Research Article

Abdulrahman A. Abdulsamad* and Khalid Adel Abdulrazzaq

Calibration and analysis of the potable water network in the Al-Yarmouk region employing WaterGEMS and GIS

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Abstract: Water supply and distribution networks play an important role in our daily activities. They make a substantial contribution to public health by providing potable water for public consumption and non-potable applications such as firefighters and other purposes such as irrigation. This study used ArcMap 10.8 and WaterGEMS CONNECT Edition update 1 version to create a hydraulic network model to simulate the pipes' network. Detailed network information, including pipe lengths, layouts, and diameters, was given by the Baghdad Water Department. The TUF-2000H Handheld digital ultrasonic flow meter has been used to measure the water flows in the network's source nodes. In eight junctions, the model was calibrated by measuring the pressures using the Bourdon gauge at selected junctions. The analysis was based on the steady-state time at the average demand. The analysis results showed that the pressures in the network ranged from 8 to 21 m H_2O with a correlation coefficient of 0.988, with a noticeable decrease in pressures in the distant pipes from the sources supplying water to the network. The velocity of the main pipes was within acceptable limits 0.5–2 m/s. While for the internal distribution network, it was noticed that there is an increase in velocity for the main pipes due to low consumption in the lateral pipes.

Keywords: hydraulic simulation, GIS, WaterGEMS, water network

*** Corresponding author: Abdulrahman A. Abdulsamad,** Department of Civil Engineering, University of Baghdad, Baghdad, Iraq, e-mail: abd.alsamad2001m@coeng.uobaghdad.edu.iq
Khalid Adel Abdulrazzaq: Department of Civil Engineering, University of Baghdad, Baghdad, Iraq, e-mail: aleoubaidy@coeng.uobaghdad.edu.iq

1 Introduction

Drinking safe and drinkable water is a prerequisite for living [1]. The most critical responsibility of every municipality is to ensure that its residents have access to clean drinking water [2]. The primary purpose of the water distribution system is to provide water to every home and public place. Each home must be provided with adequate water supply at the required pressure [3]. A good water distribution network should be easy to maintain, deliver consistent quality and quantity of water to all consumers, and be designed and laid out economically [4,5]. Models of water supply systems are practical decision support tools that can be used to construct various management scenarios to improve the efficiency and reliability of existing networks and develop new networks. The hydraulic relative equations are used in the water distribution network (WDN) to compute the hydraulic parameters, such as flow rate, velocity, and water pressure. The results are given in diagrammatical representations, which the users may review [6,7]. The accuracy was determined through input parameters or estimated, and the model calibration and verification were carried out [8]. Hydraulic simulation software is a tool that a skilled operator may use to analyze drinking water distribution networks [9]. To simulate network models, several approaches have been presented. A Hardy cross method with an advantage for the computing flow in complicated networks was used [10]. These papers assessed the analyzed results from modeling the hydraulic of the potable water in the al-Yarmouk water network using WaterGEMS and GIS.

WaterGEMS and GIS were used to analyze the Al-Karada WDN. The investigation considers two scenarios: daily average and peak consumption. Calibration was performed by measuring pressures and discharges in the network using a bourdon gauge and the number of population in the study area assuming 350 l/c/day. During peak demand, the network performed well with 0.04–1.19 m/s velocities and 0.28–1.85 bar pressures [11].

The water distribution system in Makurdi was analyzed using Watercad and Epanet programs. After entering the data into the network, the analysis process was done. The evaluation was based on the comparison data of the two programs. According to the results, the distribution system's valve placement led to a weak pressure system. An insufficient pipe count in the network leads to high velocities at high node demand, leading to increased leakage and cracks in the pipes [12].

A hydraulic model was made using GIS and Epanet to simulate the Chetouane town in Algeria. GIS provides network data such as length, topographic, and so on according to the results of the analysis; the velocity in 200 of 306 pipes had a value of less than 0.5 m/s, which may lead to deposit buildup caused by settling, while 64 pipes had a velocity between 0.5 and 1.5 m/s, which is within the permissible limits, and the remaining pipes had a velocity of more than 1.5 m/s. The pressures in 115 of 296 nodes had a value greater than 6 bar [13].

