Evaluating the Feasibility of Decommissioning Residential Water Infrastructure in Cities Facing Urban Decline

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ABSTRACT

Water infrastructure provides services essential for the health and economic well-being of societies. These systems pose potential vulnerabilities, such as their inability to provide service when a disruptor alters the network. In shrinking cities, the per capita cost for maintaining infrastructure increases due to the reduced population maintaining an infrastructure footprint designed for a larger population. Decommissioning water infrastructure may potentially reduce costs and improve a community’s public health by decreasing the presence of stagnant water and slowing pipeline deterioration rates that result from reduced flows. However, decommissioning presents challenges, such as maintaining adequate services and emergency demands. Additionally, criteria such as future land use and network connectivity must be considered to determine if decommissioning is appropriate. This paper examines the feasibility of decommissioning water infrastructure in shrinking cities. Decommissioning strategies were examined in the context of two Midwestern cities in the U.S. using water infrastructure models developed in EPANET. The disruptors modeled included decommissioning and demand decline to evaluate the systems’ ability to provide adequate service and emergency demands. This study demonstrates that decommissioning water infrastructure is a viable option for potentially reducing maintenance costs within these fiscally-strained cities.

INTRODUCTION

Shrinking cities are experiencing substantial urban population decline, both in the U.S. (e.g., Gary, Indiana; Akron, Ohio) and internationally (e.g., Leipzig, Germany; Mount Isa, Australia). This population decline in shrinking cities is not tied to the economic cycle in the short term (e.g., the 2007 U.S. economic downturn) but to a chronic decline over several decades. Typical to these cities experiencing urban decline is that the extent of the physical infrastructure (e.g., roads, water pipelines) has remained relatively constant during the decline. Consequently, the vacancies and underused infrastructure continue to increase as the decline continues. For instance, a potential issue with underused water infrastructure is the reduced flows throughout the network, which cause accelerated pipeline degradation and reduced water quality from stagnant water or water reacting with the deteriorating pipelines. Additionally,
the cost of maintaining infrastructure with a physical footprint intended for a greater population remains in place while the tax base declines (Butt and Gasteyer 2011; Rybczynski and Linneman 1999; Beazley et al. 2011). In the context of water systems, approximately 75-80 percent of the infrastructure costs are fixed (e.g., capital, personnel) (Herz 2006; Schlör et al. 2009). The financial burdens of operating and maintaining infrastructure, with the ever-increasing costs of treatment and regulatory compliance, must be recovered regardless of the reduction in customers. Thus, services become more expensive per capita (Butts and Gasteyer 2011; Herz 2006; Rybczynski and Linneman 1999; Beazley et al. 2011). The distribution of these financial burdens often corresponds to areas of lower socioeconomic status, highlighting the social inequity occurring as a result of the urban decline (Butts and Gasteyer 2011; Schlör et al. 2009). These fiscal burdens are exemplified in Detroit, MI, which declared Chapter 9 bankruptcy in July 2013. At that time, Detroit had an estimated 18-20 billion dollars in debt, and approximately one-third of its budget was allocated to retired personnel (Helms and Guillen 2013; Davey and Walsh 2013). Consolidating, reducing, and overhauling city services were proposed to reduce the cost to operate the city (Helms and Guillen 2013).

RESEARCH METHODOLOGY

This paper will use decommissioning and consolidating demand to address rightsizing the footprint to meet the needs of the current and projected population, with the goal of potentially reducing or stabilizing the per capita costs for services. Decommissioning in the context of the proposed alternatives entails cleaning and capping the water pipelines. Consolidating demand, allows for other city services, such as garbage collection or mail delivery, to be bounded to a smaller area, lowering costs. Decommissioning has been proposed by Hoornbeek and Schwarz (2009) and discussed by the EPA at the April 2012 “Retooling Infrastructure as a Strategy to Advance an Older Industrial City’s Future Vision” workshop as a potential method for reducing the infrastructure footprint. Other options (beyond the scope of this study) for managing water infrastructure, may include reconfiguring pressure zones or altering the systems flows at control valves. This work is expected to complement the efforts of researchers who are focusing on resizing the city footprint for smaller populations (e.g., Bontje 2004; Armboest et al. 2008) by directing efforts towards rightsizing underground infrastructure.

