Modern Methods to Solve an Age-Old Problem Using Modeling & GIS to Improve Fire Suppression

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The history of organized fire fighting dates back to the ancient Romans, who introduced the first public water supply system and organized "Vigiles" (watchmen of the city) to combat fires using methods such as bucket brigades. Since that time, the planning and design of water systems for fire suppression have evolved significantly to limit loss of life and property. While advanced fire suppression systems in buildings and brave firefighters are responsible for directly combating today's fires, water system utilities must have the necessary water main and hydrant infrastructure in place to deliver adequate fire flows throughout their systems.

Determining if a water distribution system can provide adequate fire flow throughout a service area can require significant data collection and thousands of hydraulic calculations to account for the numerous possible fire-flow scenarios that could occur. Performing this type of analysis may seem like a daunting endeavor, but there are modern computer software and analysis tools that can be leveraged to make this a very manageable effort.

This article discusses how current hydraulic modeling and GIS technologies can be used to help utilities effectively and efficiently evaluate the fire suppression capabilities of their water systems. A case study that illustrates how a Florida water utility recently utilized these technologies to analyze and improve its fire suppression capabilities is also provided.

Overview of Fire Suppression Planning for Water Utilities

Fire suppression planning for a water utility should include the following steps:

- Define fire suppression requirements and goals.
- Evaluate water distribution system infrastructure and operations to determine any current or projected future fire-flow delivery issues.
- Evaluate system improvement options to address fire-flow delivery issues.
- Develop recommended system improvements and/or operational modifications.

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Continued on page 6

Continued from page 4

Defining Fire Suppression Requirements & Goals

The first step in fire suppression planning for a water distribution system is to define the fire suppression requirements and goals for the service area. The fire suppression goals that are selected can have a significant impact on the water system infrastructure requirements and operating protocol for the system. Defining these goals should be a collaborative effort between the water utility department and the fire department. City managers and key staff from other municipal departments such as land-use planning and building and development should also be included.

It is common for a municipality to develop a fire prevention and protection code by adopting guidelines from water industry reference manuals such as AWWA Manuals M31 (Distribution System Requirements for Fire Protection) and M32 (Computer Modeling of Water Distribution Systems). These manuals reference information published by the Insurance Services Office (ISO), which is an advisory organization that provides guidelines for property and casualty insurance companies to rate a community's local fire protection capabilities.

Examples of the type of distribution system requirements for fire suppression that should be defined include:

- ***Minimum fire-flow delivery requirements***—The flow rate required for fire suppression in an area will vary significantly based on the type of structure being served. A single-family residential property will have a significantly lower fire-flow requirement than a high-rise condominium building or commercial building. For example, the fire flow needed for a residential area may be 750 gallons per minute (gpm) for a duration of two hours, whereas the fire flow required for a high-rise building may be 3,500 gpm for a three-hour duration.
- ***Minimum system pressures to be maintained during a fire flow event***—A typical requirement for fire suppression planning is to be able to maintain a minimum of 20 psi pressure throughout the distribution system while operating under maximum day demand conditions and also meeting the demand requirements of a fire-flow event anywhere in the system where fire service is provided by the utility.
- ***Fire hydrant spacing***—The number of fire hydrants that must be located within a specified distance from a structure should be defined. The number of hydrants required and the proximity of the hydrants to the structure can vary depending on the type of structure served. For example, a low-density residential area may require only a single hydrant to be located within 500 feet of each property, while a high-rise condominium or a commercial property may require multiple hydrants to be located within specified distances from the property. Also, a hydrant that is located closer to a property may be given more fire-flow credit than a hydrant located further from a property.
- ***Minimum water storage capacity maintained for fire flow events***—The amount of storage capacity that should be reserved for fire protection typically is defined by multiplying the maximum fire flow needed in the system by a specified maximum duration. For example, a municipality may have a maximum fire flow of 3,500 gpm for a duration of three hours, resulting in a total fire-flow volume requirement of 630,000 gallons. The average daily minimum water storage capacity for the system should be greater than the calculated maximum fire-flow volume requirement.

