Maximizing treatment resilience to threats from pathogens, emerging contaminants & climate change—Is your system ready?

Monica Emelko, Kalani De Silva Liza Ballantyne, Norma Ruecker, William Anderson, Elyse Batista, Reza Anvari

TORONTO

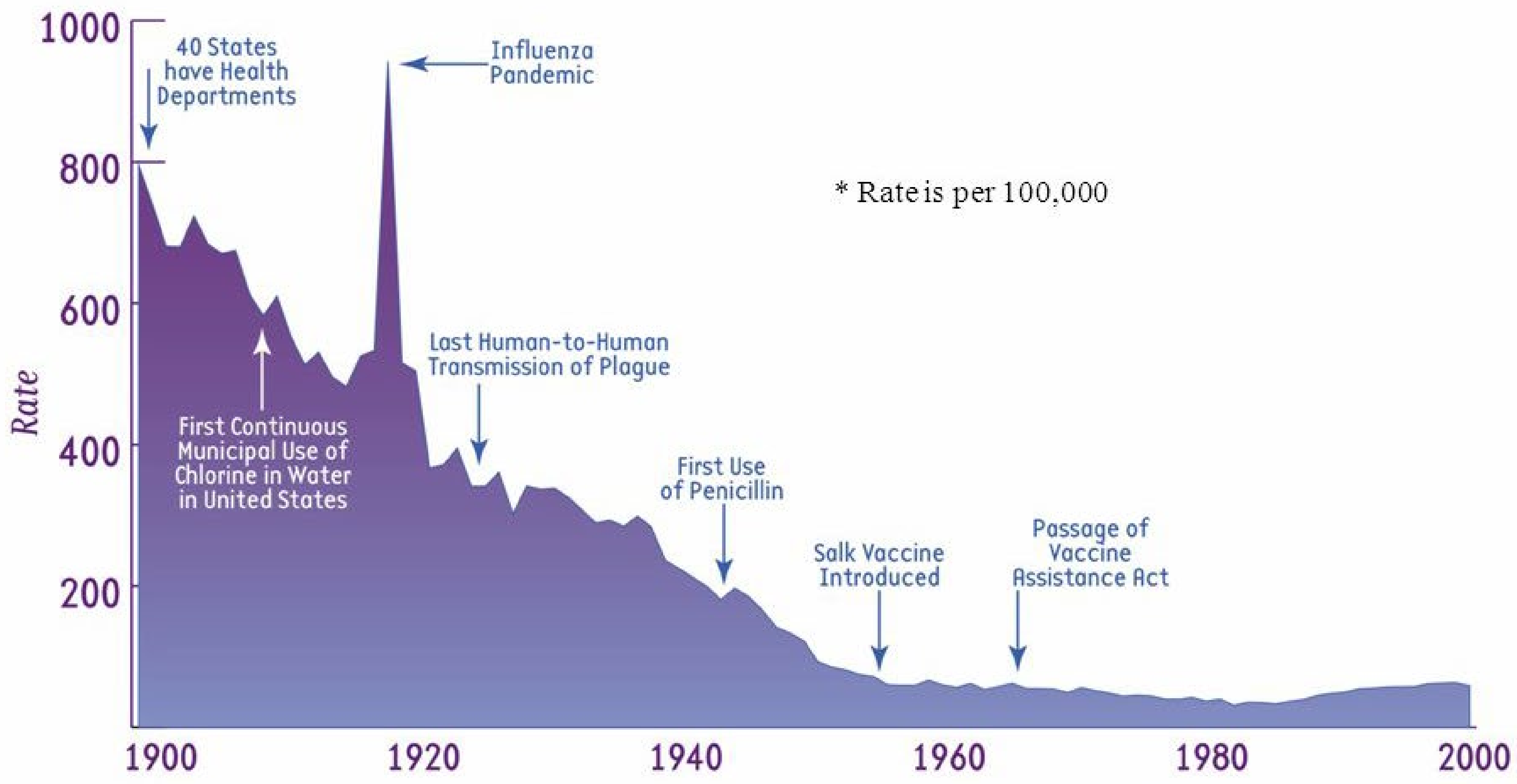
Calgary

UNIVERSITY OF WATERLOO

WATER Science, Technology & Policy Group

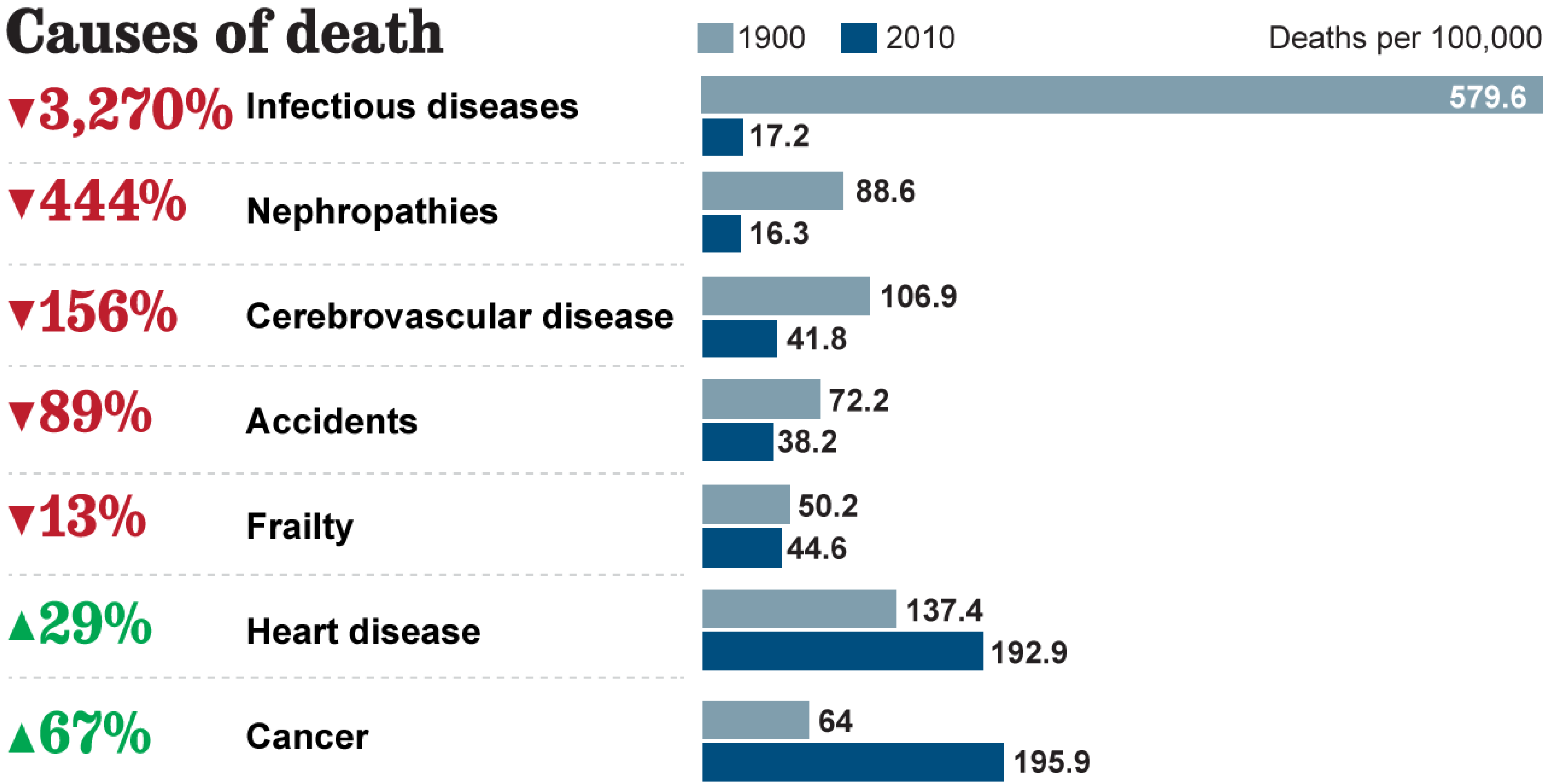
NWWC
Niagara Falls, ON
November 13, 2023

U.S. infectious disease crude death rate, 1900-2000



MMWR, CDC, 1999

Water treatment is important!



Source: New England Journal of Medicine, Randy Olson, L.A. Times reporting

How do we assess public health protection through treatment?

Health Canada | Santé Canada | *Your health and safety… our priority.* | *Votre santé et votre sécurité… notre priorité.*

Guidelines for Canadian Drinking Water Quality
Summary Table

Prepared by

Health Canada

In collaboration with the

Federal-Provincial-Territorial Committee on Drinking Water

of the

Federal-Provincial-Territorial Committee on Health and the Environment

September 2020

Canada

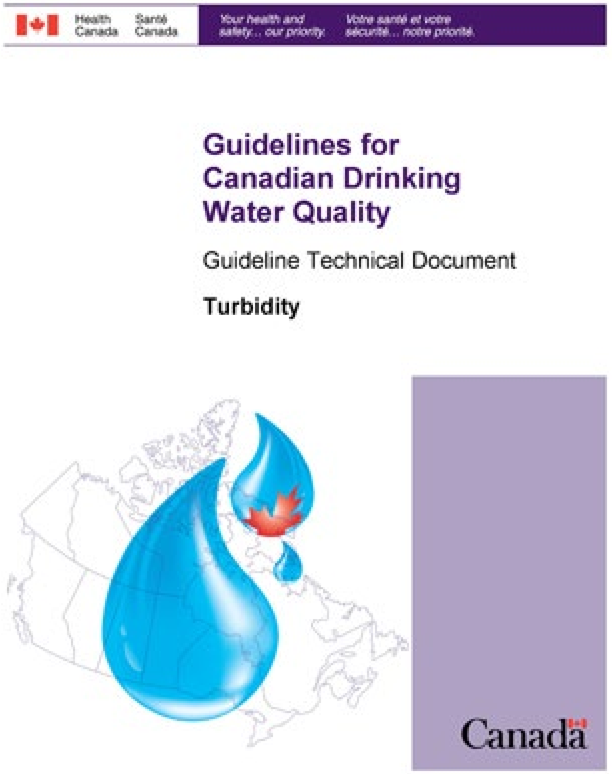
National Primary Drinking Water Regulations

EPA

Contaminant	MCL or TT[1] (mg/L)[2]	Potential health effects from long-term[3] exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal (mg/L)[2]
Acrylamide	TT[4]	Nervous system or blood problems; increased risk of cancer	Added to water during sewage/ wastewater treatment	zero
Alachlor	0.002	Eye, liver, kidney, or spleen problems; anemia; increased risk of cancer	Runoff from herbicide used on row crops	zero
Alpha/photon emitters	15 picocuries per Liter (pCi/L)	Increased risk of cancer	Erosion of natural deposits of certain minerals that are radioactive and may emit a form of radiation known as alpha radiation	zero
Antimony	0.006	Increase in blood cholesterol; decrease in blood sugar	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder	0.006
Arsenic	0.010	Skin damage or problems with circulatory systems, and may have increased risk of getting cancer	Erosion of natural deposits; runoff from orchards; runoff from glass & electronics production wastes	0
Asbestos (fibers >10 micrometers)	7 million fibers per Liter (MFL)	Increased risk of developing benign intestinal polyps	Decay of asbestos cement in water mains; erosion of natural deposits	7 MFL
Atrazine	0.003	Cardiovascular system or reproductive problems	Runoff from herbicide used on row crops	0.003
Barium	2	Increase in blood pressure	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits	2
Benzene	0.005	Anemia; decrease in blood platelets; increased risk of cancer	Discharge from factories; leaching from gas storage tanks and landfills	zero
Benzo(a)pyrene (PAHs)	0.0002	Reproductive difficulties; increased risk of cancer	Leaching from linings of water storage tanks and distribution lines	zero
Beryllium	0.004	Intestinal lesions	Discharge from metal refineries and coal-burning factories; discharge from electrical, aerospace, and defense industries	0.004
Beta photon emitters	4 millirems per year	Increased risk of cancer	Decay of natural and man-made deposits of certain minerals that are radioactive and may emit forms of radiation known as photons and beta radiation	zero
Bromate	0.010	Increased risk of cancer	Byproduct of drinking water disinfection	zero
Cadmium	0.005	Kidney damage	Corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints	0.005
Carbofuran	0.04	Problems with blood, nervous system, or reproductive system	Leaching of soil fumigant used on rice and alfalfa	0.04

