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Hydraulic Analysis of Urban Water-Supply Networks in Marivan

Mohammad Ghareb Tavosi, Maaroof Siosemarde*
Department of Water Engineering, Mahabad Branch, Islamic Azad University, Mahabad, Iran

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ABSTRACT

In this study, hydraulic analysis of water-supply networks in Marivan was performed by modeling. WATERGEMS was used for modeling and it was calibrated using existing rules and regulations. The purpose of this research is modeling urban water network and its analysis based on hydraulic criteria and meeting pressure conditions at the nodes and complying the economic speed. To achieve this goal, first the pipelines of city streets was designed in AutoCAD on a map of the city. It should be mentioned that it was tried to prevent from creating additional loops in the network and the optimal network was designed by a combination of annular and branch loops. In the next step, the pipes were called in WATERGEMS and then we continue the operation by the allocation of elevation digits to the pipes. Since the topography of this city is very specific and unique, the number of pressure zones was increased. Three zones created only covers about 20% of the population in the city. In this dissertation, the design was performed on the city's main zone with the largest density in the Figures 1,320-1,340. In the next step, the network triangulation was conducted. Finally, the Debiw as allocated based on the triangulation conducted and considering the density of the city for year of horizon. Ultimately, the network of Marivan was designed and calibrated according to hydraulic criteria and pressure zoning. The output of this model can be used in water-supply projects, improvement and reform of the existing network in the city, and various other studies. Numerous and various graphs obtained in different parts of a network modelled can be used in the analysis of critical situation, leakage.

Keywords: Water Network, Hydraulic Analysis, Modelling, WATERGEMS

* Corresponding Author, E-mail: maroof_33m@yahoo.com

1. INTRODUCTION

With regard to the growing population of the world, the need to water will be increased gradually. On the other hand, the restrictions on freshwater resources, including table and ground water and their pollution by chemical pollutants have added the concerns over the health of drinking water. The water pipelines and distribution networks in cities were developed by human progress for easy and better access to this staff of life. These networks are built to supply healthy and enough water for all consumers. The water distribution networks are designed according to the demand in different areas and considering the topography (Tabesh and Zia, 2003). The real modeling of network leads to precise analysis and predicts the network behavior accurately (Alperovits and Shamir, 1977). Given that we need network analysis both for network design and in times of the exploitation, modeling and hydraulic analysis of water networks seems essential. Most of the existing models for hydraulic analysis of water distribution networks perform hydraulic analysis assuming that demand is constant regardless of nodal pressure (Goldberg and Kuo, 1987). Accordingly, the Demand Driven Simulation Method (DDSM) is developed. In this design, it is assumed that the Debi designed for consumers is always set; this condition leads to unrealistic answers in the network analysis and even negative head in some of the nodes under critical condition that doesn't represents real conditions in the system. In reality, unexpected incidents in the network, including broken pipes, failure of pumps, excessive consumption and consequently the excessive pressure drop in network, the Debi provided for consumers will be reduced because of the pressure in the node and even some nodes will not be able to supply any water. Thus, it is necessary to consider the relationship between pressure and outflow of nodes for real simulation of the system performance; this type of analysis is called Head Driven Simulation Method (HDSM) (Murphy and Simpson, 1992). This method can be seen as a descriptive tool to show the real conditions of the network and predict its dysfunctions in water supply under critical conditions (Dandy *et al*., 1996).

The present research aims to prepare a comprehensive model of hydraulic analysis based on irrigation networks' pressure using gradient algorithm considering all of the network elements such as valves and pumps where the network dynamic analysis is possible by considering the leakage effect. For this purpose, the output Debi from node is assumed proportional to the pressure and the fundamental question is whether gradient algorithm can be used to prepare a comprehensive model of pressure driven hydraulic analysis considering all network elements. Another objective of this research is modeling urban water network using WATERGEMS and its analysis based on hydraulic criteria and meeting pressure conditions at the nodes and also complying proper economic speed. It should be mentioned that it was tried to prevent from creating additional network loops in the network and design the optimal network as a combination of annular and branch network. In this way, a comprehensive model of the city's water network can be achieved and the outcome of the model can be used in irrigation projects, improvement and reform of the existing networks in the city, and various other studies like finding leakage, finding unauthorized tributaries. Numerous and various graphs obtained in different parts of a network can be used in the analysis of critical situation, and leakage.

