Hydraulic Modeling for Esri© ArcGIS Users

A Bentley Technical White Paper

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Introduction

Water and wastewater networks are inherently geospatial, comprising interconnected assets that are often underground, buried beneath urban and rural communities. To effectively manage these assets, a utility must know what they are, where they are located, and how they are connected both physically and functionally. To optimize these assets for its customers, a utility must also know how their water and wastewater networks operate in various conditions.

Two systems are at the core of serving these related needs. A geographic information system (GIS), such as Esri's ArcGIS, manages all types of geospatial business data, including land use and parcel information, as well as the locations and basic characteristics of water and wastewater network assets. A hydraulic modeling system (HMS), such as WaterGEMS or SewerGEMS, provides additional hydraulic characteristics for the network elements and offers engineering insight into the complex behavior that defines how that network performs.

These two complementary technologies offer analytical solutions for planning, design, and operational intelligence for water and wastewater utilities. The intention of this paper is to demonstrate how modelers of water and wastewater systems and GIS professionals can leverage enterprise Esri geospatial data repositories and ArcGIS technology in an immersive single modeling application. This integration ensures that utilities attain the most value from their investment in GIS technology and related geospatial business data through their hydraulic modeling analytical capabilities.
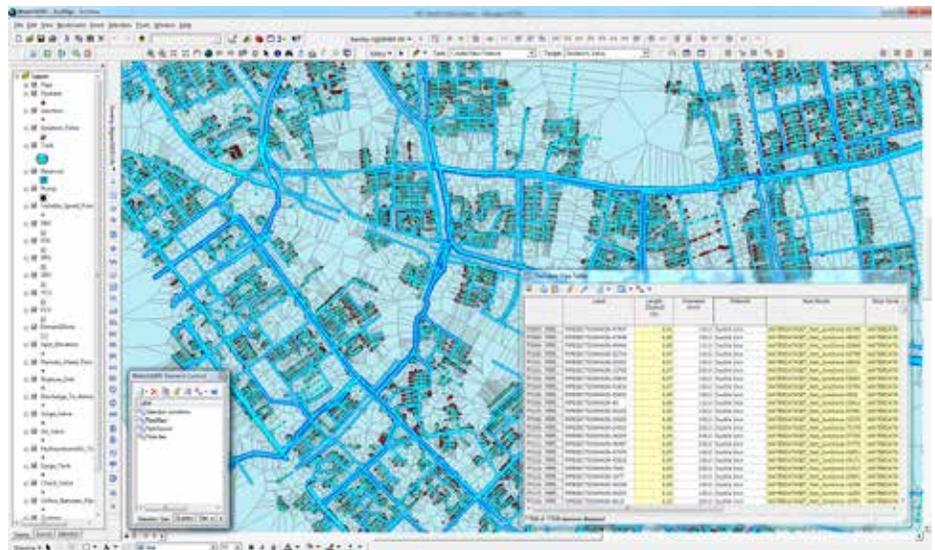
WaterGEMS users can take advantage of ArcGIS and the hydraulic modeling environment in a single application.

Water and wastewater modeling applications can seamlessly provide advanced hydraulic modeling capabilities through the ArcGIS platform that is familiar to Esri users. The applications can take advantage of any geospatial data managed in Esri's geodatabases and shapefile formats. This capability enables the hydraulic modeling and GIS communities to simultaneously build and update network models using data from Esri geodatabases and geometric networks as well as manage hydraulic network

model data in an Esri geodatabase. Additionally, these users can modify network and geospatial data using ArcGIS tools, the full power of ArcGIS for spatial analysis, and the analytical capabilities of water and wastewater modeling applications, such as WaterGEMS and SewerGEMS, to simulate network models directly within the ArcGIS platform.

Geographic Information Systems

GIS evolved from a modest beginning, in which it provided a digital map of network assets. This is a key service in delivering enterprise spatial data and advanced capabilities that allow a water or wastewater utility to better manage, operate, and maintain critical infrastructure. GIS technology, such as ArcGIS, supports geospatial data management, visualization, query, analysis, and reporting capabilities in a spatial context.

The GIS team in a water utility is typically responsible for keeping the network and its supporting geospatial data up to date and for providing efficient access to the rest of the organization. One of the most demanding groups in need of this data is the hydraulic modeling team. In fact, GIS has evolved in tandem with hydraulic modeling to become an essential capability for the water and wastewater modeling communities as a source of modeling data for spatial analysis and decision support.

