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BUILDING WATER & WASTEWATER SYSTEM RESILIENCE TO DISASTER MIGRATION: UTILITY PERSPECTIVES

Kasey M. Faust, A.M. ASCE[1] and Jessica A. Kaminsky, M. ASCE[2]

[1]*Corresponding author, faustk@utexas.edu, Assistant Professor, Civil, Architectural and Environmental Engineering, The University of Texas at Austin, Austin, Texas*

[2] *jkaminsk@uw.edu, Assistant Professor, Civil and Environmental Engineering, The University of Washington, Seattle, Washington*

ABSTRACT

This paper leverages expert knowledge from leaders in water and wastewater utilities to anticipate water and wastewater infrastructure impacts in communities that host populations displaced by disasters. These experts represent knowledge from 25 utilities across the United States, and hold a combined 555 years of professional experience. While the identified infrastructure impacts of disaster migration were both positive and negative, the responding experts indicate that impacts depend greatly on the spatiotemporal characteristics of the increased demands caused by hypothetical migrant populations. For the construction industry, both the speed and scale of response needed are particular organizational challenges. More broadly, given the technical impacts of suddenly increased populations, the results of this research suggest an urgent need for policy that can provide infrastructure funding for communities hosting displaced populations.

INTRODUCTION

In 2015, the world saw population migration on an unprecedented scale (UNHCR 2015). Fleeing violence, almost 1.3 million first-time applicant asylum seekers sought refuge in Europe in 2015 alone (Eurostat 2016a). Germany received the highest gross number of 2015 asylum applicants and refugees in an individual European country, totaling approximately 750,000 people (UNHCR 2016). In 2016, the migration continued. By September 2016, European Union President Donald Tusk stated that "*the practical capabilities of Europe to host new waves of refugees, not to mention irregular economic migrants, are close to the limits*" (Ap 2016). During the second quarter of 2016, the number of persons seeking asylum in Europe reached 305,700, an increase of 88,100 from the same quarter in 2015 (Eurostat 2016b). To date, it is an open question how many migrants will remain in Europe and how many will not. Regardless of the ultimately permanent or temporary nature of the situation, established water and wastewater utilities across Europe have been challenged to provide service to suddenly increased populations. In this paper, we use the term *disaster migration* to describe this kind of population change arising from displaced individuals, regardless of the legal status or permanence of the population shifts, and regardless if the migration was triggered by a natural or complex humanitarian crisis.

Although not of this magnitude, mass disaster migration has also been experienced in the United States (US). For example, at least 300,000 people moved to California from Oklahoma and other dust bowl states in the 1930s (McLeman et al. 2013), sparking significant conflict with the receiving communities (Reuveny 2007). In a more recent example, in 2005 Hurricanes Katrina/Rita/Wilma triggered the evacuation of over one million individuals from metro New Orleans (Landry et al. 2007). About 250,000 of these people evacuated to Houston (Settles and Lindsay 2011). In the latter half of 2005, 93,000 people became new permanent residents of the Houston metro area, far exceeding Houston's previous growth rates and at least partially linked to disaster migration (Frey and Singer 2006). In other words, overnight Houston's utilities had an extra quarter of a million people to serve. Some, but certainly not all, of this population eventually left. As we will discuss in this article, both the near instantaneous population increase and the potentially temporary nature of that increase are both technical and managerial challenges for water and wastewater utilities.

Although disaster events are low frequency, the magnitude of individuals impacted by any event is far reaching. This pressing issue is further amplified because, for a host of reasons including climate change and increased population density, both the frequency and impact of disasters have increased (Eshghi and Larson 2008), making them an increasingly important topic of study for civil and construction engineers. An estimated 65.3 million people are forcibly displaced (including refugees, asylum seekers and internally displaced persons) worldwide as of 2015, an increase of more than 50% in the previous 5 years, with developing nations receiving 86% of the worlds refugees (UNHCR 2016). Given the public health mandates of critical infrastructure sectors such as the water and wastewater systems of interest to this study, sudden disaster-based system perturbations are potentially deeply problematic for migrants and non-migrants alike. While social scientists have long described conflict in and pressures on communities that receive large numbers of migrants (e.g. Organski 1961; Weiner 1992), we lack technical analyses that seek to describe impacts to infrastructure and how these may be mitigated to better serve host and migrant populations alike. In a step towards addressing this infrastructure resiliency issue, in this paper we identify and discuss potential impacts to water and wastewater utilities from sudden population change, based on the expert knowledge of water and wastewater utility leadership around the United States.

MIGRATION & CONSTRUCTION

A key modern challenge for the CEM industry is the increasing trend of rural to urban migration. For example, in 2015, 54% of the world's population was urban, and demographers predict that this percentage will continue to increase (WHO 2015). This concentration of people in densely populated urban settings is a challenge for infrastructure. When migration instead leads to infill and densification of existing communities, increased demands may overload infrastructure systems. Alternatively, when people settle in new areas, infrastructure systems must be extended to serve the new populations. This pattern—new settlements—is the pattern in the peri-urban slums that now surround many of the world's great cities. For example, the World Health Organization estimates that 863 million people live in slum conditions in 2015 (WHO 2016). Clearly, new populations are not always connected to infrastructure services, leading to one of the great public health challenges of the modern day. For example, the most recent census data from India indicates that a third of households in slums lack on-premises toilets, and 19% of slum households reported practicing open defecation (WSP 2016).

