INVITED PAPER

SIMNET – Microcomputer Modelling of Irrigation, Water Supply and Water Distribution Systems

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ABSTRACT

Accurate calculations of pressure and flow conditions in pipe network systems are required for their efficient and economical design and operation. The required calculations are extensive and it has been recognised for some time that computers are required if these systems are to be engineered and managed properly. Modern microcomputers have sufficient capability to model large complex pipe systems and the use of these computers provides some advantages.

There are several features which are highly desirable for microcomputer pipe network programs. These include:

1. The solution algorithm should provide accurate and reliable results without requiring excessive computer memory.

2. The program should be able to handle any network configuration and accommodate a large variety of network components to encompass a sufficiently wide range of applications. Time simulations should take account of storage within the system, variable reservoir and river levels, fluctuations in demand and the starting and stopping of pumps. Variable power costs should also be accommodated.

3. Graphical displays of the networks themselves and various graphical and tabular displays of the results should be possible. Displays such as pressure distribution, various contours, storage flows, time variations of water level, and operating costs, etc., greatly enhance comprehensive presentation of modelling results.

The description of the SIMNET program which incorporates these features is presented in the paper. The application of this well developed and widely used

microcomputer pipe network model to a typical water distribution system is presented. Examples of both tabular and graphical results useful to engineers and management are included.

INTRODUCTION

Computer modelling of water distribution systems has received considerable attention in the past several years with the result that a good degree of sophistication is now possible. Highly developed hardware and software for water distribution system mapping and for real time control of water distribution systems has recently been developed[1]. As sophistication and modelling capabilities are increased the associated hardware costs and complexity of use also increases. It is likely that the vast majority of potential applications for water distribution system modelling do not require the most sophisticated modelling capability currently available and this is particularly true of applications dealing with developing countries.

The authors feel that a very comprehensive capability for computer modelling of water distribution systems is possible employing standard microcomputer hardware. Programs for carrying out hydraulic network analysis and for producing graphical displays of the results are available for microcomputers and can incorporate all the features normally required for comprehensive computer modelling of water distribution systems. Features which are essential or highly desirable include the following:

1. The hydraulic analysis must be carried out utilizing reliable and efficient procedures for solving the network equations. Conventional Hardy Cross techniques are not acceptable and matrix solutions are required.

2. General network configurations must be accommodated.

3. All normal hydraulic components must be accommodated. These include supply pumps, booster pumps, elevated storage tanks, reservoirs, pressurized storage facilities, pressure and flow control valves, altitude valves, check valves, and other fittings.

4. Time simulation must be accommodated. These simulations compute changes in storage with time and allow modelling of demand fluctuations which occur over the simulation time. Pumping control based on storage or pressure levels should be accommodated.

5. Data input must be simple and be limited to essential information. Creation and editing of data files should be relatively simple for users.

6. Comprehensive tabular reporting of results is essential. Because of the massive amount of information resulting from hydraulic analysis some user control over results reporting is desirable. This includes the capability of producing selected tables comparing significant results.

7. Graphic displays of results are highly desirable. Contour plots of pressure and hydraulic grade lines for the conditions modelled are a particularly useful technique for comprehensively presenting results. Time plots of various parameters such as storage facility levels are sometimes essential for comprehensive results presentation and the capability to produce these plots is desirable.

In this paper a program package developed by the authors called SIMNET is described. This is a comprehensive hydraulic network modelling program which was developed for use on a standard IBM PC or compatible microcomputer. For the graphics capabilities described only a microcomputer graphics card is required along with a dot-matrix printer capable of performing a graphics screen dump. The above points are addressed in the following description of the program techniques and features and are illustrated in an example.

HYDRAULIC ANALYSIS TECHNIQUES

The analysis of steady state pressure and flow conditions in a water distribution system requires that the flowrates satisfy continuity relations at all nodes. In addition it is necessary to satisfy the energy relations stating that energy changes around loops and between system supply or discharge points are correctly accounted for by summing energy changes due to supply pressure and elevation differences, line friction, fitting losses, and the presence of pumps. Continuity and energy relations may be expressed in terms of either unknown flowrates (loop equations) or node heads (node equations). In either case a system of nonlinear simultaneous algebraic equations is obtained and a direct solution of these equations is not possible. A number of indirect methods for solving the pipe network equations have been proposed and are being utilized. Because of the importance of utilizing an efficient and reliable solution technique, the approach utilized by the authors is detailed below.

The Hardy Cross method[2] has been widely used for solving either loop or node network equations. This method involves computing a flow or head adjustment which tends to satisfy a single energy or continuity relation and a single trial using the Hardy Cross method requires the adjustment of all the unbalanced network equations. Because this method does not require the simultaneous solution of large equation sets, computer programs based on Hardy Cross methods can be formulated for microcomputers with limited memory. More recently, iterative solutions of the linearized network equations have been utilized. These methods may require the simultaneous solution of large sets of equations since the number of equations are equal to the number of pipes (loop equations) or the number of nodes (node equations).

Microcomputers with limited memory capabilities are unable to handle large networks using this method. An alternative solution technique for the loop equations based on the simultaneous computations of flow adjustment for the energy equations requires the solution of much smaller equation sets. In this case the number of energy equations equals the number of pipes minus the number of nodes.

