COVID-19 Surveillance in Wastewater: Communications and Equity

October 2021

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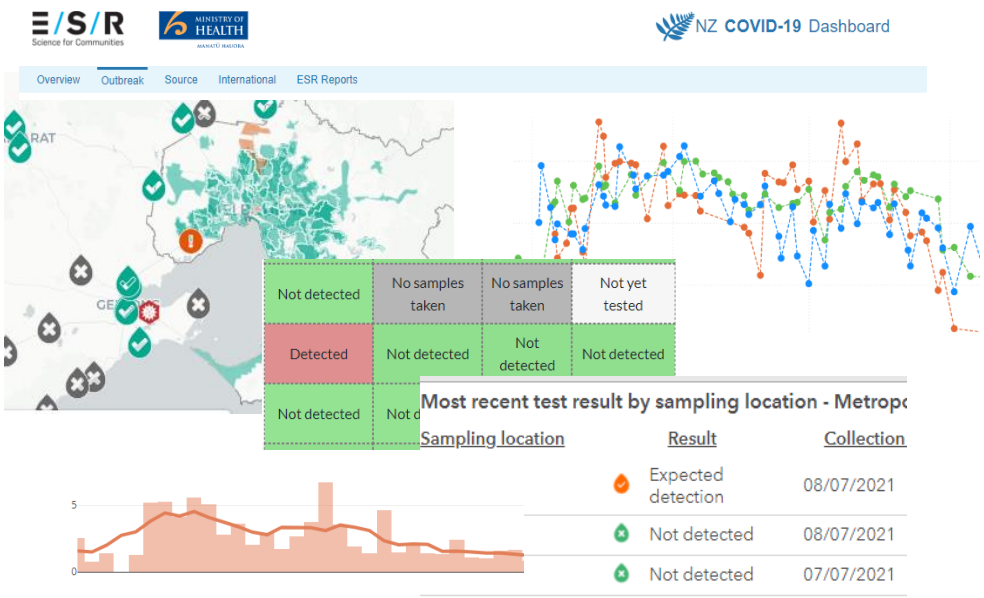

ESR REPORT No: **CSC21035**

ACKNOWLEDGEMENTS

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This work was funded by the Ministry for Business, Innovation and Employment (MBIE) through the Strategic Science and Innovation Fund (SSIF) apportioned to ESR, and by MBIE through the COVID-19 Innovation Acceleration Fund.

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1. EXECUTIVE SUMMARY

Innovation is a key part of scientific discovery and technological development. Wastewater-based epidemiology (WBE) techniques, where wastewater samples from treatment plants are tested for various substances that give insights into population health, is one such innovation. WBE has been applied to monitoring trends in illicit drug usage, and more recently it has been used to measure concentrations of the SARS-COV-2 virus to inform the COVID-19 pandemic response. Innovative technologies can challenge the accepted ethical frameworks and public acceptance, as by their very nature they move into new territory. Consideration also needs to be given as to what benefits and harms the new technologies could bring, and whether it might result in mitigating or strengthening existing social, cultural, health and economic inequities.

1.1 DRUGS IN WASTEWATER STUDY

The Social Systems team at ESR started investigating issues of public acceptance, ethics and equity related to WBE technologies in 2020. The initial interview study used a Critical Systems Heuristic framework, to explore the motivation and purpose, power and control, expertise and knowledges, and legitimacy associated with use of WBE technologies from the perspectives of participants involved in governance of WBE, ethics, or data governance. This study found that the participants were less concerned with the ethics of the technology itself than with the purpose of the WBE usage, and who was making the decision about WBE use. For example, there was less support for measuring illicit drug use through WBE for law enforcement purposes, compared to using the same data to support improved addiction and rehabilitation health services. The participants also strongly supported the idea that decisions around use of WBE should include the input of diverse voices, particularly Māori, so that the potential impact of the technology use on different demographic groups was well considered.

1.2 COVID-19 IN WASTEWATER STUDY

This research was extended when WBE technologies were used to monitor virus levels to help inform the public health response to the COVID-19 pandemic and MBIE provided funds for further research in this area. During the pandemic, the public accepted many restrictions on their liberties that would not usually be accepted, such as restrictions on travel and business activity, and submitting to testing and quarantine. The widespread acceptance of WBE to support the COVID-19 health response should be seen in that light, and not taken for granted that this meant there were no ethical issues to be considered. The need for ethics discussion was recognised by international collaborations dedicated to COVID-19 surveillance in wastewater [1-3]. The ESR Social Systems team also conducted a questionnaire with a group of WBE experts to gauge the emergent ethical and equity issues, particularly for the context of Aotearoa New Zealand and Australia.

COVID-19 surveillance in wastewater brings together different disciplines, and in some countries, bringing together people who do not always work closely. A major division between disciplines is environmental health/public health. ‘Environmental scientists’ in this context are those involved with wastewater such as environmental science researchers, water engineers and local authority infrastructure planners and operators, and ‘public health authorities’ are those involved in public health, such as epidemiologists, public health agencies, decision makers and front-line staff. A lack of collaboration and communication between these

disciplines is particularly a problem in countries where there are many institutions to coordinate, and environmental and public health expertise are siloed rather than integrated. ESR is in a unique position in that wastewater testing, viral genomic sequencing and public health epidemiology are all located within the one institution, and therefore communications between those groups and with the national health authority (the New Zealand Ministry of Health/Manatū Hauora) is comparatively straightforward and beneficial.

The ESR study, including literature review, highlighted that in terms of using wastewater testing for public health surveillance, both environmental scientists and public health authorities have ethical responsibilities. The public health authorities have primary responsibility for the pandemic health response, and for engagement with the communities to establish the needs and concerns. The environmental scientists have primary responsibility for the quality of the data, and for ensuring that the public health authorities understand the data and the limitations of the science. Both groups have responsibility for good communications and understanding the others' constraints and operating frameworks, as well as for the security of the data.

1.3 PUBLIC HEALTH SURVEILLANCE USING WASTEWATER TESTING

Wastewater testing for COVID-19 is a public health surveillance tool, and therefore the ethical guidelines for public health surveillance are applicable [1, 2, 4, 5]. The guidance can be summarised under the four principles of Common good, Equity, Respect for persons, and Good governance.

1.3.1 Common good

- Any surveillance method must contribute to the common good in a significant way, in order to justify overriding individual rights such as informed consent.
- The science of wastewater testing should be developed so there is confidence in the quality, validity and reliability of the data, that it is an effective measure of the viral load in the wastewater and that this result reliably correlates to the presence of COVID-19 cases in the community.
- Where there is a choice of methods to provide similar data, the least invasive method should be preferred. Wastewater testing is certainly less invasive than other surveillance techniques, however at this stage it provides different information, that of population-wide levels of the virus and is therefore being used as a complementary method rather than a replacement for any other surveillance.
- The method should be effective in informing the public health response. If wastewater testing is not providing additional information to other surveillance methods, then justification for its use is limited.
- There is some common good value in not only providing the data from wastewater testing to the public health authorities, but also making it publicly available in some form.

1.3.2 Equity

- Evaluation of wastewater testing, with a focus on the impact on existing health inequities, is necessary to ensure that health inequities are improved and not exacerbated. Community perspectives in this evaluation would be essential.

- Communities with existing poor health outcomes should be prioritised for receiving the benefits of wastewater testing, along with focused attention on avoiding stigmatisation of those communities.

1.3.3 Respect for persons

- The size of the catchment area that is tested and the extent of aggregation of the data that is publicly reported must be carefully considered, to meet the objectives both of informing the public health response and avoiding stigmatisation. This would probably involve reporting more detailed data to the public health authorities than to the public.
- Security of the data, particularly of the detailed data, should meet existing public health data security standards.
- The use of the data must be for the public health response. Any other use would need to be justified separately.

1.3.4 Good governance

- Governance includes established processes for decision-making, transparency and accountability. This requires the deliberate involvement of diverse voices, to be able to anticipate a variety of problems and issues.
- The diverse voices should include Māori perspectives as required by Te Tiriti o Waitangi, as input to both the environmental science and the public health aspects of wastewater testing.
- Community engagement is important, and public health authorities should have established mechanisms for community consultation on a range of issues so that these mechanisms can be called on as situations arise such as extending wastewater testing to public health surveillance for the pandemic.
- Good governance includes close collaborations and good communications.

2. INTRODUCTION

The technology and science of testing for substances in wastewater is relatively new and rapidly expanding. Wastewater-based epidemiology (WBE) uses analytical chemistry techniques to identify substances in samples of sewage collected at the inflow to a wastewater treatment plant (WWTP) over a specified period (usually 24 hours). The data generated is combined with other data sets, such as the estimated number of people contributing to the WWTP, to give insights into factors affecting the health and wellbeing of the population.

The initial use of this science was to quantify the presence and fluctuations of different illicit drugs [6-8]. The COVID-19 pandemic in 2020 presented an opportunity to use this technology to support the public health response by testing for the SARS-CoV-2 virus. This proved a rapid, viable and population-wide method of surveillance, and was therefore integrated into the routine pandemic monitoring by public health authorities in many countries. Reporting of wastewater data is now routinely incorporated in COVID-19 dashboards around the world.

Since the widespread public concern about biotechnologies in the 1990s and 2000s, there has been caution from researchers about the public acceptance of new biotechnologies [9, 10]. Further, in Aotearoa New Zealand, publicly funded research must consider the rights of Māori under Te Tiriti o Waitangi to govern personal data that is generated from Māori people [11, 12]. The Institute for Environmental Research and Science (ESR) therefore undertook a social science project in 2020 related to such issues with respect to WBE being used for detection of illicit drugs, and a further project in 2021 with respect to COVID-19 surveillance. This report discusses each of these projects in turn, and then the possible implications for the future of WBE technologies.