LEGEND: DISINFECTANT · DISINFECTION BYPRODUCT · INORGANIC CHEMICAL · MICROORGANISM · ORGANIC CHEMICAL · RADIONUCLIDES

Canadian (and U.S.) Protozoan Pathogen Treatment Credits for Filtration

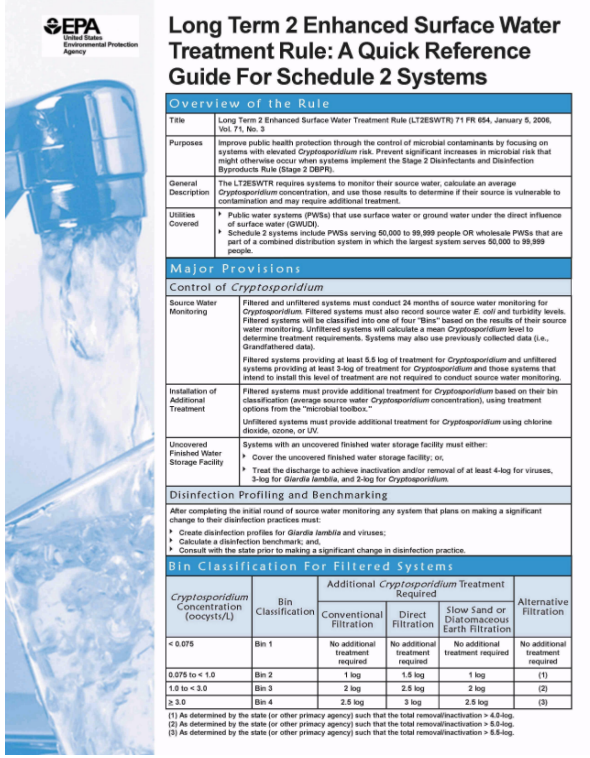

Health Canada / Santé Canada — Your health and safety... our priority. / Votre santé et votre sécurité... notre priorité.

Guidelines for Canadian Drinking Water Quality

Guideline Technical Document

Turbidity

Canada


EPA United States Environmental Protection Agency

Long Term 2 Enhanced Surface Water Treatment Rule: A Quick Reference Guide For Schedule 2 Systems

Overview of the Rule

Major Provisions

Control of *Cryptosporidium*

Disinfection Profiling and Benchmarking

Bin Classification For Filtered Systems

Technology	*Cryptosporidium* removal credit[a]	*Giardia* removal credit[b]	Virus removal credit[c]
Conventional filtration	3.0 log	3.0 log	2.0 log
Direct filtration	2.5 log	2.5 log	1.0 log
Slow sand filtration	3.0 log	3.0 log	2.0 log
Diatomaceous earth filtration	3.0 log	3.0 log	1.0 log
Microfiltration[d]	Demonstration using challenge testing	Demonstration using challenge testing	No credit[e]
Ultrafiltration[d]	Demonstration using challenge testing	Demonstration using challenge testing	Demonstration using challenge testing
Nanofiltration and reverse osmosis[d]	Demonstration using challenge testing	Demonstration using challenge testing	Demonstration using challenge testing

[a] Values from U.S. EPA LT2ESWTR (U.S. EPA, 2006b), p. 678.
[b] Values based on review of AWWA (1991); U.S. EPA (2003a); Schuler and Ghosh (1990, 1991); Nieminski and Ongerth (1995); Patania et al. (1995); McTigue et al. (1998); Nieminski and Bellamy (2000); DeLoyde et al. (2006); Assavasilavasukul et al. (2008).
[c] Values from U.S. EPA LT1ESWTR Disinfection Profiling and Benchmarking Technical Guidance Manual (U.S. EPA, 2003a), p. 62.
[d] Removal efficiency demonstrated through challenge testing and verified by direct integrity testing.
[e] Microfiltration membranes may be eligible for virus removal credit when preceded by a coagulation step.

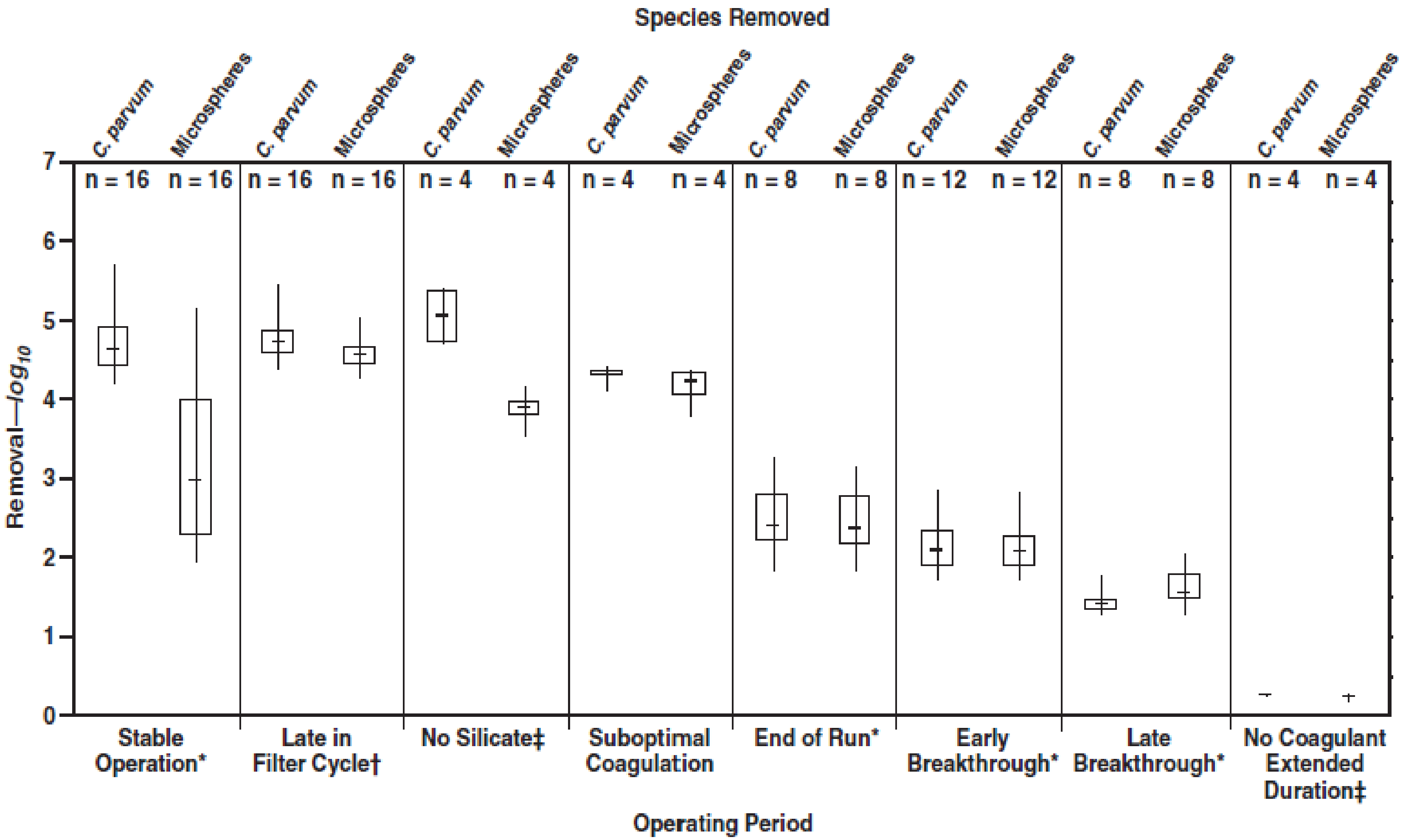
- **All surface water requires conventional filtration or equivalent treatment…regardless of water quality!**
- **Filtration avoidance is possible, but not common**

Canadian (and U.S.) Protozoan Pathogen Treatment Credits for Filtration

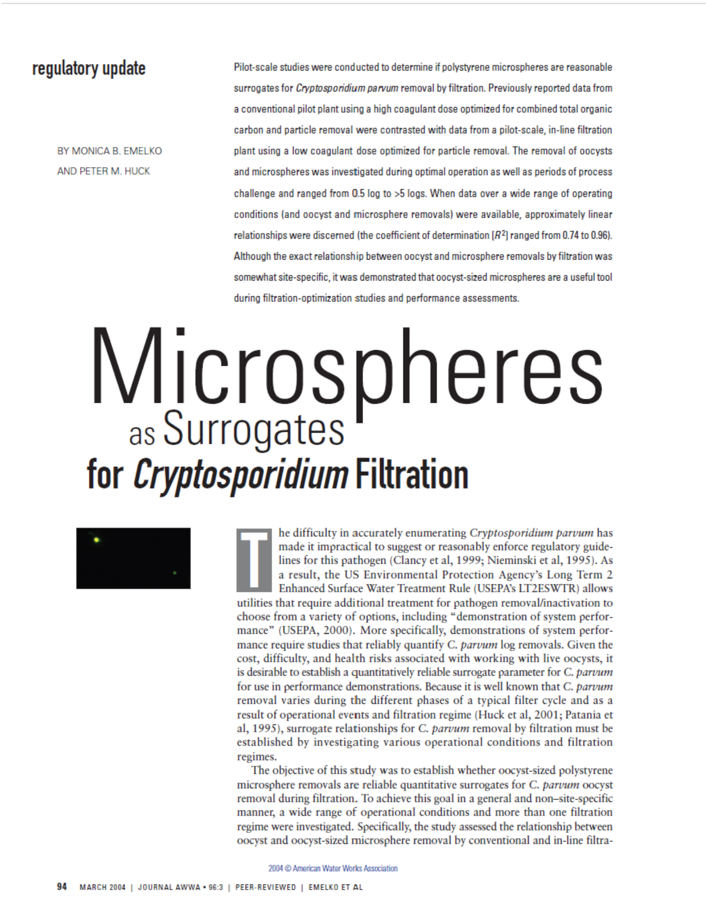
Technology	*Cryptosporidium* removal credit[a]	*Giardia* removal credit[b]	Virus removal credit[c]
Conventional filtration	3.0 log	3.0 log	2.0 log
Direct filtration	2.5 log	2.5 log	1.0 log
Slow sand filtration	3.0 log	3.0 log	2.0 log
Diatomaceous earth filtration	3.0 log	3.0 log	1.0 log
Microfiltration[d]	Demonstration using challenge testing	Demonstration using challenge testing	No credit[e]
Ultrafiltration[d]	Demonstration using challenge testing	Demonstration using challenge testing	Demonstration using challenge testing
Nanofiltration and reverse osmosis[d]	Demonstration using challenge testing	Demonstration using challenge testing	Demonstration using challenge testing

[a] Values from U.S. EPA LT2ESWTR (U.S. EPA, 2006b), p. 678.
[b] Values based on review of AWWA (1991); U.S. EPA (2003a); Schuler and Ghosh (1990, 1991); Nieminski and Ongerth (1995); Patania et al. (1995); McTigue et al. (1998); Nieminski and Bellamy (2000); DeLoyde et al. (2006); Assavasilavasukul et al. (2008).
[c] Values from U.S. EPA LT1ESWTR Disinfection Profiling and Benchmarking Technical Guidance Manual (U.S. EPA, 2003a), p. 62.
[d] Removal efficiency demonstrated through challenge testing and verified by direct integrity testing.
[e] Microfiltration membranes may be eligible for virus removal credit when preceded by a coagulation step.