2. THE STUDY AREA

Marivan is one of the towns of Kurdistan province in western Iran. The center of this city is Marivan. This town reaches to Saqez from the north, to Sanandaj from the south and southeastern, to Paveh from the south and limited to Iraq from the north and northwestern. According to the latest divisions of the country in 2011, Marivan is divided into 3 cities, 3 counties, 6 villasand 176 villages including 151 villages with habitants and 25 villages without habitants (The design criteria for urban and rural water transmission and distribution systems, 2013; Statistical Center of Iran. General Population and Housing Census, 2005).

Before 1,337, Marivan was under the title sheriffdom as a subsidiary of the city Sanandaj. At that time, Kalatrazan, Sarvabad and Sarshiv were parts of Marivan. By the combination of Kalatrazan and Sarvabad, now Marivan has three Central, Sarshiv and Khavmyrabad area (The design criteria for urban and rural water transmission and distribution systems, 2013).

The central area of Marivan has 3 districts and 74 villages, including 66 villages with habitants and 8 villages without habitants. The villasare: Sarkol by the centerof Kani Dinar, Kumasi by the center of PirKhezran and Zeribar by the center of Ney. The area of this district is about 941 square kilometers and the population consists of approximately 122,063 people (The design criteria for urban and rural water transmission and distribution systems, 2013; Statistical Center of Iran. General Population and Housing Census, 2005).

"Sarshiv" by the center of Chenareh has 2 villas and 62 villages, including 53 villages with habitants and 9 villages without habitants. The villas of this district include: "Sarshiv" by the center of Chenareh and Gol-e Cheydar by the center of Janevareh. The area of this district is about 1,047 square kilometers and the population consists of approximately 30,899 people (Statistical Center of Iran. General Population and Housing Census, 2005).

Khavmyrabad by the center of Bardehrasheh has 1 villacalled "Khavmyrabad" and 40 villages, including 32 villages with habitants and 8 villages without habitant. This area is approximately 338 square kilometers and the population consists of approximately 15,812 people (Statistical Center of Iran. General Population and Housing Census, 2005).

3. METHODOLOGY

3.1 Selecting the Best Population Estimation Method for Marivan

There are many ways to choose the best method of population estimation that we have used arithmetic method in this study. In the arithmetic method which is known as growth at a uniform rate, it is assumed that the population growth occurs during equal, fixed and population-independent periods.

So if P1 is the population at time t1 and P2 is the population at time t2, then (Tabesh *et al*., 2002; Cullinane *et al*., 1992; Gupta and Bhave, 1996; Baghchesaraei *et al*., 2015; Fujiwara and Ganesharajah, 1993):

$$K_a = \frac{p_2 - p_1}{t_2 - t_1} \tag{1}$$

If Ka is known, the population is estimated from the following relation:

$$P_t = P_0 + K_a t \tag{2}$$

Table 1. Estimated population in 1390 with different population methods of forecasting in order to choose the best method

Census year	The population of Marivan
1,375	63,747
1,385	93,686
1,390	122,063
1,390 Geometric method	113,577
1,390 Arithmetic method	108,655
1,390 Logistics method	not responding

Where P_t is the population predicted for the year t after P0, and P0 is the current population.

In order to choose the population estimation method for Marivan in 1,419, first the population of the city in 1,390 is estimated by the years 1,375 and 1,385, and then it is compared with the census results of 1,390. At the end, the method with the least error has been chosen as the dominant prediction method for Marivan (Statistical Center of Iran. General Population and Housing Census, 2005).

Logistic method doesn't work due to the negative saturation population of Marivan. However, the geometric method can be used as an appropriate method according to the results. The reasons that the city's population is less than estimates can be social events and deformities and also onrush to the large cities in the last few years.

Ka value in geometric method has been calculated for several years to get more accurate estimates, and the average is also included in calculations. So the city's population for the year 1419 is predicted to be about 321,511.

