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Application of flow path algorithm in flow pattern mapping and loop data generation for a water distribution system

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ABSTRACT

Flow pattern mapping of a water distribution network is important for operators and managers for its efficient operation, maintenance and management. Such a pattern can be developed for a water supply system from flow paths, which can be generated by travelling in the opposite direction of flow in the pipes from a demand (withdrawal) node to a supply (input) node in a pipe network. Similarly, the information about pipes forming primary loops is an essential part of the data for the analysis of a water distribution system. The loop data do not constitute information independent of the link-node information and theoretically it is possible to generate loop data from this information. Presented herein is an algorithm for flow paths generation and its application in flow pattern mapping and loop data formulation including identification of the water supply boundaries of each input point in a multi-input source water distribution system.

Key words | flow patterns mapping, water supply, pipe flow, pipe network

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NOTATION

D	=	pipe link diameter
I_p	=	pipe links meeting at a node
I_s	=	input source number for a pipe
I_t	=	pipe links in a track
i	=	pipe index
i_L	=	total pipes in network
J_1, J_2	=	pipe link node
J_s	=	starting node of a track
J_t	=	terminal node of a track
j	=	node index
j_L	=	total number of nodes
k_L	=	total number of loops
L	=	pipe link length
ℓ	=	index
m	=	pipe cost exponent
N_p	=	number of pipe links meeting at a node
n	=	input point index
Q	=	pipe link discharge
z	=	elevation

SUBSCRIPTS

p	=	pipe
s	=	starting node
t	=	track

INTRODUCTION

Generally, urban water distribution networks have a looped and branched configuration owing to reliability considerations. Unlike branched systems, the flow directions in looped networks are not unique and depend upon a number of factors, mainly topography, nodal demand including location and number of input (supply) points. The elevated reservoirs or pumping plants in the case of direct pumping systems, supplying water to the distribution network are termed input points. Information about the flow pattern mapping of a distribution network will work as a decision support system for operators/managers of water supply systems. These pipe flow patterns can be generated by pipe flow paths, which are the set of pipes connecting a demand (withdrawal) node to the supply (input) node and can be identified by moving opposite to the direction of flow in pipes.

Moreover, using these flow paths, information about the loop forming pipes can be developed. In practice, information about the pipes forming primary loops remains an essential part of the data required for the analysis of a pipe network. However, loop data do not constitute information independent of the link-node information and theoretically it is possible to generate loops from link-node data of a pipe network.

Presented herein is an algorithm for the flow path selection and its application in loop data generation and flow pattern mapping including identification of water supply boundaries of each input point in multi-input point water distribution system. It is hoped that this algorithm will be useful to the engineers engaged in the analysis, design, operation and maintenance of water distribution systems.

LITERATURE REVIEW

Shang *et al.* (2002) developed a water parcel backtracking algorithm with a particular emphasis on water quality modelling for a water distribution network, which provides information about the various paths that water takes between an input (supply) node and a demand (withdrawal) node. This algorithm was developed with specific application to water quality modelling.

Wood & Rays (1981) and Bhave (1981) indicated that information about the pipes forming primary loops should be an integral part of the data for the analysis of a water distribution network.

Epp & Fowler (1970) developed an algorithm for the generation of primary (natural) loop data from the pipe-node connectivity data using a minimum path algorithm. In this algorithm firstly all the branched pipes are detached (removed) from the network and then step-by-step the pipes identified as part of a loop are removed until all the pipes are covered. Such an algorithm has limited application in water distribution analysis and design.

NETWORK DESCRIPTION

In order to describe the algorithm properly, a typical water distribution network as shown in Figure 1 is considered. The geometry is described by the following data.