Hydraulic Modeling

Hydraulic modeling involves the simulation and analysis of water, wastewater, and stormwater network systems. It uses mathematical models to solve specific design, planning, and operational problems related to capacity, flow, pressure, water quality, energy, and other considerations that go beyond the physical characteristics and the geospatial data that GIS technology manages.

The hydraulic modeling team in a water utility or consulting firm comprises specialists in hydraulic or environmental engineering who have extensive knowledge of and experience in modeling for a wide variety of applications. These applications include master planning, pump scheduling, water quality analysis, emergency response, and others. The hydraulic modeling community requires extensive continuous education and training in the applied field of hydraulic engineering and design as well as experience with commercial hydrodynamic modeling products.

GIS technology and geospatial data play a significant role in any successful hydraulic modeling effort, supplying planners and operators with more reliable geospatial inputs into these modeling processes, so hydraulic modelers have unavoidably become GIS "savvy."

Manila Water Company wanted a comprehensive, holistic, and integrated master plan for water and wastewater that facilitated capital investment and helped them meet business and regulatory commitments for Boracay Island, a popular tourist destination. Water coverage for the island was 60 percent and water supply was available 95 percent of the time. The company wanted to increase these metrics to 100 percent while preserving natural resources. Manila Water needed to review current network capacity and growth of development, augment and expand the system to support future

development, and schedule capital investments. Planners aggregated massive and diverse data sources (including GIS files), visually analyzed the likely development on the island, and determined the best strategy to supply water to the island while minimizing environmental impacts. The planning team created a master plan that ensured prudent, cost-effective, and timely delivery of capital investments that will meet the island's current and future needs for water and wastewater management. Because the GIS data was compatible with WaterGEMS and SewerGEMS, it was easy to plot survey information as it became available and to see the actual site in comparison to initial plan assumptions.

Early modeling analysis systems used stand-alone or CAD data sources to build network hydraulic models. Working with a GIS application allowed the modeling community to visualize and interpret network elements and model results through a map-based interface rather than through a simplified schematic. The priority for the GIS community was knowing the type and location of the infrastructure, whereas the models were more concerned with network connectivity, operational settings, controls, and flow conditions. However, as GIS technology advanced, hydraulic modeling applications became further integrated, enabling network assets to be geo-referenced and spatial relationships with other geospatial data, such as soil, transportation, land-use, and parcel maps, to be developed.

Planners, engineers, and technicians have access to more reliable, concurrent, and accurate information and the integration of GIS with hydraulic modeling enables water utilities to maximize the value of their investments in both systems. This translates to tangible and measurable value to the business when evaluating capacity and supply deficiencies, avoiding sanitary and combined overflows, detecting and locating leaks, optimizing energy utilization, and lowering electricity costs, among other improvements. The integration has also fostered closer working relationships between the hydraulic modeling and GIS communities, each gaining a better understanding of the requirements of the other.

Additional benefits are also realized. For example, geospatially referenced network asset data is customarily used in the planning and operation stages of the water and wastewater infrastructure lifecycle. When an asset is rehabilitated or replaced, or when new pipes in a recently developed area extend the existing network, the geospatial database is updated. This provides an "as-operated" state of the network that benefits other enterprise business applications, such as hydraulic modeling systems. When an analysis is performed to determine how to optimize pump operations in that new area, the hydraulic model is synchronized to the geospatial database allowing simulated results to reflect what would occur in the network. Interoperability between geospatial and water and wastewater modeling applications is an important consideration for improving and sustaining water infrastructure.

In a USD 400 million project for the National Water Supply and Drainage Board (NWSDB) in Colombo, Sri Lanka, Ceywater Consultants joined Nihon Suido Consultants Co. and NJS Consultants Co. to introduce district metered area (DMA) sectorization into the existing water distribution network. The project team modeled and analyzed network hydraulics and identified opportunities to reduce non-revenue water (NRW) to 18 percent from the prevailing rate of 40 to 50 percent. Ceywater's team used

Calibrating the water system using WaterGEMS helped Manila Water Company identify water losses, reducing NRW from 29 percent in 2010 to 17 percent in 2014.