Evaluating System Infrastructure & Operations

The water distribution system infrastructure must be sized adequately to accommodate the potable water supply needs (including fire protection) for the customers throughout the service area. The system must have the capacity to accommodate a sudden high fire-flow water demand anywhere in the service area where fire service is provided.

Simply over-sizing system infrastructure (storage tanks, pumping stations, pipelines, and fire hydrants) to plan conservatively for meeting the defined fire-flow requirements is not a cost-effective solution and could also result in water quality/water age issues created by extended detention times in over-sized storage and piping infrastructure. A detailed evaluation and analysis is required to make appropriate plans for water system infrastructure improvements that will allow the water utility to meet current and projected future system demand conditions.

The following section provides a description of how water utilities can leverage the data storage and analysis capabilities of modern GIS and hydraulic modeling software to make this seemingly arduous task manageable.

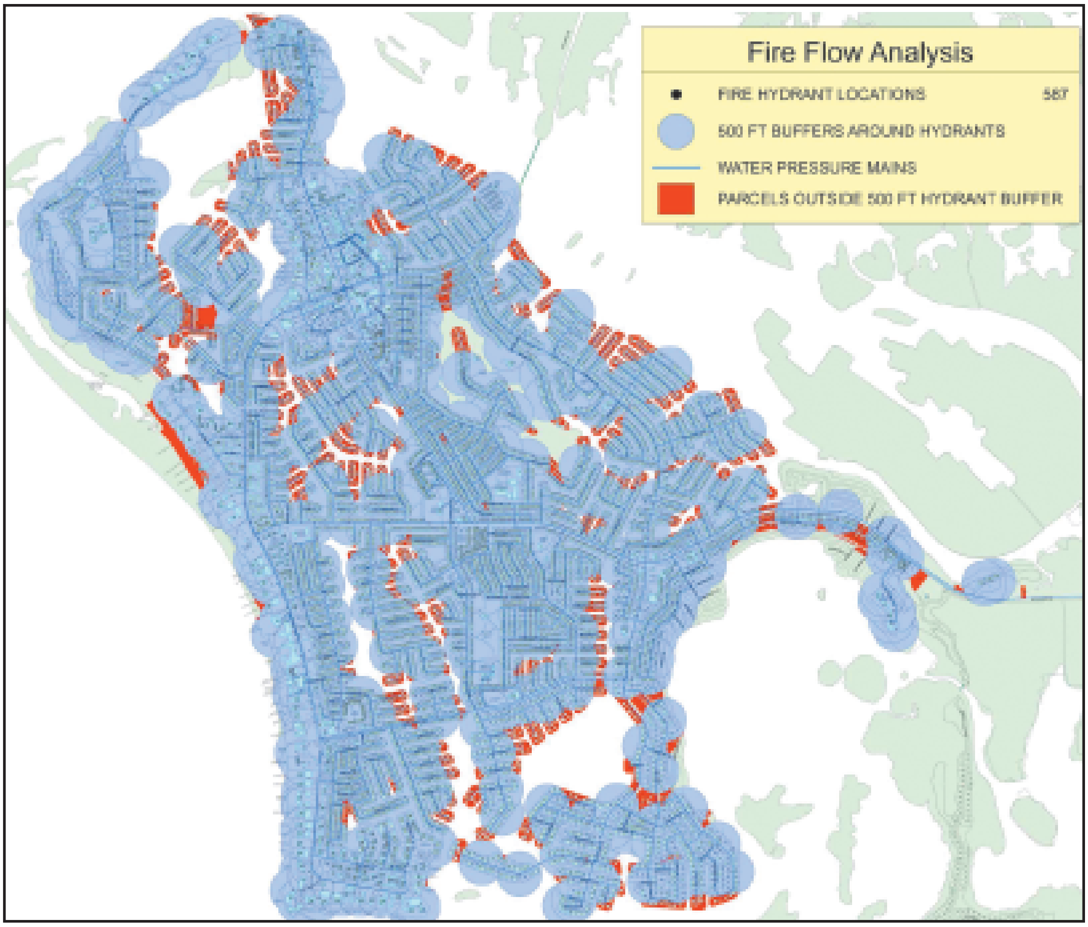

Figure 1 – GIS Created Map Illustrating 500-Foot Radius Buffer around Hydrants

Using GIS for a Hydrant Spacing Analysis

A geographic information system (GIS) is any system that captures, stores, analyzes, manages, and presents data that are linked to a location. Today it is common for municipalities and water utilities to use GIS software as a system mapping and data management tool.