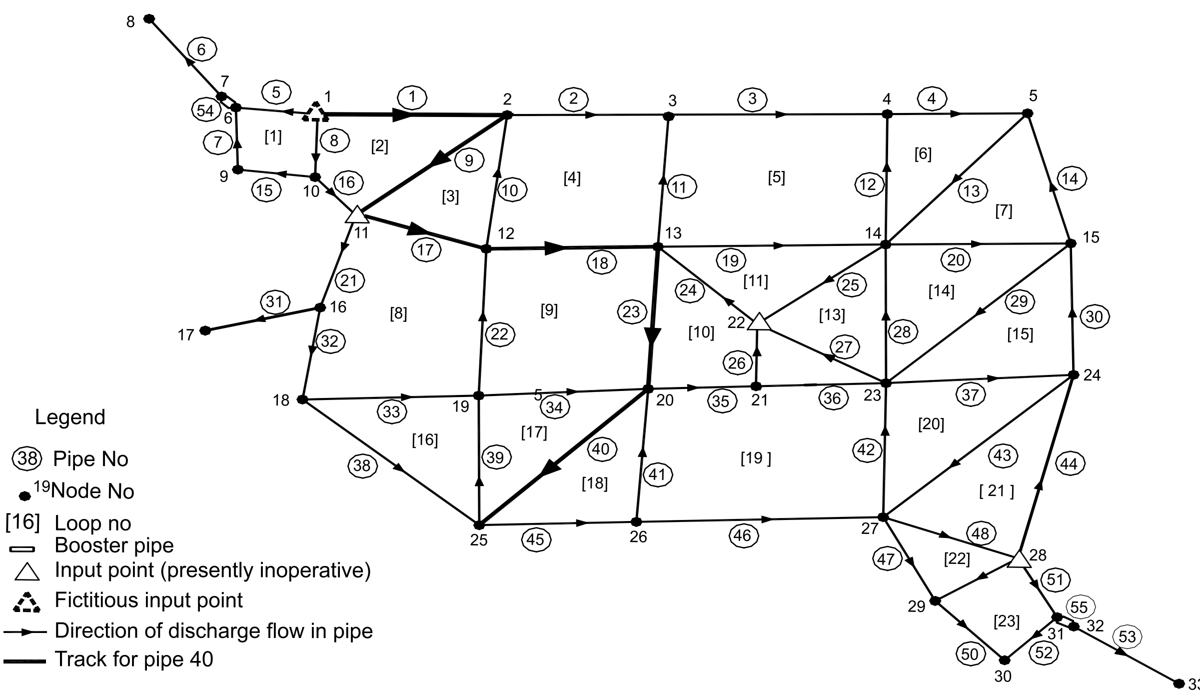

Figure 1 | Direction of discharge flows for loop data generation.

Pipe-link data

The pipe link i has two end points with the nodes J_1 (i) and J_2 (i), where J_1 (i) pertains to the lower nodal number and J_2 (i) to the higher nodal number. However, input data can be provided without any restrictions, as the node-pipe connectivity algorithm described in this paper will first modify nodal data such that $J_1(i)$ and $J_2(i)$ are lower and higher nodal numbers, respectively. Also pipe has length L_i for $i = 1, 2, 3, \ldots i_{L,}$ where i_L is the total number of the pipe links in the network, pipe diameter D (i) and the sectional population load P (i) on the pipe for water demand. The elevation of the nodal points is z (j) for $j = 1, 2, 3, \ldots j_{\mathrm{L}}$, where j_{L} is the total number of nodal points in the network. The pipe data structure is shown in Table 1.

Input point data

The nodal number of the input point is designed as S (ℓ) for $\ell = 1$ to n_{L} (total number of input points). The three input points at node numbers 11, 22 and 28 are shown in Figure 1.

NETWORK ANALYSIS

Node-pipe connectivity

Firstly, the algorithm will ensure that the pipe nodal numbers J_1 (i) pertain to the lower nodal number and J_2 (i) to the higher nodal number. In cases where this is not true the input data will be modified accordingly. Now one requires the pipes I_P (j, ℓ), to meet at node j. The index ℓ varies from 1 to N_P (j), the total number of pipes meeting at node j. I_P (1,1) can be found by scanning the nodes J_1 (i) and J_2 (i). If either J_1 or J_2 is equal to 1, I_P (1,1) is equal to i. A perusal of Table 1 indicates that I_P (1,1) = 1 and similarly I_P (1,2) = 5 and I_P (1,3) = 8. Scanning all the pipes, one can find that only pipes 1, 5 or 8 have either J_1 or J_2 equal to 1, thus the total number of pipes meeting at node $j = 1$ are 3, resulting in N_P (j) = 3. Table 2 indicates the node-pipe connectivity for the entire network.

