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Analysis of Water Quality Characteristics in Distribution Networks

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***Abstract*— *In this study, a model was developed by Epanet2.0 software to analyze water quality for parameters of hydraulic and water quality model (chlorine concentration and water age model) for a segment of Erbil city WDS by using observed and documented data. Controlling free residual chlorine properly is important to ensure meeting regulatory requirements and satisfying customer needs. For the calibration process and collecting field data digital pressure loggers for recording pressure in a WDS was installed. For discharge measurements, ultrasonic flow meters were used. To assure the reliability of the model a calibration process was carried out for extended period analysis and several alternatives had been studied as a solution to overcome negative pressure zones by the calculated Hazen William C-factor. This kind of study can be used to predict so many infrastructure projects.*

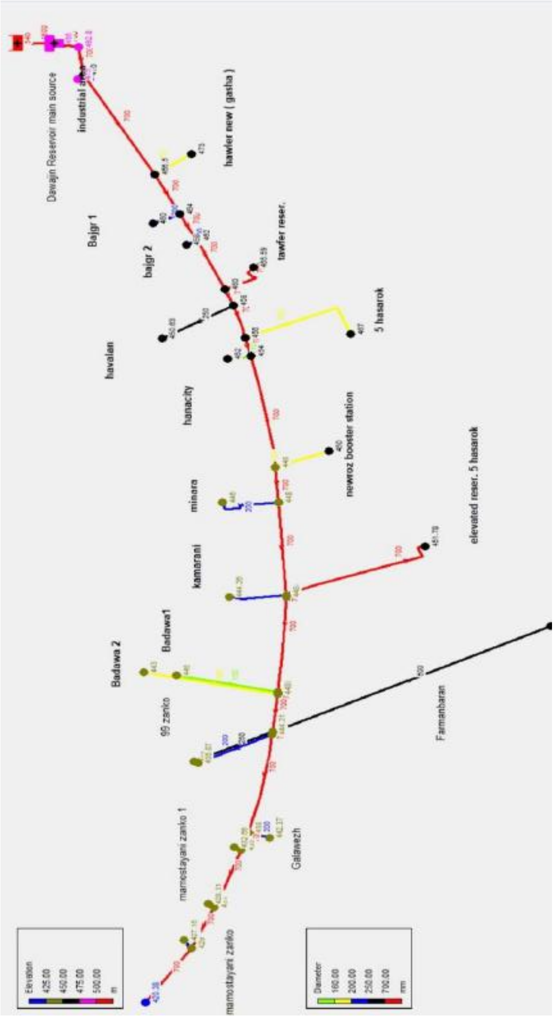
***Keywords*— Water Quality, Water Distribution system, Calibration, Chlorine Concentration, Water age.**