These techniques are described in more detail by Wood and Rayes[3], who also present data concerning the reliability of these methods. In that paper it is shown that Hardy Cross methods, while easy to utilize, suffer from recurring convergence difficulties. These are due to the lack of consideration of the effects of flow or pressure adjustments on other equations involving common pipes. Therefore, computer programs based on these methods may not have the desired reliability. Reference 3 also presents data which shows that only solutions based on either the linearized loop equations or the simultaneous computation of flow adjustments for the energy equations are highly reliable. Since the former method requires the simultaneous solution of large equation sets, the authors have concluded that the latter technique offers the ideal procedure for pipe network analysis utilizing microcomputers and have adopted this technique. It provides highly reliable solutions utilizing relatively small equation sets.

Formulation and Solution of Network Equations

Eq.1 defines the relationship between the number of pipes (p), primary loops (ℓ), junction nodes (j), and constant pressure external supply or demand nodes (s), and offers a basis for formulating a set of hydraulic equations which describes a pipe system.

$$p = j + \ell + s - 1 \qquad (1)$$

In terms of the unknown flow in each pipe, a number of continuity and energy equations can be written equalling the number of pipes in the system. For each junction node a continuity relationship equating the flow into the junction (Q_{in}) to the flow (Q_{out}) is written as:

$$Q_{in} - Q_{out} = Q_e \text{ (j equations)} \qquad (2)$$

Here Q_e represents the external inflow or demand at the junction node. For each primary loop the energy or momentum equation can be written for pipe sections in the loop as follows:

$$\Sigma E_L = \Sigma E_{in} \qquad (3)$$

where

E_L = energy loss in each pipe (including minor loss)
E_{in} = energy increase in the fluid due to a pump.

If there are s constant pressure supply nodes then (s − 1) independent energy conservations equations can be written for paths through the pipes between supply nodes as follows:

$$\Delta E_s = \Sigma E_L = \Sigma E_{in} \text{ (s − 1 equations)} \qquad (4)$$

where ΔE_s is the difference in energy between the two supply nodes. Eq.3 can be considered to be a special case of Eq.4 where the difference in energy is zero for a path which forms a closed loop. Thus, the energy conservation relationships for pipe networks are expressed by $\ell + s - 1$ path equations of the form given by Eq.4.

Both the loss term E_L, and the pump input term E_{in}, are expressed in terms of flowrate using well established relations for line friction losses, losses at fittings (minor losses) and pump energy-flowrate characteristics. This becomes:

$$E_L = F(Q) \text{ and } E_{in} = P(Q) \qquad (5)$$

The final form of the energy equation is:

$$\Sigma F(Q) = \Sigma P(Q) = f(Q) = \Delta E_s \qquad (6)$$

Algorithm for solution of network equations

The continuity equations (Eq.2) and the energy equations (Eq.6) form a set of p simultaneous equations in terms of unknown flowrates. Since these are nonlinear algebraic relationships no direct solution is possible. Simultaneous computation of flow adjustments for the energy equations constitutes a solution algorithm previously called the Simultaneous Path Adjustment Method[3], which is highly reliable and required the simultaneous solution of relatively few equations. This method is summarized as follows:

1. Determine an initial set of flowrates which satisfy continuity at each junction node.

2. Simultaneously compute a flow correction factor (ΔQ) for each path which tends to satisfy the energy equations without disturbing the continuity balance.

3. Using the improved solutions repeat step 2 until the average flow correction factor is within the specified limit.

The simultaneous determination of the flow adjustment factors requires the simultaneous solution of ($\ell + s - 1$) equations. Each equation accounts for the unbalance in the energy equation due to initial incorrect values of flowrate (Q_i). These equations include the contribution for a particular path as well as contributions from all other paths which have common pipes. Gradient techniques are used to formulate these equations. For path j, the change required to balance the energy equation is expressed in terms of the flow change in path j (ΔQ_j) and the flow changes in adjacent paths (ΔQ_k).

This is expressed in terms of E_i $(f(Q_i))$ and G_i $(f'(Q_i))$ for the pipes in the path as follows:

$$\Delta E = \Delta E_s - E_i = (\Sigma G_i)\Delta Q_j + \Sigma(G_i \Delta Q_k) \qquad (7)$$

Here E_i represents the algebraic sum of all the energy changes for all the pipes in path j, based on the initial flowrates, Q_i. $(\Sigma G_i)\Delta Q_j$ represents the head change due to the flow change for the path, and $(\Sigma G_i \Delta Q_k)$ represents head change due to flow changes in all paths with pipes common to path j.

In this manner a set of simultaneous linear equations are formed in terms of flow adjustment factors. These linear equations can be solved using standard matrix procedures, and the solution provides an improved set of balanced flowrates which can be used for another trial. Trials are repeated until the solutions obtained for flowrates converge to a stable result.

PROGRAM FEATURES AND CAPABILITIES

Considerable effort has been made over the past five years to develop the SIMNET computer program for hydraulic network analysis which addresses the needs of engineers and incorporates the features which the authors feel are essential or highly desirable.

General Considerations

By addressing a few general requirements for pipe networks, a powerful, general purpose computer model of a pipe distribution system was formulated. SIMNET allows consideration of general network configurations with no restrictions on the locations of pumps, reservoirs, and other storage facilities and accommodates various other components. In order to accomplish this each pipe section accommodates pumps and various fittings which cause concentrated energy losses (minor losses) and connections to constant pressure supply or discharge points. Pump modelling allows either the use of actual pump operating data or constant power operation. In addition the following components can be modelled.

a) check valve - allows flow only in the prescribed direction and closes the line if the flow tends to reverse.

b) pressure regulating valve - maintains the downstream pressure at a set value.

c) pressure sustaining valve - limits flow to maintain the upstream pressure at a set value.

