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Analysis of the Urban Water Requisition Demand for the Purpose of Re-engineering and Water Network Optimization (Case Study: Tabriz' Eram Urban Area)

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Abstract

Water shortage is one of the most important challenges of this century and it would be a serious obstacle for the mankind. In the near future, drinking water supply and water resources management will be at the forefront of planning for urban managers, which is becoming a crisis due to the serious shortage of water resources. This problem is more critical in country of Iran, where water depletion is now receiving serious attention. Different water management programs have been started by government to conserve and manage water more efficiently, especially in some critical areas such as Tabriz megacity located in North East of the country. Eram town is one of the problematic areas of Tabriz. Hence, in this study, we tried to do reengineering for this town to offer some solutions for the problems related with water supplying of the implemented network in this region. Regarding this issue, the GIS (Geographic information system) data of the available water supply network was used and the collected field data such as consumption rates in current conditions were applied to the network. Then the calibration of model was performed. Eram Town water distribution network reengineering has been performed considering a 2043 plan, taking into account population growth and the increase in consumption. In conclusion, it is suggested that, the network will perform more efficiently by adding new pipes or modifying the existing pipes. Also, the problem of lack of pressure in some parts of the network which cannot fulfill the requirements of subscribers at peak water usage hours, could be solved.

Keywords: Water Distribution Network; Eram Town; Calibration; Re-Engineering; WaterGEMS.

1. Introduction

Nowadays there are lots of problems related with the access to water in different areas and the expansion of existing networks for water supply in urban and industrial areas. In order to solve these issues it is necessary to recognize the hydraulic behavior of networks. Hydraulic analysis of a water distribution networks is the first step in designing of the city's water systems. Modification of the old networks along the development of residential areas requires elaborate hydraulic analysis. A well-constructed network must be able to provide adequate pressure for consumers in whole day. If the network has hydraulically drawbacks, this aim cannot be met [1]. To properly analyze the water distribution networks, having accurate information and also taking into account the operating conditions in the region is essential. These systems are generally constructed to deliver services for a range of consumers. However, the amount of consumers' needs is dynamic and may vary over time and designed systems gradually can be deteriorated. Therefore, in order to lessen the system adaptation costs, it is necessary to insert a level of flexibility under uncertainty [2]. In some

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cases, by performing the design without detailed information, the design life will be less than anticipated, and so an urgent need for modification would be arisen.

After construction, monitoring of the water distribution networks is essential for ensuring the optimized and safety performances. Some researchers used practical methods to acquire developed outputs from Water Network modeling optimizations [3]. In other studies new methods such as Demand Reverse Deduction (DRD) technology was utilized to screen the Water supply network [4]. Analysis of flow, pressure and speed in the water supply networks is vital, especially in the parts that there are changes in the rate of reserve or consumptions [5]. Also in conditions that new consumers are added to the existing network or other supply sources to be added to the system, performing such analysis will be necessary. Redesigning of a water network system is done due to improve the efficiency of it. This process is done to enhance the quality and quantity of infrastructure facilities and structures. The main purposes are modifying the current situation with the contrasts of research objectives, a review of the plan to optimize the energy consumption, utilization costs and enhance the lifetime of the network during the period.

The initial parameters modification would have different effects on re-engineering. To apply re-engineering, the following three stages are considered: 1. functional-economic analysis, 2- functional and collected information analysis, 3. the application of the obtained information from the previous phases and modifying the water network, which is necessary to improve network's performance and enhance its lifetime.

Several investigations have done on reliability of water distribution system [6, 7], and various methods are used for this purpose [8]. Furthermore, some research is concerned with the capacity of the distribution system with reference to growing demands over a planning horizon [9]. In a study for Tirunelveli Corporation the sufficiency of the existed pipelines for the design year of 2044, is investigated by utilizing Loop and WaterGEMS software [10].