I. INTRODUCTION

drinking water utilities face the challenge of supplying drinking water to their users despite the many factors that can result in the retrogression of water quality before it is delivered to the user's tap. Frequently, raw water is derived from groundwater sources that may be subject to naturally occurring or accidental contamination (ILSI 1999, Gullick et al. 2003). The first Proposition of using mathematical models to analyze water distribution systems was in 1930 s by Hardy Cross (1936). water quality models have reached operational status, but research and development continue to further the understanding of the processes taking place in the distribution system and to translate this understanding into usable tools (i.e. Epanet2.0 program).In studying water distribution system the most important thing which has apriority to determine the type of model that is most applicable because so many factors have an impact on the degree of temporal (overtime) for example, steady-state modeling represents external forces as constant in time (static) and determines solutions that would occur if the system were allowed to reach equilibrium (Wood 1980a). In dynamic modeling, demands and supplies are allowed to vary with time and the resulting temporal solution is determined (Clark et al. 1988a, Clark et al. 1988b). After the hard efforts of researchers to computerize both water quality and Hydraulic models finally in 1993 EPANET2.0 was initially developed in the united states by the Environmental protection agency as a distribution system hydraulic-water quality model to support research efforts at EPA (Rossman et al., 1994). The development of the EPANET software has also convinced the requirement for an acquisitive public-sector model and has served as the hydraulic and water quality "engine" for many scientific and commercial water quality models. Water age is considered as a time to convey particles of water or time to travel water particles from the source (after the treatment process) to the consumer's tap. There are two reasons behind studying water age, firstly to ensure the contact time with chlorine secondly, to avoid quality deterioration with time. Water age varies according to the fluctuation of demand in a model. To estimate water age in a water distribution system a mathematical model that represents the hydraulic behavior of the movement of water has been used. (Clark and Grayman, 1998). In the mid-1980s a Single period analysis travel time models were first introduced (Males et al., 1985). These models were subsequently extended to dynamic representations that determined varying water age throughout the distribution system (Grayman et al., 1988). To predict concentrations of chlorine, DBPs, and other constituents in a distribution system Both models can be used as a complement of each other it means Water quality models can be used as conjunctive models with hydraulic models (Vasconcelos et al., 1996). Relationships proposed by (Rossman et al) can be used to estimate the effect of the interaction of the flowing water with the pipe wall. (1994). In the early 1990s a simplified model of water age in tanks and reservoirs was developed (Grayman and Clark, 1993). Water quality can be deteriorating during transmission and distribution after treating in a water treatment plant. To minimize the potential of this deterioration should add chlorination for the finished water. The concentration of chlorine can vary increase/decrease according to the fluctuation of water demand while the water flows through the pipes. Treated water in the water treatment plant is disinfected then it enters the transmission system (Clark and Coyle, 1990). The expectation of bacterial contamination and growth is high in the transmission and distribution system. Therefore, the advantage of remaining a detectable disinfectant residual in the medium according to standards is to minimize the potential of waterborne diseases and biofilm growth. (Clark et al). (1993) stated that the chlorine residual by the effect of demand fluctuation can virtually disappear at various times during the day. Maul et al. (1985a) proved that lower levels of chlorine residuals and extended retention time of the water in the network causes the highest bacterial concentrations are referred. After the water is treated in the water treatment plant then transfers to the water networks temporal and spatial consumption can occur. Chemical reactions of the chlorine with water constituents and with both the biofilm and nodes(tubercles) formed on the pipe wall, as well as reaction with the pipe wall material itself causes This temporal and spatial consumption of chlorine through the water journey in water networks (Wable et al., 1991; Zhang et al., 1992; Kie´ne´ et al., 1998). chlorine is consumed in the water itself and through contact with the interior wall of the pipe.

II. CASE STUDY

Case study lies in Erbil city; Erbil city is the fourth largest governorate of Iraq. The latitude of Erbil is 36.206293, and the longitude is 44.008870. Erbil is a city is located at Iraq with the global coordinates of 36° 12' 22.6548" N and 44° 0' 31.932" E. In this study a segment of Erbil city water distribution system was used as a case study network which is consists of 700 mm ductile iron pipe as a major pipeline and the branches (i.e. connections) that conveying water to the 25 % of Erbil city consumers considered as a main pipe lines which is made up of (HDPE and ductile pipes) with different diameters. This segment of Erbil city network is being supplied by a gravity concrete reservoir with capacity (20,000) m3 of water that water had already been treated in a treatment plant then pumped to the reservoir .it means the system is a combination of gravity system and pumping system. The modeled portion of an Erbil city water network has an approximate length (10, 680) m. The reservoir Elevation of a concrete reservoir tank is about 498 m above msl and the final junction is 430 m higher than msl.. Figure below elaborates the case study WDN sources, connections diameter, major pipeline and main pipelines.



III. MODELLING

The first step to make a hydraulic model for water distribution network is to collect all observed data from all necessary components in different places and components of the network, then introduce assembled observed data and documented data from water authorities into Epanet2.0 program so as to build the hydraulic model, after completed the model in a software then began the characterization phase of the nodes and links. In the fixed piezo metric level nodes was introduced the value of its pressure. To the junction nodes were calculated and entered in the demand, elevation and consumption's patterns. For the demand were identified the branches within the DMIs and manually calculated the consumption using the ultrasonic flow meters for measuring out let major pipeline and branches. Hazen-Williams formula for the calculation of unit load losses with a roughness coefficient k was found in a field. the model can be developing by calibration process. Generally, several parameters have been taken into account in this study such as (finding actual Hazen William C- factor Value, make calibration process for whole network and make alternatives as a solution). for finding C factor some field information should be known such as Elevation of a junction, pressure data loggers for recording pressure, diameter of a pipe line segment and installing ultrasonic flow meters to measure flow rate.in order for the results to be more precise, this process should be repeated in many places then can take an average value of C- Factor. After the hydraulic model has been created and C- factor values were updated in a computer model, there was a problem occurred in the model which is appearing negative pressure zones in some DMIs in a case study area specially during peak hours. A set of alternatives has been suggested to overcome the effect of negative pressure there are three alternatives has been modeled:

