Water and Wastewater Systems and Utilities: Challenges and Opportunities during the COVID-19 Pandemic

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INTRODUCTION

The COVID-19 pandemic has changed the daily habits of communities across the world due to actions that are needed to reduce transmission of the SARS-CoV-2 virus. Guidance is provided around behaviors that include washing hands frequently, disinfecting shared surfaces, wearing masks, and social distancing, which includes maintaining distance between individuals and avoiding gatherings of large groups of people (WHO 2020). To ensure social distancing, many individuals began working from home and reducing or eliminating travel. Governments across the world enacted lockdowns and shelter-in-place orders, which led to the temporary closure of businesses that are not considered essential and a prolonged reduction in the on-site working capacity for a majority of nonessential businesses (Committee for the Coordination of Statistical Activities 2020). New behaviors that support social distancing and the economic impacts of lockdowns have been felt across almost every business, industry, and governmental service, including water utilities, water resources, and water infrastructure. Changes in behaviors that alter where and when water and wastewater demands are exerted have affected the performance of drinking water and wastewater infrastructure, global water, sanitation, and hygiene (WASH) services and have led to changes in the quality of natural water bodies. Economic losses due to lockdowns have created financial vulnerability for water utilities, and the need of the workforce to work remotely has affected how utilities can operate.

The goal of this forum is to explore and discuss the impacts of the COVID-19 pandemic for water utilities and water systems. Recent literature has documented some of these impacts, and findings are synthesized to support the discussion presented here. Experiential evidence is used to demonstrate potential impacts, and this forum reports on a survey of water utilities that was conducted to explore the approaches that utilities and managers have taken to adapt to new conditions introduced by the pandemic. This discussion explores the mechanisms by which water systems are affected and the aspects of water resources management that require a fresh perspective towards emergency response and recovery planning. The pandemic has revealed serious vulnerabilities in WASH services, due to the need for water supply to wash hands and surfaces, the effects of social distancing on household abilities to collect water, and the effects of significant economic slowdowns on household capacity. The pandemic provides a new opportunity to rethink water resources management and water infrastructure. Water utilities can improve emergency response planning and develop resilient water infrastructure policies. Analysis of ongoing dynamics present new opportunities to adopt automated and smart water infrastructure, enhance engineering education to encompass socioeconomic perspectives and emergency management, and develop an understanding of the interconnections among critical infrastructures, supply chains, and society to support planning and management activities.

WATER SYSTEMS

The effects of communities working remotely, traveling less, touring less, and engaging in less recreation can have profound effects across water systems. The following sections explore how the pandemic has affected drinking water demands and water distribution infrastructure; wastewater infrastructure; and the water quality of natural water bodies.

Drinking Water Demands and Water Distribution Systems

Demands for drinking water have changed across water use sectors, and these demand changes can affect how water distribution infrastructure and water supply systems operate. Changes in demands are the result of changes in the location of people during the day as they adopt social distancing habits, work remotely, and visit restaurants and businesses less frequently. One result of these changes in behaviors, such as taking showers later, is that weekend diurnal patterns have emerged on weekdays (Melbourne Water 2020). Balacco et al. (2020) analyzed water demand changes for five cities in Italy during the first and second stage of the Italian lockdown during March and April of 2020. Analysis shows that the diurnal pattern of demands shifted, with a notable delay in the morning peak demand for all cities, by up to 2.5 hours later for some cities. The peak associated with lunchtime disappeared for one city; the volume of water consumed during weekends significantly increased for a small town; and the peak around dinnertime was less pronounced for all cities, compared to patterns in March and April of 2019. It is expected for large cities that demands, which are typically exerted at businesses, have shifted to residential supply zones. This was seen for water consumption in Joinville, Southern Brazil, where industrial, commercial, and public demands decreased, while residential demands showed a slight increase due to social distancing measures (Kalbusch et al. 2020). The need of water for disinfection and washing hands frequently while living with COVID-19 may drive significant increases in water demands and water prices in the future (Sivakumar 2020).

Other changes in population behavior drive broader changes in the total consumption across a region due to unexpected patterns of emigration as, for example, students leave university towns when schools are closed (as shown for Bari, Itay by Balacco et al. (2020)), people avoid dense urban areas during lockdowns, and others move out of cities to holiday homes for extended lockdown periods. Balacco et al. (2020) reported that the total daily volume of demands was not affected by a lockdown for small towns, while there was some reduction in consumption at larger cities due to the lack of incoming commuters. It is expected that as people take to outdoor and cultural heritage touring instead of touring at indoor and dense urban locations, demands may shift to rural supply sources. There is a potential for increased demands during summer months, as families use at-home pools and sprinklers instead of neighborhood or city pools.

