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Optimization of Drinking Water Distribution Networks (Case Study: Assiut City-Egypt)

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Abstract: ***This research studies the optimizing and strengthening of Assiut water-distribution network, Egypt and the effect of pumping operational conditions on the pipelines pressure and flow velocity. The Results indicate the following: (1) when switching off the small pump station and increasing the head of the biggest one by 30 m, the pressure head dropped to 4 m during time of maximum demand, (2) the best scenario for present optimization process of the network under study is duplicating the large pump flow rate, and, (3) in case of achieving the present optimization process, at year 2025, the pressure head at times of maximum demands will drop to be 47 m and the velocities in some pipelines will be > 1.80 m/s.***

Keywords: flow rates, operational conditions, pipe network, pressure head.

1. Introduction

Water distribution systems are designed initially for a pre-decided design period. At the end of the design period, the water demands may exceed the system design capacity because of the increasing in population density and/or the extension of services to new growth areas. To expatiate and manage the increase in the portable water demands, it is required either to entirely design a new system or to reorganize/optimize the existing one.

Attempts to improve the carrying capacity and operational conditions of existing system and to find the optimum operational conditions of the pump stations and network, such as flow rates, water pressure, flow velocity all over the network, is called strengthening of an existing water-distribution system. Some studies have been conducted considering the reorganization and strengthen water distribution networks [1]-[11].

Ali [12] presented some potential factors such as the best area of closed loop which satisfies the minimum preliminary costs and the optimum velocity for sizing pipelines of network which affect the hydraulic and economical design of water supply networks using the hypothetical assumption of uniform lateral demands along the pipe lengths. He found that the area served by any closed loop should be about 30 hectares which in turn satisfies the min preliminary costs and the design velocity for sizing pipe diameter should be 0.7m/s.

Mohamed and Abozeid [13] conducting dynamic simulation of pressure head and chlorine concentration in the abnormal system operating conditions of Assiut city water supply network over an extended period. The effect of roughness variation with time on pressure head distribution and water quality was simulated. Also, the leakage due to failure of some pipes on the flow, pressure heads, and water quality were investigated. The study concluded that, the failure of some pipes increased the consumed discharge in the network, decreased the pressure head and changed the flow direction in some pipes through the network.

The present study aims to 1) study the improving and optimizing procedure of Assiut City portable water supply network by increasing both the pump stations flow rate and head, and 2) study the influence of the pumps flow rate and head on the entire the network nodes pressure head and pipelines water velocity.

2. Theoretical Approaches

Hydraulic models are important for simulation, analysis and design of water distribution networks. Hydraulic models are used for various important tasks by designers and engineers, such as designing new water distribution networks and systems, analysing and evaluating an existing one [14],[15].

EPANET is one of more widely used computer models, which can be used to perform extended period simulation of hydraulic and water quality behavior within pressurized pipe networks, and steady state conditions [16]. EPANET was developed by the Water Supply and Water Resources Division (formerly the Drinking Water Research Division) of the U.S. Environmental Protection Agency's National Risk Management Research Laboratory.

3. Case Study

This research is based on studying Assiut City water distribution network according to the consumption rates at the base year 2010 until year 2040 as three stages, at the base year 2010, and at years 2025 and 2040. Assiut city is the largest city in Upper Egypt region, which located 400 km southern Cairo. Its network is considered of medium size and is similar in nature to many other networks in other Egyptian cities. The city population for different years based on the population governmental records and future interpretation according to the Egyptian Code is tabulated in Table 1. The ID labels for the network’s various components are shown in Fig. 1. Average base demands for the different junction nodes at years 2010, 2025, and 2040 are listed in Table 2.

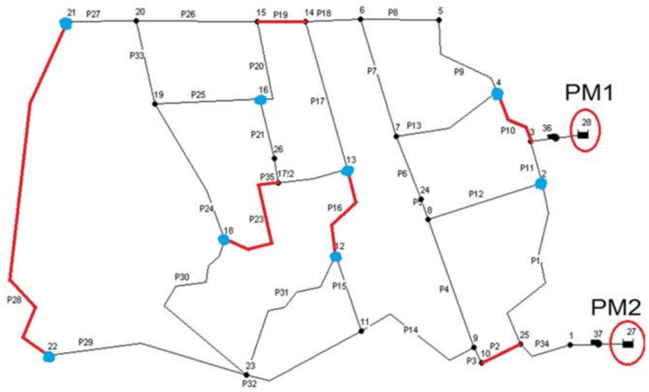


Figure 1: Assiut city water distribution network

Table 1: Population of Assiut City, Egypt

Year	*2000*	*2010*	*2025*	*2040*
Population (x 103)	372	433.5	570.1	706.6

Table 2: Average base demands (junction nodes).

