Improvement of water network reliability of Assma school avenue (Ajdabiya)

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Abstract
Water networks are one of the most important elements of the infrastructure of any urban society, providing it with the most important element of modern life, which is water. Some areas and residential areas in our country suffer from water scarcity. This paper studies one residential avenue in city of Ajdabiya Libya, which suffers the problem of water shortage. An assessment, evaluation and redesign of the existing condition of the study network are executed to see how reliable is the network, how the reliability, in terms of water quantity (discharge) and pressure to raise the level of reliability, and what are the requirements to raise up the level of reliability?. Accordingly, it was necessary to develop a simulation hydraulic model of the study area network, from which the causes of water shortage are determined, and solutions are presented as well. A hydraulic solver EPANET software was used to modelling the study network from which many scenarios to overcome the shortage problem could be studied. The adopted solution was given, tested and proved its capability to overcome the water scarcity problem in the study area.
Keywords: Ajdabiya, water network, reliability.

الملخص:

تعتبر شبكات المياه من أهم عناصر البنية التحتية لأي مجتمع عمراني، حيث تزوده بأهم عنصر في الحياة العصرية وهو المياه. تعاني بعض المناطق والأحياء السكنية في بلادنا من شح المياه. يدرس هذا البحث أحد الاحياء السكنية في مدينة أجدابيا الليبية التي تعاني

من مشكلة نقص المياه. تم تقييم وإعادة تصميم الوضع الحالي لشبكة الدراسة لمعرفة مدى وثوقية الشبكة وكيف يمكن تعزيز الوثوقية من حيث كمية المياه (التصريف) والضغط؟ وما هي متطلبات رفع مستوى الوثوقية ؟. وعليه فقد كان لابد من تطوير نموذج محاكاة هيدروليكي لشبكة منطقة الدراسة يتم من خلاله تحديد أسباب نقص المياه وتقديم الحلول كذلك. تم استخدام برنامج EPANET للحل الهيدروليكي لنمذجة شبكة الدراسة التي يمكن من خلالها دراسة العديد من السيناريوهات للتغلب على مشكلة النقص. تم تقديم الحل المعتمد وأختباره واثبات قدرته على التغلب عل مشكلة ندرة الدراسة.

Introduction

A safe supply of potable water is the basic necessity of mankind in any society, therefore water supply systems are the most important public utility. An extreme care is spent around the world for providing or upgrading drinking water facilities. The major share of capital investment in a water supply system goes to the water supply and water distribution network. Nearly 80% to 85% of the cost of a water supply project is used in the distribution system, (Prabhata K. et al 2007); therefore, assessment and redesigning a water distribution system will result in considerable attention. Generally, water distribution systems (WDSs) are designed and implemented to reliably provide the consumers with amount of flow with acceptable aesthetics, taste and odor and under a pressure not less than as designed with considering minimal interruptions while minimizing the total cost of operation and maintenance. Hydraulic reliability of the system is; its ability to supply the consumers with their designed demands under a pressure not less than the minimum limit and to all the consumers without any exceptions during all its designed life time. Therefore, pressure limits, demand and the discontinuity are vital in evaluation the network performance, particularly, the hydraulic capacity or reliability. The most frequent occurring consequences associated with pipe failure in water distribution systems and affecting the hydraulic reliability is a reduction or fluctuating in pressures. Concerns of low pressures occurring in pressurized drinking water supply distribution systems are in creating the opportunity for contaminated water to enter the pipe from outside (EPA/600/R-06/028 December 2006), increasing water retention time, in additional to the failure to meet the demand. At the same time, high water pressure has adverse mechanical impacts on the system. Thus, it is important to maintain the minimum pressure throughout the whole distribution system in order to sustain the demand and microbial quality of distributed water and avoiding any rising over the allowed maximum limit. Connectivity is other aspect of reliability measures. Connectivity characteristic is very important for investigating the system performance redundancy, and identifying the nodes with critical supply. The network reliability (discharge and pressure) is lost when consumer's requirements is not satisfied, even if it has been well designed and constructed. Making errors in network operation phase amplifies the common problems and their implications, such as:

1. Low operating pressures causing inadequate supply
2. High operating pressures causing high leakage in the system
3. Low velocities causing long retention of water in pipes and reservoirs
4. Frequent changes of flow direction causing water turbidity
5. Pipe breakage, which is the most difficult to prevent because of the wide range of potential causes.
6. Power or mechanical failure in the pumping station.
7. Deterioration of the raw water quality (source).
8. Excessive demand in other parts of the network.
9. Maintenance or reconstruction of the system.