These features allows the analysis of a large variety of situations and conditions for water distribution systems. A typical computer simulation requires a definition of network characteristics including those of the pipes, pumps and other components, along with a specification of operating conditions such as supply pressure, tank and reservoir elevations, pump status, and the magnitude and location of flow demand requirements. The computer simulation calculates the flowrate in each pipe and pressure or total head throughout the system. From these results the engineer can determine if the system operates within the required pressure and flow specifications.

For worldwide applications a number of different pressure and flow units must be considered. SIMNET allows a choice of the five English and SI flow units most commonly utilized. SIMNET is accessd through a menu which allows users to easily perform a number of operations. The English version of the SIMNET menu is presented in Table la. The operations can be loosely considered in three categories. Data input, editing and the hydraulic analysis is covered in the first category. Graphical and tabular enhancement of the results are handled in the second category of operations, and operations for viewing or printing results are included in the third category. Results presented in the next section were all obtained through these menu operations.

There is a worldwide need for the type of technology represented by the SIMNET package and this package has been translated into other languages. Table lb, for example, shows the SIMNET menu for an Indonesian version. This version is currently in use in that country.

Time Simulations

For many applications it is desirable to carry out a computer simulation of distribution system performance which varies over a period of time. An evaluation of draining and filling of storage facilities over a twenty-four hour period (or longer) is of great importance to engineering studies of water distribution systems. Other applications include the analysis of surcharged storm sewer facilities, which results in the storage of water in flooded areas. A wide variety of useful distribution system time simulations can be modelled with two time sensitive components which are incorporated into the SIMNET program. These are:

a) variable level storage facility - this accounts for changes in water levels due to flows into or out of storage facilities.

b) pressure switches - a device which controls the open-closed status of a line by the pressure (or grade) at some point in the distribution system.

The time simulations are carried out by performing a series of steady state calculations and using calculated flows into or out of storage facilities to determine changes in water level. The pressure switches provide the capability to model events which occur as a result of the system performance during the time simulation. Common applications include controlling a booster pump by the water level in a storage facility or the pressure in a remote part of the distribution system.

Tabular and Graphical Display of Results

A complete tabular display of results which includes flowrates, losses, and flow velocities in pipes, pressure and total grades at junctions, pump operating conditions, tank levels and other information is the normal result of the computer *simulation*. Various portions of such results are essential for determining performance. Example output *for* a computer simulation is presented later. One negative aspect of hydraulic network modelling *is* that large amounts of information are generated and the user must spend time sorting through the results in order to present the salient points in a concise and lucid manner. SIMNET offers considerable capability to produce various specific tables and comparisons of significant results which significantly enhances the presentation of tabulated results.

Modern microcomputers can produce graphical displays of results which are of great value for interpretation and comparison of various designs or operating conditions. Most microcomputers can produce screen graphics which can be dumped to a dot matrix printer to produce hard copy. The capability to do this is usually a standard feature or an inexpensive enhancement for a microcomputer.

Graphical displays of the network configuration with significant result superimposed are very useful and an integral part of the SIMNET package. This capability includes the following graphical displays.

1) Scaled layouts of pipe and network with nodes, tanks, reservoirs, and pumps labelled.
2) Network layouts highlighting sections of the distribution system with high or low pressure, velocity or loss per 1000 feet or metres.
3) Pressure grade line or elevation contours.

Contour plots are particularly useful for depicting a great amount of information in a concise and meaningful manner and this capability greatly enhances the presentation of the results of hydraulic analyses.

SIMNET also provides a plotting capability which allows users to compare various parameters for different situations or to produce time plots for time simulations. These include plots of variation in water levels for storage facilities, demand variations, and variation in pressure or pump heads.

Example tabular and plotted results are presented in the next section.

EXAMPLE

Example calculations are carried out using the trunk water distribution system for the city of Djakarta in Indonesia. The model contains 6 pumping stations and 8 supply reservoirs or storage tanks. The system is currently in the process of construction and some lines included in the hydraulic analysis are not yet installed. This system is utilized herein to illustrate the capabilities and features of hydraulic modelling using an existing water distribution system. However, the actual data used does not represent a specific situation and is used only to illustrate the gamut of hydraulic modelling capabilities available.

Figure 1 shows a graphic plot of the overall distribution system layout with junction nodes, pumps and storage facilities noted. This plot can be made to any desired scale. The overall plot cannot show details in areas where nodes and pumps are closely spaced and Figure 2 illustrates the ability of the graphics to zoom in on a very small section of the network (in the vicinity of pump #2).

Table 2 is an excerpt from a summary of the input data for this system. Information on pipes, junctions and pumps is summarized. An extended period simulation (EPS) for a period of 12 hours is specified and two storage tanks which are initially full are described.

An excerpt from typical tabulated results is shown in Table 3. Flowrates and node pressures and hydraulic grades are summarized along with information on flows from storage facilities and storage tank water levels. Reports similar to this are produced each hour which results in a great amount of information describing the network performance over the 12 hour period. From a practical viewpoint it is necessary to produce concise tables and plots of these results in order to effectively illustrate the network performance over the 12 hour simulation period. SIMNET offers a variety of operations to do this which are illustrated herein.