Typically, water utilities reactively manage their systems, fixing components as they fail or operate inefficiently (Selvakumar and Tafuri 2012). Decommissioning infrastructure is a technical alternative to shift to proactive management and address the larger-than-needed water infrastructure footprint. This study evaluates the impact of decommissioning water pipelines from vacant residential areas using metrics examining the ability to provide: (1) adequate service to the remaining residences and (2) emergency fire flows. Additionally, the study examines the impact of socioeconomic status on the performance metrics by applying appropriate water demand patterns to the decommissioned networks.
Model and Data

EPANET, a water network modeling tool, was used in this study to assess the viability of various decommissioning scenarios based on the aforementioned metrics. EPANET was used since it is open source and available for use by any city and the software’s modeling capabilities allow for inclusion of the necessary information to evaluate the performance of the system based on the targeted metrics. The network analysis performed with EPANET examines the topology of the water system (using GIS layers from each city) and how that topology impacts the aforementioned metrics regarding physical and demand changes to the water system. The elevations of the infrastructure intersecting nodes are assumed to follow the topography of the land, as determined by U.S. Topographic Maps. Demand is assumed to be equivalent to the national per capita daily average, and does not vary throughout the year.

Much of the excess capacity lies in the piped network due to the high number of vacancies throughout the city no longer requiring water service. Discussions with seven subject matter experts (SMEs) from shrinking cities in the Midwest, each with over 10 years experience managing and operating water systems, indicated that pipelines up to 12 inches in diameter are the underused components of the water supply infrastructure system that would tend not to alter the pressures of the system upon decommissioning. Based on these discussions, the impact of decommissioning two categories of water pipelines was evaluated:

1. Small diameter pipelines: those less than 12 inches in diameter.
2. Large diameter pipelines: those equal to or greater than 12 inches in diameter.

Providing adequate fire flow to the area during peak demand times is a critical for the safety of the residents. For a fire hydrant to be recognized as adequate by the city, it must be able to maintain a flow of 250 gpm for two consecutive hours without reducing the pressure of any node below 20 psi (Hickey 2008). Fire Flow 2.1, a tool developed by Optiwater used in conjunction with EPANET, models the increase in flow at each node until the established pressure threshold for any node in the network is violated. The fire flow ability of the network was analyzed by determining the maximum flow available for two consecutive hours during peak demand times for each decommissioning scenario using the demand patterns.

The estimated daily demand patterns: (1) Single Family Homes and (2) Single Low-Income Family Homes, used as an input in EPANET, were developed by Aquacraft, Inc. (2011) to account for the variation of water demand throughout the day. Variations throughout the day are important to consider to ensure that water demands can be met during peak demand times. However, water usage patterns vary across socioeconomic boundaries, as illustrated in Figure 1 (Aquacraft, Inc. 2011). In cities experiencing urban decline, the financial burden of maintaining the water infrastructure often falls on those likely to be in the low-income bracket (Butt and Gasteyer 2011; Rybczynski and Linneman 1999; Beazley et al. 2011), possibly making the single low-income family trends more applicable for analyses.

CASE STUDIES

Two U.S. cities are used to demonstrate the methodology. According to the U.S. Census Bureau data from 1940 to present, City A and City B have experienced a
decline in population of 43.4% and 47.5%, respectively, since each city’s peak population. These two cities were chosen due to availability of data and the opportunity to examine cities of various size classifications. City A is a medium-sized city, peaking at a population of 196,940 in 1960. City B is classified as a small city with its population peaking at 98,265 people in 1960. The median income for City A is $27,199 with 36.6% of the population below poverty level, and median income for City B is $27,051 with 37.4% of the population below poverty level, indicating that either demand pattern may be appropriate for a given neighborhood. Thus, both demand patterns were applied to each decommissioning scenario.

