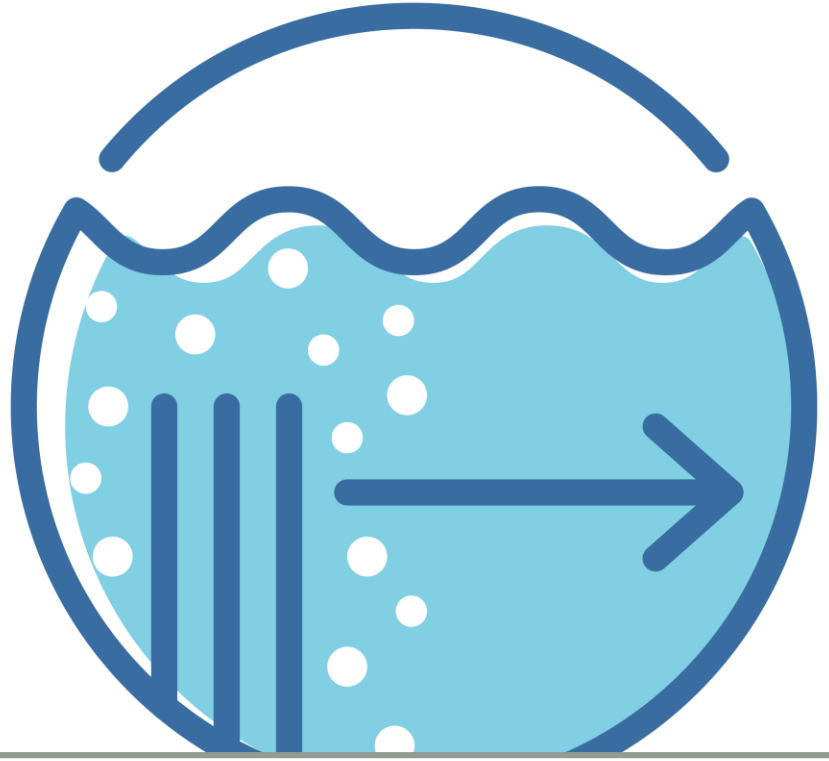
July 24, 2020

Enhanced Bacterial Removal with MBRs

TO DISINFECT OR NOT TO DISINFECT



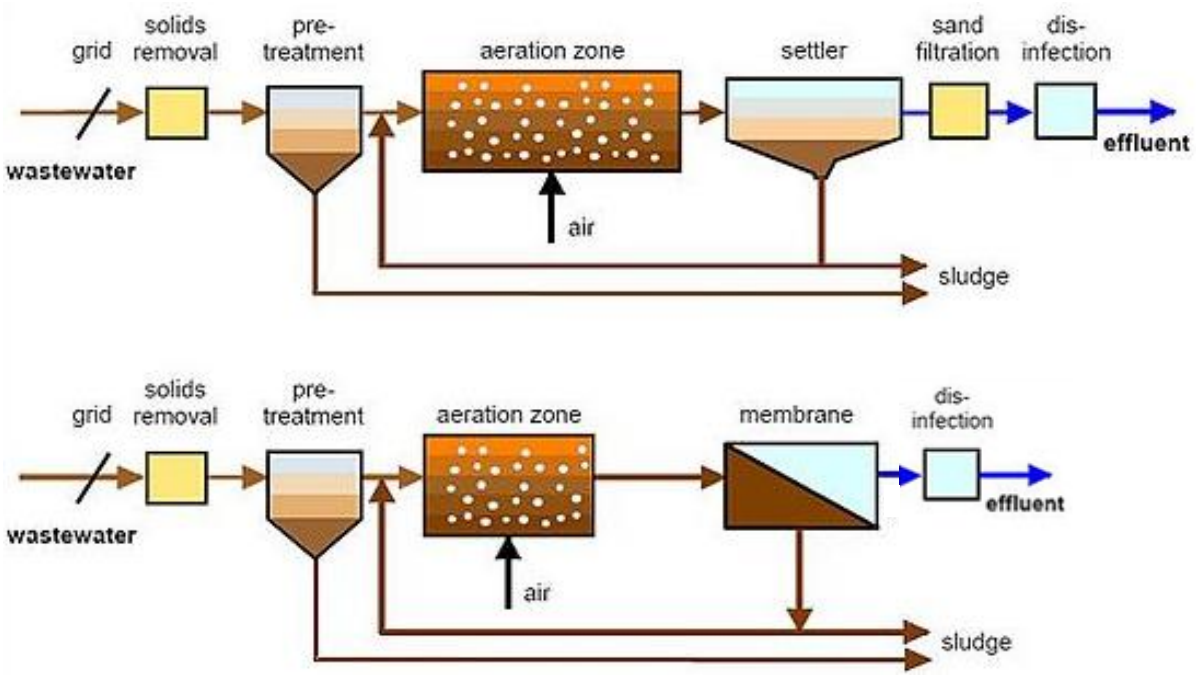
Brown AND Caldwell

Kati Bell, Ph.D., P.E.
Director of Water Strategy
615.250.1256
KBell@BrwnCald.com

Jose Jimenez, Ph.D., P.E.
Senior Process Specialist
407.661.9514
JJimenez@BrwnCald.com

What is an MBR?

- Membrane bioreactor (MBR) combines a membrane process like MF or UF with the activated sludge process.



- MBR characteristics
  - Highly screened flow (2mm or less)
  - High SRT >8 days (full nitrification)
  - High MLSS: 8,000 – 12,000 mg/L
  - High RAS flow 2 – 4 x Q
  - Flux rate 9 – 17 gpd/ft^2

Hollow fiber (SUEZ)

Flat plate (OVIVO and Kubota)

Where do MBRs fit into our industry?

- Key benefits
  - Small footprint
  - Provides treatment intensification
  - Excellent for retrofits
  - Modular expansion capability
  - High effluent quality
  - Eliminates sludge settle-ability issues
  - Highly automated operations
  - Neighbor friendly
- Secondary benefits
  - Removal of a variety of trace organic compounds
  - Potential to meet bacterial compliance with reduced disinfection costs

