RELIABILITY ANALYSIS OF WATER DISTRIBUTION SYSTEMS

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ABSTRACT

Based on node flow analysis the available nodal flows under deficient conditions is presented for determining the reliability of water distribution system (WDS). The reliability is concentration on a node-reliability factor. Volume reliability factor, and network-reliability factor.

Even though reliability of WDS depends on several parameters, only variation of consumption in daily, demand excess, and element failure conditions are considered. Computer programs have been written to determine the aforementioned reliability factors. The procedure is described and illustrated through an example.

KEYWORDS

Node, reliability factor, network-reliability factor

INTRODUCTION

The node head analysis (NHA) methods discussed in refs[1,2,3,11,16,19] presumes that the nodal demands are always satisfied in a water distribution system (WDS) and determines the available heads. However, when a pump fails or pipe breaks. the WDS may be unable to supply all nodal demands at required heads. Thus, the traditional network analysis (NHA) does not correctly describe the partially failed WDS[4]. How well a WDS can supply water in the required quantities at desired residual heads throughout its design period should be specified. This gsoal can be determined from water supply reliability. Therefore, reliability may be defined as the probability that the system performs within specified limits for a given period of time. In reliability analysis of WDS's. however, the nodal flows that would be available under deficient conditions should be evaluated and used. In this work. Therefore, an approach for the NFA, discussed in refs[3,10], that determines the available nodal flows under deficient conditions, considering the nodal demands and heads simultaneously, has been manipulated and used for determining WDS reliability. However, evaluation of WDS reliability is extremely complex because reliability depends on a large number of parameters, some of which are quality and quantity of water available at source; failure rates of supply pumps, power outages; flow capacity of transmission mains; roughness characteristics influencing the flow capacity of the various links of the distribution network; pipe breaks and valve failures; variation in daily, weekly, and seasonal demands; as well as demand growth over the years.

LITERATURE REVIEW

A complete satisfactory water distribution system (WDS) should supply water in the required quantities at desired residual heads throughout its design period. How well a WDS can satisfy this goal can be determined from water supply reliability. Reliability may, also, be defined as the probability that the system performs within specified limits for a given period of time. Despite extensive research[5,6,7,8,9,17,18,19] there is no universally accepted definition of reliability of a WDS.

Goulter and Coals (1986) suggested an approach called “node isolation probability”. This approach considers the probability of a node being isolated from the rest of the network. In other words, it considers the probability of simultaneous failure of all links connected to a node[9].

Su et. al. (1987) evaluated reliability using “minimum cut set”.A minimum cut set is a set of system components which, when failed, causes failure of the system. They presents the basic framework for a model that can be used to determine the optimal (least-cost) design of a water distribution system subject to continuity. conservation of energy, nodal head bounds, and reliability constraints. The overall model includes three functions that are linked: a steady-state simulation model, a reliability model, and an optimization model. The simulation model is used to implicitly solve the continuity and energy constraints and is used in the reliability model to define minimum cut sets. The reliability model, which is based on a minimum cut set method, determines the values of system and nodal reliability. The optimization model is based on a generalized reduced-gradient method [17].

Wagner et. al. (1988a) introduced "reachability" which states that a specified demand node is connected to at least one source node and”connectivity” which states that every demand node is connected to at least one source node[18].

Lansey et. al. (1989) considered uncertainties in nodal demands, pressures, and pipe roughness coefficients in their chance-constrained model[13]. Goulter and Bouchart (1990) proposed a chance-constrained model in which probabilities of pipe failure and demand exceedance are combined into a single reliability measure, the probability of no node failure[8]. Duan andMays (1990) and Duan et. al. (1990) used modified frequency and duration analysis considering mechanical and hydraulic failures[5,6].

Most of analytical approaches presume that as long as a node is connected to a source through at least one pipe, the demand at the node is satisfied. However, it is not so in practice. Wagner et. al. (1988a) recognized this drawback and stated that connection to source was only a necessary and not a sufficient condition to ensure that a demand node was functional and suggested that more-elaborate analysis should be carried out to determine whether a demand node that was connected to source could also meet the required demand at specified pressure [18].

Wagner et. al. (1988b) introduced the concept of service head and minimum head at a node. If the head at a node was above service head, the full demand was met, if below the minimum head, no flow was available; and if between the two heads, partial flow was available and was calculated according to a square-root law[19]. However, since their analysis presumed that demands were satisfied at all nodes and obtained corresponding nodal heads, the network behavior was not properly depicted for partial-flow situations.

Fujiwara, and De Silva (1990) also recognized such a drawback in their approach and stated that the flow capacity defined in the maximum flow model did not give a clear physical meaning and system reliability estimated did not take into account the hydraulic consistency along each loop[7].

The majority of research is analytical. based on analogous techniques from electrical and mechanical engineering wherein, generally two stages either working condition or failures are considered. The analytical research is primarily based on graph theory using cut sets, connectivity, reachability, and so forth.

