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The ethics of wastewater surveillance for public health

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Abstract

The COVID-19 pandemic has fuelled interest in the use of wastewater analysis for public health surveillance. Hydrologists, engineers, environmental scientists, microbiologists, public health experts and those in other disciplines have been tasked with the implementation of national-scale surveillance and the resultant data have been used for decision making at the highest levels of government. The widespread surveillance of communities is not without its concerns, however. This paper explores the ethics of surveillance drawing on the literature and our experiences with wastewater analysis. Consent is not typically required for wastewater surveillance, which can exacerbate perceptions of risk and undermine public trust. Seemingly innocuous communication of surveillance data can stigmatise communities and perpetuate inequities. There are tensions between the desire for the rapid delivery of information and the time needed to build confidence in surveillance data. There are also limitations and uncertainties in the science of wastewater surveillance, and these add to the pressures of communication for and with decision makers. Media representations can be problematic and perpetuate social stigma. On a positive note, the transdisciplinary nature of wastewater surveillance presents an opportunity to work across and beyond traditional disciplinary boundaries to address the ethics of surveillance, which, we expect, will be especially important as wastewater surveillance becomes further mainstreamed, particularly under the auspices of surveillance capitalism.

Key words

wastewater-based epidemiology, sewage, COVID-19, SARS-CoV-2

Introduction

We live in an age of mass surveillance. Practically everything we do is tracked, traced and recorded (Hier and Greenberg, 2007). This is particularly obvious online, where it is now difficult to visit a website without first accepting cookies. Our actions are increasingly being tracked off-line too with the rise of CCTV and facial recognition software, for example. Capitalising on such data is the core business model of major technology companies such as Google, Facebook and Apple (Zuboff, 2019). The idea is simple: to collect and collate as much data as possible about individuals to build a profile that is of value to, say, an advertiser.

It is perhaps not surprising that others have started to engage in surveillance. Finance, insurance, policing and healthcare have made decisive moves into the field. It is difficult to know where data are being collected, who is putting the data to use and for what purposes. This was starkly demonstrated by Cambridge

Analytica's involvement in the 2016 United States election (Cadwalladr and Graham-Harrison, 2018) and moves by police departments to surveil the United States via the Amazon Ring (Bridges, 2021). Closer to home there are many examples too, such as the New Zealand Police facial recognition trials that were unknown to senior officers and even the Privacy Commissioner (Smith, 2020).

What does this all have to do with hydrology? Clearly, the discipline is not immune to global politics and hydrologists have started to become involved in surveillance too. For example, today is a time that a DNA sequencer can be installed into a toilet (Erlich, 2015; Park *et al.*, 2020). The idea is to sequence your microbiome and analyse urine and stool for diagnostic purposes each time you visit the toilet, with data transmitted to a cloud-based health portal (Park *et al.*, 2020). Should irregularities arise in your microbiome, or characteristics of urine and faeces, data will be shared across platforms and an individual's healthcare providers alerted (Armitage, 2020). Whilst this may seem like something out of science fiction, Stanford University recently registered a patent for an 'analprint' scan recognition algorithm to identify who is sitting on the toilet (Park *et al.*, 2020). Such technologies clearly raise questions about privacy and the unwanted disclosure of personal information. Can and will such personal health information be shared or sold to technology companies? How might such information be used (and abused) by other interested parties, such as insurance agents or employers? What this illustrates is that seemingly benign surveillance technologies are not free of ethics, and wastewater hydrologists now find themselves part of this future.

Public health surveillance is not new for hydrologists. It has a near-legendary foundation in the story of John Snow, who mapped cholera cases in London to reveal that contaminated water, not air, was the source of London's Broad Street cholera outbreak (Snow, 1855). Surveillance is foundational to public health (Fairchild *et al.*, 2007) and came to prominence in the 14th century during the Black Death, where the premise of using infectious disease information to guide public health interventions emerged (Declich and Carter, 1994). Later in the 17th century during the Great Plague of London, the concept of systematically collecting and reporting mortality data for surveillance purposes was reportedly first employed (Choi, 2012).