Johns Creek Environmental Campus, GA – 15 MGD

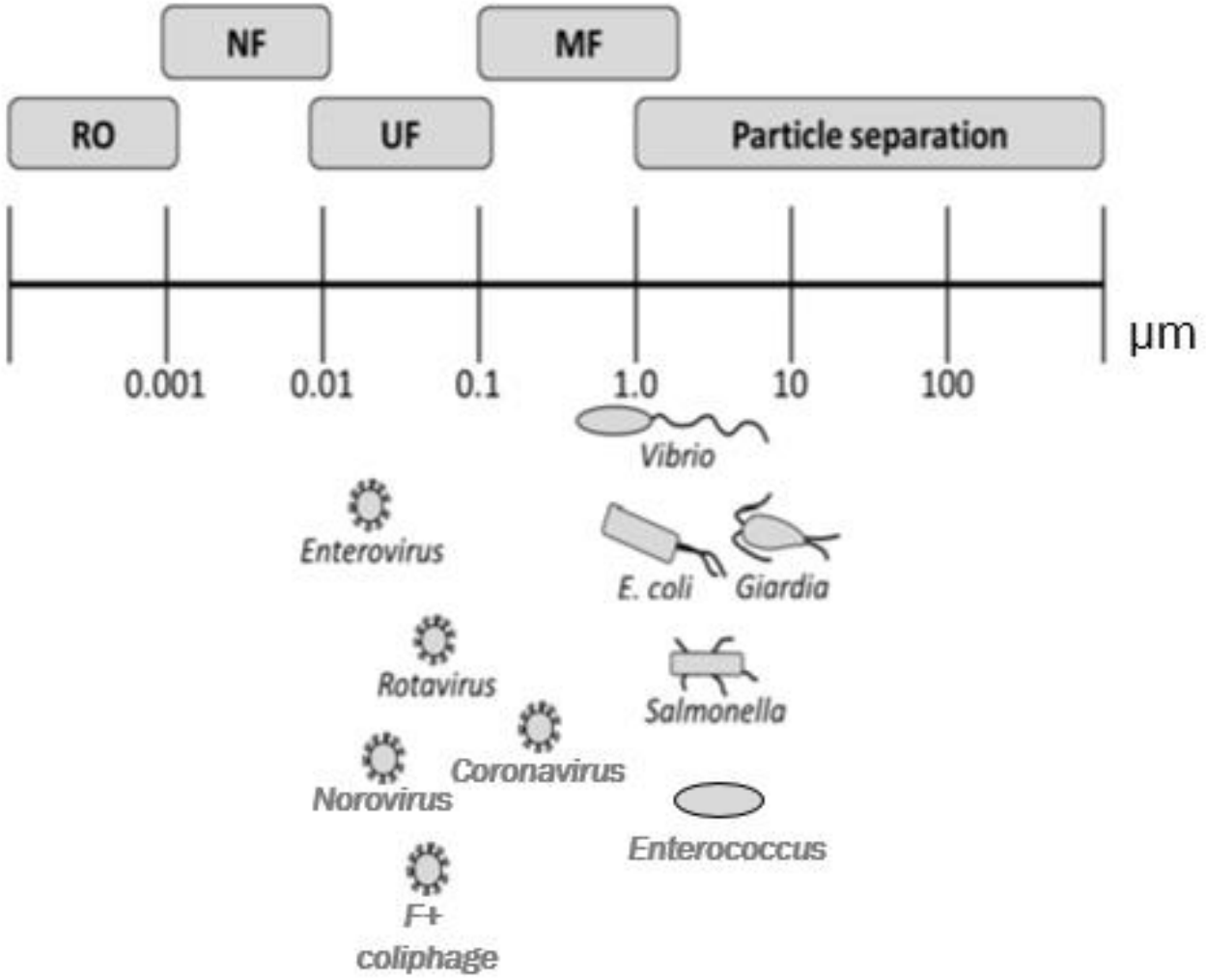
BC has installed over 40 MBRs with > 200 MGD capacity

- The MBR process was introduced by the late 1960s, but high cost and fouling issues limited its application to small flows.
- The breakthrough for the MBR came in 1989 with submerged membranes in the bioreactor where coarse bubble aeration provides both aeration and mixing, limiting fouling, it also reduced energy consumption by nearly 2 orders of magnitude.

Lighthouse Point WWTP, Blaine WA – 1.5 MGD

MBRs can achieve removal of SS, protozoa, and bacteria

- Removal of viruses and phages
- Pathogen removal through
  - Spontaneous decay
  - Aggregation/biosorption
  - Predation/biodegradation
  - Membrane rejection by size exclu
    - Norovirus (27 – 38nm)
    - Rotavirus (~75nm)
    - Coronavirus (~120nm)
    - *E. coli* (~0.5 x 1.0um)
    - Enterococcus (0.6 x 2.5um)
    - *Cryptosporidium* (4.2 – 5.4um)
    - *Giardia* (8 – 14um)

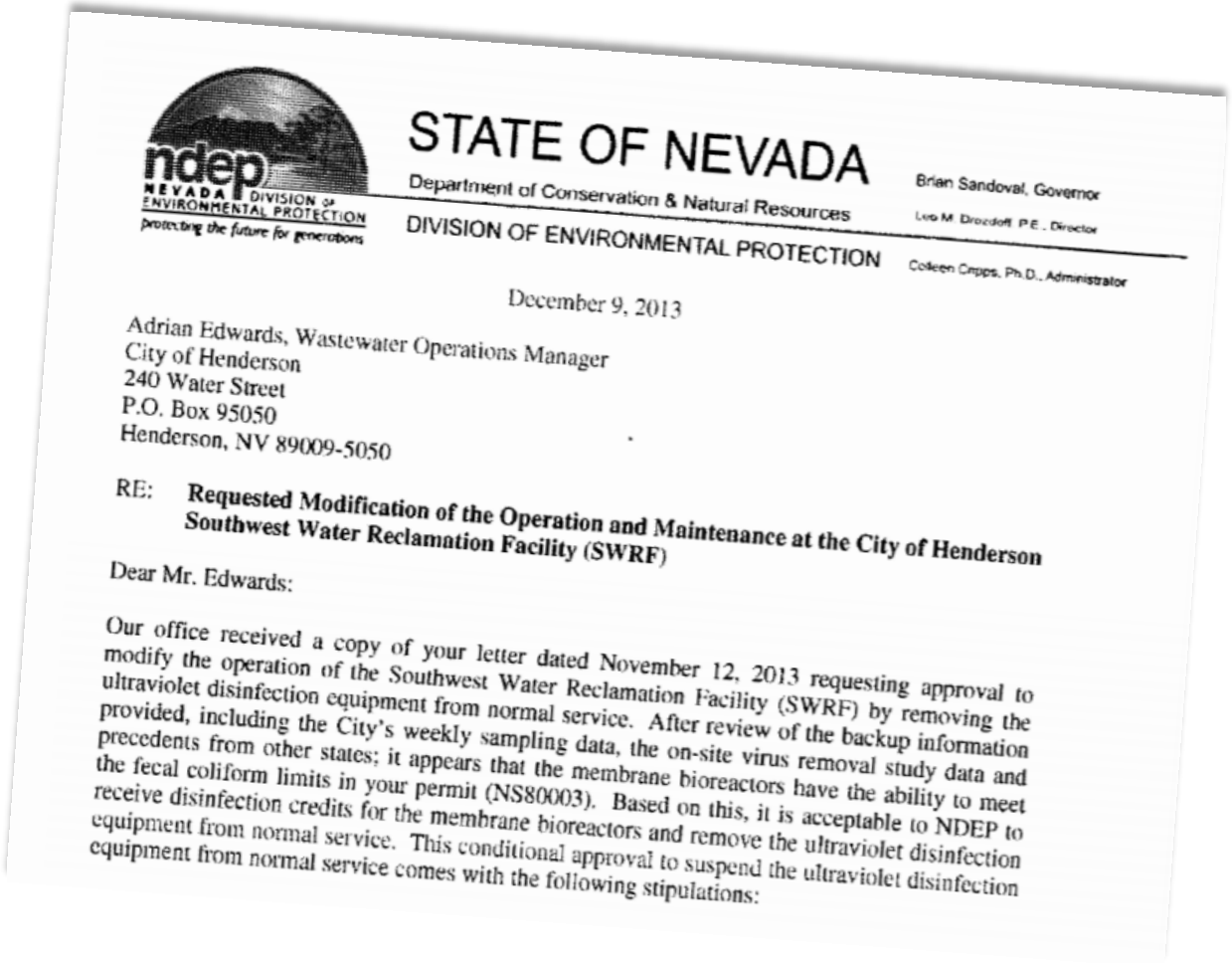


Using MBRs to achieve disinfection is not a new concept

- Hutchinson Wastewater Treatment Facility (MN) – **Effluent Discharge**
  - Implemented MBR in 2008
  - Testing conducted on bacteria discharge compliance w/o disinfection.
- Fecal coliform and *E. coli* in the MBR effluent was negligible
- Minnesota Pollution Control Agency granted permission to bypass UV

Using MBRs to achieve disinfection is not a new concept

- City of Henderson (NV) – **Reuse**
  - Nevada DEP allowed bypass of UV system for reclaimed water
  - Testing demonstrated both bacteria and virus (surrogate) removal
- Post-chlorination is still maintained to prevent biofilm growth in the reclaimed water system
- Facility bypasses UV system
- MBR system continues to meet permit requirements for bacteria



STATE OF NEVADA

Department of Conservation & Natural Resources — Brian Sandoval, Governor

DIVISION OF ENVIRONMENTAL PROTECTION — Leo M. Drozdoff, P.E., Director; Colleen Cripps, Ph.D., Administrator

December 9, 2013

Adrian Edwards, Wastewater Operations Manager
City of Henderson
240 Water Street
P.O. Box 95050
Henderson, NV 89009-5050

RE: **Requested Modification of the Operation and Maintenance at the City of Henderson Southwest Water Reclamation Facility (SWRF)**

Dear Mr. Edwards:

Our office received a copy of your letter dated November 12, 2013 requesting approval to modify the operation of the Southwest Water Reclamation Facility (SWRF) by removing the ultraviolet disinfection equipment from normal service. After review of the backup information provided, including the City's weekly sampling data, the on-site virus removal study data and precedents from other states; it appears that the membrane bioreactors have the ability to meet the fecal coliform limits in your permit (NS80003). Based on this, it is acceptable to NDEP to receive disinfection credits for the membrane bioreactors and remove the ultraviolet disinfection equipment from normal service. This conditional approval to suspend the ultraviolet disinfection equipment from normal service comes with the following stipulations:

Why do we provide disinfection of wastewater effluent?