Cullinane et. al. (1992), as given in ref.[10], considered the intermediate stage through partial pressure failure. They used the nodal availability concept, but instead of assuming zero-one relationship between availability and pressure (nodal availability index zero when the available pressure is less than required, one otherwise), they assumed continuous fuzzy relationship. The nodal availability index gradually reduced from one, when the available nodal pressure was equal to the desired to a pre-selected value (< l) when the available nodal pressure became the minimum required.

Since the reliability of WDS's is based on available nodal flow, the intermediate stage is considered herein through partial flow failure, i. e. the nodal supply in the intermediate stage is between the required flow and no flow. The available nodal flows are considered by node flow analysis. The reliability of WDS's is expressed by node-reliability factor, volume- reliability factor, and network-reliability factor.

RELIABILITY ASSESSMENT

The available nodal flow less than or equal to the required flow is a function of the demand pattern and the condition of the distribution network (pipes, pumps, and valves in working condition). A time interval during which the nodal demands and condition of the network remain constant is termed a "state". The number of states during the period of analysis depends on the number of demand patterns and the number of different combinations of pipes, pumps, and valves in working or failure conditions. Three reliability factors, namely, node-reliability factor, volume reliability factor. and network-reliability factor are used to describe the performance of WDS over the period of analysis. The isolation periods during which the elements are closed for repairs or replacement are taken in integral days so that a complete cycle of flow variation in a day is considered[10].

NODE RELIABILITY FACTOR

The node-reliability factor (Rn) is defined as the ratio of the total available outflow volume at a node to the desired outflow volume at that node for all states during the period of analysis[10] Thus. for node j:

$$R_{nj} = \frac{\sum_{s} V_{js}^{avl}}{\sum_{s} V_{js}^{req}} = \frac{\sum_{s} Q_{js}^{avl} t_s}{\sum_{s} Q_{js}^{req} t_s} \text{ . for all nodes j} \ldots\ldots \quad (1)$$

where:

V_{avl}: available volume, (L3).

V_{req}: required volume. (L 3).

q_{avl}: available discharge rate, (L 3 /T).

q_{req}: required discharge rate, (L 3 /T).

ts: time duration of a state (same for all nodes), (T).

j: subscript denoting demand node.

s: subscript-denoting state.

VOLUME-RELIABILITY FACTOR

The volume-reliability factor (R_v) is defined as the ratio of the total available outflow volume to the required outflow volume for the entire network for all states during the period of analysis[10]. Thus:

$$R_v = \frac{\sum_s \sum_j V_{js}^{avl}}{\sum_s \sum_j V_{js}^{req}} = \frac{\sum_s \sum_j q_{js}^{avl} t_s}{\sum_s \sum_j q_{js}^{req} t_s} \quad \text{...} (2)$$

NETWORK-RELIABILITY FACTOR

The node-reliably factor and the volume-reliability factor describe the performance of a distribution network considering the total volume availability at individual nodes and for the entire network, respectively. However, these factors do not completely describe the reliability of the network.

For example, consider the following three situation for a network in which all nodal demands are identical[10]:

1. 90% of demand are satisfied of 100% of time at 100% nodes, i. e. there is a uniform shortfall of 10% supply at each node during the entire period of analysis. This situation though not desirable, is tolerable.
2. 100% of demand is satisfied for 90% of time at 100% nodes. i. e. there is no supply at all the nodes during 10% of time of the period of analysis. If this time duration is not concentrated wbut is distributed throughout the period of analysis, this

situation is also tolerable, though less acceptable than situation (1).

3. 100% of demand is satisfied for 100% of time at 90% of nodes i. e. there is no supply at all at 10% of nodes during the entire period of analysis. This situation is the worst and is unacceptable.

For all three situations. R_v=0.9, For situations 1 and 2 R_n=0. 9 at all nodes, while for situation 3 R_n= 1 for 90% nodes and R_n=0 for 10% nodes. The R_v and R_n values are the same for situations 1 and 2 even though their performances are not the same. The value of R_v is also the same for situation 3. However, it is preferable to have a single reliability factor that can describe situation 3 and can also properly distinguish between situations 1 and 2. It is therefore useful to consider network reliability factor (R_{nw}) defined as:

$$R_{nw}=R_v\, F_t\, F_n \quad\text{..}(3).$$

where:

F_t: time factor,

F_n: node factor.

The time factor is defined as:

$$F_t=\frac{\sum_s\sum_j a_{js}t_s}{CJT_p} \quad\text{..}(4)$$

where:

C_J: the total number of demand nodes,

T_p: period of analysis ($\sum t_s$), (T),

a_{js}: a dummy variable taking value 1 or 0. which $a_{js}=1$, if the discharge ratio Q_j^{avl}/ Q_j^{reg} at a node for a particular state is equal to or more than an acceptable value, and $a_{js}=0$, otherwise. Thus, for example, if the acceptable value of discharge ratio is 0.5, a node is included in evaluating the time factor if it satisfies at least 50% of demand during the state.