There are obvious parallels between the disaster migration that we explore in this paper and the slum populations that were described above. In both cases, large populations arrive with little to no notice. Of course, all people require water and sanitation, and it is easy to argue that electricity, transportation, and even access to information are also universal needs. This paper takes as a given that the creation of new slums where refugees live within the United States but without access to basic infrastructure services such as clean water and sanitation is unacceptable (despite existing pockets of populations where this is already the case (Donelson and Esparza 2010; Cook Wedgworth and Brown 2013)). However, as CEM professionals are well aware, infrastructure services all require design and construction, and these cannot be created instantaneously regardless of the strength of good intentions. If established urban utilities in wealthy nations such as the US intend to serve all people, we urgently need research that can discover ways in which utilities can be made more robust against both disaster migration in particular, and sudden large population influxes in general. As a first step towards addressing this gap in the body of knowledge, in this paper we ask experienced US utility leaders to consider and share topics they would be concerned about if a large number of refugees arrived at their utility's doorsteps, as is currently happening to many European utilities.

This situation—the sudden arrival of large numbers of people—is both qualitatively and quantitatively different than the more typical growth and population dynamics utilities often plan for, and differs in ways that matter for the provision of infrastructure. In New York City, New York, the highest populated city in the United States, increased population by 55,000 between July 2014 and July 2015 (US Census

2016). Georgetown, Texas, the fastest growing city in the United States increased population by 7.8% during this same time period (US Census 2016). In contrast, in 2015 Munich, Germany received thousands of displaced persons arriving at their central train station *each day*, of which a portion of the population will remain, while others will be distributed throughout Germany (BBC 2015; Noack 2016). Quantitatively, it has been demonstrated that disaster migration causes larger and faster changes in populations than would otherwise be expected in the cities that receive them. For instance, The Federal Statistics Office in Germany reported a net migration of foreign nationals in 2015 to be approximately 1.1 million (Statistische Bundesamt (@destatis) 2016) of which almost 75% was due to forcibly displaced persons (UNHCR 2015). In a second quantitatively measurable difference, displaced individuals who are fleeing difficult circumstances may arrive with limited to no material or financial resources, and may not be able to immediately access available personal funds. As both building new infrastructure and the provision of water and wastewater service requires money, the ability of communities (and displaced individuals) to pay for these services is an important issue. In addition to these metrics, refugees are often qualitatively different than hosting populations in ways that matter to infrastructure planning and construction. For example, different dietary preferences create different loadings on wastewater treatment plants, and different regions of the world are known to use different quantities of water per capita. Despite these various and practically important differences, however, we are not aware of any technical literature that considers the challenges established utilities face as they respond to sudden population change due to disaster migration.

METHODS

To generate a list of potential impacts to utilities experiencing disaster migration, we surveyed water and wastewater professionals at 25 utilities nationwide. Respondents represented a convenience sample, and were contacted by email. These utilities span 19 states and 32 subject matter experts with a total experience of 555 years and an individual average of 19 years of experience (see Table 1). Respondents were utility directors, managers, supervisors, chief engineers, superintendents and city engineers. Prior to being sent out, the questions asked underwent Institutional Review Board approval at both the University of Texas at Austin and the University of Washington.

We asked respondents to respond to the following intentionally provocative prompt: "*Please imagine that tomorrow, a large number of refugees will arrive in your area and increase the population you need to serve by 25%. Please identify at least 5 problems and 5 benefits your utility and/or infrastructure system might experience due to this situation. If you cannot think of 5 please list as many as you can."* As an optional follow-up question, we also asked them to "*Please brainstorm ways you might try to handle each of the impacts you identified."* Interestingly, different utilities had different assessments regarding the magnitude of the hypothetical 25% population growth used in our prompt. For example, one utility said that "*25% increase is like a 10 year growth, so pretty impactful*." In contrast, a utility in a particularly fast growing region accepted that growth as business as usual: "*According to our Chamber of Commerce, 43 people per day are moving to our area. So in 581 days, your scenario will become reality. Keeping up with the infrastructure needs with this growth is the biggest issue for us*."

Of the 25 utilities that ultimately responded to our prompt, 24 also answered the optional follow-up question. Unless otherwise indicated in specific titles in Table 1, the respondent was associated with both the water and wastewater utility in a professional capacity. These responses were compiled into a research database for formal qualitative coding. Responses were coded using an emergent, in vivo scheme that captured respondent voices rather than any researcher imposed framework (Saldaña 2009). Some responses were coded to more than one theme. For example, one respondent was concerned about "*building code enforcement of sheds/shacks set up that are not plumbed for water and sanitary sewer.*" This quote was coded to two themes: New Infrastructure; and Coordination, Design, and Construction.

