 

# Virtual Cities for Water Distribution and Infrastructure System Research

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**Abstract**

In a society concerned over the possibility of terrorism, secrecy, and security of infrastructure data is crucial. However, research on infrastructure security is difficult in this environment since experiments on real systems can not be publicized. "Virtual cities" are one potential answer to this problem, and a library of these virtual cities is now under development. "Micropolis" is a virtual city of 5000 residents fully described in both GIS and EPANet hydraulic model frameworks. To simulate realism of infrastructure, a developmental timeline spanning 130 years was included. This timeline is manifested in items such as pipe material, diameter, and topology. An example of using the virtual city for simulation of fire protection is presented. The data files describing Micropolis are available from the authors for others' use. A larger city, "Mesopolis," is currently under development and will incorporate additional critical infrastructure dependencies such as electrical power grids and communications. This will supplement the development of further models to account for risks and probability of electrical power failure due to hurricane events. It is hoped that Micropolis, Mesopolis, and additional virtual cities will serve as a "hub" for the development of further research models.

 

## Introduction

Water systems security has been a significant priority for the civil engineering profession since the September 11, 2001, terrorist attacks. In efforts to ensure the safety of their customers, many water utilities have restricted access to data describing their water distribution systems, in many cases changing from publicly available web-based viewing of system data before 9/11 to post-9/11 access restrictions requiring security clearances. The paradox of these new restrictions is that research on water system security now requires more access to realistic data sets with which to test algorithms and ideas; the basic tenets of the scientific method require that experiments must be repeatable by independent investigators and that comparisons be made as experimental factors change. Thus, publicly available water distribution system data sets are needed as research in this field continues. However, security of real distribution systems should be maintained.

"Virtual cities" are an attempt to address the need for realistic, publicly available water distribution system datasets that do not compromise the security of the public. A virtual city is a collection of digital models of a "made-up" city describing its geography, infrastructure, physical elements, and demography. To replicate the "organic" nature of a real city's infrastructures, a historical timeline is created with developmental and spatial markers to guide the design of water systems, transportation networks, land-use patterns, and so on. While certain elements of real places can be used to inspire these timelines, the need to be unlike a real city requires that no virtual city be too closely modeled on a real one.

This article presents two examples of the virtual city concept. "Micropolis" has been completely developed in geographic information system (GIS) and hydraulic modeling (EPANET) frameworks, and is a small city of about 5,000 residents. "Mesopolis" is currently under development and will be a somewhat larger city of 100,000 resdients. The following sections describe the development process for these two virtual cities and illustrate some research applications. The electronic files containing data on the Micropolis virtual city may be obtained by contacting the article's corresponding author.

## Development of the Micropolis Virtual City

Micropolis mimics the development pattern of a small city of approximately 5,000 residents in a historically rural region. The city is assumed to have begun as a small settlement on a railroad line in the 1850's with gradual population growth to its present size by the 1950's. The city's buildings, land use map, and road system is shown in Figure 1. The city's municipal water system was first built in 1910 with a wellfield and a small distribution network of cast iron pipes in what is now the central business district. Progressive annexations by the city were accompanied by water system expansion and some rehabilitation projects in 1950 and 1980. The water distribution network is thus composed of a mixture of pipe materials (cast iron from 1910, asbestos cement from 1950, and ductile iron from 1980), and pipe diameters and topology have been shaped by this historical development into a somewhat inefficient and confused state with respect to contemporary operation. For example, the oldest portion of the system retains some original 2 inch (50.8 mm) diameter cast iron pipes, but some of these original mains were more recently replaced with larger diameter ductile iron pipes when "repairs" were made. A single 440,000 gallon (1,670,000 liter) elevated storage tank located in the central business district serves the system. The 1980 expansion of the water system included construction of a surface water treatment plant that now serves as the primary water input to the system, but the original wellfield remains as a back-up source. A high service pump station at the northern edge of the city pressurizes inflow as it enters the distribution system (see Figure 2).

