Research Article
Effects of Water Age Blind Spots on the Water Quality in the Water Distribution Systems with the Use of EPANET Model

Hossein Shamsaei, Othman Jaafar and Noor Ezlin Ahmad Basri
Department of Civil and Structural Engineering, Faculty of Engineering and Built Environment,
University Kebangsaan, Malaysia, 43600 UKM Bangi Selangor, Malaysia

Abstract: The increase in water age may be due to the distance travelled and the residence time in the water distribution. The water age of the blind spots in water distribution system causes deterioration in water quality systems. In general, blind spots have been causing increased water age in the water distribution network. Water age has more value in distribution systems with Lang transmission lines. For blind spots (dead end point), there has been an analysis of the primary distribution system. The goal of this study is to improve the water age and water quality as well as minimizing incidences of dead end points in the water distribution systems with the use of EPANET model software. Considering the above results this study for minimizing incidences of dead end points in the water distribution systems will be water age, smaller water and removal of the blind spots are required and need for the design of a pipe diameter that would effectively accommodate blind spots by ensuring appropriate sizes at appropriate points along the system network, so Pressure must be maintained in the distribution network system. Finally, the amount water age and generation of blind spots in the system and distribution network will be due to inaccuracies in network design and distribution systems or inability to consider some important factors when designing the distribution network system.

Keywords: Blind spots (end dead), chlorine residual, distributed network systems, hydraulic changes, network design, water age

INTRODUCTION

The need for adequate and proper planning has necessitated designers of network systems and distribution to enhance facilities and distribution systems, such that the product or result of their work would stand the test of time by rendering continuous and meaningful services to the people. By making real use of the system, same amount of water can be more productive than in a system where there is no proper planning. Current will increase through the system due to size and distribution networks and lack of intake flow during water age; this might cause some water quality problems such as inappropriate water age, hydraulic changes and high difference between production and consumption in the system and distribution network. These problems have been noticed in large treatment plant with large and long water transmission systems. DeBoer (2006) noted that systems with large and extensive area are prone to frequent deterioration of water quality, not only this, that such water encourage generation of material byproduct, this was also corroborated by EPA (2002).

Been also said that water age can be responsible for problem associated with physical, chemical or Biological quality of water in the distribution network system. The rapid growth of bacteria is one way in which the adverse effect of water age is felt in its action of affecting the water quality. Mains (2008) stated that systems where there is high residence time in the water distribution system are also prone to rapid bacterial growth. One of the important factors that increase water age is frequent changes in the hydraulic systems within the distribution networks. According to EPA (2002), hydraulic conditions can increase the residence time of water in the water distribution system and this may allow stream of microbes to survive within the system, (DeBoer, 2006) noted similar thing with respect to water age and observed that bacterial growth as well as THMs and HAAs are characteristic of systems and distribution networks with high residence time in water distribution systems and networks. Another problem associated with water age and dead end points is high consumption of chlorine in the system. Delahaye (2003) undertook a pilot study on this and the results indicate that when the water distribution system and network

Corresponding Author: Hossein Shamsaei, Department of Civil and Structural Engineering, Faculty of Engineering and Built Environment, University Kebangsaan, Malaysia, 43600 UKM Bangi Selangor, Malaysia, Tel.: 0060122847323

undergo treatments in terms of water quality and bacterial growth, more chlorine is introduced into the systems and also that the quality of water remains high in systems where the water age has been less than 6 h. However, the quality of water has been low in systems where the water age has been more. Delahaye (2003) submitted that the amount of HPC and R2A in the dead end network (branches system) had been more than at any other part of the network, in addition, consumption of chlorine in these areas were very high in the system and 76% bacterial growth has been at these points. Lahlou (2002) also carried out a study on this subject and observed that areas where there had been water detention (branches system) also have low residual chlorine levels and consequently has resulted to the water having taste and odor in addition to many other problems of water quality in the systems.

It has also been observed that along the branched systems or at the dead end part of the system, the speed is low (Laminar flow), in these areas microorganisms will start to grow and cause bio-film formation in the system and distribution network. Also, if there is no agitation in the system, it might cause deterioration in water quality in water distribution systems and networks. In the EPA (2002) booklet (June 17), it is stated that in areas where there is static flow (blind spots), a lot of activities take place and these activities which include interaction of different elements and organisms such as iron, sulfur, green algae and bacteria can bring about deterioration in the quality of the water in the system.

Also, equally stated in a study in A National Drinking Water Clearinghouse (1998) is that to prevent or to minimize the amount of iron and sulfur in the distribution network systems, it is necessary to avoid creating blind spots. One of the parameters that increase water age has been much difference between production and consumption rates and low consumption of water in the water distribution systems especially if the system is made of thick distribution lines, this particular problem can make an area to become a dead end point in the system. Burlingame (2007) observed that low consumption of water in the water distribution systems could increase the deterioration of water quality in the water distribution systems, especially, in networks and distribution system that extends over a long distance. Likewise, Rubulis *et al*. (2007) noted that

cases of least water quality have been observed in places where there are laminar flow and at places designated as blind spots (dead end points) in the water distribution system, in addition to this observation is that bacterial growth are more rampant around such areas than in other areas within the water distribution system. According to research conducted and the results obtained, it can be inferred that the presence of blind spot areas encourage the initiation of other phenomena such as high water age, hydraulic changes, high difference between production and consumption levels as well as more residual chlorine.

The aim of this study is to find means of removing or reducing these blind spots by making use of a special procedure known as Blind system identification, developed from analysis using the EPANET model software. This system studies by making use of different values of some important parameters such as flow, speed, pressure, consumption and water age.