These problems can have a serious impact on public health and coping with them also influences maintenance requirements and the overall exploitation costs. This paper is addressing the reliability problem in one area in Ajdabiya city.

Objectives :

The main two objectives of the paper is; to determining the causes of water shortage in the study network, and to solve this problem. To achieve the objectives, an assessment, evaluation and redesign of the existing condition of the study network must be done by development a simulation hydraulic model of the study area network. A hydraulic simulation based on an assumption that the quantity of water entering this part of the network is enough for the population of the avenue (300 l/cap/day), therefore if the produced simulated quantity (water supply) is larger than or equal to the consumed simulated quantity (demand) then the problem is in the network elements, such as pipes, valves, pumps,…etc. May be due to leak. However if the produced simulated quantity is less than the consumed simulated quantity, this means there are other consumption other than domestic, then we must increase the quantity of water supply to meet the demand.

Area of study:

The study area (as given by Google map 1) is known as Asma School neighborhood, is located in the centre of Ajdabiya, the area of the neighborhood is about 34 hectares, the population of the neighborhood is about 5485 people, and the number of houses is approximately 1095. The area is bordered by from north by Tripoli Street, with a length of about 850 m, and from south by the industrial district, with length about 650 meters long, and from east by Istanbul Street with a length of about 950 meters and from the west, Al Wifaq Street with length of 550 meters long. There are a number of 2 public schools, 2 private schools and 1 hospital. Drinking water is supplied to the water network through the main supply source of Ajdabiya city extending from Jallo South Road to Jazirah Al-Shuhada. The length of the line is about 15 km long, with a diameter of 700 mm. The diameters used in the city of Ajdabiya range from 50 to 700 mm, the depth of these diameters ranges from 1.5 m to 2 m to the bottom. The type of the pipes used in the networks is UPVC (6 bar pressure). The implementation of the networks almost began in 1995 until the end of the year 2001. Lengths and diameters are measured from the A0 size maps collected from the municipality of Ajdabya, Water utilities section. Number of inhabitants in each square are estimated by multiplying the number of houses(1095) by 5 (The average Libyan family), (5*1095=5475) multiplied by (0. 3 the average daily consumption per person / d), (5475*0.3= 1600 m3/d), then the value of the consumption in this square is divided by its number of nodes to find out the amount of water entering each node. Since the neighbourhood receives water from all sides in a streamlined form, a circular system. Therefore 4 tanks are assumed around the study area. The amount of water entering from each tank is (1600/4= 410 m3/d). Total length of the network is 10520 m, diameters ranges from 50 to 300 mm, no of pipes 131 segments.

Literature review

The introduction of the Hardy Cross method for analyzing pipe flow networks revolutionized municipal water supply design. Since before the method was introduced, solving complex pipe systems for distribution was extremely difficult due to the nonlinear relationship between head loss and flow. The method was later made obsolete by computer solving algorithms employing the Newton-Raphson method or other numerical methods that eliminate the need to solve nonlinear systems of equations by hand. Therefore a number of computer software were developed. EPANET is one of software applications used throughout the world to model water distribution systems. It was developed as a tool for understanding the movement and fate of drinking water constituents within distribution systems, and can be used for many different types of applications in distribution systems analysis. For instance, Alaa Hussein Al-Fatlawi 2019, simulated distribution network by using Epanet to enhance the efficiency of existing water distribution system of Al-Hilla province, and to reach an optimal solutions and assumptions in order to improve the hydraulic performance, and to increase the efficiencies of the water supply networks. The hydraulic analysis of the network is based on continuity at nodes and Hazen-Williams formula for head loss calculations by using EPANET2 software program under various scenarios. The EPAENT2 model was simulated the case study area to analysis the present water distribution network, and then a design improvement was carried out on the existing network. As a result, hydraulically balanced water distribution network for the targeted area in Al-Hilla province was accomplished. Thus, positive results of the hydraulics state of parameters around the network were successfully determined. One more research by Jahshan et al, 2012 analyzed the shortage in water supply and water services in Alsamou' town due to population growth. Hence, the water distribution network is not servicing all the areas in the town, and many pipes are old. The people in the town depend mainly on water coming through the network and on water tanking and constructed cisterns for water supply. In view of this bad condition, the need for water supply scheme that will supply the entire area of Al-Samou' town with water requirements become pressing, and subsequently this work was conducted to study and evaluate the present situation and redesign of the existing water distribution network using a water-cad software. The present study considered the annual population growth and their water demand for the coming 25 years was taken to be the design period, along. The hydraulic calculation needed for the design of the main and sub main pipelines was carried out using water-cad software. Recently, Tessema et al, 2015, reviewed the hydraulic performance of the existing distribution system of the city, Addis Ababa, Legedadi subsystem which is aimed to help the city understand its distribution system needs and assist them in long-term planning of water assets. The scope of the study was to evaluate the performance of the existing drinking water distribution system using hydraulic simulation software in integration with GIS, and recommends the possible remedies to improve the efficiency of the existing system. They proved that, there is hydraulic inefficiency in the existing water system to serve the city (Legedadi sub system) and to cope with the future demand. The outputs show that the network was exposed to relatively high and low values of pressure and velocity, which have negative effects on the performance of the network as well as in the water quality of the system. Besides, failure was forecasted in considering the age of pipes for reinstallation and maintenance. As a result, Pipes with ages more than 30 years are replaced and over and under sized pipes have been re-sized. Consequently, the Hazen Williams C-value has been totally improved and it enhances the system performance.