The city's relatively small size allows the water distribution system to be fully specified down to individual service connections in both the GIS and EPANET frameworks. Additionally, a full complement of isolation valves and fire hydrants has been included to allow for complete description of a wide range of scenarios. In keeping with the desire to develop a realistic and imperfect system, valve and hydrant locations are not completely in line with accepted codes and design practices; hydrants and valves are missing from a few locations where codes would typically require them. The EPANET hydraulic model includes: 1236 nodes, 575 mains (10.1 miles total length), 486 service and hydrant connections (7.1 miles total length), 197 valves, 28 hydrants, 8 pumps, 2 reservoirs, and 1 tank.

The water system's 458 demand nodes are composed of 434 residential, 15 industrial, and 9 commercial/institutional users. Numbers of inhabitants were randomly assigned to residences, and average per capita domestic use of 180 gallons/person/day (681 liters/person/day) was used to determine daily average demand. Commercial/institutional and industrial average daily demands were estimated from reference tables published by Haestad et al. (2003). Diurnal demand patterns for all user types were defined hourly based on patterns suggested by Haestad et al. (2003). The total daily demand on the Micropolis water system is 1.20 mgd (4.54 Ml/day) with minimum and maximum hourly demands of 0.68 mgd (2.57 Ml/day) and 1.66 mgd (6.28 Ml/day), respectively.

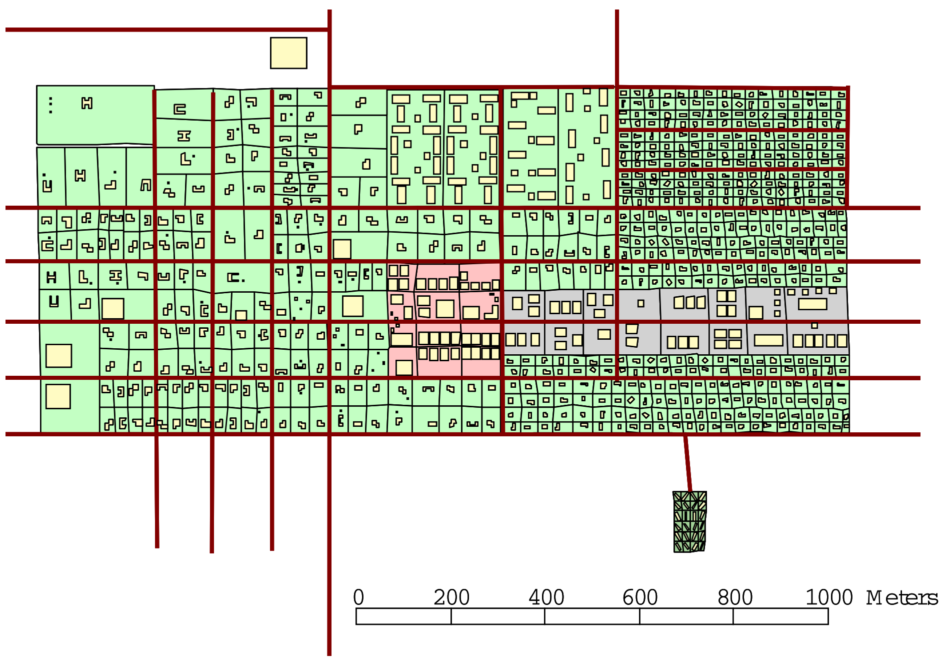


Figure 1. Micropolis building, land use, and road map. Land use is indicated by lot: residential (light green), commercial (pink), industrial (gray).