MATERIALS AND METHODS

A relatively small system and distribution network was selected. The area taken as case study is a place in the south western part of IRAN. The area was subjected to analysis using EPANET model system and the results of this analysis have shown the effects of water age and the generation of dead end points in the systems. This area has a population of 28,000 people and a distance of 72 km as the length of the distribution system. And as previously stated, some blind spots were marked in the system and other parameters considered are water age of blind spots in networks and distribution systems, flow, velocity, pressure and consumption. The values of these parameters were varied. By using the EPANET model software for analysis, (Fig. 1 shows situation The water Distribution system in Hamedeh) some results were obtained for 10 selected locations in the system and changes have been made in consumption, pipe diameter and pressure in the system.

The 1st set of data from the network systems were determined and analyzed by considering the water age and blind spots. The changes were effected for about four of the parameters (flow, velocity, pressure, demand) in the networks with about 6 other alternatives. The 1st alternative was named file H1: (Table 1).

Table 1: The first alternative H1

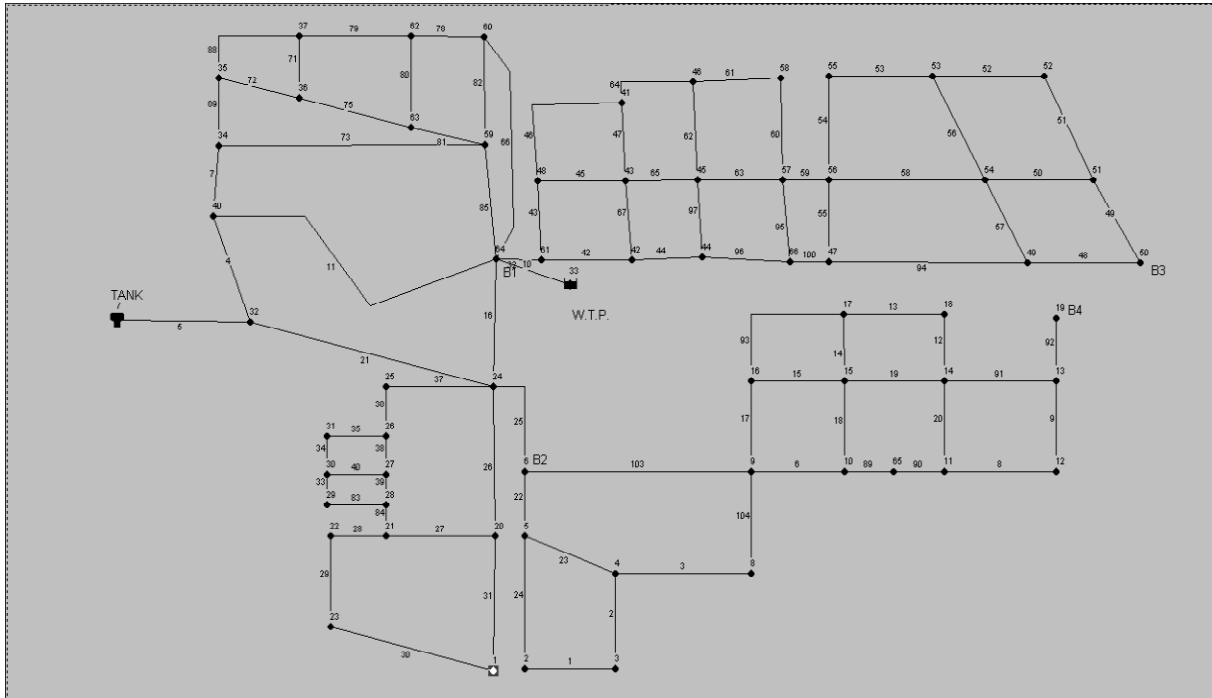| Line	H1					
	Flow (LIT/S)	Velocity (M/S)	CL (MG/LIT)	Pressure (M)	Diameter (MM)	Demand (LIT/S)
88	0.53	0.03	0.5	23.94	150	J37 = 1.5
28	0.25	0.01	0.61	23.66	200	J35 = 1.02
29	0.75	0.16	0.53	23.67	150	J22 = 3
24	3.75	0.12	0.87	23.85	200	J2 = 2.5
1	1.25	0.02	0.55	23.81	300	J3 = 3
2	1.75	0.1	0.73	23.81	150	J50 = 1.5
49	0.52	0.07	0.35	23.87	100	J52 = 2.5
48	0.98	0.03	0.42	23.87	200	
51	0.77	0.04	0.32	23.87	150	
52	1.73	0.1	0.24	23.88	150	

Fig. 1: Situation The water Distribution system in Hamedeh

Table 2: Situation the Primary of blind spots in distribution system of Hamedeh

	Hamedeh					
Line	Flow (LIT/S)	Velocity (M/S)	CL (MG/LIT)	Pressure (M)	Diameter (MM)	Demand (LIT/S)
88	0.91	0.02	0.41	23.94	25.0	J37 = 1.1
28	0.96	0.05	0.29	23.66	150	J35 = 0.8
29	2.06	0.12	0.53	23.67	150	J22 = 1.10
24	1.21	0.07	0.68	23.85	150	J2 = 0.7
1	0.51	0.03	0.39	23.81	150	J3 = 1.10
2	0.59	0.03	0.56	23.81	150	J50 = 1.10
49	0.82	0.05	0.23	23.87	150	J52 = 1.10
48	0.28	0.02	0.26	23.87	150	
51	0.2	0.01	0.1	23.87	150	
52	0.9	0.05	0.14	23.88	150	

