Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (39) No. (2) April, 2017

Hydraulic Reliability Evaluation of 1st Gathering of New Cairo City, Egypt Water Distribution Networks

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ملخص البحث

ركزت العديد من الدراسات في السنوات الاخيرة علي زيادة الموثوقية بشبكات توزيع المياة، وذلك لأن تلك الشبكات معرضة للعديد من انواع الفشل. هذة الورقة البحثية تقدم تحقيق وتقييم لشبكة التجمع الاول بمدينة القاهرة الجديدة (مصر) وتقترح حل لزيادة موثوقية الشبكة الهيدروليكية. المنهجية المقترحة تتبعد ثلاث خطوات: (١) نمذجة وتقييم الشبكة، (٢) الحصول علي مؤشرات التقييم وتحليلها، (٣) اقتراح حل واعادة حساب مؤشرات التقييم. استخدم كل من الاتي كمؤشرات تقييم: ضغط المياة بكل نقطة سحب ومنسوب المياة بالخزانات. استخدم برنامج المحاكاه الهيدروليكي EPANET2 لمحاكاة الشبكة علي مدار اليوم EPS. بالاضافة لذلك دمجه مع برنامج Microsoft Excel لاسترجاع وتقديم مؤشرات التقييم والقيام ببعض العمليات الاحصائية. اظهر التقييم أن فشل المنظومة الهيدروليكي يرجع الى عدم كفاية تصرف المضخات وقدرة التخزين الضئيله بالشبكة. اوصى الحل المقترح بزياة عدد المخضات ليصل إلي سبعة مخضات وزيادة قدرة التخزين لتصل إلي ٣٣,٠٠٠ متر مكعب واستبدال بعض المواسير. نتيجة لذلك، فإن الحل المقترح يزيد من موثوقية الشبكة ومستوى الخدمة التى يقدمها مورد المياة.

Abstract

Numerous studies in recent years have focused on increasing water distribution networks (WDNs) reliability as these networks are subjected to several types of failure. This papers presents an investigation and evaluation of the 1st Gathering of New Cairo City (Egypt) WDN and recommends a solution to increase network hydraulic reliability. The proposed methodology follows three steps: (1) model and evaluate WDN; (2) obtain and analyse evaluation indicators; (3) propose solution and recalculate evaluation indicators. Nodal pressure and tanks water levels were used as evaluation indicators. EPANET2 was used as a hydraulic simulation program to perform extended period simulation. It was also intergraded with Microsoft Excel® in order to retrieve and represent the evaluation indicators in addition to preforming statistical analysis of data. The evaluation showed system hydraulic failure due to insufficient pumps discharge and very low storage capacity. The proposed solution recommended increasing number of pumps to be 7 identical pumps, increasing storage capacity to be 33,000 m3 and replacing some pipes. As a result, the proposed solution increases the reliability of the network and the level of service offered by water supplier.

1. Introduction

Water Distribution Networks (WDNs) are designed to deliver water demand to consumers with an adequate pressure. The main components of these networks are water sources, pipelines, valves, pumps and storage tanks. Although these components are locally and mechanically independent, they are hydraulically dependent. This means that any failure of any component will cause simultaneous failures for others. That brings the need to consider reliability of the system into account while designing WDN. Gheisi and Naser (2014c) defined reliability as 'a measure of performance or the ability of a WDN to supply consumers' demands in quantitative and qualitative aspects at all circumstances'. Farmani et al. (2005) provided another definition of reliability in WDN as 'the probability of meeting a desirable operation in the system, as it had been expected in the designing period'.

WDNs are subjected to three types of failures: (1) mechanical failure; (2) hydraulic failure; (3) water quality failure (Gheisi et al. 2016). A number of researches focused on mechanical failure (partially or completely) that is a result of pipe burst (Kleiner and Rajani 2001; Rajani and Kleiner 2001; Watson et al. 2001; Nishiyama and Filion 2013, Gheisi and Naser 2013, 2014a, b, c; Perelman and Amin 2014). Hydraulic failures may occur due to several reasons; among them water supply shortage in general or during fire flow situations, unsatisfying low pressure at any demand node. This type of failure has been studied in literature by Quimpo and Wu (1997), Ghajarnia et al. (2009), and Chang and Van Zyl (2014). Also, Van Zyl et al. (2012) studied the impact of water demand variation on the reliability of municipal storage tanks.Water quality failure may happen in many situations such as biofilm growth, contaminant intrusion, and internal corrosion (NRC 2006). A high rate of other types of failure may lead to water quality failure (Le et al. 2013). Rossman et al. (1994), Gauthier et al. (2000), Constans et al. (2003), Boulos et al. (2005), Huang et al. (2005) and Karamouz et al. (2012) studied water quality reliability under different conditions.

