FINAL REPORT

Distributed Modeling of Pipe Networks
Project No: INT/01/K05/A/95/99
Perez-Guerrero Trust Fund - UNDP

Prepared by
The project team

On behalf of
Jordan University of Science and Technology
Atilim University
Middle East Technical University

October 16, 2003

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Project Background

Project Justification

Design and analysis of pipe networks are important to underdeveloped countries, not only because water is an important economical development parameter, but also because water is a deciding factor in the future of peace in the middle east. This project adds only additional tool to help in that direction by adding web accessible system that might help water network designers do some of their duties. The produced software is accessible through the web and also can be deployed to the interested parties on disks at no charge.

Beneficiaries

The obtained results are expected to impact many resource distribution systems across the Hashemite Kingdom of Jordan, Republic of Turkey, and United Arab Emirates, especially water distribution networks of the Water Authority of Jordan, the Ministry of Agriculture & Fisheries in the United Arab Emirates, and the General Directorate of Hydraulics Works in Turkey. The obtained theoretical findings of project will also benefit the scientific communities dealing with pipe systems in general. The developed parallel algorithms are applicable to a wide class of resource distribution systems.

Problem Addressed by the Project

Here we simplify the problem addressed by the project in a diagram and few words. A pipe network consists of thousands of pipes, pumps, valves, tanks, and reservoir connected together in a certain form. The network can be viewed as an irregular graph, where edges represent pipes and nodes represent pumps, valves, tanks, or reservoir. An example on pipe networks is shown in Figure 1.

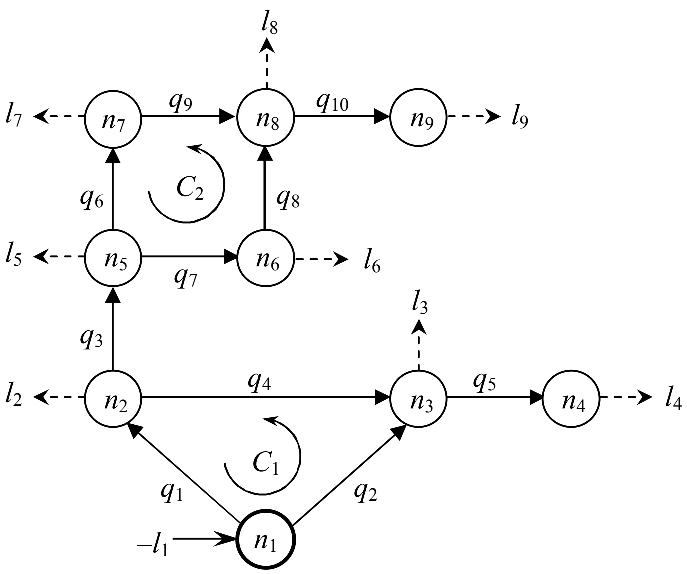


Figure 1: Graph representation of pipe networks.

In a pipe network of N nodes and M-pipes, each node is labeled by n_i, $1 \le i \le N$, and each pipe is labeled by q_j, $1 \le j \le M$. In the above example the node n_1 represents a reservoir and is distinguished by thicker circle. The load (e.g. fluid consumption) at node n_i is denoted by l_i. The negative load at node n_1 indicates production rather than consumption. The flow in q_j is denoted by f_j, $1 \le j \le M$.

A convenient way of realizing graphs for pipe networks is by using a form of an incidence matrix. The incidence matrix [A] for a pipe network of N nodes and M pipes can be expressed as follows: $[A] = [a_{ij} \mid 1 \le i \le N, 1 \le j \le M]$, where a_{ij} is 1 if q_j is incident to n_i and the flow direction is inward. The value of a_{ij} is -1 if q_j is incident to n_i and the flow direction is outward. The value of a_{ij} is zero if q_j is not incident to n_i.

Given the values of source pressures and loads in each node, the problem of simulating a pipe network is that of computing the values of node pressures and the values of flows on each pipe. There are a number of solution methods that can be used, but we used the linear theory method for one reason related its suitability to parallel computing; which the core contribution of this project. The goal is to solve this computationally intensive problem using low-cost computers. This goal has ben achieved as will be seen next.

Basis of the Project

Programme/Project Title:	Distributed Modeling of Pipe Networks
Programme/Project Number:	INT/01/K05/A/95/99
Implementation Agency:	Jordan University of Science and Technology
Project Starting Date:	June 2002
Project Completion Date:	June 2003
Total Budget (US$):	80,000 USD
Period Covered By the Report:	October – December 2002

Project Document

Project Objectives

The objective of this project is to develop distributed algorithms that will make use of cluster computing technologies to reduce the cost associated with pipe networks analysis, enabling the acceleration of tasks such as planning, operation scheduling, quality control, and leakage control in pipe networks .

The significance of this work stems from the fact that pipe systems are the cores of many real life systems including water, oil, and gas distribution as well as air-conditioning and compressed air systems. Modeling and analysis of flow in pipe networks is of great practical significance in all these areas. One common way to model these networks is by using systems of linear equations. Practical sizes for these systems usually involve exhaustive calculations that require high computational power, which can only be offered by expensive supercomputers. In this project we investigate an alternative approach that requires low-cost computing environment to offer feasible and cost-effective results. This approach is based on cluster computing as a viable alternative to the expensive supercomputer solutions .