Canadian (and U.S.) Protozoan Pathogen Treatment Credits for Filtration



n—*number of sample pairs*
**Emelko et al, 2003*
†Emelko et al, 2001a
‡Emelko et al, 2001b



regulatory update

BY MONICA B. EMELKO
AND PETER M. HUCK

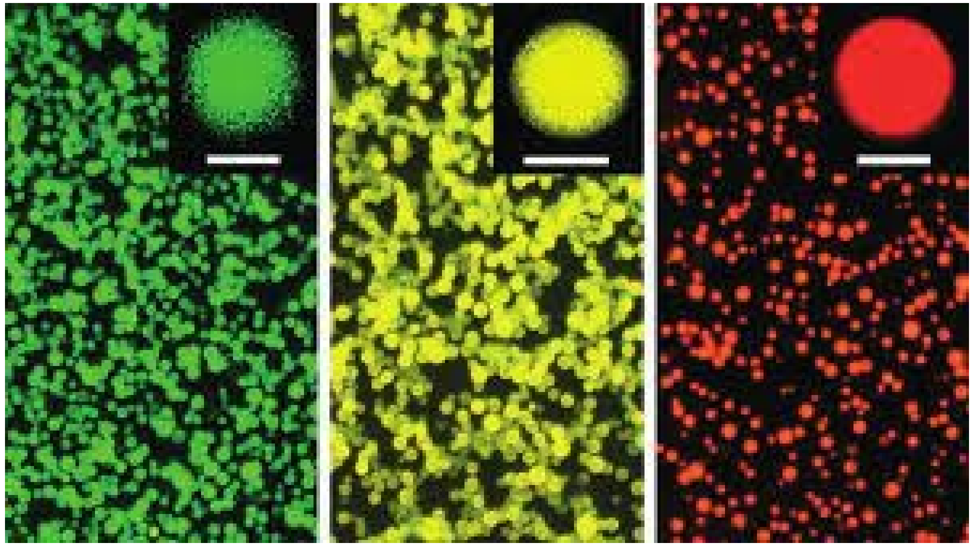
Pilot-scale studies were conducted to determine if polystyrene microspheres are reasonable surrogates for *Cryptosporidium parvum* removal by filtration. Previously reported data from a conventional pilot plant using a high coagulant dose optimized for combined total organic carbon and particle removal were contrasted with data from a pilot-scale, in-line filtration plant using a low coagulant dose optimized for particle removal. The removal of oocysts and microspheres was investigated during optimal operation as well as periods of process challenge and ranged from 0.5 log to >5 logs. When data over a wide range of operating conditions (and oocyst and microsphere removals) were available, approximately linear relationships were discerned (the coefficient of determination [R^2] ranged from 0.74 to 0.96). Although the exact relationship between oocyst and microsphere removals by filtration was somewhat site-specific, it was demonstrated that oocyst-sized microspheres are a useful tool during filtration-optimization studies and performance assessments.

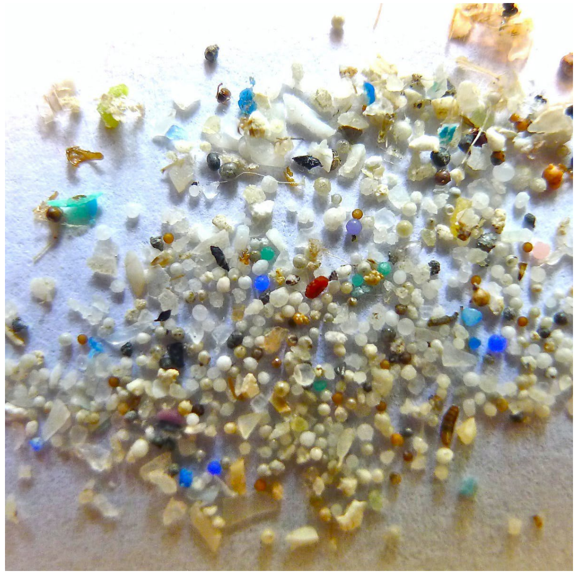
Microspheres as Surrogates for *Cryptosporidium* Filtration

The difficulty in accurately enumerating *Cryptosporidium parvum* has made it impractical to suggest or reasonably enforce regulatory guidelines for this pathogen (Clancy et al, 1999; Nieminski et al, 1995). As a result, the US Environmental Protection Agency's Long Term 2 Enhanced Surface Water Treatment Rule (USEPA's LT2ESWTR) allows utilities that require additional treatment for pathogen removal/inactivation to choose from a variety of options, including "demonstration of system performance" (USEPA, 2000). More specifically, demonstrations of system performance require studies that reliably quantify *C. parvum* log removals. Given the cost, difficulty, and health risks associated with working with live oocysts, it is desirable to establish a quantitatively reliable surrogate parameter for *C. parvum* for use in performance demonstrations. Because it is well known that *C. parvum* removal varies during the different phases of a typical filter cycle and as a result of operational events and filtration regime (Huck et al, 2001; Patania et al, 1995), surrogate relationships for *C. parvum* removal by filtration must be established by investigating various operational conditions and filtration regimes.

The objective of this study was to establish whether oocyst-sized polystyrene microsphere removals are reliable quantitative surrogates for *C. parvum* oocyst removal during filtration. To achieve this goal in a general and non–site-specific manner, a wide range of operational conditions and more than one filtration regime were investigated. Specifically, the study assessed the relationship between oocyst and oocyst-sized microsphere removal by conventional and in-line filtra-

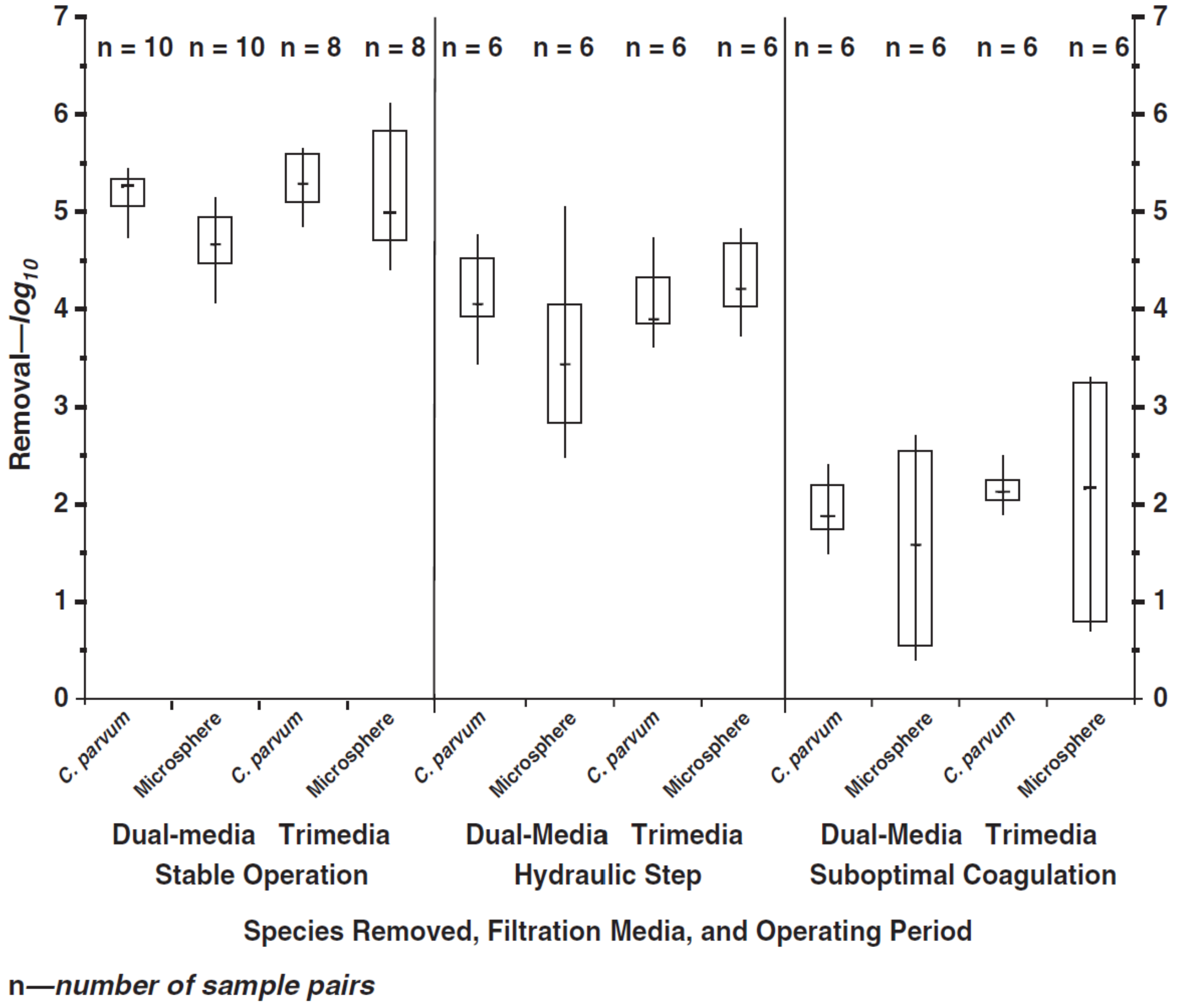
Microspheres Used for Treatment Performance Assessment





400X magnification

Microplastics Toxicity is Emerging, Treatment is Generally Understood



regulatory update

Pilot-scale studies were conducted to determine if polystyrene microspheres are reasonable surrogates for *Cryptosporidium parvum* removal by filtration. Previously reported data from a conventional pilot plant using a high coagulant dose optimized for combined total organic carbon and particle removal were contrasted with data from a pilot-scale, in-line filtration plant using a low coagulant dose optimized for particle removal. The removal of oocysts and microspheres was investigated during optimal operation as well as periods of process challenge and ranged from 0.5 log to >5 logs. When data over a wide range of operating conditions (and oocyst and microsphere removals) were available, approximately linear relationships were discerned (the coefficient of determination [R^2] ranged from 0.74 to 0.96). Although the exact relationship between oocyst and microsphere removals by filtration was somewhat site-specific, it was demonstrated that oocyst-sized microspheres are a useful tool during filtration-optimization studies and performance assessments.

BY MONICA B. EMELKO
AND PETER M. HUCK

Microspheres as Surrogates for *Cryptosporidium* Filtration

The difficulty in accurately enumerating *Cryptosporidium parvum* has made it impractical to suggest or reasonably enforce regulatory guidelines for this pathogen (Clancy et al, 1999; Nieminski et al, 1995). As a result, the US Environmental Protection Agency's Long Term 2 Enhanced Surface Water Treatment Rule (USEPA's LT2ESWTR) allows utilities that require additional treatment for pathogen removal/inactivation to choose from a variety of options, including "demonstration of system performance" (USEPA, 2000). More specifically, demonstrations of system performance require studies that reliably quantify *C. parvum* log removals. Given the cost, difficulty, and health risks associated with working with live oocysts, it is desirable to establish a quantitatively reliable surrogate parameter for *C. parvum* for use in performance demonstrations. Because it is well known that *C. parvum* removal varies during the different phases of a typical filter cycle and as a result of operational events and filtration regime (Huck et al, 2001; Patania et al, 1995), surrogate relationships for *C. parvum* removal by filtration must be established by investigating various operational conditions and filtration regimes.