WaterGEMS is a hydraulic and water quality modeling solution for water distribution systems with progressive interoperability, geospatial model-building, optimization and asset management tools. It provides an easy-to-use environment for engineers to analyze, design and optimize water distribution systems. According to some researches, the problems of providing pressure for urban water supply network in part of Yorkshire in northern England with an average demand of 400 liters per second has been studied and the modeling and optimization has been done using WaterGEMS software to provide adequate pressure at all hours of the day [11]. Jiang et al. have investigated the process of hydraulic modeling in WaterGEMS software using GIS data to achieve optimal design of water supply networks. Also, the impact of selecting optimal diameters as a very important parameter to achieve peak engineered network with economic justifications has been described [12]. Moreover, in order to apply pressure management to decrease water losses in two Greek cities (Kos and Kozani), WaterGEMS V8i was utilized to simulate the network's hydraulic operations [13]. Additionally, in Iran, some recommendations have been made for the re-engineering of Mianeh City water supply, using the neural network by the WaterGEMS software [14].

Regional development and demographic changes of Eram Town has led to some problems for the consumer and Water and Sewage Company has received several complaints. Hence, it would be necessary for the authorities to re-engineer the existing network at reasonable time periods. East Azerbaijan Water and Wastewater Company can use the results of the plans in order to solve the problems of regional water supply network and to meet the standard pressures in different parts of the network. Therefore, in this research, by considering the affecting factors, it is tried to simulate and optimize the existing network of water distribution in the area for solving water supply problems in the region. So that in addition to reach required efficiency, network maintenance costs during its operational life can be minimized and unnecessary costs such as additional piping in the network can be prevented. For this purpose, after collecting information from the (East Azerbaijan Province Water and Wastewater Company), field work and using the regional data in the ArcGIS, the water network was modeled in the WaterGEMS Software, as strongest and most advanced software in design of water supply networks, and then re-engineering of them was carried out with the objective of reducing costs during the operation of the network.

2. Problem Statement

Problems of the Eram town distribution network include:

- Insufficient pressure in some parts of the network, due to non-standard and traditional piping, which cannot satisfy the regional people;
- Ample water loss as a reason of outdated network, i.e. the problem of fracturing pipes that are wasting purified water;
- Old piping without network design;
- Low Velocity which is less than the standard range;

- Branching in some parts of the network;
- Inadequate fire hydrants in the network;
- Unauthorized withdrawals from network.

The information needed to analyze has been applied considering both nodes in the current situation, and the current population using the network. Checking the pressure of the network at its peak times shows that negative pressure can be seen in about 20% of the network; so the network engineers should take this issue into account. Also very low and negative pressures represent the inappropriate pressure distribution in the network leading to the dissatisfaction of various users in the region during its peak utilization. Also during these times, many parts of the network have the trouble of water outage. The reason for inappropriate distribution of pressure is due to the traditional and non-standard network used in this region. To fix the problems temporarily, switching valves that are used in network; however, a permanent solution to this problem is to redesign the network, which has been considered in this plan. Pressure should be distributed in such a way that on all nodes, an appropriate pressure is prepared and the network gains its standard mode. In addition to the pressure, the speed inside the pipes must also be examined. A suitable range of speed is between 0.3 to 2 m/s. In this paper, the water velocity within the nodes has been analyzed via WaterGEMS software with regard to diameter, length and pipe material.

Accordingly, in some pipes a very low speed can be measured due to the previous reason that the piping system is timeworn and also its diameters are non-standard. Studies demonstrate that if the necessary changes considering consumption and population growth in the future plan is not performed, the network will not meet the needs and in 85% of water network areas we may face water outage in high-consumption hours. Therefore, necessary actions must be taken to solve this problem altering the condition. Moreover, the studies also show that if the prospective consumption is applied in the current network, we may encounter a serious problem of water outage about 90% of the network, and actually, the network would have no ability to meet the needs of consumers. To avoid this problem, re-engineering of the network is necessary to solve the emerging problems and to reach the network's optimum efficiency. Regarding this, an efficient and effective plan must be provided. Due to economic reasons, we could not utilize the optimizing section of software in this study. To compensate this limitation, only the current size of existing pipes has been modeled, and also, by focusing on the parts with pressure problems, it was tried to modify the system, considering the minimum length and diameter possible for the new pipelines, so the pressure in the pipes can reach the standard efficiency.