Theories and methodology

For constructing a hydraulic model, categories of inputs information are needed. The basic network model inputs should follow context of the techniques described with the used program. It is very essential for the data to be based on accurate, updated, carefully entered and frequently checked. The entire modelling process consists of the following steps; Input data collection, Hydraulic model building, Model testing, Problem analyses (simulation)

Input data collection

High quality information concerning demand, system dimensions, and materials are crucial for accurate simulation and results. Well-conducted fieldwork data collection are therefore a very important initial step of the modeling procedure. A large part of this information are missing or incomplete and the only real source available was the operator in the field. This was very helpful for collection a lot of specific information as a certain consumer with/without water or sufficient pressure.

General

Layout of the system such as:

– pipe routes and junctions; location of the main components.

– Topography – ground elevations in the area of the system.

– Type of the system – distribution scheme: gravity, pumping, combined; role of each system component; pressure zones.

These information are gathered with help of Google earth pro available on internet, Fig (1). The study area is lined by yellow line, from which coordinates of nodes can be measured easily.

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Fig 1, Lay out of the study area taken from Google earth pro

Water demand

– Demand categories present in the system: domestic, industry, etc.

– Average consumption, patterns of variation: daily, weekly, and seasonal.

The study area is classified as resident area, all water use is domestic, average consumption is assumed as 300 l/cap/day, based on maximum hourly consumption, (at 7 am is the maximum hourly consumption in a day of maxim monthly consumption). Demand at each node is calculated according to: the average water consumption in each residential area has to be converted into demand at a point (nodal demand). The conversion procedure based on two assumptions: (1) An even distribution of consumers, (2) the border between the supply areas of two nodes connected by a pipe is at the half of their distance. Therefore, unit consumption per meter of the pipe length can be calculated for each loop formed by m pipes:

$$qi = \frac{qi}{\sum_{j}^{m} 1Lj,i} \tag{1}$$

Where; $Q$is the average consumption within loop l, and $L_j$the length of pipe j forming the loop. Each pipe supplies consumers within the loop by a flow equal to:

$$Q_{j,l} = q_l \times L_{j,l} \tag{2}$$

For a node i connecting two pipes of loop l, will have the average consumption:

$$Q_{i,l} = \frac{Q_{j,l} + Q_{j+1,l}}{2} \tag{3}$$

One pipe often belongs to two neighboring loops i.e. one node may supply the consumers from several loops. The final nodal consumption is determined after the above calculation has been completed for all loops in the system:

$$Q_i = \sum_{l=1}^{n} Q_{i,l} \tag{4}$$

Where; n denotes the number of loops supplied by node i.
Nodal demands for the study system calculated by the Eq. 1 through 4 are tabulated in Table 1. The required base demand at maximum and minimum consumption hours is considered as well. Worth to mention, throughout the process of model calibration, the nodal demands calculated in this way are adjusted to be very close to the reality.