- Disinfection of wastewater aims to inactivate pathogenic organisms, to the extent necessary to protect public health.
- Disinfection is NOT equivalent to sterilization - the elimination of all microbes - it is a risk reduction measure.
- Disinfection treatment objectives are set appropriate with the end use of the resource.

Current federal Ambient Water Quality Criteria

- CWA addresses microbials for protection of human health
  - Surface water quality for drinking water source
  - Recreational uses
  - Aquatic food source uses
- EPA 2012/2017 Recreational Water Quality Criteria

CRITERIA ELEMENTS	**Recommendation 1** Estimated Illness Rate 36/1,000		**Recommendation 2** Estimated Illness Rate 32/1,000	
Indicator	GM (cfu/100 mL)	STV (cfu/100 mL)	GM (cfu/100 mL)	STV (cfu/100 mL)
Enterococci (marine & fresh)	35	130	30	110
E. coli (fresh)	126	410	100	320

National Pollutant Discharge Elimination System (NPDES)

- Limits for microbial indicators are typically enforced at the “end-of-pipe” based on AWQC
- EPA has provided murky guidance
  - Ephraim King Letter (2008)
  - Prohibition on mixing zones for bacteria in primary contact recreation waters
  - States may still use mixing zones

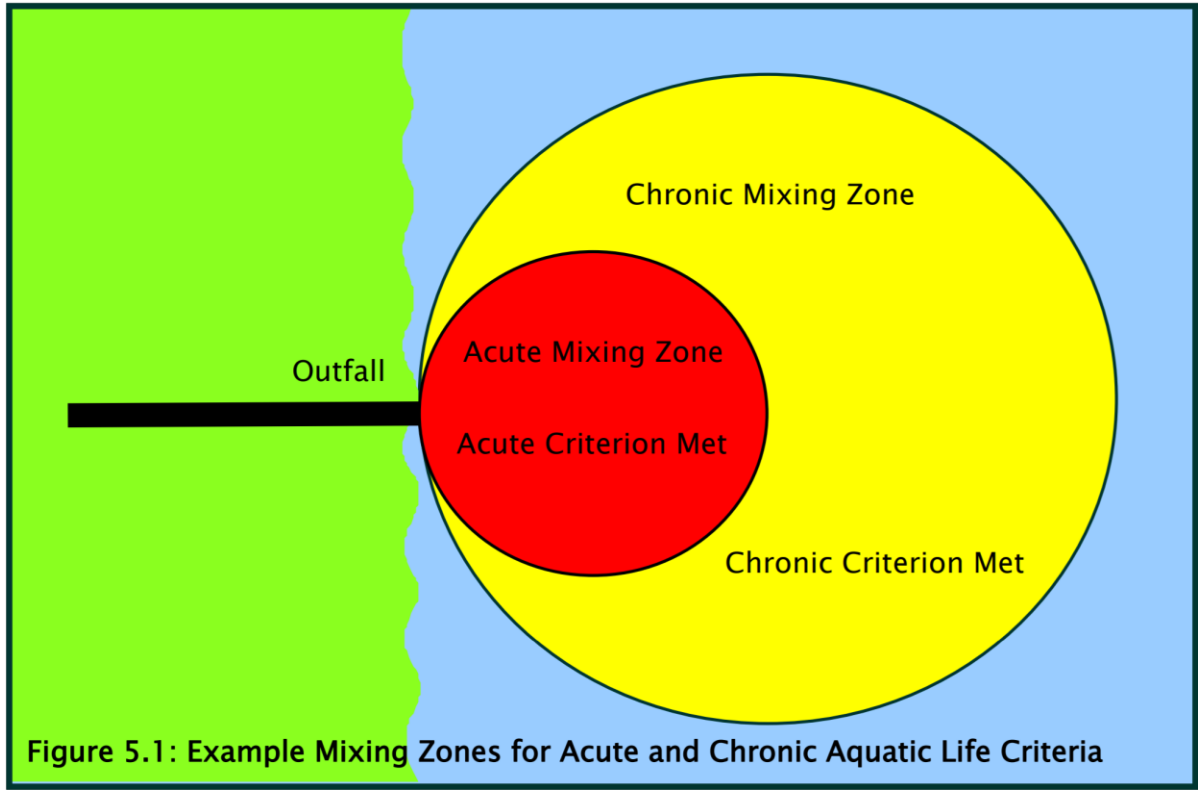
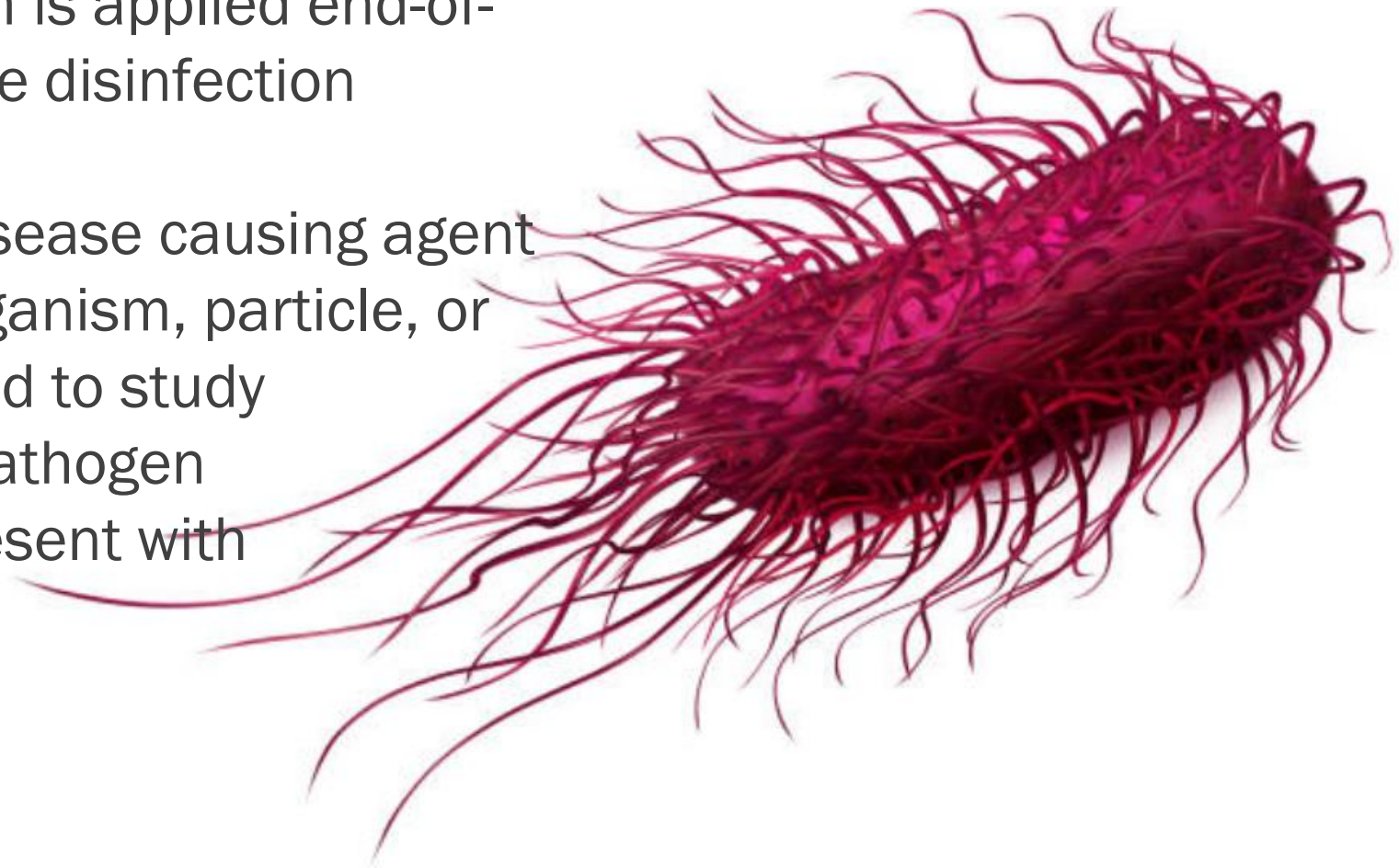