3. Materials and Methods

In this study, WaterGEMS software was used as powerful software in the design and analysis of water distribution networks. This application is one of the most accurate and up to date software in water network analysis. This software provides a common powerful graphical tool with GIS model (Geographic information system) and mode [12]. WaterGEMS is a computer program that simulates period of hydraulic and water quality behaviors in the under pressure pipeline networks. It simulate water flow in the pipe, the pressure at each node, height of the water in each tank and the concentration of a chemical substance across the network during a simulation period comprised of several time steps. The program can be used for various applications in distribution systems analysis. The technique used in this software for network analysis is the Newton-Raphson method. For modeling the network, the necessary information must be available. Information needed for Eram Town water network modeling include: a) Maps and network data in GIS environment, b) topographical map of Eram Town, c) people consumption. GIS is an extensive application created by ESRI Company that can be used for drawing engineering and industrial maps. This system is for creating, managing, integrating, and analyzing geographic data. In GIS, objects are spatial and non-spatial data and operators are commands that are related to land-based processing, applied to edit, analyze and display the objects.

Eram Town water network include 6000 water users, and 40 km distribution network made up of asbestos, polyethylene, iron and PVC pipes with 130 valves and a fire hydrant, which is outdated and without proper design. In this study, GIS data of water network has been provided by East Azerbaijan Province Water and Wastewater Company. For users consumption in terms of use, reading statistics, water production statistics, high consumptions, consumption changes (climate change, daily, seasonal, hourly), types of use (domestic, commercial, industrial, administrative, etc.), water loss factor , types of losses (tanks rinse, lines fracture, meter inaccuracies, unauthorized use, leaks, washing lines, unauthorized withdrawals) and fire-fighting consumptions should be available. To do this, annual consumption statistics was received by the East Azerbaijan Province Water and Wastewater Company, of Tabriz and the average annual consumption was determined for different applications. According to the annual consumption statistics of Water and Wastewater Company of Tabriz, consumers and calculating the average consumption for each user with different amount of use for each domestic user, 0.007 liter per second and for each commercial user 0.004 liters per second are considered. To apply consumption on nodes, firstly the number of users between two nodes considering type of use and their consumptions are determined, and then we allocated half of users between two nodes to the first node and the other half to the end node. At the end, the loss of network is also applied; other consumptions due to their low consumption are considered as domestic and are applied to network. To extract consumption pattern of Eram Town, and applying it in the program, the output flow meters installed in the tank was read 24 hours, and consumption percentage of consecutive hours obtained as shown in Table 1. The result of multiplying two coefficients of hourly and daily rate is equal to 2.61. So 2.6 are multiplied with average percent of consumption (4.17). The resulting number is 10.89. The nearest percentage of use between two hours from the reading time table is 10.29 percent which is relevant to the time of 12 to 13. So the model was implemented for the hours of 12 to 13.

Table 1. Consumption of water in 24 hours

No.	Time	Meter number	Consumption between the two hours (m^3)	Consumption percentage between the two hours
1	7	0.00000	124.98746	4.8
2	8	124.98746	146.15396	5.72
3	9	271.14142	166.42732	6.5
4	10	457.56874	185.74491	7.25
5	11	642.31365	230.99739	9.17
6	12	872.31104	263.14117	10.29
7	13	1135.45221	212.01234	8.3
8	14	1428.46455	215.84669	8.42
9	15	1347.31124	117.82988	4.59
10	16	1462.14112	71.42020	2.77
11	17	1535.56132	109.17046	4.52
12	18	1644.73178	118.36182	4.62
13	19	1762.09360	126.29601	5.01
14	20	1888.38961	101.78517	3.96
15	21	1989.17478	112.00256	4.39
16	22	2101.56315	87.02151	6.3
17	23	2188.56571	83.99943	3.36
18	24	2271.49514	63.82906	3.25
19	1	2334.32422	32.19076	1.21
20	2	2366.51496	18.35665	0.7
21	3	2384.87164	21.80487	0.82
22	4	2405.32158	24.63010	0.93
23	5	2429.30661	59.34139	2.38
24	6	2488.64801	67.68854	2.63
25	7	2555.33654		
	Sum	2555.33654	2555.33654	100.00

