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Preparing for COVID-2x: Urban Planning Needs to Regard Urological Wastewater as an Invaluable Communal Public Health Asset and Not as a Burden

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Abstract: Prior to the COVID-19 pandemic, the analysis of urological wastewater had been a matter of academic curiosity and community-wide big-picture studies looking at drug use or the presence of select viruses such as Hepatitis. The COVID-19 pandemic saw systematic testing of urological wastewater emerge as a significant early detection tool for the presence of SARS-CoV-2 in a community. Even though the pandemic still rages in all continents, it is time to consider the post-pandemic world. This paper posits that urban planners should treat urological wastewater as a communal public health asset and that future sewer design should allow for stratified multi-order sampling.

Keywords: pandemics; epidemiology; coronavirus; COVID-19; sewage; wastewater; urban planning; wastewater-based epidemiology

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1. Introduction

Soon after its existence became public in late January 2020, COVID-19, the disease caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [1], rapidly developed into a global pandemic, affecting every continent. As the year 2020 merged into 2021, several countries have experienced a second and even a third wave of infections [2]. At each national level, and even at the sub-national level, governments engaged in measures to curb or at least slow the progress of COVID-19 and to ensure that the public health system was not overwhelmed by cases requiring hospitalization. With its rapid spread and cross-sectorial impact, the COVID-19 pandemic has proven to be a social and economic disruptor on a global scale not seen since the 'Spanish flu' pandemic of 1918–19 that took between 17.4 and 50 million lives [3]. At the time of proofing (on 29 September 2021), 232.3 million people had been infected on all continents in all but seven countries, with a global death toll of 4.76 million [4].

COVID-19 is not a 'Black Swan' event, as the emergence of a coronavirus was predicted by public health professionals [5], following the outbreaks of SARS in 2004 [6] and MERS in 2012 [7]. Moreover, it is unlikely to be the last as other zoonotic coronaviruses related to SARS-CoV-2 are currently in existence in various host species [8] and some of these coronaviruses are almost certain to emerge as yet another major threat to humans [9]. It is predictable from an epidemiological point of view that another zoonotic coronavirus will manifest itself in the foreseeable future as an epidemic or even pandemic [10].

As the vaccines are being administered to reduce the severity of infection by SARS-CoV-2 and the spread of the COVID-19 pandemic, attention is moving to consider the future make-up of studying [11], working [12], and leisure [13,14]. In the planning sphere, attention has focused on the future of commuting [15], urban design [16], and public spaces [17], as well as the design of residential architecture [18].

Likewise, urban design and planning needs to focus on what lessons the COVID-19 pandemic provides the post-pandemic world. Given that other zoonotic coronaviruses are effectively 'waiting in the wings,' the profession cannot afford to continue to carry out business as usual. This paper will review the literature on sewerage testing for the successful detection of SARS-CoV-2 fragments and will advance some suggestions for future urban planning and design.

2. Sewage Testing as a Diagnostic Tool for Public Health

Humans excrete traces a wide range of chemical substances that the person has ingested, inhaled or injected, including medication and legal and illicit drugs. On an individual level, this has been used to detect doping in elite sports [19], and drug use in the workplace [20]. On a community level, sewage epidemiology utilizes the concentration of target drugs and/or their metabolites in urological wastewater, either at select points of the sewer system, or as influent at centralized wastewater treatment plants, and extrapolates the concentration of these in the wastewater in relation to the population size served by sewer system/treatment plants to calculate the per-capita rate of drug use or medication uptake.

2.1. Testing Sewage for the Detection of Drugs and Pathogens

The testing of sewage effluent has become a major instrument in the toolkit of public health professionals. It has been widely used as a means of detecting the use of illicit drugs in a population *per se* [21–27], to assess changes in drug usage over time [28], and to provide evidence of drug use at select facilities [29] or events [30–32]. In addition, sewage testing allows us to estimate uses of other detectable substances/their metabolites for general public health assessments. Urological waste water testing has been used to assess the use of depressants as well as antidepressants [33], nicotine (as a proxy for smoking) [34,35], alcohol [35], and select diseases such as gout [36]. It has been used to determine the usage of a range of medication [37], such as antibiotics [38], and decongestants [38], as well medication for other disorders such as ADHD (e.g., Ritalin) [39], Urological waste water testing allowed health authorities to assess the uptake of antiviral treatments (e.g., Tamilflu) during H1N1 influenza pandemics [38,40].