Table 1 | Pipe link data

i / j	J_1(i)	J_2(i)	Z(j)	L(i)	D(i)	P(i)
1	1	2	101.85	380	0.150	500
2	2	3	101.90	310	0.150	385
3	3	4	101.95	430	0.125	540
4	4	5	101.60	270	0.080	240
5	1	6	101.75	150	0.050	190
6	7	8	101.80	500	0.065	500
7	6	9	101.80	150	0.065	190
8	1	10	131.40	150	0.150	190
9	2	11	101.85	390	0.125	490
10	2	12	101.90	320	0.050	400
11	3	13	102.00	320	0.100	400
12	4	14	101.80	330	0.050	415
13	5	14	101.80	420	0.080	525
14	5	15	101.90	320	0.050	400
15	9	10	101.50	160	0.080	200
16	10	11	100.80	120	0.200	150
17	11	12	100.70	290	0.150	350
18	12	13	101.40	330	0.100	415
19	13	14	101.60	450	0.100	560
20	14	15	101.80	360	0.080	450
21	11	16	101.85	230	0.125	280
22	12	19	101.95	350	0.125	440
23	13	20	101.80	360	0.080	450
24	13	22	101.10	260	0.0.80	325
25	14	22	101.40	320	0.125	400
26	21	22	101.20	160	0.125	200
27	22	23	101.70	290	0.150	365
28	14	23	101.90	320	0.080	400

Table 1 | (*continued*)

i / j	J_1(i)	J_2(i)	Z(j)	L(i)	D(i)	P(i)
29	15	23	101.70	500	0.100	625
30	15	24	101.80	330	0.065	410
31	16	17	101.80	230	0.050	290
32	16	18	101.80	220	0.100	275
33	18	19	140.40	350	0.065	440
34	19	20		330	0.050	410
35	20	21		220	0.100	475
36	21	23		250	0.050	310
37	23	24		370	0.080	460
38	18	25		470	0.080	590
39	19	25		320	0.065	400
40	20	25		460	0.050	575
41	20	26		310	0.050	390
42	23	27		330	0.050	410
43	24	27		510	0.065	640
44	24	28		470	0.100	590
45	25	26		300	0.065	375
46	26	27		490	0.100	610
47	27	29		230	0.125	290
48	27	28		280	0.100	350
49	29	29		190	0.150	240
50	29	30		200	0.050	250
51	28	31		160	0.080	200
52	30	31		140	0.050	175
53	32	33		250	0.065	310
54	6	7		0.0	0.065	0
55	31	32		0.0	0.065	0

Table 2 | Node-pipe connectivity

	$I_P(j, \ell)$						
J	$\ell = 1$	$\ell = 2$	$\ell = 3$	$\ell = 4$	$\ell = 5$	$\ell = 6$	$N_P(j)$
1	1	5	8				3
2	1	2	9	10			4
3	2	3	11				3
4	3	4	12				3
5	4	13	14				3
6	5	7	54				3
7	6	54					2
8	6						1
9	7	15					2
10	8	15	16				3
11	9	16	17	21			4
12	10	17	18	22			4
13	11	18	19	23	24		5
14	12	13	19	20	25	28	6
15	14	20	29	30			4
16	21	31	32				3
17	31						1
18	32	33	38				3
19	22	33	34	39			4
20	23	34	35	40	41		5
21	26	35	36				3
22	24	25	26	27			4
23	27	28	29	36	37	42	6
24	30	37	43	44			4
25	38	39	40	45			4
26	41	45	46				3

Table 2 | (*continued*)

	$I_P(j, \ell)$						
J	$\ell = 1$	$\ell = 2$	$\ell = 3$	$\ell = 4$	$\ell = 5$	$\ell = 6$	$N_P(j)$
27	42	43	46	47	48		5
28	44	48	49	51			4
29	47	49	50				3
30	50	52					2
31	51	52	55				3
32	53	55					2
33	53						1

Fictitious input point and pipe discharges for loop data generation

In the case of single input source networks, actual input source node and actual withdrawals can be used for loop data generation. However for generalised application, instead of an actual input point a fictitious input point is considered at node 1 and instead of actual withdrawals, unit withdrawals at all the nodal points, other than the input point, are assumed.