Table 3: The Second alternation H2

	H2					
Line	Flow (LIT/S)	Velocity (M/S)	CL (MG/LIT)	Pressure (M)	Diameter (MM)	Demand (LIT/S)
88	1	0.02	0.47	23.94	150	J37 = 1.5
28	0.25	0.01	0.74	23.66	150	J35 = 1.02
29	2.75	0.16	0.55	23.67	150	J22 = 3
24	2.53	0.14	0.87	23.85	150	J2 = 2.5
1	0.03	0	0.08	23.81	150	J3 = 3
2	2.97	0.17	0.81	23.81	150	J50 = 1.5
49	0.97	0.05	0.38	23.87	150	J52 = 2.5
48	0.53	0.03	0.39	23.87	150	
51	0.71	0.04	0.34	23.87	150	
52	1.77	0.1	0.26	23.88	150	

This considered only the points of consumption in the given node as it increases. The second alternative was named file H2 (Table 3) and it considered the changes made in the level of consumption and diameters of pipe. The third alternative was named file H3H1 (Table 4). It is similar to H1, but comprised of increased pressure in the distribution system. The fourth alternative was named file H3H2 (Table 5). It is similar to H2, but also comprised of increased pressure in the distribution system. The fifth alternative was named file H4 (Table 6) and it considers changes made in the pipe diameters while the 6th alternative, named H5 (Table 7) considered changes made by pressure in the system.

Table 4: The third alternative H3H1

Line	Flow (LIT/S)	Velocity (M/S)	CL (MG/LIT)	Pressure (M)	Diameter (MM)	Demand (LIT/S)
	H3H1					
88	0.53	0.03	0.5	33.93	150	J37 = 1.5
28	0.28	0.01	0.62	33.92	150	J35 = 1.02
29	2.75	0.16	0.53	33.52	150	J22 = 3
24	3.75	0.12	0.87	33.64	150	J2 = 2.5
1	1.25	0.02	0.55	33.64	150	J3 = 3
2	1.75	0.1	0.73	33.83	150	J50 = 1.5
49	0.52	0.07	0.35	33.83	150	J52 = 2.5
48	0.98	0.03	0.42	33.83	150	
51	0.77	0.04	0.32	33.68	150	
52	1.73	0.1	0.24	33.68	150	

Table 5: The fourth alternative H3H2

Line	Flow (LIT/S)	Velocity (M/S)	CL (MG/LIT)	Pressure (M)	Diameter (MM)	Demand (LIT/S)
	H3H2					
88	0.53	0.03	0.51	33.93	150	J37 = 1.5
28	0.25	0.01	0.74	33.92	200	J35 = 1.02
29	2.75	0.16	0.55	33.52	150	J22 = 3
24	2.53	0.12	0.87	33.64	200	J2 = 2.5
1	0.03	0.02	0.08	33.64	300	J3 = 3
2	2.97	0.1	0.81	33.83	150	J50 = 1.5
49	0.97	0.07	0.38	33.83	100	J52 = 2.5
48	0.53	0.03	0.39	33.83	200	
51	0.73	0.04	0.34	33.68	150	
52	1.77	0.1	0.26	33.68	150	

Table 6: The fifty alternative H4

Line	Flow (LIT/S)	Velocity (M/S)	CL (MG/LIT)	Pressure (M)	Diameter (MM)	Demand (LIT/S)
	H4					
88	0.48	0.03	0.43	23.94	150	J37 = 1.1
28	0.1	0.01	0.1	23.66	200	J35 = 0.8
29	1.2	0.1	0.37	23.67	150	J22 = 1.10
24	0.8	0.01	0.7	23.85	200	J2 = 0.7
1	0.1	0.01	0.31	23.81	300	J3 = 1.10
2	1	0.13	0.69	23.81	150	J50 = 1.10
49	0.01	0.01	0.07	23.87	100	J52 = 1.10
48	1	0.03	0.51	23.87	200	
51	0.41	0.02	0.19	23.87	150	
52	0.96	0.05	0.27	23.88	150	

Table 7: The sixty alternative H5

Line	Flow (LIT/S)	Velocity (M/S)	CL (MG/LIT)	Pressure (M)	Diameter (MM)	Demand (LIT/S)
	H5					
88	0.91	0.02	0.41	33.93	250	J37 = 1.1
28	0.96	0.05	0.29	33.92	150	J35 = 0.8
29	2.06	0.12	0.53	33.52	150	J22 = 1.10
24	1.21	0.07	0.68	33.64	150	J2 = 0.7
1	0.51	0.03	0.39	33.64	150	J3 = 1.10
2	0.59	0.03	0.56	33.83	150	J50 = 1.10
49	0.82	0.05	0.23	33.83	150	J52 = 1.10
48	0.23	0.02	0.26	33.83	150	
51	0.2	0.01	0.1	33.68	150	
52	0.9	0.05	0.14	33.68	150	

RESULTS AND DISCUSSION

The water age of the blind spots in water distribution system causes deterioration in water quality systems. In general, blind spots have been causing increased water age in the water distribution network. Water age has more value in distribution systems with thick transmission lines. For blind spots (dead end point), there has been an analysis of the primary distribution system with EPANET (Table 2), blind spots have been identified and these points were in the six-point networks. The basis of system specifications is shown in Table 2 (Fig. 2).