Node No.	*Y2010*	*Y2025**	*Y2040**	*Node No.*	*Y2010*	*Y2025**	*Y2040**
1	0	0	0	14	40	54	69
2	61	83	106	15	16	22	28
3	0	0	0	16	32	43	56
4	64	87	11	17	66	90	115
5	36	49	62	18	97	132	168
6	40	54	86	19	61	83	106
7	63	86	103	20	46	62	75
8	55	75	95	21	80	109	139
9	30	41	52	22	80	109	139
10	30	41	52	23	114	155	198
11	57	77	99	24	0	0	0
12	87	118	151	25	40	54	69
13	62	83	106	26	0	0	0

The distribution system, Fig.1, is composed of a total length of 29.6 km of 35's different diameter pipelines. All pipes named from P1 to P35 are from Cast Iron with different lengths and diameters (Table 3). The head loss in each pipe is computed using Darcy-Weisbash formula with roughness height value =0.06 mm. As shown in Fig.1, there are two reservoirs as the sources of pure water named (R27 and R28) in addition to two pumping stations named PM36 and PM37 with characteristic data as shown in Table (4). The pump performance curve shown in Figure 2 and cited from [18] of the current designations.

The diurnal curve that makes demands at the junction nodes of the studied network varies in a periodic way over the day course has to be used to make the network more realistic for analyzing the extended period of operation. The diurnal curve for medium towns and cities such as Assiut city that documented by AWWA [17], is shown in Fig.3. It was used for the simulation process in the present study. The curve provides demand peaking factors which they are multipliers applied to the average base demand of each junction node in the distribution network to calculate its actual demand in a given time period (during the day course).

Table 3: Lengths and diameters of the different pipes.

Pipe number	*Length (m)*	*Diameter (mm)*	*Pipe number*	*Length (m)*	*Diameter (mm)*
P1	1600	800	P19	300	600
P2	300	1000	P20	600	400
P3	600	1000	P21	300	500
P4	900	500	P22	600	400
P5	200	500	P23	600	400
P6	300	500	P24	950	400
P7	1400	500	P25	950	300
P8	1100	800	P26	1200	600
P9	500	800	P27	400	600
P10	800	800	P28	2650	600
P11	150	800	P29	2100	600
P12	850	500	P30	1500	400
P13	1100	500	P31	1600	400
P14	500	1000	P32	1500	800
P15	750	500	P33	700	400
P16	850	500	P34	500	1200
P17	1000	500	P35	150	500
P18	100	800			

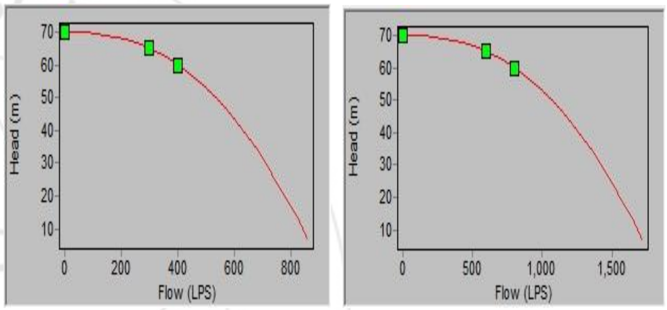


Figure 2: Pumps, PM1 and PM2 conditions (Q, H).

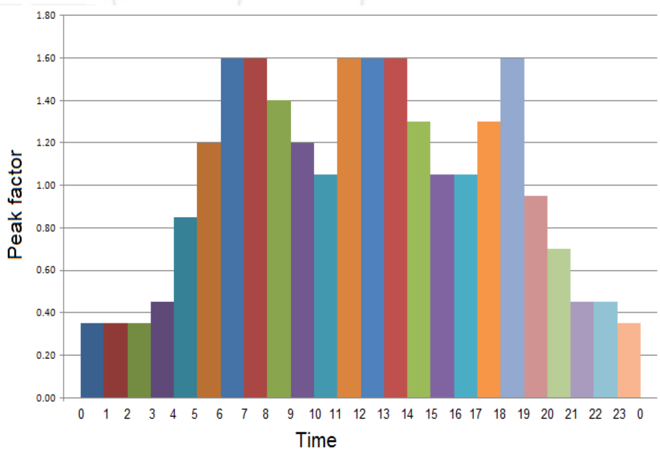


Figure 3: Diurnal demand curve for extended period simulation

4. Methodology

The study was conducted using the mathematical simulation model (EPANET). The model was used to simulate, study and analysis the operational conditions of the network's two pump stations throughout various operational conditions. In additional to two cases for future planning purpose. The pump stations are equals in the pressure head, while the flow rate of the big pump PM2 is twice the small one PM1. Those cases could be classified to three different categories according to the changes applied to the pumps' pressure head and/or the flow rate.