3.2 Per Capita Water Consumption

Given the limited water resources, socio-economic and climatic conditions of Iran, determination of the per capita water consumption should be done aiming to achieve the least desirable per capita water consumption. Per capita consumption at the year of horizon should not exceed the following table considering five capitations in cold, warm and temperate regions.

According to the values considered for residential, public, commercial and industrial, landscaping and losses for the city Varamin, the per capita water consumption for the city is calculated as follows (Fujiwara and Ganesharajah, 1993; Xu and Goulter, 1999; Baghchesaraei and Baghchesaraei, 2014; Agrawal *et al*., 2007):

Table 2. Per capita water consumption based on the type of climate for different populations

Type of City	Population (thousand)	Cold	Temperate	Warm
Small	P < 50	175	200	225
Medium	50-500	200	230	260
Large	P > 500	225	260	295

Per capita total consumption = per capita household consumption+public+green space+commercial and industrial+losses

$$120\frac{l}{c.d}+15\frac{l}{c.d}+20\frac{l}{c.d}+3\frac{l}{c.d}$$
$$+20\%(120+15+20+3)\frac{l}{c.d}=189.6\frac{l}{c.d} \quad (3)$$

So per capita total consumption for Marivan is within the limits allowed in regulations.

3.3 Zoning Distribution Network in Terms of the Pressure and Area under the Coverage and the Number of Ramifications

To carry out and implement the pressure management and distribution management properly at the level of the distribution network and reduce the real disasters and also ease of control and exploitation during the project, it is essential to zone the network. To carry out the zoning, to the following points should be considered:

Network span, volume of existing reservoirs and their development plans, topography of urban or rural areas, technical limitations and the location of water supply. For this purpose, various methods such as zoning the network with tanks, pressure changes or a combination of the two are used.

To provide the minimum pressure and prevent from increasing pressure that leads to an increase in water disasters and unnecessary use of water, pressure management should be carried out by the appropriate selection of the tank and pressure zoning of the network.

Given that one of the tasks of storage tanks is to supply and balance the pressure in distribution network, the storage and distribution tanks should be close as possible to the consumption centersin order to achieve this goal. In case of proper topography in the city or village, the tanks should be located at the height that the minimum water pressure is set during the maximum moment use and at the highest level of consumers in order to provide the pressure. It is while the height difference between the tank to the lowest level of consumers should not exceed the maximum permissible height. So it is necessary to consider other tanks in proper balance for the places with more than 50m height difference to the pressure storage and supply tanks (Taebi and Chamani, 2004; Baghchesaraei *et al*., 2016).

It is to be mentioned that to prevent the construction of several tanks that will bring many problems in the operation and maintenance for the operator, the water distribution networks of the two neighboring districts might be linked to each other by installing pressure reducing valves on the pipeline crossing the border of two different pressure areas and plays a key role in the supply of the lower pressure region.

Network pressure zoning is necessary in the existing water distribution networks or in the study of the development plans of facilities and water distribution network of towns and villages with a gap at the level of the town or village. Pressure zoning at the level of network includes all the measures that would keep the pressure within the standards or pressure management.

In order to carry out the pressure zoning plan, it is necessary to cut or unlink the pipelines of two neighboring districts with respect to the appropriate maps of height levels, urban development and distribution network status, the volume, balance, and maximum water level of reservoir, as well as technical limitations of water pressure, pressure separating lines in the static case and then identification of the location of pipelines existed on the borders of these lines.

Since the construction of several tanks at various levels to store and supply the pressure of each district creates many problems in the preparation and ownership of land, water supply to numerous tanks, the initial investment, as well as the operation and maintenance of water and sewage companies, thus the water distribution networks of the two neighboring districts might be linked to each other as a fundamental solution by installing pressure reducing valves on the pipeline crossing the border of two different pressure areas and plays a key role in the supply of the lower pressure region.

Pressure zoning of Marivan was carried out using topographical maps 1: 2,000 of National Cartographic Center. For this purpose, the elevation map of the region was drawn using GIS software.

In urban areas of Marivan, the lowest digital elevation was 1,290 m above the fresh water level and the highest digital elevation was 1,410 m. So this region is divided into five pressure zones. Because of the special topography of this city, only 10% of the population live in 4 zones and the city's main zone for which the plan has been made has a digital elevation of 1,320 to 1,340 m.

