COMPUTER APPLICATIONS ON PRESSURE PIPING SYSTEMS AND WATER QUALITY ANALYSIS

by

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Abstract

A part of Basra water network which is near to Bradia water treatment plant is analyzed by using water cad program, water cad is also used for studying the water quality in the model by calculating the age and chlorine concentration for each pipe on the model. This model consist of (21)pipe ,(15)node or junction ,(6)loops, two water pumps one is operated and the second is stand by(each pump has a discharge equal to 0.6 m^3/sec and a head of 60 m and an electrical control which related with the elevation of water in the tank),one elevated tank &one reservoir of water. The model studied hydraulically for two cases, the first case when the pump is power on and the second case when the pump is power off. Also the direction and discharge for each pipe are calculated. Different results are obtained in two cases. Also the results of water quality studies show that both the age of water and chlorine concentration at any pipe depended on its location with respect to the water treatment plant. Finally the calibration of the model is done in order to check the accuracy of the results.

تطبيقات الحاسوب على أنظمة أنابيب الضغط و تحليل نوعية المياه

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الخلاصة

جزء من شبكة ماء البصرة و القريبة من محطة معالجة ماء شرب البراضعية حللت باستخدام برنامج WaterCAD ،هذا البرنامج قد استخدم أيضا" في دراسة نوعية المياه من خلال حساب عمر المياه و تركيز الكلور لجميع الأنابيب في النموذج . هذا النموذج مؤلف من 21 أنبوب ،15 عقدة،6 حلقات،مضختان للماء واحدة تعمل و الأخرى للاحتياط (كل مضخة لها تصريف(0.6م^3/ثا) و ضاغط 60م ولوحة تحكم كهربائية مرتبطة مع منسوب الماء في الخزان)و خزان ماء واحد مع حوض(مجهز) واحد للماء. تم دراسة هذا النموذج هيدروليكيا لحالتين ،الأولى عندما تعمل المضخة و الثانية عندما تتوقف المضخة كما تم حساب مقدار و اتجاه الجريان في كل أنبوب و قد تم الحصول على نتائج مختلفة في كلا الحالتين.إما نتائج دراسة نوعية المياه فقد أظهرت إن كلا من عمر الماء و تركيز الكلور في إي عنصر يعتمد على موقع ذلك العنصر بالنسبة إلى وحدة معالجة المياه.و أخيرا"تم إجراء معايره للنموذج للتأكد من دقة النتائج.

1. Introduction

The main purpose of water distribution system is to meet demands for potable water. People use water for drinking, cleaning, gardening, and any number of other uses and this water need to be delivered in some fashion [1].

Water distribution system analysis is driven by customer demand. Water usage rates and patterns vary greatly from system to system and are highly dependent on climate, culture and local industry [10].

In practice, pipe networks consist not only of pipes, but of miscellaneous fittings, services, storage tanks, reservoirs, and meters, regulating valve, pumps and electronic and mechanical controls. For modeling purposes, these system elements can be organized into four fundamental categories [9].

Junction nodes: junctions are specific points (nodes) in the system where an event of interest is accruing. Junctions include points where pipes intersect, points where major demands on the system (such as a large industry, a cluster of houses, or a fire hydrants are located, or critical points in the system where pressures are important for analysis purpose.

Boundary nodes: boundaries are nodes in the system where the hydraulic grade is known, and they define the initial hydraulic grade for any computational cycle. They set the hydraulic grade line used to determine the condition of all other nodes during system. Boundary nodes are elements such as tanks, reservoirs, and pressure source.

Links: links are system components such as pipes that connect to junctions or boundaries and control the flow rates and energy losses (or gain) between nodes.

Pumps and valves: pumps and valves are similar to nodes in that they occupy a single point in space, but they also have link properties because head changes occur a cross them.

In the past , water distribution systems were designed and operated with little consideration of water quality , due in part to difficulty and expensive of analyzing a dynamic system , but today there are s several and different computer program which are used for analyzing and studying the quality of water . One of the most important one from these computer program is the "WaterCAD" which is power, easy to use program that helps civil engineers design and analyze water distribution system [2].

WaterCAD can be used as a stand-alone program, integrated with AutoCAD or link to a geographical information system GIS via the GEMS components. In summary WaterCAD can be used for [2],

- Piping sizing
- Pumping sizing
- Master planning
- Operational studies
- Rehabilitation studies
- Vulnerability studies
- Water quality studies

2. Model Development

Generally, this model composed of two parts, the first part is the hydraulic model, while the second part is water quality model.

2.1. Hydraulic Model

This study adopted the hardy cross continuity equation and Hazen- Williams head losses formula to analyze the hydraulic flows in pipe [i.e., determining the value and direction of discharge for each pipe in the network].