RESULTS

The identified themes shown in Table 2 are unlikely to represent a fully comprehensive list of issues that utilities might face if they experienced sudden population increases due to disaster migration. In addition, as our sampling logic was not probabilistic we cannot make claims regarding the relative importance of each of the themes. However, each of the identified themes is certainly worthy of future research to determine the extent of potential impact for each, and as appropriate, discover ways that can enable utilities to be more resilient against disaster migration or other types of sudden population growth. Although each city's water and wastewater infrastructure system is unique, with distinct, individual topologies and network structures, common themes among challenges and benefits were identified across these categories. Following common nomenclature, we organized system capacity as comprised of three components: technical, managerial, and financial. These three together determine a system's ability to achieve relevant plans and regulations (US EPA 2016a; WADOH 2013).

DISCUSSION

TECHNICAL SYSTEM CAPACITY

Almost all of the respondents (23 of 25) discussed the challenges of technical system capacity in response to our prompt. Technical system capacity may be subdivided into three categories (WADOH 2013): source water adequacy, operations, and infrastructure adequacy, all of which were identified themes discussed within this section.

INFRASTRUCTURE ADEQUACY- EXISTING PHYSICAL INFRASTRUCTURE

Population dynamics have a direct impact on the ability of infrastructure systems to provide adequate levels of service. Twenty-one of the respondents mentioned challenges with the technical capacity of the existing infrastructure. Even those utilities that felt a population increase of the scale suggested by our research prompt "*would be within our systems capacity at a macro level, however there may be significant capital improvements necessary to continuously provide this increased demand within the various parts of our service area (larger pump station, bigger tank volumes, increase pipe sizes, etc).*" Rapid urbanization has the potential to overwhelm a system's technical capacities and may result in inequitable levels of service (Varis et al. 2006). However, expansion of the physical infrastructure system's technical capacity poses risks due to the uncertainty of the displaced population remaining. In the instance the population is transient, making permanent upgrades to the technical capacity may result in underutilized infrastructure, possibly impacting the water quality, fire flow capabilities, and pressures provided to remaining residents (Faust et al. 2016; Faust and Abraham 2014)

While most respondents were responsible for both water and wastewater systems, many respondents indicated that the impacts to the wastewater system *"would be more problematic*" than for the water system. For example, respondents were concerned with insufficient technical capacity ("*the main problem for the sanitary sewer system would be lack of capacity in the collection system and at the treatment plant.*"*)* Specifically, respondents mentioned the "*lack of capacity in the collection system,*" a possible need for "*additional lift stations,*" and impacts to treatment plants both "*hydraulically*" and in terms of "*biological capacity.*" One respondent was concerned that the new population might create "*locations in which the [wastewater] discharge would exceed our [permitted] capacity*."

There were also technical capacity concerns specific to the water systems. For example, a suddenly increased population could push utilities to pump "*our well fields at near maximum capacity for a long time, potentially causing us to mine water.*" Comments regarding the availability of water supply itself, rather than infrastructure to deliver water, are discussed below in the *Source Water Adequacy* section. In general, respondents discussing both the water and wastewater system noted that "*pipes would likely need to be upsized*." Respondents were also concerned about meeting fire flows, noting that "*new buildings and areas with increased population densities would trigger the need for upsizing existing water infrastructure to meet current fire code requirements*." This might require "*upgrades to water distribution system…to maintain level of service and fire protection*." As a result of fire flows governing much of the design of water systems, in the absence of upsizing for the additional loads from displaced persons, the daily demand (or peak) flows may exceed design for the current number of customers, impacting the fire flow capabilities (NAP 2006). Ultimately this suggests that infrastructure adequacy challenges within the water critical infrastructure sector have the potential to cascade to the emergency service critical infrastructure sector.

Many respondents emphasized that these various impacts would be "*determined by the spatial distribution*" of the new population. At the scale of population impact suggested by our research prompt, respondents expected that meeting the needs of the new population "*would involve moving large volumes of water to a remote part of the system where pipelines, storage tanks, or infrastructure will be significantly undersized*." In addition, some utilities have "*water and sewer mains dating back to the late 1800s. This older system would be more easily stressed re a surge in demand*." Respondents were also concerned about the timing of flows. For example, system capacity would be impacted if the new population were "*exacerbating the peak flows or using capacity that would be available during off-peak hours*." In a related point regarding timing, one respondent noted that building new infrastructure to serve a possibly temporary population "*might ultimately result in having oversized equipment and piping that is no longer needed when people move on*."

Several respondents noted that the systems they manage could handle the increased demand: "*An instant increase in population served would not present much of a problem for our water system.*" Others expected they would be able to influence the placement of the refugee population to locations where utilities could reasonably meet the new requirements: "*the increase in population would (could) be in areas with lots of looped water mains, redundant pumping and tanks, and ample supply*." Even if a chosen location is not always able to meet a sudden increase in demand as currently configured, assuming appropriate population placement, systems "*could likely be routed within a short period of time (days – hours) to provide potable water nearly anywhere within our city boundary, extended by ½ mile or so*." This common concern of spatiotemporal demands (further discussed below in *Demands*) was mentioned by 10 utilities, indicating the importance of including utilities in the decision-making of the placement of displaced persons throughout a city. In the absence of consultation with utilities, the results can have detrimental impacts on the services provided to the community in terms of pressures and fire flows. In contrast, if utilities are included in placement decision-making, the water critical infrastructure system may benefit, improving water quality (discussed in the following section *Infrastructure Adequacy-Water Quality*).