3. DRUGS IN WASTEWATER

3.1 RESPONSIBLE RESEARCH, ETHICS AND EQUITY

The initial concept for the study in 2019-20 was to investigate the 'social licence to operate' (SLO) around WBE, both for monitoring illicit drug use and for potential other uses in the fields of public health, environmental wellbeing, and law enforcement. However, the initial literature review questioned the framing of the research by the concept of SLO, which had been developed from industries such as mining and forestry, which extracted natural resources for use at a profit [13]. The SLO concept was not considered adaptable enough to guide considerations related to the uncertainties of emerging technologies in the context of publicly funded research and Te Tiriti o Waitangi partnerships with Iwi Māori.

The concept of Responsible Research and Innovation (RRI, now commonly referred to as Responsible Innovation or RI), which originated in Europe in the 2000s, was chosen as a framework to guide the study. A widely quoted definition of this concept is "Responsible innovation means taking care of the future through collective stewardship of science and innovation in the present" [14]. Stilgoe et al. outlined four dimensions of RI: Anticipation, Reflexivity, Inclusion and Responsiveness. Anticipation meant that the research institution should make considered judgements about potential impacts of new technologies and research, and act to maximise benefits and minimise risks. Reflexivity required the institution to build in a transparent system for reflecting on its own values and potential different framings of the research. Inclusion of a diversity of voices in decision making was needed for public legitimacy. Responsiveness involved both the capacity and willingness to change the direction of the research. Importantly, RI includes the idea of questioning the societal desirability of the proposed research or technological development, and therefore not assuming innovation processes and the resultant products are always going to be wanted by society simply because they are available.

Community engagement is a core part of the RI framework, which is a broader activity than consultation or trying to convince the public to accept new technologies. RI also encompasses ethics, with different ethical frameworks investigated as part of the literature informing the study. These included the guidelines by Prichard et al. which addressed ethics for WBE in the dominant context of measuring illicit drugs [15], public health ethics [e.g. 16, 17, 18], and Māori research ethics [19].

The guidelines for WBE and related fields were developed by a group of experienced WBE researchers [15]. These guidelines drew upon biomedical human research ethics principles of minimising harm to participants, maximising benefits, and respecting autonomy through informed consent. The conclusion was that since WBE is non-invasive and individuals cannot be identified, there is a very low risk of harm to participants while generating the assumed benefits, and this justified proceeding despite the impossibility of gaining informed consent from participants. Concerns were raised about sampling from sites with small population input and about the reporting of data, were there was potential for stigmatisation of certain groups of people and/or unfair repercussions from the reported data.

Public health ethics grew out of a recognition that the bioethics model commonly used in health settings is based on a one-to-one relationship between researchers and participants. This

model does not provide adequate guidance for population level surveillance, interventions and research. Childress et al. were one of the first groups to explore ethics specifically for the public health context [16]. Their framework had five considerations for deciding whether a public health intervention was justified, using a broadly utilitarian cost/benefit perspective: effectiveness of the intervention, fair distribution of benefits and burdens, necessity of the intervention, least infringement possible, and public justification. More recent commenters have emphasised a social justice responsibility, alongside the utilitarian cost/benefit evaluation [17, 20, 21]. From this perspective, public health research, surveillance and interventions which infringe individual rights should be justified not only in terms of overall public good, but in terms of improving systemic disadvantage.

Ethics in Aotearoa are further shaped by Te Tiriti o Waitangi. A research ethics framework based on Te Ao Māori has been developed for guidance, particularly in research involving humans. The framework is *Te Ara Tika*, meaning 'the right path', and is based on cultural values of Whakapapa (relationships), Tika (research design), Manaakitanga (cultural and social responsibility), and Mana (justice and equity) [19]. Other ethical frameworks, such as the National Ethical Standards for Health and Disability Research and Quality Improvement [22] and the Royal Society Te Apārangi ethical guidelines [23], have been updated so that the principles of *Te Ara Tika* underpin the guidance. The National Ethics Advisory Committee [22] incorporated the principles from *Te Ara Tika*, to ensure that Māori ethical perspectives underpinned all parts of the guidelines. According to *Te Ara Tika*, a responsible approach to scientific research and development requires a focus on relationships and co-governance with Māori.

On the basis of the initial literature review, it was decided that the study of social issues related to WBE technologies should take a RI approach which encompassed governance of research and data, ethical considerations and a focus on addressing systemic inequities.

3.2 ETHICAL BOUNDARIES OF THE WBE SYSTEM

The first study, carried out in 2020, consisted of interviews with nine stakeholders involved with either WBE testing, data governance or ethics, framed by the Critical Systems Heuristics (CSH) approach [24]. The CSH approach focuses on articulating the boundaries of a system, such as what aspects are included or excluded, and who has the power to determine this. For example, when an institution provides data to another agency in a service provider capacity, where and with whom do the boundaries of ethical responsibility lie?

The interview questions were adapted from the standard questions of the CSH approach, based on four issues that influence system boundaries: motivation (what is the purpose of the system), power (who has control of processes and resources), knowledge (what expertise is considered appropriate) and legitimacy (how the research is justified to those not directly involved). Although more interviews had been planned, the COVID-19 pandemic meant that the study was reduced. Full details of the study are available in the report *Ethical and Responsible Development of Wastewater-Based Epidemiology Technologies* [25].

The results of the interview analysis are shown in Table 1.

TABLE 1: Systems boundaries for wastewater-based epidemiology ethics from stakeholder perspectives

Motivation	The beneficiary of ESR research and services ought to be the Aotearoa New Zealand public, even when providing data to a third party. There is a responsibility to ensure that the result is an improvement in social, health and environmental wellbeing. Providing research and data for a commercial company pushes the boundary of acceptability, although the idea of ESR making a financial profit from its research and services is not totally discounted. Acceptance for using WBE for law enforcement is dependent on the purpose, acknowledging that public safety contributes to wellbeing yet data can also be used for either support or punitive purposes. In tandem with a responsibility to the general public, there is also a responsibility to honour Te Tiriti o Waitangi, and actively address systemic disadvantage with respect to Māori.
Power and Control	ESR is expected to have robust policies and procedures which ensure that its research and services achieve the overall aim of improving public wellbeing, with ethical integrity. This extends to ESR providing services to third parties (particularly public service partners), in which case ESR is considered to be a collaborator and therefore have some influence over outcomes. Some cases are identified where ESR is an independent advisor and it is considered acceptable to provide data without ongoing control. Decision making around research is expected to actively include various perspectives, changing as required for specific research projects or programmes. Overall, there is a need for continuity of decision making and to give effect to a Tiriti-based partnership for research governance.
Knowledge	Scientific knowledge is well respected, bringing expectations of proactive self-regulation within the organisation and scientific peer networks. Professional regulation by peers is acknowledged as one mechanism, although this works retrospectively. Other knowledges and expertise are also seen as valuable. It is essential that research involving Māori should involve people with knowledge of tikanga me mātauranga Māori (Māori cultural practices and knowledge systems), as well as people who understand the local Iwi and Hapū context. The need to include a variety of knowledges, including different science disciplines, tikanga Māori and research ethics, suggests a process for dialogue between knowledges and perspectives.
Legitimacy	There is general acceptance of the benefits of wastewater-based epidemiology technologies and minimal concerns about its harmful effects, due to non-invasiveness and population level data. The issue of catchment size, i.e. whether the data is from a city wastewater treatment plant or street level sampling, raises the question of purpose. Community improvement through public health research has greater legitimacy than services for law enforcement. Acceptance is based on trust in ESR as a public research institution that commits to improving the population's wellbeing, self-regulates for high standards of scientific rigour and ethical integrity, and works in an open, transparent and collaborative manner.

These results showed that the main concerns of the stakeholders interviewed were to do with governance and decision making. The stakeholders emphasised that ethical issues were contextual and largely dependent on the reason that the testing was being carried out and the uses to which the data would be put. They were prepared to trust that ethical issues would be dealt with well if there was a robust system to assess risks of any new application of the technologies. This system would enable a diversity of perspectives to be heard and enact a meaningful dialogue with Māori as indigenous partners under Te Tiriti o Waitangi. The research also found that the commonly used bioethical framework of autonomy, justice, benefits and harm, was found to be inadequate when considering the issues related to future applications of WBE. A more systemic approach, such as RI, was required.

4. COVID-19 IN WASTEWATER

4.1 THE ETHICS OF PUBLIC HEALTH SURVEILLANCE

The CSH interview study highlighted that a traditional bioethics framework was not sufficient for the complexity of research and development of new technologies. This became even more salient with the COVID-19 pandemic, when WBE technologies were applied to measuring concentrations of the SARS-COV-2 virus to inform the public health responses in many countries [1]. The Social Systems team at ESR therefore conducted a further study in 2021 to investigate ethical and social issues related to this new use of WBE.

The literature on wastewater testing for the SARS-COV-2 virus in late 2020 and early 2021 predominantly focused on technical details of how to get accurate measurements and interpret the results, along with a concern for keeping WWTP and laboratory staff safe from infection [21, 26-29]. Initial comment on ethical issues was brief, repeating the view that had been established with testing for illicit drugs that ethics was not of concern because individuals could not be identified in the data. For example, Farkas et al. stated that “one of the benefits of wastewater is that it has limited sociological bias with few if any ethical issues” [29].