The World Health Organization (WHO) defines public health surveillance as 'the continuous, systematic collection, analysis and interpretation of health-related data needed for the planning, implementation and evaluation of public health practice' (WHO, 2017, p. 15). Public health surveillance guides our responses to numerous health issues, perhaps most notably infectious diseases such as HIV/AIDS (Prejean *et al.*, 2011), polio (WHO, 2003), Ebola (Gire *et al.*, 2014) and, recently, COVID-19 (WHO, 2020b). The WHO goes as far as to say that '[public health surveillance] provides the architecture for social well-being' (WHO, 2017). However, surveillance raises issues of ethics and has been the topic of ongoing controversy and debate.

Public health surveillance is predicated on improving social well-being but it comes with ethical risks. For example, serious concerns have been raised that name-based reporting for HIV/AIDS surveillance represents a breach of privacy and may fuel the stigmatisation and discrimination of disadvantaged communities (Fairchild *et al.*, 2007). At the regional scale, public health surveillance is often conducted without obtaining informed consent, which has sparked fierce debate about autonomy and rights (Klinger *et al.*, 2017). In response, the WHO recently developed a series of ethical guidelines for public health surveillance (WHO, 2017). However, as Klingler *et al.* (2017) note, evaluations of the ethical issues arising from public health surveillance must be contextual, and the emergence of new and potentially disruptive surveillance technologies (e.g., smart toilets and wastewater analysis) necessitates ongoing engagement with the ethical risks of collecting and reporting such data.

The COVID-19 pandemic has propelled interest in the use of wastewater for public health surveillance. Hydrologists, engineers, environmental scientists, microbiologists and others (who we collectively term 'wastewater scientists') have been tasked by government agencies around the world with implementing national wastewater surveillance (e.g., Centers for Disease Control and Prevention, 2021; Gawlik *et al.*, 2021; Ministry of Health, 2021). The work is founded on a history of using wastewater for surveillance of poliovirus (Paul *et al.*, 1940) and other pathogens, including norovirus and hepatitis A (Asghar *et al.*, 2014; Hellmér *et al.*, 2014). More recently, wastewater has been used to examine the consumption of drugs in New Zealand (e.g., Lai *et al.*, 2017; Price *et al.*, 2021; Trowsdale *et al.*, 2021).

This paper is founded on our experience with wastewater surveillance and the ethical dilemmas and challenges that have presented themselves along the way. The focus of this paper is on public health contexts and our experience with drugs and SARS-CoV-2, and, by drawing on the ethics literature, we critically evaluate the ethical risks and challenges posed by wastewater surveillance to provide guidance for those tasked with its implementation and use (Fig. 1).

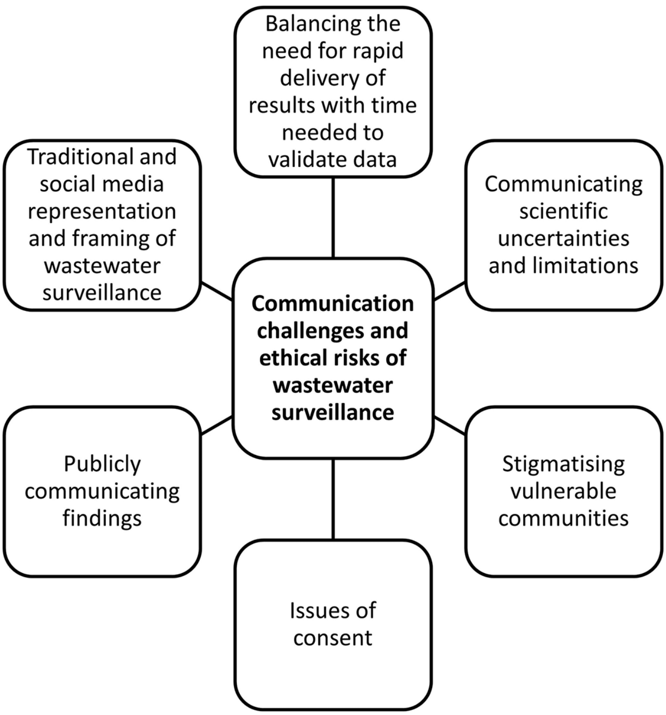

Figure 1 – Key communication challenges and ethical risks posed by wastewater surveillance for SARS-CoV-2