The general equations which are used in Hardy cross method are [1]:

$$\Delta Q_k = \frac{-\sum_{i=1}^{Np} Hli}{1.85 \sum_{i=1}^{Np} \left(\frac{Hli}{Qi}\right)} \quad \text{..... (1)}$$

Where:

ΔQ_k **:** Correction of discharge Q for all pipes in loop k (m3/sec).

Hli **:** Head losses of pipe i, (m).

Qi**:** Flow rate of pipe i in loop k (m3/sec).

Np **:** Number of pipes in loop **k.**

$$Q = Qi \pm \Delta Qk \quad \text{..... (2)}$$

And the head loss of each pipe in a loop is computed using Hazen William formula as bellow:

$$H_L = K.Q^{1.85} \quad \text{..... (3)}$$

Where:

$$K=L/[0.278.c.D^{2.63}]^{1.85} \quad \text{..... (4)}$$

L: pipe length (m).

C: Hazen William roughness coefficient which depends on pipe material.

D: pipe diameter (m).

Also:

$V=Q.A$ *(continuity equation)*

Where:

V: average flow velocity of water (m/sec).

A: cross sectional area of the pipe (m2).

In addition, the total head H, on water at any point in a pipe is given by:

$$H=Z+P/w+v^2/2g \quad \text{….. (5)}$$

Where:

Z: elevation of the point above some arbitrary datum (m).

P/w: pressure head (m).

W: specific weight of water(kg/m3)

v2/2g: velocity head(m).

g: acceleration due to gravity (m/sec2)

It is importance to mention here that minor losses are usually neglected in water network studies [10].

2.2 Water quality model

To predict water quality parameters, an assumption is made that there is complete mixing across finite distance, such as at a junction node or in a short segment of pipe [1].generally , this research will study two components of water quality which are water age and constituents as shown below.

2.2.1 Age of water

Water age provides a general indication of the overall water quality at any given point in the system .Age is typically measured from the time that the water enters the system from a tank or reservoir until it reaches a junction.

So, along a given link, water age is computed as [6]:

$$A_j=A_{j-1}+X/V \quad \text{….. (6)}$$

Where:

A_j: age of water at j-th node.

X: distance from node j-1 to node j.

V: velocity from node j-1 to node j.

If there are several paths for water to travel to the j-th node, the water age is computed as a weighted average using the equation;

$$AA_j=\sum Q_i[AA_i+(X/V)_i]/\sum Q_i \quad \text{….. (7)}$$

Where:

AAj: average age at the node immediately up stream of node j.

Qi: flow rate to the j-th node from the i-th node.

2.2.2 Constituents:

Reaction can occur within pipes that cause the concentration of substances to change as the water travels through the system. Assuming that complete and instantaneous mixing occurs at all junction nodes, the conservation of mass equation is [3]:

$$(C_k)_{x=0}=[\sum Q_i.C_j]_{x=L}+Q_e.C_e/(\sum Q_j+Q_e) \quad \text{…..(8)}$$

Where:

C_k**:** concentration at node k .

j**:** pipe flowing into node k.

L**:** length of pipe j.

Q_j**:** flow in pipe j.

C_j**:** concentration in pipe j.

Q_e**:** external source flow into node k.

C_e**:** external source concentration into node k.

3. Procedure of Work

1. The map of Bradia water network is obtained from Basra water office; from this map we obtained the length and diameter of all pipes in the model.
2. The approximately area for each zone is obtained from the map ,then the served population for each zone is estimated by multiplying the obtained area by the population density for each zone[the population density is obtained from Basra water office] see Table.(1)
3. After obtaining the population, the demand of water for each zone must be calculated too, generally for communities with population above 50000 capita, the per capita water demand vary over the range (125-200)L/day[1],since the total served population of Bradia is (165122) capita [from summation of the total served population in Table.(1)], then, in this study the per capita water demand was assumed (150 l/day) so the water demand for each zone was obtained by multiplying this value by the served population of the zone as shown in Table.(1).
4. Data for pumps [discharge, head, and control], data for elevated tank [cross section and elevations], and data for the reservoir (water surface elevation and initial dosage of injection chlorine) are obtained from Bradia water treatment plant. see Table.(2)
5. All above data are used for running WATER CAD program for the network analysis and water quality studying.
6. Samples of water are taken from different locations, and then test these samples of water in the quality control laboratory in order to measure the chlorine concentration in them.
7. The calibration for both hydraulic model and water quality model is done in order to check the accuracy of the results.

4. Results and Discussions

In this model we study different cases as bellow:

4.1 The values and direction of discharges in the system

Here we study two cases:

a-When the pump of the system is power on ,all the system will be supply with water from it, the directions of discharges in this case are shown in Fig(1),while the values of discharges are shown in Table.(3). Also the pressure and the hydraulic grade line at each junction is shown in Table (4).

b-When the pump of the system is power off(for example when the pump is choke or cut in electric power or when a pump is shut down by the control when the elevation of water in the tank is reached to the maximum elevation) here, all system will be feed from the storage tank and pipes near to the pump will have small or no any discharge , the direction of discharges for this case are shown in Fig.(2),and the values of discharges are shown in Table (5). Also the pressure and the hydraulic grade line at each junction is shown in Table (6).