4. Case Study

4.1. Eram Town Geographical Location

Eram Town is located in the North West of the Tabriz. Tabriz is the most important city of East Azerbaijan Province. It is located in the east longitude of 46 degrees and 17 minutes and north width of the Greenwich meridian of 38 degrees and 5 minutes and in the altitude of approximately 1350 meters above the sea level. Eram town also has an average altitude of 1460 meters above sea level. According to the last census in 2011, Tabriz population was over 1.800.000 people. With an area of 237.45 square kilometers, it has a population density of 7,500 square kilometers. The summary of foundations and assumptions of the water distribution network of Eram town can be seen in Table 2. The period of plan suggested in this study is 30 years from 2013 to 2043.

Table 2. Summary of principles and assumptions of the water distribution network in Eram town of Tabriz

Year 2013	Year 2043	Year
5978	10871	number of Subscription
2.01%		Population growth rate
200	200	The average per capita consumption (liters per day)
1.45	1.45	Max daily factor
1.8	1.8	The maximum hourly rate
30 years		Plan period

The last part of the water that should be considered in the calculation of water consumption per capita is water losses. The amount of losses in the network under the best circumstances should be considered about 10% to 15% [15]. About 50 percent of this loss, in the absence of suitable precautions, is related to the inappropriate distribution network. Figure 1. that shows the amount of production, consumption and loss of water between the years 2009-2013.

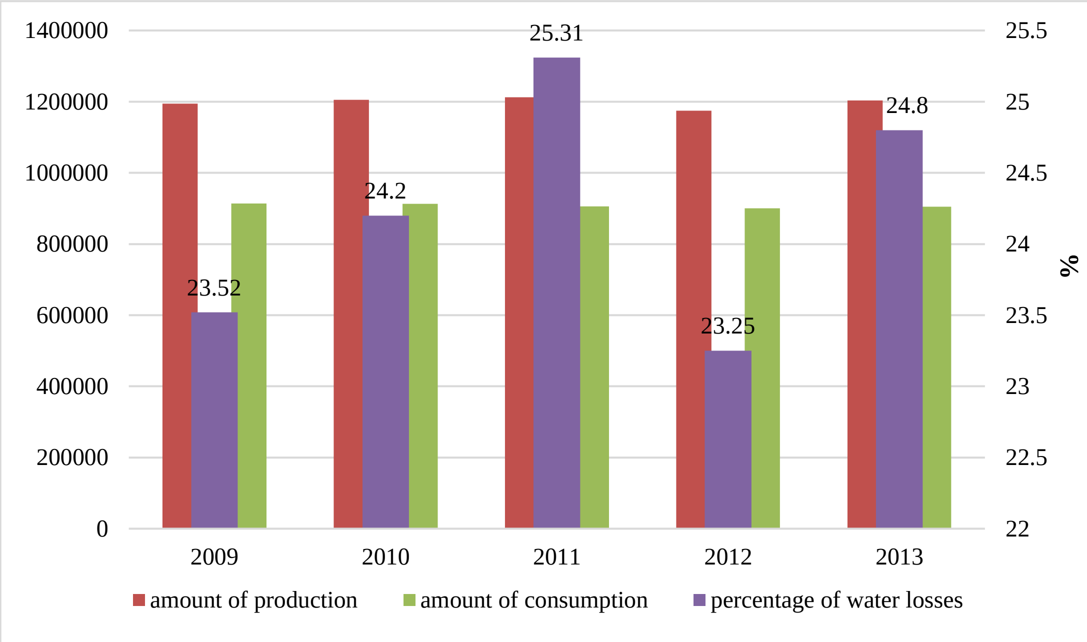

Figure 1. The amount of production, consumption and the percentage of water losses between 2009-2013

According to this diagram, and considering the report of East Azerbaijan Water and Wastewater Company, water losses due to old network is about 30%, while the average per capita water losses should not exceed 20% of the total average consumption of households, commercial, industrial and public green space [15].