Epanet and GIS programs were used to make a hydraulic model for the distribution system to Al-Hakeem Quarter at Maqil district in the Governorate of Basrah. A bourdon gauge measures the pressures at five different locations throughout the calibration procedure. Typically, parameters such as minor loss, pipe roughness, demand, and so on, were entered into the program. Trial-and-error methods are used to choose the model's best results based on three typical statistical coefficients [root-mean-squared error (RMSE), standard error,

Figure 1: The AL-Yarmouk studied area.

and correlation coefficient]. The Hazen–Williams coefficient, demands, and pattern demands significantly affect the output results [14].

2 Methodology

2.1 Study area

The Al-Yarmouk region is one of the old regions established in Baghdad, Iraq, located on the Karkh side (33°17′49.6″N 44°20′19.5″E) with an area of about 4.82 km^2, consisting of six subdivisions (608, 610, 612, 614, 616, 618) according to the division of the Municipality of Baghdad. The region consists of many residential houses, schools, mosques, recreational parks, the municipal council, the civil defense, and the police station. In the last few years, the area witnessed a huge population increase and unplanned cutting of houses and land. Although it is a residential area, it now contains many restaurants and entertainment places, and it has become a destination for many people. Figure 1 shows the study area.

2.2 Data collection

The study area's population, a general layout map of the area under study, altitudes of nodal junctions in the water distribution system derived from a topographic map, and water demand at every node in the distribution network data are all utilized in the analyses. The data were obtained from the Baghdad Municipality Department, the Ministry of Planning and the Municipality of Al-Mansour.

2.3 Description of network

The Al-Yarmouk water network was established in the last decade by French company SOBEA in 1984 and is still up to the present time. This network has not been renewed until the current time, so it is always subject to fractures due to the high pressures in the network. Also, the inner walls of the pipes consist of layers as a result of corrosion and sedimentation in the lines. The responsible authority for this network is the Municipality of Baghdad, and the pipes are water-carrying pipes. The internal network consists of pipes with a diameter of 100–200 mm;

Figure 2: The layout of the network.

it was renewed in the years 2009–2012. It is made of ductile iron and is under the responsibility of the Municipality of Al-Mansour. The WDN in Baghdad has been divided into two main networks, the Al-Rusafa WDN, symbolized by symbol R. It is divided according to the regions on this side into R_1, R_2,..., R_n. The areas on the Karkh side are symbolized by symbol K and divided according to regions K_1, K_2,...,K_n. The Al-Yarmouk region is located in part K_2, while locality 618 is located in the K_6 part of the network. The water in the network is supplied from different water treatment plants. Because it is a loop network, it is not possible to limit the supply of water to a specific station, taking into account that the primary water source in the network is the Karkh water project and the Al-Qadisiya water project.

2.4 Geographic information system

Geographic information system (GIS) has emerged as a critical water resource spatial and statistical study