Importantly, it has also been used as a means of early detection of the presence and prevalence of pathogens, such as typhoid [41], salmonella [42], tuberculosis [43], antibiotics-resistant bacteria [44]. Urological waste water testing has been successfully utilised to detect not only the presence and prevalence of specific viruses such as poliomyelitis [45] hepatitis-A [46,47] and influenza A (H1N1) [48], but more specifically of a wide range of virus types, such as adenovirus [47,49], Coxsackievirus [47,50,51], echovirus [47,50,51], herpesvirus [52], norovirus [53] and rotavirus [53].

Epidemiological studies have noted the utility of urological waste water testing to detect the presence of viruses causing Zika [54–56], West Nile fever [57], dengue fever [56,58,59] and yellow fever [56].

The quality of the resultant data is both subject to methodological considerations such as sampling locations [60], as well as bio-decay and degradation in the sewer system [35,60,61]. Common to these studies was, for the most part, a community-wide focus.

2.2. Sewage Testing as a Diagnostic Tool for the Presence of SARS-CoV-2

The ability to determine the presence of coronavirus (fragments) is urological wast water had been demonstrated for a considerable time [62], including SARS [63]. While sewage testing was a diagnostic quantitative tool for public health professionals, it was largely relegated to academic curiosity and big-picture studies. This changed dramatically in February 2020 when COVID-19 had been declared a pandemic. Since then, the sewage testing for fragments of the SARS-CoV-2 has been successfully deployed and proven in value as an early detection tool and employed by public health authorities throughout Europe including Belgium [64], England [65], France [66], Germany [67], Hungary [68], Italy [69], the Netherlands [70], Russia [71], Spain [72,73], Switzerland [74], and Turkey [75,76], The same technique was also employed in other parts of the globe such as Hong Kong [77], Israel [78,79], India [80], Pakistan [81], Saudi Arabia [82], Brazil [83,84], Chile [85], Mexico [86], the USA [87,88] and Australia [89,90].

A critical public health benefit derived from this approach is that sewage testing also provided the ability to identify the presence of SARS-CoV-2 before it presented in a clinical setting [72], and that it further allows to identify socially stratified trends in infection that otherwise would have gone undetected due to differential attendance at individual swab testing due to (communal or personal) socio-economic reasons or geographic realities (e.g., dispersed settlement) [83,91–93]. A further critical public health benefit of continued, longitudinal testing regimes is that it allows public health officials to track the emergence and geographical spread of new virus strains [65].

While a range of sampling and processing *protocols* has been developed and described in the literature [79,81,86,88,94,95], there is little critical literature on appropriate sampling *strategies*. Numerous studies comment on their sampling locations, but do not discuss the underlying rationale for the sampling strategy [79,81,83]. It has been argued, however, that all sampling strategies must be based on and adjusted to local realities rather than being generic or off the shelf [92].

3. Contemporary Sewage and Wastewater Management

The majority of sewage systems in towns and communities are a historic legacy of the nineteenth and early twentieth century [96]. The main sewers in London, for example, date to the Victorian era [97,98], as do the sewers of New York [99]. The sewer systems were originally designed for smaller communities, each with their own treatment plant. As the communities expanded and merged, so grew the complexity of sewage management with the development of centralized sewage treatment plants and an associated demand for sewage pumping stations.

The contemporary sewage and wastewater management encompasses a mixture of legacy sewer networks, network upgrades carried out in the latter part of the twentieth century, and newly developed networks or network extensions in newly developed suburbs on the urban fringe. At an individual level, terrain complexity and in particular settlement dispersion affect the optimization of wastewater infrastructures as gravity driven sewers are cheaper and thus the preferred option [100]. When deciding on the extension of existing sewer networks or the creation of new treatment plants, best practice approaches tend to balance the benefits of the shortest path against the economic return of maintaining centralization [100].