Balancing the need for the rapid delivery of results with the time needed to build confidence in the data

SARS-CoV-2, the coronavirus that causes COVID-19, can be detected in wastewater days or even weeks before the presentation of clinical cases (Medema *et al.*, 2020; Peccia *et al.*, 2020; Randazzo *et al.*, 2020). This is because COVID-19 has a relatively long incubation period of up to two weeks (Lauer *et al.*, 2020), during which time pre-symptomatic individuals can be infectious (He *et al.*, 2020; Rothe *et al.*, 2020). Additionally, many people experience mild symptoms or are asymptomatic and thus do not come forward for voluntary testing nor self-isolate. These individuals can unwittingly infect others (Gao *et al.*, 2021; Johansson *et al.*, 2021). Voluntary testing and/or surveillance testing of only a small subset of the population, such as border workers in New Zealand, means that clinical testing may not detect cases in the community. Wastewater surveillance provides public health officials with a crucial early warning of potential outbreaks and a head start in enacting a range of responses, such as targeted testing and regional lockdowns. This has been incredibly powerful to assess the emergence of SARS-CoV-2 (particularly the delta variant) in the virgin population of New Zealand.

There are various steps involved with detecting SARS-CoV-2 in wastewater: sample collection and transportation to laboratories, sample concentration, RNA extraction, RNA measurement and validation, all which take time. The pragmatics of these are often complicated by the restraints of lockdown (e.g., limited number of flights to move samples from the point of collection to the laboratory). If wastewater surveillance is to effectively guide a public health response, findings need to be delivered quickly. This inevitably creates tension between the need for the rapid delivery of results and the time required to analyse and validate the data (Canadian Water Network, 2020).

Communicating the uncertainties of wastewater surveillance to public health officials

Wastewater surveillance holds the promise of revolutionising the ways we understand the presence, spread and management of COVID-19 (and future pandemics), but the data have inherent uncertainties. The detection of SARS-CoV-2 in wastewater samples can be influenced by in-sewer conditions (e.g., temperature, pH, light, disinfectants, other biological agents), sewer residence times, sampling regimes (e.g., grab vs time/flow/volume weighted), faecal and oral shedding, toilet use frequency, and the methods involved in sample concentration, RNA extraction and RNA detection (Hart and Halden, 2020; Li *et al.*, 2021; Polo *et al.*, 2020). These all contribute uncertainties that compound the likelihood of wastewater testing returning false negatives, i.e., not detecting SARS-CoV-2 in wastewater despite COVID-19 being present in the community. Coupled to this, there are limitations to the sort of information wastewater surveillance can reveal. For example, without dynamic population estimates (where people are located and at what time) it is difficult to determine whether viral loads detected in wastewater originated from a transient visitor or from within the resident community (Sims and Kasprzyk-Hordern, 2020). In the current pandemic, however, strict lockdown measures have helped to reduce this uncertainty by limiting mobility. Additionally, directly inferring the number of infected individuals within a community from SARS-CoV-2 RNA concentrations in wastewater is complicated by the variable shedding profiles (i.e., rates and duration of shedding) among both symptomatic and asymptomatic people (Li *et al.,* 2021). Research is ongoing to establish quantifiable relationships between SARS-CoV-2 RNA measurements in wastewater and epidemiological indicators (Huisman *et al.,* 2021; McMahan *et al.,* 2021).