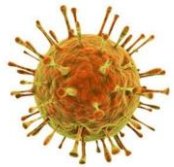
Figure 5.1: Example Mixing Zones for Acute and Chronic Aquatic Life Criteria

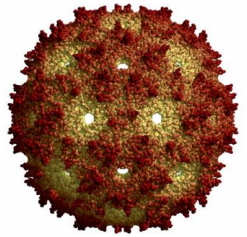
http://water.epa.gov/scitech/swguidance/standards/handbook/

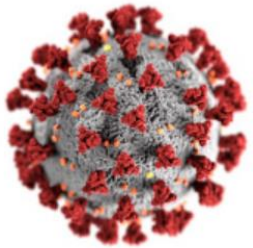
Why do we rely on bacteria for AWQC?

- EPA WQC use bacteria as an indicator which is applied end-of-pipe to manage disinfection compliance
- Pathogen – disease causing agent
- Surrogate - organism, particle, or substance used to study the fate of a pathogen
- Indicator – present with pathogens



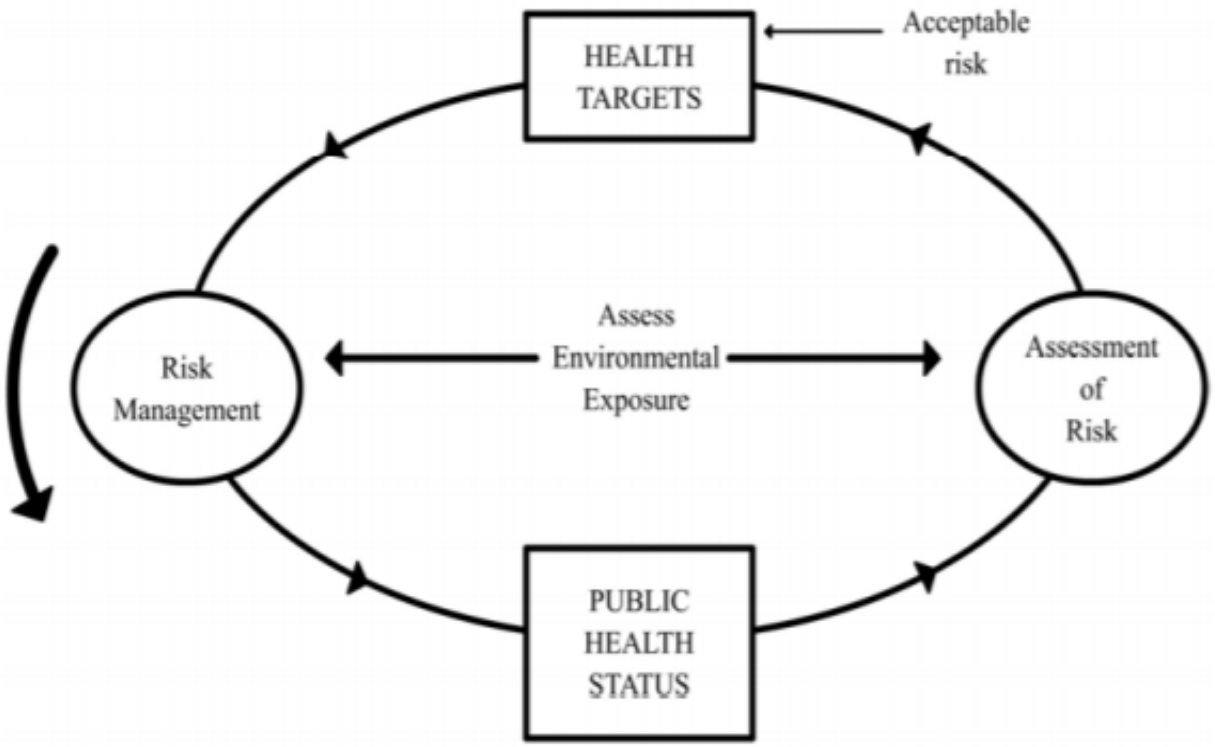






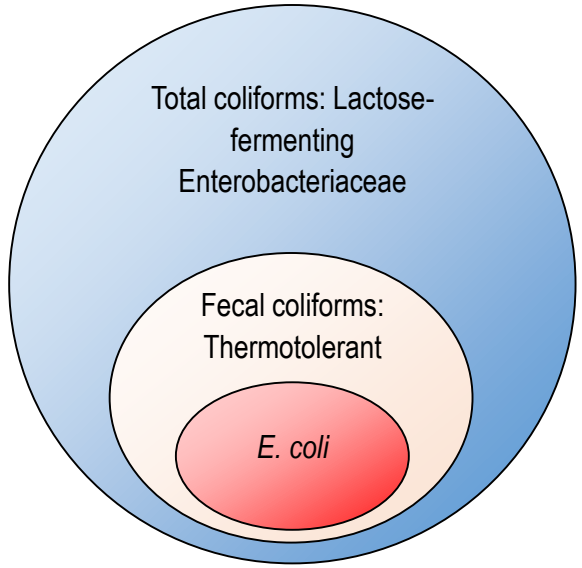
An ideal indicator organism has special characteristics

- Present in feces of warm-blooded animals
- Present with pathogens, and absent in uncontaminated samples
- Present in greater numbers than pathogen in the environment
- At least as resistant as the pathogen to environmental factors and disinfection
- Do not multiply in the environment
- Detected by easy, rapid methods
- Nonpathogenic
- Correlated to health risk
- Specific to a fecal source



Why do we use bacteria as an indicator?

- Federal criteria for total coliform were proposed in 1968 by the National Technical Advisory Committee (Department of the Interior) 1940's and 1950's studies; total coliform <2300/100 ml
- 1986 - EPA Ambient Water Quality Criteria for Bacteria
  - Fecal coliform < geometric mean of 200/100 ml
  - < 8 illness per 1,000 swimmers at freshwater beaches
  - <19 illness per 1,000 swimmers at marine beaches
  - Enterococcus was added for monitoring marine waters



- 2000 Beaches Environmental Assessment and Coastal Health
  - Monitoring for coastal beaches (including Great Lakes)
  - Evaluation of water quality at coastal beaches by use of the 1986 criteria, required by 2004
  - No changes to inland water monitoring