Table 4 summarizes the flows in and out of four storage facilities along with the HGL levels (storage elevations) for two reservoirs and two storage tanks over the 12 hour period. This table at a glance shows important simulation results for the entire period including such important details as the complete draining of the storage tanks 10 hours into the simulation. For EPS simulations, time plots of key system parameters are very useful and several of these are illustrated in Figures 3-6. Figure 3 shows the variation in total system demand over the period and Figure 4 shows HGL variation at several junction nodes in response to this demand variation. Figure 5 shows variations in several pump heads and Figure 6 shows the variation in water surface level for the two storage facilities.

Other types of plots which are very useful for depicting pipe network performance are shown in Figures 7 and 8. Figure 7 shows a HGL contour plot 5 hours into the simulation when demands are greatest and pressures are low. This plot allows the user to see at a glance how the HGL varies throughout the entire pipe network and shows the regions of low HGL (< 10 metres) *which exist under these conditions.* Pressure and HGL contour plots are excellent means of depicting the pipe system performance under a certain set of conditions and allows users to readily compare hydraulic network performance. *Figure 8 is a pipeline profile plot* which superimposes HGL values on the pipeline elevation profile. This particular plot uses a path starting at node 5 and terminating at node 39 adjacent to reservoir FF. The pipeline elevations vary only slightly from around 3-5 metres. The HGL profiles are for extreme cases of demands ranging from the lowest system demand at 2 hours to the peak system demand at 5 hours and show that the HGL actually goes below the pipeline profile (negative pressure) under the peak demand condition. This is an undesirable condition which probably cannot be tolerated and plots of this type are excellent for pinpointing potential problem areas in pipe networks.

CONCLUSIONS

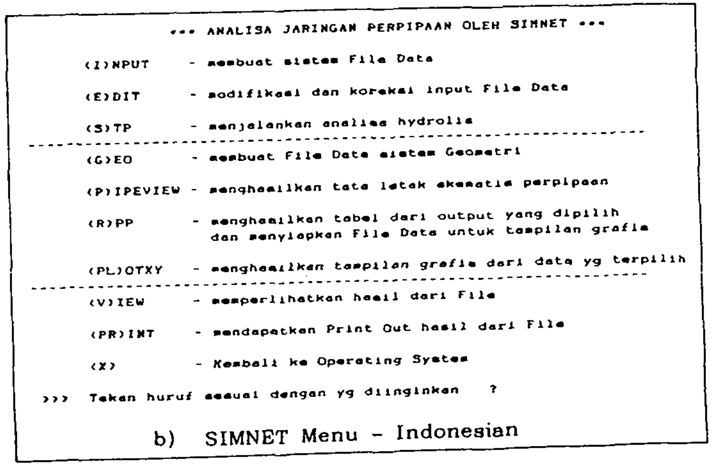
It is clear that low cost microcomputers provide an effective tool for engineers to undertake the accurate, efficient and cost effective design and operation of pipe networks. Information required by engineers, managers, and designers can be generated and presented in an easily assimilated form, and the reliability of this data is now dependent more on the uncertainty of the basic design information rather than the theoretical and numerical models used for its manipulation.

REFERENCES

1. Proceedings, International Conference on Computer Applications for Water Supply and Distribution, Leicester, England, Sept.1987.

2. Cross, H. "Analysis of Flow in Networks of Conduits or Conductors", Bulletin No.286, University of Illinois, Engr. Expr. Station, Urbana, Ill. 1936.

3. Wood, D.J. and A.G. Rayes. "Reliability of Algorithms for Pipe Network Analysis". Journal of the Hydraulics Division, ASCE, Vol.107, No.HY10, Oct.1981, pp.1145-1161.



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             *** ANALISA JARINGAN PERPIPAAN OLEH SIMNET ***

   (I)NPUT     - membuat sistem File Data

   (E)DIT      - modifikasi dan koreksi input File Data

   (S)TP       - menjalankan analisa hydrolis
---------------------------------------------------------------------
   (G)EO       - membuat File Data sistem Geometri

   (P)IPEVIEW  - menghasilkan tata letak skematis perpipaan

   (R)PP       - menghasilkan tabel dari output yang dipilih
                 dan menyiapkan File Data untuk tampilan grafis

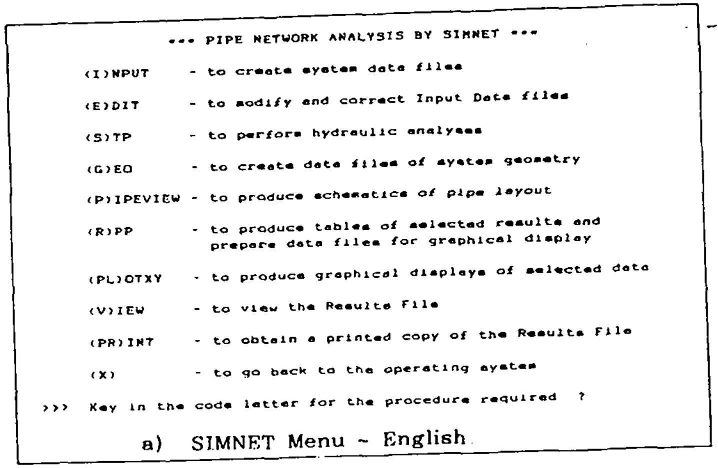
   (PL)OTXY    - menghasilkan tampilan grafis dari data yg terpilih
---------------------------------------------------------------------
   (V)IEW      - memperlihatkan hasil dari File