INFRASTRUCTURE ADEQUACY-WATER QUALITY

Water quality issues were mentioned by seven of the 25 respondents. For the water infrastructure, and in contrast to the operational impacts discussed above, most of these respondents felt that "*increased water usage would also likely enhance water quality rather than have a negative effect*". While one respondent was concerned about increased water age, five utilities expected that "*if [the] increased population and water demand happened in an area where the system could easily accommodate the change, more demand would likely improve water age / water quality.*" This possible benefit was noted system wide ("*water would be cycling through the distribution system at greater rates, and thus have 'fresher' water that has residuals more closely aligning with levels when water leaves the plant"*) and also in existing problem areas ("*addition of customers may lead to higher demand in some areas of the system that have lower demand and lower water turnover*.") Three of these five utilities identified the **chlorine residual** as benefiting from increased demand for water: "*Water age is one our biggest concerns because water that sits has the opportunity to bust through its chlorine residual and, if there is any organic matter, form more DBPs [disinfection by-products].*" Underutilization of portions of systems has been found to increase water age (e.g. Faust et al. 2016; Rink et al. 2010) that, dependent on location of infill within the system, may mitigate issues such as, nitrification, disinfection by-product formation, temperature increases, and sediment deposition

Just one respondent mentioned the wastewater system in the context of water quality; this respondent was concerned about "*wastewater effluent violations with increase in volume that wastewater treatment plant can't handle*." This fixed grid wastewater system may not be able to accommodate the immediate population increase (i.e., increased loads), causing communities to be in non-compliance with state and federal regulations, such as the Clean Water Act. For communities operating on a separate sewer system (as opposed to a combined sewer system), the concentration of such overflows may be of higher risk to the surrounding water as the point source pollutant is not diluted with runoff as with combined sewer overflows (Kenward et al. 2013).

Operations and Maintenance

Thirteen of the 25 respondents were concerned about operational issues; these comments primarily discussed in the context of technical capacity challenges. For example, one respondent was concerned about the "*timing of supplies- closer/tighter operation of water supply, storage tank operations*." Another respondent, also discussing reservoir operation, noted that "*a dramatic change in water use and wastewater flow could impact operations of reservoirs (operated by another entity) so additional coordination may be appropriate*." Different operational issues were expected at treatment plants, where utilities would need to change treatment processes in response to the increased demand. For example, one respondent noted his utility would "*need to install nitrate or minimal removal system to pull more water form inactive wells to meet the increased water usage*." Others noted the potential for "*possible pressure drop issues*" in both the water and sewer systems, with concerns focused on changes in "*pressure variations.*" In addition to system pressure concerns, respondents identified the coupled issues of "*additional stress on pumping systems*" themselves, as well as "*stressing [the] water system infrastructure by pumping more water.*" This last would mean that "*main breaks would conceivably occur with much greater frequency, due primarily to additional loads on the system*," ultimately causing an increase in water demands due to nonrevenue water loss.

Not all the identified operational impacts were negative. In some cases, the new population "*would make greater use of our primary wastewater plant, which has excess capacity compared to current wastewater demands*." Two respondents indicated that increased population would allow their infrastructure "*to operate more in line with the average daily flow that the plant was designed to*." More broadly, the identified operational challenges were typically seen as challenges that could be reasonably managed. For example, one utility said that "*we obtain our water from a regional authority that has ample supply, so it would be a matter of increased pumping through our existing meters,*" and another noted that the infrastructure systems "*might initially be stressed operationally to handle the additional capacity but [the sudden population increase] would not create a crisis either*." However, both the sheer increase in demand and possibly also the use of less optimal or otherwise secondary water supply sources would mean that "*electricity and chemicals costs would increase substantially.*" In reference to the highly disadvantaged status of refugee populations (or low-income displaced individuals), one respondent noted the potential for "*higher operating and maintenance costs without the revenue to support them*."

Five of the 25 respondents were concerned about impacts to infrastructure maintenance. For example, one noted that a "*heavier load on the water plant would not be ideal as we have a lot of deferred maintenance that we get away with since we don't operate at capacity*." In similar points, other respondents noted the new demands would mean "*less time for preventive maintenance*" and would require "*replacement of outdated infrastructure to facilitate the demand*." Another respondent was concerned about future "*maintenance costs without the revenue to support them"* if the new population for whom infrastructure was expanded do not become permanent residents.

SOURCE WATER ADEQUACY

Ten of 25 respondents mentioned "*potential raw water volume issues*" as an area of concern, "*especially in light of the recent drought and long-term trends in climate change*". For example, one utility noted that "*water supply would be impacted assuming linear demand*" from the refugee population. More bluntly, another utility simply stated that their "*current water resources would be inadequate*." Yet another noted that creatively would be needed to determine how to source more water ("*Quick response would be needed to increase well supply or surface water treatment*"). In a related point, a utility noted that existing supplies would meet the demand in the short term, it could not do so sustainably: "*we would be pumping our well fields at near maximum capacity for a long time, potentially causing us to mine* *water*." In addition, the extra demands raise doubt about having "*enough water in reserve for firefighting"* even when raw volumes for drinking water supply is met. In contrast, other utilities confidently referenced *"a ready supply of clean ground water*," or noted that due to the size and redundancy in the existing system "*there would not be any issues related to supply in dealing with a local population increase*." Still, and as might be expected, no utility identified benefits to source water adequacy because of higher demands.