4.2 Chlorine concentration values in different location of the system

Here, we use studying period equal to 72 hr and initial dosage of chlorine injection in the reservoir is equal to 2.5 mg/l, then study the chlorine concentration in three different locations (near the water treatment plant, middle distance from water treatment plant and far distance from water treatment plant) as bellow:

For pipes in different locations we take pipes No. (67,64,&7) as shown in Figs. (3,4,&5). From Fig.(3) we can show that for pipe No.67 which is so near to pump, the chlorine concentration is steady and approximately with constant value (2.5 mg/l) because of the continuous flow ,but pipe No.64 which is with middle distance to the pump we can show that the chlorine concentration is increase from zero to (1.3 mg/l) after 1 hr and after 3hr it will be increase until reaches to (1.74 mg/l) and then it will be reach to the dynamic equilibrium as shown in Fig.(4) . But pipe No.7 which is so far from the pump will have a chlorine concentration equal to zero along the studying period (see Fig.(5)). Also we study the chlorine concentration in storage tank through 72 hr as shown in Fig.(6). From this Figure we can show that the chlorine concentration in the storage tank will be increase to (2.4 mg/l) after 1 hr and then will be increase to (3.75 mg/l) then will be decrease by gradually through 72 hr. the reason for this case is that, during the first hours of flow the tank will feed continuously with water from the pump, thus the chlorine concentration in the tank will be increase until the elevation of water in the tank reaches to the referred max. elevation in the control of the pump. Here, the pump will shut down and the net will feed with water from the tank, so the chlorine concentration will be decrease gradually. Here it is important to mention that the initial dosage of injected chlorine in the water treatment plant is range from (3.5 - 4 mg/l) in the hot weather in order to be in the safe side from the risk of many disease such as cholera and other viruses while this dosage range from (2.5 - 3 mg/l) in the normal circumstances [5]. Since our study period during October 2010, so we use the initial dosage of injected chlorine in the Bradia water treatment plant is equal to (2.5 mg/l).

4.3 Age of water in different locations of the system

Water age is a major factor contributing to water quality deterioration the distribution is primary controlled by system design and system demands. Thus, water age can vary significantly within a given system. The water industry data base [7] indicates an average distribution system retention time of (1.3days) and a maximum retention time of (3days), so the age of water at any element will be "long" if greater than (3days) and will be "short" if less than (3days). Also, there are several tools for evaluating water age include hydraulic models, tracer studies and monitoring programs. In this study we use the hydraulic model tool to evaluate the water age in the model.

Here, we study the age of water in different pipes (7,25,&57),(the studying period of water age is 48 hr). Fig.(7) shows the age of water in the referred pipes. From this Fig. we can see that for pipe No.7 which is so far from the water treatment plant, the age of water will be increase gradually until reach to 16 hr after 24 hr then reach to the dynamic equilibrium.

So, we can say that the water age in this pipe is "short" since it is less than 3 days.

For pipe No.25 the water age will increase to 3hr after 4hr then reaches to the dynamic equilibrium, so the water age in this is short too. While in pipe No.57 the age of water increase to 1 hr after 1 hr then reaches to the dynamic equilibrium, so the water age along this pipe is too short.

However, water age is a function primarily of water demand, system operation and system design. As water demand increase, the amount of time any given liter of water is resident in the distribution system decreases [4]. In addition, there are several indicators that may suggest high water age. These include aesthetic consideration that may be identified by consumer, as well as the results of distribution system monitoring efforts. It should be noted that the indicators can be triggered by factors other than water age, such as an insufficient source water treatment, pipe material, and condition/age of distribution system [7].

The following indicators may be identified during water consumptions:

- Poor taste and odor-aged, stale water provides an environment conductive to the growth and formatting of taste and odor causing microorganisms and substances.
- Discoloration-water in low flow areas and dead-end often accumulate settled deposits over time. During a demand period. These deposits are entrained and degrade the clarity and color of water.
- Water temperature-stagnant water will approach the ambient temperature.