The node factor is the geometric mean of the node-reliability factors. Thus:

$$F_n = \left[\prod_{J=1}^{CJ} R_{nj}\right]^{1/CJ} \quad \ldots\ldots (5)$$

If the network is unacceptable when the flow available at the node and therefore, R_{nj} is less than a particular value, this R_{nj} is set to zero in eq. (3-5). Thus F_n and therefore, R_{nw} would be zero and the network would be unacceptable.

The values of R_v, F_t (assuming acceptable discharge ratio c 0.5), F_n (assuming acceptable $R_{nj} \geq 0.9$) and R_{nw} for three situations described earlier are shown in table (1). Herein, R_{nw} values can properly depict the reliability for the three situations. Situation 3, which is unacceptable, has zero network reliability.

PRACTICAL ASSUMPTIONS

The prediction of actual behavior and the reliability assessment of large urban networks are extremely complex. Therefore, several assumptions are necessary that includes the following[10].

DEMAND POINTS

The actual withdrawal points are scattered on the distribution mains and the minimum head required at these points, particularly in residential areas would be different depending upon the plumbing arrangement. Thus, the actual performance of a WDS depends upon the locations of withdrawal connections and the levels of individual outlet points. Even though the behavior of an actual WDS can be predicted using NFA, the computational effort would be extensive. However, as is the usual practice in NHA, it is presumed in NFA that the demands are concentrated at nodes and also that each demand has one minimum head requirement. Thus, using NFA for reliability estimation, if $H_j^{avl} > H_j^{min}$ the demand at the node is fully satisfied; if $H_j^{avl} = H_j^{min}$ partially; and if $H_j^{avl} < H_j^{min}$,the outflow is zero.

FAILURE ELEMENTS

Even though the failure or malfunctioning of any element of a WDS would affect its performance and its reliability, in this research only the failures of pipes, pumps, and valves are considered. It is presumed that such failure rates are known and each failure is an independent event. For example, let a pipeline (length=1.5 km and diameter =0.31 m) have one pump.

Assume the period of analysis equal one year = 365 days,

Assume the break rate of pipeline = 0.07 breaks, Km-1 yr-1 [9]

The failure rate = 0.07 breaks yr-1 × 1.5 Km = 0.105 breaks. yr-1

Assume the repair time = 2 days

Average outage time per year = 0.105 breaks.yr-1 ×2 days = 0.21day.

Working time per year = 365 days - .21 day = 3664.79 days .

The ratio of working time to period of analysis (rk) = 364.79/365 = 0.999425.

Assume the ratio of working time to total time for the pump (rp) =0.98 [5].

All assumption above may be deferent in other elements depending on designing and operation of real networks such as :

-Break rate of pipeline is on [14] :type of material state of ground and diameter .

-Pipe repair time and rp are depend on efficiency of operators.

In the event of a break in a pipe it is assumed that the broken pipe can be isolated and the rest of the network remains unaffected. This may not be necessarily true in practice since isolation of a pipe would depend upon the location of valves. Therefore, several pipes may though only one pipe is required to be isolated[20].

Even these cases also, the procedure suggested herein is applicable by lumping the probabilities of different elements in the isolated portion of the network and then treating it as one unit, which from above example the working time to total time ratio for pipeline and pump = rp ×. rk = 0.98 ×0.999425 = 0.97944. The average outage time for total element per year = Tp - rT Tp = 365- 0.97944× 365 = 7.504 days.

DEMAND FLUCTUATIONS

The daily variation in nodal demand and the demand excess are considered. However, all such demands are assumed to be deterministic.

PIPE CHARACTERISTICS

The pipe head loss coefficients such as Hazen-Williams coefficients are known and remain constant throughout the period of analysis. In real network the Hazen-Williams coefficients are depend on type of pipe material and aging of pipes[12]. From experiments [15] are illustrated the relationship between Hazen-Williams coefficients and age of pipes in years for some real networks, which the numerical value of C_{HW} is reduced by more than 30% in only 20 years and more than 50% in 40 years.

PERFORMANCE STATES

The failures of pipes and other components together with different loading patterns are considered in reliability estimation of WDS's. A pump or fitting and the pipe in which it is located are considered together. Thus, the number of states (time periods) for a WDS having X number of pipes and Z number of demand patterns is $Z\times 2^{x}$. However, since the probability of pipe failure is small, the joint probability of two or more pipes failing simultaneously is exceeding small. Thus, only two states groups (all pipes in working condition and only one pipe in failure condition) for each demand pattern are considered. This assumption requires the consideration of Z (X+I) states.

NETWORK BEHAVIOR

Water level in the reservoirs remains constant throughout the period of analysis and thus the performance of a WDS is assumed static.

IMPLEMENTATION ON COMPUTER

Computer programs ReLl, Rel2, ReL31 and ReL are prepared to evaluate reliability factors for WDS's. for which there are three state groups to be considered in this paper as shown in table (2).

The procedure of evaluating reliability factors for WDS's using computer programs is as follows:

I. Solving the first state group using computer program ReL 1, The output results of this program are printed out in a table form include values of available volume, required volume, and (ajs ×ts) for each nodal demand and each state. The flow chart of program ReL 1 is shown in flow chart.(1).