There are many ways that GIS can be leveraged to support fire suppression planning. The spatial data storage provided by GIS is one key benefit. Data that a utility may already have in its GIS database include a detailed mapping of the water distribution system network (pipeline layout, lengths, diameter, material, etc), fire hydrant locations, information on the type of property/structure on each parcel, and future land-use information. Having this information in the database provides a great starting point for evaluating a water system's fire suppression capabilities.

In addition to being a great source for the data required for fire suppression planning, the spatial mapping and analysis capabilities of GIS can be used to plan efficiently and effectively for fire hydrant improvements. If the GIS database includes a mapping of the distribution system, fire hydrant locations, and property tax parcel information, a user can run interactive queries to identify any properties that are not located within a specified maximum distance from the closest fire hydrant. GIS software can also generate useful maps that clearly illustrate hydrant spacing deficiencies and proposed improvements.

Once a plan is developed to ensure that there is adequate fire hydrant coverage throughout the system, an analysis should be completed to verify that adequate fire flows can be delivered to the hydrants throughout the system.

Using Hydraulic Modeling Software for a Fire Flow Analysis

Fire flow analysis is a common feature built into modern hydraulic modeling software programs. An automated fire flow analysis tool will perform a series of independent steady-state model runs that simulate an additional water demand applied to locations that are specified to have a fire-flow demand.

Each independent steady-state model run analyzes a fire-flow demand occurring at only one location at a time. The model will check for resulting residual pressure at the location where the fire flow is occurring, as well as minimum pressures maintained throughout the rest of the system during the fire-flow run.

The model can generate output in tables or figures that clearly indicate any areas that may have a fire-flow deficiency based on the parameters that the user sets for the analysis. A single push of a button can prompt the modeling software to begin analyzing hundreds of independent steady-state fire-flow runs at a time.

Depending on the modeling software that is used, the exact steps and terminology used for performing a fire-flow analysis may differ somewhat, but here is a general procedure for performing a fire-flow analysis with a hydraulic modeling software:

- Develop typical current and projected future maximum-day demand scenarios in the model.
- Define which locations (nodes in the model) require a fire-flow demand.
- Specify values for the fire flow needed and minimum residual pressure requirements.
- Run a fire-flow analysis based on the specified fire-flow requirements with the maximum day-demand scenario. Analyze current and projected future system conditions.