On other hand, New Cairo City (Egypt), that consists of 3 main areas: 1st, 3rd, and 5th gathering, recently had several failures in supplying water to its consumers. These failures made water deficit to be a daily repeated phenomenon especially in summer. In 2015, Water cut off complains by New Cairo City residents received by Greater Cairo Water Supply Company reached 10,264 complain compared with 13,786 in 2014. Maximum number of complains in 2015 was in September during peak demand consumption. Complains in general were due to either shortage in water supply, low pressure at some parts of the network, or a pipe burst.

This paper presents an investigation and evaluation of the 1st gathering WDN of New Cairo City hydraulic reliability. The evaluation is based on year 2015 status during peak consumption. The paper also recommends a solution to increase reliability of the network.

2. Methodology

The proposed methodology is a stepwise procedure which has been used to evaluate the 1st Gathering of New Cairo City WDN at its year 2015 status during peak consumption. It consists of three steps which are (1) model and evaluate WDN; (2) obtain and analyse evaluation indicators; (3) propose solutions and recalculate evaluation indicators.

EPANET2 hydraulic simulation program (Rossman 2000) was used to model and evaluate the WDN under investigation. In order to build a hydraulic model using EPANET2, WDN data should first be collected, and inspected. These data includes WDN layout, pipe diameter and material, junctions' elevation and base demand, tank shape, size, base elevation, minimum elevation, and maximum elevation, in addition to pumps elevation, type and performance characteristics curves.

In this study, the evaluation indicators used are nodal pressure and tanks water level for each time step. Nodal pressure is considered as an evaluation indicator as it indirectly represents the availability of water at demand nodes. In addition, pressure head must be ≥ 20 meter at any demand node based on local standards. Meanwhile, tanks provide balance water to fill the gap between constant rate of water supply by pumps and variable demand throughout the operational period; usually 24 hours. A tank is considered failed and unreliable when it is dry while there is demand required (Van Zyl et al. 2008). In this study, EPANET2 was intergraded with Microsoft Excel® in order to retrieve these evaluation indicators. Microsoft Excel® was used as it is a powerful tool to represent and preform statistical analysis for the huge amount of data representing all nodes for all time steps.

Based on the statistical analysis of the evaluation indicators, the problems are defined and located and a solution is proposed. The WDN then remodelled to recalculate the evaluation indicators. This procedure is repeated until the evaluation indicators are accepted.

3. CASE STUDY

The investigated case study is the WDN of the 1st Gathering of New Cairo City. The network, shown in Figure 1, has one water source and one pump station (northwest). The pump station consists of three operating identical pumps, each discharge 1800 m^3/hr with 110 m design head. The network has also one elevated tank (Tank B) located at the south end of the network with a capacity 2000 m^3. This tank works as a balance tank as it has one inlet/outlet pipe. The tank water level fluctuates between 275 m and 279 m (MSL). In September 2015, the base water demand for the WDN was 5,502 m^3/hr. This flow is demanded by 155 junctions of the network. In addition, the network has 93 km of pipes. These pipes diameter ranges from 100 mm to 1000 mm, the most common diameters are 200, 300, 400 and 500 mm. The pipes are made of ductile iron, PVC and cast iron. The Egyptian Code guidelines (HBRC 2007) demand pattern was used in this study.

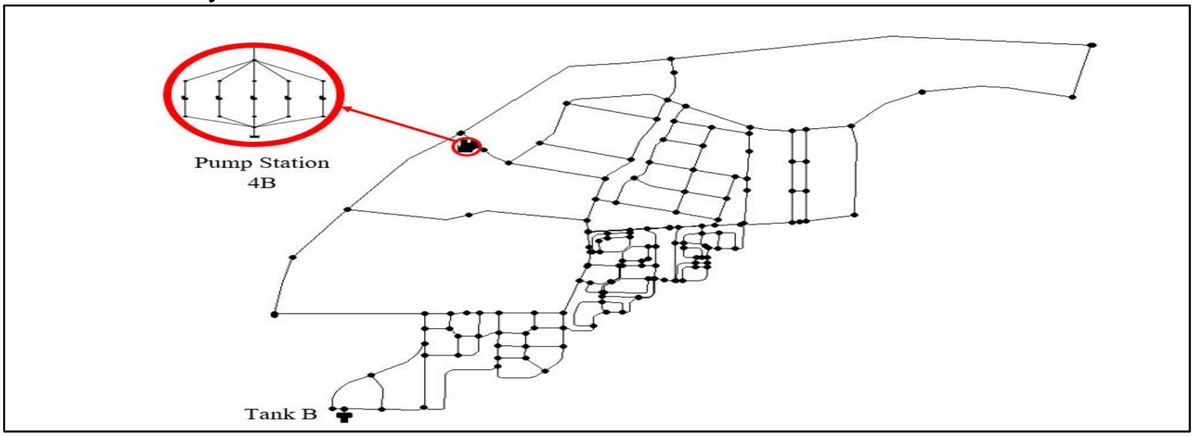

Figure (1): 1st gathering of New Cairo City WDN.