City A has not performed formal analyses or identified areas to consider decommissioning water infrastructure as of July 2013. However, discussions with City A’s representatives revealed that the city is open to exploring options to lower their infrastructure costs and are currently developing a future land use plan. City B has considered decommissioning and has developed a vision for future land use.

MODEL DEVELOPMENT: SMALL PIPELINE DIAMETER NETWORK

The small diameter pipeline analysis tests the hypothesis that pipelines less than 12 inches in diameter may be removed from the network without significantly altering the water pressures or fire flow capabilities. The model for City A is presented in detail while the model for City B is discussed briefly as its development process is similar to that of City A.

Since City A does not have a future land use plan, an appropriate location to test the methodology was determined by using U.S. Census data. City A was divided into sections aligning with the census tracts (U.S. Census Bureau 2012). Decline (or growth) was determined by the ratio of the 2010 population to the 2000 population in an individual tract. Based on the 2010 census data, in City A, the lowest area of population is in the center of the city, with the highest areas of population in the southwestern portions of the city. The tracts experiencing growth, however, are nested among tracts experiencing decline, showing a “Swiss cheese” decline pattern. The 20-block section used in the analysis for City A is zoned as primarily residential and has experienced a high number of vacancies, making it a possible candidate for decommissioning. Many of the pipelines servicing this area are less than 12 inches in diameter and therefore may be considered for pipeline decommissioning.

Within the bounds of City A’s analysis region, the demand was determined at each of the nodes located at the water supply pipeline junctions. Houses privately
owned were assumed to be occupied and houses owned by the land bank were assumed to be vacant. A vacant home contributes no demand to its respective node.

The distribution network for City A was examined under the different decommissioning configurations discussed in Table 1. The models for all scenarios were tested under typical daily demands and fire flow demands. These scenario simulations were repeated using declining demand scenarios to evaluate if adequate pressures are maintained under reduced demand within the area. This may represent residents moving away from the neighborhood or changing water use behavior.

Table 1. Select scenarios examined for decommissioning infrastructure in City A

<table>
<thead>
<tr>
<th>Description</th>
<th>Demand</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BASE CASE:</strong> The status quo network and demand</td>
<td>Demand is based on per capita averages and the average household size</td>
<td>Represents the status quo of the system and serves as a comparison for all scenarios</td>
</tr>
<tr>
<td><strong>SCENARIO 1:</strong> The status quo physical network with consolidated demand</td>
<td>Demand consolidated west of the 18-inch diameter pipeline, running north to south in the center of the analysis region</td>
<td>The network remains in place and functional, but does not have homes on vacant blocks</td>
</tr>
<tr>
<td><strong>SCENARIO 2a:</strong> Decommissioning of all of pipelines (i.e., there is no redundancy loop) in the vacant area, east of the 18-inch diameter pipeline</td>
<td>Assumes that housing swaps have occurred within the bounded network, and the total number of residents is static</td>
<td>Removing all pipelines east of the 18-inch diameter pipeline, including the redundancy loop, results in increased risk of service disruption</td>
</tr>
<tr>
<td><strong>SCENARIO 2b:</strong> Redundancy loop remains in place, decommissioning of all pipelines in the vacant area within the redundancy loop, east of the 18-inch pipeline</td>
<td></td>
<td>This redundancy loop within the network helps to ensure a more resilient system; removal of pipelines reduces maintenance costs</td>
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</tbody>
</table>

Figures 2 (a) and (b) show two different configurations of this network. Acceptable operating ranges for pressure throughout the water system varies from 20 psi to above 80 psi (e.g., LVVWD 2012).

City B, identified as a residential zone that is largely vacated, is a candidate for decommissioning infrastructure and transformation to green reserve areas. The
families residing in the area would be relocated out of the candidate area. Within this area, a majority of the pipelines have diameters less than 12 inches. City B’s total demand was determined in a similar manner for its network. City B’s distribution network was examined under the decommissioning configurations shown in Figure 3 and Table 2. The decommissioning of pipelines represents the areas that are being transformed to green reserve areas.