The planned results are expected to directly impact and possibly will be used in many resource distribution systems across the Hashemite Kingdom of Jordan, the Republic of Turkey, and the United Arab Emirates, especially water distribution networks of the Water Authority of Jordan, the Ministry of Agriculture & Fisheries in the United Arab Emirates, and the General Directorate of Hydraulics Works in Turkey.

Project Implementation/Institutional Framework

The project has been carried out mainly at Jordan University of Science and Technology – Jordan, Atilim University – Turkey, and the University of Sharjah – UAE. The experimentation and implementation used a cluster of workstations installed at JUST.

The rest of the project document can be found in the project website at www.cis.just.edu.jo/undp.

Achieved Objectives (Deliverables)

The table below is an excerpt from the project work-plan which summarizes the achieved tasks. The required equipment has been installed and the needed personnel have been hired.The needed data has also been collected, reviewed, and analyzed. Basically, all planned tasks has been accomplished.

Project Intervention	**Budget (US$)**	**Total cost per Intervention (US$) Balance**	**Responsibility**	**Indicators**	**Target group**
1. IMMEDIATE OBJECTIVE: Survey and theory development					
1.1. Output: Novel cluster algorithms for pipe network analysis					
1.1.1. Activity: Hosting PM & PCIs in JUST-Jordan & Atilim-Turkey	4,800	1,951	PM-JUST DONE	Chapters X and XI	PM and PCIs
1.1.2. Activity: Installing personal desktop publishing needs (laptops, printers, scanners, CD writers, etc)	8,100	0	PM-JUST DONE	Receipts submitted	PM and PCIs
1.1.3. Activity: Literature survey on steady state analysis of pipe networks			PCI-(Atilim & METU) DONE	Chapters I and II	All Groups
1.1.4. Activity: Development of computational algorithms and testing considering numerical and parallel computing aspects	2,250	0	PCI-(Atilim & METU) DONE	Chapter II	ATILIM-METU
1.1.5. Activity: Testing the developed algorithms utilizing the data from a full scale network that is part of Metropolitan Ankara Network System utilizing SCADA and GIS facilities	9,000	0	PCI-(Atilim & METU) DONE	Chapters I and VI	ASKI
1.1.6. Activity: Comparison of the efficiency of developed algorithm as compared to conventional methods	5,504	0	PCI-(Atilim & METU) DONE	Chapter VI	ATILIM-METU (Academic Research Institutes)
1.1.7. Activity: Collecting, reviewing, and analyzing data from full scale networks in the all three countries, Jordan, UAE, and Turkey.	2,250	0	PCI-(Atilim & METU) DONE	Chapter II	
1.1.8. Activity: Enter data into the Cluster and database	900	0	PCI (Atilim and METU) Data-entry specialist DONE	Chapter II	
1.1.9. Activity: Placing orders to install the Cluster Computing Laboratory	14,199	0	PM-JUST DONE	Receipts submitted	

1.1.10. Activity: Printing, scanning, and mobile computing equipment (scanner, printer, Tablet PC, laptops, and consumables)	10,097	~150	PM-JUST DONE	Receipts submitted	
		40,830			
2. IMMEDIATE OBJECTIVE: Establish Cluster Computing Laboratory					
2.1. Output: General purpose cluster computing environment					
2.1.1. Activity: Recruiting research assistants / Programmers	4,500	0	PM-JUST DONE	3 Contracts approved	
2.1.2. Activity: Installing and testing optical networking hardware			PM-JUST DONE	Chapter III	
2.1.3. Activity: Installing and testing cluster environment software			PM-JUST DONE	Chapter III	
		4,500			
3. IMMEDIATE OBJECTIVE: Cost-effective software System for pipe network analysis					
3.1. Output: Operational system for pipe network analysis, planning, operation scheduling, quality control, and leakage control				Chapters IV and VIII	
3.1.1. Activity: Parallel program development, testing and verification on Optical SAN based cluster computing system			PM – JUST DONE	Chapter VI	
3.1.2. Activity: Testing the parallel algorithms utilizing the data from SCADA and GIS facilities	2,000	0	PCI-(Atilim & METU) DONE	Chapter II	ASKI
3.1.3. Activity: Performance assessment and comparison of developed parallel algorithms as compared to conventional methods	2,000	0	PCI-(Atilim & METU) DONE	Chapter VI	ATILIM-METU (Academic Research Institutes)
3.1.4. Activity: Hosting Research Consultants (from SQU - Oman) and/or PM/PCIs in JUST – Jordan to Discuss the obtained solutions and agree on further design issues.	2,800	0	PM – JUST DONE	Chapter VII	
		6,860			
4. IMMEDIATE OBJECTIVE: Developing a user-friendly graphical user interface for the parallel software					
4.1. Output: A user-friendly GUI					
4.1.1. Activity: Recruit a GUI programmer	2,700	0	PCI-Sharjah DONE	Chapter VIII	
4.1.2. Activity: Design and implementation of the system interface screens			PCI-Sharjah DONE	Chapters IV and VIII	
4.1.3. Activity: Testing, debugging and verification			PCI-Sharjah DONE	Chapters IV, VIII, & IX	
		2,700			
5. IMMEDIATE OBJECTIVE: Project impacts and benefit dissemination			PM – JUST		