WaterGEMS in conjunction with the NWSDB's GIS to model the existing network, identify optimal zones for the DMAs, and pinpoint suitable locations for the new valves. GIS integration with WaterGEMS allowed hydraulic modeling specialists and GIS professionals to work on models simultaneously, saving considerable time and reducing errors.

Outcome demand allocation among the DMAs was based on prevailing water consumption rates. Low pressure zones prone to water intrusion were recommended for pipe replacement or rehabilitation. The reduction of NRW will eventually improve the NWSDB's revenue, reduce the waste of potable water, and conserve Sri Lanka's valued water resources. Seamless information mobility and interoperability permitted modelers to extract data from AutoCAD drawings to WaterGEMS and, similarly, from ArcGIS to WaterGEMS. The integration of WaterGEMS and GIS also enabled the use of existing satellite images and other GIS data for modeling purposes, minimizing the need for costly and time-consuming manual site surveys.
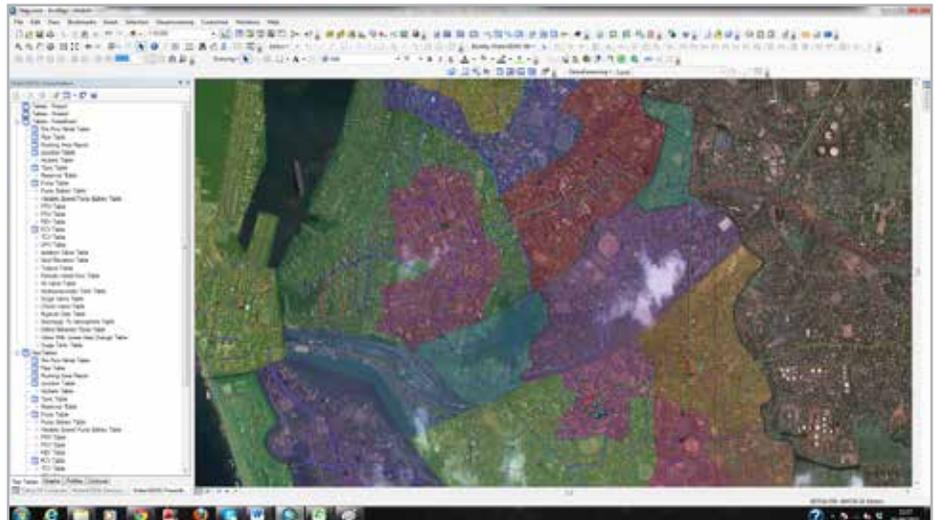
Ceywater Consultants Pvt. Ltd., Non-revenue Water Reduction Project for Colombo Municipal Area, Colombo, Western Province, Sri Lanka

Value through Data Interoperability

The Need for Model Management

Hydraulic modeling requires accurate and up-to-date information to represent existing network condition and status, but constructing and maintaining a hydraulic model over time can be time consuming, costly, and error-prone. Network data held in the geospatial database is maintained on an ongoing basis, making frequent updates to reflect the "as-operated" state of the system.

Before the integration with GIS technology, the process of building, calibrating, and maintaining the model was a specialized task, carried out independent of the utility's routine business procedures and workflows. Gathering, combining, and digitizing data from a wide variety of sources was a manual process that often resulted in

inefficiencies and inaccuracies. In response, hydraulic modeling software vendors have developed capabilities that enable the modeling community to construct and maintain network models more efficiently and accurately from an increasing volume, variety, and velocity of sources so that utilities can build and maintain precise models efficaciously.

GIS for Model Management

A GIS that supports a hydraulic model requires a high level of data quality, accuracy, and detail. This involves developing a network data model, schema, and meta-model in the GIS that supports hydraulic model creation and updates, including all physical assets to be modeled, the attribution required by the modeling system, and, most critically, network connectivity.

For general mapping purposes, pipe ends only need to visually appear close together, but not necessarily be topologically connected in the GIS. This isn't sufficient for hydraulic modeling systems, though, as accurate connection information is crucial in recognizing how water will or will not flow between pipes. Modeling systems, therefore, provide capabilities that look for topological errors in the GIS database and assist in manually or automatically fixing these errors. This is a prime example of how the hydraulic modeling community can increase the value of the geospatial data through validation, improvements in accuracy, and additional information.