   (PR)INT     - mendapatkan Print Out hasil dari File

   (X)         - Kembali ke Operating System

>>> Tekan huruf sesuai dengan yg diinginkan   ?
```

b) SIMNET Menu – Indonesian



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             *** PIPE NETWORK ANALYSIS BY SIMNET ***

   (I)NPUT     - to create system data files

   (E)DIT      - to modify and correct Input Data files

   (S)TP       - to perform hydraulic analyses

   (G)EO       - to create data files of system geometry

   (P)IPEVIEW  - to produce schematics of pipe layout

   (R)PP       - to produce tables of selected results and
                 prepare data files for graphical display

   (PL)OTXY    - to produce graphical displays of selected data

   (V)IEW      - to view the Results File

   (PR)INT     - to obtain a printed copy of the Results File

   (X)         - to go back to the operating system

>>> Key in the code letter for the procedure required   ?
```

a) SIMNET Menu – English

Table 1. SIMNET Menus

```
*** SIMNET - PIPE NETWORK ANALYSIS PROGRAM - VERSION 86/1P ***
PDAM Jaya Network

DATE OF THIS SIMULATION:  11/16/87
INPUT DATA FILE NAME       = c:j2
OUTPUT DATA FILE NAME      = oj2



NUMBER OF PIPES            =  117
NUMBER OF JUNCTION NODES =  87
   FLOW UNITS              = Litres/second
   PRESSURE UNITS          = m
   RELATIVE DENSITY OF THE FLUID =  1
   KINEMATIC VISCOSITY           =  .0000013

CLOSED LINES -  24    84    85    17    98    81    116

**** SUMMARY OF INPUT DATA ***

PIPE  NODE NODE LENGTH   DIAM. ROUGH   SUM-M  PUMP   FGN
 NO.   #1   #2   ( m )   (mm.) -NESS   FACT.  TYPE  GRADE
  1   66    1     50.0 1000.0 0.500    0.0    0.0
  2    2    3   4600.0  800.0 0.500    0.0    0.0
  3    3    4   3500.0  600.0 0.500    0.0    0.0
  4    4    5   1100.0  600.0 0.500    0.0    0.0
  5   66    2    500.0 1000.0 0.500   25.0    0.0
  6    1   10    450.0  900.0 0.500    0.0    0.0
  7   10    6   3100.0  800.0 0.500    0.0    0.0
  8    6    7    400.0  800.0 0.500    0.0    0.0
              ↓                     ↓

JUNCT. NO.   DEMAND   ELEVATION
    1           0.0       5.5
    2           0.0       5.5
    3           0.0       4.1
    4           0.0       3.5
    5           0.0       2.5
    6         155.0       6.2
               ↓

PUMP TYPE # 5  IS DESCRIBED BY THE FOLLOWING DATA:
 HEAD      DISCHARGE
 8.8          0
 7.6          45
 6.4          125.5
PUMP TYPE # 6  IS DESCRIBED BY THE FOLLOWING DATA:
 HEAD      DISCHARGE
 6.6          0
 5.7          26.25
 4.8          85.5

AN EPS SIMULATION IS SPECIFIED
SIMULATION PERIOD =  12  - TIME INCREMENT =  1

           --- TANK DATA ---
PIPE NO.  MAX. EL.  MIN. EL.  DIAMETER INIT. EL. EXT. Q(IN)
    62     46.0      36.0      42.7      44.0       0.0
    63     46.0      36.0      42.7      44.0       0.0
```

Table 2. Input Data

```
EPS SIMULATION - TIME =  2  HOURS
**** THE RESULTS FOR THIS SIMULATION FOLLOW ****

NO. OF TRIALS = 1  - ACCURACY ATTAINED = .0045

PIPE  NODE  NODE     FLOW     HEAD     MINOR    PUMP    LINE     HL
NO.    #1    #2      RATE     LOSS     LOSS     HEAD  VELOCITY   1000
  1    66     1     132.77    0.00     0.00     0.00     0.17    0.03
  2     2     3       0.00    0.00     0.00     0.00     0.00    0.00
  3     3     4       0.00    0.00     0.00     0.00     0.00    0.00
  4     4     5       0.00    0.00     0.00     0.00     0.00    0.00
  5    66     2       0.00    0.00     0.00     0.00     0.00    0.00
  6     1    10     201.61    0.05     0.00     0.00     0.32    0.11
  7    10     6      37.11    0.03     0.00     0.00     0.07    0.01
  8     6     7     -79.14    0.01     0.00     0.00     0.16    0.03
  9     7     8      56.25    0.06     0.00     0.00     0.20    0.07
 10     8     9      56.25    0.13     0.00     0.00     0.29    0.19
               ↓                          ↓

 JUNCTION   ELEVATION   DEMAND   PRESSURE  HYDRAULIC
   NO.        (MT.)               (KPA)     GRADE
    1           5.5       0.0      74.8      13.1
    2           5.5       0.0      74.9      13.1
    3           4.1       0.0      88.6      13.1
    4           3.5       0.0      94.5      13.1
    5           2.5       0.0     104.3      13.1
    6           6.2     116.3      67.2      13.1
    7           6.5       0.0      64.4      13.1
              ↓                  ↓

THE NET SYSTEM DEMAND = 1509.75
SUMMARY OF INFLOWS(+) AND OUTFLOWS(-)
PIPE NO.        FLOW
   26          425.29
   62          300.67
   63          316.35
   82           70.61
   83          292.66
  101          104.17

SUMMARY OF PUMP OPERATION

 PIPE      PUMP       PUMP     PUMP    USEFUL    EFFIC-   TOTAL
  NO.      TYPE       FLOW     HEAD    POWER     IENCY     KWH
  26        1        425.29   11.71    48.85     0.80    205.19
  71        4        127.72    6.66     8.34     0.80     32.96
  82        2         70.61   11.63     8.06     0.80     58.50
  83        3        292.66   14.79    42.43     0.80    173.42
  93        5         32.54    7.84     2.50     0.80      9.30
  95        6         62.99    5.10     3.15     0.80     12.23

 THE TOTAL POWER USED TO THIS TIME =  491.59  KWH

SUMMARY OF MINIMUM AND MAXIMUM PRESSURES
     MINIMUMS           MAXIMUMS
     56     23.45       77    186.68
     46     26.54       76    163.75
     84     30.57       35    150.08
     83     30.76       36    145.82
     81     31.11       38    145.31

        --- TANK STATUS REPORT ---
PIPE NO.   PIPE Q    EXT. Q    ELEVATION   PROJ. EL.
  62      -300.7      0.0        41.7        40.9
  63      -316.3      0.0        41.5        40.7
```