What was new and different in the 2012 RWQC

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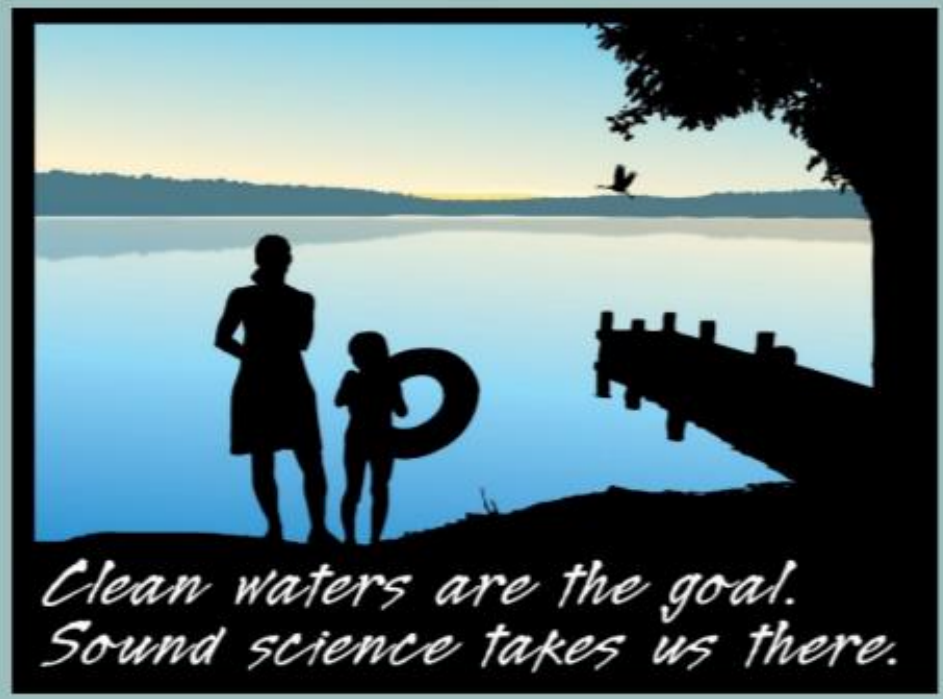
Why do we use bacteria as an indicator?

Five-Year Review of the 2012 RWQC

On May 4, 2018, EPA published its five-year review of the 2012 RWQC as required by BEACH Act amendments to the CWA (2000). It included an assessment of the state of the science and advances made since 2010. Based on the review, EPA decided not to revise the 2012 Recreational Water Criteria during this cycle. EPA believes, however, that further research and analysis will contribute to EPA's future review of the 2012 RWQC.



EPA is thinking about a virus criteria

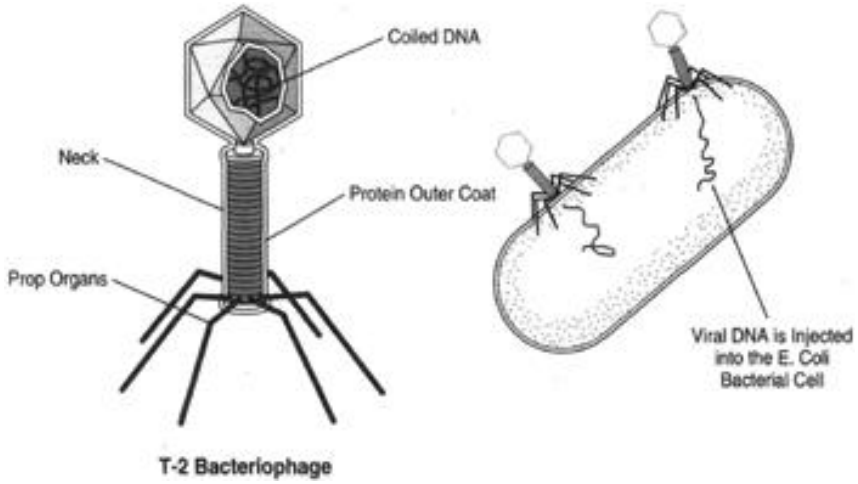
"EPA researchers are investigating the potential use of coliphage as a viral indicator for RWQC applications. Viruses cause many illnesses associated with primary contact recreation in surface waters. Compared to bacteria, viruses are typically much smaller and more persistent through wastewater treatment and in environmental waters. Coliphages may be useful for evaluating surface water quality because they may exhibit numerous desirable indicator characteristics…"

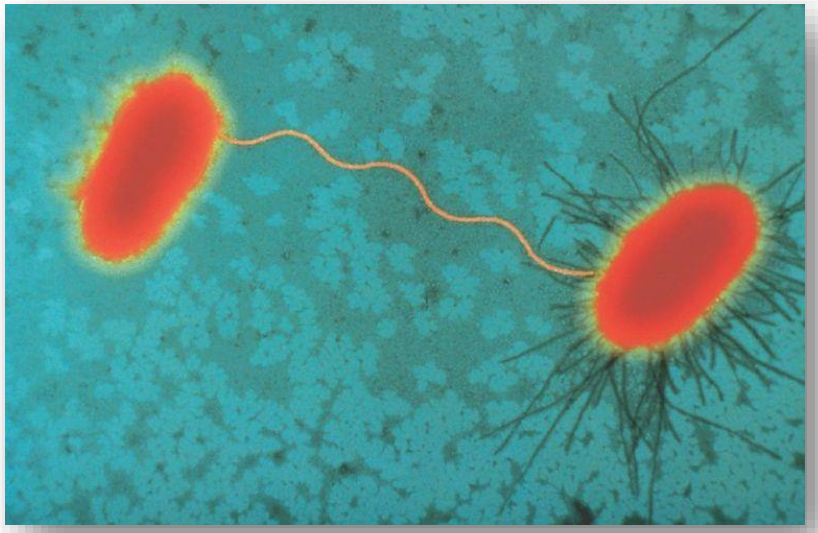
https://www.epa.gov/water-research/research-support-and-implement-recreational-water-quality-criteria-rwqc

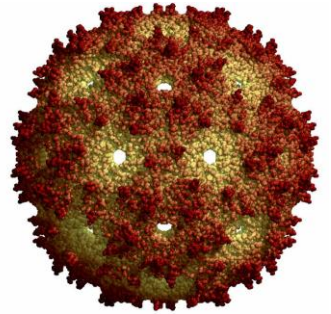
What are bacteriophage?

Bacteriophages are viruses that that infect and replicate within coliform bacteria. There are three groups of interest:

- Male-specific coliphages infect only *E. coli* bacteria that express physical appendages (pili) used during sexual conjugation
- Somatic coliphages which adsorb directly to the *E. coli* cell wall
- Phages infecting *Bacteroides fragilis*







http://www.eplantscience.com/index/introduction_to_botany/t_2_bacteriophage.php

Coming soon: Ambient water quality criteria for viruses

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

Date	Milestone
2015 – 2017	Review of Coliphages as Possible Viral Indicators for Ambient WQ Listening sessions/webinars Expert Workshop Proceedings published
2017 – 2019	Analytical method development and multi-laboratory validation for coliphage Report on 5–year review of Ambient WQC Continued research on occurrence data and risk assessments (QMRA)
2020	Publication of DRAFT coliphage criteria; external review – COVID DELAY
2022	Publication of FINAL coliphage criteria; 5-year review report required by CWA
Future	Adoption in state WQ standards (triennial review cycle) Incorporation in NPDES permits (5-year permit cycle)