4.2. Design Criteria of Water Distribution Network in the Eram Town

The highest floor of buildings that the water pressure must be provided directly from the network is equal to 5 floors. The minimum pressure at rush hour consumption is 1.4 to 3 atm. The minimum water velocity in rush hour is higher than 0.3 m/s. Maximum water velocity is 2 m/s and in fire conditions are 2.5 m/s. In the streets with a width of more than 20 meters, two parallel pipelines can be used on both sides of the street. Fire station's required regulations have been done based on their standards [15]. Friction coefficient for polyethylene pipes has been considered equal to 130. Polyethylene pipes with diameters of 75 to 125, 110 and 200 mm have been used in the town.

5. Results and Discussion

Trying to identify the parts of network facing low pressure at peak times and according to Table 3, with economic considerations, the pipes are modified with regard to the standards and by adding more pipes. This means using the lowest standard diameter pipes in the parts of network with pressure problem. Polyethylene should be chosen as its material, because of its longer durability and lesser fragility.

Table 3. Pipelines added to compensate the negative pressure

No.	Address	End node	First node	Material	Size	Length	Pipe Number
1	Between two nodes in Enghelab Eslami St.	141	107	PE	80	134.48	232
2	Between Sadaf School and Hazrat Roghaye School	128	56	PE	80	31.65	233
3	Between Jahad Elmi-Karbordi University and Nasim Alley	48	81	PE	80	22.34	234
4	Between Yasaman Alley and 12 meters	167	136	PE	110	41.5	235

As shown in Table 3. to compensate the negative pressure in network 4, a pipeline has been added to the network, which can increase the negative pressure in critical points to an acceptable level. Therefore, by adding these pipes to the distribution network, water pressure in the peak time of consumption, reaches a desirable amount and the discontent of the population from the existing situation might be resolved and there would be no need to store water during the night for the high-consumption hours of the daytime. In addition, to achieve an optimal network, some parts of the network which are branched should be amended to a loop form to prevent water stagnation. The pipes that are placed in the network for this purpose are shown in the Table 4.

Table 4. Pipeline added to create a loop network

No.	Address	End node	First node	Pipe length (m)	Material	Size (mm)	Pipe number
1	Between Sina Alley and 12 meter Kosar	116	51	27.6	PE	80	236
2	Between Shekofeh Alley and Electrical Trans	47	122	16.32	PE	110	237
3	Between Golriz Alley and Hazrat Roqayaeh Mosque	163	141	12.65	PE	80	238
4	Between Janat Shomali St. and Laleh 1 Alley	187	105	14.32	PE	80	239
5	Between Janat Shomali St. and Shahriyar Alley	217	119	18.4	PE	110	240
6	Between Janat Shomali St. and Eram Sport Saloon	64	87	14.45	PE	110	241
7	Between Golriz Alley and Shahid Rajayi St.	98	41	11.14	PE	110	242
8	Between Elmi-Karbordi Center, and Nasim Alley	35	127	100.47	PE	110	243
9	Between Behesht Alley and Kalantari 23	168	9	14.96	PE	80	244
10	Between Sherafat School and Nasim Alley	174	31	100.54	PE	110	245
11	Between Shahid Bakeri Stadium and Bonyad Maskan	103	86	31.47	PE	110	246

In addition to added pipes, some pipes of network according to Table 5. should be also modified to meet the users' needs in the prospective plan. Due to the increase in consumption, in the prospective plan, the network requires larger main pipes in comparison to their current size. So that sufficient amount of water is entered to the network providing the desired pressure.

Table 5. Modified pipelines in order to meet the increasing demand in the prospective plan

No.	Pipe number	Pipe length (mm)	Pipe size (mm)	Pipe size after modification (mm)	Material
1	117	331.36	350	400	PE
2	118	174.55	350	400	PE
3	122	849.36	350	400	PE
4	168	129.09	250	300	PE
5	159	107.15	200	250	PE

As can be seen in Table 5, for the network to be able to meet the needs of consumers in the prospective plan, it has been tried to least number of pipes with a minimum diameter to be modified for economic considerations and for a minimum costs to be spent on repairing water supply network. Considering the changes was applied to reach the network to the standard mode in the prospective plan including the addition or modification of some pipes, the network was again analyzed by WaterGEMS software. By examining the resulting pressure, it can be seen that the problems of negative and very low pressure in the network were solved and the network is in standard mode. Figure 2. shows the network models after re-engineering and modification (addition of new pipelines and modification of some pipelines).