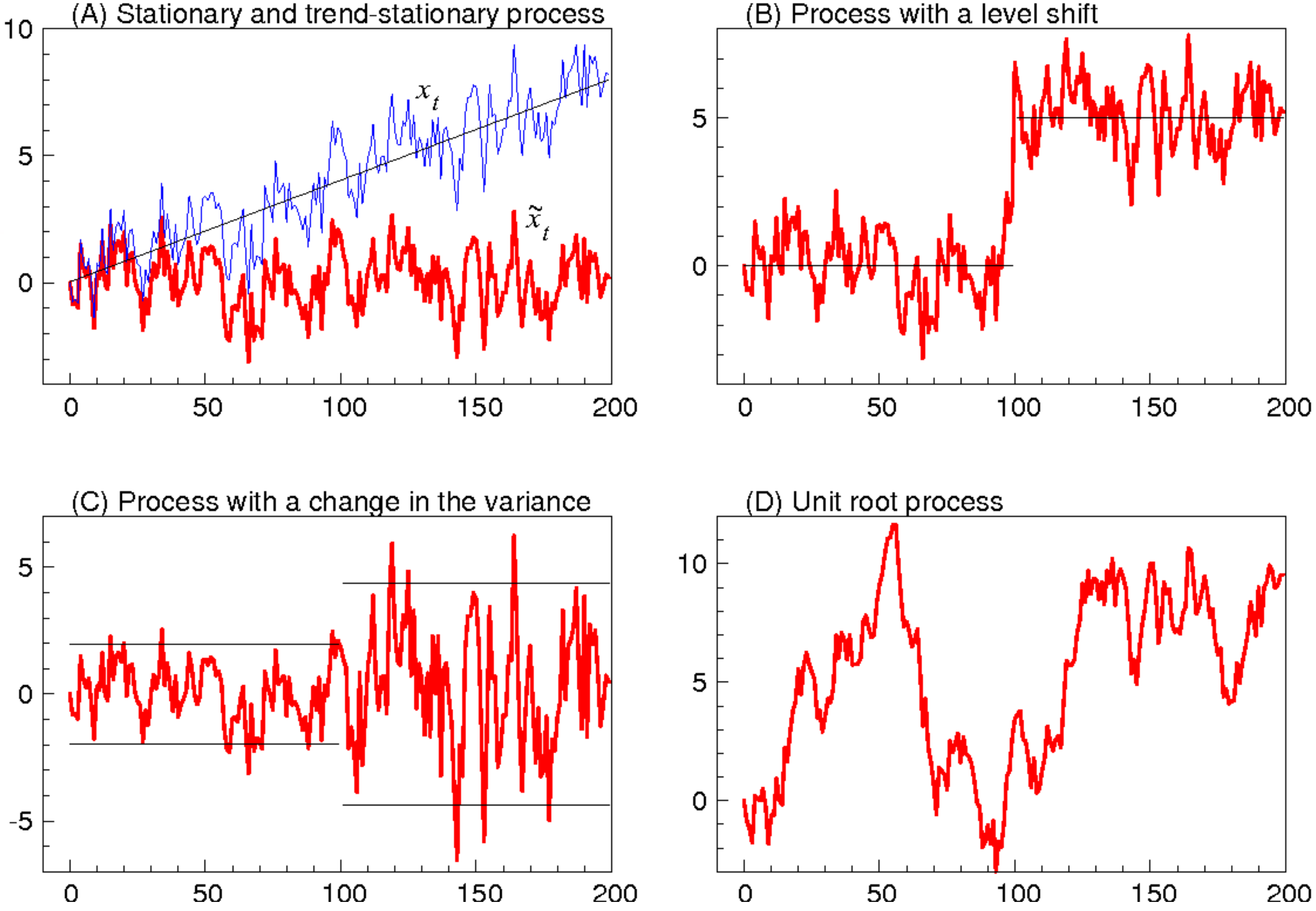
The objective of this study was to establish whether oocyst-sized polystyrene microsphere removals are reliable quantitative surrogates for *C. parvum* oocyst removal during filtration. To achieve this goal in a general and non–site-specific manner, a wide range of operational conditions and more than one filtration regime were investigated. Specifically, the study assessed the relationship between oocyst and oocyst-sized microsphere removal by conventional and in-line filtra-

Climate Change Undermines Assumption of Stationarity

POLICYFORUM

CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?



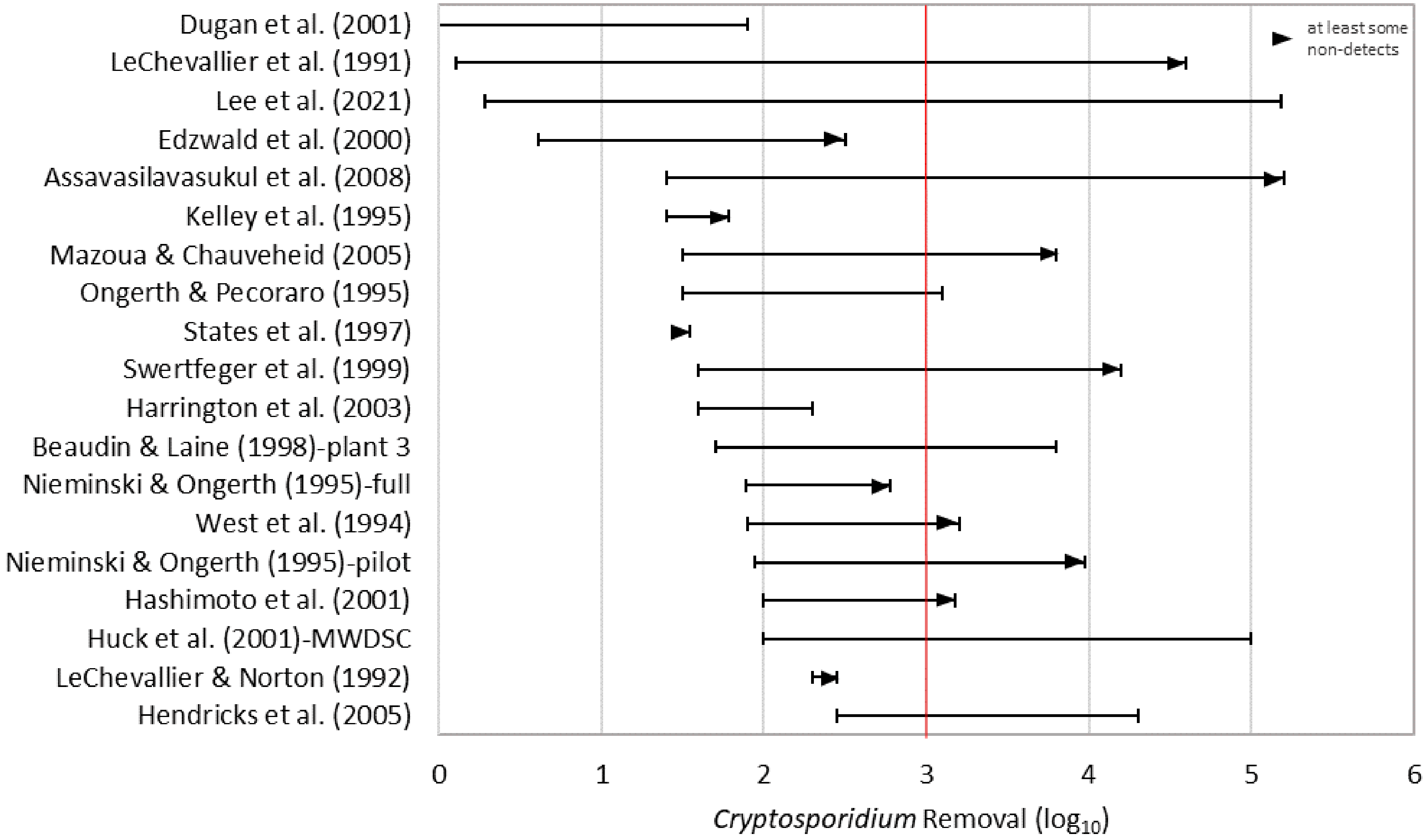
Get used to 'extreme' weather, it's the new normal

Scientists have been warning us for years that a warmer planet would lead to more extreme weather, and now it's arrived

Connie Hedegaard
theguardian.com, Wednesday 19 September 2012 16.45 BST
Jump to comments (400)

School children encounter flood water after heavy rains in Jhabua, central India. Photograph: Sanjeev Gupta/EPA

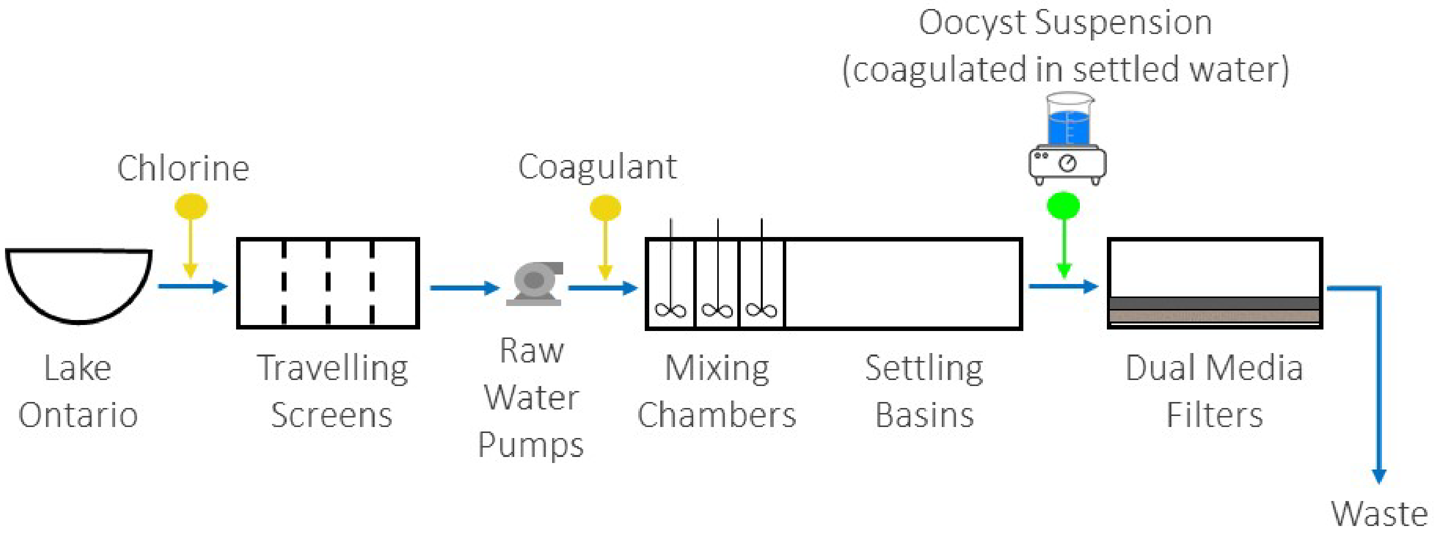
Cryptosporidium removal by filtration is not always ≥ 3-log