Network components characteristics

- Nodes (discharge points), including:
  - Ground elevation (Z) and
  - Average consumption and dominant categories.
- Pipes, including: The initial step in constructing a network model is to identify pipes to be included in the model:

- . Length,
- Diameter,
- Material
- Age, and
- Pipe roughness

These information are collected from A0 size maps provided by Water sector utility, Municipality of Ajdabiya. Length of pipes in the network is 10520 m, about 77% of the pipes with 50 mm diameter, about 4% of the pipes with 300 mm diameter as given in table 2. Pipe roughness are estimated by;

Table 1, Nodal demands for the network

Base demand	Nodes	Base demand	Nodes
7.5	4-3-2-1	21	77-78-56-58
8	10-9-8-7	21	74-76-75-69
12	17-13-12-10	22.5	51-56-77-71
15	20-19-15-18'	22.5	60-70-51-48
16.4	21-21-20-19	22.5	61-67-69-64
16.5	24-23-22-21	23	48-60-47-64
16.5	76-73-74-76-78-79	24	41-42-34
18	75-72-74-73	26.7	41-48-38-36
18	68-67-61-69	27	8-6-32-30
18	66-63-46-65	27	29-31-26-30
18	42-44-45-46	27	8-33-32-34
18	34-43-44-"-45	27	36-38-37
18	79-76-73-78	30	33-35–37-36
33	-49-48-51-50	30	40-36-39-35
36	54-56-57-58	32.4	25-2-6-26
36	54-56-51	33	48-49-13-47'2
39	50-24-57	45	29-25-28-27
39	51 -53-52-555	45	51-60-48-41
39	53-55-50-54	200	3-4-6-5
200	7-6-5-4		

$$C = 18.0 - 37.2 \log X \quad where\ X = \frac{(e_0 + at)}{D} \tag{5}$$

Where e_0 = initial height of internal pipe roughness at time t=0 (mm); a= growth rate in roughness height (mm/year); t = age of a pipe; . D = pipe inner diameter (mm); and X = time-varying relative roughness. The literature on pipeline hydraulics was reviewed to find appropriate values of initial roughness height e_0 and roughness growth rate a. Sharp & Walski (1988) reported an initial roughness height e_0 for new metal pipe is 0.18 mm in common sizes (150–600 mm). Moreover, they performed a regression analysis using Eq.5 and data from Lamont (1981) and Hudson (1966) to find roughness growth rate a with relating to the corrosivity of the water, those growth rate are shown in Table 3.

Table 2, Summary of pipe lengths and diameters of the network

diameter (mm)	no of pipes	Length (m)
50	105	8130
63	8	630
75	3	350
110	3	350
225	4	260
233	2	340
300	7	460
Total		10520 m

Table 3, Roughness growth rate *a* (mm/year) in literature

Researcher(s)	Water corrosivity		
	Slight	Moderate	Severe
California Section of the AWWA (1962)	-	0.34	0.61
Hudson (1966)	0.015	-	0.61
Lamont (1981)	0.025	-	0.76

In this paper, by considering the water quality (moderate to severe), type of the pipes material and the low maintenance services in Ajdabya distribution system, growth rate a was set to 0.5 mm/year for all pipes. In addition, an initial roughness height e_0 of 0.2 mm was chosen for all diameter pipes encountered in the study system to roughly match the relative roughness value reported in Sharp & Walski (1988) and to obtain a C factor of 140 for new ductile pipe. However, pipe friction factors were calibrated and adjusted after the first run of the model to represent the effect of aging over the simulation duration. The adjustments were made to account for increase in resistance to flow caused by corrosion as a pipe ages and to simulate the real system behavior.

Other Network components characteristics are:

- Service reservoirs – type (ground, elevated), capacity, minimum and maximum water level, shape, inlet/outlet arrangement.
- Pumping stations – number and type (variable, fixed speed) of pumps; duty head and flow and preferably the pump characteristics for each unit; age and condition of pumps; efficiency and energy consumption.
- Valves, type and settings.

Four ground tanks (reservoirs) are assumed to control the water flow into the network, their characteristics are given in table 4. No pumps neither valves are fixed on study network.