FINANCIAL CAPACITY

This theme was mentioned by 18 of 25 respondents. Respondents primarily discussed the revenue benefits of increased customers (assuming the ability to pay). This benefit was coupled with the financial challenge of capital intensive upgrades and expansions to the system without the guarantee of emergency funding as the host communities are likely to have no or minimal physical impact from the primary disaster that migrants are fleeing.

BILLING AND REVENUES

Fifteen of the 25 respondents identified potential challenges and benefits with utility billing and revenue. For example, several anticipated the situation would involve "*a lot of federal or state involvement and possibly funding*." There was also awareness that "*refugees may not have the funding to accommodate the payment for services*." While the utilities anticipated that "*some influx in revenue would accompany the arrival but if it not it would be a significant funding problem to address the needed growth*." Revenue streams would be a significant short term challenge for the responding utilities.

Accordingly, "*customers could see sewer surcharges due to immediate increase in wastewater flows*." Specifically, and "*again depending on the location of the additional people new water and sewer mains would need to be extended at a cost of tens of millions of dollars. Bonding would be required. Rates and charges would likely go up*." Regarding these rate increases, utilities were concerned about "*the public reaction from existing customers to any cost of improvements that are principally or solely for the benefit* *of the displaced persons, especially if this is a transient population or camp.*" In a related point, a private utility noted that they would be hard pressed to "*justify how these improvement costs should be passed on to existing customer bills if they are not directly improving existing customers as well*."

Utilities that felt they could meet the demand with existing infrastructure noted the population increase "*could result in a short term boost in water sales and sewer service*." For example, one calculated that the "*benefit of this scenario would be the increase in water customers served. Since the system is built to handle daytime populations over 250,000 the additional sales volume would increase operating revenues without adding capital costs*." Regardless of the need for new construction, in the longer term, and "*assuming that the water consumed by the addition of users is paid for there would be additional revenue for the utility*." Another utility noted that "*long-term this was still seen as a generally positive situation since these people would still become integrated into our service area over time, which results in an increase in customers, revenue***,** *system upgrades, and improved water quality*." Adding to this, a utility noted that this might even result in reduced per capita customer costs: "*more users/consumers of the utilities, able to spread fixed costs over a greater number of users*."

FUNDING AND COSTS

Ten of the 25 respondents emphasized the "*significant investment*" needed to serve the hypothetical, sudden population increase: "*This would equal additional money spent at the plant*." Utilities expected that "*bonding would be required*" to fund the needed scale of investment. For instance, the increased demand would cause "*accelerated depreciation of equipment value*." At the same time, "*the increase in water usage will increase our revenue and allow for increased spending on capital projects, which also increase our revenue*." Given the emergency response scenario, "*it was also thought that outside Federal or State funding might be made available*." Because these hosting communities are not themselves impacted by a disaster, utilities were unsure if government emergency response funding would be available. At the federal level, funding through agencies, such as the EPA and FEMA, primarily focus federal funds on major disasters in the area physically impacted (post-disaster recovery) or the individuals displaced (FEMA 2016a; US EPA 2016b) Government funding is available to individuals and households to meet housing needs; however FEMA does not pay utility bills, instead advising individuals to seek out local charities (FEMA 2016b). After major disasters, the President may provide each state with an Emergency Declaration for supporting evacuees with life-sustaining efforts, intended for mass care in consolidated/congregated settings (e.g., shelter, hydration, medical). Unfortunately, and as the utilities suspected, to date there is no direct avenue to send federal funds to cities hosting displaced individuals to relieve strain on the infrastructure systems citywide in the short-term or long-term post disaster.

PEOPLE

This theme was mentioned by 19 of 25 respondents. The categories within this theme fall under the utility workforce (i.e., those managing the system and interfacing with customers) and the human-infrastructure interactions between the end users and the critical infrastructure systems.

PERSONNEL

Eleven of the 25 respondents mentioned workforce or personnel challenges involved in meeting the water and wastewater needs of the hypothetical displaced population. For example, "*to operate more facilities/increase loading at facilities would require more operators and maintenance of said facilities*." For example, if the "*increase in population resulted in new development, [we] would be concerned with department staffing levels to read meters and maintain the infrastructure*." Another utility noted that changes in the treatment process needed to meet the demand would require "*additional sampling work*" and staff, while another was concerned that "*additional coordination*" would be required with an outside entity that manages part of the infrastructure system. Beyond these technical operational needs, utilities also noted increased demands on personnel resulting from "*a sudden increase in the demand for new customer accounts. Temporary staffing could be utilized to assist our Utility Billing personnel in setting up new customer accounts*." One utility reflected that "*with water rates largely determined by peak use,* *[we] would have to provide more public education about using water during off peak periods*." While recognizing that "*additional people would need to be hired,*" utilities were also cognizant that an "*increase in staff, but not necessarily in revenue, is a huge challenge*." In addition to scaling up to serve a larger number of people, another key challenge that was identified by three utilities is that "*serving customers would be more difficult due to possible language barriers*." For example, "*Bilingual customer service personnel might be extremely difficult*" to find, but would be required if utilities observed "*an increase in the non-English speaking customers*."