5. Calibration of the Model

Model calibration is a process of adjusting model parameters so that the simulated and observed hydraulic conditions become similar. Here. We'll calibrate both the hydraulic model and water quality model as shown below:

5.1 Calibration of hydraulic model

There are many uncertain parameters that need to be adjusted to produce the discrepancy between the model predictions and field observations of junction hydraulic grade line (HGL) and pipe discharges. Pipe roughness coefficients and junctions demands are often considered for calibration [11]. In WaterCAD program the calibration will be done by the trial and error procedure. First the model parameters must be estimated, run the model to obtain a predicted pressure and flow, and finally compares the simulated values to the observed data. IF the predicted data doesn't compare closely with the observed data, it must be return to the model, make some adjustments to the model parameters, and calculate it again to produce a newest of simulation results. This may have to be repeated many times to make the best calibration. However, the calibration is conducted by satisfying two type of constraints which are used to set the minimum and maximum limit for pipe roughness coefficient and junction multiplier as below [2]

$$RFmin_i \le RF_i \le RFmax_i \qquad i = 1,2,3,...,nPipeGroup$$

$$DMmin_i \le DM_i \le DMmax_i \qquad i = 1,2,3,...,nDemandGroup$$

Where:

RF_{min}, RF_{max} **=** minimum & maximum roughness coefficient for roughness group.

DMmin, DMmax= minimum & maximum demand multiplier for demand group.

After each calibration, water cad will make fitting between the simulated results and observed data in order to obtain the best correlation between them, three fitting types are available: **(minimize difference squares**, **minimum difference absolute values and minimize maximum difference)**.

The best one which gives a lower fitness that indicates the better calibration. Here we use the second type which give us a lowest fitness of (0.0246373), the formula of this type is[2]:

$$\frac{\sum_{np=1}^{NH} w_{nh}\left|\frac{Hsim_{nh}-Hobs_{nh}}{Hpnt}\right| + \sum_{nf=1}^{NF} w_{nf}\left|\frac{Fsim_{nf}-Fobs_{nf}}{Fpnt}\right|}{NH+NF}$$

Where:

H_{obsnh},H_{simh} **=** nn-th-*observed* and simulated hydraulic grade line.

F_{obsnf},F_{simnf} **=**observed and simulated flow.

Hpnt=hydraulic grade per fitness-point.

F_{pnt} **=** flow per fitness-point.

NH **=**No. of observed hydraulic grade.

NF **=** No. of observed pipe discharged

Also in this calibration, we use the minimum roughness coefficient is 70 and maximum of 130 with increment of 10 while the minimum demand multiplier is 0.1 and max. of 1.0 with increment of 0.1.the observed data for both junction HGL and pipes flows are obtained from plant Bradia W.T.P as shown n Table(7).Figs.(8)&(9) show the best correlation between simulated and observed data for both junction HGL and pipes flows . The report of calibration summary is shown in Table (9).

5.2 Calibration of water quality model

However, there is no guarantee that the measured values are correct and may contain large errors that will be progressed throughout the water distribution system water quality simulation. For this reason, the concentration at each hydraulic time step will be allowed to vary up to 0.3 mg/l from the measured values [8].The observed chlorine concentration data which obtained from quality control laboratory are shown in Table (7).Fig.(10) Show the comparison between observed and simulated chlorine concentrations before calibration is done. But after the calibration of hydraulic model is done, the discharges of pipes are changed so the chlorine concentrations are changed too, the comparison between both observed and simulated concentration is shown in Fig.(11).

6. Conclusion

Based on the results of the study, the conclusion can be summarized as the following:

1. When the pump of the system is power on, all the system will be supplied with water from the pump and some of pipes will supplied from both the pump and the storage tank based on the water pressure in the system, but when the pump of the system is power off all the system will be feed from the storage tank and , the pipes which are near to the pump will have either very small discharge or their discharge will be equal to zero. Also the directions of discharges in both cases will be completely different.

2. The model results showed that the pipes near the water supplier received more chlorine and the distribution of chlorine reaches to the steady state at a shorter time.

3. According to the data base of water industry, the age of water at the different studied locations are "short" but this age will vary according to the pipe locations with respect to the water treatment plant (the nearest pipe is the shortest age of water).

7-Recommendations

1. From the above results, we suggested to use WaterCAD program in each water treatment plant for controlling the flow cases in different locations of the network, also to predict and control the leak of water in any location by note the fluctuation in the water pressure through the program.

2. Placing of booster stations of chlorine injection at the location where the chlorine concentration value is equal to zero in order to be in the safe side from the health risks.