![Figure 3. Decommissioning scenarios for City B](image)

Table 2. Select scenarios examined for decommissioning infrastructure

<table>
<thead>
<tr>
<th>Description</th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>BASE CASE:</strong> The status quo bounded distribution network and demand</td>
<td>Demand is based on per capita averages and the average household size</td>
<td>Basis for comparison for all scenarios</td>
</tr>
<tr>
<td><strong>SCENARIO 1a:</strong> The right hand side of the network in Fig. 4 is decommissioned</td>
<td></td>
<td>By removing all eligible pipelines maintenance costs will be reduced</td>
</tr>
<tr>
<td><strong>SCENARIO 1b:</strong> The middle and right hand side of the network in Fig. 4 are decommissioned</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SCENARIO 2:</strong> All pipelines less than 12 inches in diameter in Fig. 4 are decommissioned</td>
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**MODEL DEVELOPMENT: LARGE PIPELINE DIAMETER NETWORK**

The large pipeline diameter analysis extends the above analysis to include the large diameter pipelines (i.e., those equal to or greater than 12 inches) that are within City A’s original analysis area and within the census tracts surrounding this area. The large pipeline analysis is performed only for City A and not for City B due to the locations and sizes of the pipelines in and surrounding the analysis area. The analysis area in City A is located in the center of the city, with large pipelines traveling through the area connecting to other regions of the city. However, in City B, there are no large diameter pipelines from the analysis area to the surrounding areas of the city. The demand was determined at each of the nodes located at the pipeline junctions. Table 3 discusses the decommissioning scenarios considered, while Figure 4 depicts
the four decommissioning scenarios examined. All scenarios were tested under typical daily demands, as well as under fire flow demands.

Table 3. Select scenarios examined for decommissioning infrastructure

<table>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>BASE CASE: The status quo distribution network and demand</strong></td>
<td>Used as a basis for comparison for all other scenarios</td>
</tr>
<tr>
<td><strong>SCENARIO 1: Center 18-inch pipe removed</strong></td>
<td>Scenarios examine the impact of removing large diameter (diameters 12-inch or greater) pipelines from the analysis area; the analysis area for the large pipeline diameter analysis is extended to evaluate the change in pressure to surrounding areas of the city</td>
</tr>
<tr>
<td><strong>SCENARIO 2: Center and Top 18-inch pipe removed</strong></td>
<td></td>
</tr>
<tr>
<td><strong>SCENARIO 3: Center 18-inch pipe removed and select 6-inch components removed</strong></td>
<td>These scenarios build upon Scenarios 1 and 2 to examine if removing the small diameter (12-inch or smaller in diameter) pipelines further alters the pressures or fire flow capabilities within the analysis area</td>
</tr>
<tr>
<td><strong>SCENARIO 4: Center and Top 18-inch pipe removed and select 6-inch components removed</strong></td>
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</table>

Figure 4. Decommissioning scenarios considered (numbers indicate each scenario)

RESULTS OF ANALYSES

Decommissioning small diameter pipes: The trends of the nodes’ pressures vary between the Single Family Demand Pattern and the Low-Income Single Family
Demand Pattern for each demand alternative, but they do not vary significantly between decommissioning scenarios. The pressure drops in the system, as expected, mimic the peak demand hours of each demand pattern. For instance, the Low-Income Single Family Demand Pattern has two peak demand periods each day, one in the morning and one in the evening. These peak demand periods are reflected as drops in the pressures during those peak times. These drops in the node pressure become less pronounced as the demand declines.

For the decommissioning scenarios examined, regardless of demand pattern or decline in demand, the water pressures throughout the system fell within the acceptable range of 20-80 psi. Furthermore, for each scenario all pressures were greater than the ideal minimum pressure of 35 psi, indicating that each decommissioning scenario can provide adequate service. The analysis also indicates that for each scenario and demand alternative, the system has the ability to provide adequate fire flow for two hours, exceeding the minimum threshold for fire hydrants to be recognized as functionally viable by a city.