Shifting demands can have multiple effects on infrastructure systems and water supply. The increased use of water for hygiene and disinfection may increase water consumption and exacerbate water shortages, especially in water-scarce areas where there is a heightened tension between water conservation efforts and increased water demand for hygiene and disinfecting surfaces. For example, the City of Auckland in New Zealand is experiencing a severe drought (Newton 2020), which further complicated the City's handling of COVID-19. Public information campaigns about conserving water were implemented carefully to avoid discouraging hand-washing and disinfecting, which would increase the risk of COVID-19 transmission. Despite low dam levels, mandatory restrictions were briefly delayed to avoid increasing public stress during the severe first lockdown (Radio New Zealand 2020). When water restrictions were later implemented, reports of violations, such as use of water for outdoor purposes, increased substantially due to more time spent at home by residents, who increased their use of water at home or were more likely to notice violations in their neighborhood.

Changes in water demands can also affect the water quality of drinking water in distribution systems. A lack of flow in indoor pipes increases the water age in premise plumbing systems, which might lead to low disinfectant residuals, formation of disinfection byproducts, intensification of corrosion, nitrification, re-growth of microorganisms, and biofilm formation (Asadi-Ghalhari and Aali 2020). Guidance for recommissioning buildings through flushing to protect building inhabitants should be developed based on decontamination practices for premise plumbing systems (Proctor et al. 2020). Research is needed in this area to guide emergency preparedness planning. At a system-level scale, the closing of multiple industries or businesses in a neighborhood can affect circulation in a network and lead to high water age and degraded water quality. Shifting demands can also lead to changes in energy consumption and nodal pressure values. Potential changes in the level of service associated with shifting demands should be explored to develop resilience planning for water infrastructure management.

The impact of COVID can serve as a wake-up call for a more “resilient” water infrastructure that can recover from external shocks caused by a future pandemic or other types of natural and manmade disasters. Water demand fluctuation is especially evident for centralized water supply systems. This can be at least partly attributed to the use of treated water for all domestic purposes (e.g., drinking, hygiene, toilet flushing, and irrigation). Data from systems with “decentralized” water supply infrastructure (e.g., “Net-zero” water buildings or communities) may show less water demand fluctuation as some portion of the water demand is satisfied onsite through rainwater harvesting or other techniques (Guo and Englehardt 2015). Assuming economic feasibility, the combination of centralized (e.g., from a water treatment plant for drinking and hygiene purpose) and decentralized (e.g., from rainwater harvesting for toilet flash and yard irrigation purpose) water supply sources could increase the resilience of the water system and better prepare for the community in the uncertain future.

Wastewater Systems

Wastewater demands and wastewater infrastructure may also be impacted by the COVID-19 pandemic. Increased use of water to wash hands and clean surfaces with soap and disinfectants may increase the quantity and affect the quality of wastewater coming from homes, hospitals, workplaces, and public spaces (Sivakumar 2020). Sewer and treatment capacities may not handle increasing demands for under-designed or aging infrastructure, with negative impacts on receiving water bodies. The fate of the SARS-CoV-2 virus outside of the human host should be explored to safely manage the treatment and application of sludge. New challenges for circular economy issues arise around the reuse of treated sewage, as the effects of aerosolization in the context of COVID-19 and the persistence in reclaimed water need to be deeply understood to advocate for the sustainable use of resources while protecting public health (Yang et al. 2020). Premise plumbing for wastewater can act as a transmission route for the virus within or among buildings. New research in the mechanisms of transmission, system design, and monitoring of wastewater plumbing systems is needed to minimize the risk of transmission in hospitals, health care facilities, and dense urban housing (Gormley et al. 2020).