Technical discussion on implementation is ongoing

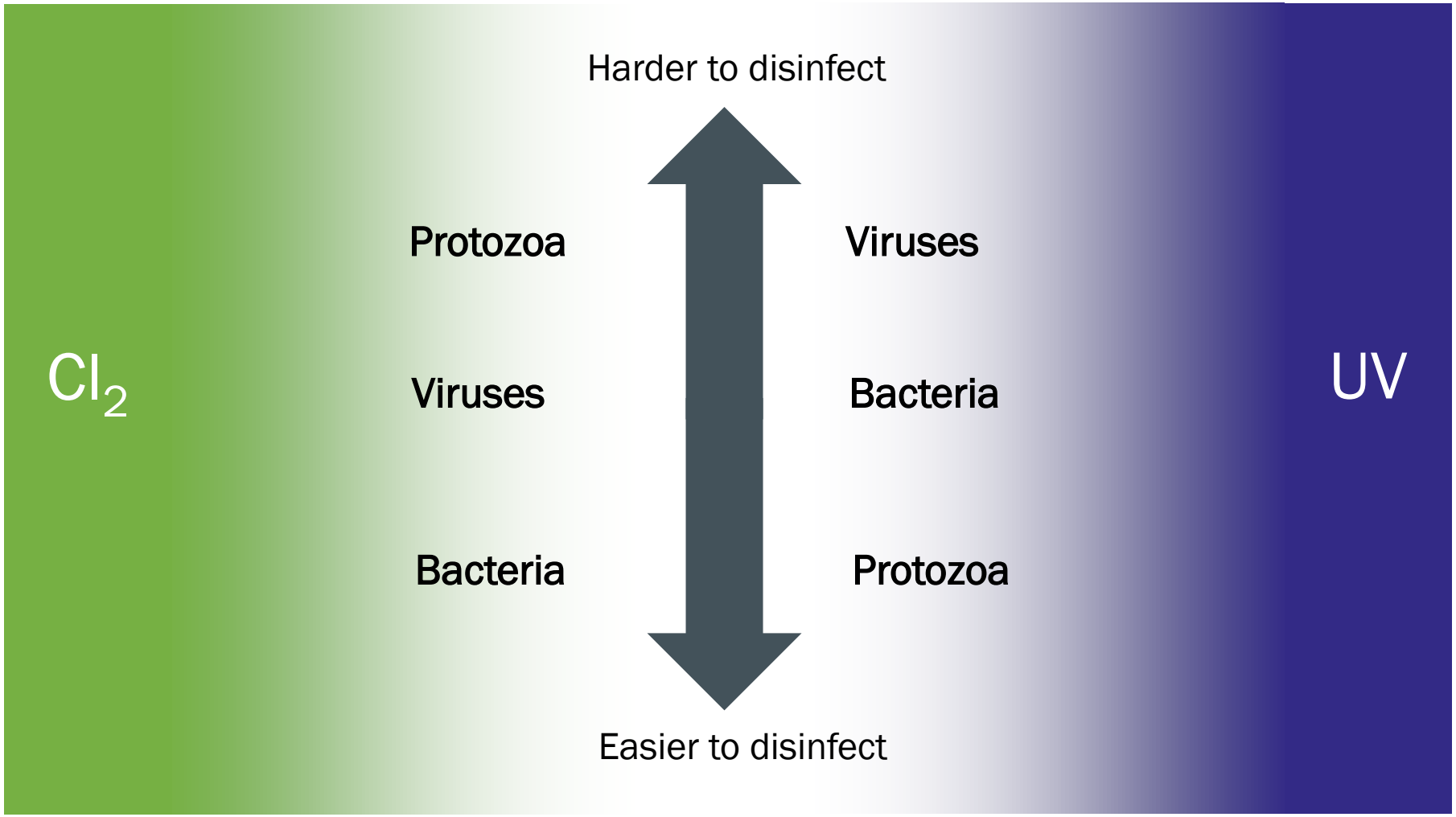
…at beaches with **point sources** of sewage contamination, FIB correlate better with the incidence of disease in bathers than coliphages (Wade et al., 2010). At beaches with **unknown sources or nonpoint sources** of fecal contamination, the presence of coliphages has correlated with onset of diseases more often than the presence of FIB (Colford et al., 2007; Abdelzahel et al., 2011).

Wade, T.J., Sams, E., Brenner, et al. (2010). Rapidly measured indicators or recreational water quality and swimming-associated illness at marine beaches: A prospective cohort study. *Environmental Health*, 9: 66.

Colford, J.M., Jr., Wade, T.J., Schiff, K.C., et al. (2007). Water quality indicators and the risk of illness at beaches with nonpoint sources of fecal contamination. *Epidemiology*, 18(1): 27-35.

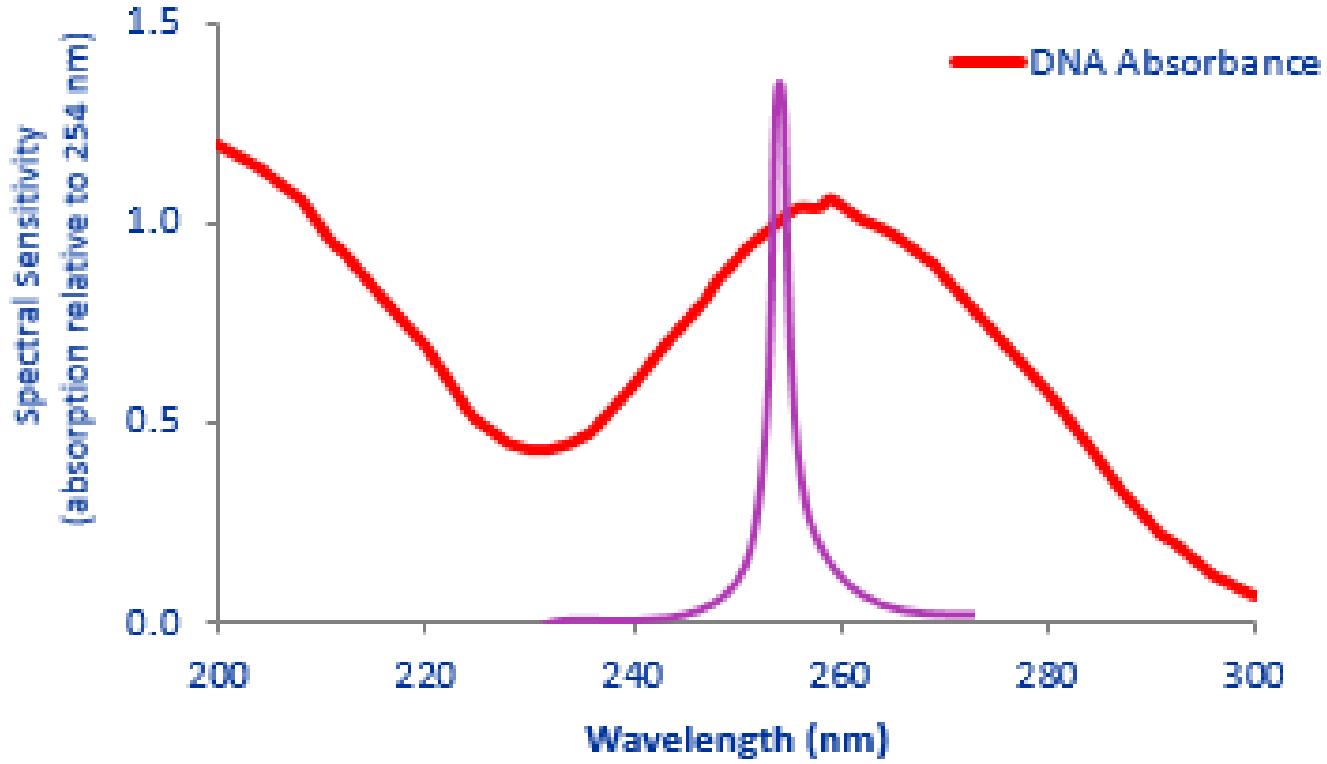
Abdelzaher, A.M., Wright, M.E., Ortega, et al. (2011). Daily measures of microbes and human health at a non-point source marine beach. Journal of Water and Health, 9(3): 443-457.