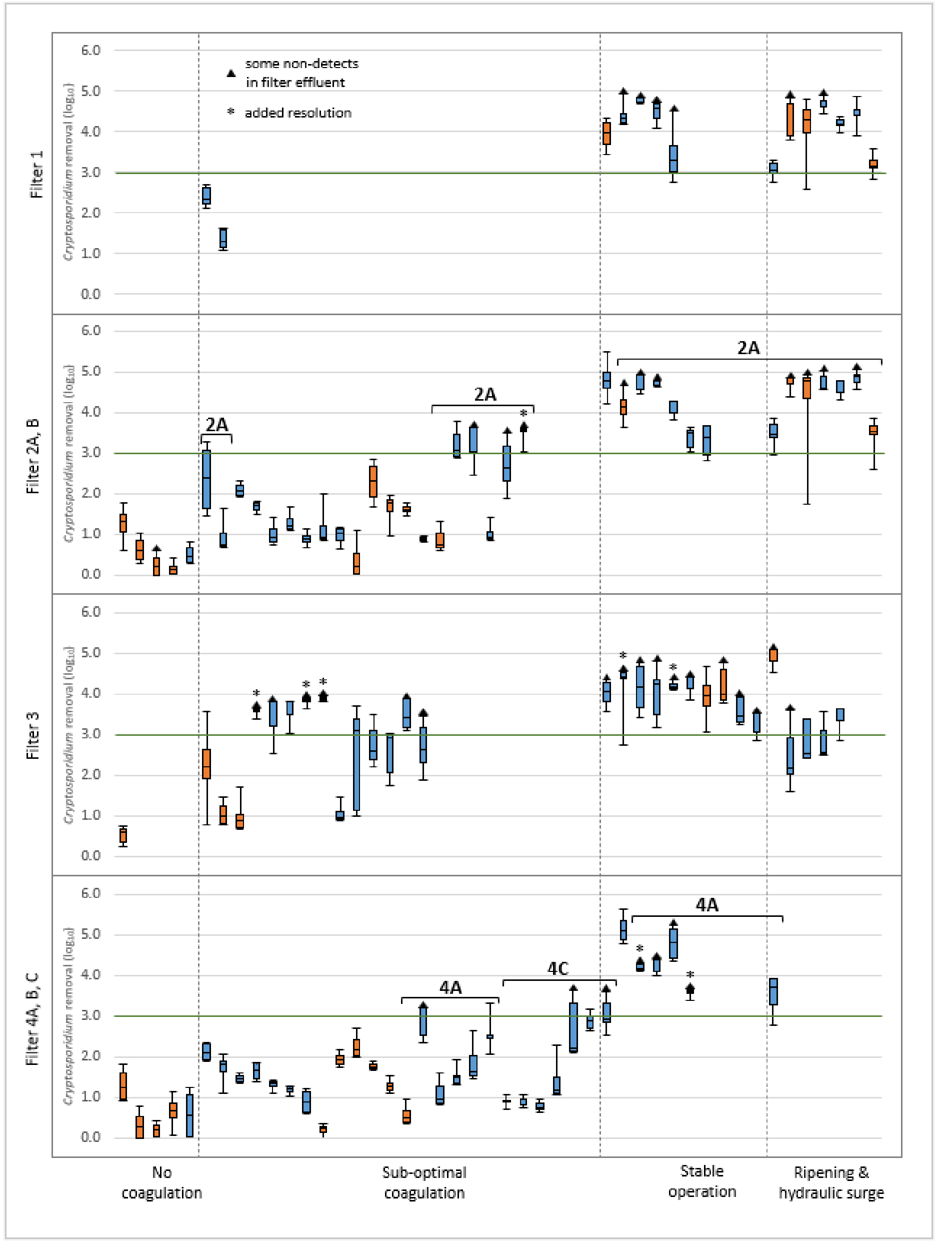
How do we ensure "well-operated" filtration?

Pilot Tests: Filter Design, Operation & Monitoring Approaches

- Evaluate *Cryptosporidium* removal:
  (1) by deep and shallow filters,
  (2) at cold (<10˚C) and warm (>20˚C) water, and
  (3) at **typical (~5-10 mg/L)** and **zeta potential-informed** (+/-5 mV of ZPC) **coagulant doses** (with replication)



WRF Project 5110 Phase 1 Overview

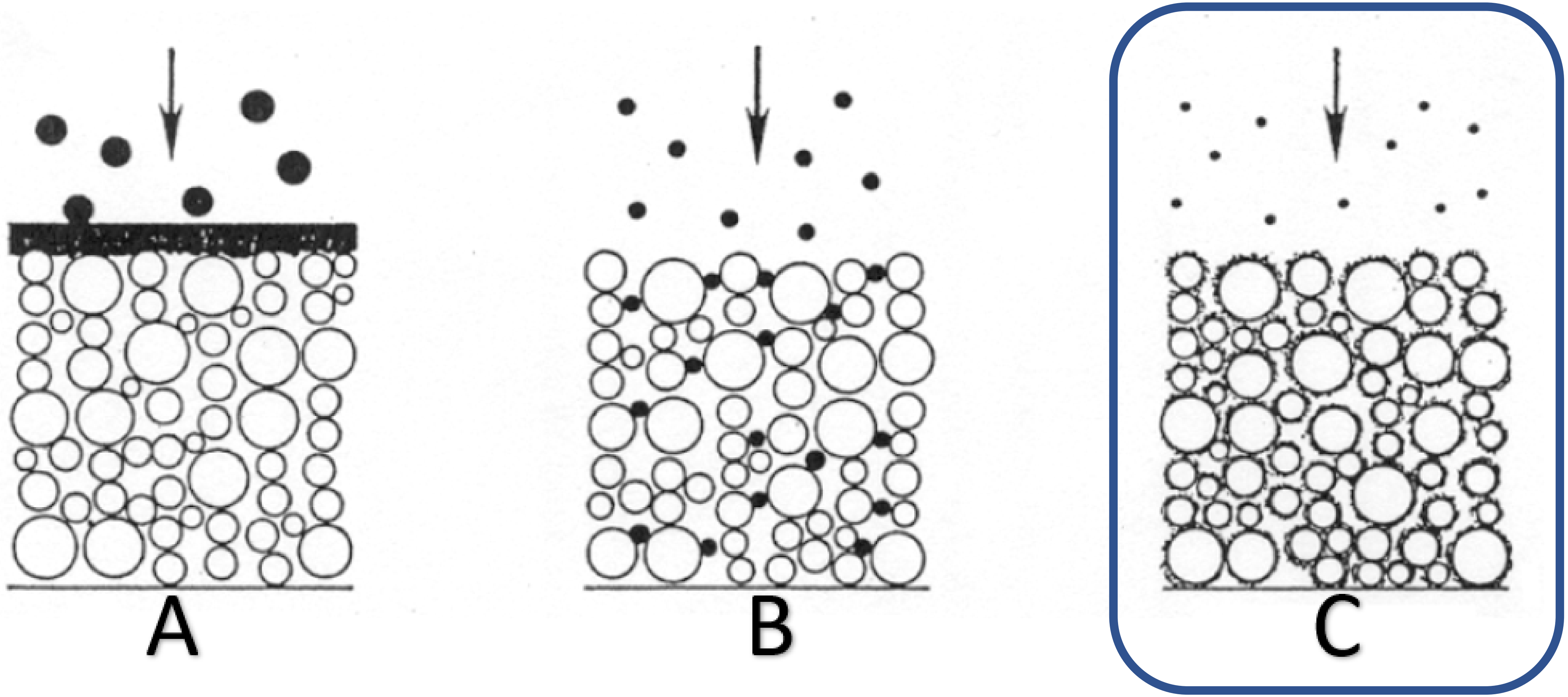


Filter #		Coagulant	HLR (m/h)	ID (cm)	Media depth (mm)			
					Anthracite	GAC	Sand	Ceramic
1		alum	2	15	250		250	
2	A	alum	2	15	450		300	
	B	alum/PACl	9.8-24.4	7.5				
3		alum	4.1	15	1000		300	
4	A	PACl	9.7	15	900		300	
	B	alum/PACl	9.8-24.4	7.5				450/300
	C	PACl	4.7	15		1500	300	

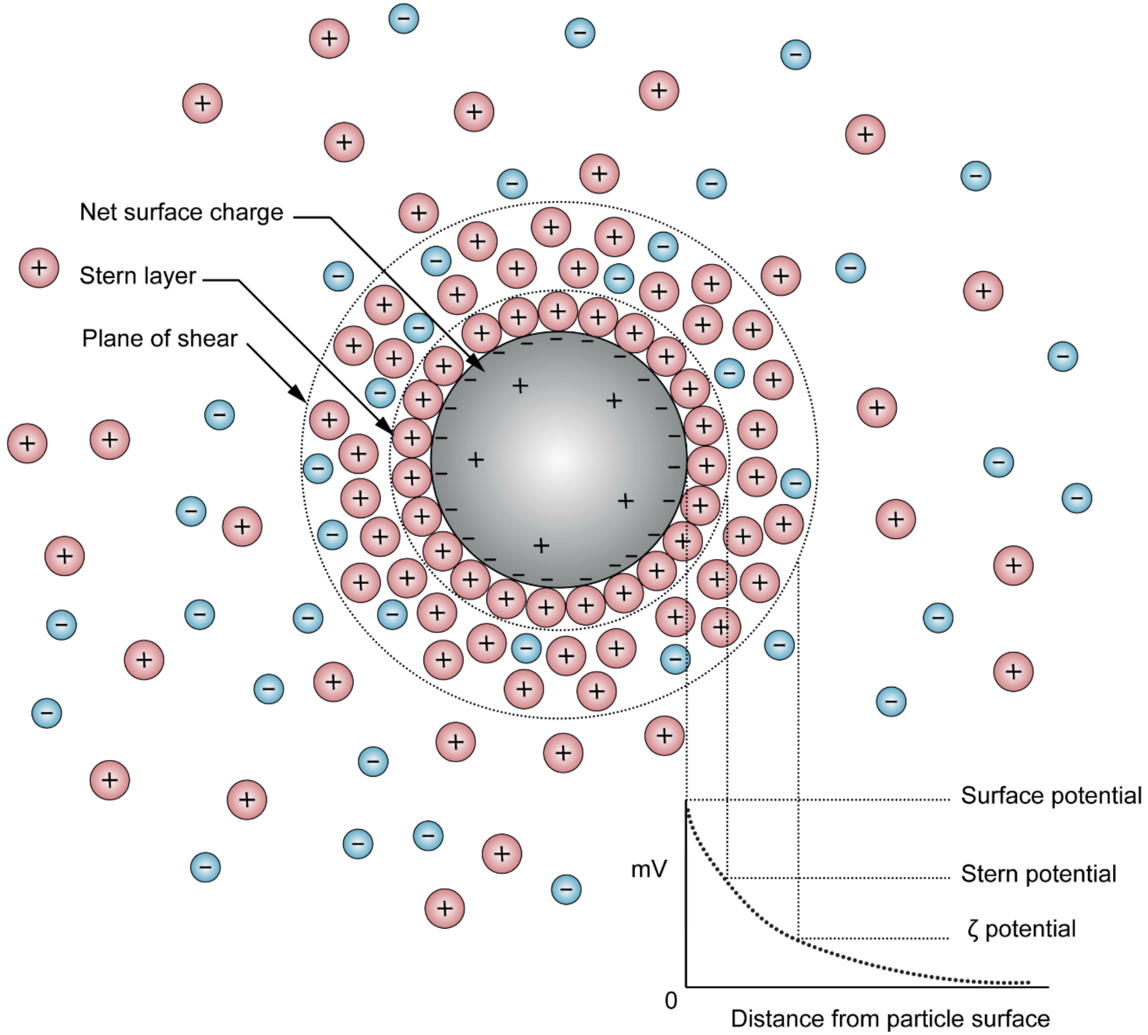
- **Goal #1:** Demonstrate the importance of sufficient particle destabilization for oocyst removal by filtration (regardless of filter design)
- **Goal # 2:** Highlight that sufficient particle destabilization by coagulation alone does not guarantee oocyst removal by filtration → hydraulics also play a role

