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Overview of WaterGEMS Software: Applications in Optimizing Water Distribution Systems and Addressing Water Scarcity

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ABSTRACT

Water, as an essential natural resource, plays a crucial role in sustaining life and supporting various human activities, such as industrial processes, household consumption, irrigation, power generation, navigation, and livestock watering. However, the global challenge of water scarcity presents significant obstacles. This study provides an overview of WaterGEMS software, an advanced tool for modeling and optimizing water distribution systems. WaterGEMS offers extensive capabilities for hydraulic analysis, network optimization, and asset management, utilizing genetic algorithms and real-time data integration via SCADA systems. This research highlights the software's application in various case studies, including network rehabilitation, leak detection, valve operation, pipeline flushing management, water quality analysis, network development, and real-time simulation. The study demonstrates WaterGEMS' effectiveness in optimizing pipe diameters, improving pump scheduling, and addressing water scarcity issues in urban and rural settings. Results indicate significant improvements in network performance, energy efficiency, and cost reduction, underscoring the software's potential in enhancing water distribution system resilience and sustainability.

Keywords: Bentley WaterGEMS; Water distribution network; Optimization; Pipeline Flushing Management

OVERVIEW OF WATERGEMS SOFTWARE

Water, as one of the most indispensable natural resources, plays a pivotal role in sustaining life and facilitating numerous human activities worldwide. From industrial processes to household consumption, irrigation, power generation, navigation, recreation, and livestock watering, water is fundamental to a multitude of human endeavors [1]. However, the global challenge of water scarcity presents a formidable obstacle to overcome. The water distribution network forms an integral component of the broader water supply distribution system, serving as the conduit for transporting water from service reservoirs to end-users. Comprising pipes, nodes, pumps (acting as either links or nodes), reservoirs, junctions, valves (often synonymous with pumps), and storage tanks, these systems represent complex infrastructural frameworks essential for ensuring reliable water delivery [2]. For water authorities worldwide, the foremost challenge lies not merely in the operational functionality of water distribution systems (WDS) but also in their establishment and ongoing maintenance [3]. These systems demand substantial investments from asset owners, with approximately 80% of the total expenditure allocated to water supply projects being directed towards WDS development [4]. This underscores the substantial financial commitment required to construct and sustain WDS infrastructure, particularly in planned urban environments. Water consumption patterns are subject to multifaceted influences, notably stemming from population expansion, urbanization trends, and climate variability. These factors collectively exert additional pressure on water systems, exacerbating the existing challenges associated with supply-demand imbalances [5]. The burgeoning population, coupled with limited water sources and the imperative to enhance living standards in urban areas, underscores the critical need for proactive measures in water management. Of paramount importance in addressing these challenges is the design and operation of water distribution systems tailored to withstand the projected demands over their operational lifetimes. The evolving landscape of population dynamics and urban development necessitates a forward-thinking approach to infrastructure planning and management. The intricate interplay between demographic shifts, environmental factors, and socio-economic drivers underscores the complexity inherent in ensuring water security and resilience in urban settings [6].

Furthermore, the disparity between water supply and demand underscores the urgency of implementing sustainable water management practices and infrastructure upgrades. As communities strive to meet the evolving needs of their inhabitants, strategies encompassing demand management, infrastructure optimization, and resource diversification emerge as indispensable tools in mitigating the impacts of water scarcity and enhancing the overall resilience of water systems [7]. By integrating innovative technologies, robust regulatory frameworks, and community engagement initiatives, stakeholders can work collaboratively to address the intricate challenges posed by escalating water demands and environmental stresses.

Therefore, the optimization of a water distribution network is directed towards determining the most efficient pipe diameters within the network, taking into account the specified layout and demand criteria.