Table 4,characteristics of network reservoirs (tanks)

Type	No	Dia (m)	Min. water level	Max. water level	Shape	Inlet/ outlet
Elevated	4	50	2 m	10 m	Cylinder	300/400 mm

Operation control Inputs

Finally, a number of parameters which control the simulation run itself have to be specified in the input: duration of the simulation (72 hrs is considered), time intervals (1 hr is considered), accuracy (as defaulted in software is considered), preferred format of the output, etc. Based on the earlier input, the raw results of hydraulic simulation are flow patterns for links, and piezometric heads recalculated into pressures and water levels for junctions. With the correct execution of all the previous steps, the analysis of the problem is the final step of the modeling process and probably the shortest one. A lot of typical problems can be solved by the help of a computer model. However, in this paper the problems being analyzed is the analysis of failures scenarios of the main system pipes. Solution techniques used to iteratively solve the set of non-linear equations typically have various global parameters that control the solution technique. These parameters may be time-step lengths for EPS runs or tolerance factors that tell the model when a solution is considered to have converged. The user must specify A Reference Guide for Utilities the values for the solution parameters, or (as is frequently done) accept the default values that are built into the software products. The specific solution parameters vary between solution techniques and specific software products.

Results and discussion

As mentioned previously, the hydraulic simulation was based on an assumption that the quantity of water entering the network is 1600 m^3/d which is enough for the population of the avenue (5475 people), therefore ,it was stated, for the existing condition problems of the network, if the produced simulated quantity (water supply) is larger than or equal to the consumed simulated quantity (demand) or if the produced simulated quantity is less than the consumed simulated quantity then the problem is relating to the network, specifically deterioration of pipes, valves or pumps. However. This problem can be happened too, if there are consumptions other than domestic, or illegal connections, or due to geometry arrangement of the network or sizes of number pipes in the network, in this case either finding the reason or simply increase the quantity of water supply to meet the demand specially if the problem relating to geometry arrangement of the network or need to large work of network rehabilitation . Accordingly, the hydraulic simulation was built. Once simulation is being running the amount of produced water found less than consumed along the 24 hours of the day, this is shown in the following figure 2.

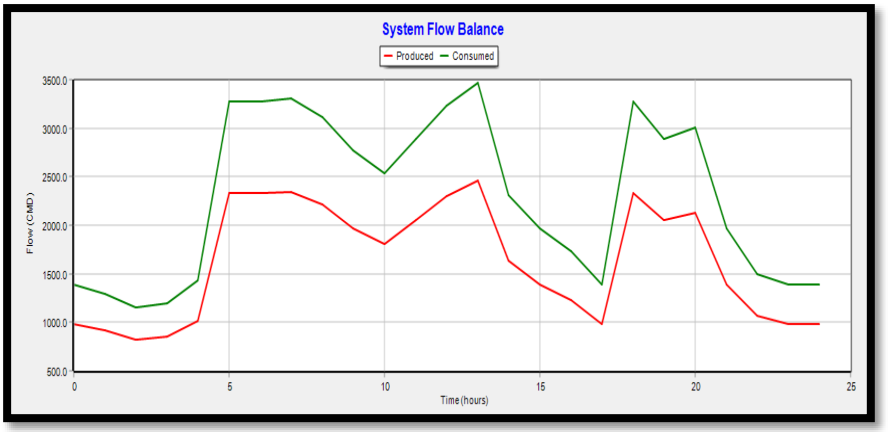

Fig 2, produced water comparing with consumed quantity of water

This shows that there is an actual problem in the network, where demand (consumed) in the study area are larger than the supply quantity. However, to find the pipes that are suffering of water shortage, simulation is running at peak hours (between 7-8 am), fig 3 shows the flow in each pipe and the pressure at each node in the network, it is obviously pipes with blue colors are pipes with small flows.

A Solution proposal to the study water network

From the information gathered from Asma neighborhood and from Ajdabiya network facilities on the neighborhood. It was found that the network consumption is 1640 m^3 / day is not enough. Even though it is calculated on bases of population and average water consumption of $0.3m^3$/d/capita. Among the mentioned probable reasons of this kind of water supply problem, it is obvious this shortage due to deterioration of the network and large water leakage in additional to pipe sizes, where 77% of the pipes are relatively very small in size (50 mm). This size expose the pipes to very rapid deterioration specially in presence of low quality of water and aggressive soil. Hence to supply water on 24 hours a day without any shortage , the neighborhood needs to be supplied by 2360 m^3 / day and not 1640 m / day. i.e at least 720 m^3/d must be added to the existing supply. This is done by maintaining a tank located in the neighborhood or to pump directly from the source. The effect of this additional amount of water let the supplied amount of water is just larger or equal to the consumption amount, fig 4 illustrated that.