Table 3. Tabulated Results

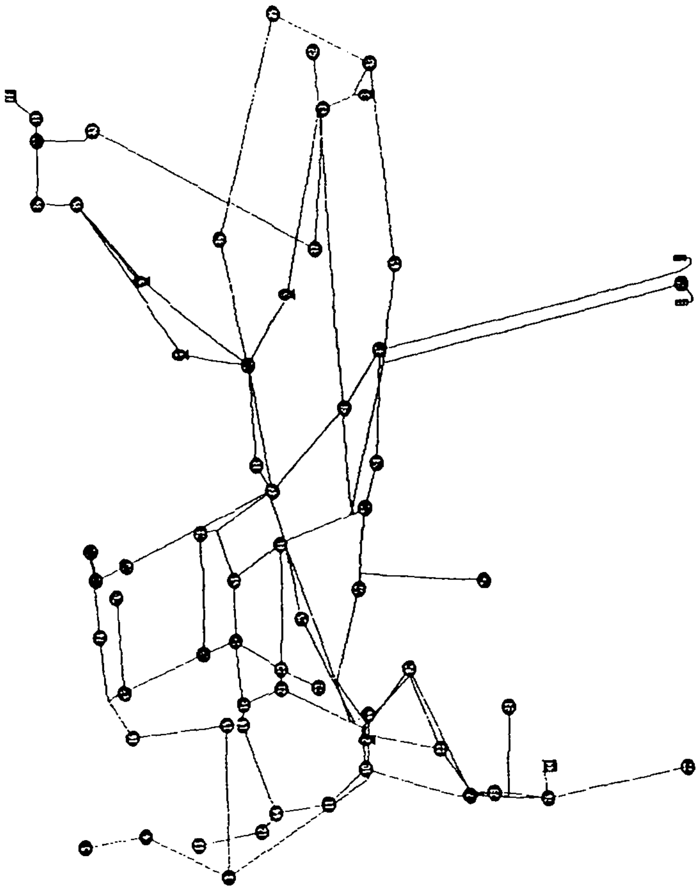

Figure 1. Layout of the PDAM JAYA water distribution system in Djakarta - including pipelines currently under construction.

••••••••••••••••• TABLE OF FGN INFLOWS (OUTFLOWS) AND GRADES ••••••••••••••

	LOCATIONS FOR FIXED GRADE NODES							
	RESERVOIR AA		RESERVOIR EE		TANK B		TANK C	
TIME	HGL	FLOW	HGL	FLOW	HGL	FLOW	HGL	FLOW
0.00	1.50	600.47	1.50	383.65	44.00	315.22	44.00	334.31
1.00	1.50	453.77	1.50	310.03	43.21	309.19	43.16	326.21
2.00	1.50	422.66	1.50	292.08	42.43	304.71	42.34	320.87
3.00	1.50	531.52	1.50	348.36	41.66	302.07	41.53	318.99
4.00	1.50	862.40	1.50	496.94	40.90	303.21	40.72	323.14
5.00	1.50	1249.88	1.50	659.20	40.13	306.72	39.91	330.85
6.00	1.50	1124.65	1.50	607.28	39.36	300.02	39.08	321.99
7.00	1.50	872.77	1.50	499.04	38.60	291.05	38.26	309.42
8.00	1.50	626.81	1.50	388.66	37.87	282.72	37.48	297.84
9.00	1.50	475.41	1.50	314.78	37.16	276.29	36.73	289.24
10.00	1.50	411.17	1.50	278.22	36.46	271.30	36.00	282.94
10.02	1.50	497.39	1.50	301.10	36.45	272.88	36.00	0.00
10.68	1.50	604.73	1.50	311.36	36.00	0.00	36.00	0.00
11.00	1.50	727.62	1.50	369.56	36.00	0.00	36.00	0.00
12.00·	1.50	853.01	1.50	427.87	36.00	0.00	36.00	0.00