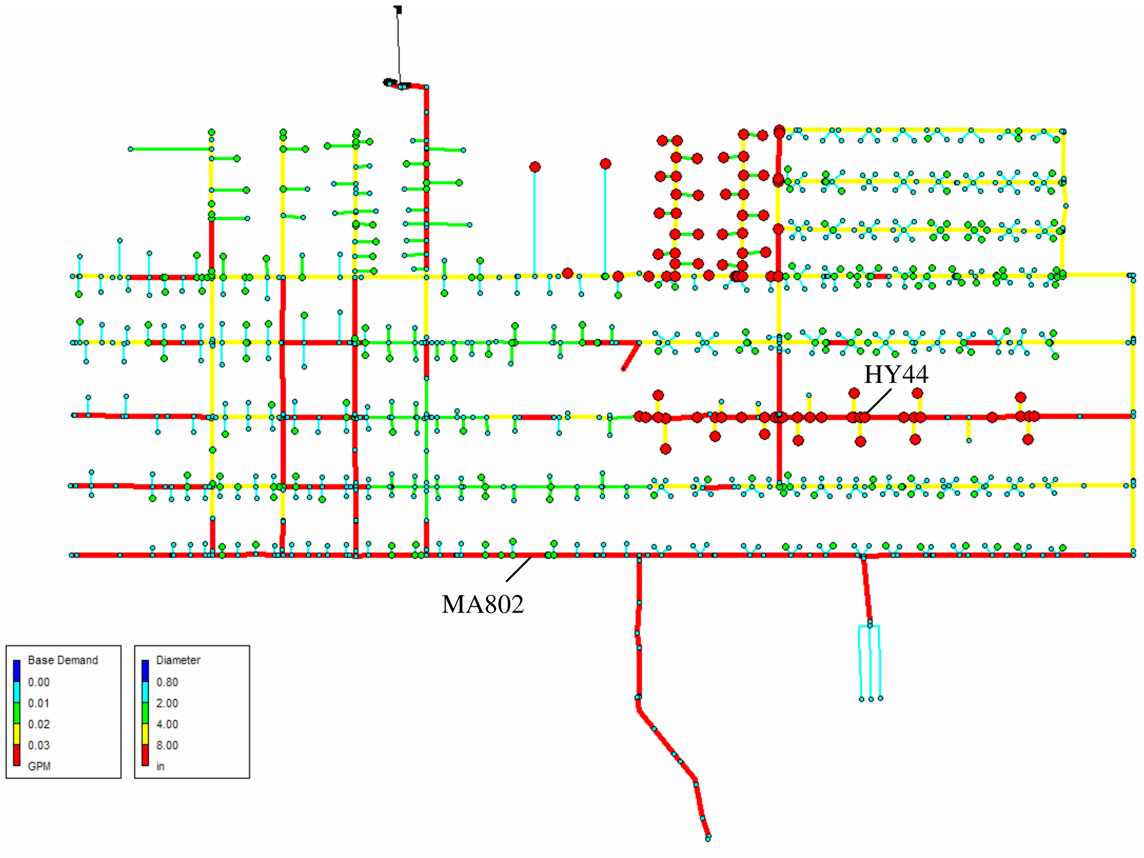


Figure 2. Micropolis water distribution system as modeled in EPANet.

## An Example Application: Fire Flow under System Damage

The utility of the Micropolis virtual city is illustrated here with a simple example of analysis of fire flow under a system damage scenarios. A prominent feature of the Micropolis water system is its retention of much of the “original” infrastructure in its core. This circumstance has been observed by the authors in real systems. A more recently constructed 12 in (305 mm) diameter main runs along the southern edge of the system and effectively acts as the major supply conduit to the eastern half of the city. The importance of this main under the imperfect system topology is illustrated by a fire flow need at hydrant HY44 (Figure 2) in the city’s industrial area. A pair of simple simulations were run with a 500 gpm (31.5 l/s) fire flow drawn from HY44 starting at 12:00 noon with the city’s elevated storage tank level at 117 ft above ground level (90% full). The two simulations differed by the status of main MA802: in the first it was open, and it was closed in the second. System static pressure maps for 1:00 PM for the two runs are given in Figure 3. As can be seen in this figure, the inoperability of a single main carries grave consequences under the system’s imperfect topology. Much more complex examples of research applications of Micropolis are given by Bristow et al. (2007), Bristow (2006), and Kanta (2006). Torres et al. (2006) use Micropolis in a contaminant propagation analysis.