II. Solving the second state group using computer program in ReL2. The output results of this program are identical to these of program ReL I. The flow chart of program Rel2 is shown in flow chart(2).

III. Solving the third state group using computer program ReL3. The output of this program is also identical to these of program ReL 1. The flow chart of the Program ReL3 is shown in flow chart(3)

IV. To evaluate reliability factors. computer program Rel is used. for which the flow chart is shown in flow chart(4).

V. Repeat the same procedure (I-IV) for alternate networks. Then compare their results of reliability factors, the large factor is chosen as a best alternate.

ILLUSTRATIVE EXAMPLE

Network K (fig. 1) has been discussed by ref [10]. Nodes no. 1 and 2 are source and sump nodes with fixed hydraulic grade line (HGL) values of 100 m and 80 m. respectively. Nodes no. 3-9 are demand nodes, nodes no. 3, 5, and 7 in predominantly residential localities, nodes no. 4 and 8 in office areas, and nodes no. 6 and 9 in commercial localities. Six demand patterns were considered at each node as shown in table (3). Minimum WL requirement at each demand node was 85 m. A uniform fire demand of 5 m^3/min. with WL requirement of 70 m was assumed at each node. Only one fire was presumed to occur at a time. Fire flow requirement at a node was assumed to occur for 12 h in one year. The period of analysis was one year (365 days). The head discharge relationship for the pump fitted in pipe no. 11 was:

$$Q_P = 0.1683359-2.02285 \cdot 10^{-3} (H_p-7.742497)^2$$

In which the head HP was in (m) and discharge Qp was in (m^3/sec). Assume acceptable discharge ratio $Q_j^{avl}/Q_j^{req} \geq 0.999$ and acceptable node-reliability factor (R_n) ≥ 0.7.

Head loss in a pipe was given by Hazen-Williams head loss relationship with coefficient $C_{HW} = 100$ for all pipes. Rates of pipe breaking, were taken from Goulter and Coals [9]. Repair time for a pipe was taken as 2 days. The length and diameter of pipes along with other details are given in table (4). For example. for pipe no 'I the failure rate was 0.05 breaks yr^{-1} (0.05 breaks. km^{-1} yr^{-1} ×1 km. the pipe length), average outage time per year was 0. 1 days (0.05 breaks. Yr^{-1}×2 days the repair time), working time per year was 364.9 days (365-0.1), the ratio of working time to period of analysis r_2 was 0.9997, (364.9/365).

The ratio of working time to total time for the pump $r_p$was assumed to be 0.98. Since the working time to total time ratio for pipe no. 11,i.e., r_{11} was 0.9994 (table 4). the ratio of the time during which water was supplied to the network from sump at node no. 2 to the total time was $r_{11} \times r_p$,i.e.. 0.9994 × 0.98 = 0.9794. which total outage time for pipe no. 11 = 365 - 0.9794 × 365=7.519.

Considering no-pipe failure and one-pipe failure conditions (except pipe no. 1. due to it represent the main source flow) the total number of states for six demand patterns was 6 (1 +10) = 66 states. Since the joint probability of pipe failures and fire occurrence is small, it was presumed that fire flow was required only when all pipes and pumps were in working condition. The network demand was a maximum between hours 6-18. Therefore, the 12 h period for the fire flow requirement was assumed to occur from hour 6-18. The number of states with fire flow requirement was 3 × 7 = 21 states (three 4-h periods, at each of the seven demand nodes). Thus, the total number of states considered in reliability analysis was 66 + 21 = 87 states.

An alternate network also was considered and was obtained by interchanging pipes no. 2 & 5; 6 & 10; plus 7 & 8 (pipes in each pair were of the same length had a different diameter). Different states and corresponding time duration are shown in table (5). Available flows during 87 states were obtained using NFA. Since the HGL requirement for normal flow and fire flow at a node were different (85 & 70 m. respectively) for NFA to be feasible, an imaginary node, node no. 10 was introduced and connected to the respective node by a dummy pipe of 1 m in length, 0.25 m in diameter, with 100 as Hazen-Williams coefficient.

The first state group shown in table (5) was solved by using computer program ReL 1, the second state group was solved by using computer program ReL2. and the third state group was solved by using computer program ReL3 which all requirement input data for programs were summarized in tables (3, 4, 5). The flows available at each node for original network during the fire-flow conditions as obtained from NFA (using computer program ReL2) are given in table (4-22). Fire flow was available at every node during all three 4-h periods, but the normal flow decreased at some nodes. Decreased nodal flows are shown in parentheses, in table (6). For example, for time duration of hours (6-10), normal flow was partially satisfied at node no. 7 for fire demand at any other node, while no flow was available for normal use at node no. 7 during the period in which fire flow was taken at node no. 7 it self.

The reliability factors are shown in table (7) were obtained by using computer program Rel, the alternate network was obtained by interchanging pipes in the original network: time durations for different state groups in table (5) for the alternate network was the same as those in the original one. Furthermore. the cost of the alternate network practically remained the same as that of the original one.