Wastewater infrastructure is an important component of early warning systems to detect disease. Significant research is being conducted to develop new monitoring systems and digital tools can be developed in an opportunity to detect the virus and guarantee the early warning of authorities. SARS-CoV-2, the virus causing COVID-19, is excreted in the feces of infected individuals. Recent studies have shown that tracking the RNA of SARS-CoV-2 in wastewater, a practice known as wastewater-based epidemiology (WBE), provides a rapid and cost-effective means to monitor COVID-19 infections in cities (Ahmed et al. 2020a). By sampling the wastewater generated by millions of people, WBE can provide early warning of emerging COVID-19 outbreaks compared to traditional testing, because SARS-CoV-2 RNA is excreted by pre- and asymptomatic individuals. In addition to sampling at wastewater treatment plants (WWTPs) to track the disease prevalence in an entire community, emerging outbreaks can also be traced back to local source locations with high infection rates by collecting samples directly from the sewer network upstream of WWTPs (e.g., at manholes). The spatiotemporal distribution of COVID-19 within cities can also be further revealed by coupling in-network WBE sampling with hydraulic and transport modeling of sewer networks. The latter can track the fate and transport of SARS-CoV-2 RNA by determining water flow paths, travel times, and other hydraulic and environmental factors that affect the decay of the RNA signal as it is carried through the network (Hart and Halden 2020). Specifically, hydraulic modeling can account for the dynamic changes in wastewater and stormwater inputs (in case of combined sewer systems), while water quality and transport simulations can track the changes in the parameters that affect the decay rate of the SARS-CoV-2 RNA in the network, including pH and water temperature (Ahmed et al. 2020b). Such models can serve as the basis for inverse modeling methods that can be used to reveal infection hotspots of COVID-19 within communities. Decision support tools can enable local public health departments to track new outbreaks, evaluate reemergence of the disease following relaxation of control measures, assess vaccine uptake, and rapidly deploy mobile resources for COVID-19 testing and control in affected communities. These tools can serve to map and analyze the spread of the virus to guide plans to screen vulnerable urban populations and proactively test communities and neighborhoods. Herein, a foremost challenge is to develop a COVID19 wastewater detection system based on surrogate measures for COVID19 presence instead of tracking the RNA of SARS-CoV-2 directly (Barcelo 2020).

Water Quality of Natural Water Bodies

Natural water bodies that provide important functions, including water supply, flood protection, recreation, transportation, and ecological services have been impacted by the COVID-19 pandemic. Both improvement and degradation in the water quality of water bodies have been documented at locations across the globe. In some locations, the reduced travel associated with lockdowns, social distancing, and shelter-in-place directives has led to improvement in the water quality of water bodies. For example, reduced traffic in water transport associated with the COVID-19 lockdown led to improved water transparency in the lagoons around Venice, as fewer boats traversed the canals (Braga et al. 2020). Lockdowns have also led to reduced urban traffic on roadways, and as a result, there have been significant reductions in air pollution, including nitrogen dioxide, over major cities across the globe. Consequentially, waterways are expected to experience reduced deposition from point sources (e.g., industrial sites) and nonpoint sources (e.g., traffic) of pollution (Hallema et al. 2020). Effects from reductions in nonpoint sources cannot be measured immediately, however, and effects will emerge after some time. Improvement in groundwater quality has also been linked to reduced anthropogenic activities associated with lockdowns, leading to a reduction in the wastewater generated by fisheries and industry (Selvam et al. 2020). In a similar vein, an improvement in suspended particulate matter in a lake in India was observed due to reduction in pollution from industries and tourism, though residential wastewater loads remained at pre-pandemic levels (Yunus et al. 2020). Although changes in water quality are expected to be ephemeral and to dissipate as economic activities recover, the reduction in human activities provides a unique opportunity to test the impact of different pollution sources on environmental systems and guide policy development.

Unfortunately, detrimental environmental effects, including water quality changes, have also been observed related to the COVID-19 pandemic. In many parts of the world, fleets of trucks, drones, and mini-tankers have been deployed to spray disinfectants in public areas, such as streets, gardens, and beaches (Nabi et al. 2020; Silva et al. 2021). The discharge of large volumes of disinfectants threaten water bodies and aquatic ecosystems (Zhang et al. 2020; Silva et al. 2021), as some chemicals persist in the environment for years (Horn et al. 2020). Research around the toxic effects of disinfectants on aquatic organisms, the development of non-toxic and effective disinfectants, and decision support tools for guiding the use of disinfectants in urban areas and near waterways is needed (Nabi et al. 2020). An increase in the use of single-food packaging and plastic bags and an increase in the use of disposable personal protective equipment, including masks and wipes, has led to more litter reaching the environment and waterways (Chavel et al. 2020; Silva et al. 2021). P that are not effectively removed by wastewater treatment plants and plastics pollute receiving water bodies and harm shorelines and aquatic ecosystems. Impacts to the quality of open water systems may be especially severe in dense urban areas with inadequate sanitation (Horn et al. 2020). Further research is needed to explore the fate and transport of disinfectants and pharmaceuticals in the environment and develop strategies for mitigating pollution in waterways.