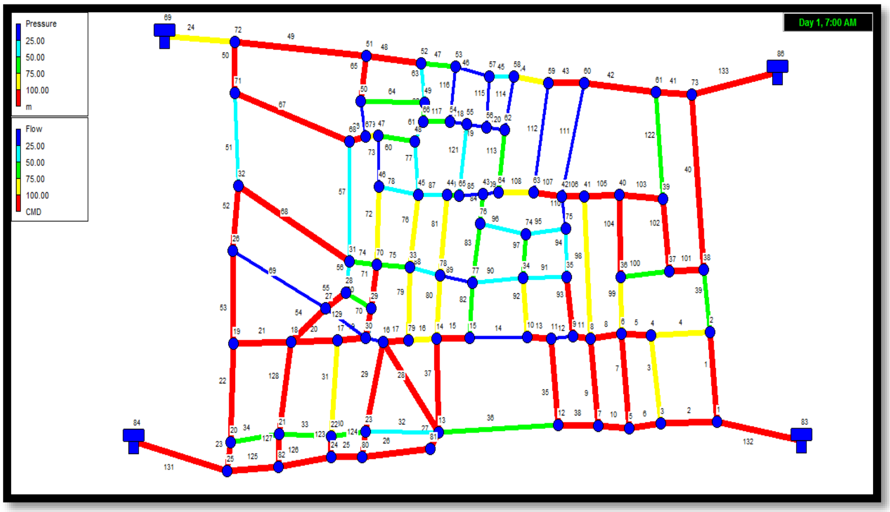

Fig 3 flow in each pipe and the pressure at each node in the network at peak hour 7 am

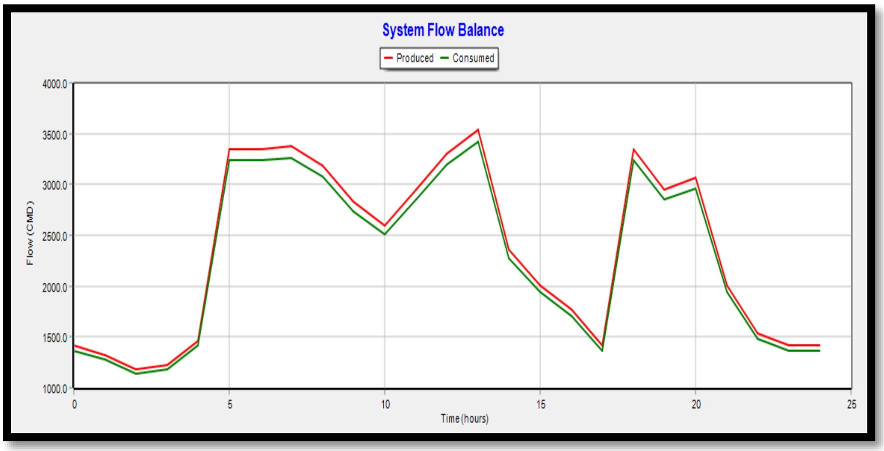

Fig 4 shows how water supplied is larger than water consumed by adding 720 m^3/day to the water network.

Following to this additional quantity, the flow and the pressures at nodes are improved as well. Table 5 shows how pressure improved in the network, where minimum pressure increased to 7 m instead of 5m.

Table 5 pressures and flows in the network before and after adding 720 m^3/day

Nodes with pressure less than:	Number of nodes in:	
	Existing status of the network	Status after network enhancement
10 m	81 out of 85	76 out of 85
9 m	61	64
8 m	56	50
7 m	49	12
6 m	37	0
5 m	25	0
4 m	0	0
3 m	0	0
2 m	0	0
1 m	0	0
0 m	0	0

Conclusion

In this paper, Epanet program was used to solve the problem of water shortage in one of the neighbourhoods of the city of Ajdabiya. The hydraulic model was built according to the available data from the water sector in the municipality and the data obtained from Google Earth. We found that the problem that the study area suffers from is; the water in the network is less than the requirement (demand), although we assumed that the amount of water reaching the area (supplied) corresponds to the number of residents and their average daily consumption. This means that there is a problem in the network elements, i.e aging of the pipes (more than 25 years old), or due to the small size of the pipes, as we noticed that 77% of the network pipes are 50 mm in diameter which is relatively small. The water shortage was determined through the hydraulic model. Many scenarios to solve the problem are tested, we thought that the most cost effective an fastest solution is to pump a determined difference amount of water between produced (supplied) and consumed (demand). With this added quantity, all the area's water demands were covered.

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