The first group includes the influences of increasing the pressure head only. The second group includes the variation of the pumps flow rates only. While, the last group includes the influences of the variation of both the pressure head and the flow rate on the nodes water pressure and the pipelines water velocity. The pump best operational conditions for the present time were chosen and selected as the base of the future network optimization process.

The study included many cases but in the next sections only the important cases will be discussed and highlighted as shown in Table (5). The first group includes two cases (Case 1and 2) in which the pressure head only was increased. The first case presented the simulation of increasing simultaneously the pressure head of the two pump stations by 10 m. While in the second case the, the pressure head of the second pump station PM2 only was increased by 30m while the PM1 was switched OFF. The second group also includes two cases (Case 3 and 4).

Table 5: Summary of the studied cases

Case No.	*Case1*			*Case2*			*Case3*		
Pump No.	*Q (l/s)*	*H (m)*	*Status*	*Q (l/s)*	*H (m)*	*Status*	*Q (l/s)*	*H (m)*	*Status*
*PM1 PM1**	0	80	ON	0	70	OFF	0	70	ON
	300	75		300	65		600	65	
	400	70		400	60		800	60	
*PM2 PM2**	0	80	ON	0	100	ON	0	70	ON
	600	75		600	95		600	65	
	800	70		800	90		800	60	
Case No.	*Case4*			*Case5*			*Case6*		
Pump No.	*Q (l/s)*	*H (m)*	*Status*	*Q (l/s)*	*H (m)*	*Status*	*Q (l/s)*	*H (m)*	*Status*
*PM2 PM2**	0	70	ON	0	75	ON	0	75	ON
	300	65		600	70		600	70	
	400	60		800	65		800	65	
*PM2 PM2**	0	70	ON	0	70	ON	0	75	ON
	1200	65		600	65		600	70	
	1600	60		800	60		800	65	

In Case 3, the flow rate of PM1 was only duplicated and that of PM2 was kept without changes, vise versa was used in Case 4. Later the two pump stations in case of increasing their flow rates to be 2-times their original rates were recognized and named by PM1* and PM2* respectively. The last group consists of two cases (Case 5 and 6) as both the pressure head and flow rate were increased. In Cases 5, the head pressure of PM1* was increased by 5 m while the second pump station PM2 was kept with its original flow rate and pressure head values. In Case 6, the pressure head of both the two pumps (PM1*) and (PM2*) was simultaneously increased by 5 m. The simulation and analysis were mainly conducted at two different times, at 0:00 and 6:00, times of peak minimum and maximum demands, respectively.

5. Results and Discussions

5.1 Influences of Pump Pressure Head on the Network Pressure Head Distribution and Water Velocity

The maximum pressure head of the two pump stations was simultaneously increased by 10 *m* to reach 80 *m*. It was found that during minimum demand time, the pressure head in the network was ranged from 78 to 80 *m* with maximum head loss approximately 2 *m* (2.5%). During the maximum demand time, the network's pressure head was about 41 *m* at nodes 16-19, at the region far away from the two pump stations, and 44 *m* at nodes 1, 2 and 3, near the stations with head loss across the network pipelines evaluated by 3 *m* (7%) (Figs. 1 & 4a).

As shown in Figs. 1 and 4b, in case of increasing the head of the second and large capacity pump by 30 *m*, and switching off the small one during the time of maximum demand, the pressure head at region closer to the pump station dropped approximately to 4 *m*. Furthermore, from the pump station, the pressure dropped to less than 2 *m* with head losses evaluated approximately by 72%.