WaterGEMS (developed by Bentley Systems, USA) is an advanced application for building hydraulic models of water distribution systems. WaterGEMS offers high interoperability with features for building geospatial models, optimizing design, and asset management. From analyzing fire flow and water quality to energy consumption and cost management, WaterGEMS provides an easy-to-use environment for engineers to analyze, design, and optimize water distribution systems [8]. The software leverages Bentley CONNECT services by linking a hydraulic model with a cloud-based CONNECT project. WaterGEMS incorporates state-of-the-art genetic algorithms for optimization, enabling users to automatically calibrate models, detect leaks, design, rehabilitate pipelines, and manage pump operations. The Darwin® Calibrator module within WaterGEMS helps users evaluate millions of potential solutions to quickly select the best calibration hypothesis that aligns with flow, pressure, and on/off states. This ensures users can make reliable decisions based on accurate real-world model simulations. Additionally, the Darwin Calibrator supports proactive leak detection by identifying potential leak locations within the network.

The SCADAConnect® module of WaterGEMS software facilitates the automatic acquisition of data from Supervisory Control and Data Acquisition (SCADA) systems, enabling real-time system simulation that accurately reflects current system conditions [9]. This module also allows users to publish model results to the existing SCADA control room display within the organization, aiding in forecasting operational conditions and potential issues. The Darwin Designer module autonomously identifies designs that maximize benefits or minimize costs and restoration strategies based on specified budgets, construction costs, and constraints on pressure and velocity.

OUTSTANDING FEATURES OF WATERGEMS

WaterGEMS assists in analyzing energy consumption to determine the most efficient pump scheduling strategies. Darwin Scheduler helps users optimize tasks for both fixed-speed and variable-speed pumps, as well as tank storage, to minimize energy usage or energy costs based on pressure, velocity, pump start constraints, and tank level constraints. Energy costs can be aggregated across pump stations and can account for complex rate tables and unplanned energy expenses, helping users analyze the true value of pump operation scenarios [10]. WaterGEMS can be utilized to address the following issues:

- Conducting extended period hydraulic analysis of water distribution systems, including components such as pumps, tanks, pipes, connectors, sewers, open channels, and valves.
- Performing extended period simulations to analyze the hydraulic system's response to varying supply and demand scenarios.
- Analyzing fire flow under extreme system conditions.
- Utilizing scenario management functions to compare different situations within the hydraulic system.
- Manually calibrating models using the Darwin Calibrator tool through genetic algorithms.
- Operating within other software applications such as MicroStation, AutoCAD, and ArcGIS, allowing for the application of geographic information systems (GIS) to address hydraulic network issues for water supply and drainage systems [11].

This comprehensive functionality ensures that WaterGEMS provides robust tools for the effective management and optimization of water distribution systems. The outstanding features of WaterGEMS include:

- Network Rehabilitation: The Darwin Designer algorithm assists engineers in deciding on balanced solutions for network rehabilitation, considering both constraints and investment costs.
- Leak Detection: The Darwin Calibrator tool, utilizing genetic algorithms, helps identify leak locations in pipelines, reducing the time and manpower needed for network inspections.
- Valve Operation: Optimizes the isolation of incident areas using valves, analyzes the impact on pressure and flow when valves are closed across the network, and assesses demand reduction in the network when valves are closed. Provides DMA solutions for the network.
- Pipeline Flushing Management: Identifies pipelines that require periodic flushing or flushing in case of incidents. Analyzes required indicators (velocity, pressure) during the flushing process (Figure 1).

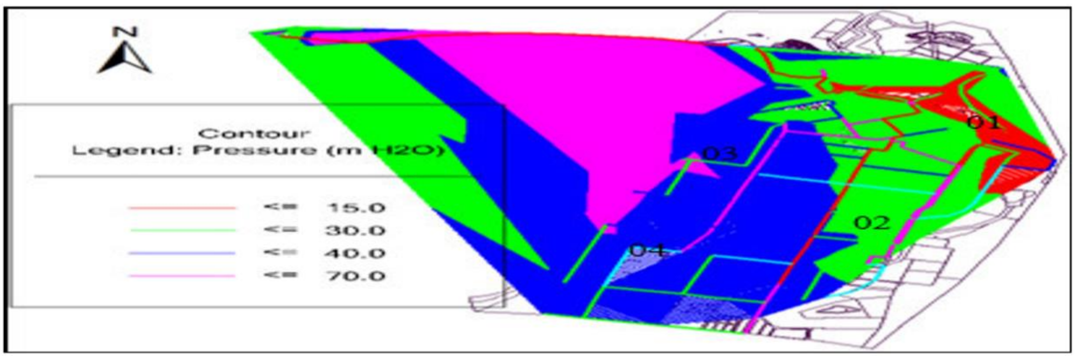

Figure 1 - Map of pressure existing distribution system at peak hour demand in study of Tewelde G.B. and coworker [12]