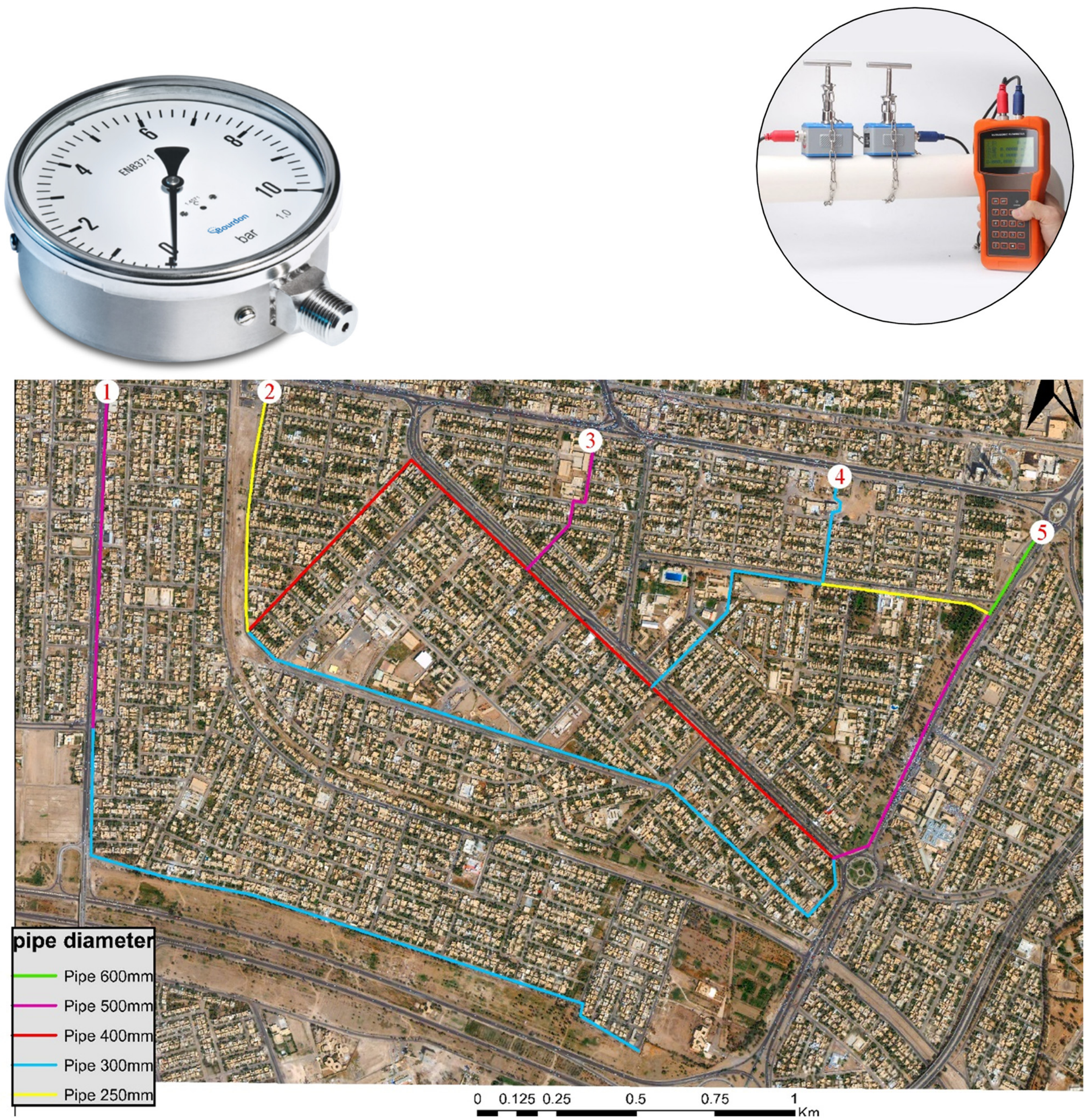

Figure 3: Locations of measuring points and tools used.

Table 1: Field data for source point

Point	Flow (m^3/h)	Pressure [m (H_2O)]
1	1,543	17.2
2	309	19.6
3	894	20.2
4	308	21.2
5	1,697	22.8

instrument, allowing for more effective management [15]. GIS offers a consistent environment for viewing the display model and the input/output data. This ability is beneficial in the choice process in urban hydraulic systems since it allows for faster decision-making. In addition to being time-consuming and expensive, developing a GIS model and creating the information necessary for successful water services management are challenging to achieve [16]. It has become evident that it is impossible to accomplish all of the intended management objectives without linking GIS applications in water distribution systems and hydraulic simulation models. Additionally, the integration of GIS with external models improves the overall management of the efficiency of water distribution systems [17]. The network layout was achieved using a GIS, as shown in Figure 2.

2.5 WaterGEMS program

Designed for water distribution systems, WaterGEMS is a hydraulic modeling program that includes enhanced interoperability, GIS model construction, optimization, and asset management features. WaterGEMS is an easy-to-use environment for engineers to study, design, and optimize water distribution systems. Assessments of fire flow, constituent concentration and power consumption, and total cost management can all benefit from its utilization. In addition to enhanced interoperability, GIS model building, optimization, and asset management features, WaterGEMS is a multi-platform hydraulic and water quality modeling solution for water distribution systems. WaterGEMS is an easy-to-use environment for engineers to study, design, and optimize water distribution systems. Other data related to water systems and infrastructure may be managed using WaterGEMS [18].

Table 2: The comparison between the analytical data and the field data

No.	Node label	Predicted pressure (m H_2O)	Observed pressure (m H_2O)	Error (%)
1	J-34	15	14.1	0.04
2	J-686	19	17.5	0.079
3	J-448	18	17.5	0.02
4	J-660	15	13.8	0.08
5	J-570	19	17.4	0.084
6	J-587	8	6.8	0.15
7	J-31	18	17.3	0.038
8	J-676	9	8.1	0.1

2.6 Field work

The field measurements that were taken are divided into two parts. The first is measurement of pressures in the network. It was accomplished by using the bourdon gauge located within the washing chamber. Second, a TUF-2000H handheld digital ultrasonic flow meter was used for flow rate measures. The measurement was performed inside the valve chamber. The points at which field measurements were taken are shown in Figure 3. The data were obtained from fieldwork are shown in Table 1. The points taken represent the water sources entering the network.

