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Research Paper

Could smart growth lower the operational energy of water supply? A scenario analysis in Tampa, Florida, USA

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ABSTRACT

Cities are coming under increasing pressure to minimize energy use and greenhouse gas emissions. Consequently, drinking water utilities must improve the efficiency of their management systems while guaranteeing a clean effluent that satisfies drinking water standards. One possible solution is via smart growth, an urban development paradigm with the goal of reducing the environmental impact of urbanization. Therefore, this study aims to determine the effect of smart growth on the operational energy of drinking water distribution. Projected water use in Tampa's drinking water service area was estimated based on several urban growth projections. Then, each scenario's associated projected water consumption is integrated in an EPANET simulation of Tampa's water distribution system for the subsequent estimation of the operational energies of drinking water distribution. Results show that smart growth has no exclusive influence on the operational energy of water supply. However, location of added demand relative to the location of the water treatment plant has more of an influence on the operational energy. Also, smart growth in the City of Tampa Water Service Area is responsible for a decrease in per-capita residential water and energy use of about 6–10% and 0.5–6.2% respectively. In conclusion, smart growth in areas near the water treatment facility may minimize water-related energy use.

1. Introduction

By 2050, the world's population is expected to reach 9.6 billion people with 60% living in cities (United Nations, 2010). This highly urbanized and increasingly affluent population will require more energy, land conversion, resource use, and agricultural development, all which may result in elevated greenhouse gas (GHG) emissions (Yeh & Huang, 2012). Another important resource required for community well-being is water, which, in many cities, is provided via centralized water treatment and supply schemes. The energy use associated with water provision over its life cycle can be quantified with embodied energy, defined as the direct (i.e., on-site) and indirect (i.e., consumed offsite) energy needed to produce a unit volume of treated water (Amores, Meneses, Pasqualino, Anton, & Castells, 2013; Del Borghi, Strazza, Gallo, Messineo, & Naso, 2013; Mo, Zhang, Mihelcic, & Hokanson, 2011; Santana, Zhang, & Mihelcic, 2014). Because the water sector is responsible for up to one-third of total municipal energy use (Yonkin, Clubbine, & O'Connor, 2008), cities and water utilities must confront the challenge of achieving energy efficiency in addition to water availability and quality.

Water treatment and supply systems consist of three main energy-consuming components: collection, treatment, and distribution (storage is considered a part of distribution). Past studies have estimated the total energy use of water treatment and supply systems at the regional (Del Borghi et al., 2013), metropolitan (Lundie, Peters, & Beavis, 2004), and municipal scales (Amores et al., 2013; Mo et al., 2011). Estimated embodied energies from these studies ranged from 5.2–54.1 MJ/m^3 of water produced, with factors including the water source, treatment process, and piping distance responsible for this wide range. For instance, desalination consumes about 8–10 times more energy per unit of water produced than conventional treatment systems included in the same studies, making treatment (desalination process) responsible for about 65–81% of the total energy use in water management systems where it is included (Amores et al., 2013; Cornejo, Santana, Hokanson, Mihelcic, & Zhang, 2014; Del Borghi et al., 2013). Conversely, when water systems rely on conventional systems, treatment is only responsible for 17–30% of the total energy use, making distribution the greatest contributor (Amores et al., 2013; Lundie et al., 2004).

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Table 1
The ten principles of Smart Growth (Smart Growth Network, 2006).

- Mix land uses
- Take advantage of compact building design
- Create a range of housing opportunities and choices
- Create walkable neighborhoods
- Foster distinctive, attractive communities with a strong sense of place
- Preserve open space, farmland, natural beauty, and critical environmental areas
- Strengthen and direct development towards existing communities
- Provide a variety of transportation choices
- Make development decisions predictable, fair, and cost effective
- Encourage community and stakeholder collaboration in development decisions

In the United States, since centralized potable water systems tend to rely on conventional treatment of surface water and groundwater, distribution is often the largest contributor to overall embodied energy.

Distribution systems usually follow transportation networks and are influenced by urban form. Filion (2008) modeled the distribution systems of three theoretical cities with distinct urban forms: gridiron, radial, and satellite. For each "city", three distinct population distributions were applied: "uniform", "monocentric", and "polycentric". A life cycle energy assessment (LCEA) was conducted for each scenario. Cities that followed a radial form (similar to older European cities) as well as a higher population density in and near the center of each city resulted in lower life cycle energy values.