Useful volume of the tank consists of three parts as follows:

- The volume needed to compensate hourly fluctuations (moderating volume)
- The volume needed to meet the firefighting needs
- The volume needed to supply water when the water entering the reservoir is off. (In most
- The fractures and damages to the water ducts and lines or the failure of pumps and repairs, etc.).

The water tanks should be able to supply the consumers' needs during the peak hours. The volume required for this purpose should be determined by processing daily consumption changes over several years in a row and the curve of changes should be depicted. If it is not possible to draw consumption curve changes, it is necessary to calculate the required volume using the changes in consumption under the same conditions or by the use of standards in the table below (Agrawal *et al*., 2007; The design criteria for urban and rural water transmission and distribution systems, 1996).

The total volume of tank is obtained as follows:

$$V_{tN} = 55,470 + 450 + 11,241 = 67,161 m^3 \quad (4)$$

According to the district area, two tanks of 33,600 cubic meters in volume were considered for this area.

This volume should be able to supply the water required for distribution network when the water inflow was cut.

The factors in creasing the volume are as follows:

- Unique water supply
- Unique water pipeline or water supply
- High likeliness of power outages and lack of emergency power system where the pump is used.
- Limited resources and quick repair of pipelines or other installations
- The vulnerability of water supply facilities

According to the standards, if the above conditions were desired, at least 10 percent of daily maximum consumption at the end of the project is considered as emergency reserves. With regard to the probability of power outages in this project, other parameters listed and the number of tanks due to less consumption in the region, 20 percent daily maximum consumption is considered as emergency reserve.

$$V_s = 37,469 \times 1.5 \frac{m^2}{day} \times 20\% = 11,241 m^3 \quad (5)$$

If the tank is fed with a constant Debi rate, the required volume will be 15 to 25 percent of the maximum daily consumption of the distribution network (regarding the population and consumption type). If the tank is not fed with a constant Debi rate, the required volume will be determined in accordance with the pumping conditions.

The volume in the study area, assuming 24-hour operation of pumps, is calculated as follows:

Balancing volume = maximum daily Debi×the percentage obtained

$$V_s = 37,469 \times 1.5 \frac{m^2}{day} \times 9.87\% = 55,470 m^3 \quad (6)$$

4. RESEARCH METHODOLOGY

In this study, urban water network has been modeled using the software WATERGEMS complying the technical terms according to the paper 3-117 of Planning and Budget Organization and the final standard diameter and pressure across the network were obtained after reviewing various conditions. In hydraulic analysis of water-supply networks, the Debi of pipes and Head of nodes are unknown according to the specifications of each network. These unknowns can be calculated by resolving the continuity and energy equations in pipes. To write these equations for the network pipes, all effective phenomena in the network should be considered in order to obtain answers close to reality. More accurate answers lead to more appropriate design and better utilization of the network.

The first step in modeling water distribution network is drawing the network pipelines. As noted in the third chapter, water distribution network can be branch annular or combined that each of them has their own pros and cons. The combined network has been used to draw water distribution network of each pressure zone in Marivan, because the water can go to the pipe downstream areas in case of break of cut. At the same time, it was tried to minimize the number of branches and pipes of each branch as possible for cost savings purposes. The pipes were drawn on a map of the city using AutoCAD. It causes the length of pipelines to be in real scale. In the process of piping, the distribution network in branching parts was designed in such a way that the water moves along the slope and is secured from such pressure reduction. To this end, topographical map of the region was used as the background of Auto CAD software when drawing distribution network. In the following, the map relating to the distribution network of Marivan pressure zones has been presented.

The second phase is importing the information related to the pipelines. The pipes' diameter was initially assumed all alike in water distribution network design by Water GEMS, and after the implementation of the software, the main diameter is designed with regard to the velocity of water in the pipes and the pressure in picked up points. The network pipelines were also made of cast iron and the relevant information, including diameter, Hizen Williams's coefficient, Darcy fraction coefficient, the maximum nominal pressure were extracted from the catalog.

The third phase is the allocation of elevation digitals to the picked up points. At this stage, there is a need to topographical lines of the region drawn by using GIS software and topographical map of National Geographic Organization.