In the past, a network model was typically built as a "snapshot" of the geospatial database and only updated intermittently. Now, models can be updated more frequently because GIS and hydraulic modeling teams can leverage the most appropriate capability from either the GIS or the hydraulic model. Current advantages to be gained include:

- GIS manages large volumes and increases velocity of updates to the network.

- GIS capabilities automate the model building process, making it faster and more efficient.

- Hydraulic modeling systems incorporate specialized geospatial and network editing and data clean up capabilities.

- Elevation information from geospatial sources can be used to assign elevations to network elements, such as manhole covers and customers.

- Digital ortho-photographs and other geospatial data (e.g. soil, land-use, land parcels) provide background geospatial reference and context.

- Georeferenced customer billing records are used to generate and allocate water demands and sewer loadings through the capabilities of LoadBuilder provided with Bentley's hydraulic modeling application.

With the GIS community maintaining an appropriately constructed geospatial database of network elements, the hydraulic modelers can spend more time running simulations and carrying out engineering analyses to evaluate the performance of their water and wastewater systems. This allows for consideration of more options for capital and operational expenditure, which results in better and more expedited recommendations and decisions.

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Integrity through Synchronization

There are significant risks involved if a hydraulic model uses enterprise GIS data directly, and at times hydraulic modelers will intentionally need to simulate adjustments to GIS data. This is often done as part of model validation and calibration, where changes to physical and topological issues are tested as part of finding and fixing GIS errors that would otherwise go undetected.

By using a synchronized copy of GIS data, a hydraulic modeler can test an unlimited number of changes to any type of attribute, without fear of inadvertently impacting other enterprise users and systems. When the modeler is confident that a simulated change should be made in the source data, that change can be carefully and intentionally synchronized into the GIS.

Esri ArcGIS Integration with Bentley WaterGEMS and SewerGEMS

The principal data source provided by Esri GIS professionals to the hydraulic modeling community are from shapefiles and geodatabase exchange. Each shapefile represents a single feature class and uses a simple storage model for feature coordinates. Geodatabases come in many sizes, have varying numbers of users, and can scale from small, single-user databases built on files up to larger workgroup, department, and enterprise geodatabases accessed by many users.

WaterGEMS and SewerGEMS, Bentley's premier modeling software applications, can employ a wide range and combination of data sources, including ArcGIS geodatabases and other geospatial data, CAD data, and even unstructured data, such as spreadsheets and XML files.

Bentley's commitment to support relevant interoperable technologies is best illustrated in the integration of Esri and Autodesk technology within these hydraulic and hydrology applications. Bentley has continuously supported integration with Esri ArcGIS technology since 2007, and integration with AutoCAD dates back even further. Bentley continues to use the latest versions of AutoCAD and ArcGIS in its WaterGEMS and SewerGEMS applications as a key strategy for serving the needs of water and wastewater utilities.

To best leverage enterprise GIS data while maintaining data integrity as described previously, Bentley uses a synchronization process to separate modeling data from GIS source data, using a built-in capability called ModelBuilder. This architecture not only allows for better data management flexibility, it also allows for platform and interface flexibility, which will be discussed later in this document.

Multi-Platform Modeling Architecture
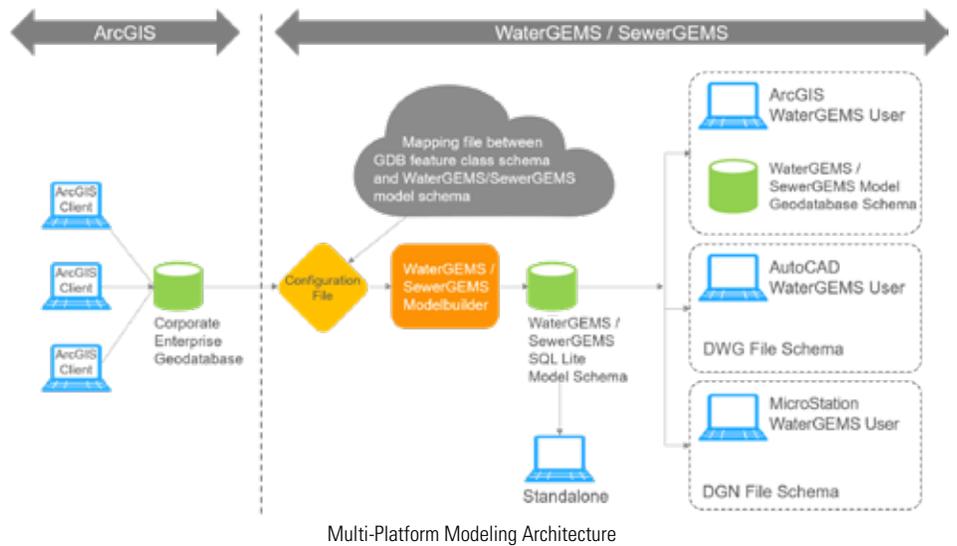
WaterGEMS and SewerGEMS ModelBuilder