5.1. Output: Project impact measures			PM – JUST		
5.1.1. Activity: Project website	900	900	PM – JUST DONE	Chapter V	JUST
5.1.2. Activity: Workshop			PM – JUST DONE	Chapter XII	WA in Jordan, ASKI & ISKI in Turkey, and AWEA in UAE
5.1.3. Activity: Training			PM – JUST DONE	Chapter XII	WA in Jordan, ASKI & ISKI in Turkey, and AWEA in UAE
5.1.4. Activity: Project outcomes presentation and dissemination			PM – JUST DONE	Chapters VI and XII	
		900			

Spent	**68,999**				
Balance		**3,001**			
TOTAL BUDGET (in USD)		**72,000 + 8,000**			

Chapter I: The Developed Linear Models

Introduction

The formulation of different types of equations that are used in network analysis will be described in a separate report attached to this progress report. The analysis of water distribution networks can be performed by using three methods. These methods, in chronological order of their application to network analysis are (1) Hardy Cross method, (2) Newton-Rapson method and (3) Linear Theory method. The latter one will be used in our implementation.

Hardy Cross was suggested a systematic iterative procedure for network analysis in 1936 [2,3,9]. His procedure is based on loop-flow correction equations which is also known as the method of balancing heads. Later, Cornish [5] also applied the principles to nodal-head correction equations which is known as method of balancing flows. Both of these approaches are collected under the name of Hardy Cross method. This method attempts to solve the nonlinear equations involved in network analysis by making certain assumptions. The higher power correction terms can be neglected and the iteration number is small for a single loop although the initial guess is poor. However, neglecting adjacent loops and considering only one correction equation at a time can affect the solution and also number of iterations required for convergence increases as the size of the network increases. Modified Hardy Cross method can be applied to improve convergence and reduce the number of iterations. However, this number can be quite large for real networks. Therefore, instead of considering only one correction equation at a time, all the correction equations can be solved by considering the effect of all adjacent loops. So that convergence can be achieved in a smaller number of iterations. Also, some of the equations involved in pipe network analysis are nonlinear. Because there is no direct method for their solution, these equations are linearized and then solved. Since the solution is approximate, it is corrected and the iterative procedure is continued until satisfactory accuracy is reached. The Newton-Raphson method and the Linear Theory method try to solve all the concerned equations simultaneously by applying the iterative procedure.

The Newton-Raphson method expands the nonlinear terms in Taylor's series, considers only the linear terms by neglecting the residues after two terms. Since the nonlinearity in the equations for pipe network analysis is uniform and simple , the nonlinear term can be easily linearized by merging a part of the nonlinear term into the pipe resistance constant. This principle was first used by McIlroy [11], Marlow et al. [10] and Muir [12]. Then, Wood and Charles [13] developed it and it is now widely used in practice [13-15]. This principle can be used to linearize all types of equations. However, in practice it is applied to pipe-discharge equations and nodal-head equations.

A node with a known head is usually a source node, such as an elevated storage tank. A node with a known flow is a demand node .

- At the source node, the flow is generally unknown,
- While at the demand node, the head is generally unknown.

However, occasionally the flow also may be known in addition to the known head at a source node, while the flow may also be unknown in addition to the unknown head at a demand node.

The parameters involved in hydraulic network analysis are the

(1) pipe discharges, Q
(2) nodal heads, H
(3) pipe resistance constants, R
(4) nodal inflows or outflows, q

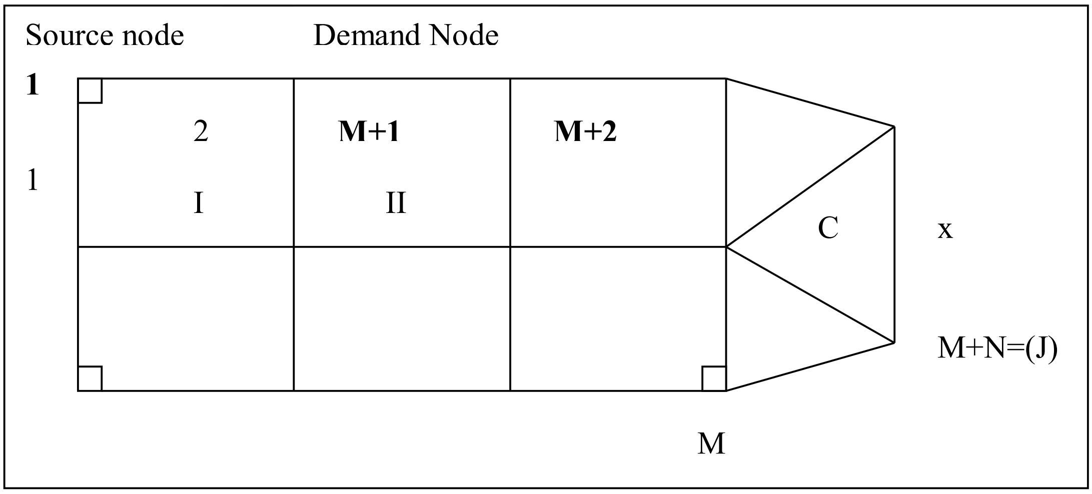
When the unknown pipe discharges are taken as the basic unknown parameters, the equations formed are known as Q-equations. When the nodal heads are taken as the basic unknown parameters, the equations formed are known as H-equations.

Parameter Interrelationships

Consider a looped network shown in the following figure. Let the network have M source nodes, labeled 1.....M, and N demand nodes, labeled M+1, ...M+N (=J), so that the node labels are j, j=1,2,........J (=M+N). Let the pipe labels be x, x=1,....X and the loop labels be c. c=I, II,......C. According to graph theory

$$X=J+C-1 \quad (1)$$

The several parameter relationships available for network analysis are as follows.