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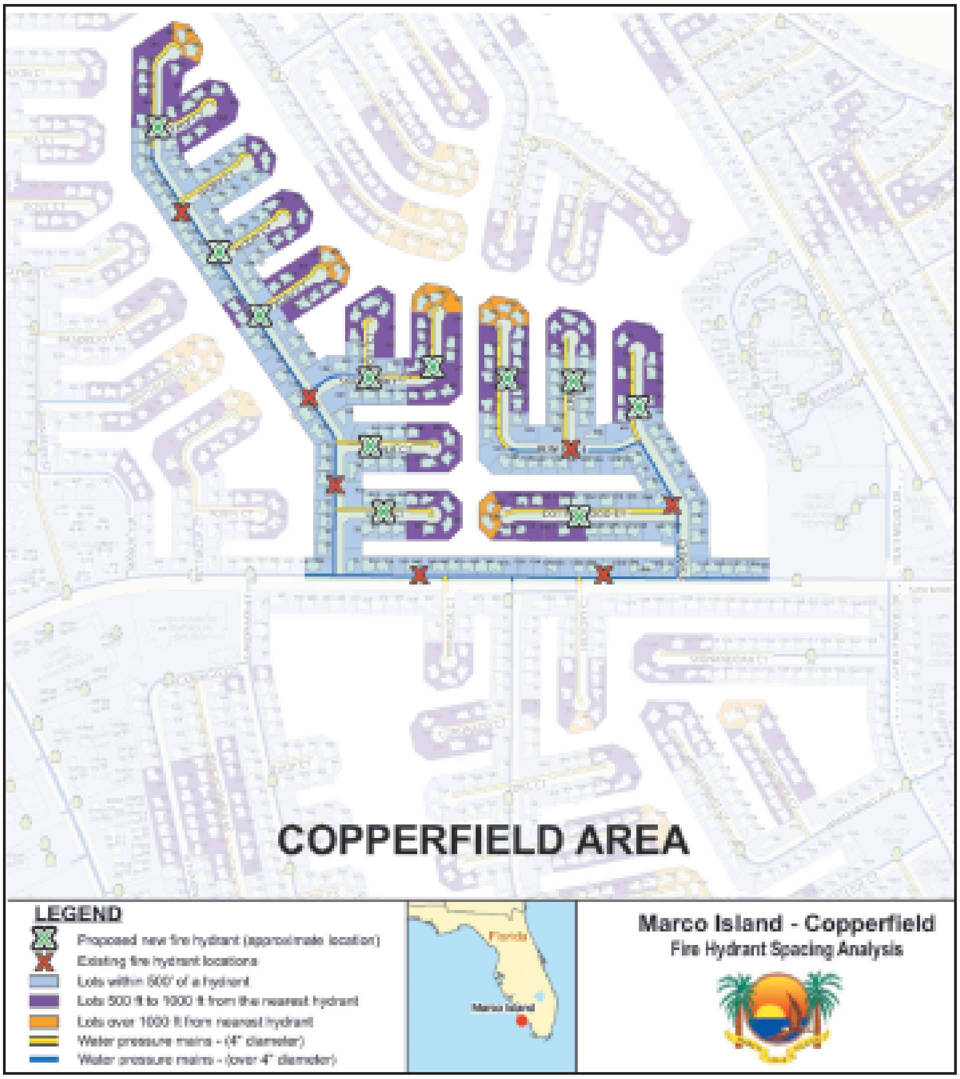

Figure 2 – Recommended Fire Hydrant Improvements in the Copperfield Area

Continued from page 7

- View results in a tabular format or as figures generated with the modeling software.
- Identify any areas with fire-flow deficiencies.
- Simulate potential improvement options in the model to determine appropriate recommendations for improvements.

Each water utility system is unique and may have its own fire-flow delivery goals and issues. The remainder of this article describes how one Florida water utility was able to utilize some of the strategies and tools described previously to perform a successful comprehensive evaluation of the fire suppression capabilities of their system.

Case Study: City of Marco Island

The city of Marco Island owns and operates a water supply and distribution system that provides a reliable supply of potable water to the residents on the island. The system is made up of over 500 miles of four-inch through 36-inch diameter piping and delivers an average potable water supply of approximately 8 million gallons per day. In conjunction with the fire department, the utilities department provides fire protection services to the properties throughout the island, which include single-family residential properties, multi-family buildings, commercial properties, and high-rise condominiums and hotels.

The city recently completed a comprehensive fire-flow and fire hydrant spacing analysis for its water distribution system, using GIS and hydraulic modeling software extensively. Following is a summary of the analyses performed and some graphics that illustrate the results.

Verifying Fire Suppression Requirements & Goals

Fire-flow requirements and goals were based on the “Fire Prevention and Protection Code” of the Marco Island City Code, which references ISO Rating Schedules and AWWA Manuals M31 and M32. Per the city’s code, one- and two-family residential properties have a fire-flow requirement of 750 gpm. In commercial and multi-family areas not more than two stories high, the fire-flow requirement is 1,500 gpm. The fire-flow requirement for all other buildings is 3,500 gpm.