It is assumed that the flow of discharge in a pipe from a lower magnitude to a higher magnitude node is positive. With this sign convention and using Table 2, the pipe discharge sign coefficients $s\ (j, \ell)$, where ℓ varies from 1 to $N_P\ (j)$, for the entire network are generated. $s(j, \ell)$ is $+1$ if a positive discharge in ℓth pipe approaches the node j.

The pipe discharge $Q(I_P(j, \ell))$ is now calculated by applying continuity equation as

$$Q(I_P(j,\ell)) = s(j,\ell)\left[q(j) - \sum_{\ell=1}^{N_P(j)-1} s(j,\ell)Q(I_P(j,\ell))\right] \quad (1)$$

where $q(j)$ is the jth node withdrawal assumed 1 unit as above.

For obtaining the pipe discharges satisfying the nodal continuity equations only, firstly nodes connecting a single pipe link are identified. Applying a reduced form of Equation (1) at such nodes results in a unit discharge in the connected pipe link.

$$Q(I_P(j,\ell)) = s(j,\ell)q(j) \quad (2)$$

Once the discharge in all pipes connected to the nodes with $N_P(j) = 1$ are known, the network is now scanned node by node to find two pipe links with zero discharges. Out of these two pipes, the discharge in lower index numbered pipe is assumed to be 0.1 units. Now applying Equation (1) the discharge in the second pipe is obtained and this process is extended to all nodes. The process is repeated till the discharge distribution by this method is complete. After completion of the process covering the entire network it can be found that many nodes, at which there were three or more zero discharge pipes, are converted to nodes having only two zero discharge pipes. Thus the second cycle of discharge distribution is started to cover the network again. These cycles are continued until there is no node left that has two zero discharge pipes.

Now the pipe network is scanned node by node to obtain three pipe links with zero discharges. Out of these pipes, for the two pipes with the lower index number a discharge of 0.1 units is assumed and the discharge in the third pipe is computed by satisfying the nodal continuity equation. Such an assumption (of two pipe link discharges and calculation of the third discharge) results in many nodes of the network reducing to two pipes with zero discharge. Applying the continuity equation and assuming the lower index number pipe discharge is 0.1, the discharges in other pipes can be obtained. The process is continued until the entire network is covered. These cycles are repeated until no such computations are possible.

The process is repeated until the discharge distribution lasts. If required, this process is extended to four or more zero discharge pipes meeting at a nodal point. In the case of nodes with four pipes with zero discharges, a discharge of 0.1 units is assumed in the three lower index number pipes and the discharge in fourth pipe is computed satisfying the nodal continuity equation. A similar process can be repeated for nodes with more than four pipes with zero discharges. However, it has been found that such assumptions are not necessary in an actual network. Table 3 depicts

Table 3 | Pipe discharges

Pipe (*i*)	1	2	3	4	5	6	7	8	9	10	11
Q (*i*) units	0.1	0.1	0.1	0.1	0.1	1.0	−2.9	31.8	0.1	−1.1	−1.0
Pipe (*i*)	12	13	14	15	16	17	18	19	20	21	22
Q (*i*) units	−1.0	0.1	−1.0	−3.9	26.9	0.1	0.1	0.1	0.1	25.9	−2.1
Pipe (*i*)	23	24	25	26	27	28	29	30	31	32	33
Q (*i*) units	0.1	−2.1	0.1	0.1	−2.9	−2.0	0.1	−2.0	1.0	23.9	0.1
Pipe (*i*)	34	35	35	37	38	38	40	41	42	43	44
Q (*i*) units	0.1	0.1	−1.0	0.1	22.8	−3.1	0.1	−0.1	−6.9	0.1	−3.0
Pipe (*i*)	45	46	47	48	49	50	51	52	53	54	55
Q (*i*) units	18.8	16.8	0.1	8.9	0.1	−0.8	4.8	−1.8	1.0	2.0	2.0

the pipe discharges obtained by applying nodal continuity equations as described above.