3 Calibration of the model

Models of water distribution systems can help design, manage, and analyze water distribution systems. Calibration is typically regarded as one of the essential parts of simulating water distribution systems. Therefore, it is included in this category. It is the method of producing changes to the model's initial input data. Following this procedure, one may discover that the output of the simulated hydraulic and water quality simulations is sufficiently similar to that of observed field data [19]. In order to achieve high levels of precision, calibration is costly and time-consuming, and it is difficult to achieve with low precision. By generating a realistic set of fundamental inputs that accurately replicate the entire network and its components, the scope and complexity of calibration may be reduced to a minimal

Table 3: Statically coefficients

No. of junctions	RMSE	R^2
8	1.12	0.988

level [9]. The parameters that have been relied upon to reach high accuracy in the calibration process are pipe roughness and demands at junctions. A process of trial-and-error process has been implemented. Differentiation values for Hazen–William coefficients were determined through the calibration process ranging between 120 and 150 for the main pipes due to the age of the network being approximately 40 years, while for the internal network, a fixed value of 130 was adopted since the laid pipes are new. As for water, demand has relied on the population and the assumed consumption rate of 350 l/day for each person. The water requirement was distributed in the

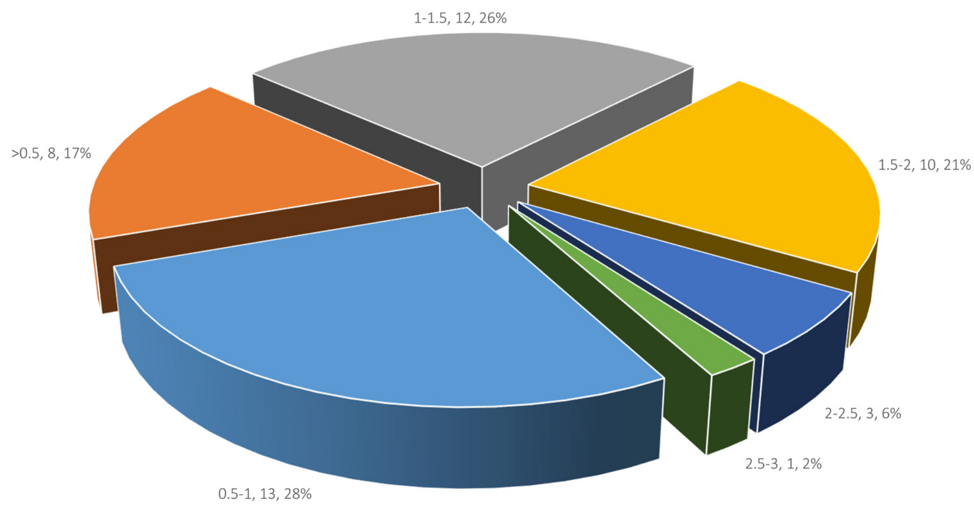

Figure 4: velocity distribution in the main pipes.