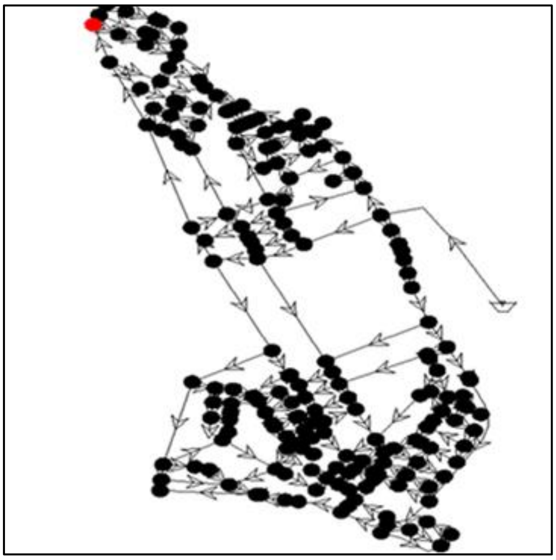

Figure 2. The network model after re-engineering

The results show that after re-engineering, the pressure of critical points has reached to standard mode, that considering this issue, the water outage in the network will be resolved. In addition to the above points, the pressure in the distribution network will be on an optimal situation. Due to the re-engineering has been done to improve the situation of pressure nodes, the velocity values in pipes also rapidly increased and reached to the standard range. Pipes that currently and in the prospective plan have velocities lower than 0.3 m/s, after modification and addition of the appropriate diameter pipes increased to an acceptable level. Pressure condition and the speed of the network after the re-engineering shows the importance of good design and optimization of the distribution network. If this can be performed, a significant progress will be provided in solving the problem of inadequate pressure and inappropriate speed network and the satisfaction of consumers.

Comparing the results of performing the re-engineering on the network with the current status and the condition of network in the prospective plan before modification, shows that at the peak hours pressure in some parts of the distribution network is negative and at this time they are faced with the problem of water outage. The pressure in these points is compared as can be seen in Figure 3.

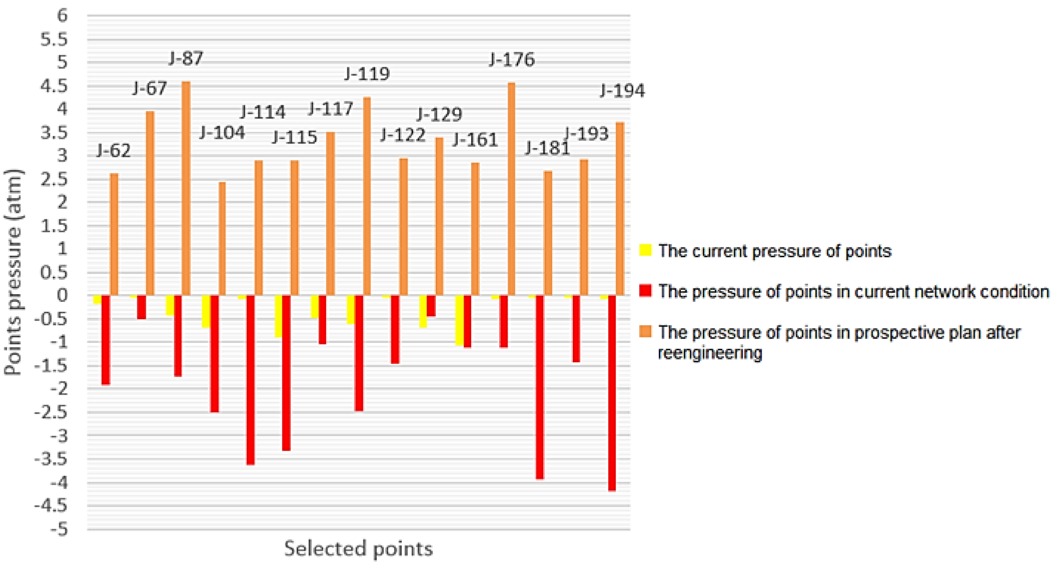

Figure 3. Comparing the low pressure points before and after re-engineering of network