The fourth stage is the allocation of Debi to each of the picked up points. Each picked up point covers an area of the city that is called water-supply area. Each pressure zone is triangulated to determine the area covered by picked up points. After specifying the area covered by each picked up point, the picked up Debi of that point can be obtained by calculating the population of the region and multiplying it to the daily per capita consumption. The population of the region covered by each point is calculated using density population of Marivan. So, first the density of each is attributed to the desired map by calculating the area using Software ARC GIS.

The final step is entering the information of the tanks. After importing all the required information to the software, the distribution network is modeled using the option Compute in Analysis menu. Unfortunately, Water GEMS software is not able to design the pipe diameter, so the diameters must be corrected according to the hydraulic criteria of distribution network after modeling the network.

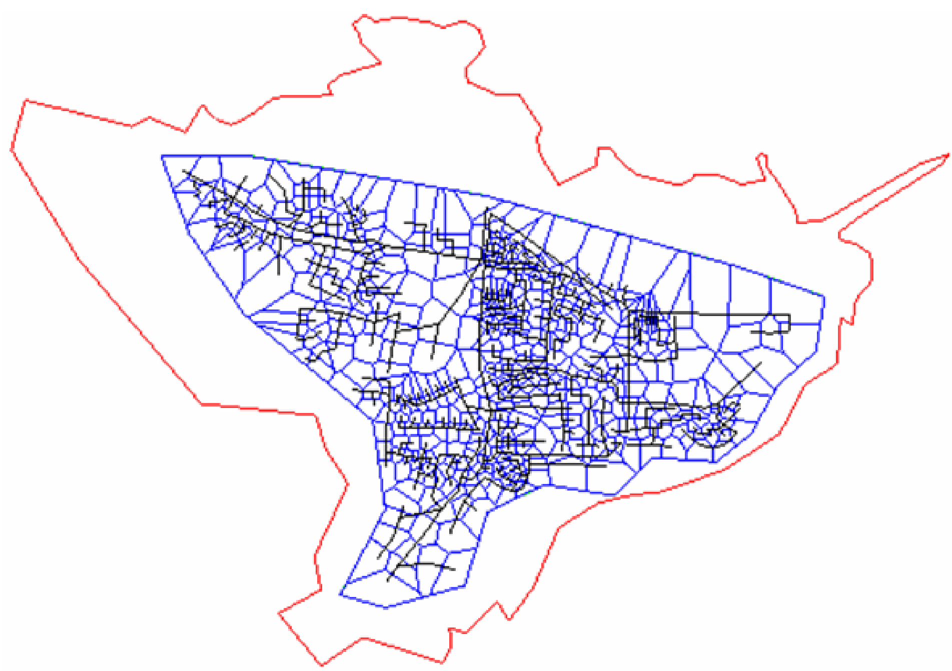

Figure 1. Triangulation of the city' main zone.