Labeled looped network

Pipe Head Loss Relationship

For all pipes in the network,

$$h_x = H_i - H_j = R_x Q_x^n, x = 1,.....X \quad (2)$$

in which,

- h_x =head loss in pipe x
- H_i, H_j = HGL values at the upstream node i and downstream node j of pipe x
- Q_x= discharge in pipe x
- R_x= resistance constant of pipe x
- n= an exponent

This equation shows nonlinear relationship between h_x and Q_x . Considering the direction of flow,

$$h_x = H_i - H_j = R_x |Q_x|^{n-1} Q_x, x = 1,.....X \quad (3)$$

Thus, $|Q_x|^{n-1}$ is always positive while Q_x can be positive or negative depending upon the direction of flow in the pipe. When the flow in a pipe occurs in the assumed direction, Q_x and h_x are positive and $H_i > H_j$. When the flow direction reverses, Q_x, and therefore h_x become negative and $H_i < H_j$.

Equation 3 can be expressed as

$$h_x = R'_x Q_x, x = 1 \ldots X \tag{4}$$

R'_x = modified resistance constant of pipe x and is given by

$$R'_x = R_x |Q_x|^{n-1}, x = 1, \ldots . X \tag{5}$$

Equation 4 is the linearized form of the general head loss relationship, expressing h_x as a linear function of Q_x. The modified resistance constant R'_x depends upon Q_x and therefore it must be reevaluated when the value of Q_x changes.

Equation 2 can be expressed as

$$Q_x = \left(\frac{H_i - H_j}{R_x} \right)^{\frac{1}{n}}, x = 1, \ldots \ldots X \tag{6}$$

To take care of the change in the flow direction,

$$Q_x = \frac{H_i - H_j}{R_x^{\frac{1}{n}} |H_i - H_j|^{\left(1 - \frac{1}{n}\right)}}, x = 1, \ldots \ldots X \tag{7}$$

or the same equation can be written as,

$$Q_x = C'_x (H_i - H_j), x = 1, \ldots \ldots \ldots X \tag{8}$$

in which C'_x =modified conductance of pipe x, and is given by

$$C'_x = \frac{1}{R_x^{\frac{1}{n}} |H_i - H_j|^{\left(1 - \frac{1}{n}\right)}}, x = 1, \ldots \ldots X \tag{9}$$

Equation 8 is the linearized form of equation 7, but C'_x should be reevaluated when H_i,H_j or both change.

Node Flow Continuity Relationship

For steady incompressible flow in a network, the algebraic sum of the inflows to and outflows from a node must be zero. Thus,

$$\sum_{xconnectedtoj} Q_x + q_j = 0, j = 1, \ldots \ldots J \tag{10}$$

qj=external flow that is supply (inflow) or demand (outflow) at node j.

Equation 10 gives a set of J linear relationships in terms of the pipe flows Qx. Using equation 6, equation 10 can be expressed in terms of Hi and Hj, as

$$\sum_{xconnectedtoj} \left(\frac{H_i - H_j}{R_x} \right)^{\frac{1}{n}} + q_j = 0, j = 1, \ldots\ldots.J \tag{11}$$

Using equation (7), the node flow continuity relationship becomes

$$\sum_{xconnectedtojthroughx} \frac{H_i - H_j}{R_x^{\frac{1}{n}} \left| H_i - H_j \right|^{\left(1-\frac{1}{n}\right)}} + q_j = 0, j = 1, \ldots..J \tag{12}$$

Equation 10 which is linear in terms of Qx has become nonlinear in terms of Hi and Hj in equations 11 and 12 . Therefore using equation 8 equation 10 can also be expressed linearly in terms of Hi and Hj as follows

$$\sum_{iconnectedtojthroughx} C'_x \left(H_i - H_j\right) + q_j = 0, j = 1, \ldots\ldots.J$$

(13)

Loop Head Loss Relationship

For all the loops of a network, the algebraic sum of the head losses in the pipes forming a loop must be zero.

$$\sum_{x \in c} h_x = \sum R_x Q^n{}_x = 0, c = I, II, \ldots\ldots C \tag{14}$$