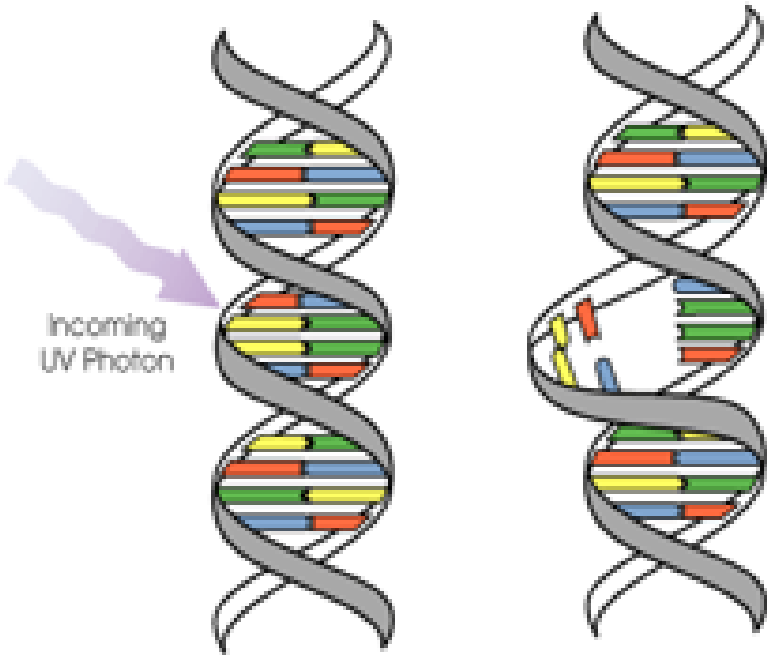
Addressing disinfection compliance could be difficult



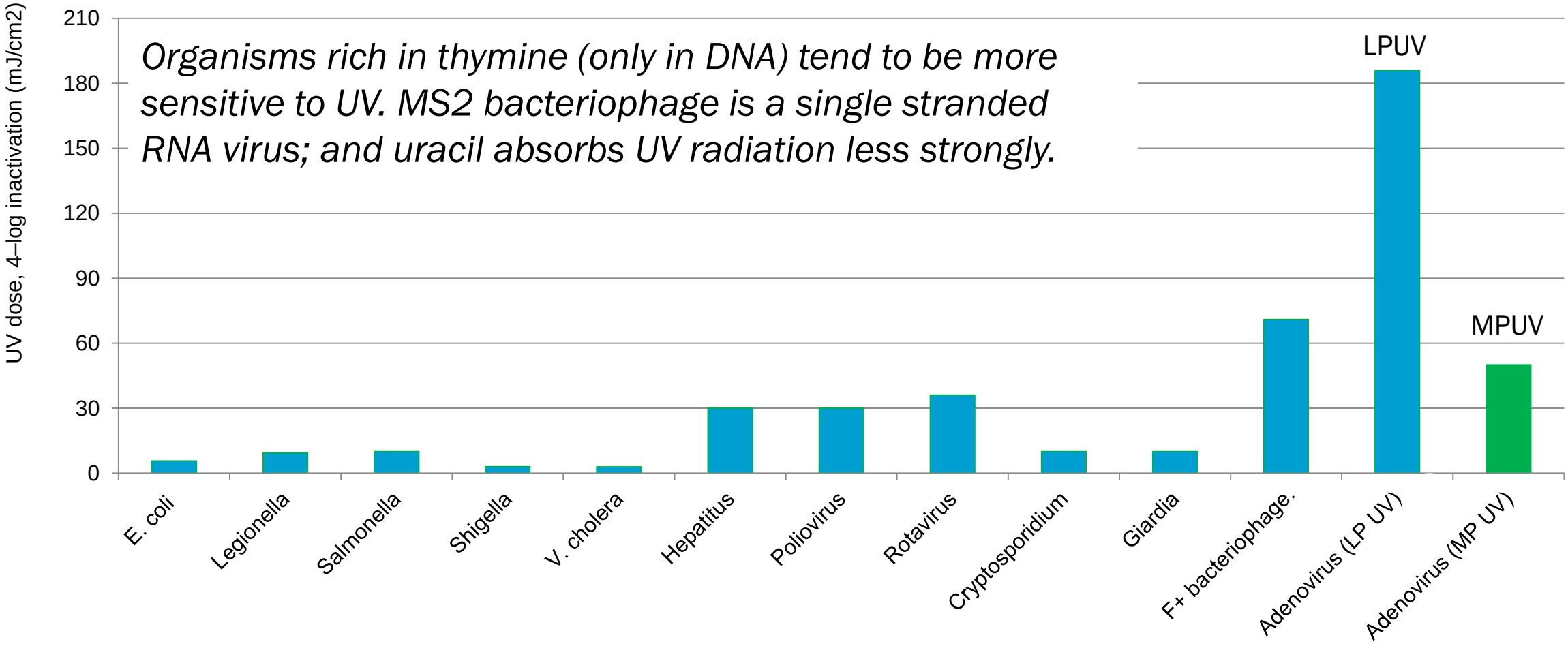
UV (irradiation) Disinfection

- Germicidal action of UV is a result of photochemical reactions
- Nucleic acid absorption/reactions are10 - 20X greater than for proteins



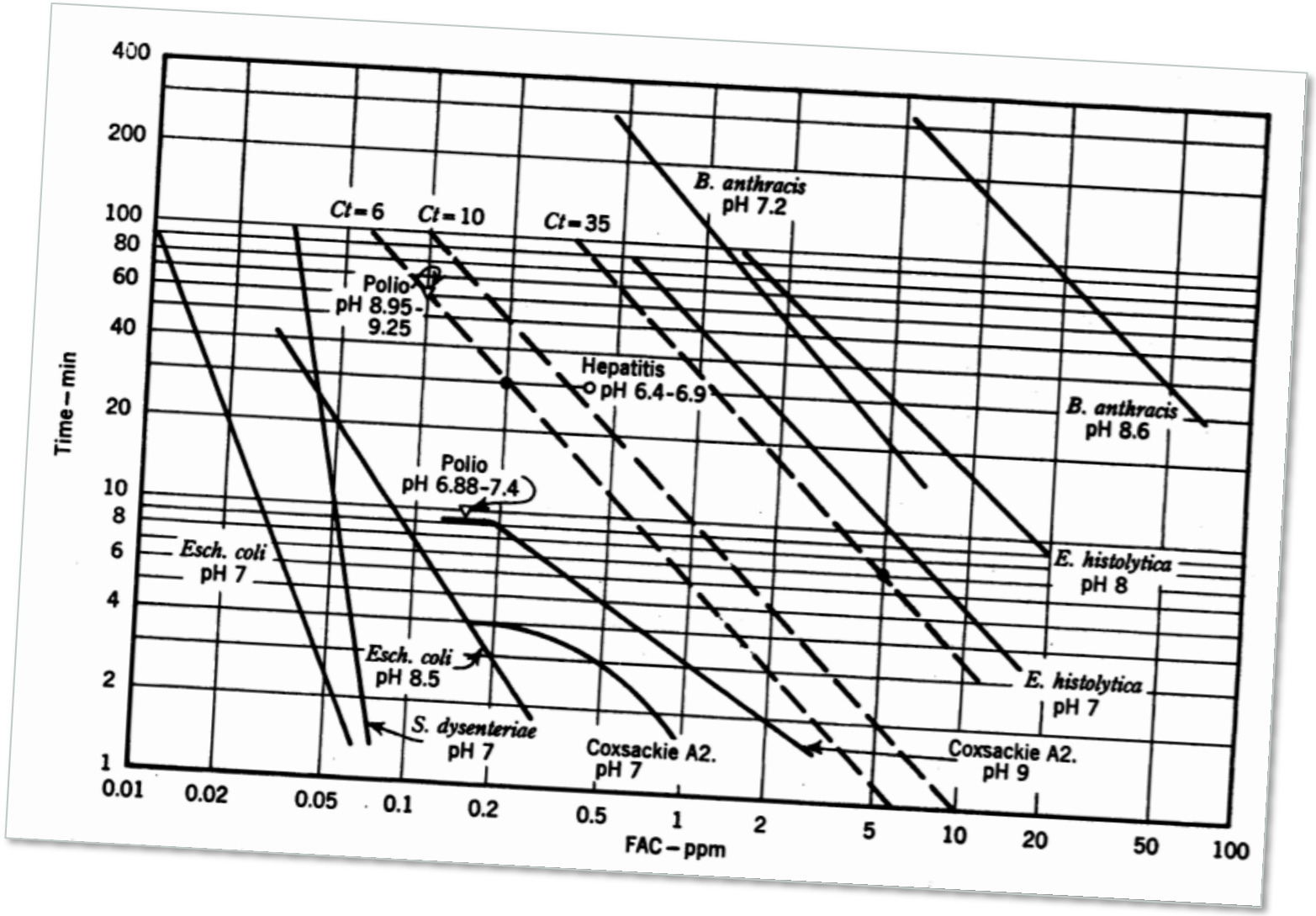


What does this mean for UV disinfection?