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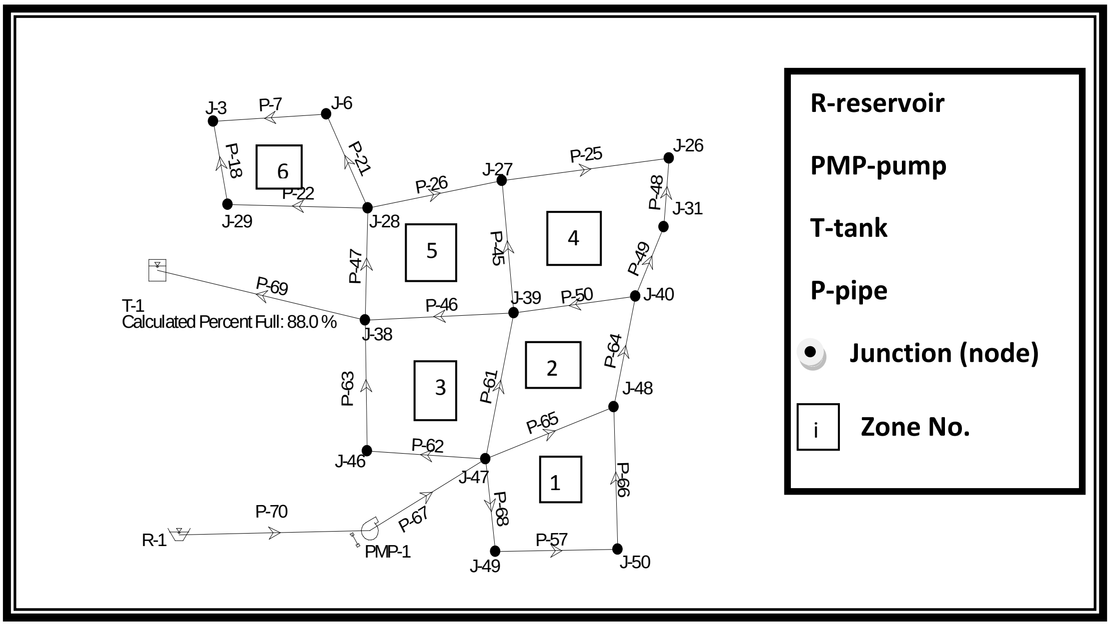