To meet this communications challenge, one utility noted that "*we would seek out refugees who would join our staff and learn of our department and help us to understand the service needs of the refugees…These new refugee employees would be available to help the rest of the new population understand how to use our services and how to interact with our department.*" More broadly, another utility noted that "*assuming that the additional residents would need to and would be able to work there will be larger candidate pools from which to hire*," itself is a significant benefit to any utility.

DEMANDS

Sixteen of 25 respondents discussed the benefits and challenges of the "*increased demand on water and wastewater treatment plants*" that would result from a suddenly increased population. The increased demand was described in terms of flow volumes ("*dumping 25% more wastewater into some of those may overload portions of the collection system*"), and the way users use the system ("*some of our collection system struggles today due to fats, oils, and greases eating flow capacity*"). As discussed previously regarding the impacts to existing infrastructure, the impact of the new demands "*would be determined by the timing of the additional flows,*" by "*spatial distribution*," and by "*how quickly would the water demand / wastewater flow happen.*"

A key point raised by the utilities is the impact of the location of the new water and wastewater demands. For example, "*In the scenario of a large number of refugees that would be housed in a central location,* *then water and sewer service would be a major consideration*." In other words, "*If they [refugees] are clustered they would likely have an impact on the local system. If they are dispersed, the likelihood of significant capacity issues in the local system is less.*" Another utility noted that their "*capacity model would have to be run to identify if, and where, any restrictions would have to be addressed on an accelerated program.*" A more constrained utility stated simply "*We have nowhere to put an influx of that many people*." A utility that does not have existing infrastructure capacity assumed that centralized housing would need to be at least a temporary solution while longer term solutions were developed.

Seven utilities thought that, with appropriate planning, the increased demand could be beneficial to the infrastructure system: "*In fact an increase would be welcomed and it would help offset the slow decline in water consumption over the past few decades.*" Some of these utilities are in places with shrinking populations or shrinking per capita water usage, while others saw the refugee population as a potential solution for addressing problematic system locations: the "*addition of customers may lead to higher demand in some areas of the system that have lower demand and lower water turnover*." Other utilities are in locations with policies for increasing the density of development: "*The sudden influx of people would speed the City's planning goals of infill and densification*." For example, one noted that the hypothetical sudden population increase "*maximizes use of existing infrastructure, depending on where the new customers would live and work (i.e., infill development).*"

RESILIENCE

Resilience of the utility was mentioned twice by one of the 25 respondents. That utility noted that they "*would learn from the experience and could improve our systems and services to be better prepared for the next event*." This utility noted the existence of consultants that specialize in disaster relief: "*We would draw on their expertise*." While this utility was the only one who explicitly noted that "*our staff is very innovative and resilient and has a can-do attitude*" when facing challenging engineering situations, this attitude is widely reflected in the content and tone of the answers of the responding utilities. For example, while many noted inherent challenges in serving a suddenly larger population that may not be able pay for services in the short term, none suggested that declining to provide services to the displaced population was an acceptable option.

TEMPORARY INFRASTRUCTURE

Three of the utilities called attention to the differences in providing infrastructure services on temporary and permanent bases. Existing legislation assigns responsibilities to various levels of the government and utilities for emergency services post disaster and disruption to infrastructure systems (AWWA 2011). Although planning for alternative methods of providing infrastructure services is intended for emergency planning post disaster, existing plans are in place spanning from water transport to coordination with various response partners (AWWA 2011). With this in mind, it is likely that these plans may be applied to provide off grid service to displaced person in the host communities in the short-term. "*In the case of refugees, it is anticipated they will have a limited time in the city, so infrastructure would have to be put in place to serve and then as the population moved, it would no longer be needed*." Another utility mentioned they would be able to supply "*temporary accommodations, including portable restrooms, to accommodate a large group quickly*." In contrast, other utilities assumed the new population would come to stay, necessitating longer term solutions: "*It is likely that water would be trucked to the camp or service area until pipes, pumping equipment, and other infrastructure can be installed/upgraded to service this influx of people*."

NEW INFRASTRUCTURE NEEDS

Thirteen of the respondents discussed new infrastructure needs. This topic differs from that discussed in the *Infrastructure Adequacy-Existing Physical Infrastructure* section in that this theme considers the *expansion* of the network, as opposed to the previous discussed upsizing of the existing network. For example, "*water main extensions would be necessary*," "*sewer mains would need to be extended*," "*lift stations might need to be reconstructed*," utilities would need to "*add wells*," "*add elevated storage,*" and add "*looping for [the] distribution system*." Two utilities suggested these sudden needs could ultimately benefit the infrastructure system as, for example, it "*would allow us to tie directly into the sewer plant with new infrastructure rather than going through old infrastructure*." Similarly, another noted that this scenario could "*kick-start deferred capital improvements.*" As noted above in the section discussing *Billing and Revenues*, utilities were concerned about "*the local community support[ing] additional improvements if the primary trigger is not normal growth or expected improvements to meet demands, regulation.*"