Uncertainties in the data have important implications for how much confidence can be placed in observations. While wastewater scientists will be familiar with these uncertainties, many of the decision makers who are in public office will not. Consequently, there is work to be done to communicate uncertainties and confidence in the findings, so that informed decisions can be made (i.e., to ensure data are not over- or under-interpreted). Of course, given the novelty and constantly evolving state of the pandemic, challenges exist in understanding and quantifying the degree of influence that these uncertainties have for interpreting findings. Communicating this to health officials and the public is a balancing act, with the need being not to overwhelm individuals with unnecessarily complex information.

Issues of consent

Consent is an ongoing process of agreeing boundaries. It can and will change. It can be given and withdrawn at any time. What was consented to in the past may be different to the present. Understood in this way, it is relatively easy to see how consent works between, say, sexual partners, or a doctor and patient. But consent is often complicated in larger group situations such as in the case of community-scale wastewater analysis. The issue of consent raised its head noticeably in 2018 when the General Data Protection Regulation reforms were enforced (Hoofnagle *et al.*, 2019). This led to the now familiar request when you visit a website to 'accept cookies'. Many of us simply click 'yes' rather than attempting to navigate the labyrinth of obscure and confusingly termed settings. But by doing so, we give consent for that website to track our clicks and that means share our personal information, the cornerstone of surveillance capitalism.

Respect for autonomy is a key ethical principle which is about acknowledgment and respect for an individual's right to make their own decisions. In biomedical, epidemiological and research contexts, respect for autonomy is most often adhered to by requiring a person to give voluntary consent to participate in an activity. This typically involves being informed of the risks and harms that may arise from participation (Farrimond, 2013). Normally, however, informed consent is not required for wastewater surveillance. This is because material is not directly taken from individuals. Instead, a 'waste' that has been excreted and discarded is used for the analysis. The logic follows that because individuals cannot theoretically be identified by wastewater surveillance, they cannot be harmed, obviating the necessity for consent (Hall *et al.*, 2012; Klingler *et al.*, 2017). However, as we will discuss, this is problematised by surveillance conducted on communities of difference and this is compounded in small and marginalised communities.

Furthermore, for pragmatic reasons, consent is not typically required for wastewater surveillance because it would be prohibitively difficult to obtain informed consent from all individuals in the catchment of a wastewater treatment plant (WWTP), which can number from tens to hundreds of thousands of people, and indeed even more. Additionally, if individuals were able to opt out, this would compromise the efficacy of surveillance efforts. The WHO (2017, p. 40) notes that individuals 'have a reciprocal obligation to contribute to surveillance and thereby promote the common good'. However, such justification faces scrutiny where the harms and benefits of wastewater surveillance are unequally distributed amongst the population. This would quickly become the case if targeted wastewater surveillance were to inform localised lockdowns, particularly in marginalised communities.

Notions of ownership are inherently linked to consent. Ownership of information imparts that people have an exclusive right to control how their data are used. Subsequent loss or intentional relinquishment of ownership of that information may obviate the need for consent. In their book *History of Shit*, Dominique Laporte (1978) notes that the development of modern reticulated sewers marked the development of the individualised body, whereby waste was transformed into something of ill-value, foreign to the body and in need of removal. Such ontological understandings are echoed in *Powers of Horror: An Essay of Abjection* (Kristeva, 1982), which argues that waste products are seen as the antithesis to self-images of health and cleanliness and, therefore, something to be flushed and forgotten. More recently, these ideas have gained traction in sociology through a reframing of the way collective conventions transform normal practices in the home (Shove, 2003), such as the flush toilet and, by extension, the Apple Watch linking smart toilets and user's microbiome to whoever can pay for the information.

Taking this a step further down the constructs of economics and law, the exclusion or ostracism of waste enables a renegotiation of the property rights attached to such material, thereby allowing for its non-consensual collection and use. This is exemplified in the landmark 1990 court case *Moore v. Regents of the University of California*, where after undergoing treatment for hairy-cell leukaemia, Roy Moore's cancer cells were developed into patented cell lines. The California Supreme Court ruled that Moore had no property rights to his cells given that individuals lose their property rights to tissue and blood once discarded. Through categorising discarded tissue as 'waste', the Supreme Court established an important legal distinction and separation between body and tissue (Waldby and Mitchell, 2006).

