Alternate Indicator Organisms for Reclaimed Water in North Carolina

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ABSTRACT

New reclaimed water rules that include limits for multiple microbial indicator organisms went into effect in North Carolina in 2011. One of the primary updates in these new rules is the establishment of two classes of reclaimed water: Type 1 is the less stringent class that is analogous to the older reclaimed water standard, and Type 2 is the higher quality reclaimed water, which requires the use of dual disinfection and which has additional permissible uses and stricter treatment requirements to protect public health. For Type 2 reclaimed water, the rules require treatment plants to provide a minimum 6 log reduction for *E. coli*, 5 log for coliphage, and 4 log for *Clostridium perfringens* in addition to single-digit concentration limits. To the author's knowledge, no other US state currently uses coliphage and *C. perfringens* as indicator organisms for reclaimed water regulatory compliance.

This paper reviews published data from various plants in the United States on the effectiveness of municipal wastewater treatment for removing or inactivating these alternate indicator organisms, as well as new data from one of the larger producers of reclaimed water in the state of North Carolina, the City of Raleigh. Data from the published studies suggest that relatively high disinfection doses may be required to meet Type 2 reclaimed water standards; however, the data from the City of Raleigh show that the Raleigh treatment plant would likely meet Type 2 microbial concentration standards with their current reuse regime of UV followed by sodium hypochlorite.

The published data suggest that an MS2 Reduction Equivalent Dose (RED) of 100 mJ/cm^2 may be required to meet the *C. perfringens* requirements for Type 2 reclaimed water, if the 4-log overall reduction requirement is met with 2-log inactivation by UV and 2-log removal by upstream processes. In this example, the energy required for Type 1 reclaimed water assuming basic UV disinfection with an MS2 RED of 30 mJ/cm^2, is less than one third the energy required to treat Type 2 reclaimed water with an MS2 RED of 100 mJ/cm^2.

KEYWORDS

Reclaimed water, reuse, coliphage, *Clostridium perfringens*, North Carolina, disinfection, UV, sodium hypochlorite

INTRODUCTION

Planned water reuse in North Carolina began in 1988 with the irrigation of several golf courses near the coast with treated wastewater (Safrit 2010). The rules initially established in the late 1980s underwent several iterations as interest in reclaimed water increased, especially during drought years. The most recent round of reclaimed water rules in North Carolina were adopted in 2011 and are referred to as the 2U rules, named after the North Carolina Administrative Code section 15A NCAC 2U that replaces previous reclaimed water regulation.

One of the key changes in the 2U rules was the establishment of two classes of reclaimed water. Type 1 is the lower quality class, which is equivalent to the previous reclaimed water standard in North Carolina. Typical uses of this class of water include irrigation of golf courses, ball fields, and crops such as corn for animal feed. Type 1 reclaimed water has microbial limits based either on *E. coli* or fecal coliform. Type 1 microbial standards are actually slightly less strict than the previous standard since *E. coli* is a subset of fecal coliform and the Type 1 limits have the same numerical criteria as the previous rules, which only included fecal coliform. Table 1 shows the microbial indicator concentration limits for both classes of reclaimed water. Each class also has limits for BOD_5, TSS, ammonia, and turbidity.

Table 1: North Carolina Reclaimed Water Microbial Indicator Requirements

Indicator	**Type 1 Concentration (Monthly Geo. mean/daily max.)**	**Type 2 Concentration (Monthly Geo. mean/daily max.)**	**Type 2 Log Reduction Required**
E. coli or fecal coliform	14 / 25 CFU/100mL	3 / 25 CFU/100mL	6 log
Coliphage	N/A	5 / 25 PFU/100mL	5 log
C. perfringens	N/A	5 / 25 CFU/100mL	4 log

Type 2 reclaimed water is the higher class of reclaimed water, and it has additional approved uses such as wetland augmentation and non-contact irrigation of food chain crops. This class of water must meet stricter microbial indicator organism limits for *E. coli* and also has strict microbial limits for the indicator organisms coliphage and *C. perfringens*.