Another option called H1 (Fig. 3), have been done to increase consumption and have done relevant changes in the diameters of pipe are as Table 1.
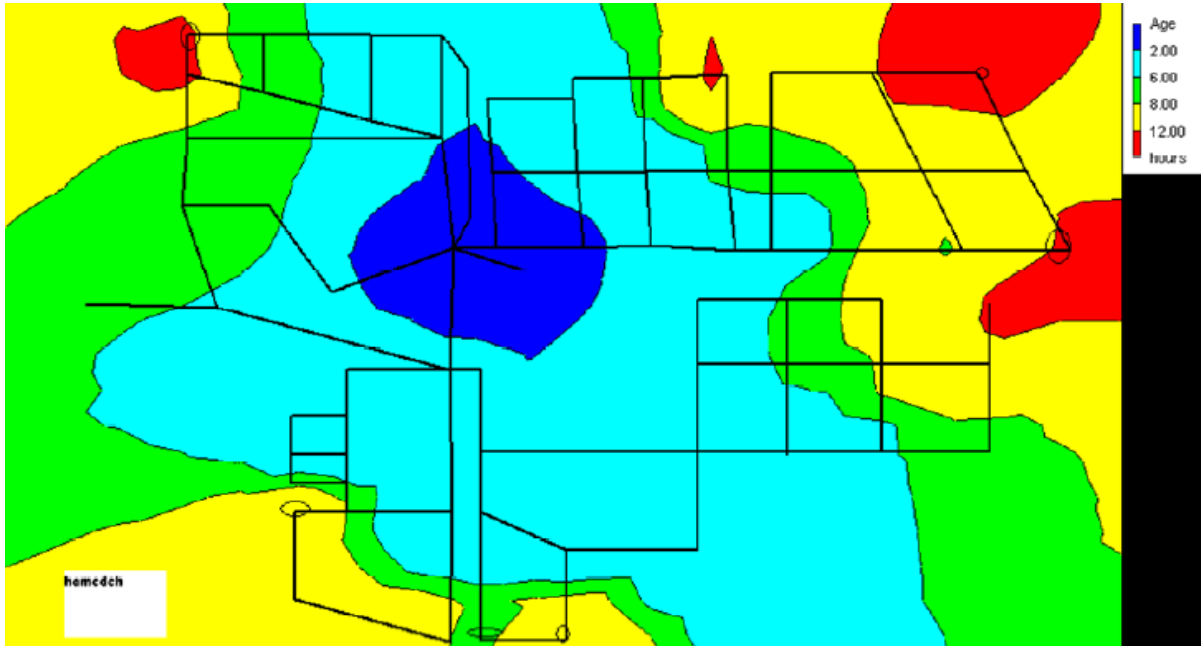
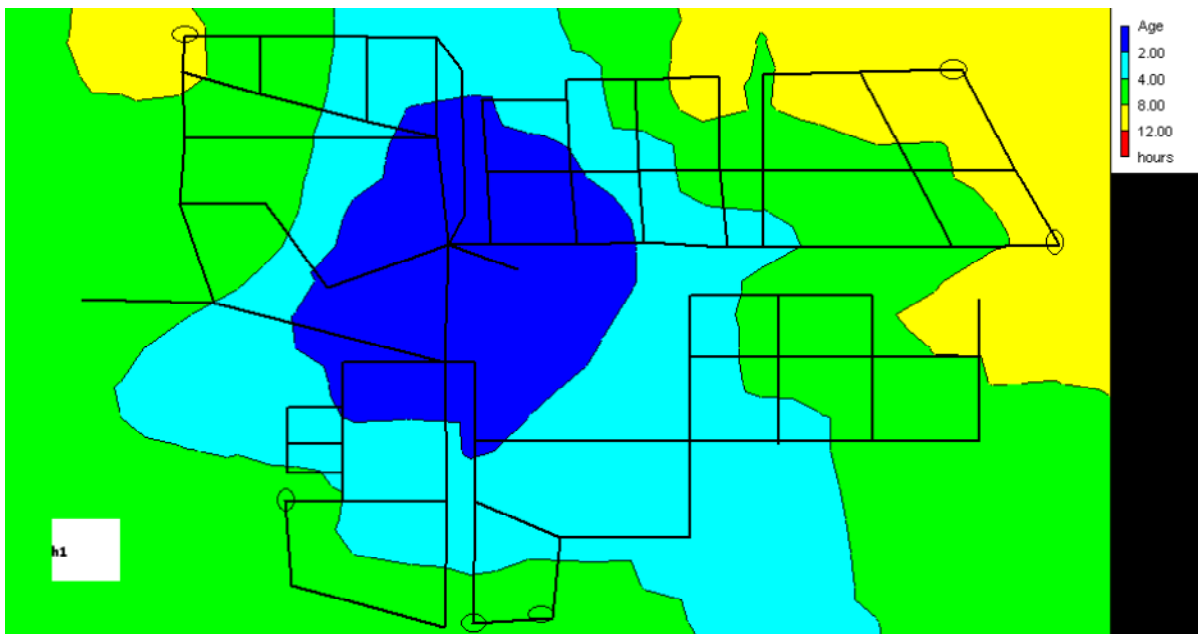Fig. 2: Situation water age in The Primary of blind spots in distribution system of Hamedeh

Fig. 3: Situation water age The first alternative H1 of blind spots in distribution system of Hamedeh

Given the changes made, results have been achieved. The flow had been through small changes and has been oscillating in those points and coupled with increased velocity, so, water age and consumption of chlorine has decreased in the area. The resulting changes are in Table 1.