Creating hydraulic network models from GIS data sources such as Esri Geodatabases and Geometric Networks requires the import of:

• Geometry (i.e. lines, edges, nodes, polygons) and geographic coordinates representing the shape and location of each network element.

• Network topology providing flow direction and network connectivity.

• Selective attributes that describe the type (e.g. pipe, hydrant, manhole, valve, pump etc.), sub-type (e.g. valve sub-type PRV, PSV, FCV, TCV, PBV), and physical characteristics of the network element.

This is achieved using extract, transform, and load (ETL) procedures from common spatial data stores (such as geodatabases), supporting highly configurable and repeatable workflows managed in ModelBuilder. ModelBuilder supports all major Esri ArcGIS geodatabase functionality, including geodatabase feature datasets, feature classes, tables, geometric networks, and subtypes.
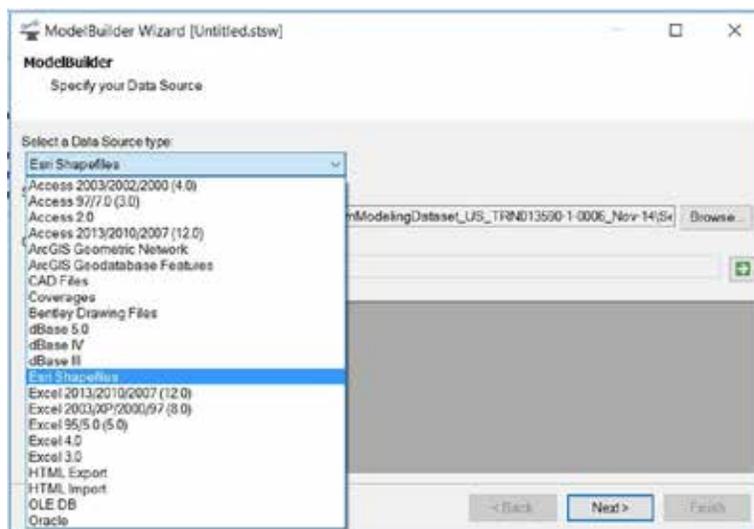
ModelBuilder supports a wide variety of formats.

After extraction from the enterprise geodatabase, data is transformed to comply with the geodatabase data structure and schema of WaterGEMS and SewerGEMS, which is configured and optimized for hydraulic modeling purposes. As a result, efficient interchange of network data occurs, making the process configurable, automatic, reliable, and repeatable. This guarantees accurate and representative synchronization between the corporate GIS and the hydraulic model.

Appropriate Complications and Solutions

Complications can arise in the ETL process that involve translating between the differences in terminology and attribute schema used for describing the network element types, sub-types, measurements, and units of measurement, as well as their physical characteristics and geographic projection coordinate system. Examples of these are shown below.

Network Element Types and Sub-types	Domain/ Sub-class Properties	Units of Measurement	Measurement Conversion	Projection Conversion
GIS network element types and sub-types defined differently to hydraulic model, e.g. Pump sub-types PRV, PSV etc.	Network element physical characteristics, like pipe material, may be coded differently in the GIS and HMS, e.g. PVC and Poly Vinyl Chloride, CONC and Concrete	Depths and sizes represented in the GIS and HMS may be in different measurement systems (i.e. imperial/metric) or in the same but in different units (i.e. feet/inches, meters/centimeters) both of which require conversion during exchange	GIS asset register can store attribution of depth to pipe inverts in meters/ centimeters or feet/ inches that need to be converted to absolute elevations relative to a datum - achieved by subtracting the depth measurement from the manhole or ground level elevation calculated during loading	Hydraulic network model can inherit the projection coordinate system from the GIS data source

To accommodate these appropriate but impactful differences, ModelBuilder guides users through the process of, first, mapping feature classes in the Esri geodatabase feature dataset to the equivalent network model elements. Next, each set of attributes can be matched among the feature classes and their respective hydraulic model elements, including unit conversion and type coercion. It is also possible to extend the default data model schema of WaterGEMS/SewerGEMS to accommodate GIS attributes that, although unnecessary for hydraulic modeling purposes, provide useful ancillary information like installation year or location reference.