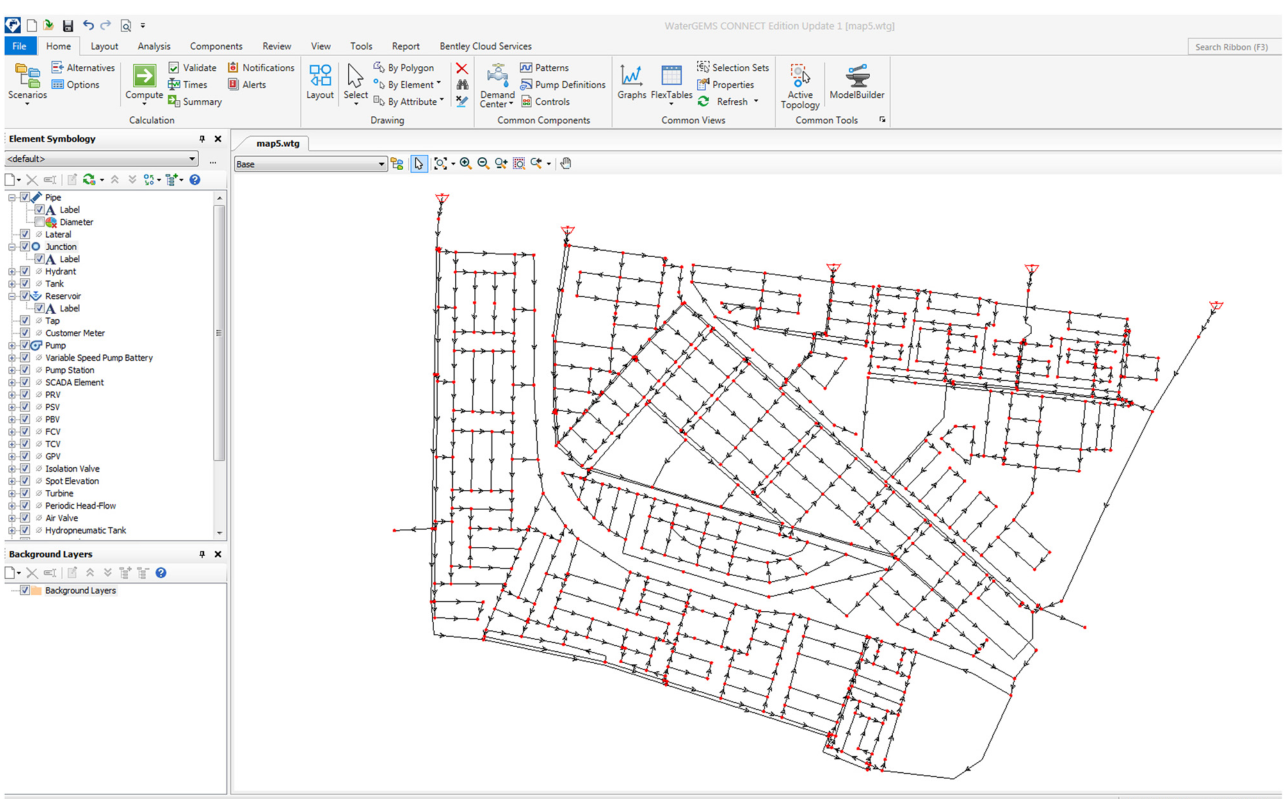

Figure 5: Results output example for the al-Yarmouk water network distribution.

junctions relative to the area covered by each junction, and then, the water demands were modified in a number of junctions.

4 Results and discussion

After analyzing the entered data by WaterGEMS software and using steady-state time analysis type in the base calculation options, the results showed that the pressures in the network had a value ranging 8 m, which is located at 614 localities. It is considered the end of the network to 19 m at the beginning. The pressure data results show a significant degree of matching between the analytical data and the field data, as shown in Table 2. The two following standard statistical coefficients were used to determine the results of the tests, and Table 3 shows the results for the statistical coefficients:
1. Root-mean-squared error.
2. Coefficient of correlation (R).

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{1}^{n}(y_i - y)^2}, \quad (1)$$

$$R = \frac{\sum_{1}^{n}(y_i - y_i^{-})(y - y^{-})}{\sqrt{\sum_{1}^{n}(y_i - y_i^{-})^2\sum_{1}^{n}(y - y^{-})^2}}, \quad (2)$$

where n is the number of readings, y_i is the observed reading, y_i^{-} is the average of the observed reading, y is the predicted reading, and y^{-} is the average of the predicted reading.

The results of the velocity analysis at the main pipes consisting of 47 pipes showed that the velocity ranged from 2.83 to 0.13 m/s with an average rate of 1.14 m/s and a standard deviation of 0.62 m/s, which refers to that about 83% of velocity is more than 0.5 m/s (Figure 4).

As for the internal distribution network consisting of 732 pipes, the velocities in the pipes range from 0.01 to 1.68 m/s at a rate of 0.32 m/s with a standard deviation of 0.31 m/s. The overall analysis shows that the Al-Yarmouk WDN works correctly in the main pipelines, except for 614 subdivisions where the velocities and pressures are low compared to the rest of the network. The direction of flow in pipes is shown in Figure 5.

5 Conclusion

Al-Yarmouk water network's hydraulic analysis and modeling were conducted in this study, and the following was found, as a consequence of this analysis:

1. It is safe to say that the main pipes of the network are working well when using steady-state time analysis during the research period in the winter season.
2. All of the resulting pressures at all junctions are sufficient for supplying water to the consumer.
3. At times of high demand, water pressures will be low at the source of the supply, resulting in users depending on their home pumps to boost water levels, which leads to damage to the pipes network.
4. The results indicate that coupling GIS and WaterGEMS allows the network to have a management system that can investigate problems, respond to incidents, and evaluate network operations.
5. Multiple scenarios may simulate the network under various situations to make network administration more manageable.

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