Decommissioning large diameter pipes: Removing the large diameter pipelines from the network alters pressures significantly throughout the system. The pressures at select nodes fell below the acceptable operating range of 20 psi, indicating that the large diameter pipelines are integral for providing connectivity and sufficient water pressure throughout the network. Removing the small diameter pipes, in conjunction with the large diameter pipes, caused negligible changes in pressure beyond the pressure changes caused by removing the large pipes.

The nodes most impacted by the removal of large pipes are those with connectivity to the removed large pipes in the northern portion of the network. The 18-inch diameter pipelines were integral, in this configuration, to supplying potable water for the demand at these nodes at acceptable pressures. Removing the 18-inch diameter pipelines would cause an inability to provide sufficient pressure during typical peak demand periods and the inability to meet emergency fire flow needs.

Decommissioning large diameter pipes when the Single Family Demand Pattern is considered resulted in pressures at nodes falling below the acceptable pressure range during peak demand times. However, when considering the Low Income Single Family Demand Pattern, the pressures at the nodes did not fall below the acceptable pressure range. The Low Income Single Family Demand Pattern had two smaller peak periods in a 24-hour time frame, as opposed to one larger peak period at hour “7” for the Single Family Demand Pattern. The changes in pressures at nodes due to demand changes indicate that considering the water used trends associated with the socioeconomic status of the area is important for determining the eligibility of decommissioning scenarios.

The different patterns in daily water use due to varying socioeconomic statuses changed the ability to provide emergency fire flows to the city. Fire flow needs were not able to be met during peak hours for the Single Family Demand Pattern for any of the decommissioning scenarios. However, in the case of the Low Income Family Demand Pattern, fire flow needs were met for scenarios (1) and (3) but were NOT met for Scenarios (2) and (4). Scenarios (1) and (3) involved the removal of only one large diameter pipeline while Scenarios (2) and (4) involved the removal of two large diameter pipelines.
CONCLUSIONS

The model development and assumptions were verified by five SMEs, each with more than 10 years of experience in hydraulic modeling or management. The most current data (as of May 2013) provided by the cities were used in this study, and the results yielded from the status quo/baseline models (e.g., fire flows, typical operating pressures) were confirmed as reasonable values for what is observed within the two cities used as case studies. This study demonstrates that decommissioning small diameter pipelines is a viable alternative for rightsizing water infrastructure in cities experiencing urban decline. Pipelines less than 12 inches in diameter that were removed from the network did not hinder the ability of the system to provide adequate pressures during typical daily demands or to address emergency fire flow demands. Decommissioning large diameter pipelines is a case-dependent alternative. The viability of decommissioning large diameter pipelines, based on the metrics used in this study, depends on the location/connectivity of the particular pipeline, as well as the socioeconomic status of the area. Decommissioning scenarios using the Single Family Demand Pattern were not able to provide adequate pressures for typical daily use or fire flows. However, when using the Low Income Single Family Demand Pattern, certain decommissioning alternatives provided adequate services and may be feasible alternatives for consideration. Other considerations to determine the feasibility of reconfiguring each infrastructure system by decommissioning includes, but is not limited to, examining the necessary changes to the pumps and valves, as well as the possibility of surge or hammer effect occurring at possible dead ends resulting from the decommissioning scenarios.

Decreased demand may reduce the flow through the pipeline system, causing the pipelines to degrade faster. This deterioration, as well as low flow rates, may reduce the quality of the water reaching the residents, which could have impacts on the health of the residents due to stagnant water or water reacting to the deteriorating walls of the pipelines. Decommissioning infrastructure may potentially improve the water quality for both drinking water and surface water. By decommissioning decaying infrastructure, the city is reducing the footprint of aging pipes that are internally corroded, failing, leaking, and sometimes vandalized by thieves to recover and resell the metal. Additionally, the removal of excess infrastructure also reduces the risk of stagnant water and may improve the age of the water in the system. Lower demands in cities with systems intended to operate at higher demands may increase the water age, causing chemical (e.g., disinfection by-product formation), biological (e.g., nitrification, microbial regrowth), and physical issues in the system (e.g., sediment deposition, color). These issues may potentially be mitigated through rightsizing the infrastructure for the population.

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REFERENCES