Using equation 4 the linearized version of equation 14 becomes

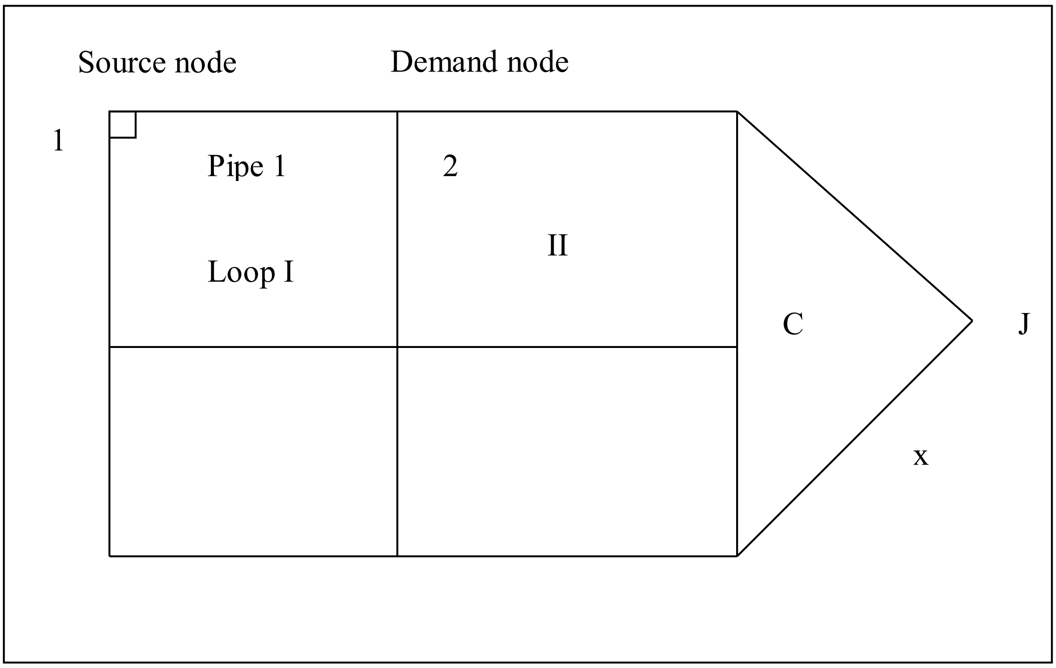
$$\sum_{x \in c} h_x = \sum R'_x Q_{\ x} = 0, c = I, II, \ldots\ldots C \tag{15}$$

where R'x = modified resistance constant of pipe x and is given by

$$R'_x = R_x \left| Q_x \right|^{n-1}, x = 1, \ldots..X$$

Bhave (1991) will be mainly followed for expressing equations of pipe network systems.

Single Source Networks: Looped Networks



Demand node, j=2,.......J
Pipe, x=1,.......X
Loop c=1,.......C
Pipe resistances are known, R_{ox}, x=1,.....X
Demand-node flows are known, q_{oj} , j=2,.....J
Head at the source node is known, H_{o1}

Unknown parameters,
Q_x , x=1,.......X
H_j , j=2,.......J

Q-EQUATIONS

Q_x, x=1,...X are taken as basic unknown parameters

General Formulation :

Applying node-flow continuity relationship

$$\sum_{x connected to j} Q_x + q_{oj} = 0, j = 2,.....J \quad (16)$$

which are J-1 linear equations

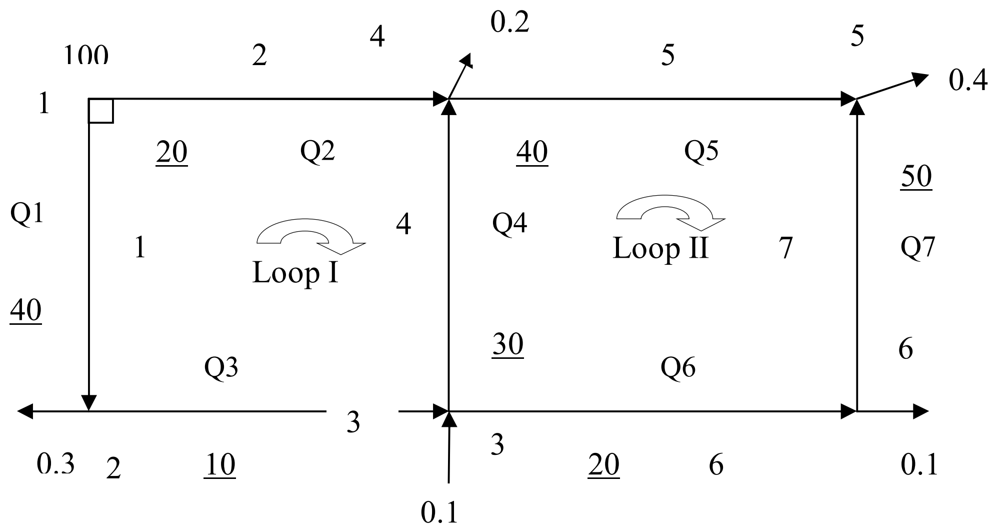
Applying the loop-head loss relationship for the basic loops

$$\sum_{x \in c} R_{ox} Q_x^{\,n} = 0, c = I, II,.....C \quad (17)$$

which are C nonlinear equations.

Therefore, total number of Q equations is J-1+C=X (I suggest to add node numbers)

Example:



*node-flow continuity relationships,

$$F_1 = Q_1 - Q_3 - 0.3 = 0$$
$$F_2 = Q_3 - Q_4 - Q_6 + 0.1 = 0$$
$$F_3 = Q_2 + Q_4 - Q_5 - 0.2 = 0$$
$$F_4 = Q_5 + Q_7 - 0.4 = 0$$
$$F_5 = Q_6 - Q_7 - 0.1 = 0$$

*head loss relationships in basic loops,

$$F_6 = 20Q_2^n - 30Q_4^n - 10Q_3^n - 40Q_1^n = 0$$
$$F_7 = 40Q_5^n - 50Q_7^n - 20Q_6^n + 30Q_4^n = 0$$

- seven equations, seven unknowns.

H-EQUATIONS

H_j, j=2,.....J are taken as basic unknown parameters

General Formulation :

Applying node-flow continuity equation,

$$\sum_{xconnectedtoj} \left(\frac{H_i - H_j}{R_{ox}} \right)^{\frac{1}{n}} + q_{oj} = 0, j = 2,.......J \qquad (18)$$

H_i , H_j heads at upstream and downstream node.