Node-reliability factor for node no.3 was unaffected as it got its requirement through pipe no. 1, that had not changed in the alternate network. Node-reliability factors for nodes no. 4, 5, 6, and 9 changed marginally. while for nodes no. 7 and 8. they decreased considerably. However. node no. 8 was the most affected. The volume-reliability factor and network-reliability factor were much less for the alternate network, which it can be seen that the original network was the best.

CONCLUSIONS

1 .An approach based on node flow analysis that simultaneously considers the demands and minimum-required heads at nodes is developed for predicting the reliability of WDS's. Several loading patterns including demand excess are considered, However, reliability is estimated for pump, fitting. and pipe failure conditions only. Three reliability parameters (node-reliability factor, volume-reliability factor, and network-reliability factor) are proposed for comparing different alternatives in the design of WDS's. Computer programs ReL 1, Rel2, ReL3, and ReL, have been prepared to determine the reliability factors for comparing different alternatives and select the alternate has larger factors as the best.

2. The study of reliability for networks is proved two advantages, first, it permits to determine the degree of reliability of networks under different states which, in this

work, considered the daily pattern flow (solved by program ReLl), the demand excess (solved by program ReL2), and the break pipes (solved by program ReL3). Then the reliability factors (using program ReL) is to be determent. Second advantage, is to improve the network by using different alternatives based on modification the head at nodal demands by various methods such as increase diameters. friction coefficient CHW, booster pumps increase fixed head nodes or any method of improvement to the head at nodal demands with small different in cost considering the original network is conserved. Then the best alternate with least cost can be selected.

NOTATIONS

a_{js}	A dummy variable takinca value 1 or 0.
a_{vl}	Superscript denoting available.
C_{HW}	Hazen-Williams roughness coefficient.
C_J	Number of consumption nodes.
F_n	Node factor.
F_t	Time factor.
H_p	Head gain of pump. (L).
min	Superscript denoting minimum.
NFA	Node flow analysis.
NHA	Node head analysis.
NJ	The total number of junctions in the network.

NRM	Newton-Raphson. method.
Q_j	The external flow rate. (L^3 /T).
Q_P	Pump flow rate, (L^3 /T).
req	Superscript denoting required.
R_n	Node-reliability factor.
R_{nw}	Network-reliability factor.
R_v	Volume-reliability factor.
S	Subscript denoting state.
T_P	Period of analysis, (T).
t_s	Time duration of a state. (T).
v	Volume. (L^3).
WDS	Water distribution system
X	Number of pipes.
z	Number of demand patterns.

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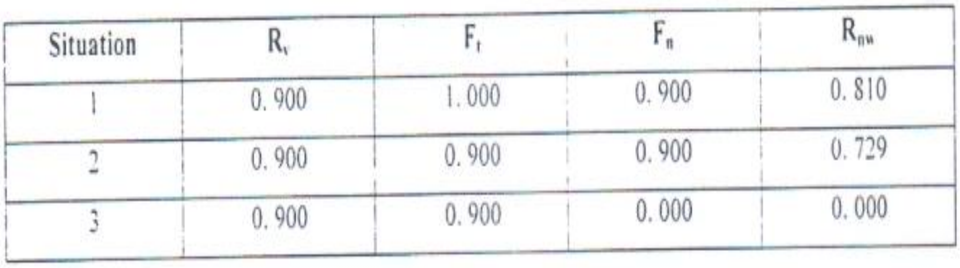
Table (1) Reliability Factors For Different Situations[12].

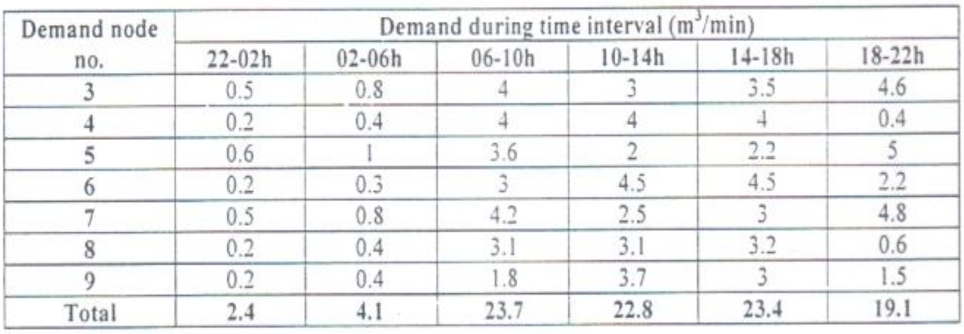


Situation	R_v	F_t	F_n	R_{nw}
1	0. 900	1.000	0. 900	0. 810
2	0. 900	0. 900	0. 900	0. 729
3	0. 900	0. 900	0. 000	0. 000