However, more recent literature has highlighted that wastewater testing for COVID-19 does have ethical issues that must be considered [1, 2, 30]. As wastewater testing is a population-level monitoring technology, public health surveillance ethics are applicable to this situation. Public health ethics, and surveillance in particular, considers the tension between individual rights and collective interests [3, 4]. Surveillance is seen as the foundation for maintaining the wellbeing of the population on an ongoing basis, and the foundation for any epidemic or pandemic public health response [5, 31]. Public health surveillance has the potential to reduce health inequities, but also comes with ethical challenges such as privacy, discrimination and stigmatisation. Surveillance is not a neutral tool [32].

A key aspect is that public health surveillance overrides individual rights in order to provide benefits to the population as a whole, and therefore public health authorities need to explicitly justify the methods used. To guide this justification, four principles have been summarized from the World Health Organisation (WHO) public health surveillance ethics guidelines [5] by Hrudey et al. [1]: common good, equity, respect for persons and good governance. “Common good” means that the surveillance should be shown to contribute benefits to the population, above and beyond benefits to any individuals. “Equity” requires that the surveillance benefits and burdens are fairly distributed, and the technologies not only do not exacerbate existing inequities but preferably improves the situation. “Respect for persons” recognises that despite surveillance being undertaken for the good of the population, individual people must still be accorded respect and dignity. “Good governance” addresses the issue of who decides whether surveillance is justified and in what form, and encompasses community engagement, transparent processes and communications, and accountability.

Justification for public health surveillance using wastewater testing must consider these four principles, and ultimately, the surveillance itself must contribute to the primary purpose of informing the health response to the COVID-19 pandemic.

4.2 SPECIFIC ETHICAL ISSUES FOR WASTEWATER SURVEILLANCE

Two main issues have been discussed in relation to public health surveillance using wastewater - catchment size and data usage. The issue of catchment size highlights that testing for illicit drugs has different requirements and boundaries than testing for infectious diseases such as COVID-19 [3, 21, 28]. With testing for illicit drugs, small catchment sizes were problematic. Testing at a small WWTP or single site, for example a prison, school or festival, could lead to stigmatisation of that small group or to punitive repercussions. In contrast, testing for COVID-19 at a population level provides information of limited use for targeted public health measures. For infectious disease surveillance, the ideal is a smaller catchment size, precisely so that a community can be targeted for beneficial interventions. This leads to the question of who makes the decision as to whether the purpose of the wastewater testing justifies sampling from small catchments, and how small that catchment could be. The current pandemic situation means that there is widespread support for any measure that can help the public health response, but it is conceivable that the ethics of future uses of wastewater testing might not be so clear cut.

The second issue is the use of data collected through wastewater testing, including storage, interpretation and communication. A key point is that although wastewater testing is generally carried out by environmental scientists, in the context of the COVID-19 pandemic the data is for public health and therefore subject to public health surveillance ethics. For some environmental scientists, this is new territory. The communication gap between those carrying out the wastewater testing and those responsible for using the data for the public health response has been highlighted as a barrier to effective use of this surveillance technology [1-3, 29].

Communications between the groups involved in wastewater surveillance was a common theme in ethical guidelines focused on this specific context, particularly the advice from McClary-Guttierez et al. [2] and Hrudey et al. [1]. In order for the data from wastewater surveillance to usefully inform the public health response, environmental scientists need to not only provide reliable data in a timely manner, but also ensure the public health authorities understand the data and its limitations. Conversely, the public health authorities must collaborate closely with the environmental scientists to ensure the data provided is as useful as possible for informing the response. If this communication is not effective, then the justification for overriding individual rights for the common good is not present.

Ensuring the benefits and impacts of wastewater surveillance are equitable was another theme, where the literature is clear that the needs and concerns of different communities should be taken into account. This requires community engagement and a critical lens cast over the decisions regarding where and when to conduct wastewater testing [1-3, 5].

To summarise, common themes from those working with ethical issues of wastewater surveillance for COVID-19 were effective communications, community engagement, and equity of impact for different demographic groups. These were themes that the ESR Social Systems team independently sought to explore in 2021 by gathering together experts in Aotearoa New Zealand and Australia to give advice on equity impacts of communications (note that the research began before the papers by Hrudey et al. and McClary-Guttierez et al. were available).

4.3 EQUITY IMPACTS OF COMMUNICATING WASTEWATER SURVEILLANCE DATA

This research was designed as a Delphi survey study [33], where a panel of people with expertise in the area of concern give independent responses to a survey. The responses are aggregated, and a new survey based on these responses are sent back to the panel who have a chance to see the other perspectives, and then to add more information. The Delphi technique is often used where knowledge is incomplete or uncertain, and the iterative surveys with a panel of experienced people are used to come to some form of consensus on the topic. Ethics approval for the Delphi study was obtained through the New Zealand Ethics Committee/Te Roopu Rapu i te Tika[1].

An invitation to participate in the panel was sent to scientists and communications personnel within ESR (the provider of wastewater testing in Aotearoa) and contacts within the Collaboration on Sewage Surveillance of SARS-CoV-2 (ColoSSoS), which is part of Water Research Australia. The survey questions are detailed in Appendix A. As the response rate was low, further invitations were sent, including to the COVID-19 Wastewater Coalition of the Canadian Water Network. A final sample of 11 responses were received; two from communications staff and the rest from scientists; five from Aotearoa, five from Australia and one from Canada. To support this data, a brief overview of some publicly available dashboards was also undertaken.

The survey responses were uploaded into Dedoose, and this software was used for coding and thematic analysis. A summary of the study and findings to date was prepared and sent to the original respondents, along with a further survey (see Appendix B). The second survey was designed to test the boundaries of the ethical principles and values identified in first survey. Participant views on governance and community engagement related to wastewater surveillance were also sought. However, the timing of this second survey coincided with outbreaks of Delta variant COVID-19 on both sides of the Tasman, and our participants were all fully involved in managing this crisis. The decision was therefore made to stop the study after the first survey.

4.4 DELPHI SURVEY ONE

4.4.1 General findings

Most people did not consider they were experienced enough to contribute to an ‘expert panel’ as this is an evolving field, everyone is learning on the job, and there has been little time for reflection. In addition, the COVID-19 pandemic response has been such a large-scale response with multidisciplinary teams, that most people have only had a small part in the overall process, and therefore found it difficult to answer some of the high-level questions.

A key point from the responses was that scientists involved in wastewater testing primarily communicate with the public health authorities, and it is the health authorities’ responsibility to communicate the results to the public as part of their overall public health response. The role of scientists was to make sure that the public health authorities understood the nuances of the reported data, and to respond to requests for different information as the situation evolved. Occasionally scientists explained the science between the wastewater testing to the media. The health authorities were concerned with presenting understandable information to the

[1] NZEC Application 2021_15, approved 3 May 2021

public, with a particular focus on the call to action: what the health authorities want the public to do. As the pandemic progressed, more dashboards were developed as collaborations between health authorities and scientists, which presented data to the public directly.

In Australia and Aotearoa where there was little ongoing community transmission at the time of the first survey, the focus had moved to reporting unexpected detections of the virus in wastewater. This supported the call for people to get tested and self-isolate as required, and for implementation of temporary restrictions. In Canada, the US and Europe, where there was widespread community transmission, the focus was on reporting viral loads in the wastewater for monitoring and to inform public health measures.

Ethics processes varied widely. Generally, COVID-19 surveillance in wastewater was considered to be covered by Public Health legislation and processes already in place, and therefore no extra ethical process was seen as necessary. Other examples were ethics discussions at ColoSSuS communications group meetings, internal review of varying levels of formality, research ethics committee review for a case control study, or no consideration given to ethics.

Community engagement for addressing difficult equity and ethics questions is recommended in the literature, but there was little evidence of this in the survey responses. Responses suggested that this was the responsibility of health authorities more than the scientists.

4.4.2 Thematic coding using Dedoose

Two high level themes were identified, each with sub-codes. Figures 1 and 2 below illustrate sub-themes within each of the two high level themes, Communications and Ethics. The size of the words indicates the number of excerpts within that code, followed by an explanation of the themes.

Figure 1: Communications coding

Respondents were clear on the purpose of the wastewater surveillance, which was to help inform the public health response to the pandemic, and comments reflected commitment to that purpose. Communications to the public were therefore seen as appropriately under Health Department control, and the wastewater surveillance data was part of the overall response so became aligned with existing COVID-19 surveillance reporting.

Communications between scientists and the Health Department were negotiated and evolved over time as the situation changed and more information about the virus and pandemic became available. This evolution also showed in the themes of continual improvement, and a sense that – at least in the beginning – the communications were ad hoc and reactive.

From the scientists' point of view, consideration of different audience needs was more about whether the information was specifically for the Health Department or was destined for the public. The idea of different communications for different population groups was not often mentioned.

Overall, consistent with the idea that the purpose of communications was to support the public health response, the respondents stressed early communications, consistency, and clarity of the key messages for the public. Several respondents noted that there should be an analysis of whether the communications were effective in producing the desired public actions, for example increased surveillance testing within a region with positive wastewater result. Such tracking of communication effectiveness was lacking at time of the survey.

Figure 2: Ethics coding

Aligned with the clear purpose of informing the public health response, the question of ethics was seen within the umbrella of a public health communicable disease surveillance framework, for which governance processes were in place following relevant legislation. There was a distinction between wastewater testing being done as a service for public health purposes, in which case the legal frameworks for public health were seen to apply, and testing in the research phase, where research ethics frameworks could apply. The concept of 'public health ethics' as a specific framework outside legislation was referred to in a minority of cases.