Fig. (1) Direction of discharge in the pipes when the pump status is power on

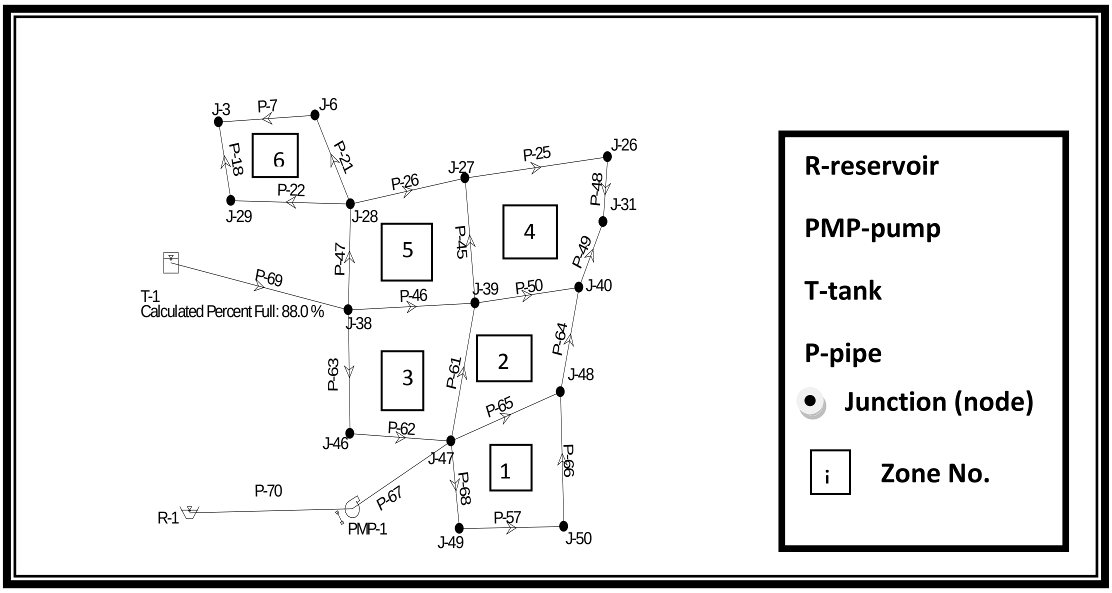

Fig. (2) Direction of discharge in the pipes when the pump status is power off

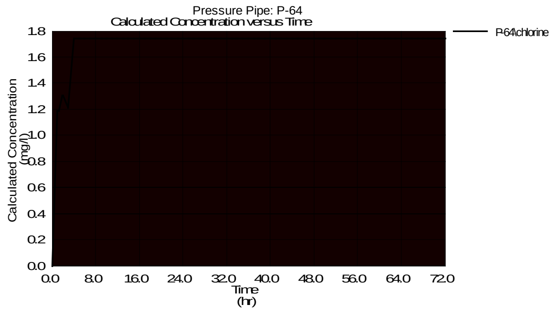

Fig.(4) Chlorine concentration distribution through pipe No.64

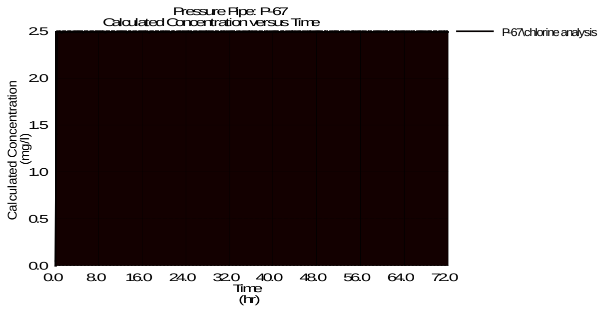

Fig.(3) Chlorine concentration distribution through pipe No.67

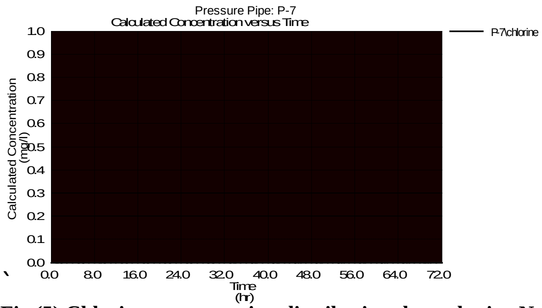

Fig.(5) Chlorine concentration distribution through pipe No.7

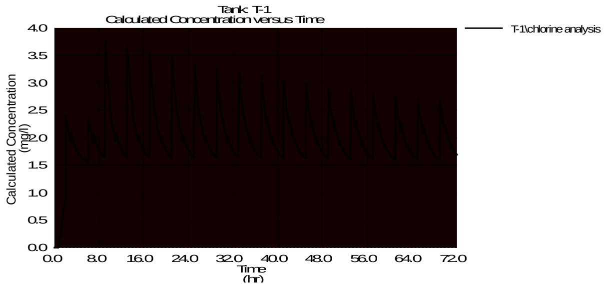

Fig.(6) Chlorine concentration distribution in tank T-1

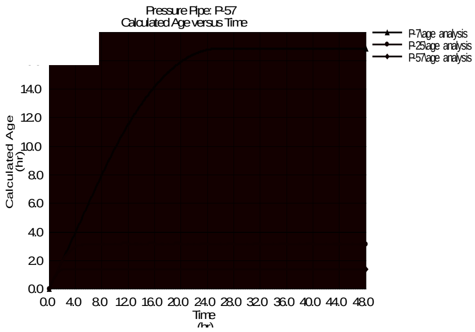

Fig.(7) Age of water in pipes No.7,25,&57 for 48 hr

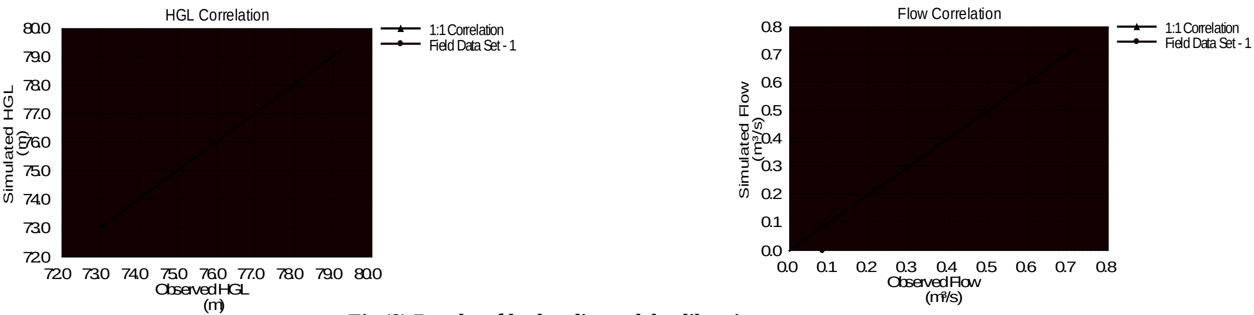

Fig.(8) Results of hydraulic model calibration

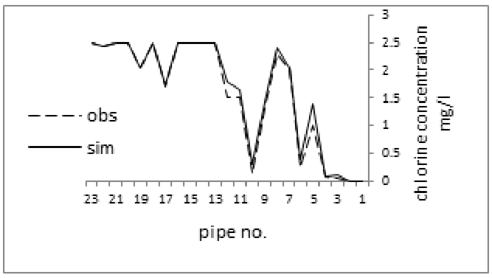

Fig.(9) Comparison between obs. and sim. chlorine conc. before calibration is done

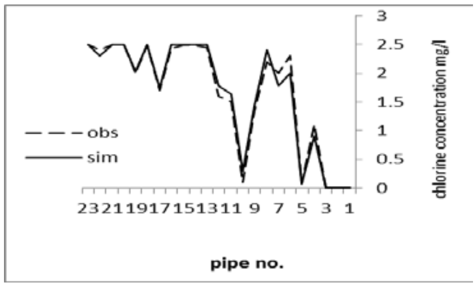

Fig.(10) Comparison between obs. and sim. chlorine conc. after calibration is done