Table (2) different state groups used to compute relibility factors

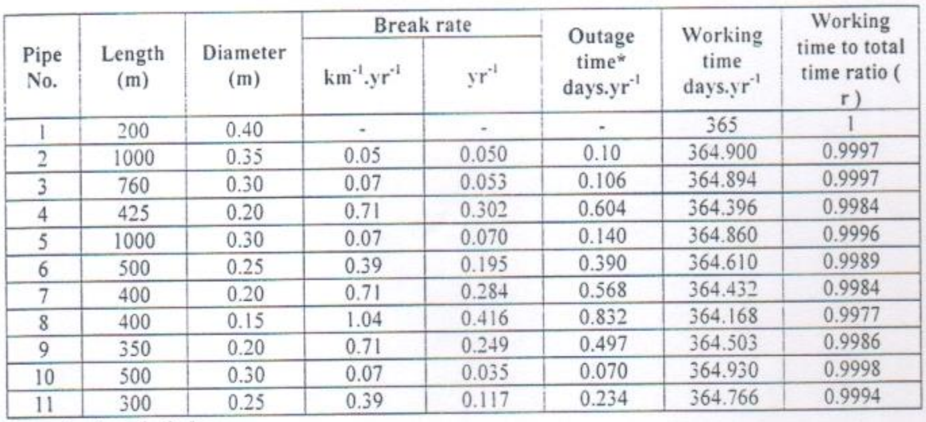
State agroupe	Describtion
1	No shutdown pipe normal flow and no demand excess
2	No shutdown pipe flow and demand excess requirement
3	One shutdown normal flow & no demand excess

Table (3) Nodal demand.



Demand node no.	Demand during time interval (m^3/min)					
	22-02h	02-06h	06-10h	10-14h	14-18h	18-22h
3	0.5	0.8	4	3	3.5	4.6
4	0.2	0.4	4	4	4	0.4
5	0.6	1	3.6	2	2.2	5
6	0.2	0.3	3	4.5	4.5	2.2
7	0.5	0.8	4.2	2.5	3	4.8
8	0.2	0.4	3.1	3.1	3.2	0.6
9	0.2	0.4	1.8	3.7	3	1.5
Total	2.4	4.1	23.7	22.8	23.4	19.1

Table (4) Pipe data.



Pipe No.	Length (m)	Diameter (m)	Break rate		Outage time* $days.yr^{-1}$	Working time $days.yr^{-1}$	Working time to total time ratio (r)
			$km^{-1}.yr^{-1}$	yr^{-1}			
1	200	0.40	-	-	-	365	1
2	1000	0.35	0.05	0.050	0.10	364.900	0.9997
3	760	0.30	0.07	0.053	0.106	364.894	0.9997
4	425	0.20	0.71	0.302	0.604	364.396	0.9984
5	1000	0.30	0.07	0.070	0.140	364.860	0.9996
6	500	0.25	0.39	0.195	0.390	364.610	0.9989
7	400	0.20	0.71	0.284	0.568	364.432	0.9984
8	400	0.15	1.04	0.416	0.832	364.168	0.9977
9	350	0.20	0.71	0.249	0.497	364.503	0.9986
10	500	0.30	0.07	0.035	0.070	364.930	0.9998
11	300	0.25	0.39	0.117	0.234	364.766	0.9994

* Pipe repair time is 2 days.

Table (5) Different state group and time duration.

State group	Description	No. of states	Original network		Alternate network	
			Total time days	Cumulative time days	Total time days	Cumulative time days
1	No shut-down pipe, normal flow & no fire flow.	6	350.674	350.674	350.674	350.674
2	No shut-down pipe, normal flow & fire flow requirement.	21	3.5	354.174	3.5	354.174
3	One shut-down pipe (except pipe no.1), normal flow & no fire flow.	60	10.826	365	10.826	365

Table (6) Available nodal flow for original network during fire-flow conditions.

Available for fire at node	Flow at node (m^3/min)								
	1*	2*	3	4	5	6	7	8	9
a) Time duration 6-10h									
required	-	-	4	4	3.6	3	4.2	3.1	1.8
3	-22.32018	-5.78750	4	4	3.6	3	(3.6077)	3.1	1.8
4	-19.40352	-5.80234	4	(3.986)	3.6	(2.427)	(1.2920)	3.1	1.8
5	-19.02647	-5.91587	4	4	(1.9246)	(1.937)	(3.6660)	(2.614)	1.8
6	-18.96058	-5.94129	4	4	3.6	(0.0)	(3.4010)	3.1	1.8
7	-18.63348	-5.86653	4	4	3.6	3	(0.0)	3.1	1.8
8	-18.66120	-6.10200	4	4	3.6	3	(3.3630)	(0.0)	1.8
9	-18.59400	-6.25	4	4	3.6	3	(2.6840)	(1.218)	(1.342)
b) Time duration 10-14h									
required	-	-	3	4	2	4.5	2.5	3.1	3.7
3	-21.3030	-6.0600	3	4	2	(4.063)	2.5	3.1	3.7
4	-18.3506	-6.1240	3	4	2	(2.895)	(0.779)	3.1	3.7
5	-18.1386	-6.0544	3	4	2	(1.991)	2.5	(2.0)	3.7
6	-17.3340	-5.9659	3	4	2	(0.0)	2.5	3.1	3.7
7	-17.7930	-6.2140	3	4	2	(3.899)	(0.0)	(2.407)	3.7
8	-17.5687	-6.2501	3	4	2	(3.892)	2.5	(0.0)	(3.426)
9	-17.4538	-6.25	3	4	2	(4.099)	2.5	(1.677)	(1.427)
c) Time duration 14-18h									
Required	-	-	3.5	4	2.2	4.5	3	3.2	3
3	-21.7870	-6.0170	3.5	4	2.2	(3.904)	3	3.2	3
4	-18.7640	-6.0156	3.5	4	2.2	(2.896)	(0.983)	3.2	3
5	-18.5609	-6.0215	3.5	4	(1.994)	(1.94)	3	(2.147)	3
6	-17.9269	-5.9730	3.5	4	2.2	(0.0)	3	3.2	3
7	-18.2403	-6.1590	3.5	4	2.2	(3.859)	(0.0)	(2.840)	3
8	-18.0340	-6.2456	3.5	4	2.2	(3.787)	(2.790)	(0.0)	3
9	-17.9175	-6.2501	3.5	4	2.2	(3.955)	(2.721)	(1.604)	(1.185)