In alternative 2nd (H2) which has the same basic system, but with changes only in the consumption and the pipe diameter (Fig. 4). The diameter has been changed to diameter of pipe No. 88 from 250mm to 150mm. And according to Table 3 (Fig. 4), the water flow rate and velocity was fluctuating instead of increasing which causes the amount of chlorine spent in the system to be low. With this alternative, water age has been minimized in the water distribution network system and all the blind spots have been removed in from within the system. This alternative has been the best option.

In the 3rd option called H3H1 (Fig. 5), which is similar to the option H1 but with changes in pressure.
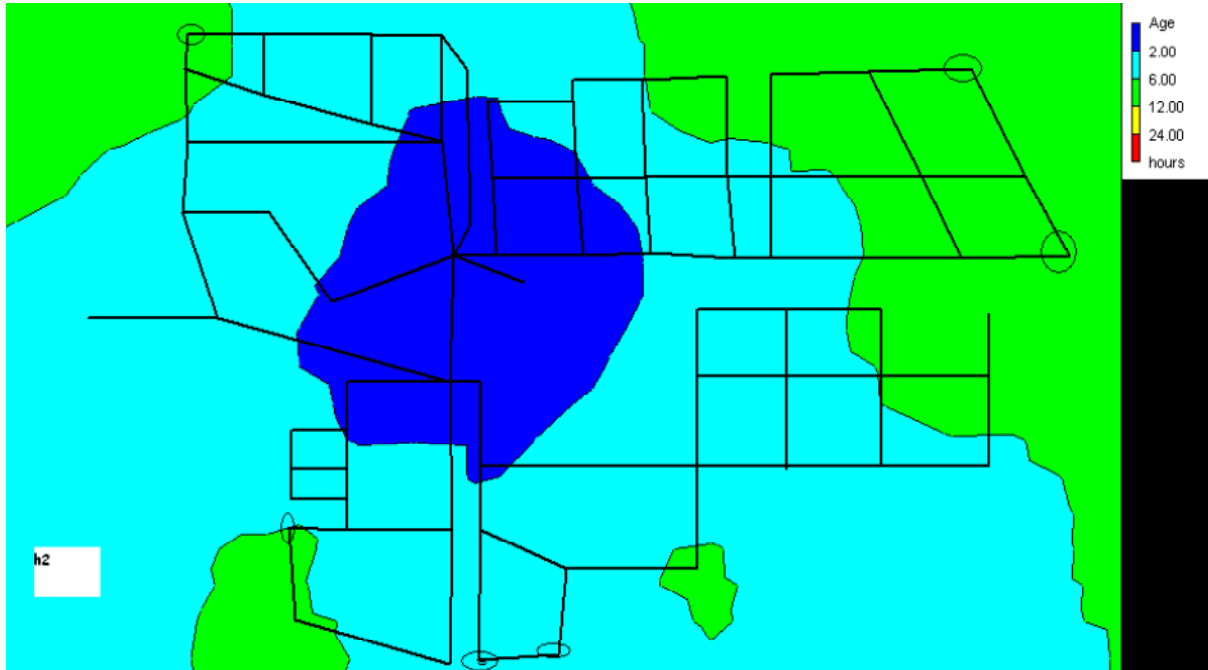
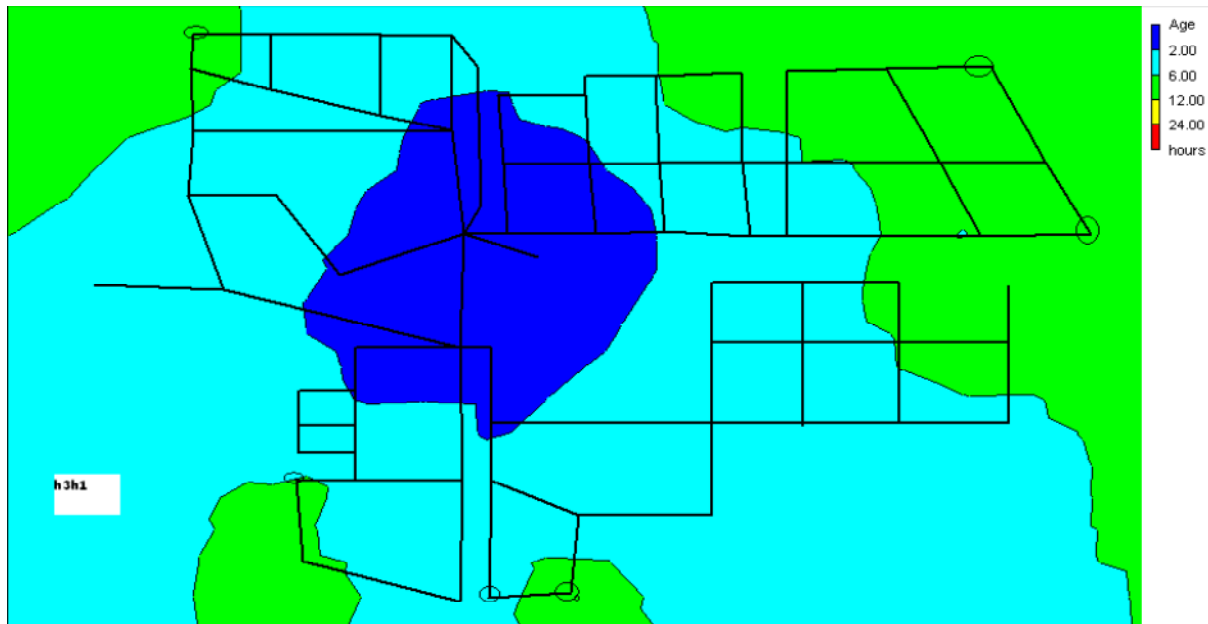Fig. 4: Situation water age The Second alternative H2 of blind spots in distribution system of Hamedeh

Fig. 5: Situation water age The third alternative H3H1 of blind spots in distribution system of Hamedeh

However, within the system, there are pressure increases, the changes made to the chlorine consumption, no changes in velocity consequently, no changes in residual chlorine and flow.