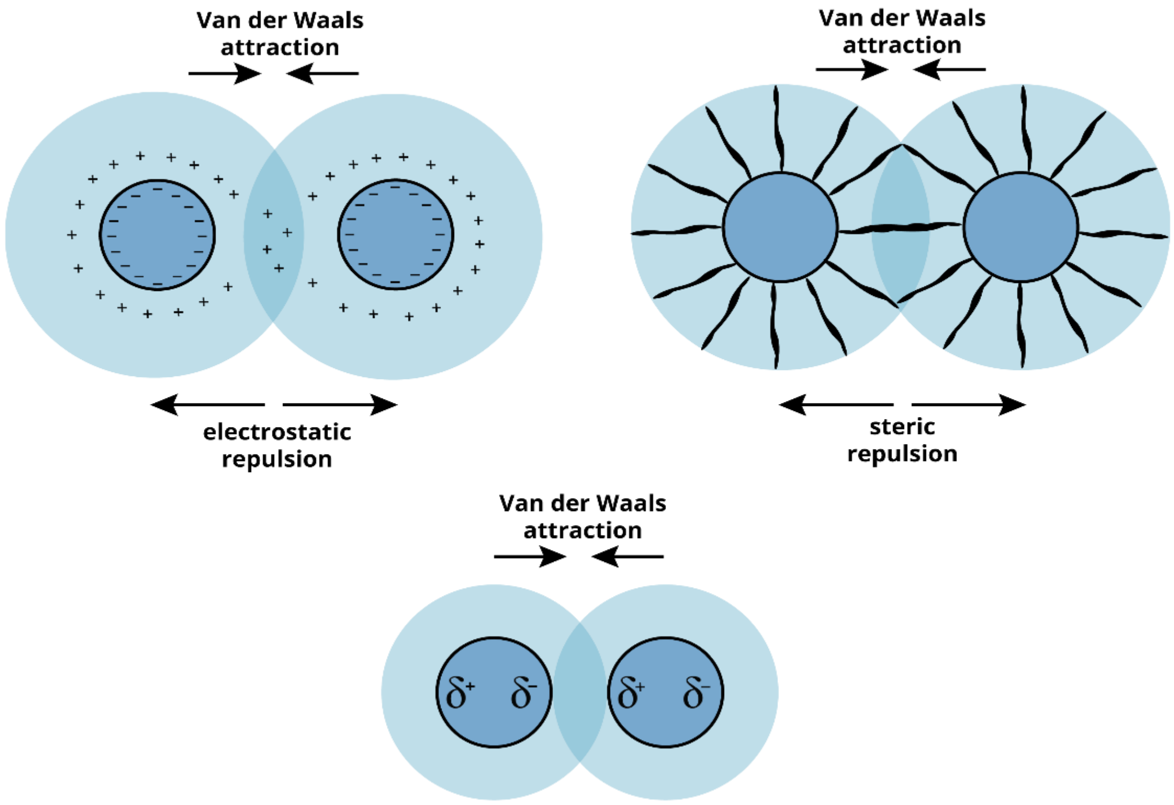
WATER STP |

Physico-chemical filtration is not a size exclusion process



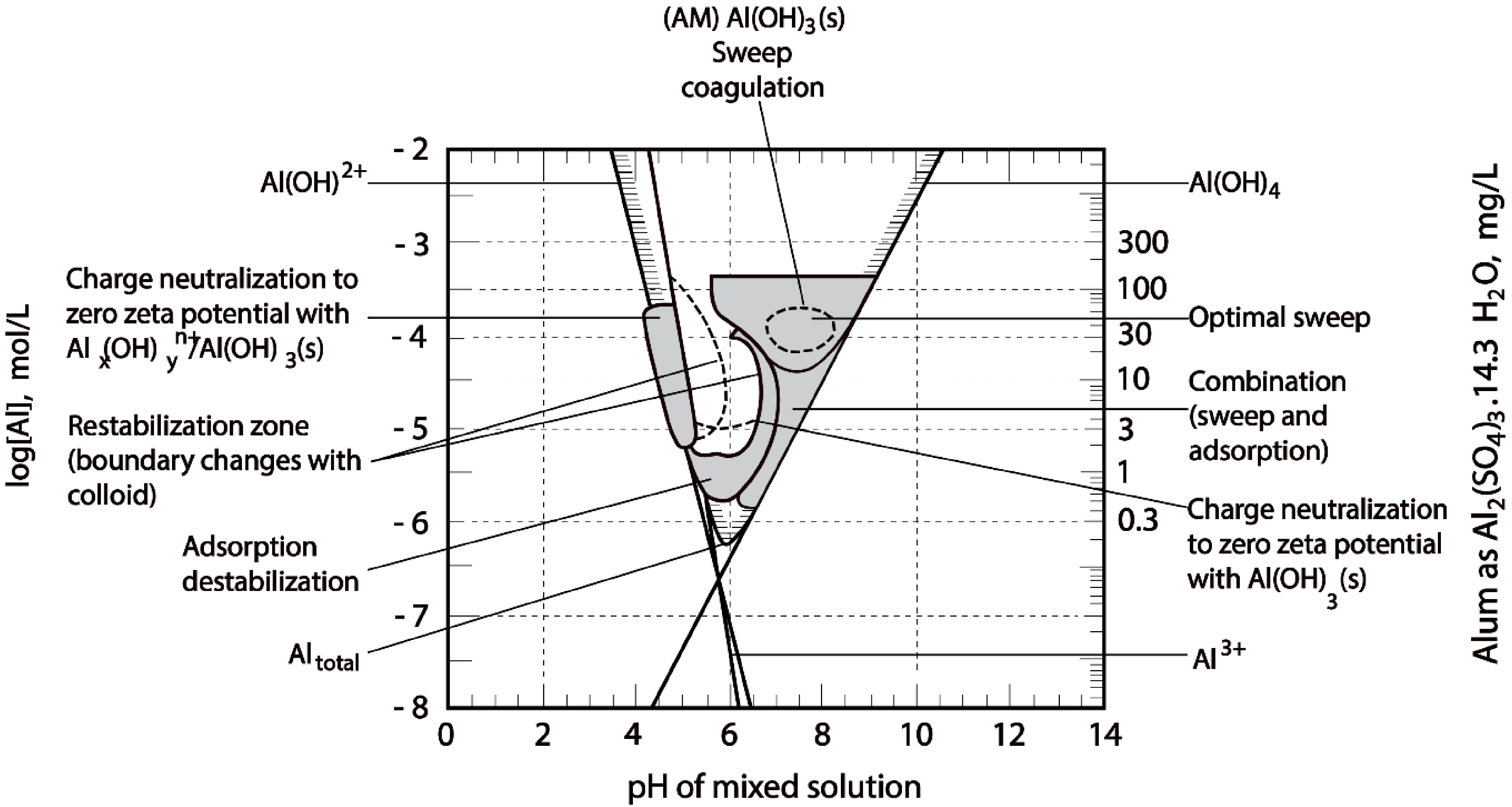
Particle deposition on surfaces requires particle destabilization





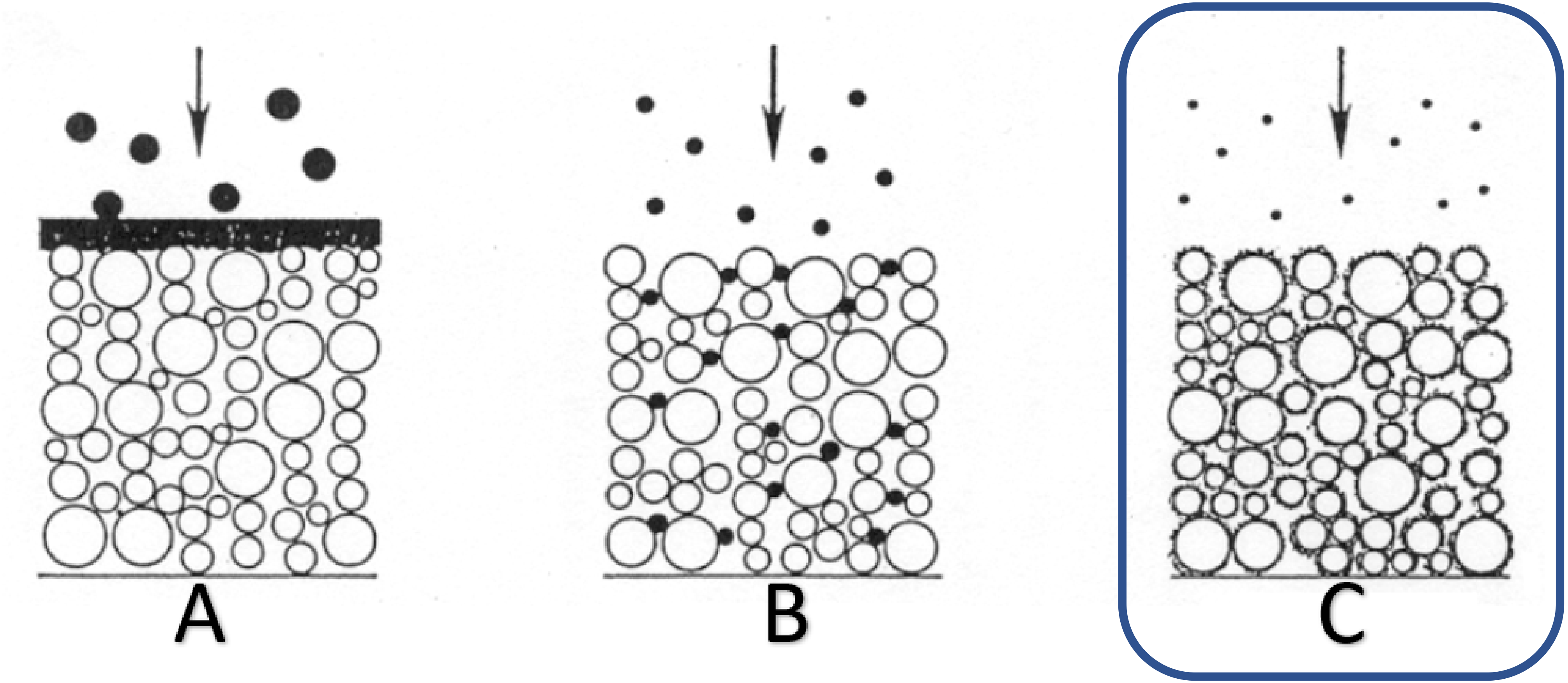
This pertains to the attachment aspect of filtration