While *E. coli* and fecal coliform are commonly used indicator organisms both in the United States and worldwide, coliphage and *C. perfringens* are not typically used for regulatory purposes in the United States. *E. coli* and fecal coliform are bacterial indicator organisms and are relatively easy to inactivate with chlorine and UV disinfection.

Coliphage has been used in academia for many years as a viral indicator. They are viruses that infect *E. coli* bacteria, and are thus relatively easy and safe to quantify. Coliphages are classified as either somatic or male specific (F+) depending on the type of *E. coli* they infect. Somatic coliphage attaches to the cell wall of *E. coli*, while male specific coliphage attacks “male” strains of *E. coli* with pili. Coliphages, and viruses in general, are much smaller than bacteria or

protozoan pathogens, and this may affect what treatment processes in a wastewater plant are effective for removing or inactivating them.

Clostridium perfringens is a spore-forming anaerobic bacterium. It has also been suggested for use as an indicator organism for decades due to the fact that it forms extremely hardy spores that can survive both the environment and wastewater treatment processes. The spores may have some similarities to the cysts and oocysts forms of the protozoa *Giardia lamblia* and *Cryptosporidium*, although *C. perfringens* spores are somewhat smaller. One other difference is that *C. perfringens* spores are very resistant to UV disinfection, while cryptosporidium is inactivated relatively easily by UV.

Many utilities currently producing Type 1 reclaimed water in North Carolina already have advanced wastewater treatment to satisfy NPDES permits and often have secondary disinfection that meets the reclaimed water fecal coliform limits. The disinfection employed at plants that produce reclaimed water is often UV plus a form of chlorine, or chlorine disinfection followed by a second application point for chlorine. Little data from North Carolina is available regarding the ability of the plants to meet the Type 2 concentration and log reduction requirements for coliphage and *C. perfringens,* since these organisms have not previously been used for regulatory purposes in NC. In addition, few local laboratories are qualified and willing to do the analyses for these organisms.

The City of Raleigh currently produces Type 1 reclaimed water at their Neuse River wastewater treatment facility and recently commissioned testing of their reclaimed water to determine if they could meet the Type 2 alternate indicator standards. The Neuse River plant is a 227 mld (60-mgd) facility with primary clarifiers, 5-stage biological nutrient removal, and tertiary deep bed monomedia dentrification filters. The facility has a low pressure, high output horizontal UV system designed for basic disinfection of the entire plant flow, as well as supplemental sodium hypochlorite for the reclaimed water system.

COMPARISON OF PUBLISHED DATA TO TYPE 1 AND 2 REQUIREMENTS

Table 2 compares the North Carolina regulations to the results from a 2004 WERF report (Rose et al) examining six water reclamation facilities in Florida, California, and Arizona.
Only one of the six plants in this study (Plant F) met all of the microbial concentration limits associated with Type 2 reclaimed water in North Carolina. While all of the plants showed 6 log reduction of fecal coliform on average, no plants demonstrated 5 log reduction of coliphage, and only some of the plants could show 4 log reduction of *C. perfringens*. In general, these plants did not demonstrate 5 log removal or inactivation of coliphage because the influent concentration was not 5 logs greater than the detection limit for coliphage in this study. Plant E was the only plant with UV, and while specific dose data was not given, this plant achieved an average of 2-log reduction of *C. perfringens* through their medium pressure UV system.

Data from the WERF study showed that activated sludge and filters generally provided 2- to 3-log removal of both coliphage and *C. perfringens* and 3-to 5-log removal of fecal coliform at the plants in this study. By extension, dual disinfection for Type 2 reclaimed water in North

Carolina could potentially be designed to achieve a minimum of 3 log removal for fecal coliform and coliphage, and 2 log removal for *C. perfringens*. In practice, the design log removal or inactivation may need to be higher to account for higher influent concentrations and variations in water quality and plant operations. Designers should verify specific requirements with state regulators. While fecal coliform and coliphage are relatively easily inactivated using chlorine and/or UV, *C. perfringens* spores are extremely resistant to chlorine disinfection (Linden et al 2004) and require significantly higher UV doses than fecal coliform or coliphage. In addition, many reclaimed water providers use chlorine downstream of UV to provide a residual in the distribution system and do not currently rely on microbial inactivation from chlorine.