However, Water age and blind spots have been better than in H1 in the third option. The fourth option named H3H2 (Fig. 6) is similar to the option H2 but with changes in the pressure which was increased in the system. According to the changes made, no changes in

velocity consequently, no changes in the residual chlorine as well as flow. Nevertheless, Water age and blind spots have been better in the system than in H1.

Option 5 was called H4 (Fig. 7) and in this system, the pipe diameter size has been varied, also, changes have been made in the amount of chlorine in the system. The results are shown in Table 6. This had led to the need to increase flow and consumption of chlorine. However, this has not led to any changes in
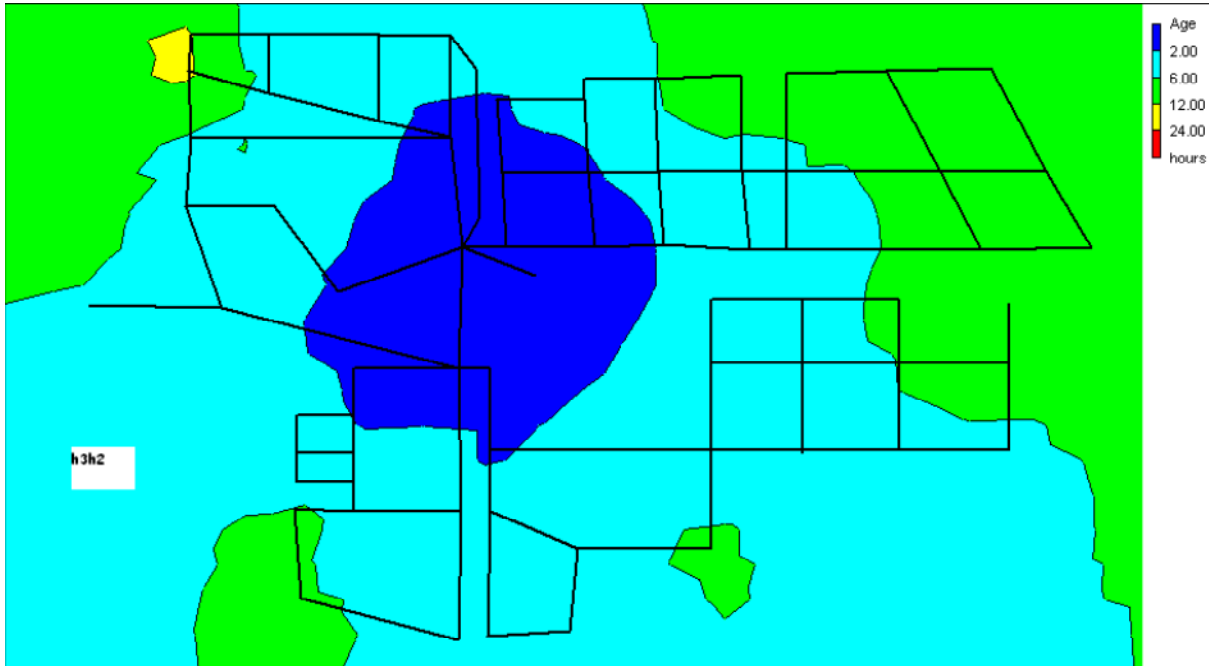
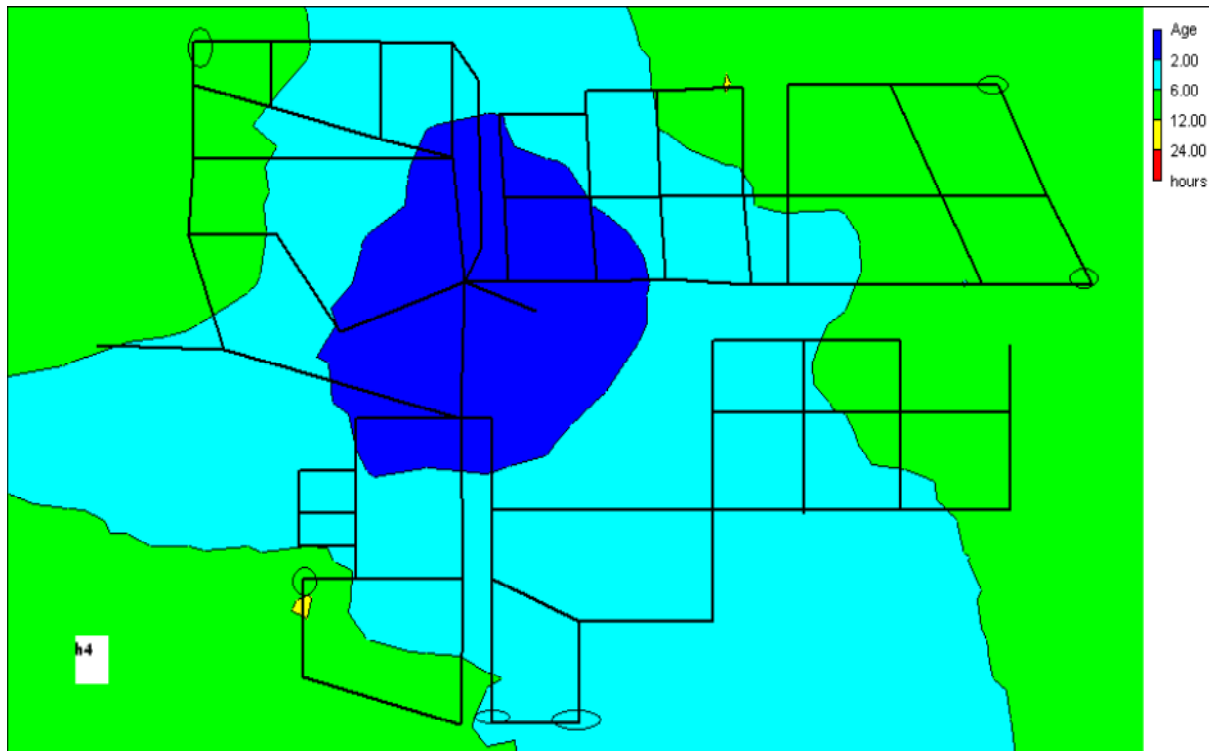Fig. 6: Situation water age The fourth alternative H3H2 of blind spots in distribution system of Hamedeh