Catchment size and the principle of aggregation in reporting data was the main area respondents highlighted as needing extra consideration or debate, beyond the public health processes already in place to meet legal requirements. There was a tension between a small enough area for detection of the virus to be useful in targeting health responses, and a large enough area so that the data could be aggregated in a way that did not identify or stigmatise

specific communities. The approach to an appropriate catchment size varied widely among the respondents, linked to their specific context.

Specific communities mentioned by respondents included rural, indigenous, and aged care facilities. The perspective was generally that these communities needed specific consideration in order to be included and therefore benefit from the COVID surveillance.

4.5 COVID-19 WASTEWATER SURVEILLANCE REPORTING

See Appendix C for examples of data reporting from different dashboards.

ESR provides a COVID-19 surveillance dashboard for the Ministry of Health in Aotearoa. A public version of this dashboard is also made available (https://nzcoviddashboard.esr.cri.nz/#!/).The dashboard reports confirmed cases, with demographic breakdowns. Wastewater testing results are reported on a separate webpage within the COVID-19 response section of its website. Results are reported as Not detected/Detected (green/red) at each site tested, along with a map of test sites. The information shared on the Queensland in Australia website has similar graphics and content.

New South Wales in Australia also reported Not detected/Detected tables while the overall incidence of COVID-19 was relatively low. As the Delta variant outbreak progressed, the tables became less informative because of the high numbers of detections and large numbers of sampling sites. In September 2021, the weekly reports changed to lists of places where there had been detections, detections with no known cases, and no detections. Data was also reported on the website using maps, and a not detected/detected (blue/red) colour coding.

Victoria in Australia uses an interactive map updated weekly with a wider range of coding, which includes distinguishing between expected and unanticipated detections. Separate charts give historical details about individual sites. Western Australia uses a similar system.

In North America and Europe, where COVID-19 levels are high and the virus is widespread, the focus of data reporting is the levels of virus in the wastewater and the trend lines. Ottawa in Canada updates the graphs on its website with daily viral concentrations over the previous week with a line indicating the seven-day midpoint mean viral signal, and weekly with the average signal on a graph showing the trends over the past year – comparing this with reported cases. They have also tracked the proportion of the Alpha variant since February 2021. In contrast, the Northern Territories in Canada, with far fewer cases, reports their data in a fashion similar to Victoria, Australia.

The city of Boston, in the US, has had a pilot study to track the SARS-COV-2 virus in wastewater at the Deer Island Treatment Plant since March 2020. The viral signals are added to the graphs (total/north systems/south system) every few days. The City of Burlington had a similar system, taking data from three different sewersheds. In July, the Burlington website was publicly available, however by October the website required login credentials.

The Netherlands produce a national COVID-19 dashboard, and have made it a requirement for all 323 municipal WWTPs to contribute daily COVID-19 monitoring data. The data is presented as the average number of virus particles per 100,000 participants over time and on a map.

Overall, then, there has been significant effort worldwide to produce dashboards and other web-based data reporting that present the information to the public in understandable ways.

The dashboards are generally embedded in or connected to health authority websites that also contain information about the COVID-19 response for that area, answers to frequently asked questions, and information about the science of wastewater testing. Apart from design and formatting differences, the biggest difference between public dashboards in Aotearoa and Australia versus those in North America or the Netherlands is reporting on viral concentration loads and not just simply detections. This reflects the different pandemic conditions in these countries. In North America and Europe SARS-CoV-2 is detected in most samples, requiring therefore viral concentrations to be useful. In Aotearoa, any level of detection has been cause for concern, with most samples not containing any viral fragments. This is an example of tailoring the public data to the context. These examples also show the evolving nature of the dashboards, particularly the changes in New South Wales reporting as the Delta outbreak increased, and the City of Burlington imposing stricter data security on what had public data from relatively small catchments. Of interest, too, was the decision of the New South Wales health authorities to change colour coding from the symbolic green/red to a blue/red coding to avoid the public thinking of the results as simply good/bad (comment from survey one).

5. DISCUSSION

Innovation is a key part of scientific discovery and technological development. Wastewater-based epidemiology (WBE) techniques, where wastewater samples from treatment plants are tested for various substances that give insights into population health, is one such innovation. WBE has been applied to monitoring trends in illicit drug usage, and more recently it has been used to measure concentrations of the SARS-COV-2 virus to inform the COVID-19 pandemic response. Innovative technologies can challenge the accepted ethical frameworks and public acceptance, as by their very nature they move into new territory. Consideration also needs to be given as to what benefits and harms the new technologies could bring, and whether it might result in mitigating or strengthening existing social, cultural, health and economic inequities. For government funded research institutions such as ESR, these social justice considerations are essential when defining what counts as public good science.

The Social Systems team at ESR started investigating issues of public acceptance, ethics and equity related to WBE technologies in 2020. The initial interview study, based on Critical Systems Heuristic questioning, found that key stakeholders were less concerned with the ethics of the technology itself than with the purpose of the WBE usage, and who was making the decision about WBE use. For example, there was less support for measuring illicit drug use through WBE for law enforcement purposes, compared to using the data to support improved addiction and rehabilitation health services. The stakeholders also strongly supported the idea that decisions around use of WBE should include the input of diverse voices, so that the potential impact of the technology use on different demographic groups was well considered.

This work was extended when WBE was used to monitor virus levels to help inform the public health response to the COVID-19 pandemic. During the pandemic, the public accepted many restrictions on their liberties that would not usually be accepted, such as restrictions on travel and business activity, and submitting to testing and quarantine. The widespread acceptance of WBE to support the COVID-19 health response should be seen in that light, and not taken for granted that this meant there were no ethical issues to be considered. The need for ethics discussion has been recognised by international collaborations dedicated to COVID-19 surveillance in wastewater [1-3]. The ESR Social Systems team also conducted a questionnaire with a group of WBE experts to gauge the emergent ethical and equity issues, particularly for the context of Aotearoa New Zealand and Australia. Combined with a literature review and a brief survey of publicly available wastewater data dashboards, we were able to come to some conclusions around the responsibilities of different groups within the WBE system as used for the pandemic response.

5.1 MULTIDISCIPLINARY CHALLENGES

COVID-19 surveillance in wastewater brings together different disciplines, and in some countries, bringing together people who do not always work closely. A major division between disciplines is environmental health/public health. ‘Environmental scientists’ in this context are those involved with wastewater such as environmental science researchers, water engineers and local authority infrastructure planners and operators, and ‘public health authorities’ are those involved in public health, such as epidemiologists, public health agencies, decision makers and front-line staff. Despite growing awareness of the holistic One Health concept

which views the health of people, animals and the environment as interrelated, collaboration can be limited between environmental scientists and public health authorities. This is particularly a problem in countries where there are many institutions to coordinate, and environmental and public health expertise are siloed rather than integrated. Yet there will arguably be more need for such collaboration as climate change accelerates and the incidences of zoonoses increase accordingly [34]. ESR is in a unique position in that wastewater testing, viral genomic sequencing and public health epidemiology are all located within the one institution, and therefore communications between those groups and with the national health authority (the New Zealand Ministry of Health/Manatū Hauora) is relatively straightforward. The literature shows that this type of integrated One Health approach would contribute to future resilience within the health sector.

5.2 RESPONSIBILITIES OF ENVIRONMENTAL SCIENTISTS

In the specific context of wastewater surveillance for the SARS-COV-2 virus, environmental scientists have a responsibility to ensure that data is collected safely and ethically. Safety includes ensuring that WWTP and laboratory staff are safe from infection [35, 36]. Ethics would include ensuring that only virus genomic material, and not that of humans, is being collected and analysed [2].

Environmental scientists have a further responsibility of continuing to improve the quality of the science of WBE, including its validity and reliability, and methodological standardisation, which any search of the science literature will show is currently occurring at a great rate. It is important the limitations of WBE are widely known, so that no claims are made that are not supported by the data. The fact that wastewater surveillance has been adopted as complementary to other public health COVID-19 monitoring tools, and not as a replacement, speaks well of the caution of environmental scientists and public health authorities.

There needs to be reciprocal knowledge exchange between the two groups, where environmental scientists must adequately explain the science, the data and the limitations to public health authorities, and in return, must come to adequately understand the public health context and ethical frameworks.

This mutual understanding is necessary for responsible management of the data generated by wastewater testing. While data security and individual privacy is important, the data being collected is public data and should be made available to the public in a way that supports the public health response and does not unfairly target certain demographic groups. This requires the environmental scientists to work closely with public health authorities to separate the detailed data that is for the public health authority decision makers and the data that will be made public, to present the data in dashboards and reports in meaningful ways that are explained carefully, and to respond both proactively and reactively to changing pandemic situations which require different data analysis and presentation. The publicly available dashboards with wastewater testing results show that this is not a small task, and the Delphi survey reported above gave evidence of the evolving nature of such reporting as a collaboration between environmental scientists and public health agencies.

5.3 RESPONSIBILITIES OF PUBLIC HEALTH AUTHORITIES

The responsibilities of public health authorities connect with those of environmental scientists. It is not enough for the science to be explained; public health authorities must ensure that they

understand the data sufficiently to be able to use them effectively and appropriately for decision making. Likewise, public health authorities have a responsibility to ensure that public health surveillance ethics are followed, which requires them to explain these appropriately to environmental scientists where necessary.

Since the purpose of wastewater surveillance is to inform the public health response, it is the responsibility of public health authorities to ensure testing results are accompanied by clear and consistent messages about the impact on the public health response. The public have given an implicit mandate for surveillance so that they can be protected from COVID-19, so the public health authorities have an ethical responsibility to provide that protection as best they can. Further, the experts in our Delphi survey emphasised the importance of clarity and consistency of messaging for effectiveness of the response, and collaboration between scientists and authorities can help those aspects. Authorities also have a responsibility to consider the messaging carefully to avoid labelling or stigmatisation of certain geographic or demographic communities; and to try to prevent sensationalism of the data, by media or a vocal sub-section of the population, which could have negative impacts on specific communities.