Illustration:

*Node flow continuity relationship

$$F_1 = \left(\frac{100 - H_2}{40}\right)^{\frac{1}{n}} - \left(\frac{H_2 - H_3}{10}\right)^{\frac{1}{n}} - 0.3 = 0$$

$$F_2 = \left(\frac{H_2 - H_3}{10}\right)^{\frac{1}{n}} - \left(\frac{H_3 - H_4}{30}\right)^{\frac{1}{n}} - \left(\frac{H_3 - H_6}{20}\right)^{\frac{1}{n}} + 0.1 = 0$$

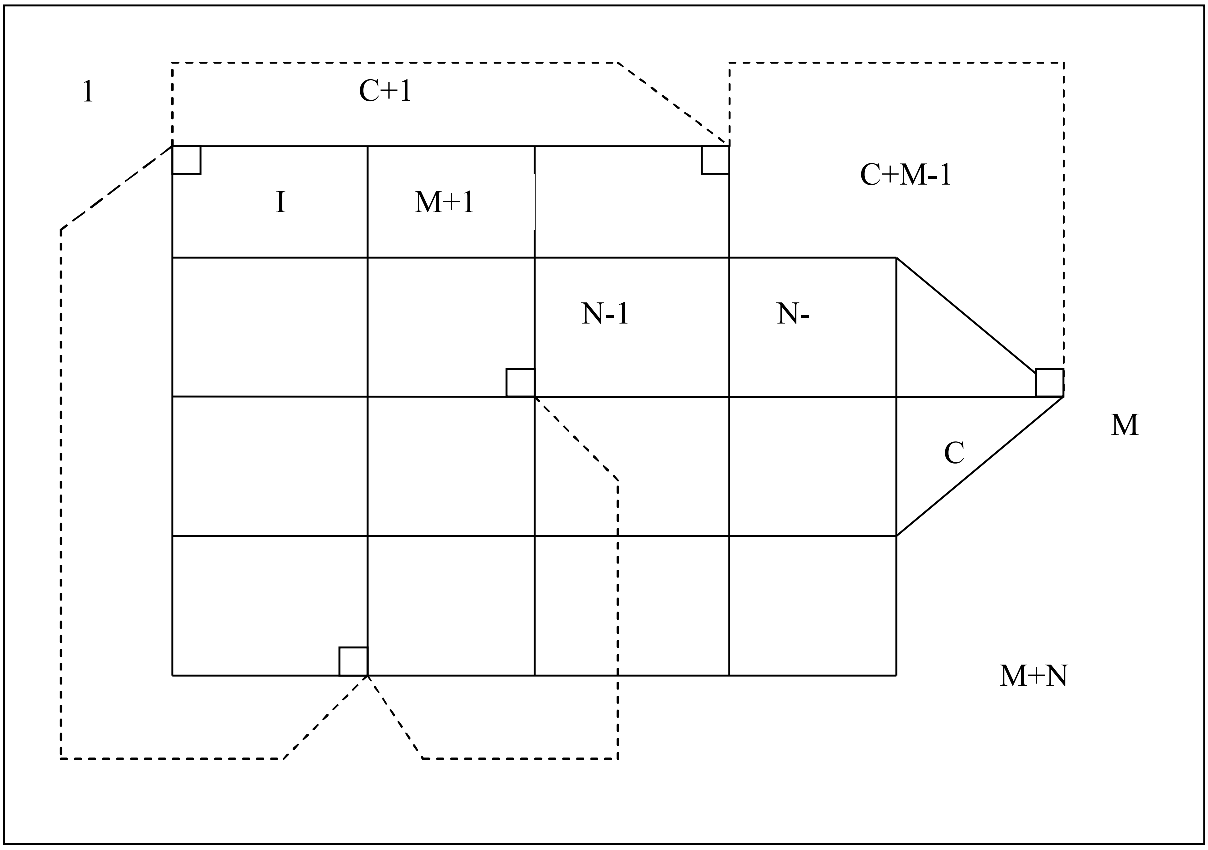
$$F_3 = \left(\frac{100 - H_4}{20}\right)^{\frac{1}{n}} - \left(\frac{H_3 - H_4}{30}\right)^{\frac{1}{n}} - \left(\frac{H_4 - H_5}{40}\right)^{\frac{1}{n}} - 0.2 = 0$$

$$F_4 = \left(\frac{H_4 - H_5}{40}\right)^{\frac{1}{n}} - \left(\frac{H_6 - H_5}{50}\right)^{\frac{1}{n}} - 0.4 = 0$$

$$F_5 = \left(\frac{H_3 - H_6}{20}\right)^{\frac{1}{n}} - \left(\frac{H_6 - H_5}{50}\right)^{\frac{1}{n}} - 0.1 = 0$$

*Five non-linear equations, five unknowns.

