Abstract

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Urban decline in once vibrant cities has introduced many challenges to managing civil infrastructure. The fixed infrastructure footprint does not contract with the declining population, but remains relatively stable, resulting in underfunded and underutilized infrastructure. The focus of this dissertation is on the assessment of urban decline on the coupled human and water sector infrastructures. Aspects such as the drivers of population decline and transitioning to a smaller city for the current and projected populations in shrinking cities have been well-studied by political and social scientists. However, the repercussions of urban decline on underground infrastructure systems have thus far been underappreciated. Arising from urban decline are water sector infrastructure issues such as, increased water age, operating on reduced personnel, and underutilized impervious services contributing to stormwater runoff. As cities begin to right-size, understanding the impact of the underutilization on underground infrastructures, and the technical viability of retooling alternatives to aid in right-sizing are important to ensure infrastructures continue to provide adequate services to the residents. This dissertation aims to fill the gap in the body of knowledge and the body of practice regarding the impact of urban decline (and underutilization) on the coupled human and water sector infrastructure systems, the technical viability of retooling alternatives, and the public views towards these infrastructure systems and retooling alternatives.

To accomplish the research objective, a mixed-method qualitative and quantitative framework is demonstrated using two case study cities: Flint, Michigan and Saginaw, Michigan. The two case studies demonstrate the applicability of the framework spanning different size classification of cities. Flint is a medium sized city with its population peaking at 196,940 in 1960, whereas Saginaw is classified as a small city with its population peaking at 98,265 in 1960. As of 2010,

both cities have since lost over 40% of their population from their peak populations. Qualitative analyses use data from literature, the water infrastructure data from the case study cities, interviews with subject matter expert, and survey observations from the residents of shrinking cities in the US. First, the dissertation begins with synthesizing the data to identify infrastructure issues typical to shrinking cities, discern possible retooling alternatives, establish relationships between the water infrastructure system, wastewater/stormwater infrastructure system(s), and the types of human-infrastructure interactions relevant to the models. Next, metrics are selected to measure individual water and wastewater/stormwater infrastructure performance in the presence of physical (retooling alternatives) and non-physical (population dynamics, price elasticity, consolidation of demand to more populous areas of the city) disruptors. These metrics include: water infrastructure system pressures, fire flow capabilities, and the reduction of runoff. Following the qualitative analyses, four quantitative analyses were performed using data provided by the case study cities, interviews with subject matter experts, published data, and survey observations from residents of US shrinking cities. Network analyses evaluate the impact of non-physical and physical disrupters on the water infrastructure's ability to provide adequate service. The specific physical disruptor evaluated for the water infrastructure system is decommissioning water pipelines. Hydraulic simulations estimate the impact of decommissioning impervious surfaces, transitioning land uses, and incorporating low-impact development on the generated stormwater runoff entering the wastewater/stormwater infrastructure. After examining the individual infrastructures, survey analyses and statistical modeling is used to evaluate the public views in 21 US shrinking cities towards water and wastewater infrastructure issues and retooling alternatives. Finally, the aforementioned three components are integrated into the interdependency analysis to evaluate the water, wastewater, and stormwater infrastructures and human-infrastructure interaction interdependencies.

This study demonstrates that the retooling alternatives evaluated are technically viable for proactively right-sizing water and wastewater/stormwater infrastructure. The statistical modeling framework estimated the demographic and geographic variables influencing the support (or opposition) of different water retooling alternatives. For instance, the statistical models indicated that residents in Flint, Michigan are more likely to support decommissioning, whereas, residents in Ohio's shrinking cities are more likely to oppose decommissioning. Age of residents is an example of a recurring demographic variable in the statistical models, since the analyses indicates that residents over the age of 50 are more likely to oppose repurposing infrastructure and residents younger than 35 are more like to support maintaining the current infrastructure. The statistical analyses demonstrate a method for incorporating public opinion into the pre-planning process for potentially reducing public opposition. The interdependency analyses component demonstrates a framework for evaluating the impacts of urban decline on the coupled human-infrastructure systems. The interdependency analysis model can predict future water and wastewater needs based on projected rate increases and population trends, as well as the complex interaction between billing rates, financial return, and water demand. This model can be applied to different size classification of cities, as well as different decline/growth trajectories by updating the parameters in the model to reflect the characteristics of the city. Emergent behavior is captured in this model that is absent from other models in literature, such as the impact of water price elasticity cascading into the wastewater system, impacting the total generated revenues and the systemic interaction of agents to generated desired levels of support. Furthermore, the developed hybrid agent based-system dynamics model enables the estimation of the maximum achievable level of support that may be gained in a time period using market adoption strategies. In conclusion, this dissertation provides a framework for insight into right-sizing water sector infrastructure operations and management in shrinking cities.