Global Water, Sanitation, and Hygiene (WASH) and Underserved Communities

Access to water is a key determinant for infectious disease control and prevention. Yet, millions of people across the globe live in water stressed environments and do not have access to WASH services. Many households cannot follow advice to frequently wash hands under running water, and social distancing may be impossible due to lines that form in accessing or purchasing water (Anim and Ofori-Asenso 2020). Due to the lack of resilience policies around water and sanitation, African countries are susceptible to high levels of transmission of SARS-CoV-2 (Sunkari et al. 2021). Water is the most important resource needed to mitigate the COVID-19 pandemic through maintaining hospital, domestic, and work hygiene (Vammen and Guillen 2020). Beyond the need of water for washing hands, COVID-19 will impact water scarcity through complex mechanisms of economy and poverty. Containment strategies that rely on lockdowns and reduce the financial means of households will tragically impact the water and food security of households in developing and water scarce localities (Boretti 2020). For example, small Pacific islands are isolated from virus transmission, but have been affected by supply issues due to shutdowns that have closed economic opportunities, leading to further loss of income and water insecurity for households (Daniell 2020). Refugee camps have historically been plagued by a lack of clean water and sufficient treatment of wastewater, and these conditions foster severe disease outbreaks in refugee populations (Kassem and Jaafar 2020; Rafa et al. 2020). There is a need for research to explore water resources management to enable hygiene, while accounting for fragility in household economics and water security. Computational modeling and water resources simulation have had limited application for finding solutions for global WASH challenges. The convergence of the COVID-19 pandemic and water insecurity in developing areas are bringing to light the need to prioritize water supply, climate resilience, and mitigation of the COVID-19 pandemic (Armitage and Nellums 2020) and to develop the computational tools and decision support systems to inform policy development.

In the U.S., the coronavirus has disproportionately affected minority and underserved communities, due to in part to a combination of lower access to quality healthcare, less opportunity to work from home and higher housing density which impede social distancing guidelines, as well as communication gaps due to health literacy issues and socioeconomic disadvantages (Bambino et al. 2020). While financial impacts of the pandemic have been widespread, utility shut offs and financial burdens are also disproportionately affecting these groups (Duster 2020; Fitch 2020a). The New Georgia Project Black + Green Agenda has called the disparate utility shutoffs in their state a new form of systemic environmental injustice (Duster 2020). State responses to COVID-19 and the consequent financial challenges placed on homeowners have varied greatly. While some have issued orders to suspend utility service disconnections, the vast majority of the population has not benefited from this as state issued orders do not necessarily have to be enforced at the municipal level. In 13 states, there has been no legal protection offered to homeowners concerning disconnection for any utility during the pandemic (Matthew and Levine 2020; U.S. Senate Committee on Environment and Public Works 2020). For example, the Natural Resources Defense Council reported that at least 1,838 homes were disconnected for non-payment in North Carolina by the end of March (Matthew and Levine 2020). Even after the governor issued a statewide moratorium on March 31st, only 8% of these homes had been reconnected by April 25th. Some states are working to assist homeowners struggling to pay their bills. In Illinois, a COVID-19 Bill Pay Assistance Program to support those with outstanding utility charges (Ruppenthal 2020). The bill has offered $500 to cover late payments for families who qualify for the Low Income Home Energy Assistance Program and prohibits utility companies from reporting delinquencies to credit bureaus until six months after the state shutoff moratorium has lifted. However, not all states have such programs in place. It is imperative that local governments keep in mind that even with the partial and total reopenings that have allowed individuals to return to work, utility debt will continue to be a burden on families if it is not addressed (Fitch 2020b). Finally, the economic crisis COVID-19 has invoked will outlast shutoff and late fee moratoriums in the water sector, and utilities may be forced to take more liberal approaches to debt forgiveness in order to ensure the safety and health of vulnerable families (Bambino et al. 2020; Fitch 2020b).

WATER UTILITIES

The COVID-19 pandemic has shocked a number of industries, including airlines, food service industry, and public utilities. Water utilities are not an exception. They have experienced unprecedented impacts, including a need to operate systems remotely and securely, protect on-site workers, unpredictable supply chains, loss of revenue, and personnel issues associated with replacing quarantined or sheltering staff. At the same time, utilities must comply with regulations and provide uninterrupted services while dealing with unpredictable shifts in the timing and composition of water demands and wastewater flows (Sowby 2020). The following sections describe economic challenges and changes in the workforce that require adaptation by water utilities.