Published data show that the required dose to achieve 2 log reduction for *C. perfringens* is approximately 100 mJ/cm^2 (Hijnen et al 2006) while the dose required for 3 log reduction in somatic coliphage is only about 15 mJ/cm^2 (Linden et al 2004).

Table 2: Comparison of Facilities Producing Reclaimed Water From 2004 WERF Study (Rose et al) to North Carolina's Type 1 and Type 2 Reclaimed Water Standards

	NC Type 1 *E. Coli*/ Fecal Coliform Standard (25 CFU/ 100mL max)	NC Type 2 Coliphage Standard (25 CFU / 100 mL max)	NC Type 2 *C. perfringens* Standard (25 CFU / 100 mL max)	>6 log Fecal Coliform Removal	>5 log Coliphage Removal	>4 log *C. perfringens* Removal
Plant A: Activated Sludge, Cloth Filters, Chlorine	Pass	Fail	Pass*	Yes	No#	No
Plant B: Activated Sludge, Traveling Bridge Filters, Chlorine	Pass	Fail	Pass*	Yes	No#	Yes
Plant C: Activated Sludge, Anthracite Filters, Sodium Hypochlorite	Pass	Fail	Fail	Yes	No#	Yes
Plant D: Activated Sludge, Dual Media Filters, Chlorine	Fail	Pass**	Pass	Yes	No#	No
Plant E: Nitrification, Continuous Upflow Filters, UV	Fail	Pass**	Pass	Yes	No#	Yes
Plant F: BNR, Dual Media Filters, Chlorine	Pass	Pass*	Pass	Yes	No#	Yes

*Pass, but some values are over the monthly geometric mean limit
**Limit of detection for coliphage was 10 pfu/100mL in this study; proposed monthly limit is 5 pfu/100mL
>5 log removal coliphage could not be demonstrated since influent counts were generally 10^5 and detection limit was 10

(Adapted From Drummey Stiegel and Mann 2012)

RALEIGH DATA

The City of Raleigh staff at Neuse River collected samples of filter effluent (UV influent) and reclaimed water on several occasions in October, November and December 2012, and tested for total *C. perfringens*, spores of *C. perfringens*, somatic coliphages and F-specific coliphages, as listed in Table 3 and Table 4. On the final two sampling dates, the City also collected samples of UV effluent prior to the application of hypochorite for the reclaimed water, to show the separate effects of the UV disinfection process and hypochlorite on the alternate indicator organisms.

Table 3 – *Clostridium perfringens* in Pre-UV, Effluent, and Reuse Water at Neuse River WWTP

Sample Date	Total *Clostridium perfringens* (microbes per 100 mL)			Spores *Clostridium perfringens* (microbes per 100 mL)		
	Pre-UV	Effluent	Reuse	Pre-UV	Effluent	Reuse
09Oct2012	80	--	<0.3	93	--	<0.3
23Oct 2012	26	--	<0.3	13	--	<0.3
06Nov2012	87	--	<0.3	77	--	<0.3
13Nov2012	73	--	<0.3	97	--	<0.3
04Dec2012	26	21	<0.3	--	--	<0.3
18Dec2012	163	97	0.6	--	--	<0.3
Geo mean	62	45	<1	55	--	<1

Table 4 – Somatic Coliphage and F-Specific Coliphage in Pre-UV, Effluent, and Reuse Water at Neuse River WWTP

Sample Date	Somatic Coliphage (microbes per 100 mL)			F-Specific Coliphage (microbes per 100 mL)		
	Pre-UV	Effluent	Reuse	Pre-UV	Effluent	Reuse
09Oct2012	399	--	<1	2	--	<1
23Oct 2012	288	--	<1	2	--	<1
06Nov2012	602	--	<1	8	--	<1
13Nov2012	595	--	<1	<1	--	<1
04Dec2012	241	<1	<1	3	<1	<1
18Dec2012	496	12	<1	4	<1	<1
Geo mean	412	3	<1	3	<1	<1

The target UV dose at the Neuse River plant in this period was 35 mJ/cm^2, based on a point-source summation model. The target chlorine dose in the reclaimed water was 7 mg/L. The total chlorine residual in the reuse water storage tank varied from 0.10 mg/L to 0.54 mg/L.