Hydrant spacing requirements were defined as follows: One- and two-family residential properties shall have at least one hydrant located within 500 feet of the property; commercial, multi-family areas and high rise properties shall have at least one hydrant within 300 feet of the property and a sufficient number of hydrants available within 1,000 feet of the property to deliver the required fire-flow amount.

Using GIS for the Fire Hydrant Spacing Analysis

The city’s existing GIS database included a detailed mapping of the water distribution system, fire hydrant locations, and parcel data. The GIS database was used extensively to complete the fire hydrant spacing analysis. Here is a description of how the city’s GIS was leveraged to efficiently and effectively perform the fire hydrant spacing analysis:

- First, an attempt was made to analyze the hydrant spacing adequacy by creating a 500-foot radius buffer around each of the fire hydrants. Figure 1 is a map that was created to illustrate hydrant coverage based on applying the 500-foot radius buffer around each hydrant. While this map provided some useful information, simply applying a 500-foot radius buffer did not consider the “accessibility” of the hydrant to a property. For example, if there is a feature (such as a waterway) located between a hydrant and a property that would prevent the fire department from being able to use the hydrant to combat a fire at that property, it should not be given credit for providing fire protection to that property.
- In order to address the issues associated with using a general 500-foot radius buffer, the analysis performed with the GIS software was revised as follows.A network dataset (named “Water”) was created in ArcCatalog using the city’s water main feature class, and the analysis run through the GIS software was directed to follow the water mains and not transverse waterways.
- Next, a map was created in ArcMap and the “Water” network dataset was added, as well as the property parcel polygon layer and a hydrant point layer. With these two layers in the map, a hydrant “Service Area Analysis Layer” was created using ESRI’s Network Analyst Toolbar. The properties of the newly created “Service Area” from the Net-

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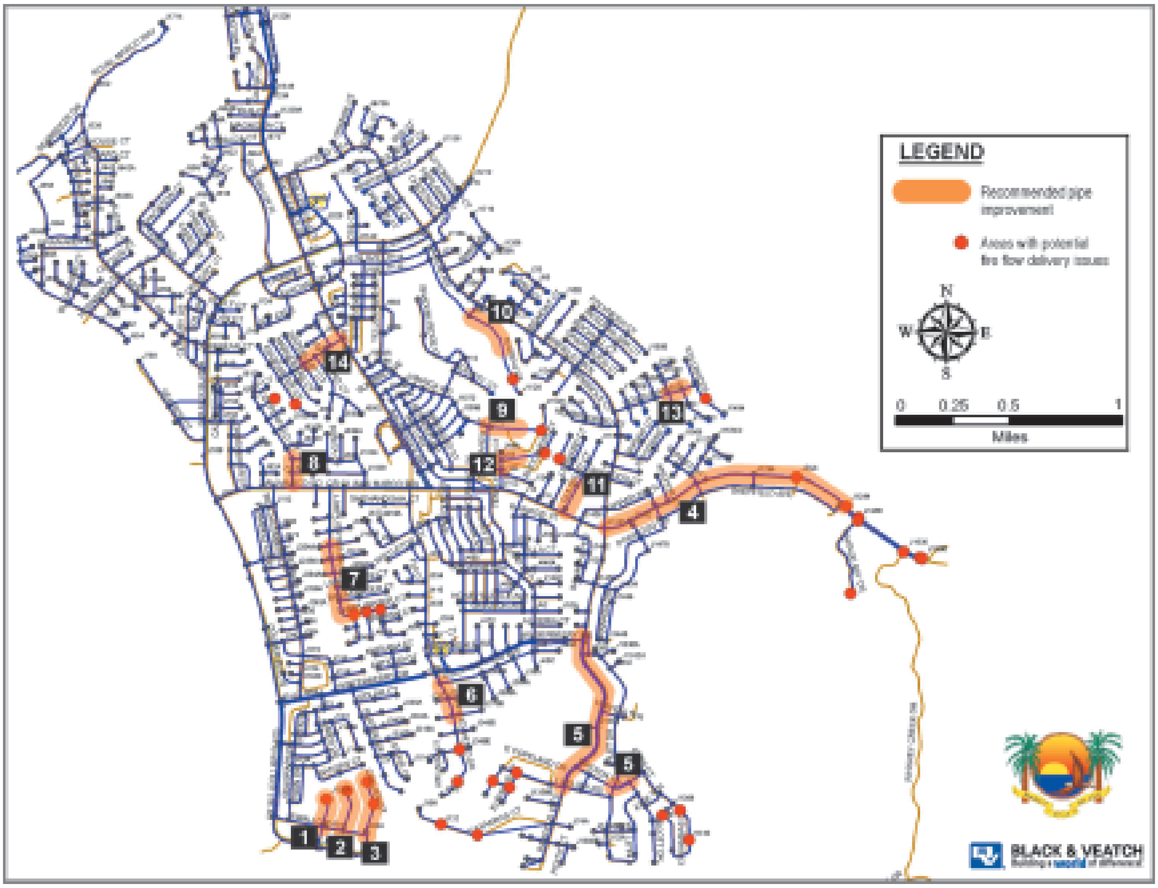