Each network element in WaterGEMS or SewerGEMS maintains associations to the source records in the enterprise GIS, with advanced logic for keeping the model and GIS source data synchronized. These mappings are even maintained if simplifications or other changes are made to the hydraulic model, such as skeletonizing a model to handle branch collapsing (trimming), series and parallel pipe merging capabilities, and so on.

Through this type of synchronization, any changes in the GIS, such as material type or invert level, can be easily updated in the model, and any elements deleted from the enterprise GIS can also be automatically deleted in the model. Additionally, changes to the geometry of a line or polygon element are automatically updated to ensure harmony between the two systems.

Technology Flexibility – GIS, CAD, or Both

A versatile, multi-platform environment liberates users from a specific platform, allowing modelers to share a single modeling dataset derived from any major CAD vendor or from ArcGIS. This means that modelers can use and open the same model file in any of the supported CAD or GIS applications. For Esri users, that means working in the ArcGIS ArcMap interface they are most familiar, and leveraging the existing geospatial capabilities built into ArcGIS.

As with all modeling applications that are developed and limited to an ArcGIS platform, the hydraulic modeler will require an additional ArcGIS license. This is also true for WaterGEMS and SewerGEMS, but Bentley Systems provides the flexibility to carry out hydraulic modeling projects using a GIS-agnostic platform using WaterGEMS or SewerGEMS through a "stand-alone" geospatial interface, or through alternative GIS/CAD platforms, such as MicroStation and AutoCAD. Uniquely, Bentley users can leverage a common modeling application and connected data environment shared across these platforms, with the same model, data, and functionality, regardless of platform.

About Bentley, WaterGEMS, and SewerGEMS

Bentley Systems is a global leader in providing engineers, architects, geospatial professionals, constructors, and owner-operators with comprehensive software solutions for advancing the design, construction, and operations of infrastructure. Bentley users leverage information mobility across disciplines and throughout the infrastructure lifecycle to deliver better-performing projects and assets. Bentley solutions encompass MicroStation applications for information modeling, ProjectWise collaboration services to deliver integrated projects, and AssetWise operations services to achieve intelligent infrastructure – complemented by worldwide professional services and comprehensive managed services.

Bentley's hydraulics and hydrology applications allow water resources professionals to work with an entire set of interoperable Bentley applications that access Esri ArcGIS data, Oracle Spatial, relational database management systems (RDBMS), and more. Bentley software's interoperability with users' existing technologies (including ArcGIS, AutoCAD, and MicroStation) extends the value of those technologies and training investments.

WaterGEMS is the leading hydraulic modeling software application used by water utilities and their consultants to plan, design, maintain, and operate raw water and potable water distribution systems. The application provides automated fire flow, water quality, criticality, and flushing studies as well as energy cost analysis, pipe renewal optimization, and genetic algorithm optimization modules for automating pipe design, calibration, water loss detection, and pump scheduling.

SewerGEMS is a comprehensive hydraulic modeling decision-support application for utilities and wastewater professionals to plan, design, maintain, and operate sanitary and combined sewer infrastructure. SewerGEMS is used to solve wastewater engineering problems from overflow remediation and water quality analysis to urban sewer planning and detailed network design. SewerGEMS enables engineers to detect

system bottlenecks easily, improve capacity, and limit sewer overflow, allowing utilities to comply with sewer regulations set by regulatory agencies and, therefore, minimize customer complaints.

In the WaterGEMS and SewerGEMS applications, the acronym "GEMS" stands for "Geographic Engineering Modeling System," emphasizing the integrated geospatial and CAD capabilities available to both the water and sewer modeling communities. Modelers around the world take advantage of the versatility of working across CAD and GIS interoperable MicroStation, ArcGIS, AutoCAD, and standalone platforms while accessing a single shared data source that allows them to build and collaborate across any combination of CAD drawings and GIS systems.

For more information about WaterGEMS and SewerGEMS, please visit www.bentley.com/haestad.