 

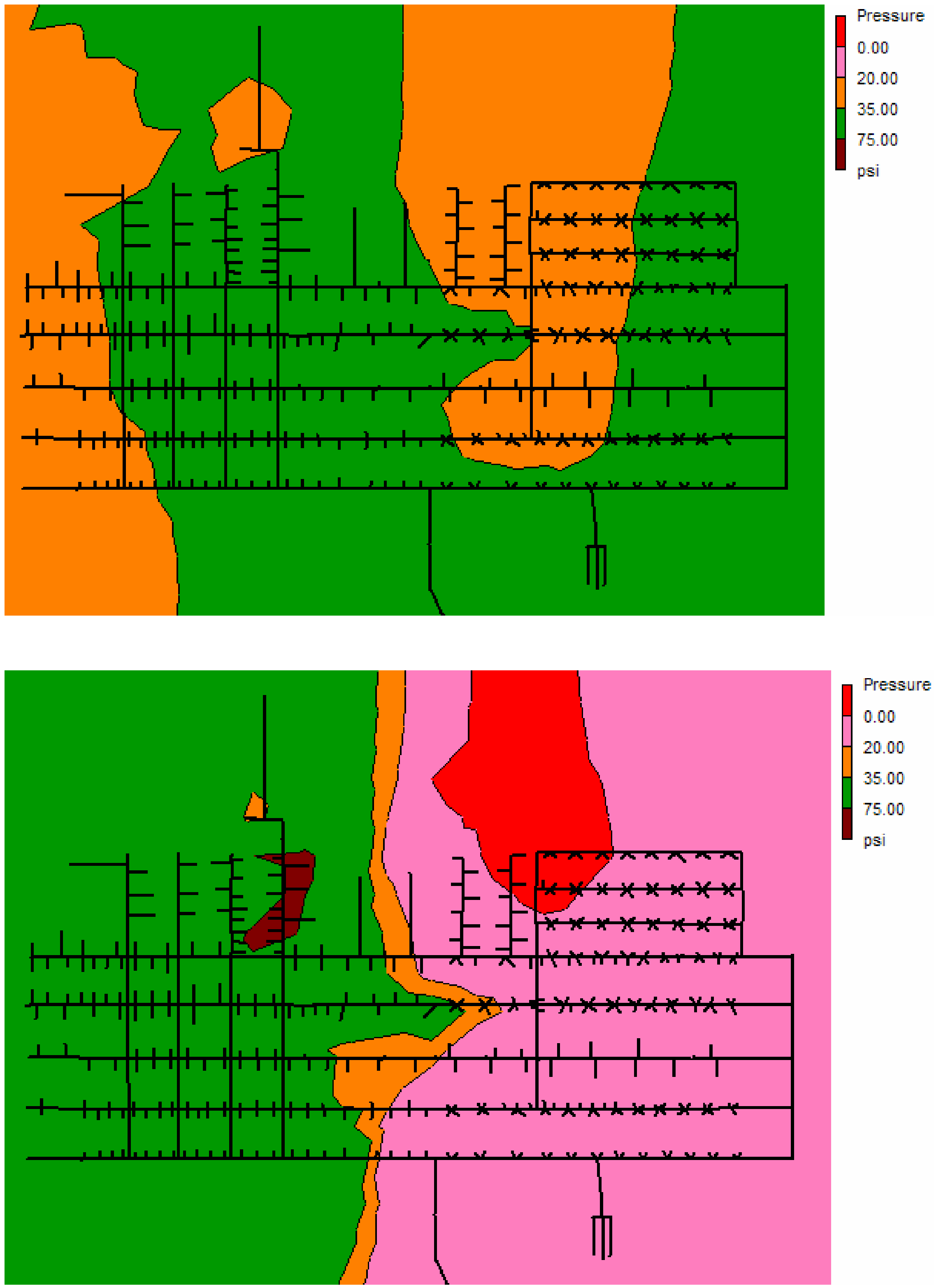


Figure 3. Maps of system static pressure under 500 gpm fire flow at HY44 with main MA802 open (top) and closed (bottom).

 

## The Mesopolis Virtual City

A second generation virtual city is currently under development.  "Mesopolis" is a coastal city of 100,000 residents with a developmental timeline spanning 300 years (Figure 4).  The larger size of this city includes significant topographic variation and greater sophistication in its water distribution network design.  While the small size of the Micropolis virtual city allowed for vary detailed specification of many system elements (e.g., individual water service connections), it is prohibitively difficult to do so at the scale of this larger city.  A system of "nested resolution" will instead be used where