Finding out about community needs and concerns is primarily the responsibility of public health authorities. Engagement with communities is necessary to guide the choice of sites of testing and ensure that communities are not unfairly targeted or ignored. This is particularly important for small catchment sizes. Conventional ethical approaches to WBE suggests that catchment sizes need to be sufficiently large enough to provide data that is fully anonymised. However, for a public health response there is value in testing from a small catchment area, even a single building, and public health surveillance ethics [1] allows for this if it is the least invasive, effective method of surveillance that yields benefits for the people concerned. The consensus among the experts from literature and our study is that such decisions should be made after engagement with the community affected. The smaller the size of the community, the bigger the impact of targeted surveillance, and also the easier it is to engage with and listen to that community.

As a more general principle, it is expected that public health authorities have established relationships with communities that they are responsible for, either directly or through a local health agency. It was emphasised that there was no time or resource during the pandemic crisis to establish such relationships, even if such community engagement was seen as ideal. Planning for future resilience in pandemics and other health emergencies should prioritise out-reach to communities for reciprocal exchange of information and concerns.

6. WASTEWATER TESTING IN AOTEAROA

Testing wastewater for infectious diseases such as COVID-19 is an example of an emerging technology that has been rapidly added to the public health toolkit, bringing together scientific disciplines and public officials who do not always work together. This brings communication challenges, and reciprocal responsibilities to ensure that those conducting the testing and those using the data to inform the public health response have clear and mutual understanding of the scientific limitations, ethical issues, and logistical challenges.

Wastewater testing for COVID-19 is a public health surveillance tool, and therefore the ethical guidelines for public health surveillance are applicable [1, 2, 4, 5]. The guidance can be summarised under the four principles of Common good, Equity, Respect for persons, and Good governance.

Common good:

- Any surveillance method must contribute to the common good in a significant way, in order to justify overriding individual rights such as informed consent.
- The science of wastewater testing should be developed so there is confidence in the quality, validity and reliability of the data, that it is an effective measure of the viral load in the wastewater and that this result reliably correlates to the presence of COVID-19 cases in the community.
- Where there is a choice of methods to provide similar data, the least invasive method should be preferred. Wastewater testing is certainly less invasive that other surveillance techniques, however at this stage it provides different information, that of population-wide levels of the virus and is therefore being used a s complementary method rather than a replacement for any other surveillance.
- The method should be effective in informing the public health response. If wastewater testing is not providing additional information to other surveillance methods, then justification for its use is limited.
- There is some common good value in not only providing the data from wastewater testing to the public health authorities, but also making it publicly available in some form.

Equity:

- Evaluation of wastewater testing, with a focus on the impact on existing health inequities, is necessary to ensure that health inequities are improved and not exacerbated. Community perspectives in this evaluation would be essential.
- Communities with existing poor health outcomes should be prioritised for receiving the benefits of wastewater testing, along with focused attention on avoiding stigmatisation of those communities.

Respect for persons:

- The size of the catchment area that is tested and the extent of aggregation of the data that is publicly reported must be carefully considered, to meet the objectives both of informing the public health response and avoiding stigmatisation. This would probably involve reporting more detailed data to the public health authorities than to the public.
- Security of the data, particularly of the detailed data, should meet existing public health data security standards.
- The use of the data must be for the public health response. Any other use would need to be justified separately.

Good Governance:

- Governance includes established processes for decision-making, transparency and accountability. This requires the deliberate involvement of diverse voices, to be able to anticipate a variety of problems and issues.
- The diverse voices should include Māori perspectives as required by Te Tiriti o Waitangi, as input to both the environmental science and the public health aspects of wastewater testing.
- Community engagement is important, and public health authorities should have established mechanisms for community consultation on a range of issues so that these mechanisms can be called on as situations arise such as extending wastewater testing to public health surveillance for the pandemic.
- Good governance includes close collaborations and good communications.

GLOSSARY

Aotearoa	Māori name for New Zealand
Hapū	Māori sub-tribe(s)
Iwi	Māori tribe(s)
Mana	Prestige, dignity, influence, status, spiritual power
Manaakitanga	Showing respect, generosity, and care for others
Māori	Indigenous people of Aotearoa New Zealand
Mātauranga Māori	Māori knowledge systems
Te Tiriti o Waitangi	The Treaty of Waitangi
Tikanga	Cultural processes and protocols
Te ao Māori	The Māori world/worldview
Whakapapa	Genealogical relationships

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APPENDIX A: DELPHI SURVEY ONE

Project title: **Reporting COVID-19 wastewater surveillance results: ethics and impacts**

Information and consent

The Institute for Environmental Science and Research (ESR) Social Systems team wishes to learn from international experience in reporting COVID-19 surveillance testing in wastewater. The particular focus of the study is on the ethical issues and equity impacts of data reporting. We wish to recruit a panel of 20-30 experts in COVID-19 surveillance through wastewater testing and reporting, including both scientists and communication team members. If you agree to take part, you will be asked to complete online surveys, where the results from one survey will be aggregated and used to inform the next survey. We expect:

- 3-4 rounds of online surveys
- Each survey would take less than 20 mins to complete
- Each survey should be completed within a week of receiving it
- Surveys would be sent fortnightly (for 3-4 rounds)

The completed results will be then discussed by Māori data sovereignty experts to give an indigenous Aotearoa New Zealand perspective. The findings from the whole project will be shared directly with Delphi participants, made available as a resource for the Australian ColoSSoS group, used by the New Zealand Ministry of Health and ESR COVID-19 in wastewater surveillance team, and published as a journal article.

We would be grateful if you would commit to completing all the survey rounds, however, you may withdraw at any time up until you have completed the final round. Your contact details will only be used for the purpose of sending you the links to the online surveys, and your answers will be reported in an aggregated form so that you and your responses will not be able to be identified.

If you have any further questions, you may contact Dr Suzanne Manning (Suzanne.manning@esr.cri.nz) or Dr Mathew Walton (Mathew.walton@esr.cri.nz).

Continuing with this survey implies that you give consent for your involvement.

To continue, please tick here to confirm that you have read and understood the study information provided: ☐

You and your organisation are involved in some way with COVID-19 surveillance using wastewater testing, and in reporting this data for a wider audience. Please answer these questions with respect to this reporting.

Mode and format

1. Initially, how did you decide which data would be communicated?
2. Initially, how did you decide on the frequency, mode and format of communications?
3. What differences do you have between public-facing and health authority-focused communications?
4. What do you think has worked well in your communications? Why?
5. What have you abandoned, changed or has simply not worked well in your communications? Why?

Ethics

6. Did you have any ethical oversight process in how COVID-19 wastewater testing was conducted? YES/NO
7. If YES, please briefly describe the ethical oversight process used.
8. If YES, what ethical issues were raised and addressed (e.g. catchment size, ethnicity and other demographics of the catchment area)?
9. Did you have any ethical oversight process in how COVID-19 wastewater testing was communicated? YES/NO
10. If YES, please briefly describe the ethical oversight process used?
11. If YES, what ethical issues were raised and addressed (e.g. aggregation of data, stigmatisation of communities)?

Equity impacts

12. How do you evaluate the effectiveness and impact of your communications on different audiences, such as indigenous peoples, differing age groups, rural/urban locations?
13. In what ways have your evaluations of effectiveness and impact changed how you collect your data or the way you report it?
14. What is missing from your current communications?
15. What are three pieces of advice you would give to someone setting up communications from scratch?

Demographics

16. Which best describes your current professional role? Scientist/Communications/Other (please specify).
17. Which best describes your current employer? Government agency/Tertiary education institution/ research institution/private company

18. One final question: do you have a suggestion for someone else (who could be considered an expert in this field) who you think we should contact?

You can go back and review and edit your answers before submitting the survey if you wish.

Thank you for your time.

APPENDIX B: DELPHI SURVEY TWO

The second and final survey for the panel to answer is designed to focus on clarifying your boundaries for ethical decisions.

You can find your personal link to the Qualtrics survey in the covering email.

B.1 Ethical boundaries

Minimum catchment sizes cited in the previous survey and literature review were from 500 people to at least 10,000. The different sizes reflected the different purposes that the wastewater surveillance served. Smaller catchment sizes tended to be associated with cities or towns with a local health focus, and reporting viral loads. The concern was monitoring the ongoing community transmission. Larger catchment sizes tended to be associated with regional or state surveillance and reporting unexpected detections, where the concern was to avoid stigmatising a small community. SE Hrudey, DS Silva, J Shelley, W Pons, J Isaac-Renton, AH-S Chik and B Conant [1] have suggested that testing from smaller catchment sizes than would otherwise be the norm could be justified in some situations.

1. Please describe a situation where you would consider it ethically acceptable to test from a smaller catchment size than is the set minimum for your jurisdiction.

2. What principles or criteria would you use to justify this decision?

   Consider the possibility that you are asked to report data from a smaller catchment size than is the set minimum, and your criteria for justifying this (as in question 2) have not been met – that is, you are being asked to do something you consider to be unethical.

3. What options do you have to influence the decision?

4. Here is a list of public health ethical principles and values from the literature. Please rank these in order of importance to the specific case of surveillance of COVID-19 in wastewater.