Faeces and urine are different to discarded tissue within a hospital context, however. Today, individuals are typically required to give consent to relinquish their tissue in a hospital. Similarly, with other forms of surveillance and public health information (such as clinical testing data for COVID-19) consent is typically required prior to collection. However, it could be argued that people involuntarily excrete urine and faeces. This raises an interesting question. Given the involuntary nature of defecation, does this mean people have not *willingly* discarded the material, and, therefore, have not voluntarily relinquished the property rights attached to such material?

What does this mean for wastewater surveillance? It is clear that individuals cannot easily choose to opt out of wastewater surveillance. This is true even if they object. We pause here to acknowledge that the perception of risk to a hazard is greater when involuntarily imposed on people. Hazardous activities in which people participate by choice are typically perceived to be less risky (Sandman, 1993). If we consider wastewater surveillance to be analogous with a hazard, then involuntary exposure and, more precisely, a lack of control in moderating such exposure (i.e., not being able to opt out) may partly explain why wastewater surveillance is perceived as risky. A lack of meaningful consultation may undermine support for wastewater surveillance and trust in those conducting it. Furthermore, the lack of formal guidelines to obtain informed consent may open the door to abuse by state, private and other interests. Here we might draw from the critical literature on big data that reminds us 'Just because it is accessible does not make it ethical' (Boyd and Crawford, 2012, p. 671).

Where does this leave us? Well, in lieu of obtaining informed consent, wastewater scientists might try to 'ensure their work engages with and is cognisant of community concerns and values' (Canadian Water Network, 2020, p. 7). This is all well and good, but many wastewater scientists have not had experience working in public health contexts and may not be equipped to meaningfully engage with ethics. We have found it important, therefore, to work alongside those who are skilled and trained in the humanities and social sciences to ensure the ethics of surveillance aligns with community values and concerns.

Risk of stigmatising disadvantaged populations

Wastewater surveillance is usually conducted at WWTPs. This is largely for pragmatic reasons of obtaining a sample for analysis. However, there are moves to sample upstream and at the 'neighbourhood scale' (i.e., sampling of subcatchments) (Nicoll *et al.*, 2022). Early in the pandemic, we witnessed interest in targeted wastewater surveillance in high-risk areas such as universities, hospitals, nursing homes, international airports, shipping ports and travel hubs (Medema *et al.*, 2020; Scott *et al.*, 2021; Spurbeck *et al.*, 2021). The benefit of sampling at fine spatial scales is the ability to identify the presence of infection clusters and, accordingly, guide more targeted allocation of resources, such as clinical testing. Additionally, sampling up the pipe is likely to reduce the variability of in-sewer processes such as sewer residence times and viral degradation when compared to sampling from WWTPs (Thompson *et al.*, 2020). However, sampling from small and specific areas (such as individual buildings) raises concerns about the violation of individual privacy and the stigmatisation of specific and localised communities. This is especially concerning for the surveillance of marginalised and disadvantaged communities.

Disadvantaged communities are disproportionately affected by COVID-19. Reasons for this include higher incidences of pre-existing health conditions, more crowded living situations and less capacity to stay at home and telecommute for work (Campbell *et al.*, 2021; Jefferies *et al.*, 2020; McLeod *et al.*, 2020; Steyn *et al.*, 2020). Wastewater surveillance of disadvantaged communities can be a double-edged sword. If a positive detection is acted upon fast enough, it may stymie the spread of COVID-19, reducing the number of individuals required to self-isolate or stay in managed isolation and quarantine facilities, which can prove challenging for individuals unable to work remotely. Timely public health responses may also preclude the necessity to impose costly region-wide lockdowns, which can exacerbate pre-existing socioeconomic inequalities (Jones, 2020; Prickett *et al.*, 2020). However, the findings of wastewater surveillance, especially when results can be tied back to specific communities, can also perpetuate discrimination and stigmatisation. This has certainly been the case in New Zealand, where we have seen abhorrent racism and targeted discrimination, vitriol and scapegoating directed at communities in which members have tested positive for COVID-19 (Foon, 2020; Palmer and McRae, 2021).