-Water Quality Analysis: Analyzes water quality parameters across the network over time, including residual chlorine, pH, TDS, water age, tracing, and THMs (Figure 2)

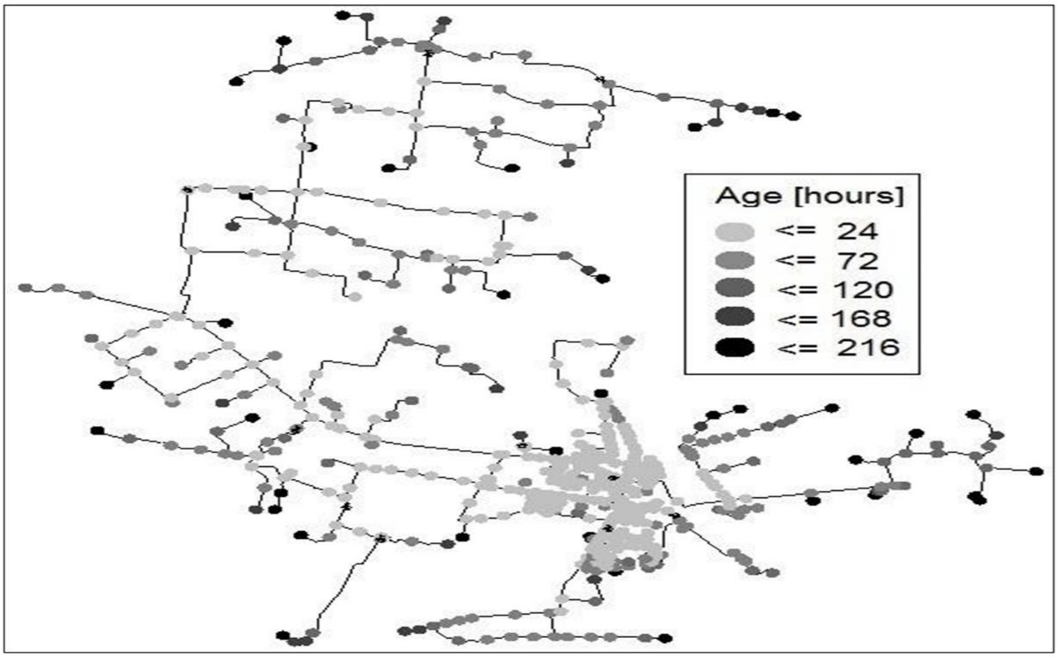

Figure 2 - The prediction and optimization of water age in water distribution systems were analyzed using WaterGEMS in the study conducted by Karolina et al. [13]

- Network Development: Analyzes the scale of network expansion needed and its impact on the overall network, balancing constraints (pressure, velocity, flow) with investment costs.
- Real-Time Simulation: Automatically retrieves data from the SCADA server and simulates the network in real-time.
- Pressure Zoning and Management: Establishes pressure zones to ensure adequate pressure in areas with significant elevation differences within the network. Adjusts pressure zone boundaries and pressure settings via valves to meet required pressure and flow when the pressure zone does not meet the desired parameters.

These features make WaterGEMS a comprehensive tool for the effective management and optimization of water distribution systems, ensuring efficiency and reliability in various operational scenarios.