Table 4. Enhanced Tabulated Results

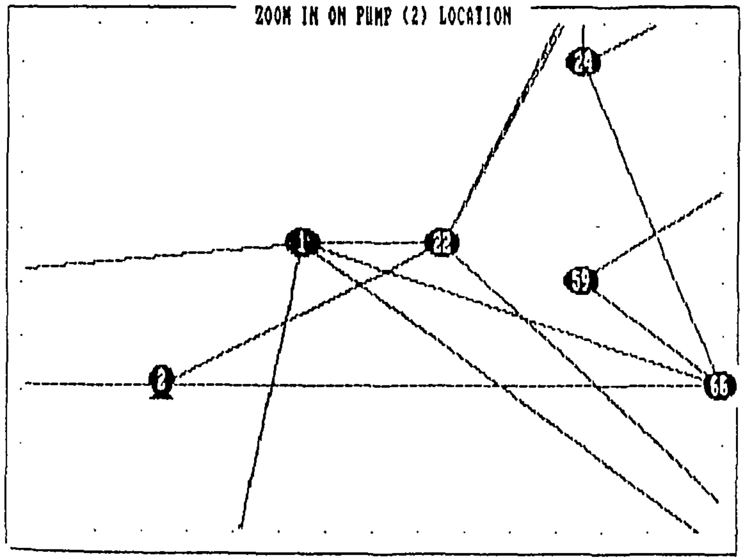

Figure 2. Close up example to illustrate the zoom-in feature of the graphics displays. Pump 2 and node 66 can be seen left-centre of Figure 1.

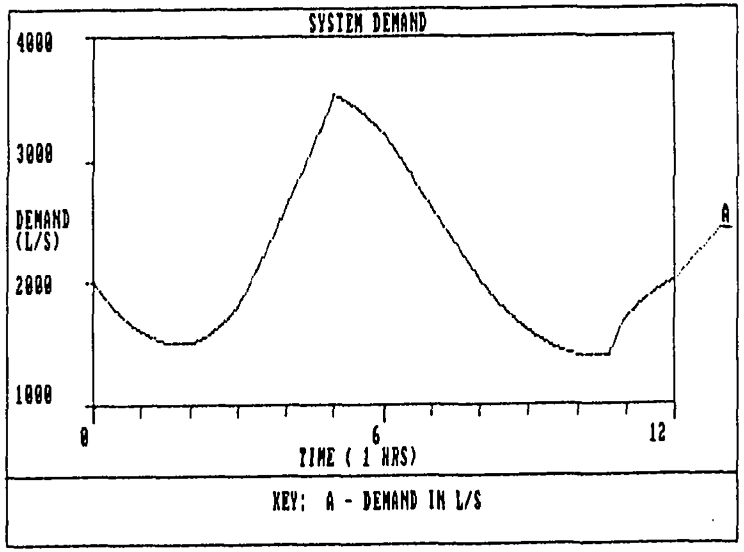

Figure 3. Variation in total system demand over 12 hours.

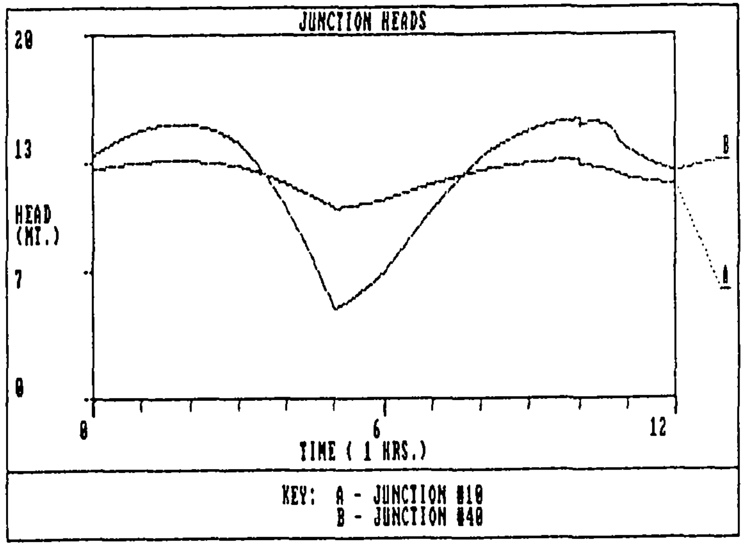

Figure 4. Changes in pressure head at two junction nodes as a result of changing demands on the system.

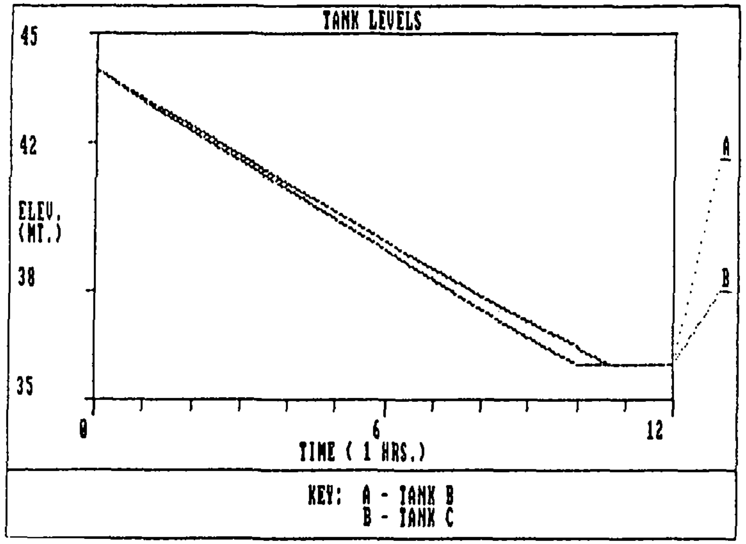

Figure 5. Falling tank levels which are unable to cope with a 12 hour demand on the system.