Wastewater analysis is typically deemed to be a low-risk form of surveillance because it is done at the WWTP scale (Prichard *et al.*, 2016). However, anonymisation matters little if individuals are grouped according to geographical boundaries (which is inherently the case in wastewater surveillance), because subsequent group-level harms can ultimately affect all members of such groups (Choudhury *et al.*, 2014; Mittelstadt and Floridi, 2016). Therefore, despite individuals not being identifiable in wastewater data, the findings of wastewater surveillance can lead to the stigmatisation and discrimination of individuals and groups.

The common practice within the wastewater monitoring community to protect privacy has been to anonymise site locations (Prichard *et al.*, 2016). However, such an approach has not always been appropriate for COVID-19 surveillance, given the importance of having a fully informed public about the presence of COVID-19 in the community so they can act appropriately. Consequently, there is a need to carefully consider how to balance the protection of specific communities with that of transparently communicating findings.

Stigma and discrimination resulting from surveillance can also erode public trust in monitoring and public health in general (WHO, 2017). Understandably, if it is felt that wastewater surveillance stigmatises communities, it will reduce support for surveillance. There is a history of this occurring. For example, local governments in the United States have barred wastewater investigations of drug use for similar reasons (Bohannon, 2007; Hagerman, 2008). More widely, ill-consideration of the ethical concerns of wastewater surveillance can undermine public confidence in other health measures (e.g., hand washing, mask use, social distancing, clinical testing and vaccination) and trust in public health officials (Canadian Water Network, 2020). This is clearly problematic and doubly so as these activities rely on a degree of voluntary cooperation. Ensuring that the unintended harms resulting from wastewater surveillance are pre-emptively addressed will be crucial to ensuring the long-term sustainability of wastewater surveillance programmes and, importantly, other public health measures.

Challenges of publicly communicating findings

There have been marked increases in anxiety, depression, fear and stress during the COVID-19 pandemic (e.g., Poulton *et al.*, 2020; Torales *et al.*, 2020). Communication from health officials and scientists has an influence on how people variously understand and respond to COVID-19 (Finset *et al.*, 2020; Malecki *et al.*, 2021). At the time of writing, quantitative relationships between viral concentrations in wastewater and the prevalence of cases in the community is unclear, unlike clinical case data whose magnitude can be perhaps more easily communicated to and interpreted by the public. Viral concentrations in wastewater likely mean little to the public. Simply reporting that SARS-CoV-2 has been detected in wastewater is rather ambiguous and leaves uncertainty about the number of infected individuals and the appropriate action to take. Such uncertainties are a contributor to public anxieties (Arora *et al.*, 2020).

Wastewater surveillance may detect SARS-CoV-2 days before the presentation of a clinical case. Such a discrepancy between wastewater data and clinical cases (the latter of which has been the standard to quantify COVID-19) may create the impression that COVID-19 is circulating in communities unbeknownst to public health officials. A lag in clinical case data may inadvertently undermine public confidence and trust in clinical testing (or those conducting it) to accurately quantify the spread of COVID-19. Public fear and anxiety can lead to problematic fear-related behaviours like panic buying, the fleeing of cities and regions (which may facilitate the spread of the virus) and the discrimination and scapegoating of specific communities, scientists and public health officials (Shigemura *et al.*, 2020). Addressing these concerns will need to be a priority for those tasked with the public communication of wastewater surveillance.