   - Common good: the benefits accrue to the population, not specifically to individuals
   - The benefits of surveillance are distributed fairly
   - The burdens, costs and impositions of surveillance are distributed fairly
   - The surveillance contributes to reducing health inequities
   - People's right to liberty of action is respected
   - People's right to consent to their data being utilised is respected
   - People's right to privacy is respected
   - Communities' values are considered when decisions are made
   - Communities are involved in decision making around surveillance
   - The method of surveillance used is effective for the purpose
   - The method of surveillance is the one that imposes the least enfringements on the public
   - The method of surveillance is necessary for the purpose
   - Public health authorities can adequately justify their surveillance decisions
   - Public health authorities are open and transparent about their surveillance decisions
   - Public health authorities do not step beyond accepted mandates for surveillance
   - Data is stored securely
   - Data is shared with other public health authorities to build up knowledge
   - Data is used for research purposes to advance knowledge
   - Data is made available to the public
   - Results of surveillance are communicated to the public

5. Is there any other ethical or equity consideration that you would add to the list in the previous question?

B.2 Wastewater surveillance – Governance and community engagments

Good governance of the wastewater surveillance programme, including communications, has been identified as an essential part of ensuring equitable health outcomes.

6. In your opinion, what factors contribute to good governance in this context?

7. Who should be involved in governance in this context?

8. Who represents the interests of the most marginalised communities?

Community engagement has been identified as important for designing ethically sound programmes of public health surveillance.

9. From your point of view, what are the benefits of community engagement to inform the wastewater surveillance programme?

10. What challenges are there in community engagement to inform the wastewater surveillance programme?

11. Whose responsibility should it be to undertake such engagement?

12. Are there any structures or processes already in place for such engagement?

13. Which communities would be the priority for engagement processes?

14. What factors should specifically be taken into account when engaging with indigenous communities, rural communities, and communities where there is widespread socioeconomic disadvantage?

B.3 Demographic questions

15. Which best describes your current professional role? Scientist/communications/other - If other, please specify.

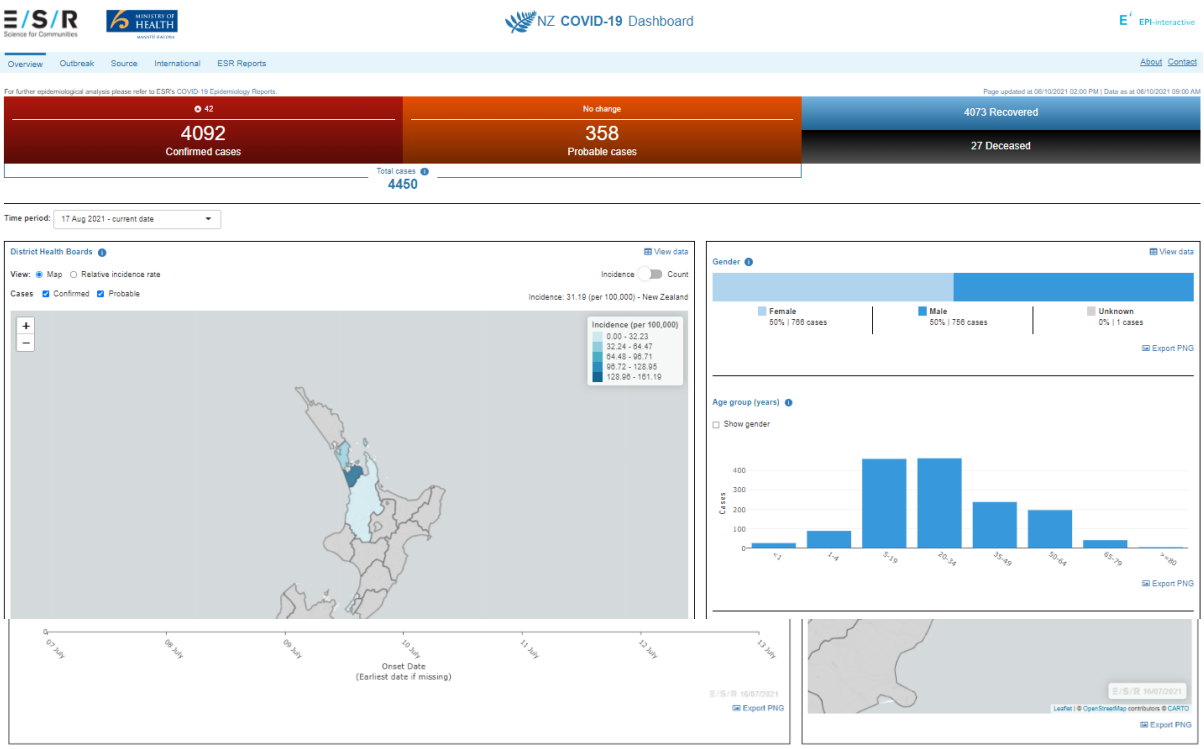
16. Which best describes your current employer? Government agency/Tertiary education institution/Research institution/Private company

Thank you for your time 😊

APPENDIX C: COVID-19 WASTEWATER SURVEILLANCE REPORTING

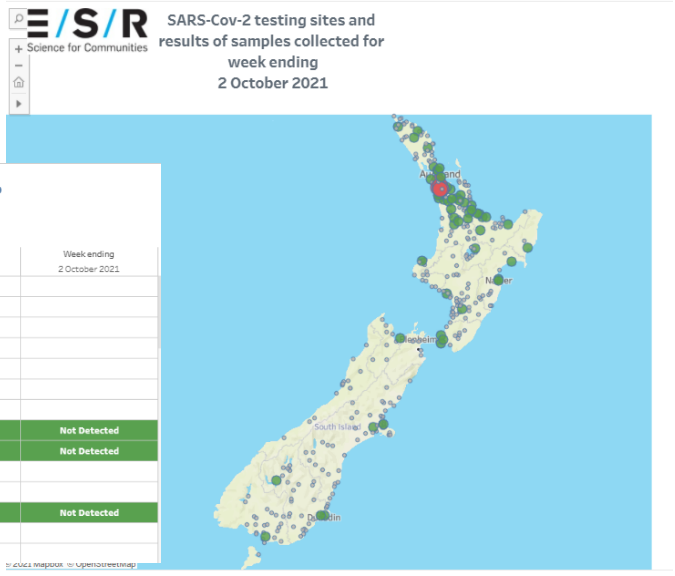
C.1 ESR, Aotearoa New Zealand

https://esr.govt.nz/our-expertise/covid-19-response



Above: A partial screenshot of the ESR COVID-19 intelligence dashboard.

Below and right, examples of the wastewater testing results.



Science for Communities

SARS-Cov-2 testing sites and results of samples collected up to 2 October 2021

Region	Location	Week ending 11 September 2021	Week ending 18 September 2021	Week ending 25 September 2021	Week ending 2 October 2021
Northland	Ahipara	Not Detected	Not Detected		
	Awanui	Not Detected	Not Detected		
	Dargaville	Not Detected	Not Detected		
	Hihi	Not Detected	Not Detected		
	Hikurangi		Not Detected		
	Houhora	Not Detected			
	Kaeo	Not Detected	Not Detected		
	Kaikohe	Not Detected	Not Detected	Not Detected	Not Detected
	Kaitaia	Not Detected	Not Detected	Not Detected	Not Detected
	Kaiwaka	Not Detected	Not Detected		
	Kawakawa	Not Detected	Not Detected		
	Kerikeri	Not Detected	Not Detected	Not Detected	Not Detected
	Mangawhai	Not Detected	Not Detected		
	Maungaturoto	Not Detected	Not Detected		

C.2 New South Wales, Australia

https://www.health.nsw.gov.au/Infectious/covid-19/Pages/sewage-surveillance.aspx

Downloadable weekly reports up until September 2021 included sewage surveillance results as tables:

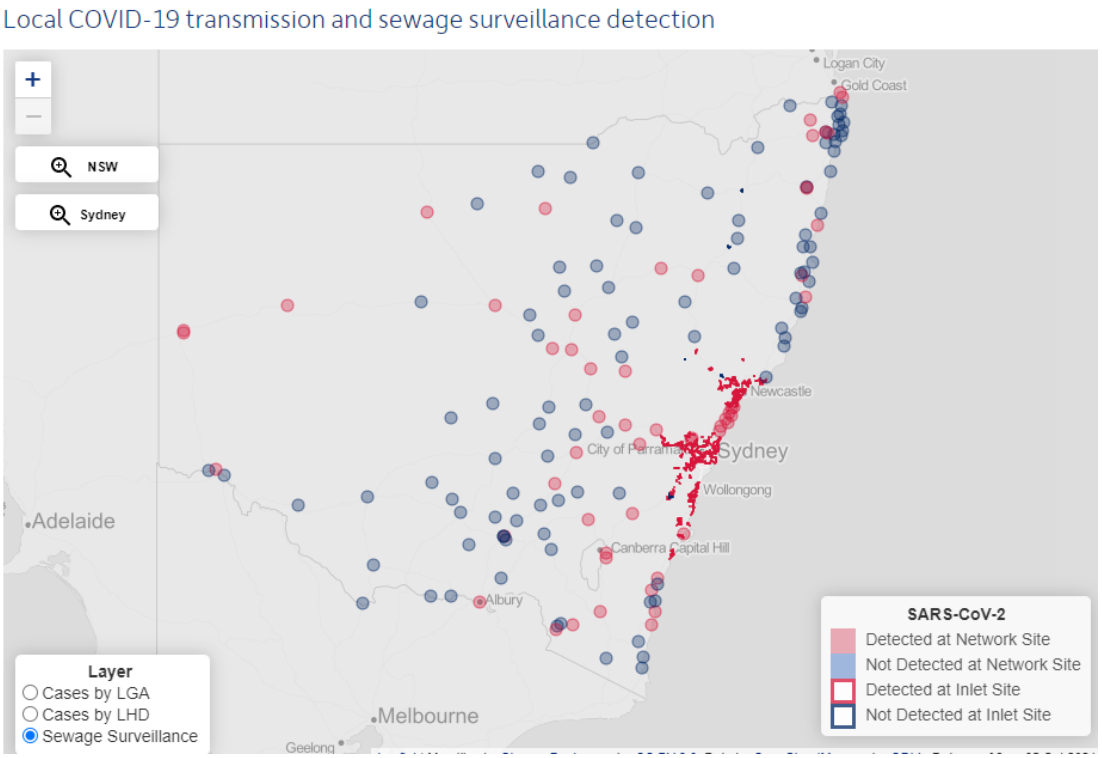
Table 7. Locations with SARS-CoV-2 detections in sewage samples in the last 10 weeks, NSW, 11 April to 3 July 2021