* Including fire-flow of (5 m^3/min) at the concerned node.

Table (7) Reliability factors for original and alternate networks.

Item	Original network	Alternate network
Node-reliability factor, node no. 3	1	1
Node-reliability factor, node no. 4	0.9997462	0.9976699
Node-reliability factor, node no. 5	0.9994367	0.9995012
Node-reliability factor, node no. 6	0.9930077	0.995056
Node-reliability factor, node no. 7	0.9927415	0.9366541
Node-reliability factor, node no. 8	0.9854999	0.7256098
Node-reliability factor, node no. 9	0.9817002	0.9806121
Volume-reliability factor	0.9939569	0.9557108
Time factor	0.9903264	0.8731951
Node factor	0.9931387	0.9426529
Network-reliability factor	0.9775879	0.7866645

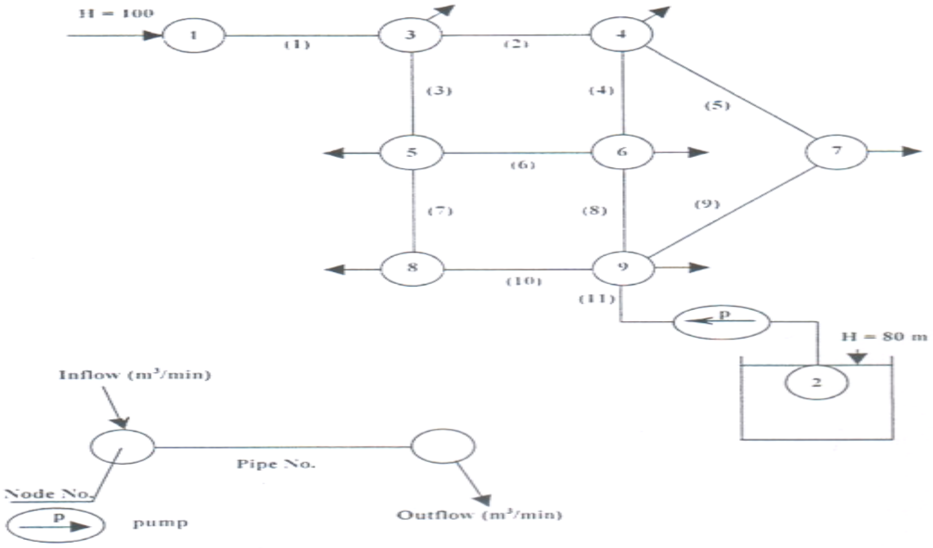
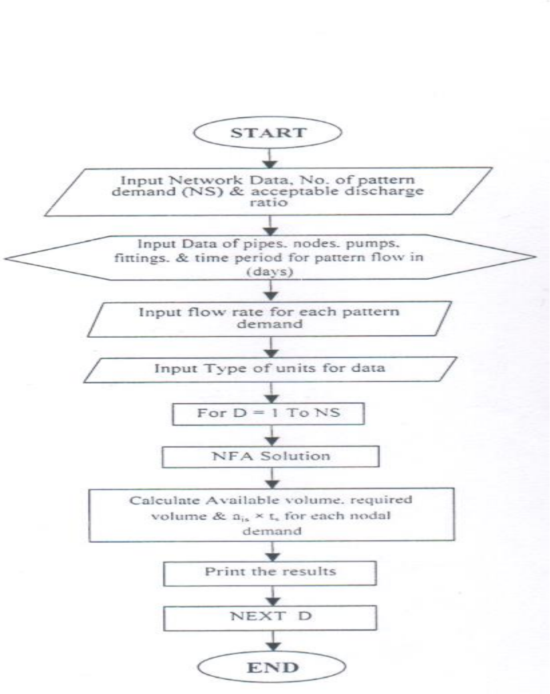