4. Results and Discussion

4.1. Evaluation Results and Discussion

As mentioned earlier, nodal pressure and tank water levels was used as evaluation indicators in order to evaluate the 1st gathering of New Cairo City WDN. Figure 2 presents the 24 hour tank level in addition to pump discharges (one pump discharge is shown to represent pump station discharge), both obtained from performing an EPS of case study WDN. From the figure, it was found that the simulation can be divided into four time periods. The first period; 0:00 to 5:00; pumps delivered water to demand nodes in a satisfying pressure and caused tank water level to increase from the initial condition till full capacity. Resulting in, a hydraulically feasible model with no errors obtained. During the second period; 5:00 to 7:30; the tank water level decreased dramatically in 2.5 hours to support the three operating pumps in satisfying the demand, despite that the demand is still below average flow. In following period; 7:30 to 22:00; the demand started to increase above the average flow level while the tank was empty. As a result, pumps alone failed in discharging water to nodes as they exceed their maximum flow. In addition, water pressure in all nodes was in negative values. As water demand decreased in the fourth period; 22:00 to 24:00; pumps achieved an acceptable pressure in all demand nodes and eventually increasing tank water level to set it up back to its initial condition.

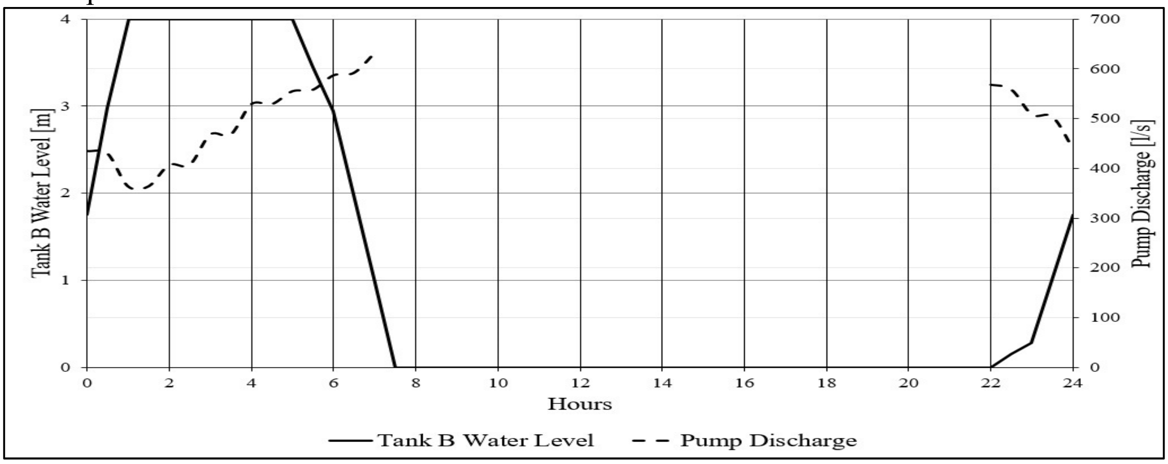

Figure (2): Tank B water levels and pump discharge (Evaluation results).

According to Egyptian Code guidelines (HBRC 2007), lift station pumps have to supply the average demand which ranges from 1.58 to 1.8 of base demand. This means that pumps should have the ability to supply water with adequate pressure from 0:00 to 8:00 and from 16:00 to 24:00. When comparing operating pumps flow capacity with the guidelines, it is noticed that the required flow ranges from 8,693 m^3/hr to 9,904 m^3/hr which is larger than the current capacity of the three operating pumps (5,400 m^3/hr). The period from 8:00 till 16:00, the water demand is above average. Thus, water from storage tanks has to support pumps in suppling water to consumers. Therefore, the required storage capacity equals to 5.97 of base demand and this equate to 33,000 m^3 which is larger than the existing 2,000 m^3 tank. Hence, the previous indicators results show that the system hydraulic failure is due to insufficient pumps discharge and a very low storage capacity.

4.2. Proposed Solution

A proposed solution was suggested to increase reliability of the 1st Gathering of New Cairo City WDN by increasing flow capacity, increasing storage capacity, replacing some pipelines. The flow capacity shall be increased by increasing the number of pumps to be 7 identical pumps (5 operating and 2 standbys) with a total operating flow capacity of 9,000 m^3/hr. Four elevated tanks (each 8,250 m^3) were proposed to be located as shown in figure 3 to increase the system storage capacity. This location was selected due to its availability and high elevation of 265 m. The tanks base elevation was selected to be 293.5 m (MSL) and shall be connect to WDN by two 800 mm pipes. On the other hand, Tank B will be out of service because it has low base elevation. In order to sustain pipe water velocity in acceptable range, the pipelines (from node A to B) shown in figure 3 shall be replaced by 800 mm pipeline. The proposed solution was remodelled using EPANET2 and the evaluation indicators were recalculated.