Until the outbreak of COVID-19, little consideration was given to a systematic, large-scale and continuous sewage sampling.

4. Planning

Numerous governments are concerned with the impact of the repeated lockdowns and extended restrictions in movements and sizes of public gatherings on their national economy [101,102].To prop up the construction sector, some countries have embarked on economic stimulus packages that encompass wage subsidies and spending on public infrastructure development and upgrades [103–105], as well as subsidization of the building of private homes, the bulk of which will be built in new housing estates. A significant variable to be considered here is that even though economic depreciation is commonly set at 30 years [106], sewer networks have a relatively high average life-span of about 80 years [100] compared to domestic new builds (25–50 years) [107,108] or water treatment plants (25 years) [100]. Consequently, unless lessons from the COVID-19 pandemic are embedded into the design of these new builds, such as private dwellings [18], this spate of new builds will create an encumbering legacy, rather than a future-focused investment.

4.1. Concepts

Conceptually, most communities cognitively still consider sewage as waste and thus a burden that needs to be speedily removed [109]. Yet, as the preceding discussion (Section 2.2) has shown, sewage is a public health asset. Source separation in sewage systems, i.e., separating domestic greywater (derived from shower and laundry) from domestic blackwater (derived from toilet wastewater) has been advocated in some countries [110]. Not only do the injected volumes (and thus the resulting treatment costs) differ between grey- and blackwater, but, source separation also allows for increased water re-use and recovery of energy and nutrients from wastewater [111–113]. In a pandemic situation, the dilution of blackwater effluent will be less in source separated systems, thus increasing the detectability of low virus loads.

In Australia, for example, housing developments and housing subdivisions are connected to existing sewers subject to the stipulations of the Sewerage Code of Australia [114–116]. Of these, only the Pressure Sewerage Code makes any reference to sampling points, but does not specify their patterning or their design.

Conceptually, blackwater sampling points should be structured hierarchically to allow for flexible responses with increasing granularity of results (Figure 1). The first order sampling at the inflow to the sewage treatment/wastewater management plant allows for community level testing. Second order sampling would occur at sewage nodes at the confluence of a suburb cluster. Third order sampling then increases granularity to the level of suburbs, while fourth order sampling can bring the granularity to the level groups of streets. Where required, a fifth order sampling can occur at small complexes such as retirement homes, apartment blocks and high rises (Figure 1). In smaller communities, second order sampling would be omitted, and sampling would occur at the inflow to the sewage treatment/wastewater management plant (first order) and then at sewage nodes delineating individual suburbs (third order).