COORDINATION, DESIGN, AND CONSTRUCTION

Nine of 25 respondents identified "*engineering and construction*" impacts. The construction of new infrastructure is not an instantaneous process, even assuming available funds: "*It would take two to five years to meet demand and maintain reserve primarily due to design, permitting and construction time, again assuming revenue increase accordingly.*" For example, six utilities noted the need for "*a bit of time to predict impacts and coordinate operations,*" noting that such a large population increase "*would require significant planning and response.*" Even utilities with sufficient capacity emphasized the need for planning: "*we have sufficient water rights but a sudden population increase would shave years off our long range plan. We would want to update master plans.*" At the same time, utilities recognized the inherent need for "*quick response*" in terms of providing services to the hypothetical population: *"the challenge would be to coordinate, design, and construct the infrastructure as quickly as possible."* Although post disaster reconstruction has received attention (e.g. Schwab 1998; Johnson 2007; Sun and Xu 2010), we are not aware of any studies evaluating immediate infrastructure construction needs with limited (if any) front end planning time due to mass migrations from displaced individuals. As discussed in the literature review, translational studies may include meeting the infrastructure needs of rapid urbanization; however, even in these instances, the rate of change is far slower than that experienced in disaster migration (WHO 2014).

The utilities also noted practical issues with performing construction projects to meet the sudden needs of disaster migration. The concern of declining workforce throughout the US has been a concern for multiple decades (e.g. Federle et al. 1993; Burleson et al. 1998; Gomar et al. 2002; Chih et al. 2016). Post disaster, there is a temporary demand for increased workforce during the recovery phase of the areas initially impacted directly by the disaster (Arneson et al. 2016), but issues regarding the construction workforce demand in the context of secondary, cascading sudden, migration impacts has not yet been explored. These secondary impacts in this study refer to mass migration of people to areas *outside* the recovery area and the construction needs of the host communities. This concern regarding available workforce to upsize and expand existing infrastructure to provide adequate levels of service to the new and pre-existing customers in the host communities was expressed within the utility responses. For example, one respondent was concerned about coordination with other projects: "*There is a lot of new construction activity in the area already. Additional distribution system extensions would be difficult to construct*." In another example, a different utility noted that "*The engineering and construction community would have an increase in work. This could also create a bit of a scarcity of resources and increased costs*." Yet another utility emphasized that impacts to the construction industry would be regional: "*the staggering [population] increase is happening in multiple locations in a region, which would impact the available skilled workforce to accomplish infrastructure improvements*." In fact, the difficulty of finding "*sufficient contractors to fulfill the need for infrastructure improvements*" was seen as a key challenge. One utility identified this issue as "*the greatest hurdle to overcome the demand brought on by such a quick influx [of population]*."

CONCLUSION

In sum, the responding utilities identified a list of concerns they would have when facing a substantial and hypothetical disaster migration situation. Per the discussion above, many of these concerns are well founded in the engineering literature. For example, utilities noted impacts to source water adequacy, water age, fire flows, and wastewater treatment plant loading. However, these concerns have not previously been linked to disaster migration. As such, there is a significant opportunity to leverage this existing body of knowledge to improve utility resilience against sudden influxes of population such as that currently being experienced in many European communities, or such as that experienced in Houston from disaster migration after Hurricanes Katrina/Rita/Wilma. As such, the primary contribution of this work is to extend consideration of infrastructure impacts of a disaster to secondary sites that receive displaced populations.

In a key point, the results demonstrate that utilities need to have input into where disaster migrants settle, in order to mitigate impacts on infrastructure. The impacts to water and wastewater infrastructure depend heavily on where new populations settle within existing communities, and can vary from catastrophic to beneficial. However, these impacts are not sufficiently prioritized when housing disaster migrants. At a minimum, disaster response plans should establish procedures for communicating with water and wastewater utilities as disaster migrants are housed. More optimally, pre-event system analyses could identify locations where disaster migrants can and cannot reasonably be served by existing infrastructure systems. These identified locations might be within communities, or in contrast, could identify infrastructure systems that would be more or less able to receive disaster migrants.

In a related point, one respondent anticipated that expedited permitting or other forms of expedited code enforcement would be needed to prevent situations where disaster migrants are housed without adequate access to infrastructure services. The required speed for design and construction response also anticipates issues with availability of the construction and utility workforces. While this issue is currently being explored for disaster impacted communities themselves (Arneson et al. 2016), we need additional research to explore this issue for the communities that receive displaced populations.

Given the potential, serious infrastructure impacts to communities that host displaced individuals, we urgently need policy that addresses how to support host communities as they strive to meet immediate increased demands for infrastructure services. Emergency funding should not solely consider the primary impacted regions, individual households, and life-sustaining community needs for congregated areas, but should also consider the secondary impacts to other communities. The secondary impact of displaced individuals may have detrimental consequences on the level of service of critical infrastructure sectors provided to both the pre-existing community and displaced individuals entering the community. Support is needed at the city level to meet immediate critical infrastructure needs to sustain both new and established populations in hosting communities.