WATERGEMS APPLICATION

Currently, numerous studies are employing this software to optimize water supply processes globally. Tewelde et.al used WaterGEMS to optimize the optimal pipe diameter for supplying an adequate quantity of water at satisfactory pressures to end users in the Wukro town, Ethiopia [12]. Additionally, the Darwin Scheduler tool in WaterGEMS was employed for optimal control and operation of pump systems. The WaterGEMS model encompassed a water distribution network comprising 117 pipes (40.67 km) and 99 demand nodes, equivalent to 50,480 end users, distributed across a hilly area with elevations ranging from 1989m to 2046m. The model calibration at selected nodes exhibited very good performance. Results indicated that maximum pressure increased from 31.1m to 38.1m after optimization, while minimum pressure during peak hour demand rose from 7.9m to 16m (Figure 3). A comparison of results demonstrated that optimized networks reduced costs by 9.6% compared to traditional hydraulic networks before optimization. Moreover, optimizing tank filling/emptying arrangements led to a 12.5% reduction in daily energy consumption costs compared to the currently scheduled pump. These findings suggest that the WaterGEMS model is a promising approach for optimizing pipe sizing in design water distribution networks and pumping operational schedules.

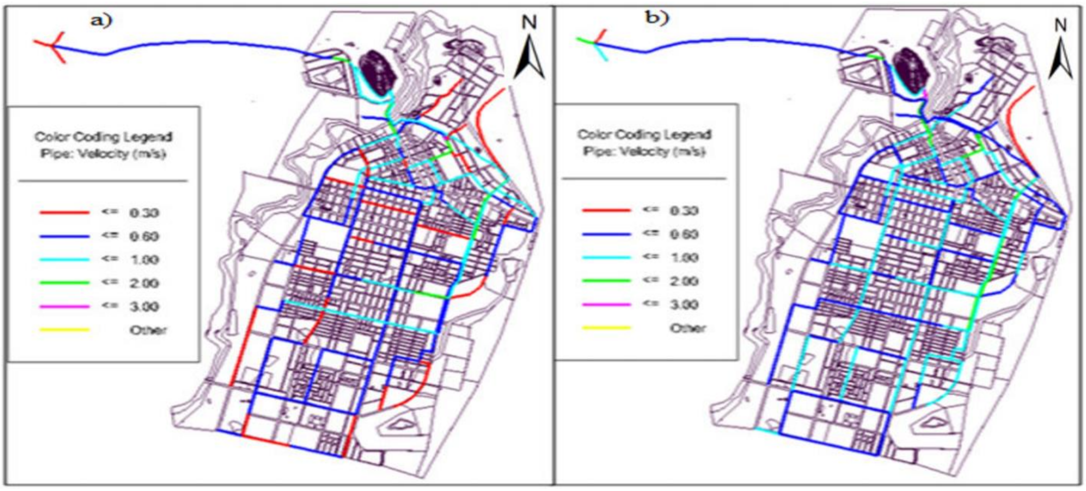

Figure 3 - Velocity of pipes at peak hour demand before optimization (a) and after optimization (b) [12]

In another study, Mohseni U. and colleagues utilized Water GEMS to to evaluate the impact of the growing population on the water distribution system from 2020 to 2050 for Narangi village, Maharashtra, India [14]. Water distribution network of Narangi Village is illustrated in Figure 4.