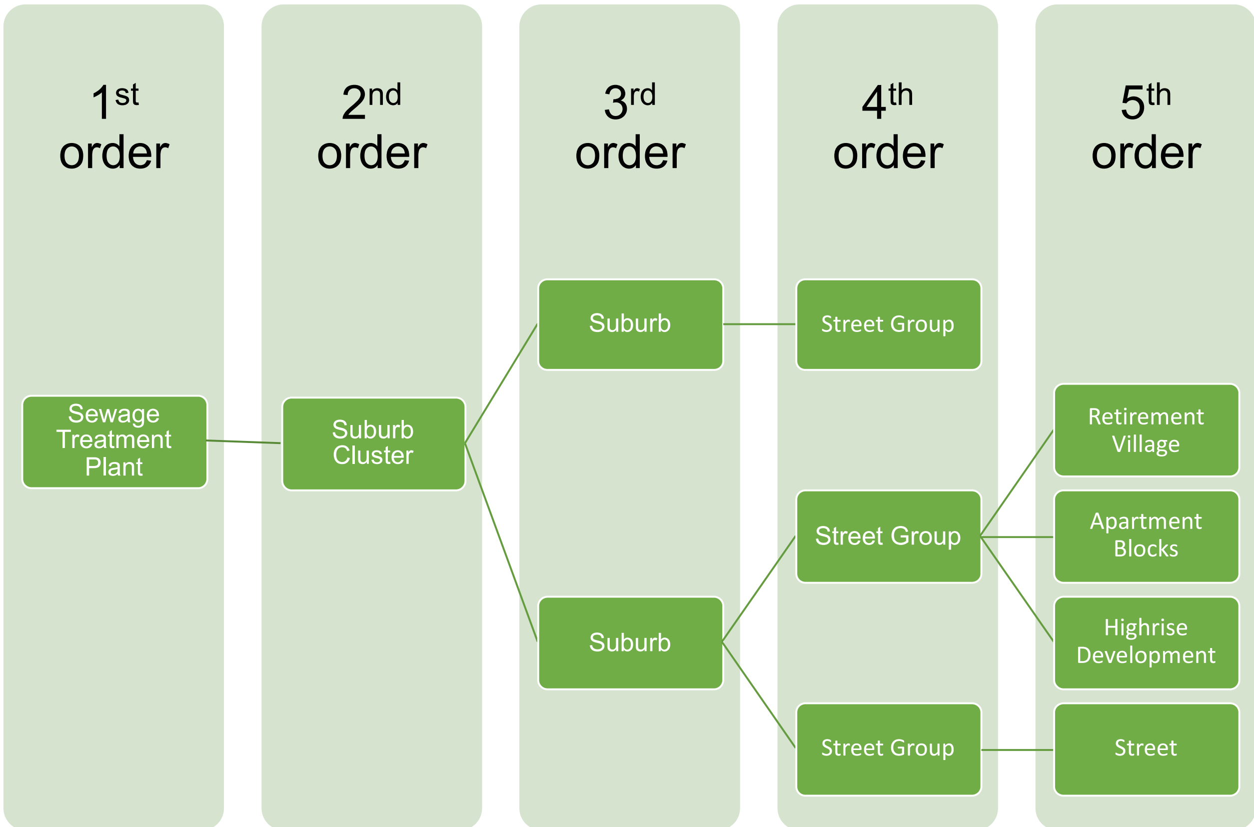

Figure 1. Conceptual example of hierarchical clustering of sampling points.

In the current scenario of COVID-19, testing occurs at the inflow to sewerage works and, if virus fragments are detected, additional sampling and testing occurs upstream to identify the presence of SARS-CoV-2 at the suburb level. The current sampling regimes usually do not allow for retrospective testing, yet this is a valuable tool to understand how long a pathogen has been circulating in the community.

4.2. Sampling Framework

In a practical sense, first order sampling and testing should occur on a regular basis, as soon as diagnostic kits are available. Upstream sampling would commence once a disease has manifested itself on a wider scale at a location within the country or state (but not necessarily yet at the community, or an epidemic has been identified in the country or other countries where there is potential that might seed in the country in question and then spread through communities. The sampling regime, including frequency, will need to be defined by epidemiologists and will vary from disease to disease. Critical here is that physical infrastructure has been put in place to facilitate such sampling and that sewerage management authorities embrace the necessity of sampling.

Ideally, if so determined by epidemiologists, sampling could occur daily at all sampling points, regardless of order, but at least at third order level, with samples stored on site (see below). Depending on staffing and funding levels, fifth order sampling can be omitted at the expense of granularity or can be carried out at longer intervals at the expense of immediacy. Figure 2 exemplifies a third order (star) and fourth order (dots) sewer network.