For water and wastewater infrastructure disaster migration demands may be temporary or permanent, with impacts varying from positive to negative depending on the details of the local infrastructure systems and the locations of the displaced populations within the city. As such, we need CEM research that can quantify and theorize these impacts. More broadly, we anticipate that giving utilities input into where disaster migrants are housed will reduce the costs involved in supplying water and sanitation services. However, once again more research is needed to validate and enable this and other recommendations provided here.

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Table 1. Sample respondent pool

State	Title	Public vs. Private	Population Served[2]
Alaska	City Engineer	Private	55,000
Arizona	Deputy Public Works-Utilities Director	Public	*171,000*
California	Associate Civil Engineer, Sanitary Sewer Division	Public	*90,000*
California[1]	Senior Civil Engineer	Private-Regional	1,000,000
	Director of Engineering		
	Supervisor		
	Senior Civil Engineer		
	Senior Civil Engineer		
	Senior Civil Engineer		
	Senior Civil Engineer		
	Associate Civil Engineer		
Colorado	Water Engineer	Public	50,000
Delware	Water Division Director	Public	*72,000*
Idaho	Public Works Director	Public	*90,000*
Idaho	Wastewater Superintendent	Public	*49,000*
Indiana	Director of Public Works and Engineering Services	Public	*17,000*
Kansas	Strategic Services Manager	Public	*390,000*
Michigan	Director of the Department of Public Services	Public	*73,000*
Michigan	Manager of Public Works Operations	Public-Regional	4,000,000
Minnesota	Chief Engineer for Utilities	Public	*86,000*
Missouri	Director of Public Works	Public	*23,000*
North Carolina	Chief Operating Officer	Public	400,000
North Carolina	Water Resources Director	Public	*89,000*
Ohio	City Engineer	Public	55,000
Ohio	City Engineer	Public	*32,000*
Oregon	City Engineer	Public	*80,000*
South Dakota	City Engineer/Public Works Director	Public	*28,000*
Texas	Supervising Engineer for Systems Planning	Public	1,000,000
Utah	Development Engineer	Public	*193,000*
Vermont	Acting Director of Public Works	Public	*9,000*
Wisconsin	Utility Manager	Public	*40,000*
Wisconsin	City Engineer-Director Of Public Works	Public	12,500

[1]*Focus group; considered 1 utility representation and 7 subject matter experts*

[2]*Italics populations indicate quantity based on 2015 US Census estimates (rounded for anonymity, not provided by utility)*

Table 2. Topical frequencies of US utility concerns

	Unique Cities	Total References
TECHNICAL SYSTEM CAPACTIY	**23**	**82**
Infrastructure Adequacy- Existing Physical Infrastructure	**21**	**36**
Problems	***17***	***26***
Insufficient Capacity (Short term)	15	10
Fire flows	3	3
Upsizing	4	12
Excess Capacity (Long Term)	1	1
Benefits	***8***	***10***
Sufficient Capacity	8	10
Water Quality	**7**	**11**
Problems	***2***	***2***
Increased Water Age	1	1
Effluent Violations	1	1
Benefits	***6***	***9***
Reduced Water Age	5	6
Chlorine Residual	3	3
Operations and Maintenance	**14**	**23**
Problems	***14***	***21***
Technical Challenges	11	13
Costs	3	3
Deferred Maintenance	1	1
Preventative Maintenance	2	2
Reactive Maintenance	1	1
Costs	1	1
Benefits	***2***	***2***
Technical Benefits	2	2
Infrastructure Adequacy- Source Water Adequacy	**10**	**12**
Problems	***7***	***8***
Volume	6	7
Fire flows	1	1
Benefits	***3***	***4***
Volume	3	4
FINANCIAL CAPACITY	**18**	**41**
Billing and Revenues	**15**	**29**
Problems	***7***	***12***
Payment for Service Rendered	5	5
FINANCIAL CAPACITY *CONT.*		
Funding and Costs	**10**	**12**
Problems	***6***	***7***
Capital Costs and Funding	5	6
Facility Depreciation	1	1
Benefits	***4***	***5***
Emergency Funding	4	4
Other Funding Sources	1	1
PEOPLE	**19**	**45**
Personnel	**11**	**17**
Problems	***10***	***13***
Increased Personnel Needs	7	8
Interagency Coordination	1	1
Customer Interaction	3	4
Benefits	***2***	***4***
Available Workforce	2	4
Demands	**16**	**26**
Problems	***12***	***19***
Location	10	12
Usage Trends	1	2
Increased Demands	3	4
Diets	1	1
Benefits	***7***	***7***
Location	7	7
Resilience	**1**	**2**
Benefits	***1***	***2***
TEMPORARY INFRASTRUCTURE	**3**	**4**
Problems	***3***	***4***
NEW INFRASTRUCTURE	**13**	**23**
Problems	***13***	***23***
Main Extensions	3	5
General Infrastructure	10	15
Unpermitted Development	1	1
Community Support	2	2
COORDINATION, DESIGN, AND CONSTRUCTION	**9**	**15**
Problems	***9***	***15***

Surcharges and Rate Increases	4	5			
Customer Satisfaction	2	2	*Front End Planning*	6	7
Benefits	***14***	***17***	*Timeframe*	3	3
Increased Revenues	13	16	*Coordination*	1	1
Reduced Per Capita Costs	1	1	*Workforce*	2	4