According to the results of the re-engineering on the network and compare it with the current status and network conditions before modifications, the status of some parts of the distribution network which have negative pressure and water shortage in peak hours, are improved to an accepted level. Hence, critical nodes in peak hours would not face with water outage. Figure 4. is illustrated the status of other low pressure points.

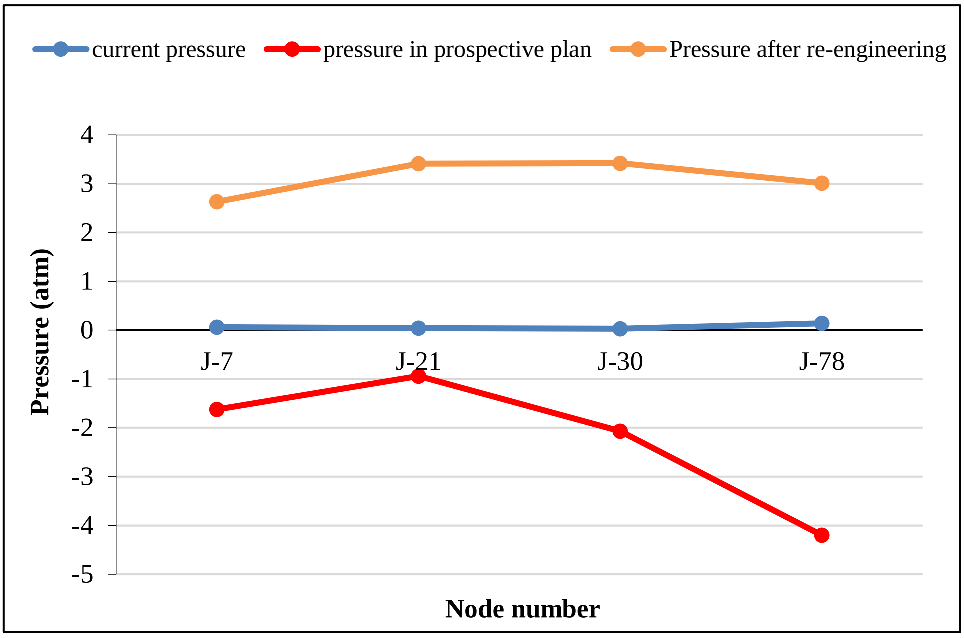

Figure 4. Comparison of pressure condition in the nodes of 7, 21, 30, 78 currently, before and after the re-engineering in the prospective plan

As can be seen in the figure, the pressure in points that already has a value close to zero, and in the prospective plan would be negative pressure, after redesigning has reached to an acceptable level and network re-engineering has fully addressed the certain problem of these points.

Furthermore, in the current status of plan, the velocity of water in network's pipes is very low. In some cases, less than 0.3 m/s, which is the minimum amount of regulation, was observed. In Figure 7, the speed status in current conditions and after the re-engineering is studied. According to this figure, it is observed that water velocity which has very low values currently, after the network re-engineering and modification improved and placed in a standard range.