FLOW PATH SELECTION

The flow path is a set of pipes through which a pipe is connected to an input point. Generally, there are several paths through which a node j receives the discharge from an input point and similarly there can be several paths through which a pipe is connected to an input point for receiving a discharge. Such flow paths can be obtained by proceeding in a direction opposite to the flow.

Considering pipe $i = 40$ at node $j = 25$, we need to find out a set of pipes through which pipe 40 is connected to the input point. Following Table 3, the discharge in pipe 40 is positive, meaning that the water flows from node 20 to 25. Thus, if one travels from node 25 to node 20, one will be moving in a direction opposite to the flow. In this manner one reaches node 20. The directions of discharges in the network pipes, as per Table 3, are shown in Figure 1.

Scanning Table 2 for node 20, one finds that it connects five pipes: namely 23, 34, 35, 40 and 41. One has already travelled along pipe 40, therefore only pipes 23, 24, 35 and 41 are considered. Table 3 shows that the discharge in pipe 23 is positive and from Table 1, that the other node of this pipe 23 is 13, thus a positive discharge flows from node 13 to node 20. Also by similar argument one may discover that the discharge in pipe 35 flows from node 20 to 21 and the discharge in pipe 41 flows from node 26 to 20. Thus, to move against the flow from node 20, one of the pipes 23, 34 and 41 can be selected. Pipe 35 is rejected as the movement in this pipe will be in the direction of flow. Selecting a lower numbered pipe, one moves along pipe 23 and reaches node 13. Repeating this procedure one moves along the pipes 18, 17, 9 and 1, thus one reaches node 1 (fictitious input point). The flow path for pipe 40 thus obtained is shown in Figure 1.

Thus starting from pipe $i = 40$, one encounters six pipes before reaching the input point. The total number of pipes in the flow path N_t is a function of pipe i (in this case pipe 40), thus N_t $(40) = 6$ and the flow path is originating from the node $J_t(i = 40) = 25$. The pipes encountered on the way are designated $I_t(i, \ell)$ with ℓ varying from 1 to $N_t(i)$. For pipe 40 the following $I_t(i, \ell)$ were obtained:

$$I_t(40,1) = 40,\ \ I_t(40,2) = 23,\ \ I_t(40,3) = 18,\ \ I_t(40,4) = 17,\ \ I_t(40,5) = 9 \ \text{and}\ It(40,6) = 1$$

Following a similar procedure, the flow path for the entire network and their originating nodes are given in Table 4.

Table 4 | Pipe tracks

	$I_t(i,\ell), \ell = 1, N_t(i)$														
i	1	2	3	4	5	6	7	8	9	10	11	12	13	$N_t(i)$	$J_t(i)$
1	1													1	2
2	2	1												2	3
3	3	2	1											3	4
4	4	3	2	1										4	5
5	5													1	6
6	5	54	5											3	8
7	7	15	8											3	9
8	8													1	10
9	9	1												2	11
10	10	17	9	1										4	2
11	11	18	17	9	1									5	3
12	12	13	4	3	2	1								6	4
13	13	4	3	2	1									5	14
14	14	20	13	4	3	2	1							7	5
15	15	8												2	9
16	16	8												2	11
17	17	9	1											3	12
18	18	17	9	1										4	13
19	19	18	17	9	1									5	14
20	20	13	4	3	2	1								5	15
21	21	9	1											3	16
22	22	33	32	21	9	1								6	12
23	23	18	17	9	1									5	20
24	24	25	13	4	3	2	1							7	13
25	25	13	4	3	2	1								6	22
26	26	35	23	18	17	9	1							7	22

Table 4 | (*continued*)