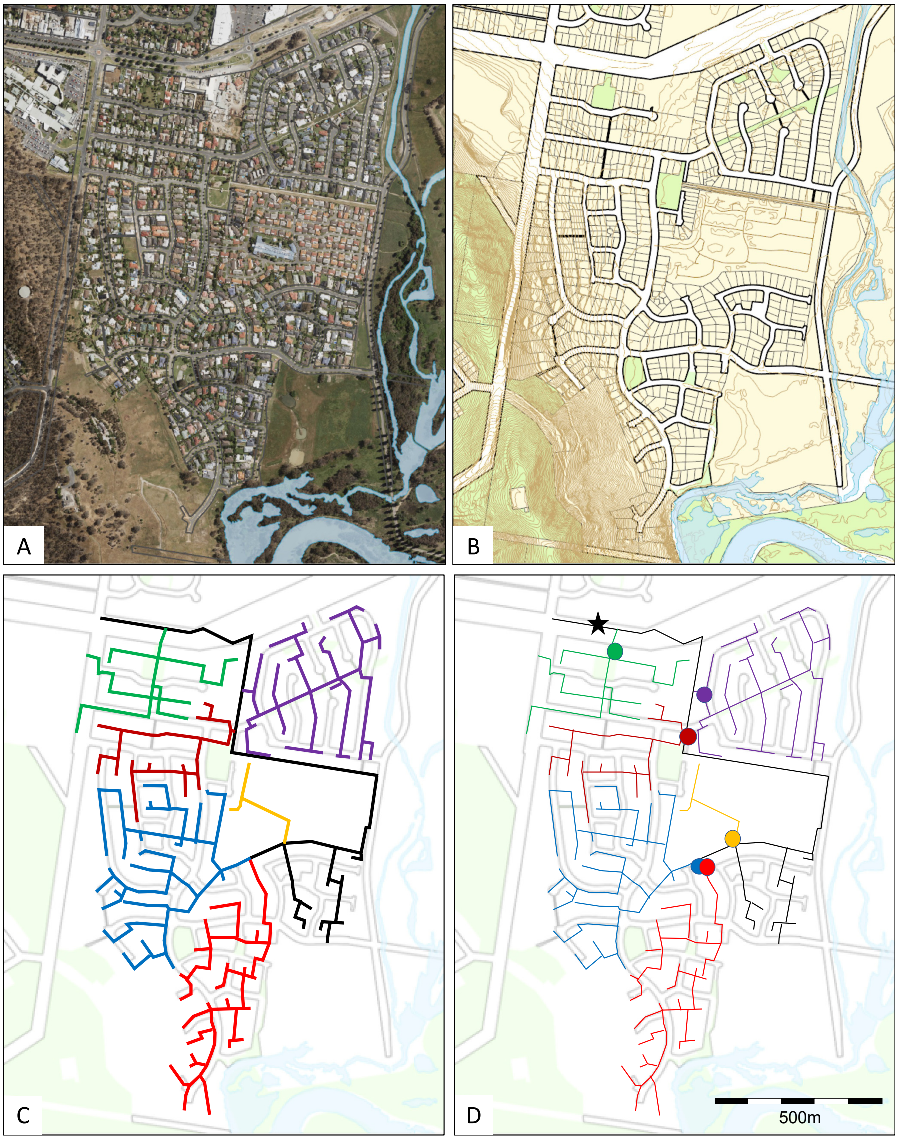

Figure 2. Conceptual example of retrofitting stratified sampling points to an existing development in Albury, NSW, Australia. (**A**) Aerial image; (**B**) street and contour map; (**C**) existing sewerage net-work color coded to show subnetworks; (**D**) suggested interception and sampling points (aerial photograph, base map and sewer alignment based on data derived from the Albury City Mapping Portal).

Such multi-order sampling will inevitably result in a considerable volume of samples that will need to be collected, transported to a sample archive, and stored there for potential analysis. Such centralized processes can pose a considerable strain on the system, especially in larger communities. More apposite would be a decentralized design where samples are stored, under correctly refrigerated conditions, at the sampling location itself and are only moved to the analytical laboratory if and when required.

Any sample collection and retention pattern is governed by the incubation period of coronaviruses causing respiratory infections or other pathogens (as required). At the present pandemic, with the current strains of SARS-CoV-2, these range, depending on the strain, from as low as two to about fourteen days. It is desirable to implement a collections regime that allows for retrospective analysis. Thus it may be desirable that daily sample collection and retention occurs on a rolling 21-day pattern, with retention of a weekly sample for an additional three weeks. Combined, this would extend the window of a retrospective analysis to six weeks. Any given sampling location, therefore, will only need to allow for cold storage of 24 samples.