Figure 3 – Location of Proposed Pipe Improvements to Address Areas with Potential Fire-Flow Delivery Issues

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work Analyst Toolbar were set as follows: Length was in feet; defaults breaks were 500 feet from a hydrant.

- Once the settings were input, the "Solve" icon from the same toolbar was selected. The Network Analyzer then created polygons which followed the water mains 500 feet from each hydrant point.
- Using the "Location Selection" tool in ArcMap, all the parcel layer polygons which intersected with the newly created network polygons were selected. This resulted in selecting those parcels which met the 500-foot limit but were not selected because they did not intersect with the network polygons. The selected parcels were extracted and a separate parcel feature class was created and then added to the map.
- From the original parcel layer, the parcels that did not intersect with the newly created 500-foot limit parcel layer were selected. This selection contained all the parcels which were outside the 500-foot distance from each hydrant.
- Similar analyses were run to evaluate other relevant hydrant distances (300 feet and 1,000 feet), and maps were created using GIS software that clearly highlighted the areas that did not meet the city's fire hydrant spacing goals.
- These maps were used to develop recommended hydrant improvements for the areas where hydrant spacing issues were identified. Figure 2 illustrates the proposed fire hydrant improvements identified for one area of the city. In the figure, you will notice that properties that did not have an accessible fire hydrant located within 500 feet were highlighted in one color, and another color was used to identify the properties that did not have an accessible hydrant located within 1,000 feet. This information helped the city prioritize the fire hydrant improvements recommended throughout the system.

Using a Hydraulic Model for the Fire Flow Analysis

The city maintains a hydraulic model of its water system that recently was updated and calibrated. The updated model included maximum-day demand scenarios for existing conditions as well as projected future conditions.

Fire-flow values consistent with the city's fire-flow goals and minimum residual pressure requirements were entered into the model for the fire-flow analysis runs. The model was run for existing conditions as well as projected future conditions.

The model predicted that adequate fire flows could be provided to most locations throughout the system through the future projected conditions, although some potential fire-flow deficiencies were identified.

The city's hydraulic model then was used to evaluate potential improvement options to address the predicted fire-flow delivery issues. Figure 3 illustrates the locations where fire-flow delivery issues were identified and the improvements that were recommended to address the issues.

The city has added the identified improvements to its capital improvement program. Implementing the proposed improvements identified through the hydrant spacing and fire-flow analysis will give the city confidence that they can continue providing a reliable supply of potable water to the residents of Marco Island.

Summary & Conclusions

This article has presented an overview of modern techniques and tools that water utilities can use to analyze the fire suppression capabilities of their distribution systems. GIS and hydraulic modeling software have proven to be very valuable tools for completing this type of analysis, as illustrated by the case study involving the city of Marco Island's recent system evaluation.

Fire suppression planning is just one of the numerous types of analyses for which GIS and hydraulic modeling software can be used. Utilities, engineering firms, and software developers continue to find more ways to leverage these tools to perform system analyses more effectively and efficiently.