	$I_t(i,\ell), \ell = 1, N_t(i)$														
i	1	2	3	4	5	6	7	8	9	10	11	12	13	$N_t(i)$	$J_t(i)$
27	27	29	20	13	4	3	2	1						8	22
28	28	29	20	13	4	3	2	1						8	14
29	29	20	13	4	3	2	1							7	23
30	30	37	29	20	13	4	3	2	1					9	15
31	31	21	9	1										4	17
32	32	21	9	1										4	18
33	33	32	21	9	1									5	19
34	34	33	32	21	9	1								6	20
35	35	23	18	17	9	1								6	21
36	36	29	20	13	4	3	2	1						8	21
37	37	29	20	13	4	3	2	1						8	24
38	38	32	21	9	1									5	25
39	39	38	32	21	9	1								6	19
40	40	23	18	17	9	1								6	25
41	41	45	38	32	21	9	1							7	20
42	42	43	37	29	20	13	4	3	2	1				10	23
43	43	37	29	20	13	4	3	2	1					9	27
44	44	48	43	37	29	20	13	4	3	2	1			11	24
45	45	38	32	21	9	1								6	26
46	46	45	38	32	21	9	1							7	27
47	47	43	37	29	20	13	4	3	2	1				9	29
48	48	43	37	29	20	13	4	3	2	1				9	28
49	49	48	43	37	29	20	13	4	3	2	1			10	29
50	50	52	51	48	43	37	29	20	13	4	3	2	1	13	39
51	51	48	43	37	29	20	13	4	3	2	1			11	31
52	52	51	48	43	37	29	20	13	4	3	2	1		12	30

Table 4 | (*continued*)

	$I_t(i,\ell), \ell = 1, N_t(i)$														
i	1	2	3	4	5	6	7	8	9	10	11	12	13	$N_t(i)$	$J_t(i)$
53	53	55	51	48	43	37	29	20	13	4	3	2	1	13	33
54	54	5												2	7
55	55	51	48	43	37	29	20	13	4	3	2	1		12	32

LOOP DATA GENERATION

Starting from a particular node many times, it is possible to get two different flow paths to reach the input point. Combining these two paths a loop is formed. Two paths are feasible when the two pipes connected at node j have a direction of flow towards the node under consideration (supplying discharge to the node).

The procedure is illustrated by considering node 12. Referring to Table 2, it can be seen that pipes 10, 17, 18 and 22 are connected to node 12. As explained earlier using Table 1 and Table 3, it is found that the direction of flow in pipes 17 and 22 is towards node 12 (see Figure 1) and the direction of flow in pipe 10 and 18 is away from the node under consideration. Thus, the flow path of pipes 17 and 22 will generate a loop. According to Table 4, the flow path of pipes 17 and 22 are as follows:

$$\text{Pipe } 17: 17, 9 \text{ and } 1 \tag{3}$$

$$\text{Pipe } 22: 22, 33, 32, 21, 9 \text{ and } 1 \tag{4}$$

For forming a loop the flow path of pipe 22 has to be reversed and combined with the path corresponding to pipe 17. Such a procedure yields the following loop:

$$17, 9, 1, 1, 9, 21, 32, 33, 22 \tag{5}$$

The sequence in (5) has repeated entries of pipes 1 and 9. These entries are scored off as they do not constitute a proper loop. Scoring off the pipes 1 and 9 occurring twice, sequence (5) can be written as:

$$17, 21, 32, 33 \text{ and } 22 \tag{6}$$

which is generating a loop. The loop thus generated will have total number of pipes $N_k(k)$ as 5 in this case and loop pipes $I_k(k, \ell)$ as a function of loop index k and index ℓ varying from 1 to $N_k(k)$. Loop index k represents the order in which various loops are generated.

Examining node by node for the entire network and following the loop data generation process, various loops can be generated. Every loop generated should be examined for any new pipe link contained in it. If no new pipe is contained in the new loop, it should be rejected and other pipes in which the discharge approaches the node under consideration should be explored. The loops thus generated are assembled in Table 5.

The total number of loops k_L required for the analysis of a water distribution network is:

$$k_L = i_L - j_L + 1 \tag{7}$$

After the required number of loops is generated the algorithm can be stopped. In case the required number of loops is not formed and the index j is exhausted, the fictitious input point should be moved to another location (next node) and the process should be repeated until the required number of loops is generated.