Economic Challenges

The major drivers of negative impacts of the COVID-19 pandemic on water utilities include: (1) moratoriums on shut-offs; (2) increased delinquency in paying water bills; (3) reduction in commercial revenue; (4) delay in maintenance actions; (5) increase in personnel expenses; (6) reduction in system development charges; and (7) lower customer growth. The estimated combined loss due to these areas, which does not include increased residential water demand revenue, is approximately $16.5 billion, with loss in commercial revenues and increased delinquencies making up 45% and 30% of this amount respectively (American Water Works Association, 2020b).

Amid varying promises of rent freezes and eviction moratoriums countrywide, water utilities have put forth measures to prevent individuals from going without clean running water during the pandemic. Survey data collected by the American Water Works Association and the Association of Metropolitan Water Agencies found that although actions taken varied by utility, a number of American utilities choosing to eliminate shut offs due to nonpayment saw both increased delinquencies and non-residential water demand reductions offset by residential water demand increases (American Water Works Association, 2020a). In North Carolina, 770,000 households were reported to be behind on their water bills by the end of April 2020 (Matthew and Levine 2020). At the same time, Oklahoma City had 11,000 accounts late on payments for either water, sewer, or trash payments compared to only 300 before the pandemic. With the average amount of money due for each household sitting at $315, this equates to $3.2 million of missing revenue in the city's utility department (U.S. Senate Committee on Environment and Public Works 2020). Many utilities have found themselves providing water even to those unable to pay their bills on time and forgiving consequential late fees. In addition, water utilities have not been able to make planned raises during the pandemic and will not be able to raise water rates in the near future.

Non-essential tasks, such as monthly water meter readings were not completed during high-level lockdown periods, and estimates of consumption were used instead. Consumption patterns could, thus, only be tracked via zonal water meters, implying that water balances could not be done to the same level of reliability, resulting in an increased uncertainty about the actual water consumption, and in turn, resulting in an increased uncertainty about utility income.

Another important factor affecting municipal and industrial water use, and in turn commercial revenues of utilities, has been "stay-at-home orders". Many employees began teleworking or working from home in early 2020. By July 2020, about 25% of employed people in the U.S. still worked from home due to the COVID-19 pandemic (U.S. Bureau of Labor Statistics, 2020). Many utility companies experienced increases in residential demand, such as a 0.05 hundred cubic feet (CCF) increase in residential consumption seen in Charlotte, North Carolina. Toho Water, a Florida water utility, reported an anticipated decrease in commercial water use by 52%, whereas a large utility in Colorado reported to have experienced a 35% decrease in all non-residential water usage, which was met with only a 10% increase in residential demands (American Water Works Association, 2020b).

System development and user charges from new growth are likely to be stunted due to the general slowing of economic growth amid the pandemic. This problem is also tied to the additional revenue loss attributed to lower customer growth, constituting about 2.5% of total losses (American Water Works Association, 2020b). It is expected that companies across the country will see increased spending on personal computers, servers, software, and personal protective equipment ranging from respirators and disinfectants to thermometers and additional sanitation services.

Finally, utility companies hope to remain financially independent for the duration of the crisis, though local communities are likely to see a decrease in economic activity and fewer job opportunities as a result. About 9.6 million people of the 16.9 million people unemployed in July have lost their job or have been unable to work because their employer closed or lost business due to COVID-19 (U.S. Bureau of Labor Statistics, 2020). As the pandemic continues, revenue and choices from both consumers and providers are bound to take on new shapes. This will continue to lead to uncertainties about commercial and industrial water demand and utility's financial stability, creating difficulties in planning. It is clear that a more agile and adaptive planning processes is needed for water utilities.

Workforce Changes

Social distancing policies have altered how water utilities' workforce operates to ensure both the safety of employees and the continuity of services (American Water Works Association, 2020a). These changes (e.g., working remotely, shift changes) spanned multiple divisions of the workforce (e.g., operators, field staff, management). Based on 30 semi-structured interviews that spanned 28 US water utilities including over 50 utility employees, we discuss water utilities' response to the pandemic. This study was submitted to the Institutional Review Board (IRB) at the University of Texas at Austin and the University of Washington. Grey literature and media are used to support the findings from interviews. Complementing these data is experiential evidence provided by co-authors from Auckland, New Zealand, confirming much of what was seen in the US. In accordance with the Centers for Disease and Control and Prevention (CDC) guidelines for essential workers, 98% of 472 water utilities surveyed by the American Water Works Association (AWWA) incorporated social distancing in the workplace (American Water Works Association, 2020a). Interviews show that water utilities used various methods to adhere to social distancing policies and address COVID-related challenges. Overall, utilities experienced challenges ranging from a shortage of skilled staff resulting in a loss of institutional knowledge to increased managerial workloads. In Auckland, New Zealand, regulations guiding field staff to undertake repairs or install new network connections while working alone, travelling to site in separate vehicles, and maintaining social distancing inevitably resulted in lower efficiency and delays.