In general, the Neuse River reclaimed water met the Type 2 reclaimed water microbial concentration standards. It is not known if the plant processes, taken together, provided the required log inactivations for Type 2 water because the plant influent was not tested at this time.

DISCUSSION

The data show that dual disinfection, as required for Type 2 reclaimed water and provided at Neuse River by UV disinfection and addition of hypochlorite to the reclaimed water, was necessary to achieve the *Clostridium perfringens* concentration limit. This result was expected given that the UV system at this plant is designed for Type 1 reclaimed water limits, and *C. perfringens* is quite resistant to UV disinfection. Higher UV doses may be required at some facilities to inactivate *C. perfringens*, especially those that have higher concentrations of *C. perfringens* entering the disinfection system. As expected, most of the *C. perfringens* that survived secondary treatment and filtration at the Neuse River plant were spores.

While the Neuse River UV system did not provide significant reduction of *C. perfringens*, the one plant with a UV system in the 2004 WERF study showed an average of 2 log reduction with UV. The delivered dose is not stated, but Florida and California both require MS2 REDs of 100 mJ/cm^2 for reclaimed water. With a higher UV dose, additional chlorine and contact time may not be required to meet log removal goals for Type 2 standards.

At Neuse River, coliphage concentrations were generally reduced to below the Type 2 microbial standard, with one data point higher than the allowable monthly geometric mean but lower than the allowable daily maximum.

CONCLUSIONS

The new data on coliphage and *C. perfringens* collected by the City of Raleigh at the Neuse River WWTP demonstrate that its existing UV and hypochlorite disinfection systems can meet the microbial concentration limits for North Carolina's new Type 2 reclaimed water. This data provides a valuable point of reference for North Carolina regulators and utilities.

REFERENCES

Blatchley, E. et al. 2007. Effects of Wastewater Disinfection on Waterborne Bacteria and Viruses. Water Environment Research 71, Number 181-92.

Burbano-Rosero, E. et al. 2011. Diversity of Somatic Coliphages in Coastal Regions with Different Levels of Anthropogenic Activity in Sao Paulo State, Brazil. Applied and Environmental Microbiology, Vol 77, No. 12, p. 4208-4216

Drummey Stiegel, P.N., Mann, M.A. Impact of North Carolina 2011 2U Reclaimed Water Rules on Design of UV Disinfection. Proceedings from NC AWWA/WEA 92nd Annual Conference, Raleigh, North Carolina, November 12-14, 2012

Hijnen, et al. 2006. Inactivation credit of UV radiation for viruses, bacteria and protozoan (oo)cysts in water: A review. Water Research 40 (1), 3–22.

Linden, K. et. al. Water Environment Research Federation, 2004. *Fate and Persistence of Pathogens Subjected to Ultraviolet Light and Chlorine Disinfection.* Report Number 98-HHE-2.

Novak, J. et. al. 2003. An ultrastructrual comparison of spores from various strains of *Clostridium perfringens* and correlations with heat resistance parameters. International Journal of Food Microbiology 86 (2003) 239-247

Rose, J, et. al. Water Environment Research Federation, 2004. *Reduction of Pathogens, Indicator Bacteria, and Alternative Indicators by Wastewater Treatment and Reclamation Processes.* Report Number 00-PUM-2T.

Safrit, D. The State of Reuse in North Carolina. Proceedings from NC AWWA/WEA 90th Annual Conference, Winston-Salem, North Carolina, November 15-17, 2010.

North Carolina Administrative Code 15A NCAC 2U. Published June 18 2011.