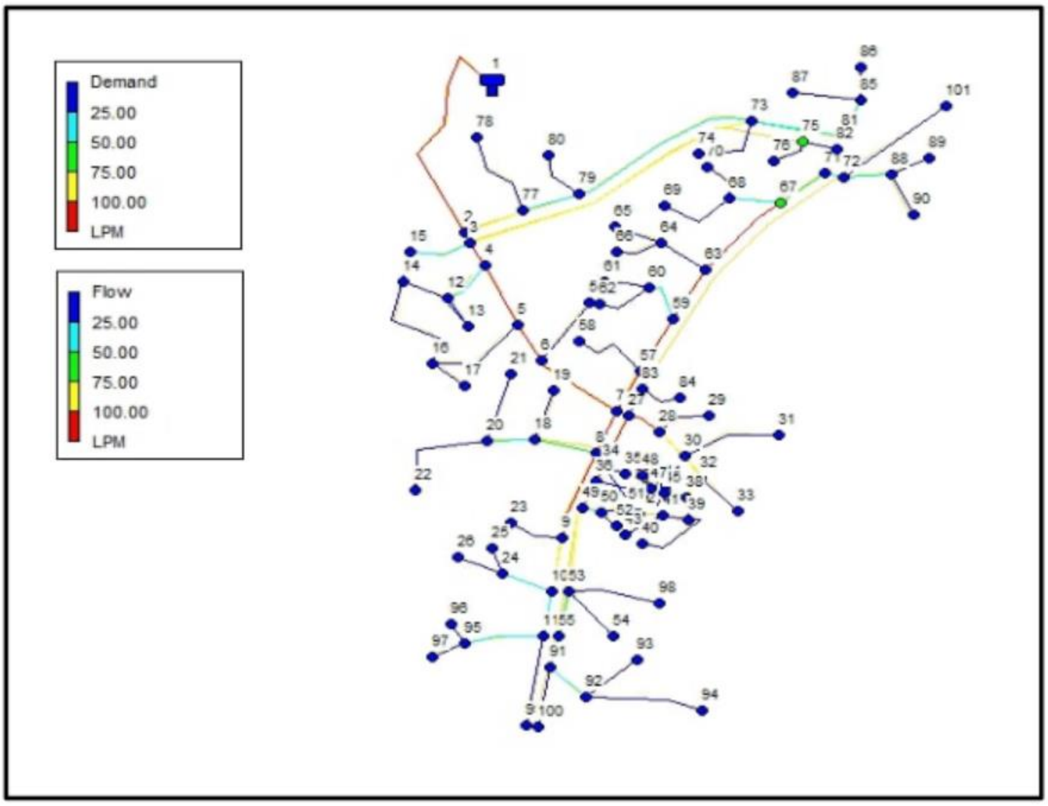

Figure 4 – The water distribution framework of Narangi Village [14]

The analysis revealed that the maximum flow occurred in pipe 1, and the highest demand was at junction 67. In 2020, the flow rate in pipe 1 was 1036 liters per minute, which increased to 1655 liters per minute by 2050. Similarly, the demand at junction 67 rose from 54 liters per minute in 2020 to 86 liters per minute by 2050 (details in Table 1). This indicates an increasing trend in both pipe flow and junction demand due to population growth over the decades [14].

Table 1 - Projected Increase in Flow Rate of Pipe 1 and Demand at Junction 67 (2020-2050) for Narangi Village [14]

Year	Flow in pipe 1	Demand at junction 67
2020	1036	54
2030	1145	59
2040	1400	72
2050	1655	86

Additionally, flow in pipes and future water demand were also estimated using this program under low population growth scenario and high population growth scenario. The comparison showed that unmet water demand under the HGS, at 0.223 and 0.601 million m³ for the years 2040 and 2050 respectively, exceeded that of the LGS, which was 0.035 and 0.174 million m³ for the same years. This indicates that unmet water demand in both scenarios will result in water scarcity in the study area. Figures 5 distinctly demonstrates an increasing trend in pipe flow, resulting from the population growth over the decades.