In response to social distancing policies, several utilities staggered the shifts of critical staff (e.g., operators) to ensure availability of staff if there was a COVID-19 case related to the critical staff, while other utilities restricted access to certain areas to only essential personnel. Notably, many of these changes were focused around ensuring the safety of operators because, often, utilities had few operators, and thus, the lack of trained operators before the pandemic led to operations and management challenges during the response to the pandemic. In fact, one utility sequestered 40% of their operators to prevent the virus from spreading; this was possible due to decreased system demand.

Critical field work, such as that necessary to meet regulatory sampling requirements, continued uninterrupted. In these cases, employees were encouraged to use personal vehicles to minimize the need to ride with other employees, wear masks, and maintain social distancing (Weikel et al., 2020). For personnel continuing to work on-site or in the field, utilities introduced new cleaning protocols. For example, in addition to having a cleaning crew for the office, one utility said they have "an internal disinfectant crew and a [disinfectant] fogger crew." Another utility utilized its lab capacity to produce its own hand sanitizer. Some utilities that were interviewed scaled back non-critical work (e.g., postponed capital projects, system-level flushing) to reduce the number of employees working in the field. For instance, one utility said that "there was some effort to separate work groups…and also keep some people at home in reserve, so we would have backup staff should anyone get sick and maybe contaminate the rest of the work group." Overall, utilities had to prioritize critical work to ensure they had staff on standby in case employees got sick. At most utilities, those in office-based roles continued their work via telecommunication, as many office spaces and call centers were temporarily closed (Lopez et al. 2020). Other utilities were able to transition call centers to remote operations or creatively altered the office space to allow for on-site centers. For instance, one utility utilized a drive-through customer service center. Depending on the size of the utility and the office configuration, some utilities allowed office staff to work in the office for parts of the week.

The COVID-19 pandemic and changes to operations caused challenges with personnel management. For example, one manager said she had “another job packed on top of [her] job” and another said they “quickly realized labor management was an administrative nightmare”. While continuing to operate the water utility, managers had to quickly adapt their workforce to the changing policies. Additionally, the morale of utility workers was a challenge. For instance, one utility manager stated: “staff morale is just rough. Because we paid some people to stay home, and some people still had to show up and work. That [didn’t] feel very [equitable]” while another discussed that they had little support or tools to help with managing the pandemic. The challenge to keep employee’s morale up was coupled with a loss of face-to-face contact, which hindered communication and information transfer between managers and other personnel. Measures are needed to ensure well-being of employees and their families, based on the risk of contracting the virus for employees performing field work. Some utilities did try to solve communication challenges through the use of internal social media applications to encourage a collaborative environment while working remotely. The City of Auckland utility prioritized its staff wellbeing by maintaining connections with colleagues through online meetings, regular communications and online learning modules and ensured that employees remained busy.

The communication environment between utilities’ administration and workers’ representatives plays an important role when facing challenges brought by the new tasks to be developed. Meetings with unions in situations of this type contribute to smooth out some reluctance to accept some critical tasks during the pandemic. A survey of workers in the water sector in the UK found that communication and signposting of additional support were very important to employees to combat feelings of isolation (Cotterill et al. 2020).

Many utilities were challenged by a lack of staff. Some employees decided to retire early, leading to a sudden loss of institutional knowledge. For instance, one utility said sudden retirements led to a “transition of duties all at once from one person to another person”, meaning they had to capture as much institutional knowledge as possible in a short time. Other employees lost childcare services and were unable to work, leaning on support from the Family and Medical Leave Act which provides expanded leave for parents whose childcare providers closed (US Department of Labor, 2020). One utility had “three fairly important employees that had childcare needs who [were not planning to come back]”. Another utility slowed down hiring, which may cause future issues as 50% of the staff is set to retire in the next five to ten years. In Auckland, New Zealand, staff are often recruited from other countries, and closure of New Zealand's borders left some staff stranded in other countries and led to a smaller pool of candidates. Managing these changes proved to be especially challenging for utilities with a smaller workforce and customer base (Lopez et al. 2020). In fact, almost half of rural and tribal water systems rely on one full- or part-time operator, contract, or volunteer staff to operate their systems (Rural Community Assistance Partnership 2020).