Table (1) Estimated water demand for the model

Zone no.	Estimated area(km2)	Pop. Density/km2	Served pop.(capita)	Water demand(m3/sec)
1	1.22	20016	24420	0.0420
2	1.22	20016	24420	0.0420
3	1.22	48946	58714	0.1036
4	3.95	5163	20394	0.0896
5	1.88	5163	9706	0.0168
6	3.52	6388	27468	0.0480

Table (2) Data obtained from Bradia water treatment plant

Pump data		
Discharge(m3/sec)	**Head(m)**	**Control**
0.6	60	On if T-1bellow 70 m
		Off if T-1 above 78 m
Tank data		
section	**Diameter (m)**	**Elevations (m)**
circular	15	Max elev.=80
		Initial elev.=75
		Min elev.=70
		Base elev.=65
Reservoir data		
Surface elevation(m)	**Initial dosage of injection chlorine(mg/l)**	
70	2.5	

Table (3) Discharges values when the pump status is on

Label	Length (m)	Diameter (mm)	Material	Hazen-Williams C	Discharge (m³/s)
P-7	1,800.00	900.0	Riveted steel (r	110.0	0.01789
P-18	1,800.00	900.0	Riveted steel (r	110.0	-0.04311
P-21	2,060.00	900.0	Riveted steel (r	110.0	0.07189
P-22	2,200.00	1,000.0	Riveted steel (r	110.0	-0.07711
P-25	700.00	500.0	Riveted steel (r	110.0	0.03884
P-26	900.00	500.0	Riveted steel (r	110.0	0.03691
P-45	2,060.00	500.0	Riveted steel (r	110.0	-0.08793
P-46	700.00	500.0	Riveted steel (r	110.0	0.10570
P-47	2,800.00	900.0	Riveted steel (r	110.0	0.22291
P-48	1,300.00	500.0	Riveted steel (r	110.0	-0.03016
P-49	2,200.00	500.0	Riveted steel (r	110.0	-0.08716
P-50	700.00	450.0	Riveted steel (r	110.0	0.02681
P-57	1,100.00	700.0	Riveted steel (r	110.0	0.07315
P-61	1,000.00	450.0	Riveted steel (r	110.0	0.22382
P-62	600.00	500.0	Riveted steel (r	110.0	-0.25328
P-63	900.00	500.0	Riveted steel (r	110.0	-0.24828
P-64	1,060.00	450.0	Riveted steel (r	110.0	-0.17697
P-65	800.00	450.0	Riveted steel (r	110.0	-0.13182
P-66	460.00	450.0	Riveted steel (r	110.0	0.06115
P-67	600.00	1,000.0	Riveted steel (r	110.0	0.70207
P-68	700.00	375.0	Riveted steel (r	110.0	0.07815
P-69	10.00	500.0	Riveted steel (r	110.0	-0.11607
P-70	5.00	1,000.0	Riveted steel (r	110.0	0.70207

Table (4) Junctions head values when the pump status is on

Label	Demand (Calculated) (m³/s)	Pressure (kPa)	Pressure Head (m)	Calculated Hydraulic Grade (m)
J-3	0.06100	435.00	44.45	74.45
J-6	0.05400	532.89	54.45	74.45
J-26	0.06900	531.47	54.30	74.30
J-27	0.08600	532.34	54.39	74.39
J-28	0.03700	533.35	54.50	74.50
J-29	0.03400	533.02	54.46	74.46
J-31	0.05700	532.48	54.41	74.41
J-38	0.01500	538.37	55.01	75.01
J-39	0.05700	543.89	55.57	75.57
J-40	0.06300	544.62	55.65	75.65
J-46	0.00500	572.89	58.54	78.54
J-47	0.01500	596.76	60.98	80.98
J-48	0.01600	580.89	59.35	79.35
J-49	0.00500	583.95	59.67	79.67
J-50	0.01200	583.09	59.58	79.58