To increase temporal granularity, a storage capacity of 31 samples would allow for twice-daily collection for one week, the retention of daily samples for the two weeks before that and weekly retention for the three weeks prior. From an epidemiological perspective, it is important to be able to reconstruct how long a virus has been circulating undetected in a given community. Such sample retention regimes allow for focused retrospective assessment once virus fragments have been detected at first order level. The sampling regimes will be determined by the epidemiological community and will, inevitably vary depending on the pathogen.

4.3. Ensuring Future Testing Capacity

There are three components to ensure future testing capacity: (i) the design of sewer networks in new housing estates; (ii) ensuring ready access to the sewer lines for manual or automated sampling and finally (iii) retrofitting of existing sewer networks.

4.3.1. Design of Sewer Networks in New Housing Estates

First and foremost, in order to future proof post-pandemic communities, government authorities need to become proactive and embrace urological wastewater as an invaluable communal public health asset. This has two consequences, longer-term strategic planning and the passing of legislation at the state level and regulations at the local government level. At present, at least in the Australian situation, too much of the thinking of urban expansion revolves on short-term, piecemeal opening up of housing estates rather than development trajectories that allow for the conceptualizing of larger, hierarchical networks. Once individual housing estates are being proposed, all new housing estate developments should be required to design and build hierarchically based, uniquely branched sewer networks that allow for well circumscribed fourth and fifth order sampling. As land developers tend to prioritise company profits over community welfare, there is a need to develop legislation and executing regulations that compel developers to include such sampling chambers in their subdivision designs. As the costs will, inevitably, be passed onto the purchasers of building allotments, any such legislative change needs to be accompanied by public awareness campaigns.

4.3.2. Ensuring Ready Access to the Sewer Lines

At present, sampling is possible by accessing laterals, utility holes ('manholes'), sewerage pump stations, and of course at the inflow at the treatment plants. While these, theoretically, provide access, this is cumbersome since the majority of access points, such as utility holes and inspection holes as laterals are designed for occasional maintenance access than daily sampling. The installation or retrofitting of automated sampling is possible but difficult for channel systems.

To facilitate ready and, when required, continual sampling, new developments which require the establishment of sewerage networks should include a sampling chamber at each second, third and fourth order node, as well as at selected fifth order nodes, such as retirement villages, high-rise developments or apartment blocks. Such sampling chambers should allow for easy keyed access to an underground space that provides access to the sewer line for effortless automated or manual in-line sampling and be large enough to provide storage space for sample collection including cold storage for 50 samples in a small refrigerator.

4.3.3. Retrofitting of Existing Sewer Networks

Without doubt, this will be the most difficult component of future proofing post-pandemic communities. Here, we need to distinguish between old, historic netweorks and those that are more recent. As the example of an existing development shown in Figure 2 shows, not all developments provide fully and uniquely branched networks. In these cases, fourth and fifth order sampling points can be retrofitted, but may result in some low granularity for some homes.

There can be no doubt that the construction of sampling chambers at second, third, fourth and select fifth order nodes will represent considerable costs for the developer of new estates and will require considerable investment for communities to retrofit existing systems. In this context it needs to be considered that the economic cost of the COVID-19 pandemic has been considerable [117], with evidence that the costs were higher where community lockdowns were delayed due to political inaction [118,119] or due to lack of early detection [120], with a concomitant cost of human life [121]. This cost, let alone the possibly preventable loss of human life, far outweighs the cost of installing sampling chambers in new developments and the retrofitting of existing systems where feasible.

5. Outlook

The COVID-19 pandemic not only has laid bare the vulnerabilities of modern society living in high density housing, it has also shown that sewage testing proved to be a diagnostic tool for the presence of SARS-CoV-2 well before it manifested itself in clinical settings. Urban planners will need to focus their attention on the post-pandemic world, which includes a reconsideration of approaches to domestic housing design, public transport and urban recreational greenspaces. While these have high visibility, it will be the humble, underground sewer system that will provide a detection and early working system when the next epidemic or pandemic develops.

Urban planners, as well as their communities' political leaders, are required to engage in a cognitive shift and to consider sewage and blackwater wastewater as an invaluable communal public health asset rather than as a burden of waste that needs to be speedily removed.

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