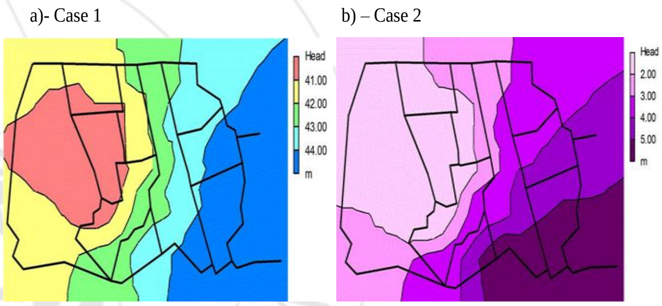


Figure 4: Pressure head distribution maps at time of maximum demand (6:00) for Cases 1 and 2

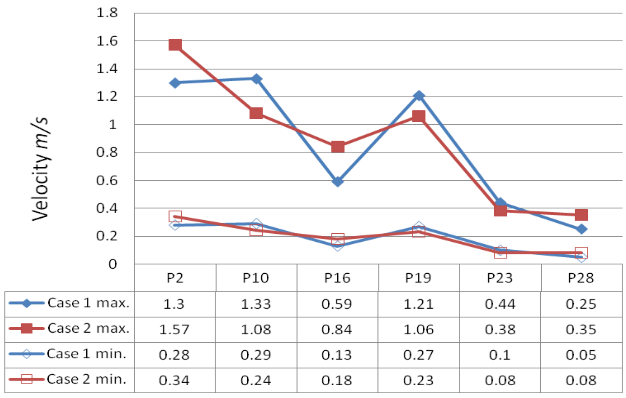


Figure 5: Effect of increasing the pumps pressure head on the network pipelines maximum and minimum flow velocity, Cases (1 & 2)

As shown in Fig. 5, the flow velocity in the network pipelines next to the station and on main lines at the maximum demand times was more than 1.0 *m/s* and with the acceptable value in other region. The pipelines with high velocity need to be replaced by other pipes with larger diameter or adding some closed loops.

5.2 Influences of Pumps Flow Rate on the Network Pressure Head and Water Velocity

In case of duplicating the small pump flow rate to be 800 *l/s* and keeping the second one flow rate with no change, the head all over the network during times of minimum demands was constant with neglected variation and equaled to 69 *m* with total head loss not more than 0.4%. While at the time of maximum demand 6:00 AM, the pressure head at the network nodes ranged from 49 to 52 *m* with total head loss = 8.5% (Fig. 6a).

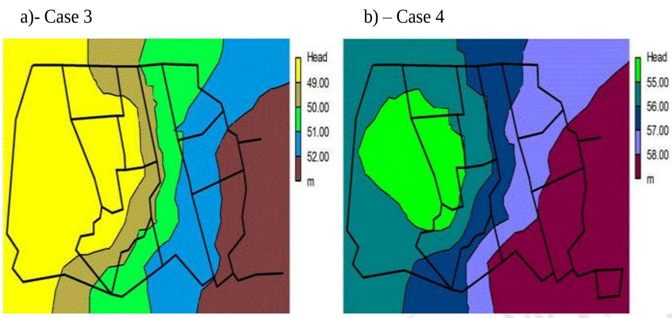
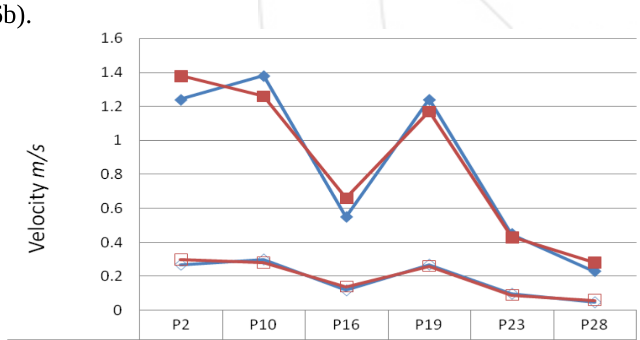


Figure 6: Pressure head distribution maps at time of maximum demand (6:00 AM) for Cases 3 and 4

In case of duplicating only the flow rate of the larger pump to be 1600 *l/s* and keeping the condition of the first pump without changes, a slight improvement in the network pressure was found and its maximum values, at minimum demand time, ranged from 69.4 to 69.7 *m* with total head loss=0.3%, while at time of maximum demand, the network head ranged from 55 to 59 *m* with total head loss=6.2% (Fig. 6b).



	P2	P10	P16	P19	P23	P28
Case 3 max.	1.24	1.38	0.55	1.24	0.45	0.23
Case 4 max.	1.38	1.26	0.66	1.17	0.43	0.28
Case 3 min.	0.27	0.3	0.12	0.27	0.1	0.05
Case 4 min.	0.3	0.28	0.14	0.26	0.09	0.06

Figure 7: Effect of increasing the pumps flow rate on the network maximum and minimum flow velocity, Cases (3 & 4).