LESSONS LEARNED, PIVOTING, AND LOOKING FORWARD

Accelerating the use of smart technologies

The pandemic has brought a surge of changes to the way that water utility employees work, at least for the time being, creating a new environment in which connected devices enabled through Information and Communication Technology (ICT) are necessary. Kala Variavamoorthy from The Source Magazine, an International Water Association publication, provides a succinct description of these sea changes (2020): "Before the pandemic struck, cities were broadly aware of advanced metering infrastructure, remote sensing, real-time controls, modelling and optimisation. Each was known to bring a greater degree of automation, safety and security to utility operations – but the tools were too often seen as curiosities, or luxuries, and so were deferred to the future. That future arrived at the dawn of 2020."

Automated infrastructure is needed to address changes in the way the water utility works and in the expectation of employees around working remotely. Data analytics can be applied in a wide range of applications to support automation of infrastructure. Data analytics can continue to be applied to metering infrastructure to establish demand characterization, forecasting short and long-term future service levels over various scales, as well as enterprise-level management strategies (e.g., water rights, allocations, and transfers). Data analytics can also be used to identify non-revenue water issues through integration with asset management applications (Güngör-Demirci et al., 2018a). Data analytics can continue to be used to improve the understanding of strategic processes related to the water industry's asset management efforts (Martínez García, 2018, 2019 a, b, 2020). This includes performance-driven screening and assessment, showcasing failure modes and effects, risk identification and characterization, and capital investment allocation and prioritization (Güngör-Demirci et al., 2017). These aspects will continue to lead to better life cycle planning, analysis, design, and operational decision-making due to improved business intelligence even while working remotely (Güngör-Demirci et al., 2018b).

Integrating simulation modeling with data analytics can also support hydraulic, energy, and water quality simulation efforts, which link to a robust enterprise-level data structure built upon pressure and water quality surveys, surface and groundwater reservoir profiling, pump tests, and energy audits, subzone (DMA) monitoring, Supervisory Control and Data Acquisition (SCADA), and Advanced Metering Infrastructure (AMI). Cloud-based SCADA and real-time modeling will provide a continuous baseline to facilitate operational optimization decisions and support a sustained way systems model calibration and validation which can be performed while working remotely (Keck and Lee, 2015).

Data analytics can be applied to formulate and solve systems-level multi-objective problem definitions that balance the cost of investment against the net benefits gained to establish effective prioritization models (Güngör-Demirci et al., 2018b). In this effort, it is crucial to define clearly the level of service goals, assumptions, and key performance indicators, all of which necessitates careful consideration of reliability, resilience, customer satisfaction and other strategic variables (Keck and Lee, 2015). Over time, this will allow water distribution systems to operate at greater levels of efficiency and with higher levels of confidence and transparency. New research is needed to develop digital tools for easing the mobility of workers of water utilities, interactions with customers, and new ways of working remotely.

Engineering Education

The COVID-19 pandemic has disrupted schools and universities in an unprecedented way. Because of the high risk of transmission on campuses, most classes have migrated online, which has forced teachers, instructors and professors to rethink how content is delivered to students. These new educational experiences might impact students adversely, but might offer opportunities for enhancing the quality of several courses, including the ones in which the subject matter involves water infrastructure. In the beginning of the pandemic, concepts that relates to systems (e.g. health), models (exponential transmission models), projections, uncertainty, and others, were widely discussed in the mainstream media. One could argue that the application and dissemination of epidemiological models of the COVID 19 pandemic have contributed to a better understanding of students and the public about the field of systems analysis. The COVID19 pandemic offers the opportunity for universities to rethink some programs, courses and content that might benefit significantly the field of water infrastructure. For instance, engineering courses should focus on developing content related to the field of water infrastructure resilience or new event detection methods in wastewater. Students and future professionals that will work in the field need to be well educated in related concepts such as modeling of water and wastewater systems, optimization for water and wastewater operation, management and planning, disruptions caused by natural and manmade disasters, among others.

Enhancing management of water infrastructure and water resources

The COVID-19 pandemic has altered the way water is consumed, and therefore, how water and wastewater networks are operated. This change is an opportunity for enhancing our understanding about water infrastructure. For instance, hydraulic models are typically calibrated and validated utilizing water consumption patterns (e.g. diurnal curves) which are not valid during the period of the pandemic. The change in the systems can provide new data which could be used for better validating models of water and wastewater networks. Managing water resources effectively for variable and changing systems is an old problem for planning. Many water systems have been designed using flawed logic, and the emerging insight can be applied to redesign infrastructure and inform future infrastructure policy (Daniell 2020).