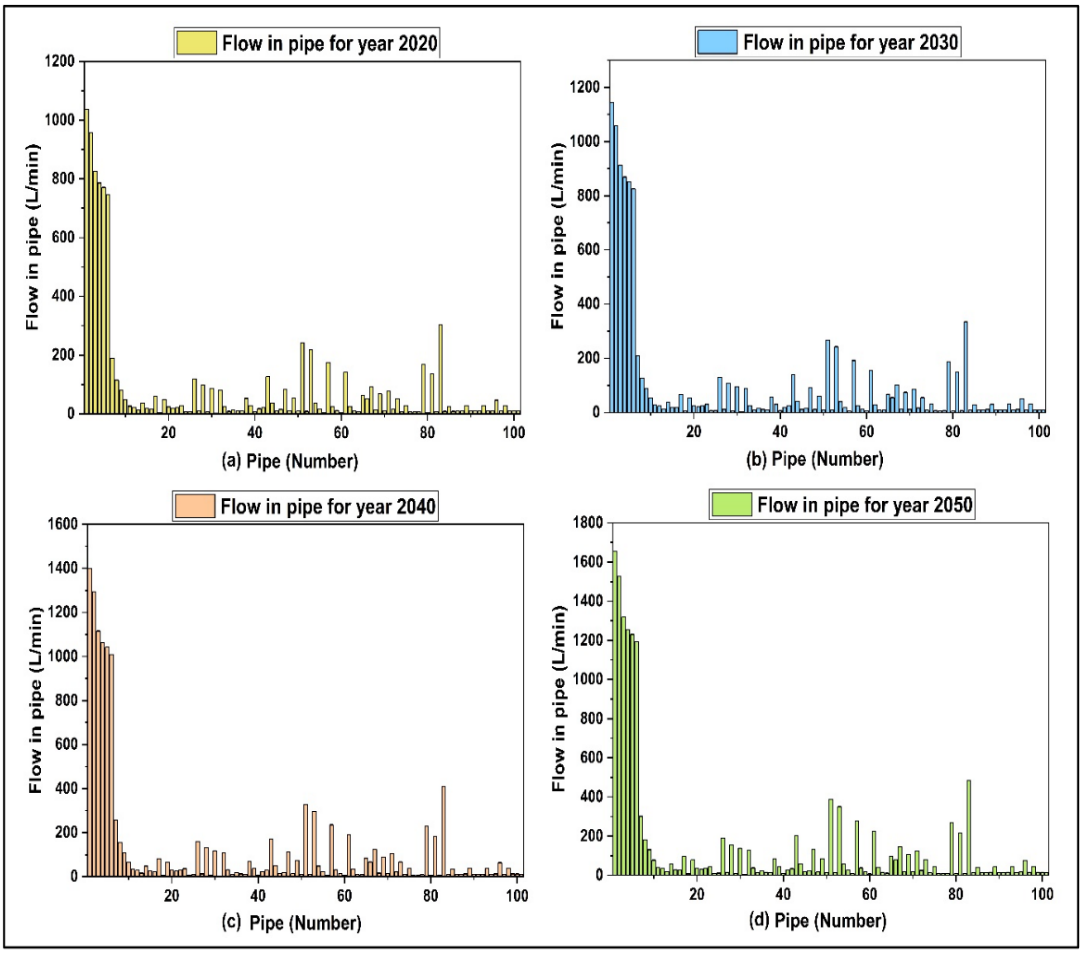

Figure 5 – Estimated flow rate in each pipe at Narangi Village from 2020 to 2050 [14]

Based on the results, the authors warn that water shortages are imminent in this locality and are likely to escalate sharply without timely measures to develop new water sources and construct additional storage tanks. Due to the impending water scarcity, the majority of the population will have to rely on water supplies from tankers. Therefore, addressing this issue necessitates a focus on ensuring the long-term sustainability of water resources.

In their study, Kowalska B. and colleagues utilized WaterGEMS software with the DMA-Tool module to separate the district metered areas (DMAs) within the municipal water supply network zone [10]. Accordingly, While the automatic division of DMAs expedited the process, it also led to a significant overestimation of the number of DMAs. The software initially generated 81 areas, including 5 major ones, necessitating subsequent modification of the results. These indicated areas were consolidated into three main DMAs—DMA 01, DMA 02, and DMA 03. Analysis of the water supply system's operation subsequent to DMA division revealed that DMA 01 and DMA 02 exhibited no disruptions in network operation, with flow rates and pressure values ensuring uninterrupted water supply to recipients. However, DMA 03 presented challenges, as computer simulations identified issues with maintaining adequate pressure at certain recipients and difficulties in supplying adjacent water tanks. Consequently, proposals were made for implementing double-pipe water supply and adjusting operational parameters at the pumping station in this area (Figure 6).