Multi-Source Networks: Looped Networks



M, source nodes
N, demand nodes
X, pipes
C, basic loops
M-1, pseudo loops

Q-EQUATIONS

*Node flow continuity equation,

$$\sum_{x connected to j} Q_x + q_{oj} = 0, j = M + 1,....M + N \tag{19}$$

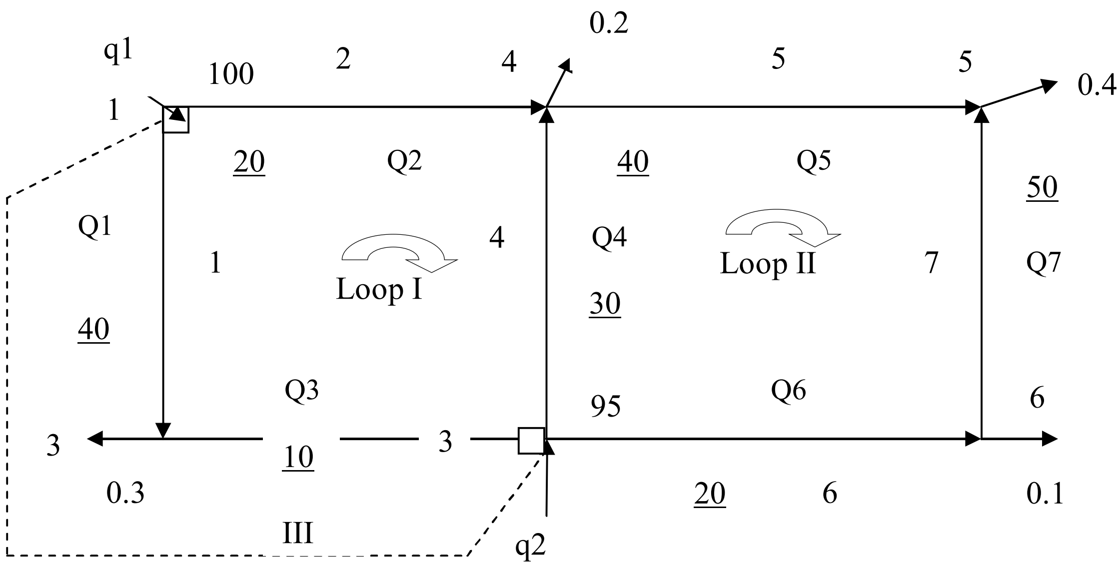
which are N independent equations

- Loop-head loss relationship

$$\sum_{x \in c} R_{ox} Q_x^{\ n} = 0, c = 1,....C, C + 1,....C + M - 1 \tag{20}$$

which are C+M-1 independent linear equations
Therefore both equations together,

N+C+M-1 i.e. J+C-1 independent equations for the X basic unknowns Q_x=1......X
As X=J+C-1 (already defined)
X independent equations are available for X basic unknowns.
(I suggest to put node numbers).



*node-flow continuity relationships,

$$F_1 = Q_1 - Q_3 - 0.3 = 0$$
$$F_2 = Q_2 + Q_4 - Q_5 - 0.2 = 0$$
$$F_3 = Q_5 + Q_7 - 0.4 = 0$$

$$F_4 = Q_6 - Q_7 - 0.1 = 0$$

*head loss relationships from two basic loops,

$$F_5 = 20Q_2^n - 30Q_4^n - 10Q_3^n - 40Q_1^n = 0$$
$$F_6 = 40Q_5^n - 50Q_7^n - 20Q_6^n + 30Q_4^n = 0$$

* and from the pseudo loop,

$$F_7 = 40Q_1^n + 10Q_3^n + (95 - 100) = 0$$

<u>H-EQUATIONS</u>

The unknown nodal heads are taken as the basic unknown parameters in formulating H-equations.

<u>General Formulation :</u>

Node flow continuity equations

$$\sum_{xconnectedtoj} \left(\frac{H_i - H_j}{R_{ox}} \right)^{\frac{1}{n}} + q_{ox} = 0, j = M + 1, ...M + N \qquad (21)$$

N independent nonlinear equations.

<u>Illustration:</u>

Node-flow continuity equations,

$$F_1 = \left(\frac{100 - H_3}{40} \right)^{\frac{1}{n}} - \left(\frac{H_3 - 95}{10} \right)^{\frac{1}{n}} - 0.3 = 0$$

$$F_2 = \left(\frac{100 - H_4}{20} \right)^{\frac{1}{n}} - \left(\frac{95 - H_4}{30} \right)^{\frac{1}{n}} - \left(\frac{H_4 - H_5}{40} \right)^{\frac{1}{n}} - 0.2 = 0$$

$$F_3 = \left(\frac{H_4 - H_5}{40} \right)^{\frac{1}{n}} - \left(\frac{H_6 - H_5}{50} \right)^{\frac{1}{n}} - 0.4 = 0$$

$$F_4 = \left(\frac{95 - H_6}{20} \right)^{\frac{1}{n}} - \left(\frac{H_6 - H_5}{50} \right)^{\frac{1}{n}} - 0.1 = 0$$

*four independent nonlinear equation, four unknowns.

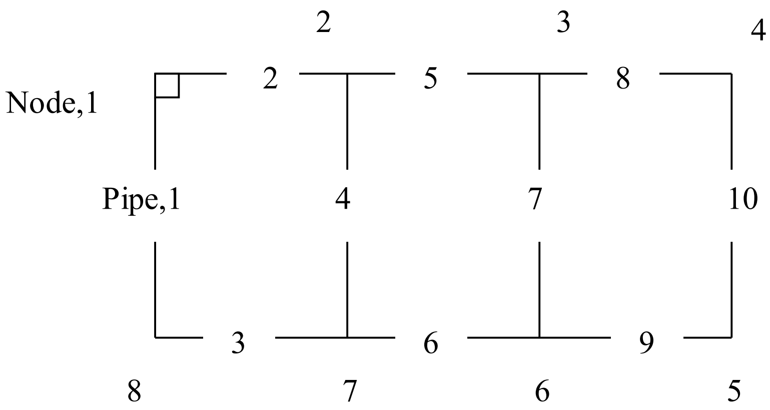
Pressure Reducing Valves

A pressure reducing valve (PRV) maintains a constant preset pressure downstream of it regardless of how large the upstream pressure becomes. Thus, several PRV's together can reduce pressure in an excessive zone of a pipe network. For example, if PRV's are provided in pipes 5 and 6 of the network of the following figure, they can control the pressures of at the downstream nodes 3.......6.

