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Editorial Perspectives: will SARS-CoV-2 reset public health requirements in the water industry? Integrating lessons of the past and emerging research

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Naddeo and Liu recently published the following editorial: "2019 novel coronavirus (SARS-CoV-2): what is its fate in urban water cycle and how can the water research community respond?"[1] The editorial raises important questions about the impact of SARS-CoV-2 on our water systems, and rightfully encourages the water community to ensure that our treatment systems are providing protection against this new threat. The dialogue also highlights a broader question, namely, have we developed water systems that are sufficiently robust to handle not just SARS-CoV-2, but emerging and unknown pathogens both today and in the future? As researchers and engineers who have focused on the detection and fate of viruses through natural and engineered treatment processes (*e.g.*, physical removal and disinfection), we would like to provide perspective on what is known, what is being learned through current research, and how it will help to answer the essential question: do our existing water systems adequately protect public health?

To begin, the water industry should be commended for the speed with which it identified SARS-CoV-2's potential importance and mobilized resources to better understand it. For example, the March 2020 recommendation by Drs. Naddeo and Liu for targeted SARS-CoV-2 monitoring campaigns has already materialized—even as early as February and March in the Netherlands, France, Australia, the United States, and other countries—and the effort has helped address critical knowledge gaps.[2–4] Beyond individual research studies, the Water Research Foundation (WRF) also convened a virtual research summit comprised of ~50 scientists, engineers, public health experts, and other water industry professionals to establish best practices for environmental surveillance of SARS-CoV-2. Other professional organizations, such as the Water Environment Federation (WEF), quickly published documents providing general information about SARS-CoV-2 and specific guidance for the wastewater industry, much of which was also applicable to drinking water and water reuse.[5]

Numerous groups throughout the world continue to track concentrations of SARS-CoV-2 RNA in wastewater with the aim of addressing questions specific to the water industry and also broader questions relevant to public health. By coupling these data with clinical research findings, we can reduce some of the uncertainty around SARS-CoV-2, better understand the magnitude of the potential threat, and also evaluate the effectiveness of existing treatment systems. Collaborations and funding for these campaigns have materialized rapidly, with widespread support from universities, local agencies and utilities, and state and national research programs. These recent efforts support the wealth of information that the industry has already accumulated on similar viruses from past outbreaks (*e.g.*, SARS, MERS, and Ebola).[6,7] We are able to

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leverage this collective knowledgebase to address many of the authors' questions in the recent editorial, specifically as they relate to predicting and understanding the fate of coronaviruses through our water and wastewater treatment systems. This knowledge provides important grounding as we assess whether SARS-CoV-2 will require higher levels of treatment to ensure the safety of potable water supplies.

As noted in the editorial, one of the greatest concerns for emerging wastewater-derived constituents is the potential impact on potable reuse supplies, since these systems will be most directly impacted by wastewater. The authors suggest that California's indirect potable reuse (IPR) log reduction value (LRV) requirements for virus, *Giardia*, and *Cryptosporidium* may need to be increased beyond 12/10/10 in response to SARS-CoV-2. In evaluating this concern (or for any pathogen that might be found in wastewater), it is important to consider the following factors: (a) the range of concentrations of infective pathogens in the source water, (b) the effectiveness of natural and engineered treatment barriers in removing or inactivating the pathogen, and (c) the risk that consumption of the treated water will lead to an infection. This process—named quantitative microbial risk assessment (QMRA)—has been used over multiple decades to inform a wide range of regulatory frameworks, including the U.S. EPA's Surface Water Treatment Rules, WHO's potable reuse guidelines, and California's IPR regulations. Comparing SARS-CoV-2 to these historical QMRA efforts can help identify if there are unique characteristics about this virus that might raise concerns for our existing regulations and approaches to treatment and public health protection.