Figure 6 - The directions of DMA water supply were indicated by blue arrows. Transmission segments were delineated in red, while the new pipe supplying DMA 03 was denoted by a green arrow [10]

Simulation results indicated that the increased pressure significantly improved hydraulic conditions not only in DMA 03 but also across the entire system. However, due to the poor technical condition of pipes in the analyzed network section, heightened pressure may result in considerable water losses. Therefore, the replacement or repair of existing pipes is recommended. Additionally, the installation of pressure-reducing valves at locations supplying each DMA emerges as a viable solution.

Access to safe and potable drinking water is essential for sustainable living. Along with hydraulic analysis of pipe networks via WaterGEMS software, for real-time visualization of pressure head and average daily flows through household connections and stand-posts, Pankaj and co-workers have designed the safe drinking water networks. In this study, it is indicated that WaterGEMS provided robust modeling capabilities for hydraulic analysis, allowing for comprehensive modeling of water distribution systems [11]. It also demonstrated the feasibility of the proposed network through hydraulic modeling. The extended period simulation analyzed network performance over 24 hours, ensuring acceptable service levels (Figure 7).

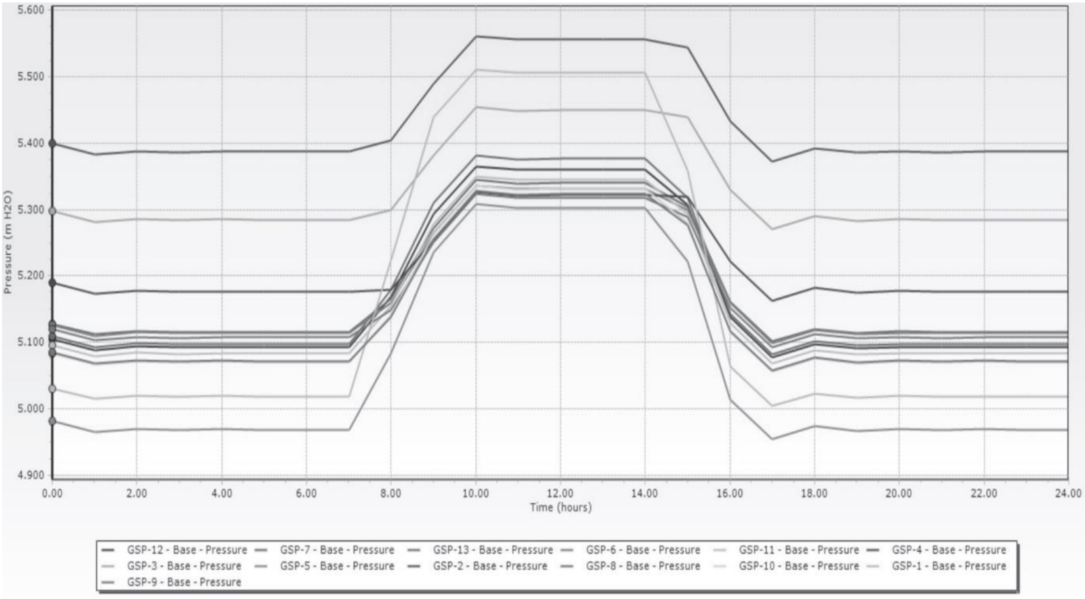

Figure 7 - The extended period simulation illustrates the variation in pressure head of water flowing from stand post taps over a 24-hour period [11].

Although the study primarily used the Hazen-Williams friction method for its accuracy, other methods like Darcy-Weisbach or Manning's are also applicable. The successful implementation of these findings offers a practical solution to address water scarcity and allocation problems in the study area.

CONCLUSION

The primary outcome of this analysis is the operational scenario outlined for the water utility company. This scenario encompasses several steps aimed at integrating and enhancing the maintenance of water distribution systems. The integration of different water distribution systems into a unified network and the optimization of its operation is a complex process. Therefore, it is highly recommended to simulate and predict subsequent actions using modeling software prior to implementation. Bentley WaterGEMS software, equipped with genetic algorithm modules, has demonstrated significant utility and versatility, providing essential support for decision-making processes in maintenance planning.

Declaration by Authors

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