		1-May	8-May	15-May	22-May	29-May	5-June	12-June	19-June	26-June	3-July
Pop.	**Location**	17	18	19	20	21	22	23	24	25	26
Sydney sewage treatment plant (inlet sites)											
110,114	Penrith										
1,241	Brooklyn										
31,924	Hornsby Heights										
318,810	Bondi										
233,176	Cronulla										
1,857,740	Malabar 1										
	Malabar 2										
181,005	Liverpool										
98,743	West Camden										
161,200	Glenfield										
1,341,986	North Head										
26,997	Castle Hill Cattai										
	Castle Hill Glenhaven										
119,309	Rouse Hill										
163,147	St Marys										
68,000	Port Kembla										
93,000	Bellambi										
Sydney network sites											

Table 13. Locations with SARS-CoV-2 detections in sewage samples in the last 10 weeks, NSW, week ending 19 Jun to 21 August 2021

		19 June	26 June	3 July	10 July	17 July	24 July	31 July	7 August	14 August	21 August
Pop.	**Location**	24	25	26	27	28	29	30	31	32	33
60,514	Blue Mountains (Winmalee)										
3,700	North Richmond										
13,052	Richmond										
110,114	Penrith										
12,000	Lithgow										
19,000	South Windsor										
8,000	McGraths Hill										
69,245	Warriewood										
1,241	Brooklyn										
31,924	Hornsby Heights										
57,933	West Hornsby										
318,810	Bondi										
233,176	Cronulla										
1,857,740	Malabar 1										
	Malabar 2										
181,005	Liverpool										
98,743	West Camden										
6,882	Wallacia										
161,200	Glenfield										
1,341,986	North Head										
26,997	Castle Hill Cattai										
	Castle Hill Glenhaven										
163,147	Quakers Hill										
119,309	Rouse Hill										
37,061	Riverstone										
163,147	St Marys										
73,686	Shellharbour										
55,000	Wollongong										
68,000	Port Kembla										
93,000	Bellambi										

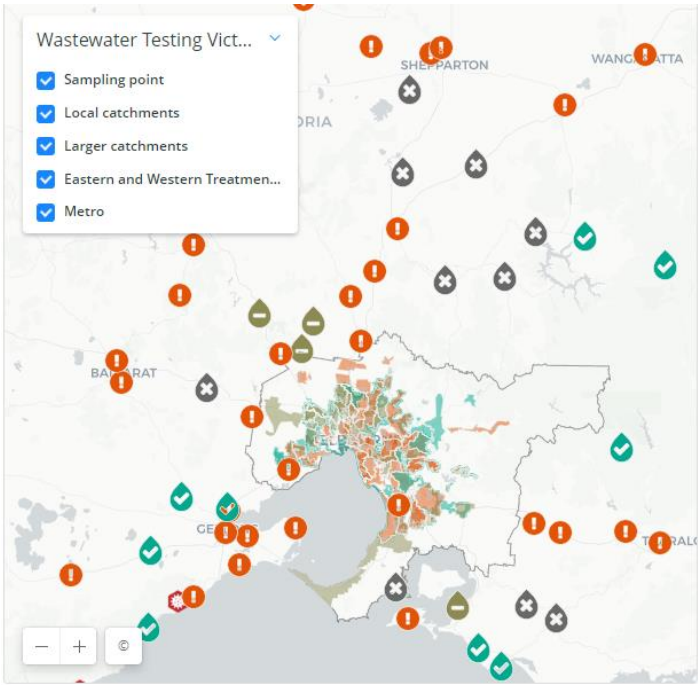
The website also has an interactive map that shows, among other data, sewage surveillance results for NSW or for Sydney:



C.3 Victoria, Australia

https://www.coronavirus.vic.gov.au/wastewater-testing

The data for wastewater testing is on the main website and is in the form of an interactive map, and separate charts for individual sites:



Status	Wastewater treatment plant	Network area
Unexpected detection		
Anticipated detection		
No detection		
Test result pending		
Inconclusive		
No tests performed in this period		
Testing site suspended		Not applicable

Hover over each icon to see the date of sample collection.

Site/Last 28 day results	Localities include...
Altona	Altona, Altona Meadows, Seaholme, Sanctuary Lakes, and parts of Laverton, Point Cook, and Williams Landing
Altona Outfall - Laverton North	Deer Park, Altona, Laverton North, Ravenhall, Derrimut, Truganina
Aurora	Epping

C.4 Queensland, Australia

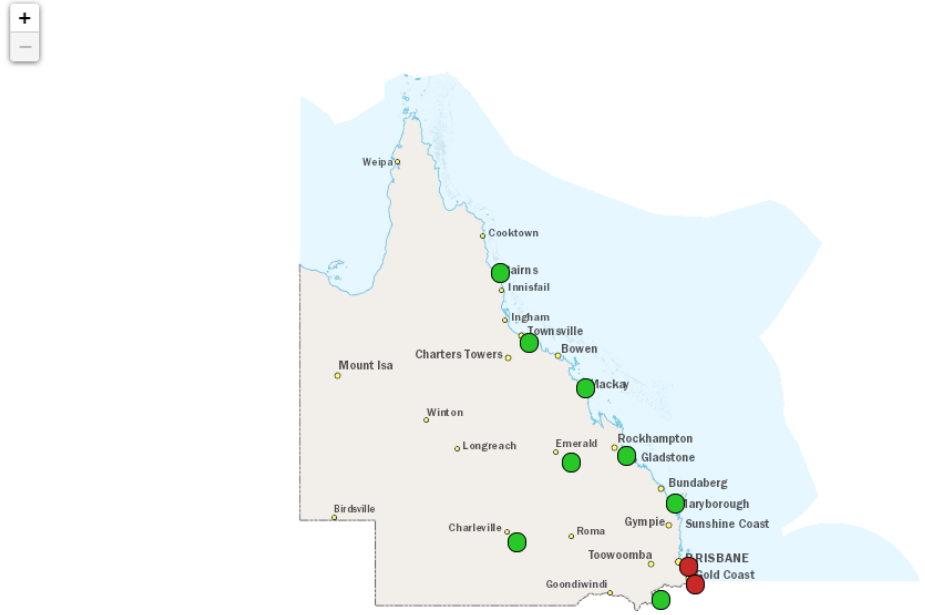
https://www.qld.gov.au/health/conditions/health-alerts/coronavirus-covid-19/current-status/wastewater

The website dashboard is similar to ESR, Aotearoa, with a Not detected/detected (red/green) coding on a map, and in a table that gives historic details about individual sites:

Wastewater test results for the past four weeks

Location	Week ending 20 Jun	27 Jun	4 Jul	11 Jul
▶ Cooktown	Not detected	Not detected	Not detected	Not detected
▶ Port Douglas	Not detected	Not detected	Not detected	Not detected
▶ Marlin Coast	Not detected	Not detected	Not detected	Not detected
▶ Pulgul	Not detected	No samples taken	No samples taken	Not yet tested
▶ Maryborough	Detected	Not detected	Not detected	Not detected
▶ Noosa	Not detected	Not detected	Not detected	Not detected

Map of recent wastewater testing results



Map legend & help

This map summarises the most recent results from the last two weeks of available data.

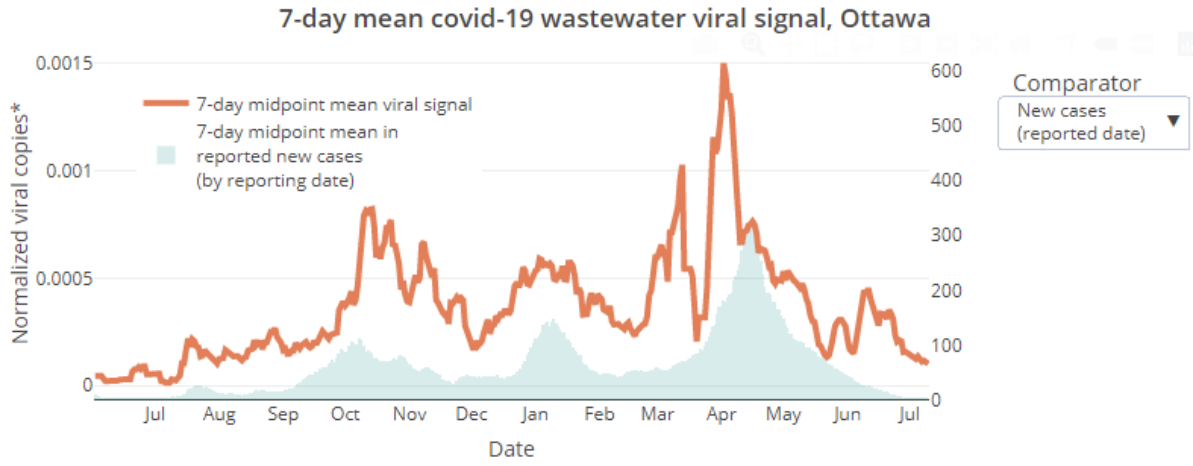
- Recent detection
- No recent detections
- No samples taken recently

Markers may denote tests from multiple locations. Hovering over a marker will show the dates, places and results of those tests.