With regard to concentrations and infectivity in source water, a growing body of literature shows that the genetic material of SARS-CoV-2 can be detected in raw wastewater. Reported concentrations vary by several orders of magnitude, perhaps depending on the local prevalence of infections and other sewershed-specific conditions. Importantly, the data show that concentrations are either consistent with or less than those of enteric viruses (*e.g.*, enteroviruses, adenoviruses, and noroviruses), which are the traditional focus of potable reuse regulations and treatment. One important limitation of the molecular methods used to detect SARS-CoV-2 RNA (*e.g.*, RT-qPCR) is the fact that they cannot generally distinguish between infectious and inactivated viruses, but we can leverage data from clinical research to better understand the implications of detecting SARS-CoV-2 RNA in raw wastewater. Although SARS-CoV-2 is primarily respiratory in nature, the virus has been shown to replicate in cells of the gastrointestinal (GI) tract, perhaps explaining why its RNA can be detected in feces and ultimately raw wastewater. However, several studies to date have been unable to recover infectious SARS-CoV-2 from stool samples, with one meticulous study demonstrating rapid inactivation of SARS-CoV-2 in the colonic (gut) fluids of the lower GI tract.[8,9] This likely explains the general lack of infectious SARS-CoV-2 in the feces of infected individuals.

Source water concentrations are important to know because regulations—and ultimately treatment requirements—are informed by calculating how much reduction is needed to reduce source water concentrations down to acceptable drinking water levels. For example, in developing the 12-log virus reduction requirement for its existing IPR regulations, California conservatively selected the highest raw wastewater enterovirus concentration reported in the literature. An international panel of experts recently reviewed the data and confirmed the acceptability of this approach.[10] In comparison with SARS-CoV-2, infective enteroviruses are likely present in raw wastewater at concentrations that are orders of magnitude higher. In other words, existing potable reuse regulations are based on a more conservative starting point in specifying treatment requirements. From the perspective of source water concentrations, SARS-CoV-2 is unlikely to set a higher bar. Additional studies to confirm this are recommended.

The second topic is the effectiveness of natural and engineered treatment barriers. In designing treatment processes and developing operational criteria (*e.g.*, disinfectant CT values and UV doses), the water industry often identifies representative pathogens with demonstrated resistance to treatment. Notably, *Cryptosporidium* oocysts are known to be highly resistant to chlorine disinfection, and adenovirus is known to be resistant to UV disinfection. One of the defining features of SARS-CoV-2 —and consistent with other respiratory viruses such as influenza, SARS-CoV-1, and MERS—is the lipid envelope that surrounds its protein capsid and genetic material. Because of the fragile lipid envelope, coronaviruses are less persistent in the environment and more sensitive to treatment than the non-enveloped enteric viruses targeted in potable reuse.[6,11] For Ebola, another enveloped virus, previous research demonstrated 3.5-log inactivation with a chlorine CT as low as 0.05 mg min L^{-1}—approximately 50 times lower than existing EPA CT requirements for virus inactivation.[5,12] With respect to UV disinfection, the double-stranded genomic DNA of adenovirus—and more specifically its propensity for DNA repair—is thought to be responsible for its reported resistance to germicidal UV irradiation. This resistance is reflected in the UV dose requirements for virus inactivation in the U.S. EPA's Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). In contrast, the relatively large RNA genome of SARS-CoV-2 is expected to be highly susceptible to UV disinfection, with previously published data suggesting UV doses <5 mJ cm^{-2} for 6-log inactivation of a coronavirus surrogate.[6,13] For reference, the UV-based advanced oxidation processes (AOPs) in California's potable reuse treatment trains operate at UV doses well above 300 mJ cm^{-2}. Finally, considering the large diameter of SARS-CoV-2 ($\sim$100 nm) relative to some other enteric viruses (*e.g.*, $\sim$30 nm diameter of norovirus) and the tendency for enveloped viruses to partition to solids more than non-enveloped viruses, physical removal processes are also expected to be similarly or more effective against SARS-CoV-2. This includes conventional wastewater treatment processes such as activated sludge and secondary clarification in addition to advanced treatment with membranes.

In summary, SARS-CoV-2 is likely to be more susceptible than the reference pathogens (*e.g.*, enteric viruses) used to develop our existing regulations. Based on the combination of both lower source water concentrations and higher removal through treatment, we would expect much lower exposures to SARS-CoV-2 in drinking water than the enteric viruses targeted by existing regulations and treatment.