The water distribution system as shown in Figure 1 is analysed without loop data (using the loops generated with this algorithm), the pipe discharges for the given pipe diameters and nodal demand are the same as when the system was analysed with primary loop data. The CPU time taken in the generation of loop data by this algorithm for a water distribution network with 100 pipes, 71 nodes and 30

Table 5 | Loops generated

	$I_k(k,\ell)$, ℓ = 1, $N_k(k)$														
i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	$N_k(k)$
1	9	17	10												3
2	2	9	17	18	11										5
3	4	13	12												3
4	13	20	14												3
5	5	8	15	7											4
6	9	1	8	16											4
7	17	21	32	33	22										5
8	18	17	9	2	3	4	13	25	24						9
9	13	4	3	2	9	17	18	19							8
10	20	29	28												3
11	29	37	30												3
12	33	38	39												3
13	23	18	17	21	32	33	34								7
14	23	18	17	21	32	38	45	41							8
15	35	23	18	17	9	2	3	4	13	20	29	36			12
16	25	13	4	3	2	9	17	18	23	35	26				11
17	25	20	29	27											4
18	37	43	42												3
19	43	48	44												3
20	38	32	21	17	18	23	40								7
21	43	37	29	20	13	4	3	2	9	21	32	38	45	46	14
22	47	48	49												3
23	47	48	51	52	50										4

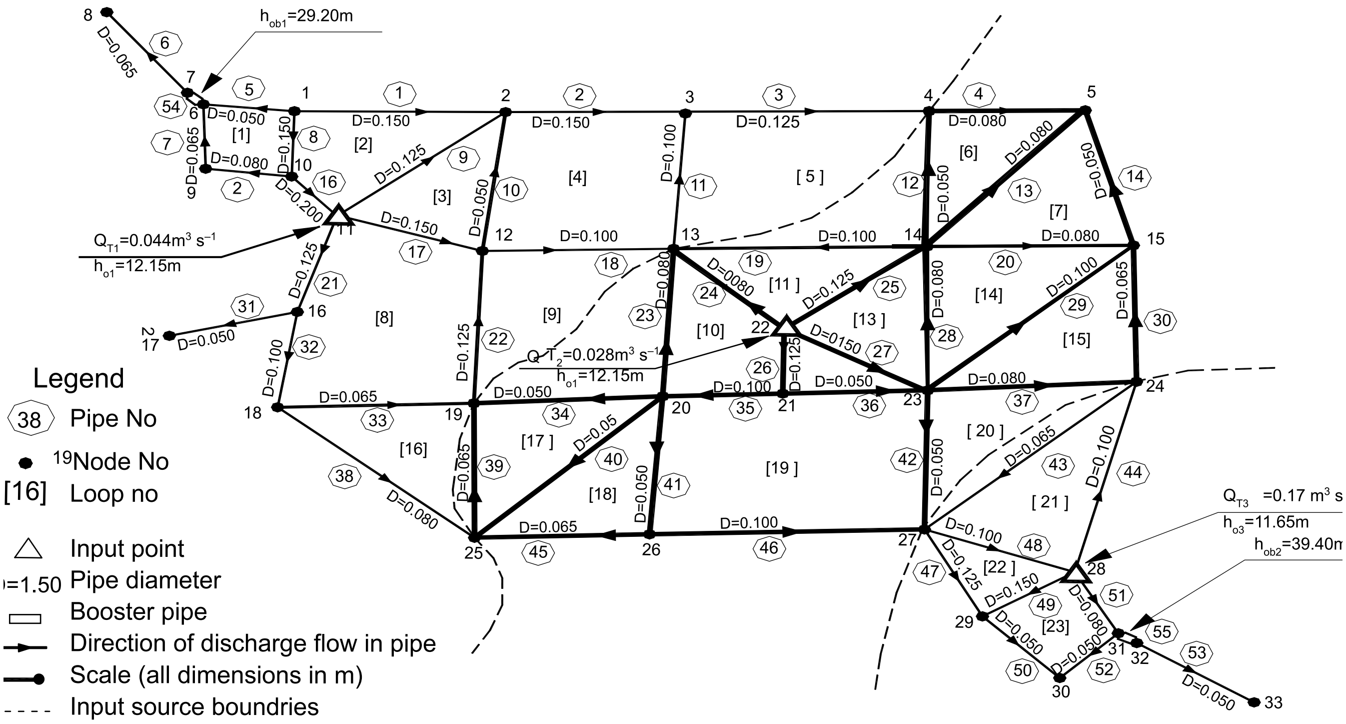

Figure 2 | A typical looped water distribution system.

primary loops was 20 s on a 1.9 GHz P4 personal computer system.