Table (5) Discharges values when the pump status is off

Label	Length (m)	Diameter (mm)	Material	Hazen-Williams C	Discharge (m³/s)
P-7	1,800.00	900.0	Riveted steel (	110.0	0.01789
P-18	1,800.00	900.0	Riveted steel (	110.0	-0.04311
P-21	2,060.00	900.0	Riveted steel (	110.0	0.07189
P-22	2,200.00	1,000.0	Riveted steel (	110.0	-0.07711
P-25	700.00	500.0	Riveted steel (	110.0	0.07993
P-26	900.00	500.0	Riveted steel (	110.0	0.11348
P-45	2,060.00	500.0	Riveted steel (	110.0	-0.05245
P-46	700.00	500.0	Riveted steel (	110.0	-0.16314
P-47	2,800.00	900.0	Riveted steel (	110.0	0.29948
P-48	1,300.00	500.0	Riveted steel (	110.0	0.01093
P-49	2,200.00	500.0	Riveted steel (	110.0	-0.04607
P-50	700.00	450.0	Riveted steel (	110.0	-0.06872
P-57	1,100.00	700.0	Riveted steel (	110.0	0.02338
P-61	1,000.00	450.0	Riveted steel (	110.0	0.01504
P-62	600.00	500.0	Riveted steel (	110.0	0.10338
P-63	900.00	500.0	Riveted steel (	110.0	0.10838
P-64	1,060.00	450.0	Riveted steel (	110.0	-0.04035
P-65	800.00	450.0	Riveted steel (	110.0	-0.04496
P-66	460.00	450.0	Riveted steel (	110.0	0.01138
P-67	600.00	1,000.0	Riveted steel (	110.0	0.00000
P-68	700.00	375.0	Riveted steel (	110.0	0.02838
P-69	10.00	500.0	Riveted steel (	110.0	0.58600
P-70	5.00	1,000.0	Riveted steel (	110.0	0.00000

Table (6) Junctions head values when the pump status is off

Label	Demand (Calculated) (m³/s)	Pressure (kPa)	Pressure Head (m)	Calculated Hydraulic Grade (m)
J-3	0.06100	429.37	43.87	73.87
J-6	0.05400	527.27	53.87	73.87
J-26	0.06900	516.33	52.76	72.76
J-27	0.08600	519.62	53.09	73.09
J-28	0.03700	527.72	53.92	73.92
J-29	0.03400	527.39	53.89	73.89
J-31	0.05700	516.18	52.74	72.74
J-38	0.01500	536.39	54.81	74.81
J-39	0.05700	524.06	53.55	73.55
J-40	0.06300	519.91	53.12	73.12
J-46	0.00500	528.96	54.05	74.05
J-47	0.01500	524.42	53.58	73.58
J-48	0.01600	522.25	53.36	73.36
J-49	0.00500	522.45	53.38	73.38
J-50	0.01200	522.35	53.37	73.37

Table (7) Observed data obtained from AL-Bradia water

Pipe no.	Observed flow(m3/sec)	Observed chlorine concentration (mg/l)	Junction no.	Observed HGL(m)
7	0.018	0.00	3	75.83
18	0.0391	0.00	6	76.87
21	0.069	0.00	26	74.42
22	0.083	1.10	27	75.60
25	0.025	0.09	28	79.36
26	0.026	2.30	29	70.00
45	0.075	2.00	31	77.65
46	0.095	2.20	38	75.87
47	0.198	1.33	39	74.44
48	0.033	0.10	40	75.21
49	0.0900	1.50	46	77.50
50	0.0367	1.60	47	77.34
57	0.083	2.45	48	76.65
61	0.198	2.49	49	77.83
62	0.207	2.49	50	77.45
63	0.200	2.43		
64	0.156	1.70		
65	0.103	2.49		
66	0.0586	2.00		
67	0.687	2.50		
68	0.0699	2.50		
69	0.0989	2.40		
70	0.720	2.50		

Table (8) pipes sim. Chlorine conc.

Label	Calculated Concentration (mg/l)
P-7	0.00
P-18	0.00
P-21	0.11
P-22	0.09
P-25	1.39
P-26	0.40
P-45	2.04
P-46	2.40
P-47	1.43
P-48	0.29
P-49	1.64
P-50	1.78
P-57	2.50
P-61	2.50
P-62	2.50
P-63	2.50
P-64	1.74
P-65	2.50
P-66	2.03
P-67	2.50
P-68	2.50
P-69	2.44
P-70	2.50

Table (9) Calibration results summary

Fitness: 0.246373

Roughness Adjustments	[adjusted]	[original]	
Roughness Group - 1	130.0		
Demand Adjustments (m^3/s)	[adjusted]	[original]	
Demand Group - 1	1.00		
Status Adjustments	[adjusted]	[original]	
P-7	Open	Open	
P-18	Open	Open	
P-21	Open	Open	
P-22	Closed	Open	
P-25	Open	Open	
P-26	Open	Open	
P-45	Open	Open	
P-46	Open	Open	
P-47	Open	Open	
P-48	Open	Open	
P-49	Open	Open	
P-50	Open	Open	
P-57	Open	Open	
P-61	Open	Open	
P-62	Open	Open	
P-63	Open	Open	
P-64	Open	Open	
P-65	Open	Open	
P-66	Open	Open	
P-67	Open	Open	
P-68	Open	Open	
P-69	Open	Open	
P-70	Open	Open	
HGL Observations (m)	[simulated]	[observed]	[difference]
Field Data Set - 1			<RMSE: 0.72>
Flow Observations (m^3/s)	[simulated]	[observed]	[difference]
Field Data Set - 1			<RMSE: 0.03411>