The final step of a QMRA relates to estimating the probability of an infection given a certain exposure. SARS-CoV-2 could still theoretically be problematic—even with lower concentrations and greater susceptibility—if it is significantly more infective in drinking water than the viruses targeted by our regulations. Both EPA and California utilized a highly infectious virus (rotavirus) when developing regulatory criteria for both the 1989 Surface Water Treatment Rule and the California IPR regulations. Rotavirus was selected because it is a virus transmitted *via* the fecal–oral route that has been shown to cause infections at very low levels of exposure. In fact, prior to the development of the rotavirus vaccine, health organizations reported that infection with rotavirus was nearly universal by age 5.

While SARS-CoV-2 is also highly infective, its main mode of transmission appears to be through inhalation and colonization of the respiratory tract. To date, it remains unclear whether SARS-CoV-2 can be transmitted through the ingestion of drinking water. As with all of the other unknowns surrounding this virus, further study on this topic is merited. However, based on today's knowledge, it is unlikely that SARS-CoV-2 will be more infective in drinking water than rotavirus. To cause infection, other human coronaviruses require doses that are about 2 orders of magnitude greater than rotavirus, resulting in much lower infectivity risk.[14] On this final point, we expect existing potable reuse regulations developed in the context of a highly infectious enteric virus to be more conservative than if based on drinking water exposure to SARS-CoV-2.

In light of new data specific to SARS-CoV-2, prior knowledge on similar viruses, and an understanding of the basis for existing regulatory frameworks, SARS-CoV-2 is unlikely to drive new, stricter requirements for the treatment of potable water supplies. Based on our current understanding, SARS-CoV-2 is likely (a) present at lower concentrations in source waters, (b) more sensitive to treatment, and (c) less infective than the viruses upon which existing drinking water and potable reuse regulations are based. Further study of this virus should be pursued to confirm these assumptions. One reason for optimism is the seriousness and speed with which the industry is tackling these issues. In California, the State Water Resources Control Board is allocating additional resources to understand the impact of SARS-CoV-2 on the treatment requirements for direct potable reuse (DPR). The State is evaluating SARS-CoV-2 nucleic acid concentrations in the raw wastewaters of multiple California facilities covering the period between 2019 and 2021.[15] These data will be used to determine if SARS-CoV-2 (or other potential challenges brought to light by the current pandemic) will be a driver for stricter treatment requirements for DPR.

In conclusion, we recommend that the industry leverage past findings on similar coronaviruses and the growing body of research on SARS-CoV-2 to estimate its impact on our water systems. To date, the preliminary findings provide reassurance that SARS-CoV-2 is unlikely to be the 'black swan' that will reset the requirements for public health protection in the water industry. Our current requirement for robust, multiple-barrier treatment systems evolved to reliably control a diversity of waterborne pathogens identified in the past. This same approach appears to be a solid foundation for the control of emerging and future pathogens as well.

References

1 V. Naddeo and H. Liu, Editorial Perspectives: 2019 novel coronavirus (SARS-CoV-2): what is its fate in urban water cycle and how can the water research community respond?, *Environ. Sci.: Water Res. Technol.*, 2020, **6**, 1213–1216, DOI: 10.1039/D0EW90015J.

2 G. Medema, L. Heijnen, G. Elsinga, R. Italiaander and A. Brouwer, Presence of SARS-Coronavirus-2 in sewage, *medRxiv*, 2020, DOI: 10.1101/2020.03.29.20045880, 2020.2003.2029.20045880.

3 W. Ahmed, N. Angel, J. Edson, K. Bibby, A. Bivins, J. W. O'Brien, P. M. Choi, M. Kitajima, S. L. Simpson, J. Li, B. Tscharke, R. Verhagen, W. J. M. Smith, J. Zaugg, L. Dierens, P. Hugenholtz, K. V. Thomas and J. F. Mueller, First confirmed detection of SARS-CoV-2 in untreated wastewater in Australia: A proof of concept for the wastewater surveillance of COVID-19 in the community, *Sci. Total Environ.*, 2020, **728**, 138764.