The loops thus generated are not the primary loops but are higher order loops. Unlike primary loops, pipes in higher order loops can be members of more than two loops. In a large network higher order loops can be preferred, as the discharge correction in such loops will affect a large number of primary loops, thus rapidly bringing stability in pipe discharges compared with primary loops.

Thus the algorithm will not only reduce data requirements but also save manpower required in the preparation of data. This will also reduce the chances of human error in preparing the data.

NETWORK FLOW PATTERN MAPPING

The three input point water distribution network (Figure 2) has been analysed for the given pipe diameters and sectional population load using the generated loop data. The water demand is assumed as 150 litres per capita per day and the peak factor as 2.5 times the average demand. The population of the pipe is transferred equally on both the nodes $J_1(i)$ and $J_2(i)$. In case of pipes having one of their nodes as the input node, the total population is transferred to the other node for nodal withdrawal computation. Summing up the nodal population transferred by various pipes connected to a particular node, the nodal population $P(j)$ is obtained as:

$$P(j) = 0.5 \sum_{\ell=1}^{N_P(j)} P(I_P(j,\ell))$$

Multiplying $P(j)$ by per capita water demand and peak factor, the nodal demand (withdrawal) in $m^3\ s^{-1}$ is obtained. A water distribution analysis program has been written using the Hardy cross method for the loop discharge correction. The sign convention of pipe discharge flow is adopted as discussed above. That is, the flow of discharge in a pipe from a lower magnitude node to a higher magnitude node is positive.

For network flow pattern mapping the flow path selection algorithm developed for loop data generation is slightly modified. Starting from a pipe for flow path generation as described above, one moves opposite to the direction of flow, instead of selecting a lower numbered pipe where two or more pipes are available in which the movement can be possible in the opposite direction of flow, select a pipe with maximum discharge. In this process the flow path will terminate at an input point (source node) contributing maximum flow into the flow path particularly for the pipes that are close to the boundary of two input points, and the flow path identified in such a way is most likely to have the minimum path length. Thus going pipe-wise one can identify the flow paths and the corresponding input source number $I_s(i)$ for each pipe. $S(I_s(i))$ is the input point (source node) of pipe i.

Combining the information for pipe input source generated, the flow pattern for the pipe network is shown plotted in Figure 2 along with the boundaries of each input point.

CONCLUSION

From the foregoing development the following conclusions are drawn.

An algorithm has been given to identify a flow path through which a pipe node is connected to an input point (source) to receive discharge. The flow path is a set of pipes identified by moving opposite to the direction of flow from a pipe node to the input point in the network. The flow paths are required for formulating the minimum head constraint equations in a pipe network optimisation problem.

A methodology for the loop data generation for a water distribution network has been developed. The loops thus generated are high order loops in which the pipes can be the members of more than two primary loops. This brings down the pipe discharge correction in the looped network quickly in comparison to corrections associated with primary loops. It is hoped that the loop data generation algorithm will not only reduce the amount of data but also reduce the chances of human error while preparing the data.

A procedure for the flow pattern mapping of a water distribution network has been developed. In multi-input (sources) water supply systems, it is not only important to analyse the network for pipe discharges but also to identify the corresponding input point (source) contributing the flow in pipes. When the withdrawal pattern is varied, the area under command of an input point is changed. Thus simulating various withdrawal patterns one may get the feel of the change in the command area of the input points. Using the algorithm, the change in pipe flows and flow directions can easily be predicted in case of any valve closure for operation and maintenance. The flow pattern mapping of a network will not only help in better operation and management of the water supply system but also be used as a management decision support system for the network managers.

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