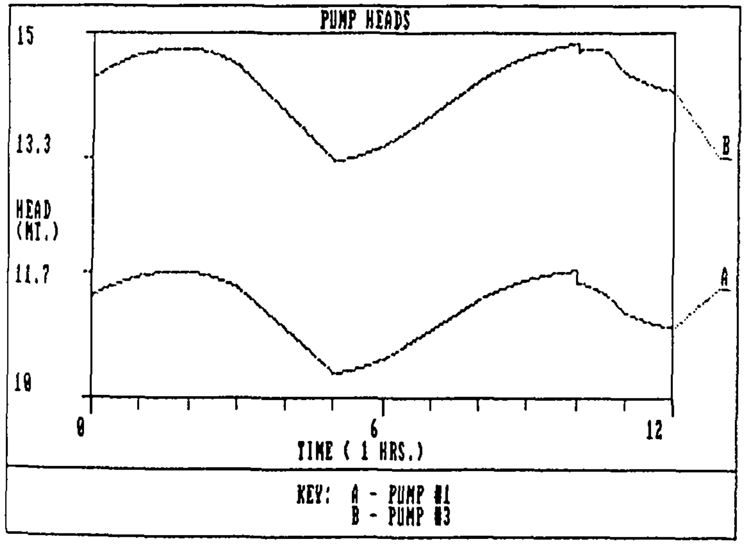

Figure 6. As the demand on the system changes, so too do the pump discharge heads. At the peak demand they are at a minimum.

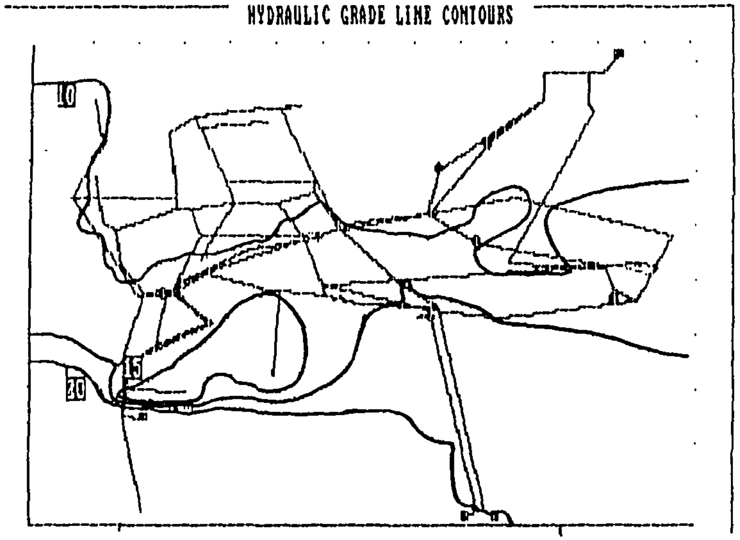

Figure 7. Superimposed on the network are contour plots of constant values of hydraulic grades - shown here at 10, 15 and 20 metres above datum 5 hours into a simulation.

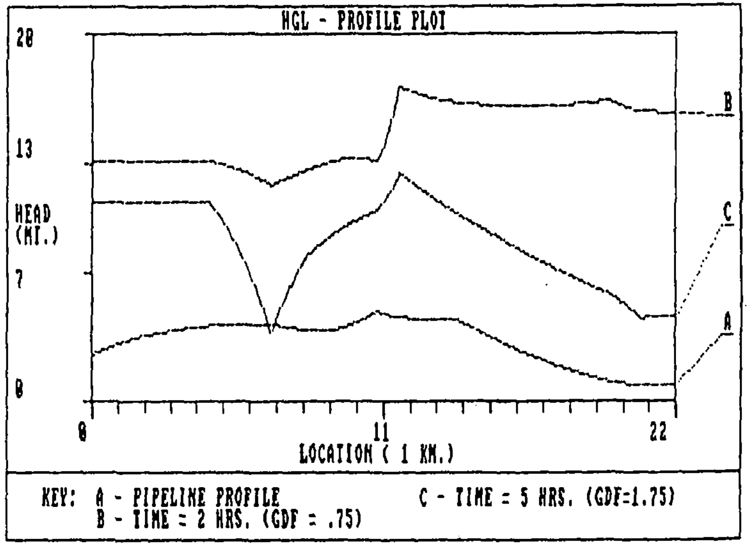

Figure 8. Pipeline profiles plot from node 5 to node 39 (near reservoir FF in Fig.1) passing through several other nodes on the way. Note the sub-atmospheric region on curve C at the 7 km point.

INVITED PAPER

Optimal Design of Pipe Networks: A Review

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ABSTRACT

Networks of pipes for conveying water form a major part of a country's investment in water resources. Whilst the cost of these networks is high, their design is still performed on a largely intuitive basis.

It is at present unusual for any systematic comparison of alternative designs with different layouts and pipe sizes to be carried out on a cost basis.

However, with the widespread availability of computers, it is now possible to take a much more systematic approach to achieve the best value for money in design.

This paper describes the formal computer-based optimization techniques that have been developed for pipe network design. These systematically examine a range of schemes involving alternative layouts and/or pipe sizes, the schemes all being of equivalent technical merit but varying in cost.

The techniques described use Dynamic, Linear and Non-linear Programming and heuristic methods.

The historical development of these techniques is outlined, with a summary of published work. The present state of knowledge is presented, and likely areas for future development indicated.

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