Events associated with the pandemic demonstrate the degree of interconnection among water systems, the populations that they serve, and other infrastructure systems (Daniell 2020; Neal 2020). Public health is not separate from water resources management questions, especially in water-stressed areas, and needs to be considered in strategic risk analysis for planning and decision making on investments for water infrastructures and their operation. The interrelationship between local water resources and food supply chain issues has grown more salient, as some communities respond to shutdowns and lockdowns by increasing local sourcing of food. However, this can deplete water resources in water stressed areas, and groundwater sources that are not replenished may fall short for future generations. Water-scarce countries need access to the world food market and food-importing economies to mitigate their local water shortages (Keulertz et al. 2020). New dynamics may emerge in the water-energy nexus, as well, as working from home has led to changes in the demand for energy. For example, changes in electricity demands during lockdown-like measures led to significant reductions in the water footprint of thermal power plants across Europe (Roidt et al. 2020). The COVID-19 pandemic has also brought to light the ways that water is tied to society and human rights. One of the challenges of extreme disasters is that their impacts are typically greater for socio-economically disadvantaged, who lack the means to protect themselves. They are vulnerable across education, health, housing and basic necessities and lack the capacity to adapt to disasters (Daniell 2020). COVID-19 is deepening the inequalities experienced by the marginalized, including the poor, persons with disabilities, and women and girls, as these groups are likely to be most affected in crises, lose opportunities in education and livelihood, and experience threats to personal safety (Neal 2020). Mental health issues are expected to persist for some time after the pandemic (Daniell 2020; Wang et al. 2020). These societal challenges present an opportunity to focus attention on underlying environmental and social stressors and to invest in wellbeing. Through the unfolding events, new insights can be gained about water resources as an interconnected socio-technical infrastructure system and the resilience and vulnerability of natural resources and communities.

COVID-19 brought new challenges due to unknown future conditions for designing and operating water infrastructures, as well as for the management of water utilities. Scenario generation for future "states of the world" should be envisaged to improve emergency response plans. Such scenarios should be embedded into optimization & simulation models so that adaptation strategies can be defined. Scenarios should consider the interconnected nature of water, power, telecommunications, and transportation systems, to explore cascading and simultaneous failures (Sowby 2020). Tabletop exercises are important tools in demonstrating and improving how water infrastructure and management would perform in emergencies (Sowby 2020); however, more research is needed in developing and applying these tools as little attention has been paid to advance the insight and tools for enhancing preparedness activities (Berglund et al. 2020). The COVID-19 pandemic can also help researchers and operators to better prepare for future disruptions, caused, for instance, by natural and manmade disasters. Other crises and natural disasters (e.g. hurricanes, wildfires, and flooding) can also cause changes in water consumption through mass migration of people to new cities, and water infrastructure can be designed and managed to ensure resilience during and after these hazards. The insight we can gain through the way our water systems and water governance structures are functioning during the pandemic can be used to rethink the design of contingency plans for the years to come. Redefinition of governance models can drive institutional organization toward a higher operational, financial, and social efficiency.

CONCLUSIONS

The COVID-19 pandemic and water are interconnected in many ways. The pandemic has affected water systems, including water demands, drinking water infrastructure, sustainable reuse of wastewater, and natural water bodies, and the crisis has clearly demonstrated the effects of unequal access to WASH services. The COVID-19 pandemic and associated social distancing policies led to significant management challenges and changes at water utilities. Water utilities have experienced significant financial challenges and changes in the workforce. Despite these challenges, utilities throughout the US were able to adjust accordingly and ensure continuity of services to customers. However, it is worthy of note that the scale of impact was such that many systems would likely have experienced failures without such proactive management, which could imply ongoing and underreported problems at many smaller, low resource utilities. New innovations are under development to use wastewater sewer networks as early warning systems of coronavirus hotspots, and new advances in smart technologies can support remote work through secure automation of infrastructure components. Engineering education can build on this opportunity to rethink content related to the field of water infrastructure resilience or new event detection methods in wastewater.

The pandemic provides new opportunities to re-evaluate and re-vision water resources planning and emergency preparedness of water infrastructure. Lessons learned from the performance of water infrastructure and water utilities can be used to envisage actions to keep the sense of commonality acquired during the pandemic and benefit knowledge integration, information sharing, and data transfer between utilities. New water resources management policies and methodologies based on insight gained through the COVID-19 pandemic should be developed to create more inclusive societies, implement reforms, and promote innovation.

Data Availability:

Utility interviews were conducted as part of this research. The dataset of responses generated during through these interviews are confidential in nature and may only be provided with restrictions. No other data were generated through the development of this manuscript.

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