1. **Adding Elevated water tank at the beginning of negative pressure zones:** installing water tank before negative pressure zones which is works with such a system that the Elevated tank is filled during night (no peak hour times) and it will empty during peak hour to compensate the shortage of water. Adding an elevated tank before the area of negative pressure zones so that when there is water the tank will be filled then the stored water can be used during water shortages (i.e. peak hour) to overcome negative pressure. That's why this alternative was chosen because it's an easy way to execute, it has a low cost compared to the other alternatives and it considers as a reliable solution to improving the case study water distribution system
2. **By adding a parallel pipe:** Because of the water Distribution network is exist so there is no way to increase the diameter of transition lines, therefore, to deliver excessive water in a reservoir it is preferred to add another (700 mm) pipe which is 20% of the total length of case study network. The second alternative that is selected among alternatives is putting a pipe that has the same diameter as existing pipeline and is parallel to it as shown in a figure. The philosophy behind this kind of model is to increase the suppling discharge, because of the existing pipe diameter not sufficient to supply demand discharge in peak hours specially summer times and there is enough treated water in reservoir so it needs to increase the pipeline diameter by replacing the existing pipeline not economic and not reliable
3. **By adding the pump station at the outlet of the reservoir:** installation of pump station needs maintenance, electricity and for this study the unit headless increases but it overcomes the negative pressure zones in the system. This alternative is developed by to set a pump station after water storage. The philosophy behind this alternative is to increase energy to supply sufficient water to study area water distribution system. The main advantage of this alternative is that water discharge is much higher and ensuring that water is accessible to all users.

Subsequent to the proper calibration of a hydraulic model, another calibration of parameters in a water quality model may be required. Such as chlorine concentration and water age. both the field and laboratory experiments were used to calibrate water quality parameters or in general, they contribute to the calibration process in water quality. laboratory tests can be used to find the bulk chlorine decay coefficient (kb) however, the chlorine residual was obtained from the field measurements. For finding the bulk chlorine coefficient was obtained from three samples in three places along the major pipeline. For calculating chlorine decay calibration of the Water Distribution networks many samples were taken in four different for over 3 days with a splinter but in regular time intervals. For introducing the collected field data to the model, the data should have converted to text file format then the model can calibrate the model by a process known as trial-and-error which make up of comparison of both the simulated and the observed chlorine residual data to adjust the coefficient of wall decay (kw) in the software. Water age is the most important parameter that has a great influence on the determination of chlorine bulk coefficients because it depends upon how much time is available in the system for bulk reactions and how long the treated water that is transported will remain in the pipe. The longer it stays, the more it affects the pipe wall and contact with it to take place the reactions. Also, there is no such facility to measure water age in WDS only it can be simulated. Generally, Epanet2.0 simulates the water age for the whole model for an extended period of 72 hours or more.