Fig. 7: Situation water age The fivth alternative H4 of blind spots in distribution system of Hamedeh

velocity. Water age and the emergence of blind pots have been better than in options 1 and 4 in the system.

The 6th alternative is named H5 (Fig. 8). This option is similar to the primary system, though, there has been increase in pressure in the in the system. But, despite these changes, there has been no changes in speed and in the amount of residual chlorine and flow but the emergence of water age and blind spots, H2, H3H1, H4 H3H2, H1, (HAMEDAH) and H5 in the system have led to an increased primary system.
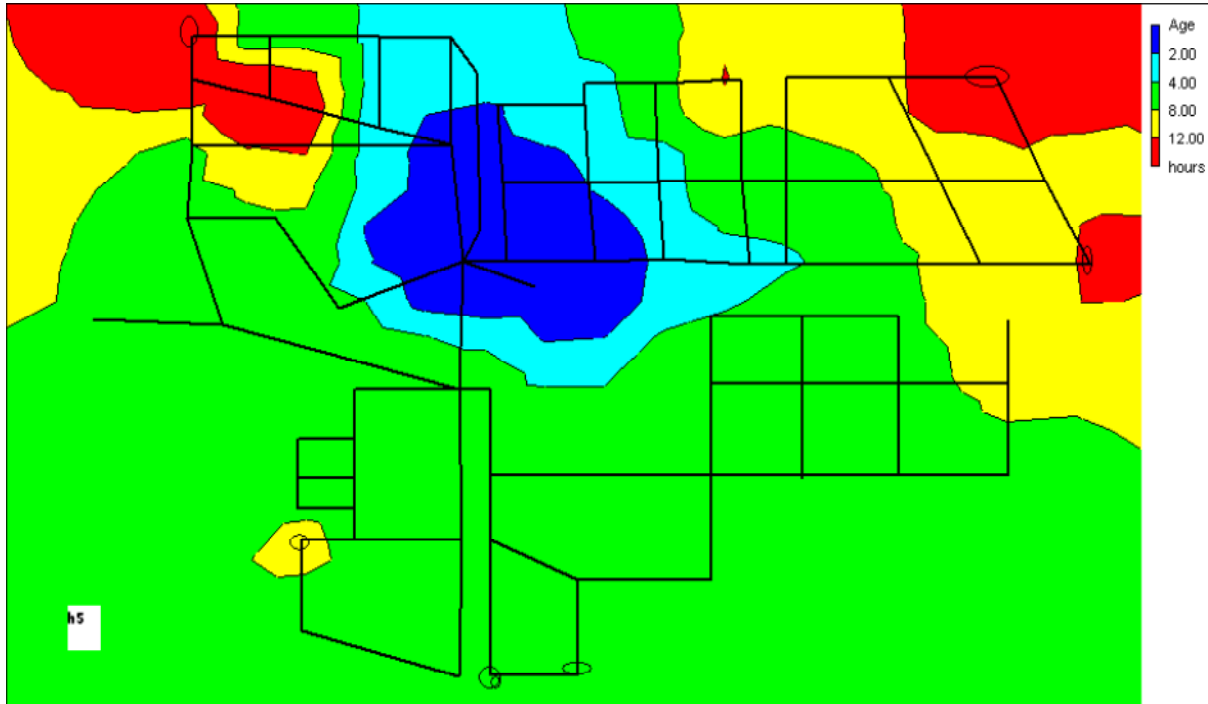
Fig. 8: Situation water age The sixth alternative H5 of blind spots in distribution system of Hamedeh

In distribution systems and networks with thick water transmission lines, the amount of water produced in these facilities is very high. The amount of water age of these facilities is high due to lack of precise control system in the distribution network and there is a consistently large difference between what is produced and what is consumed. One of the important factors in increasing the water age is the emergence of water points in core systems and distribution networks. When water passes through the pipes at high currents, water consumption is disproportionate. When water situation is static, the limit of velocity tends to zero at that point. And even if there haven't been any bacteria in these points, some chlorine will be spent in the water distribution system. According to Table 2 and 3, on line 1 when the rate was zero velocities, high chlorine levels were spent. The function of chlorine in the system is to attack and render bacterial ineffective and probably eliminate them in the system and distribution network. Whenever, the flow volume in the system is low in the system and distribution network the amount of chlorine spent is less than when there is large volume flow, this reduction in flow volume might be as a result of reduction in the flow pipe diameter. The exact residual chlorine in the system is higher. For appropriate water age to be maintained in the network and distribution system the bypass flow rate must not be too high and the pipe diameters must be designed to give a predicted minimal consumption. In addition, chlorine level must be maintained at the minimum. Blind spots are areas in which resources are at a high distance to the consumers.