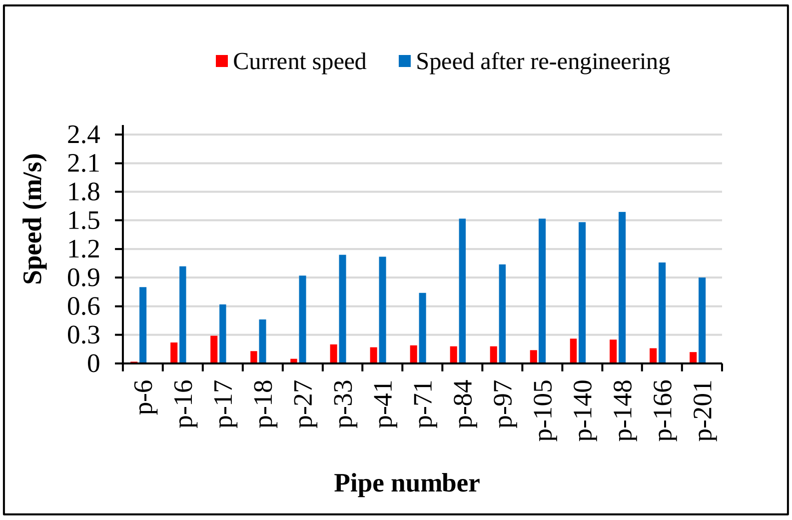

Figure 7. Comparison of the current velocity and the velocity after re-engineering

Moreover, according to Figure 8, it can be seen that by the addition of the standard diameter pipe into water distribution network of Eram Town, the pressure and velocity conditions which currently and in the prospective plan are not in a good situation, have improved. This figure shows the pressure and velocity of the entire network in different times.

Also, the entire distribution network in the prospective plan considering consumption increase, after re-engineering of the network and modification of main pipes diameters about 15%, in terms of pressure and speed is placed in a desirable status. These changes will cause the network outages to not face water outage in peak hours of consumption.

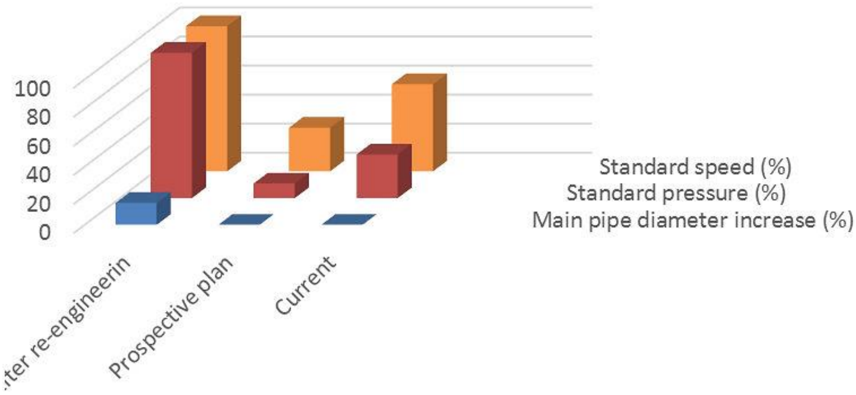

Figure 8. Standard Velocity (%), Standard pressure (%), Main pipe diameter increase (%) After re-engineering, in Prospective plan and in Current situation

6. Conclusion

In this study, first, the problems regarding the water distribution network of Eram town have been addressed, considering the current hydraulic conditions; then, according to the prospective plan of the year 2043, the Eram town water-supply network has been redesigned applying the necessary changes, and its results have been analyzed. Maximum consumption discharge in the current condition has been analyzed in WaterGEMS software, and the causes of problems regarding to the utilization of this network have been examined. By performing re-engineering in Eram town of Tabriz and applying the previously-suggested alternations, the problems of the network were resolved. In addition, the network pressure mentioned in the prospective plan, would uphold the standard pre-defined ranges in times of consumption peak demand, and hydraulic conditions would be closer to the ideal state. Due to the economic viability of the plan, least number of pipes was added to the network or was modified in case of necessity. As a result, by applying minor changes in the network, the problems of (a) pressure privation and (b) consumers’ needs fulfillment have been resolved, and the hydraulic conditions of the network have approached to its ideal state. Also it is worth mentioning that due to the outdated system of the network, the pressure distribution within the network is incompatible; to be precise, some areas tolerate an atmospheric pressure of 8 and above, while adjacent areas contain low pressures. High pressures may cause damage to the network, wasting a considerable amount of the expenses. By performing re-engineering of the network, this problem was resolved and the pressure distribution within the network is now ameliorated. The proposal should have economic justification. Hence, the points of network with problems are paid more attention and modification and adding new pipes to the network is commenced from these points.

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