C.5 Ottawa, Canada

https://613covid.ca/wastewater/

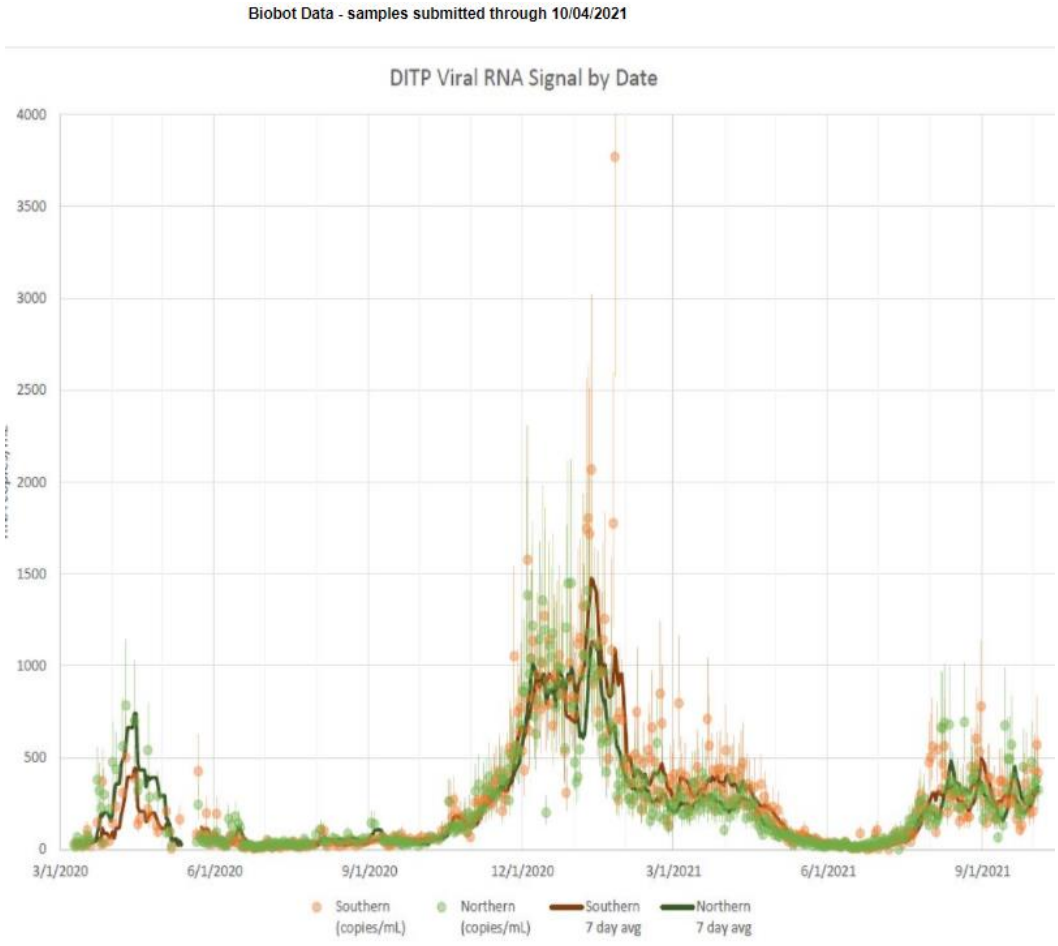
The data on the Ottawa website is displayed as graphs of viral loads:



C.6 Boston, US

https://www.mwra.com/biobot/biobotdata.htm

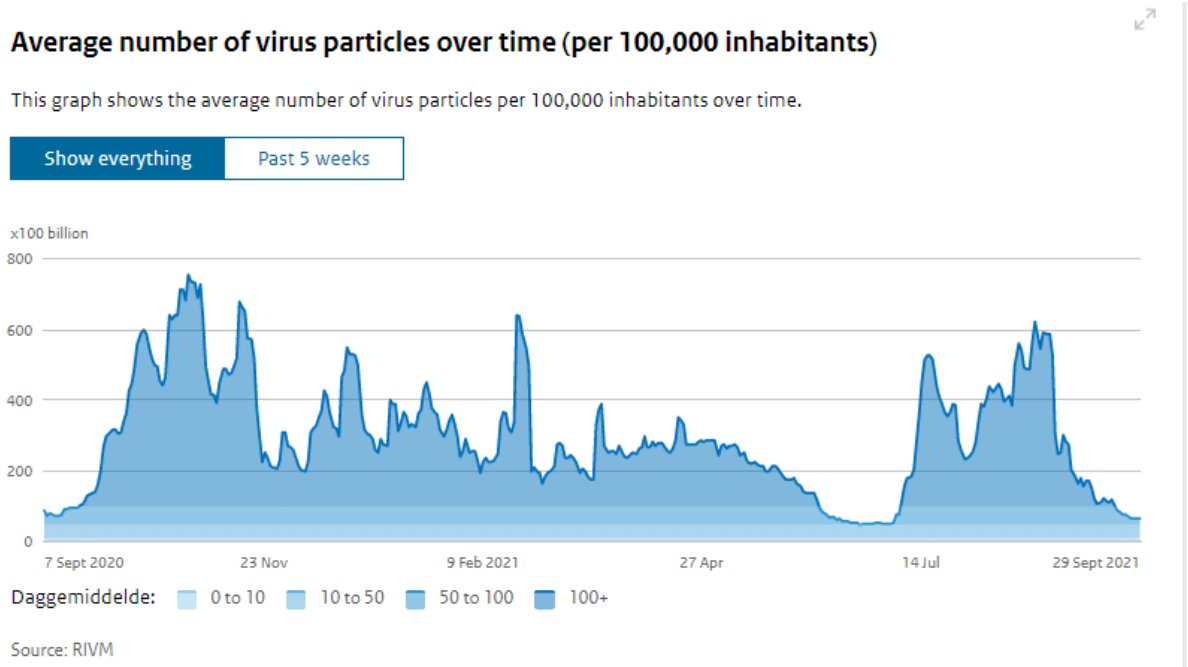
The data of viral loads is added to continuously in this ongoing pilot study:

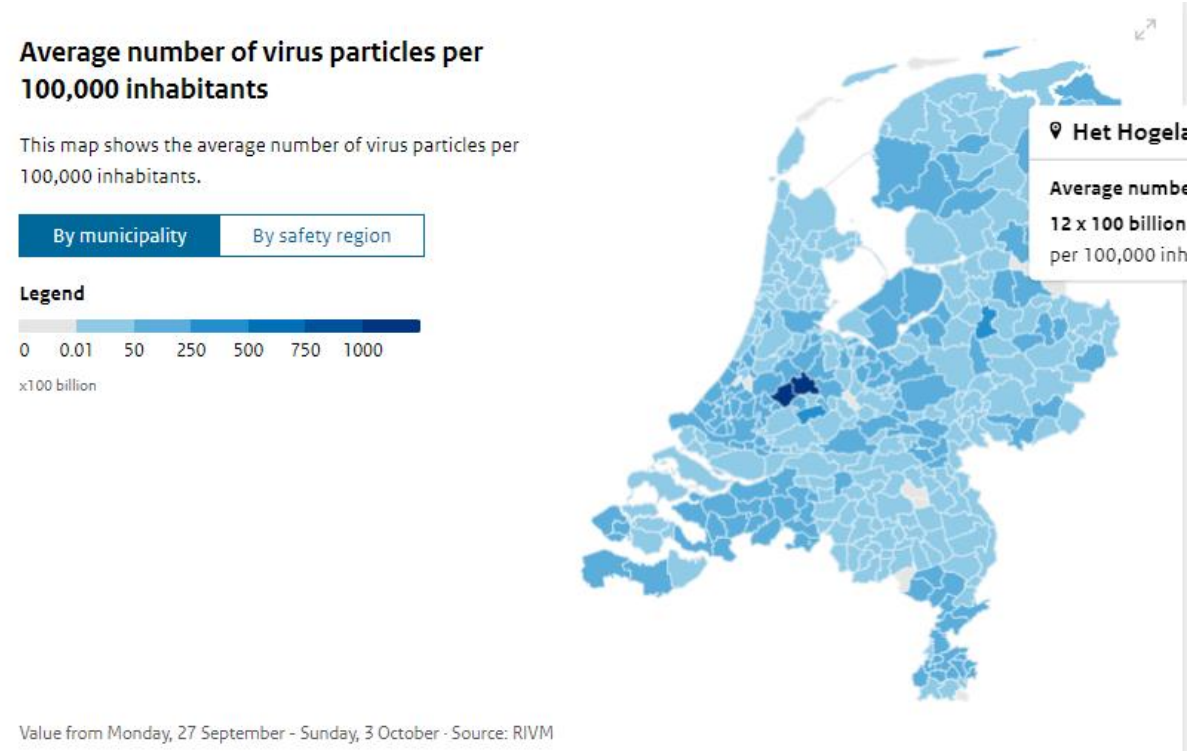


C.7 The Netherlands

https://coronadashboard.government.nl/landelijk/rioolwater

The national dashboard collects daily monitoring information from municipal WWTPs and produces a temporal graph and a geographical map:





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