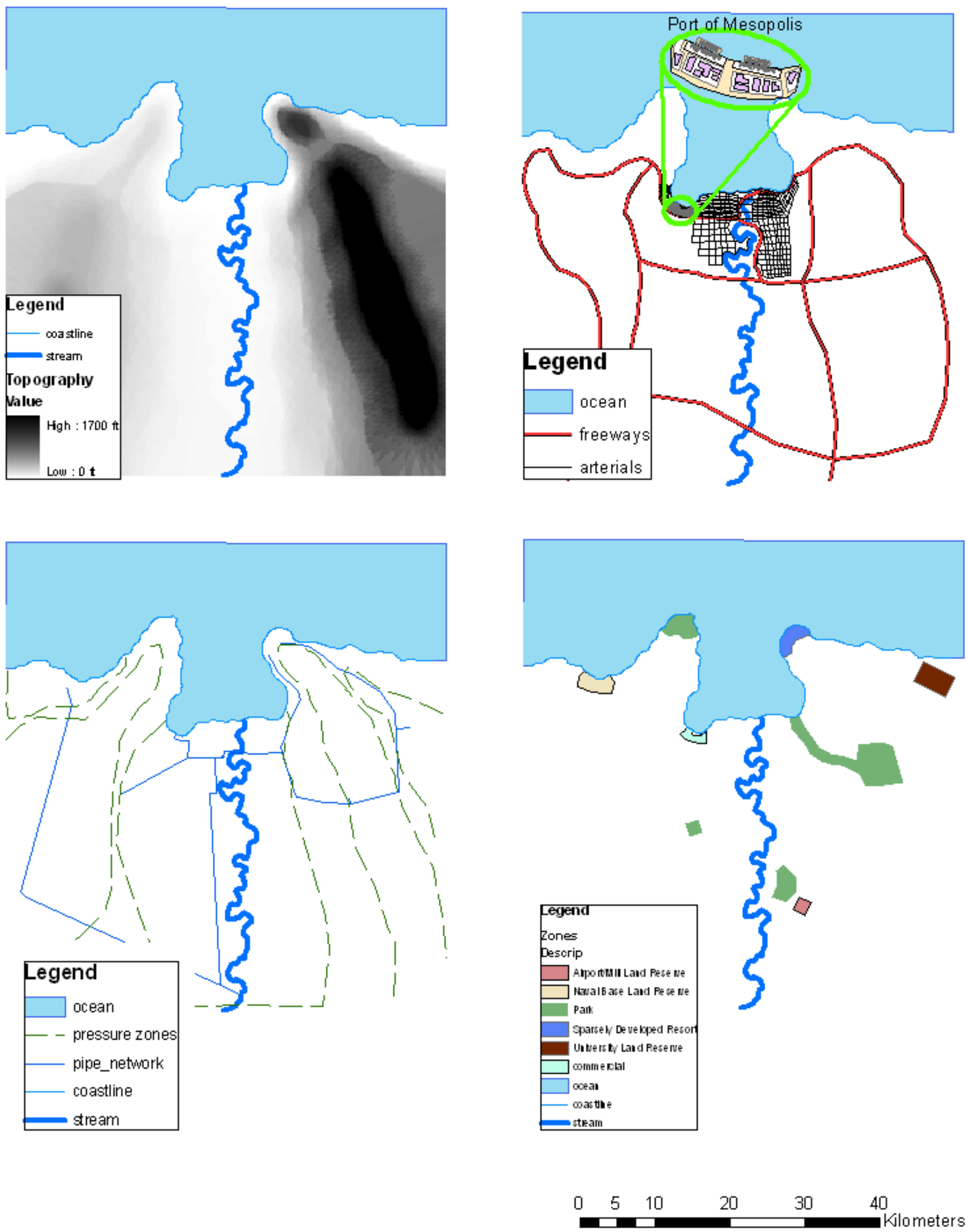


Figure 4. Preliminary maps of the Mesopolis virtual city.

mapping is done at coarse resolution for the full city, and smaller areas will be selected for more detailed mapping of important infrastructures. At present, work is underway to physical geography, land use, transportation, water, and electrical systems. Other important urban features can be added later.

## Conclusion

The virtual city concept is an attempt to produce publicly available digital datasets for infrastructure research. This paper is intended as a starting point for discussion on the utility of this concept and to invite others to undertake similar efforts. A library of virtual cities of varying characteristics could be a valuable experimental resource.

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