Particle destabilization is achieved by coagulation

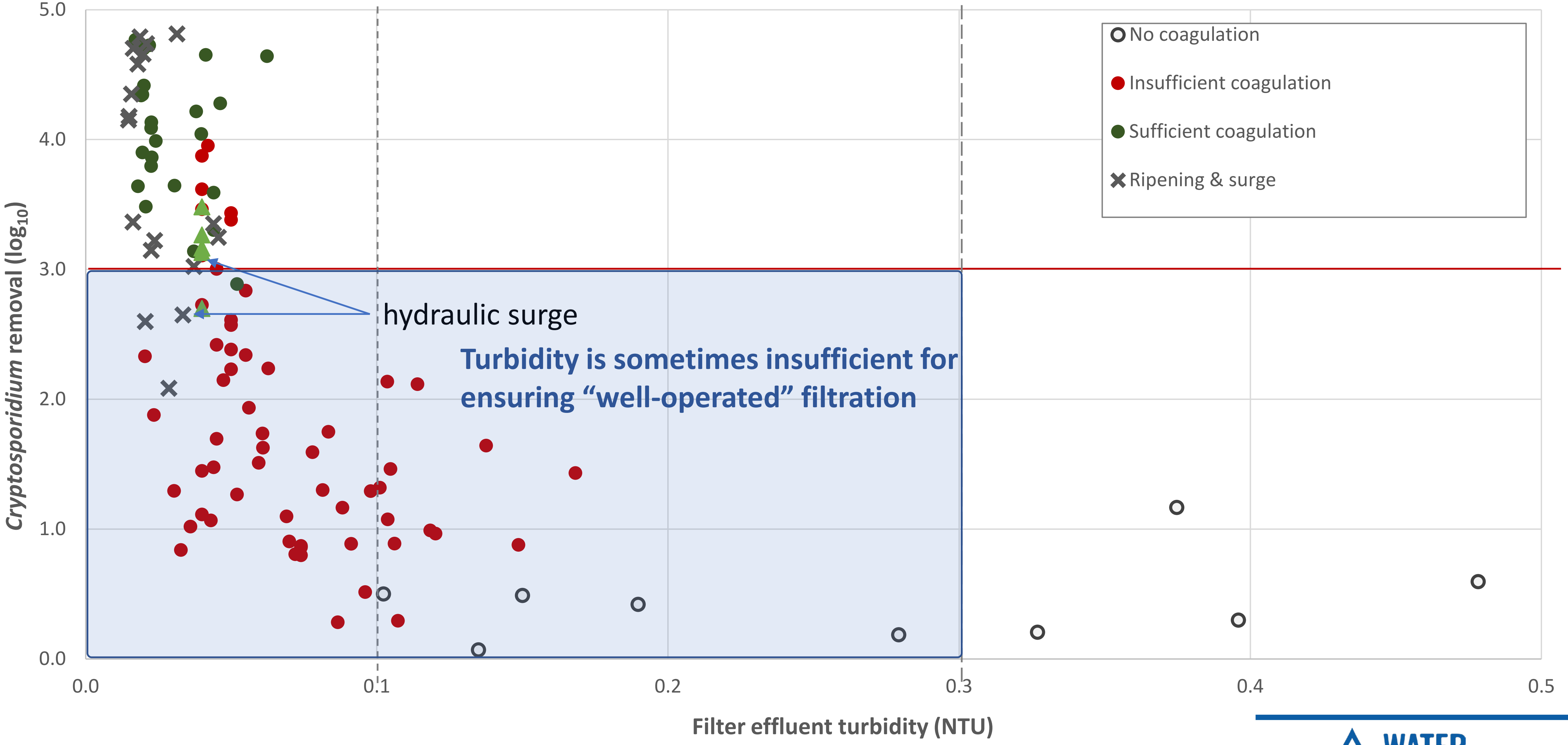


Adapted from Amirtharajah & Mills (1982) as cited in Crittenden et al. (2012)

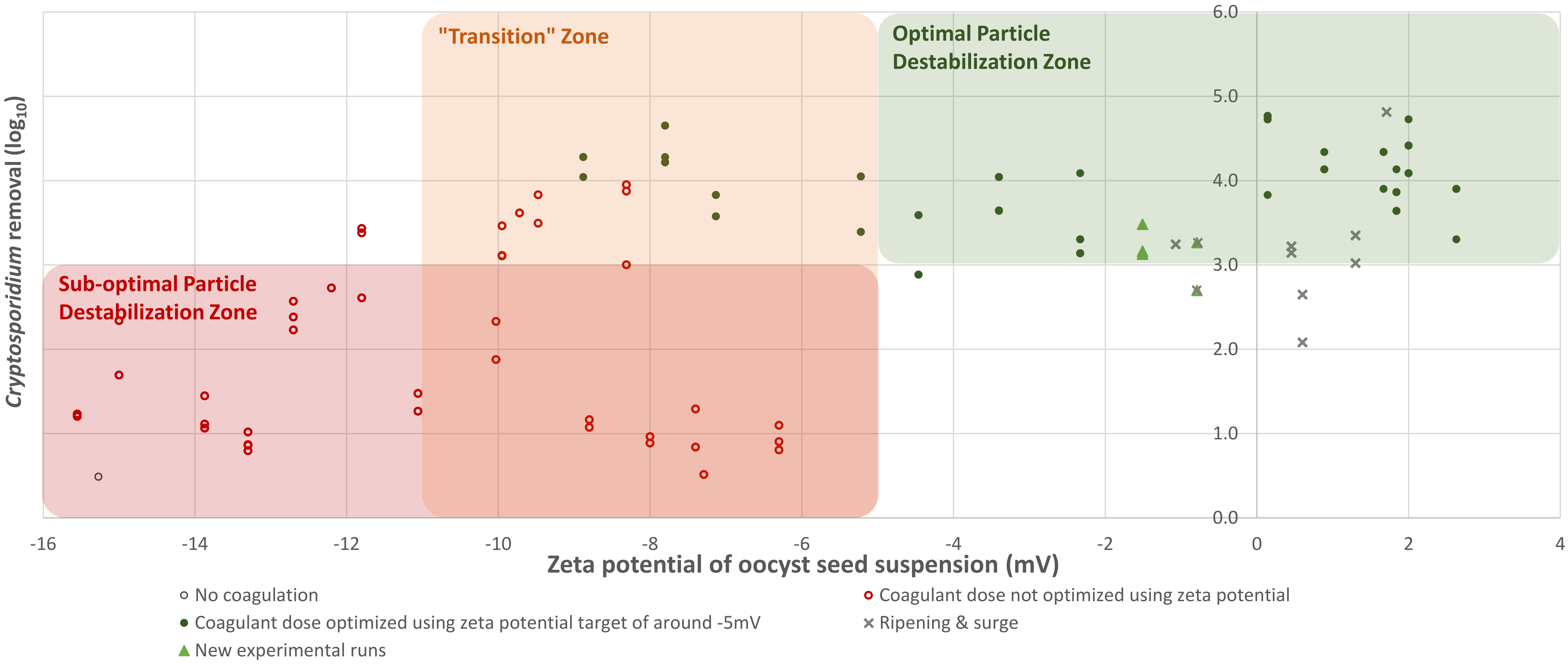
Filtration: Sometimes called “Chemically-assisted Filtration” (CAF)



Low CAF effluent turbidity does not guarantee ≥3-log oocyst removal

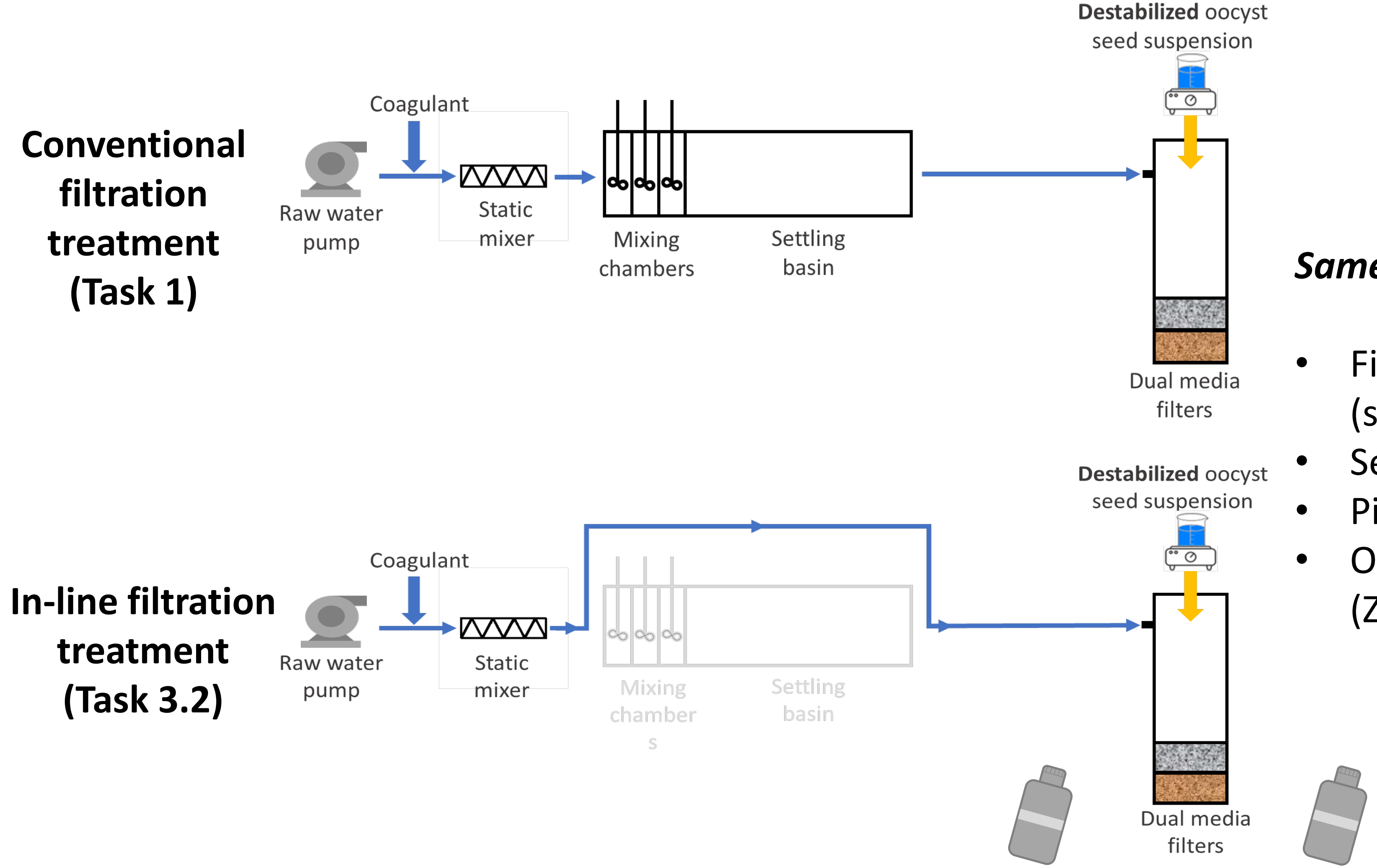


WRF 5110: *C. parvum* removal by CAF during various operational periods



WATER STP

WRF 5110: Performance Comparison: Optimal Oocyst Destabilization



Same experimental conditions:

- Filter configurations (shallow/deep)
- Seeding protocol
- Pilot coagulant dose
- Oocyst seed suspension ZP (Zero point of charge ± 5 mV)

Resilience in Risk Management

Received: 17 May 2023 | Revised: 8 September 2023 | Accepted: 20 September 2023
DOI: 10.1002/aws2.1357