The flow velocity in the network pipelines also increased in the region near the station in the same pipelines and still above the acceptable limits (Figs. 7 and 9). The pipelines with high velocity are main lines with small length and large diameter. This insures that those pipelines need replacement with new ones with larger diameters or the system need new closed loop or extra feed points to be added.

5.3 Influences of Both the Pump Pressure Head and Flow Rate

At the time of maximum demands, in case of increasing both of the head and flow rate, a clear and obvious improvement could be happened in the entire network pressure head that mainly ranged from 50 to 57 *m*. While at the time of minimum demands, the network corresponding pressure head ranged from 72 to more than 80 *m*.

Power consumption, system safety together with the pressure head and flow rate are the most important factors those affect on the selection of the pump most suitable operational conditions. The most economical operating/working case can be defined as the case in which the operating conditions are optimal in providing and maintain both the flow rates and pressure heads with both the low cost, high safety and the acceptable levels that satisfy the consumers' requirements.

According to the pervious discussed results regarding to the pressure head, the best operational conditions were found in Case 4 which can be applied to the pump stations upgrading process and may be the base for satisfying the future needs where the nodes pressure head values at time of maximum demand are in the range from 54 to 69 *m*.

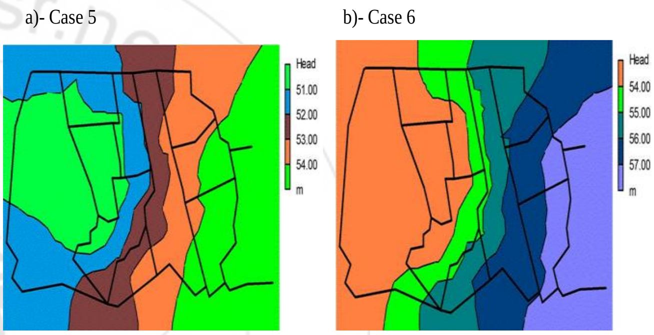
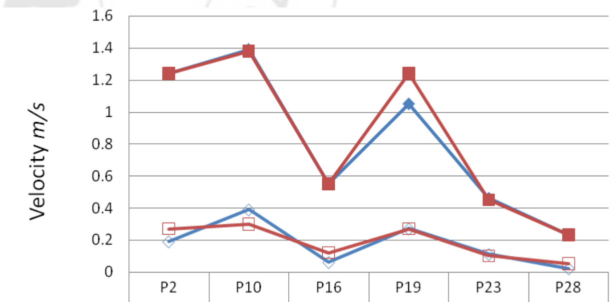


Figure 8: Pressure head distribution maps at the time of maximum demand (6:00) for Cases 5 and 6



	P2	P10	P16	P19	P23	P28
Case 5 max.	1.24	1.39	0.55	1.05	0.46	0.23
Case 6 max.	1.24	1.38	0.55	1.24	0.45	0.23
Case 5 min.	0.19	0.39	0.06	0.27	0.11	0.02
Case 6 min.	0.27	0.3	0.12	0.27	0.1	0.05

Figure 9: Effect of increasing both the pump pressure head and flow rate on the network maximum and minimum flow velocity, Cases (5 & 6).

6. Conclusion

This study includes optimizing and strengthening of water-distribution network and the effects of pumping operational conditions on the pressure and flow velocity in an existing water supply network (case study-Assiut city network). The following conclusions can be drawn from this study:

1) By improving only pump station operational conditions,

flow rate and/or head, the current system can satisfy the near future requirements and meet the increase in the water demands for at least one decade,

2) In case of switching off the small pump and increasing the head of the second one by 30 *m*, the pressure head at region closer to the large pump station dropped to approximately 4 *m* during the time of maximum demand.
3) In case of increasing only the flow rate of the larger pump to be 2-times of its current capacity, 1600 *l/s* while no changes occurred in the small one, there was a slight improvement in the pressure along the network,
4) The recommended conditions of the two pump stations for the future improvement strategy are duplicating the flow rate of the larger pump to be 1600 *l/s* while no changes in the small station and pressure head.
5) With the upgrading the pump station, the current network is in most need for strengthening, re-evaluation and capacities re-building of some pipelines, new water feeding points and sources, and may be new closed loops.

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