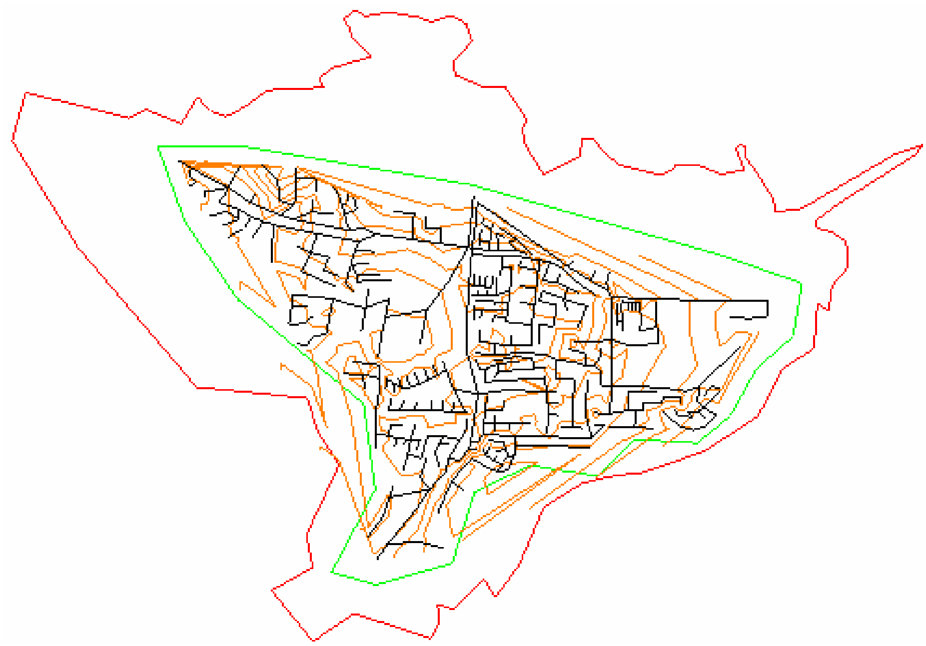

Figure 2. Isobar lines of the city' main zone.

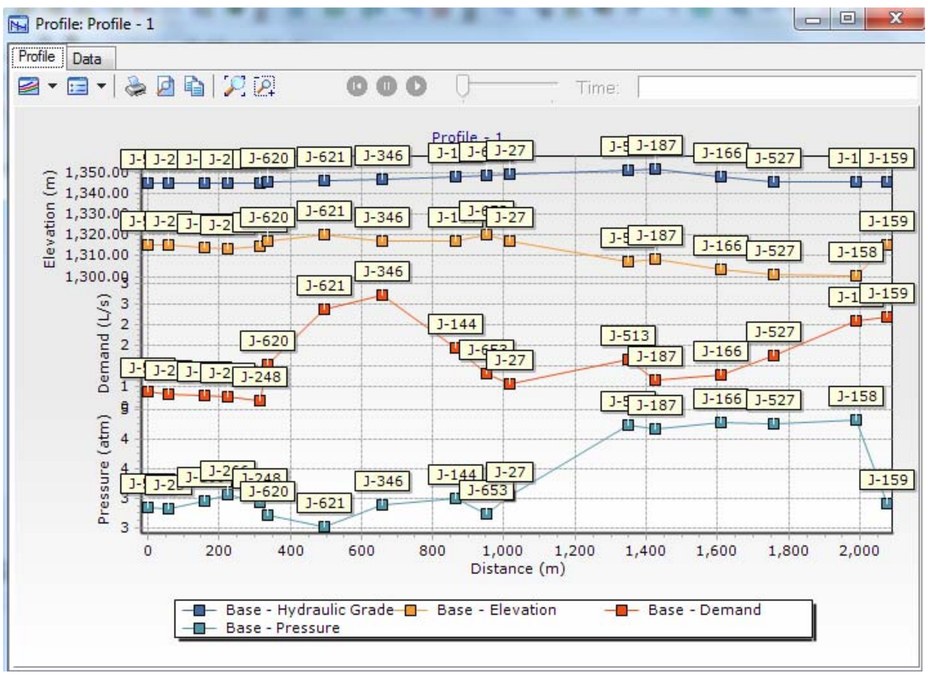

Figure 3. Profiles of hydraulic gradient, elevation digitals, Debi of each node and pressure in the network of Marivan.

5. ANALYSIS OF THE MODELING

5.1 Analysis of Pressure in the Network

In modeling, urban water network was designed based on pressure criteria and in accordance with the existing criteria on minimum and maximum pressure in the network. Figure 2 shows isobar lines in the network. As it is shown in the figure, the network pressure conditions have been observed in all parts of the city and the initial design is based on pressure.

5.2 Network Profile

The software has the potential to give a variety of information, including hydraulic profile, velocity profile, and pressure gradient at any point in the network to the user. One of the city's main line is shown in Figure 3 as a sample.

5.3 Optimization of the Pipes' Diameter

In order to minimize the costs and observe economic speed, the network pipes' diameter is optimized using the software. It was attempted in the design to meet the optimal diameter and minimum pressure in the network.

5.4 Conclusion and Recommendations

In this paper, urban water-supply network for the main zone of Marivan city was designed. Hydraulic regulations governing the flow have been considered. By the use of this model, the network can be rehabilitated and reconstructed. The economic and cost analyses, analysis of the tank displacement and its optimization and etc. can be considered as the topics proposed for future studies.

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