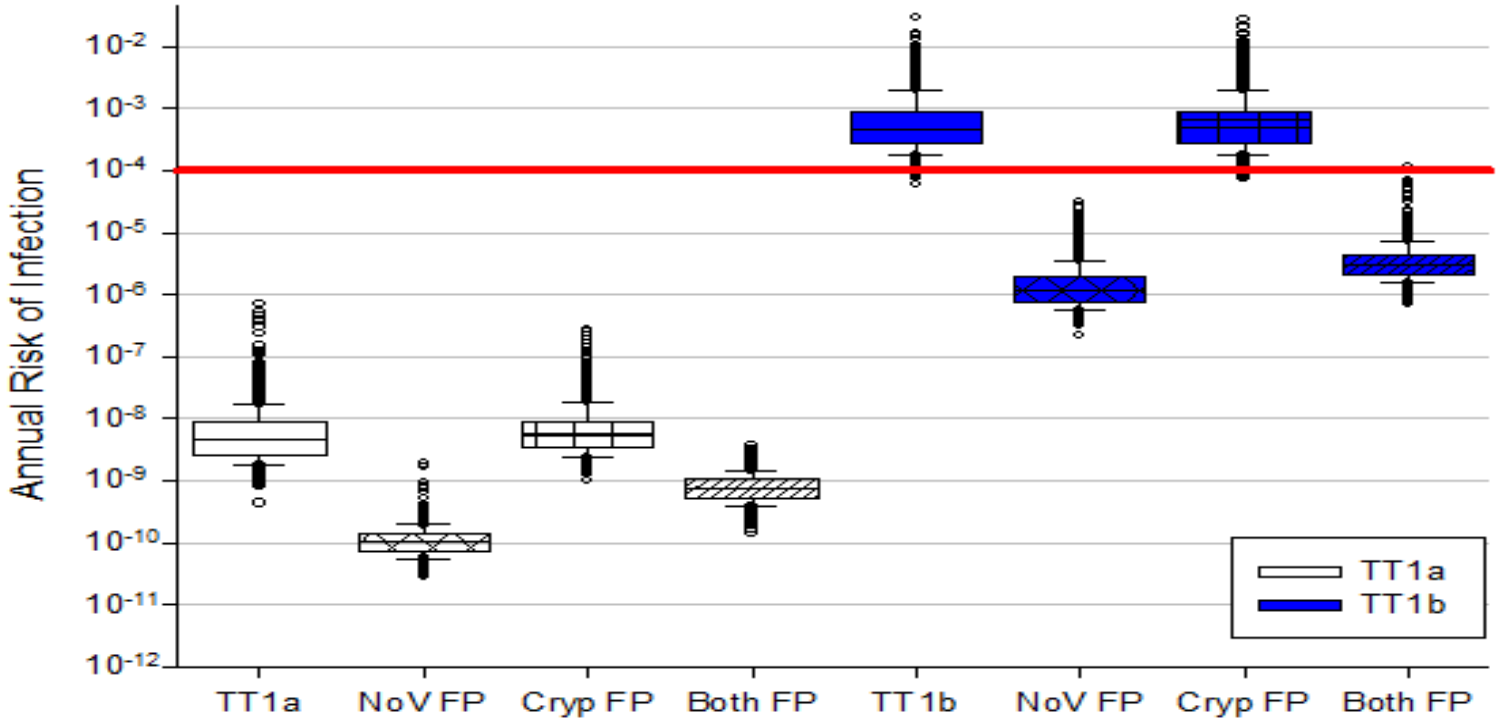
- This work provides insights about the relative level of public health protection provided by DPR treatment trains
  - resulted in several important insights for DPR implementation
  - could easily be adapted for other DPR treatment trains
  - could be iteratively refined as additional data become available for any of the reference pathogen / unit treatment processes evaluated
- This approach will be useful for
  - federal and state regulators considering DPR as source water
  - state and local decision makers as they consider whether to permit a particular DPR project
  - design engineers as they consider which unit treatment processes should be employed for particular projects
  - risk managers determining the impact of a treatment failure
- For all the gory details, refer to – Soller et al. (2016), Microbial Risk Analysis, In Press, http://dx.doi.org/10.1016/j.mran.2016.08.003

Disclaimer

The views expressed in this presentation are those of the authors and do not necessarily reflect the views or policies of the U.S. Environmental Protection Agency. The work described here was funded by the U.S. EPA Office of Water, Office of Science and Technology. No official endorsement should be inferred.

Supplemental Slides

Sensitivity Analyses – Alternative Dose Response Relationships



NoV - Norovirus
Cryp - *Cryptosporidium spp.*
FP - Fractional Poisson
TT1a and TT1b - NoV dose response is hypergeometric and Cryp is exponential
Alternatives as same as TT1a and TT1b except as specified

Dose Response Relationships

Reference Pathogen	Published Dose Response Model	Model parameters
Adenovirus	Exponential (Crabtree, et al., 1997)	0.4172
Campylobacter	Hypergeometric (Teunis, et al., 2005)	0.024, 0.011
Cryptosporidium	Exponential (U.S. EPA, 2006)	0.09
	Fractional Poisson (Messer and Berger, 2016)[1]	0.737
Giardia	Exponential (Haas, et al., 1999)	0.0199
Norovirus	Hypergeometric (Teunis, et al., 2008)	0.04, 0.055
	Fractional Poisson (Messer et al., 2014)[1]	0.72
Salmonella enterica	Beta-Poisson (Haas, et al., 1999)	0.3126, 2884

1 Used in sensitivity analysis