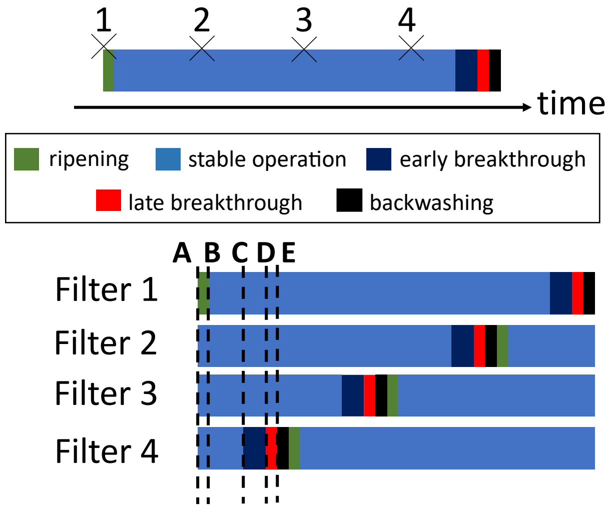
ORIGINAL RESEARCH

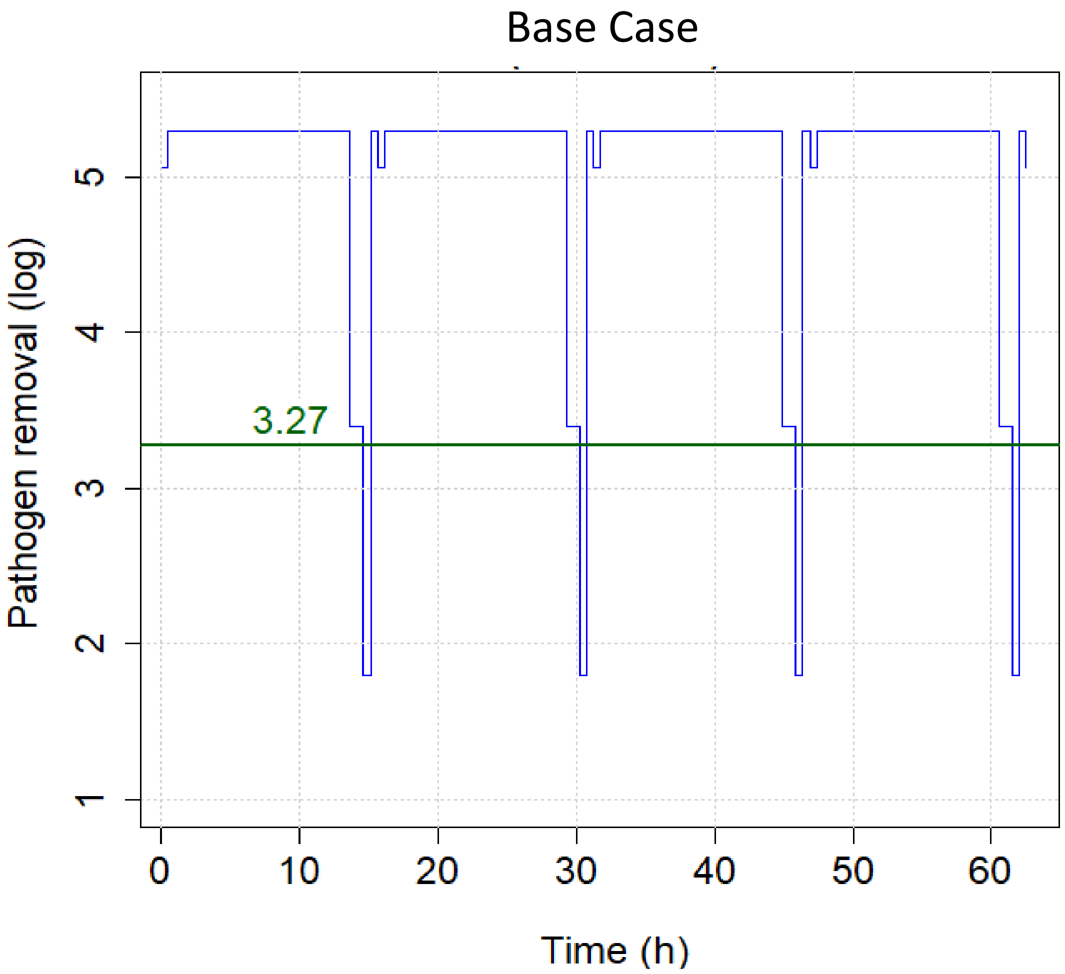
AWWA WATER SCIENCE

Filter operation effects on plant-scale microbial risk: Opportunities for enhanced treatment performance

Dafne de Brito Cruz[1] | Trevor J. Brown[1,2] | Chao Jin[1,3] | Kelsey L. Kundert[4] | Norma J. Ruecker[4] | Liza Ballantyne[5] | Philip J. Schmidt[1] | William B. Anderson[1] | Monica B. Emelko[1]

[1]Department of Civil and Environmental Engineering, University of Waterloo, Waterloo, Ontario, Canada
[2]Region of Waterloo, Waterloo, Ontario, Canada
[3]School of Environmental Science and Engineering, Sun Yat-Sen University, Guangzhou, Guangdong, China
[4]The City of Calgary, Calgary, Alberta, Canada
[5]Toronto Water, Toronto, Ontario, Canada





Resilience in Risk Management: It's time to rethink our targets!

Received: 17 May 2023 | Revised: 8 September 2023 | Accepted: 20 September 2023
DOI: 10.1002/aws2.1357

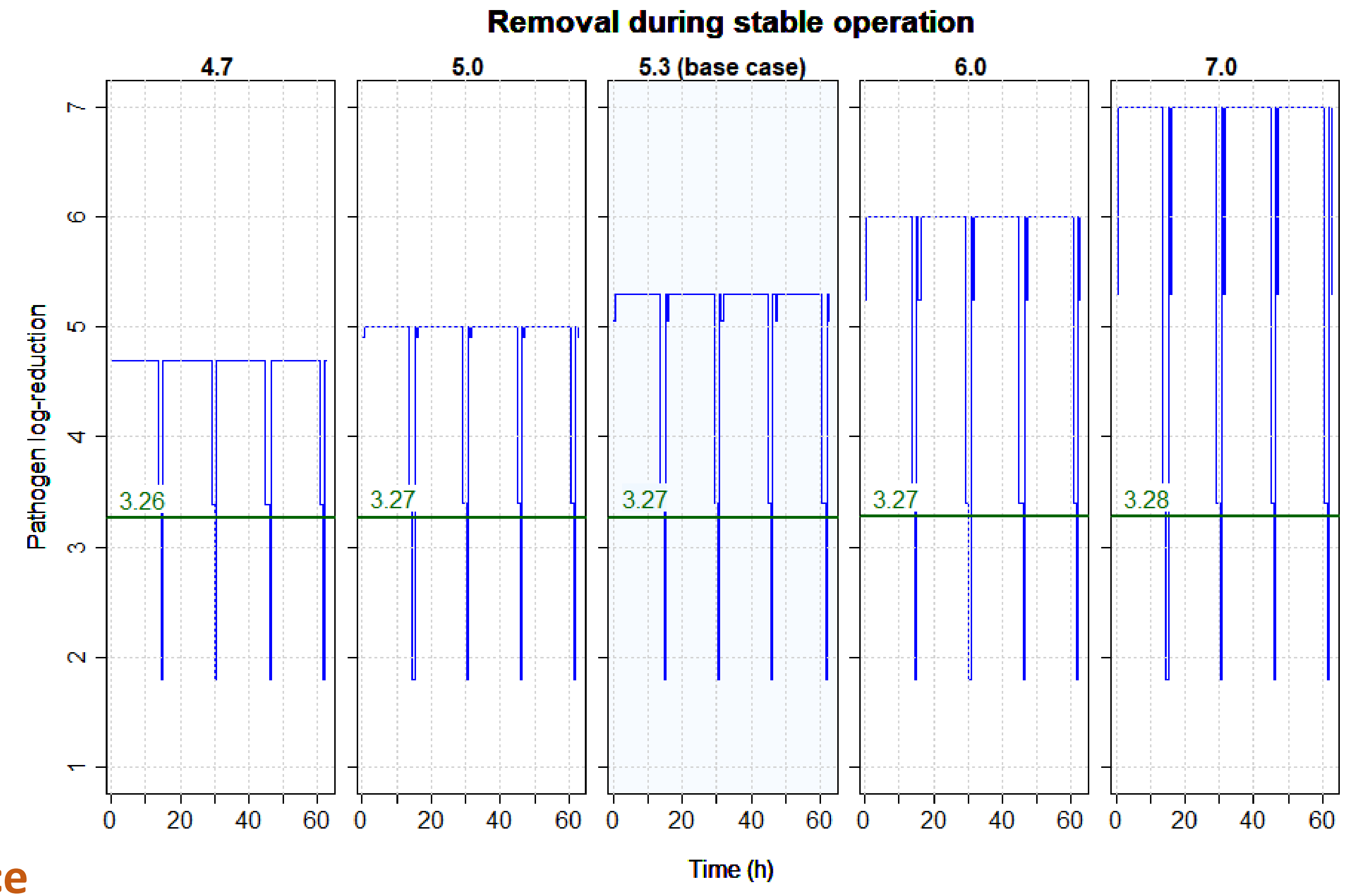
ORIGINAL RESEARCH

AWWA WATER SCIENCE

Filter operation effects on plant-scale microbial risk: Opportunities for enhanced treatment performance

Dafne de Brito Cruz[1] | Trevor J. Brown[1,2] | Chao Jin[1,3] | Kelsey L. Kundert[4] | Norma J. Ruecker[4] | Liza Ballantyne[5] | Philip J. Schmidt[1] | William B. Anderson[1] | Monica B. Emelko[1]

[1]Department of Civil and Environmental Engineering, University of Waterloo, Waterloo, Ontario, Canada
[2]Region of Waterloo, Waterloo, Ontario, Canada
[3]School of Environmental Science and Engineering, Sun Yat-Sen University, Guangzhou, Guangdong, China
[4]The City of Calgary, Calgary, Alberta, Canada
[5]Toronto Water, Toronto, Ontario, Canada



Focusing on increasing individual filter performance (beyond a minimum threshold) typically has a negligible impact on plant-scale performance!

Significant Findings & Implications to Water Industry

(1) Filter effluent turbidities of 0.3 NTU, 0.1 NTU, or lower do not *ensure* 3-log removal of *Cryptosporidium* by CAF without optimal particle destabilization by coagulation

(2) "Well-operated" (and designed) CAF plants sufficiently optimized for particle removal *should* be capable of achieving 3-log removal of *Cryptosporidium* oocysts… and microplastics

(3) Zeta potential analysis is very useful for ensuring that coagulant dosing is sufficient for achieving particle/pathogen destabilization and 3-log (or higher) removal of *Cryptosporidium*, microplastics, and other colloidal particles by CAF

(4) In Toronto, post-coagulation zeta potential of ~-4 to -5 mV (or closer to the zero point of charge) appears to indicate sufficient coagulant addition for particle destabilization such that at least 3-log removal of oocysts is achieved by chemically-assisted filtration

Significant Findings & Implications to Water Industry

(5) Treatment of particulate contaminants (e.g., microplastics) should be considered in the broader, established mechanistic context of treatment processes.

(6) Holistic risk management approaches (e.g., plant-scale microbial risk assessment) are essential to developing

(7) Well-operated inline filtration appears to achieve oocyst removals that are equal to or higher than those achieved by conventional filtration

(8) Well-operated inline/direct) filtration likely deserve 3-log oocyst removal credit

(9) Increasingly variable source water quality can be expected in a changing climate. Even in systems such as the Great Lakes! Tools for ensuring treatment process, operational resilience, to these changes, and associated risk management will be integral to ensuring public health protection from waterborne disease in the future

Acknowledgments

Toronto · Calgary · The Water Research Foundation

WRF Project 5110 Filtration Process Control for Pathogen Removal & Climate Change Adaptation

Alberta Innovates · NSERC CRSNG

Partners

- Alberta
- Alberta Innovates
- Balsillie School of International Affairs
- BC Centre for Disease Control
- Canadian Water Network
- Canfor
- Calgary
- City of Guelph
- COST European Cooperation in Science & Technology
- CRD Making a difference...together
- Dalhousie University
- eawag aquatic research
- Environment Canada
- EPCOR
- ERG
- Halifax Water
- Health Canada / Santé Canada
- McMaster University
- National Collaborating Centre for Environmental Health / Centre de collaboration nationale en santé environnementale
- Natural Resources Canada / Ressources naturelles Canada
- Canada
- Nova Scotia
- NSERC CRSNG
- Ontario
- Public Health Agency of Canada / Agence de la santé publique du Canada
- Region of Waterloo
- Regional Municipality of Wood Buffalo
- Rothamsted Research
- SFU Simon Fraser University
- Southern Rockies Watershed Project
- SLS Spray Lake Sawmills
- TU Wien Technische Universität Wien Vienna | Austria
- Toronto
- Trent University
- University of Alberta
- UBC The University of British Columbia
- University of Calgary
- uOttawa
- UNICAMP
- Vancouver Island University
- Veolia
- the water Institute University of Waterloo
- The Water Research Foundation
- West Fraser
- Weyerhaeuser
- forWater NSERC Network for Forested Drinking Water Source Protection Technologies

WATER STP

Thank you

Monica B. Emelko

mbemelko@uwaterloo.ca

www.waterstp.ca