Chlorine disinfection

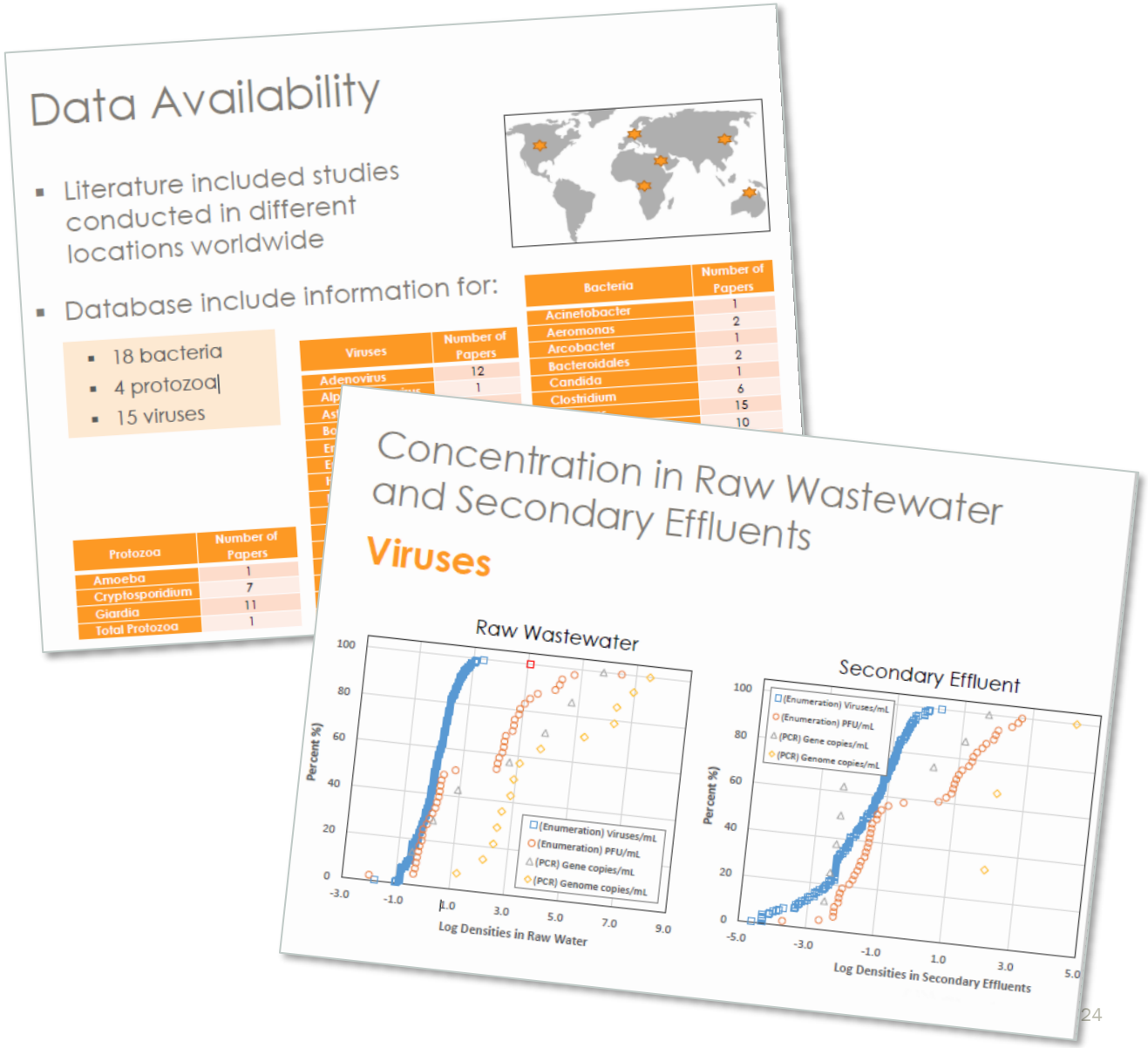
- Assuming MBR provides full nitrification, free chlorine is mechanism of disinfection
- CT table for 3-log removal of pathogens with FAC (in drinking water)
- Baumann and Ludwig (1954) JAWWA, 54:1397



We do not know virus concentrations in wastewater

Project WERF 14-02

- Limited data is available on virus concentrations in wastewater
- Description of wastewater quality and operations are often lacking in literature
- Data on climate conditions or outbreaks are often not well characterized
- Quantification methods vary from study to study, and details are often not entirely reported



We do know that MBRs are effective at removing viruses, but they have variable performance

- Virus removal through MBRs is generally better than CAS
- Factors affecting virus removal through MBRs
  - Membrane material, pore size and flux
  - Membrane cleaning
  - Membrane imperfections and/or breaches

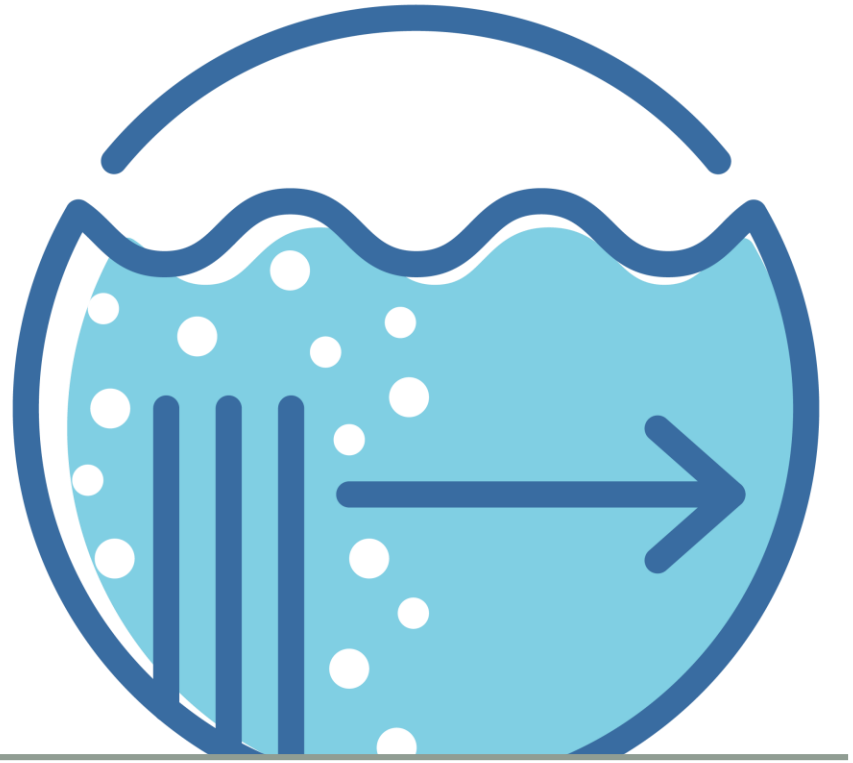
Table 4. Reported virus removal in full-scale wastewater treatment plants (WWTP).

Virus	Log Removal	
	Conventional WWTP	MBR
Adenovirus	1.3–2.4 [a]	3.4–5.6 [b]
Enterovirus	0.44–3.6 [c]	3.2–6.8 [d]
Norovirus I	−0.2–2.7 [e]	0–5.5 [f]
Norovirus II	−1.6–3.0 [g]	2.3–4.9 [h]

- While virus spiking studies are the gold standard for assessing virus removal, there are challenges because spiked viruses often behave differently than native viruses due to particle (floc) association.

Summary

- MBRs provide excellent wastewater treatment
- MBRs are not just for small flows, they can be cost-effective for many larger applications
- Reduction or elimination of disinfection, post-MBR is a site-specific decision that should consider ongoing monitoring
- A bacteriophage criteria could challenge the viability of MBR for disinfection



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