Smart growth is a development paradigm commonly employed in North America in which urban growth has a lower environmental impact as well as a positive social impact. In other parts of the world, the terms compact city or urban intensification describe similar principles of sustainable city planning. It is guided by the ten principles listed in Table 1 (Smart Growth Network, 2006). Smart growth generally encourages a more compact urban form, which is amenable to pedestrians and various alternative forms of transit (i.e. buses, light rail). UN-Habitat (2013) and UNEP (2011) see similar principles of compact urban planning, walkability, stakeholder engagement, and access to green space as key features of a sustainable city and the new green economy. Past research has shown that smart growth and similar forms of urban development can result in decreased environmental impact, especially via transportation through reductions in air pollution emissions due to less vehicular traffic. For instance, Behan, Maoh, and Kanaroglou (2008) used an integrated transportation simulation model to simulate current and smart growth trends and found that smart growth was projected to use about 25% less fuel and emit 30% less carbon monoxide (CO) than the "base case." Other studies have modeled a reduction in emissions of the greenhouse gas carbon dioxide (CO_2) when smart growth is the preferred urban transportation scenario (Hankey & Marshall, 2010; Lee & Lee, 2014). The implementation of transit-oriented development (TOD) was studied by carrying out a life cycle assessment (LCA) of the areas surrounding two bus lines in Los Angeles and observed a relative decrease in greenhouse gas (GHG) emissions, smog formation and associated particulate matter, compared to the "business-as-usual" scenario (Nahlik & Chester, 2014).

Though not specifically mentioned in its ten principles, smart growth does have an impact on water. For example, watersheds with at least 10% impervious area have been associated with degraded water quality and increased sprawl and are expected to create 43% more stormwater runoff (Pelley, 2004). However, only a few studies have looked specifically at the effects of smart growth on water supply management, especially focusing on how it impacts residential water use (Guhathakurta & Gober, 2007; Runfola et al., 2013). There has been no study investigating how the urbanization paradigm of smart growth may influence the energy performance of an existing water distribution system. Because water management can be responsible for a significant amount of municipal energy use, the impact that the type of urban development has on energy use in water management should be important, especially as it relates to the economic cost of providing water, and consequently, associated greenhouse gas (GHG) emissions. Therefore, this study examines the impacts of smart growth on the energy performance of water management by comparing the operational energy of water distribution in four future development scenarios in rapidly growing city, three of which incorporate principles of smart growth.

The research is guided by the following hypothesis: urban planning that incorporates principles of smart growth will reduce the operational energy of a piped water distribution system. One basis for this hypothesis is that water consumption is expected to be reduced for planning scenarios that result in a more compact city. The second is that because urban intensification is expected to reduce the energy associated with transporting people, it should similarly result in less energy required to move water. Tampa (Florida) provides the case study to test this hypothesis and is a representative example of a large, and rapidly growing coastal urban area with multiple decisions for its future development, similar to many other growing coastal cities of the world, which comprise three-quarters of all cities in the world (UNEP). In addition, Tampa is an example of an urban area with a development paradigm dominated by urban sprawl (Hillsborough County Metropolitan Planning Organization, 2009). The methodology and conclusions reached in this study are thus relevant to not only coastal, but other urban centers in the world, as many cities face the same challenges of providing water to a growing urban population, while realizing the need to better plan their communities, limit energy use, and curb emission of greenhouse gases.

2. Methods

2.1. Site description

Tampa is one of the main cities of the Tampa St. Petersburg-Clearwater Metropolitan Area. The city's current population has grown 10.7%, since 2000 (Florida Center for Community Design and Research, 2015). The city is relatively sprawled with a population density of about 1862 people per square mile. The city lies within the City of Tampa Water Service Area (Tampa WSA), which is responsible for providing potable water to Tampa and a small number of outlying unincorporated communities (Fig. 1). About 68 million gallons per day (MGD) (257,000 m^3/day) of water is extracted from the Hillsborough River Reservoir, treated via the David L. Tippin Water Treatment Facility (Tippin WTF), and pumped through a 134,000-pipe distribution system to provide potable water to approximately 588,000 customers.

2.2. The one Bay urban development initiative

One Bay is a consortium of public and private entities in the Tampa Bay area with the objective of encouraging development that incorporates the principles of sustainability. In 2007, over three hundred leaders were invited by One Bay to participate in a workshop called "Reality Check" to determine priority areas of future development in the Tampa-St. Petersburg-Clearwater (TSC) metropolitan area. In 2008, One Bay created four future growth scenarios to simulate the effects of different development paradigms on land use, transportation, water use, employment, and housing (Fig. 2). "Business as Usual" (BAU) is a continuation of current growth patterns. The "Preferred" scenario is the resultant plan of the "Reality Check" workshops. The "Compact" scenario projects more compact urban design via a clear preference for multi-family housing development concentrated in existing urban areas. Meanwhile, the "Green" scenario avoids construction in or near protected or sensitive areas. The latter three scenarios will be referred to as smart growth scenarios, as they are guided by the principles of compact design and "development towards existing communities", resulting in an increased addition of multi-family households and a focus on residential and commercial development within existing urban