4 F. Wu, A. Xiao, J. Zhang, X. Gu, W. L. Lee, K. Kauffman, W. Hanage, M. Matus, N. Ghaeli, N. Endo, C. Duvallet, K. Moniz, T. Erickson, P. Chai, J. Thompson and E. Alm, SARS-CoV-2 titers in wastewater are higher than expected from clinically confirmed cases, *medRxiv*, 2020, DOI: 10.1101/2020.04.05.20051540, 2020.2004.2005.20051540.

5 R. Maal-Bared, R. Bastian, K. Bibby, K. Brisolara, L. Gary, C. Gerba, L. Olabode, N. Munakata, R. S. Reimers, A. Rubin, S. Schaefer, S. Sherchan and J. Swift, The water professional's guide to COVID-19, *Water Environ. Technol.*, 2020, 26–35.

6 K. R. Wigginton and A. B. Boehm, Environmental Engineers and Scientists Have Important Roles to Play in Stemming Outbreaks and Pandemics Caused by Enveloped Viruses, *Environ. Sci. Technol.*, 2020, **54**, 3736–3739.

7 K. R. Wigginton, Y. Ye and R. M. Ellenberg, Emerging investigators series: The source and fate of pandemic viruses in the urban water cycle, *Environ. Sci.: Water Res. Technol.*, 2015, **1**, 735–746.

8 R. Zang, M. F. G. Castro, B. T. McCune, Q. Zeng, P. W. Rothlauf, N. M. Sonnek, Z. Liu, K. F. Brulois, X. Wang, H. B. Greenberg, M. S.

Diamond, M. A. Ciorba, S. P. J. Whelan and S. Ding, TMPRSS2 and TMPRSS4 mediate SARS-CoV-2 infection of human small intestinal enterocytes, *bioRxiv*, 2020, DOI: 10.1101/2020.04.21.054015, 2020.2004.2021.054015.

9 R. Wölfel, V. M. Corman, W. Guggemos, M. Seilmaier, S. Zange, M. A. Müller, D. Niemeyer, T. C. Jones, P. Vollmar, C. Rothe, M. Hoelscher, T. Bleicker, S. Brünink, J. Schneider, R. Ehmann, K. Zwirglmaier, C. Drosten and C. Wendtner, Virological assessment of hospitalized patients with COVID-2019, *Nature*, 2020, **581**, 465–469.

10 A. W. Olivieri, J. Crook, M. A. Anderson, R. J. Bull, J. E. Drewes, C. N. Haas, W. Jakubowski, P. L. McCarty, K. L. Nelson, J. B. Rose, D. L. Sedlak and T. J. Wade, *Evaluation of the Feasibility of Developing Uniform Water Recycling Criteria for Direct Potable Reuse*, California State Water Resources Control Board, Fountain Valley, CA, 2016.

11 P. M. Gundy, C. P. Gerba and I. L. Pepper, Survival of Coronaviruses in Water and Wastewater, *Food Environ. Virol.*, 2009, **1**, 10–14.

12 K. Bibby, R. J. Fischer, L. W. Casson, N. A. de Carvalho, C. N. Haas and V. J. Munster, Disinfection of Ebola Virus in Sterilized Municipal Wastewater, *PLoS Neglected Trop. Dis.*, 2017, **11**, e0005299.

13 C. D. Lytle and J. L. Sagripanti, Predicted inactivation of viruses of relevance to biodefense by solar radiation, *J. Virol.*, 2005, **79**, 14244–14252.

14 T. Watanabe, T. A. Bartrand, M. H. Weir, T. Omura and C. N. Haas, Development of a dose-response model for SARS coronavirus, *Risk Anal.*, 2010, **30**, 1129–1138.

15 Water Research Foundation, *Project #4989: Measure pathogens in wastewater*, https://www.waterrf.org/research/projects/measure-pathogens-wastewater, (accessed May 15, 2020).