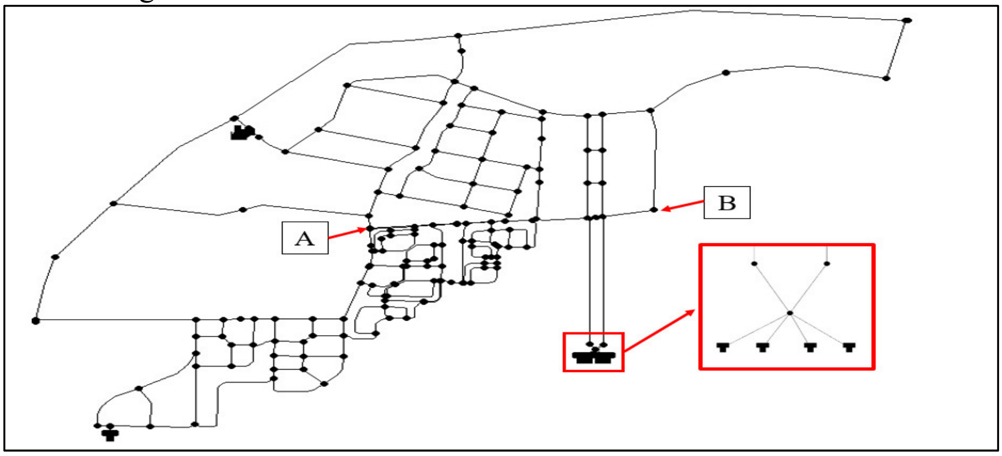

Figure (3): The proposed tanks location and the replaced pipelines route (from node A to B).

The results of the proposed solution indicate that the modified model is hydraulically feasible as it had no errors generated by EPANET2. As shown in figure 4 the proposed tanks water level increased for its initial condition to full capacity before 8:00 and started to support the pumps in supply demand till 20:00 as required. Afterward, the tanks regain its initial condition by the end of the operational period. Figure 4 also shows that the pump discharges were in its allowable range of design flow. The pressure in all nodes during the operational period was above the minimum allowable pressure and below the maximum limit. As a result, the proposed solution can increase the reliability of the network and the level of service offered by water supplier.

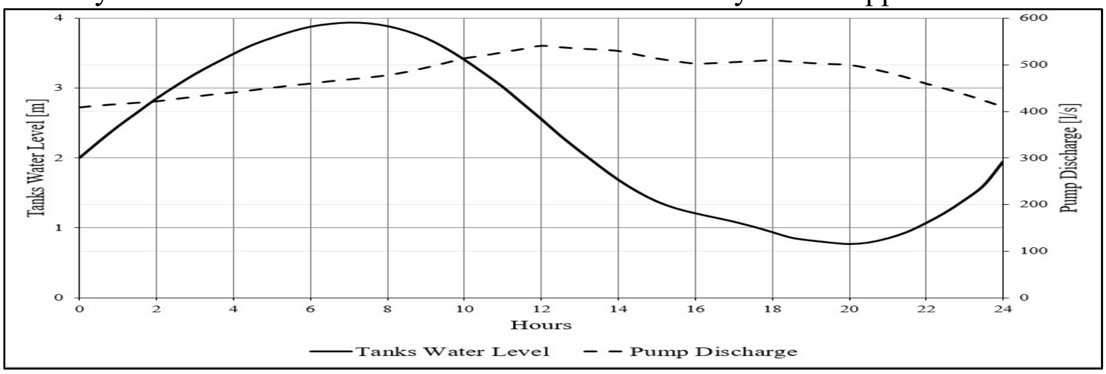

Figure (4): Tanks water levels and pump discharge (Proposed solution results).

5. Conclusion

In this paper, an investigation of the repeated hydraulic failure of 1st Gathering of New Cairo City WDN was carried out and evaluation of the network was performed. EPANET2 was integrated with Microsoft Excel® in order to perform hydraulic simulations and retrieve the evaluation indicators. The evaluation showed that the system hydraulic failure was due to insufficient pumps discharge and a very low storage capacity. A solution was proposed by increasing the number of operating pumps from three to five, increasing the storage capacity from 2,000 m^3 to 33,000 m^3 and replacing some pipelines to be 800 mm diameter. Remodelling the WDN using EPANET2 showed a significant increase in network reliability.

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