Increase in the pressure of the system might not decrease the water age so also are changes in the flow volume or consumption of chlorine are not likely to affect the water age most especially at the dead ends. Nevertheless, in order to reduce the effects of increasing pressure and decreasing water age as well as to omit the blind spots, the pipe diameter must be designed to accommodate the projected appropriate intake. According to our results, the best case H2 shows that water consumption increased in the system and this minimized the amount of water age and blind spots in the system have also been deleted. Nevertheless, sometimes it couldn't control the amount of water in nodes.

According to the results that have been obtained, the best option might be option 5 (H4). This is so because there had not been any changes in the pressure and consumption of the water in the parts, the only changes had been in pipe diameters and almost the same result as obtained in option 2 was achieved. Accordingly, it can be concluded that the most important factors that could increase the water age are blind spots in the system and the inaccuracies in the design and distribution network systems. Also, the size of pipe diameters predicted in these places can make the amount of flow in the pipes to be more than the amount consumed in the system. And this will cause an unbalance in the system which may at times slow down the system and cause the velocity to tend toward zero in the system. Also, the amount of chlorine spent in these areas had increased. Of course, other factors such as

temperature will also increase the effects of the water age. According to the results of this study, the result is that the emergence of water age and generation of blind spots in the water system and distribution network causes deterioration in water quality and distribution systems networks. And these had been consequences of absence of a careful design planning. The problems associated with water quantity and quality in the water distribution systems are partly due to presence of blind spots in networks and distribution systems and this had been responsible for the high water age and high volume water flow within the system. The following situation often accompanies these problems; zero velocity i.e. static condition within the system, cases of spent chlorine along the system and bacterial growth. (Assuming that initially, the system is free of bacteria). Increasing pressure hasn't had any effect on the water age and blind spots in the system. According to the outcome of this study and its analysis using the EPANET model approach, the following results have been obtained:

- For water age, smaller water and removal of the blind spots are required. The quantity of water produced got to the consumer at the earliest shortest time. The flow rate of water getting to the consumption point is desirable.
- Need for the design of a pipe diameter that would effectively accommodate blind spots by ensuring appropriate sizes at appropriate points along the system network. This will also ensure appropriate consumption at all times.
- To reduce the water age of the water system and distribution network, the first step is to consider the production system, after this, the pipe diameters must be designed such that they are proportional to the water current passing through. This means that high flow-rate passing through the pipes must be discouraged.
- Pressure must be maintained in the distribution network system according to the gap between production and consumption rate or else, this in addition to taking a little time to increase the water age of declining water quality might lead to a break down in the system.
- The amount of chlorine spent is more at the blind spots. And high consumption of the chlorine in blind spots points affects the volume of bacteria in the system.
- To increase the rising water levels in parts where chlorine has affected and where the current has been reduced.
- There are equal pressure points for the current through a node in two different directions (in stagnant water and the desire to quickly zero); the amount of chlorine to be spent will be more at such point (blind spots). And consider the point where

the difference will be mentioned at the beginning or at the end of the network system.

Considering the above results, the amount water age and generation of blind spots in the system and distribution network will be due to inaccuracies in network design and distribution systems or inability to consider some important factors when designing the distribution network system. Also, when designing, consideration must be made for a long-term planning of up to 20 or 30 years. This assists in planning for expansion issues from the patrons. Methods of increasing the water age of the system must be part of the design planning as inappropriate methods leads to deterioration in the water quality and once deterioration of the quality sets in, all the physical, chemical and biological properties of the system are prone to easy attacks which is a big problem in the system, having thick water transmission lines might not be enough to cater for all these problems.

ACKNOWLEDGMENT

REFERENCES

A National Drinking Water Clearinghouse, 1998. Iron and Manganese Removal. Fact Sheet, pp: 1-4.

Burlingame, G., A. Camper, G. Kirmeyer, M. LeChevallier, P. Parekh and C. Smith, 2007. Distribution System Water Quality Strategic Initative Plan. Awwa Research Foundation, 6666 West Quincy Avenue, Denver, CO., pp: 80235-3098.

DeBoer, D.E., 2006. Fate of disinfectants and disinfection by-products in water distribution systems. Report for 2005SD38B.South Dakota State University, pp: 3-8.

Delahaye, E., B. Welt, Y. Levi, G. Leblon and A. Montiel, 2003. An ATP-based method for monitoring the microbiological drinking water quality in a distribution network. Water Res., 37(15): 3689-3696.

EPA, 2002. Health Risks from Microbial Growth and Biofilms in Drinking Water Distribution Systems. Retrieved from: http:// www. epa. gov/ safewater /tcr/pdf/biofilms.pdf, (Accessed on: March 16), Washington, DC.

Lahlou, Z.M., 2002. Water Quality in Distribution Systems. A National Drinking Water Clearinghouse, Fact Sheet

Mains, C., 2008. Biofilm control in distribution systems. Natioal Environmental Services Center, NESC Eng. Sci., 8(2): 1-4.

Rubulis, J., J. Talis, H. Lars and K. Andreas, 2007. Methodology of Modeling Bacterial Growth: In Drinking Water Systems. Techneau, D5.5.4 (March 2007), pp: 11-28.