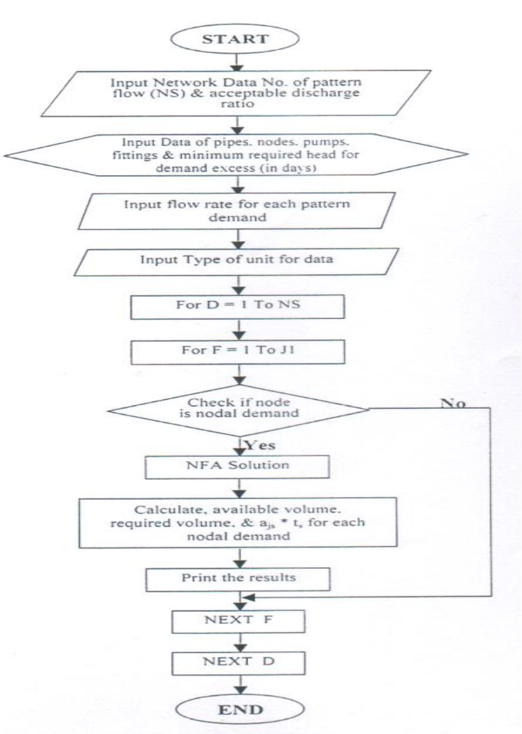
Fig. (1) Network K [12].

FLOW CHARTS

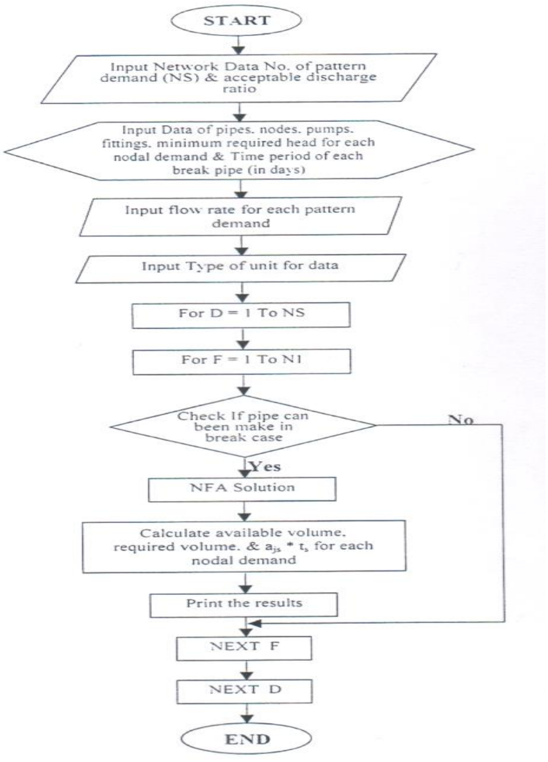
(1) FLOW CHART FOR COMPUTER PROGRAM (REL1)



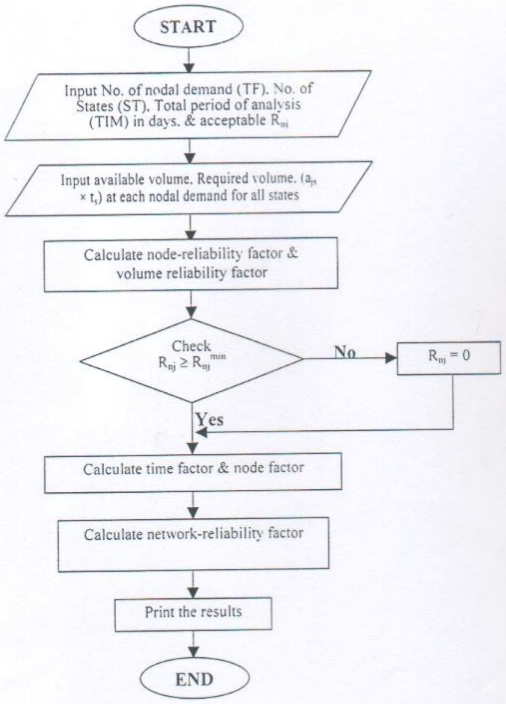
(2) Flow chart for Computer program (ReL2)



(3) FLOW CHART FOR COMPUTER PROGRAM (REL3)



(4) FLOW CHART FOR COMPUTER PROGRAM (REL)



النمذجة الهيدروليكية لاعتمادية تشغيل شبكات مياه الشرب

الدكتور كريم خلف الجميلي
قسم هندسة البناء والانشاءات
الجامعة التكنولوجية

علاوي حسين راضي
قسم هندسة البناء والاننشاءات
الجامعة التكنولوجية

الخلاصة

لقد تم دراسة موضوع الاعتمادية التشغيلية لشبكات المياه على اساس تحليل الجريان في العقد ، وتم اعداد البرامج الخاصة بها بحيث يمكن الحصول على المعاملات الخاصة بالاعتمادية .

وبالرغم من اعتماد موضوع الاعتمادية على الكثير من المتغيرات التي تحدث في الشبكة إلا انه وفي هذا البحث تم التركيز على التغير اليومي في الاستهلاك والزيادة المفاجئة في الطلب على المياه وانسداد او فشل اي جزء من اجزاء الشبكة كالانابيب والصمامات .

الكلمات الدالة

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