Media reporting of wastewater surveillance

Wastewater analysis has garnered considerable media attention, and there is a need to be mindful of the ways in which the media represents the science (Prichard *et al.*, 2014). The Sewage Analysis CORe Group Europe (SCORE) highlighted the importance of media communication in wastewater studies (Prichard *et al.*, 2016). They outlined the necessity to consider what sorts of information should and should not be communicated, e.g., at what community population size should sampling sites be anonymised when relaying information to the media, what the data can (and cannot) tell us, and how the findings of wastewater surveillance are being used. It has also been pointed out that consistent reporting amongst members of wastewater surveillance teams is essential, as inconsistent reporting may undermine public trust and perceptions of competence (Benham *et al.*, 2021). Another important consideration is who will act as the key media contact. This comes from experience of dealing with difficult and purposefully tricky questions where the press has been looking for a contentious soundbite to perhaps sensationalise or generate interest for a particular readership. For wastewater scientists with little experience in dealing with the media and with little training in media theory, navigating these encounters may prove challenging. Even basic media theory (e.g., Herman and Chomsky, 1988) is not the typical reading material on the wastewater curriculum.

The framing of wastewater surveillance on social media

Traditional media is under strain. Reportedly, journalists are among the least trusted people in society, ranking below estate agents and bankers in the United Kingdom and United States (Ipsos MORI, 2017; McCarthy, 2019). Most people in the minority world have access to a smart phone (Rainie and Perrin, 2017) and can produce news and commentary for their own audience through independent blogs, channels, podcasts, websites, posts, messages etc. It is unsurprising, therefore, that many people are turning away from traditional media outlets and to social media platforms for information and guidance on COVID-19 (Limaye *et al.*, 2020).

Social media has dramatically shaped the ways people receive, digest, and respond to scientific and public health information. Termed an ‘infodemic’ by the WHO (2021), social media platforms have facilitated the spread of conspiracy theories, rumours and misleading information (e.g., that SARS-CoV-2 was created as a biological weapon or caused by 5G cell phone towers). Traditional media platforms (such as newspapers and television news) have tended to be aligned with well-known political ideologies. This is perhaps best exemplified by the highly partisan media in the United States, which allows readers or watchers to know what to expect from a news outlet and arguably develop a healthy cynicism or in the least an awareness of the reporter’s angle. Social media has eroded this awareness. Social media allows the sharing of information from anywhere and anyone and can make it difficult to determine the credibility of the source (Limaye *et al.*, 2020).

We live in a time of relative stability punctuated by moments of mass hysteria that fuel clicks and posts. These reactions are often done quickly and anonymously, the latter of which galvanises and abets the posting and sharing of vitriolic ideas and sentiments. These characteristics have promoted the spread of xenophobic and racial discrimination online during the COVID-19 pandemic (Foon, 2020; Human Rights Commission, 2021). It is not difficult to see how a positive detection of SARS-CoV-2 in wastewater from a certain group of people or community, especially those that are disadvantaged, may fuel similar damaging narratives online.

The absence of contextual information creates the ideal conditions for misinformation and rumours to thrive (Chou *et al.*, 2021). Providing contextual information is tricky, however, and is made more difficult by small character limits of online platforms (e.g., 280 characters on Twitter posts). There are many contextual factors relevant to interpreting the findings of wastewater surveillance, such as where within the catchment a detection originated and whether a positive detection reflects a new case of COVID-19 in the community or a recovered, non-infectious person who has returned to the community and is shedding non-infectious RNA. Elucidating these factors (and many others) takes time to investigate and are always nuanced, and the simple reporting of 'facts' can lead to misinformation and rumours spreading quickly online (e.g., Farrier and Reeve, 2020).

There was a wide range of reactions on social media to the publication of a wastewater study, which observed a moderate positive correlation between neighbourhood-level methamphetamine use and community disadvantage (Price *et al.*, 2021). Responses online ranged from 'It's a health issue and should be treated as such' and 'they use it to escape reality stress...' to 'No excuses for it. It's a life style (*sic*) they have a choice'. It is not difficult to see how public responses could similarly vary if SARS-CoV-2 was detected in the wastewater from a disadvantaged community. Interpretations could range from 'poorer communities are disproportionately affected by COVID-19 and thus must be prioritised in public health responses' to 'the presence of COVID-19 in wastewater confirms that poorer communities are unclean and are responsible for spreading the virus.' It is clear that care must be taken when communicating the findings of science given the various ways seemingly 'objective facts' can be interpreted and framed online.