IV. RESULT AND DISSCUSSION

Table1: computed pressure results of all alternatives

Pressure in m				
Node ID	pump station	Parallel pipes	Normal condition	Add tank
J2indust	68.94	29.34	26.53	28.26
J3	63.53	24.02	22.12	22.97
J4Gasha	58.54	30.49	24.08	25.85
J5	39.61	19.51	5.15	18.6
J6bajgr1	56.12	32.92	23.49	26.31
J7	57.1	34.62	24.47	28.19
J8bajgr2	55.08	34.89	23.63	27.09
J9	57.92	38.01	26.47	30.28
J10tawfer	51.98	36.89	22.58	27.11
J11	46.38	31.29	16.99	21.51
J12havalan	52.55	30.88	23.73	28.57
J13	50.2	30.84	21.38	29.09
J14hasarok	52.18	31.08	25.18	29.75
J15	34.68	15.13	7.68	14.17
J16hanacity	52.9	32.1	25.89	30.84
J17	31.66	16.39	4.65	16.49
J18qalat	51.86	32.73	24.85	31.89
J19	25.2	12.94	**-1.8**	14.53
J20minara	50.06	31.36	23.05	31.62
J21	45.15	28.1	18.15	27.76
J22	45.82	28.13	18.82	27.64
J23	41.82	24.18	14.81	23.7
J24kamarani	45.79	28.11	18.78	27.61
J25	44.2	28.43	18.05	27.6
J26badawa1	43.29	26.2	16.29	25.86
J27	26.44	14.08	**-0.56**	14.89
J28badawa2	43.25	26.18	16.25	25.83
J29	24.42	19.02	**-2.58**	16.06
J30Aso	44.61	27.69	17.61	27.38
J31	49.19	33.08	22.19	32.97
J32farmnbaran	45.6	28.68	18.6	28.37
J33	39.08	22.52	12.08	22.3
J34zanko99	46.37	29.46	19.38	29.15
J35	42.53	28.52	15.54	28.92
J36	52.14	35.33	25.14	35.04
J37	44.37	28.37	17.37	28.28
J38	55.09	38.3	28.11	38.01
J39	56.62	40.02	29.63	39.78
J40	59.03	42.25	32.05	41.97
J41	61.03	44.41	32.05	44.17
J42	61.01	44.24	32.44	43.96
J43	61.67	45.18	32.7	44.97
J44	69.63	52.86	33.66	52.58

After developing a model for both hydraulic and water quality for three alternatives as a solution to compensate water for negative pressure zones during periods of low pressure or critical times. Epanet2.0 can display analysis results for a network for each alternative. To make a comparison of all three alternative analysis results for a network includes display the difference between these three alternative analysis results for both node and pipe values as discussed in detail in this study such as node pressure, hydraulic total head, water quality parameters after calibration, flow, velocity, and hydraulic head loss while the demand, demand pattern observed chlorine concentration is fixed in analysis for all alternatives. The analysis results can be used to compare three analyses according to the following criteria.

1. Velocity: the existing system hasn't an economic velocity, this term is true for the third alternative and sometimes to the second alternative but the first alternative has an economic velocity.
2. Pressure: The third alternative have a higher pressure compared with the rest alternatives. However, the second alternative has the lowest.
3. Flow: The third alternative has the highest discharge, and the third alternative is alternative two.

4. Unit head loss: The third alternative has the highest unit head loss however the other alternatives have a lower unit head loss.
5. Hydraulic calibration: although all alternatives have matchmaking with the existing system it means they are well fitted to the working system but the first and second alternatives have a better conforming with the system.
6. Water quality calibration: first and second alternatives have more response to the existing system.
7. Water age: The first alternative has the highest water age while the third alternative has the lowest due to effect of pump station.
8. Chlorine concentration calibration: both first and second alternative calibration were more compatible with the existing system than the Third alternative.
9. cost: The third alternative needs the highest cost while the first alternative needs a lower cost. The third alternative requires the cost of supply boosters, construction of booster station, monitoring, power supply, and maintenance while alternative one has an only cost of construction.
10. Long-term solution: third alternative can work for longer term than the rest alternatives even number of populations in case study area increased if water treatment plant has a capacity to provide sufficient water.
11. Reliability: the similarity of alternatives is that all alternatives are reliable but the first alternative and second alternative have more reliability compared with the third alternative.
12. Constancy: First alternative and second alternative can work under different conditions.
13. Confidence: during the system works, the third alternative has more confidence for water to reach every point.
14. Inviolability: Third Alternative can't work if one of its parts fails such as the sudden failure of pumps or power supply.
15. Communicability: both the first and second alternatives are easy to treat and system problems are understandable.
16. Simplicity: alternative one considers as the easiest to carry out, while alternative three is complex needs cost and experience.
17. Compatibility: all alternatives are conforming with existing norms and procedures of the case study area.
18. Reversibility: alternative three if fails the model cannot return to the prior state, however, there are no such criteria in alternatives one and two.
19. Wholesomeness: Alternative three has a capability of success in different future states and alternative two seems to be a solution for the long term if alternative three and alternative two integrated may have more success however alternative one seems to be a solution for a shorter period especially if case study area had more population density in near future.