Social media and search engine algorithms play a significant role in curating the sorts of information people are exposed to online, based on what these algorithms consider specific individuals want to see (Pariser, 2011). This seemingly innocuous concept has been responsible for nudging people towards polarised and politically charged anti-vaccination content (Hussein *et al.*, 2020; Juneja and Mitra, 2021). The relevance for wastewater surveillance is that those who are more inclined to hold disparaging perspectives (and thus have searched for content along similar lines) may be exposed to online content that affirms these sentiments (e.g., media stories or social media posts that frame wastewater surveillance as 'confirming' that disadvantaged communities are sources of COVID-19 or drug users).

For many scientists (the authors included), the realms of social media as a means of communication are very much unchartered territory. As such, many wastewater scientists are unequipped to deal with the various ways disparaging rumours are spread and scientific information framed online. The trolling and abuse directed at prominent online science communicators is also clearly an issue to contend with (Nogrady, 2021). There is a growing body of literature that is beginning to explore and address these issues (Chou *et al.*, 2021; WHO, 2020a), but we reiterate our point that it is critical to work alongside those who are trained in science communication and media theory when engaging in the communication of wastewater surveillance. This is perhaps a challenge for many in academia where strong disciplinary boundaries exist, and it is not helped by academic pressures for scientist to generate impactful research. Space must be made, therefore, in grant applications and research programmes for social scientists with the skills to engage with the challenges of science communication.

Conclusion

The COVID-19 pandemic and the decision making that has gone alongside it has necessitated broad engagement across, between and beyond the usual disciplinary boundaries. This is no different for the numerous national wastewater surveillance projects that have sprung up around the world. The transdisciplinary nature of these projects presents a series of challenges for the wastewater community.

Informed consent is not required for wastewater surveillance, which means that individuals cannot willingly choose to opt out of being observed. Involuntary surveillance can exacerbate public concerns and undermine trust. The targeted surveillance of discernible communities, particularly those that are already marginalised, can fuel stigmatisation and discrimination. This can erode public support not only for wastewater surveillance but, importantly, for other public health measures too. Representations and discussions of wastewater surveillance in the media, particularly social media, can facilitate the spread of damaging rumours and misinformation and perpetuate the stigmatisation of disadvantaged communities. Publicly communicating the findings of wastewater surveillance also presents challenges, namely, how to report findings in a manner that does not perpetuate public fears and anxieties. More practically, there are inevitable tensions between the need for the rapid delivery of results and the time needed to build confidence in the data. Challenges also exist in the communication of uncertainties in wastewater surveillance, which are compounded when working with public health officials and decision makers who are perhaps not trained in science.

Some of these challenges are likely familiar territory for wastewater scientists. However, those challenges associated with ethics and public and media communication are not the typical pedagogy or practice in the discipline. Engagement with these ethical challenges is crucial because, as has been seen with other surveillance technologies, failure to do so has been met with major opposition (Moreau, 2019; Roussi, 2020). But how should wastewater scientists without the experience and expertise contend with these issues? It is clear that wastewater scientists will need to meaningfully engage with those trained in ethics, social science, public communication and media theory, but meaningful transdisciplinary collaboration in itself can be challenging.

On a positive note, many hydrologists are well positioned to engage in transdisciplinary collaboration. Some are trained in geography, a discipline that bridges the physical and social sciences (Pitman, 2005) and with a foundation to move between social–natural boundaries. Immanuel Kant, a pioneer of geography who was famous for exploring topics ranging from moral philosophy to theoretical physics and physical geography, serves as an example of such transdisciplinarity (Paulsen, 1902). Water is also commonly used to investigate culture, nature and power (e.g., Gandy, 2014; Sofoulis *et al.*, 2015; Strang, 2015; Swyngedouw, 2004) and so hydrologists have often engaged with these concepts in their teaching and practice. That is not to say that hydrologists are experts in ethics and science communication, but through exposure to a range of disciplines in their training and practice are well positioned to meaningfully work alongside those in other disciplines to best address the challenges and ethics of wastewater surveillance.

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