V. CONCLUSION

1. A conclusion Calibration of the hydraulic model explained a reduced C-factor for 700mm from 140 according to standards to 92 which is very low compared with normal conditions. This could have two reasons may because of the high age of installed pipes in the network and the velocity in the pipe, not economic velocity causes high unit head loss.
2. Major pipeline not sufficient for future demands.
3. From the obtained results of all alternatives, the pressure is quite enough to serve all nodes.
4. the First alternative is applicable when the solution is required for short terms, the second alternative is applicable when the solution is for long terms, the third alternative is applicable when the solution requirement is for long terms in addition to availability experience and higher cost.

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REFERENCES

[1] American Water Works Association (1989). "Distribution Network Analysis for Water Utilities." AWWA Manual M-32, Denver, Colorado
[2] American Water Works Association (1996). "Ductile Iron Pipe and Fitting." AWWA Manual M-41, Denver, Colorado.
[3] American Water Works Association (1998). "Distribution System Requirements for Fire Protection." AWWA Manual M-31, Denver, Colorado.
[4] Basford, C., and Sevier, C. (1995). "Automating the Maintenance of Hydraulic Network Model Demand Database Utilizing GIS and Customer Billing Records."

Proceedings of the AWWA Computer Conference, American Water Works Association, Norfolk, Virginia.

[5] Bowen, P. T., Harp, J., Baxter, J., and Shull, R. (1993). Residential Water Use Patterns. AWWARF, Denver, Colorado.

[6] Brainard, B. (1994). "Using Electronic Rate of Flow Recorders." Proceedings of the AWWA Distribution System Symposium, American Water Works Association, Omaha, Nebraska.

[7] Buchberger, S. G., and Wells, G. J. (1996). "Intensity, Duration, and Frequency of Residential Water Demands." Journal of Water Resources Planning and Management, ASCE, 122(1), 11.

[8] Buchberger, S. G., and Wu, L. (1995). "A Model for Instantaneous Residential Water Demands." Journal of Hydraulic Engineering, ASCE, 121(3), 232.

[9] Cesario, L. 1995. Modeling, Analysis, and Design of Water Distribution Systems. Denver, Colo.: AWWA.

[10] Clark, R.M. (2012). Modeling Water Quality in Drinking Water Systems Second Edition. AWWA

[11] Clark, R.M., and D. L. Tippen. (1990). "Water Supply" in Standard Handbook of Environmental Engineering. Edited by Robert A. Corbitt, NY, McGraw-Hill, Chapter (5), 173-220.

[12] Grayman, W. M., Clark, R. M., and Males, R. M. (1988). "Modeling Distribution System Water Quality: Dynamic Approach." Journal of Water Resources Planning and Management, ASCE, 114(3).

[13] Gullick, R.W., M.W. LeChevallier, R.C. Svindland, and M. Friedman. 2004. Occurrence of Transient Low and Negative Pressures in Distribution Systems. Journal AWWA, 96(11):52–66.

[14] Haestad Methods,Thomas M. Walski,Donald V. Chase, Dragan A. Savic, Walter Grayman, Stephen Beckwith, Edmundo Koelle.(2003). ADVANCED WATER DISTRIBUTION MODELING AND MANAGEMENT. First Edition, Second Printing.

[15] Males, R. M., Clark, R. M., Wehrman, P. J., and Gates, W. E. (1985). "An Algorithm for Mixing Problems in Water Systems." Journal of Hydraulic Engineering, ASCE, 111(2).

[16] National Research Council (NRC). 2006. Drinking Water Distribution Systems: Assessing and Reducing Risks. Washington, D.C.: National Academies Press, 15–46.

[17] Panguluri, S., W.M. Grayman, and R.M. Clark. 2005. Distribution System Water Quality Report: A Guide to the Assessment and Management of Drinking Water Quality in Distribution Systems. Cincinnati, Ohio: USEPA Office of Research and Development.

[18] Santiago Arnalich, Maxim Fortin, Amelia Jimenez (2011). Epanet and development (How to calculate water network by computer), Arnalich, Printed by Amazon.