There are two exceptions to this usual, pressure-reducing behavior of a PRV. These exceptions are the following:

(a) If the pressure becomes less than the pressure setting of the PRV, the PRV becomes inoperative and has no effect on the flow, except for the head loss though it. The head loss coefficient for a PRV,i.e., K_{PRV} can be taken as 10.

(b) If a PRV is bypassed and the downstream pressure exceeds its pressure setting, the PRV acts as a check valve, prevents flow in the opposite direction, and allows the pressure immediately downstream of it to exceed its pressure setting. In this case, several PRV's can effectively control the sources from which supply is withdrawn under different demand conditions. As the network demand increases, additional sources of supply becomes operative.



Consider a PRV fitted in pipe x, connecting nodes i and j with HGL values H_i and H_j respectively (figure a). The PRV is oriented such that flow can take place along ij only. Let u and d represent the upstream and downstream ends of the PRV, respectively. Let H_u and H_d be the HGL values at u and d, respectively. Let H_{set} be the preset HGL value at the downstream end d of the PRV.

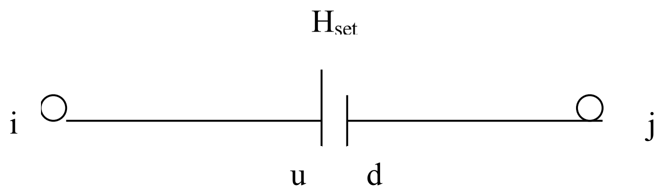


Figure a

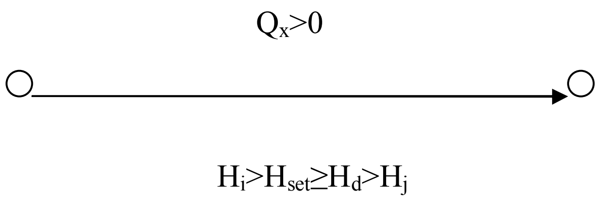


Figure b

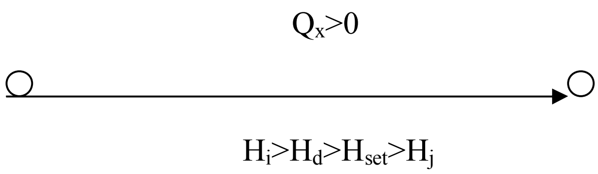


Figure c

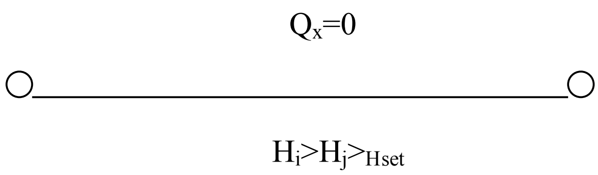


Figure d

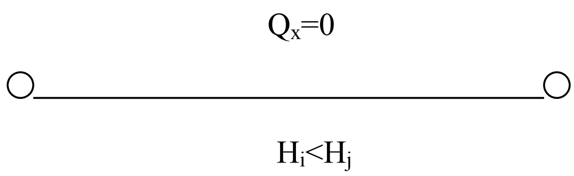


Figure e

The following four modes of operation may occur for the PRV:

(1) $H_i > H_{set} \geq H_d > H_j$ (figure b) : As $H_i>H_j$, flow takes place from i to j. Further, as $H_d \leq H_{set}$, the PRV is inoperative. If K_{prv} is the head loss coefficient, the resistance constant of the PRV, i.e.,

$$R_{PRV} = \frac{8K_{PRV}}{\pi^2 g D_x^4} \tag{22}$$

The PRV acts as an ordinary valve with fixed resistance constant, R_{prv}, and the head loss through it is $h_{L_{PRV}} = R_{PRV} Q_x^2$

(2) $H_i>H_d>H_{set}>H_j$ (figure c): As $H_i>H_j$ flow takes place from i to j. As $H_d>H_{set}$ the PRV is operative and Hd becomes equal to H_{set}. The head reduction through the PRV is (H_u-H_{set}). The PRV has a variable resistance so that

$$R_{PRV} = \left(\frac{H_u - H_{set}}{Q_x}\right)^{0.5} > \frac{8K_{PRV}}{\pi^2 g D_x^4} \tag{23}$$

(3) $H_i>H_j>H_{set}$ (figure d) : It may happen that a PRV is bypassed so that H_j becomes more than H_{set}. As $H_i>H_j$ flow should take place from i to j. However, as the intervening Hset is less than Hj, The PRV prevents flow,i.e., Q_x =0. The pressures on the upstream and downstream ends of the PRV increase so that H_u=H_i and H_d=H_j.

(4) $H_i<H_j$ (figure e) : As $H_i<H_j$, flow direction would have been from j to i in the absence of a PRV. However, the PRV shuts off when $H_i<H_j$ and prevents flow from i to j. The PRV behaves as a check valve so that Q_x=0, H_u=H_i and H_d=H_j.

Inclusion of PRV's

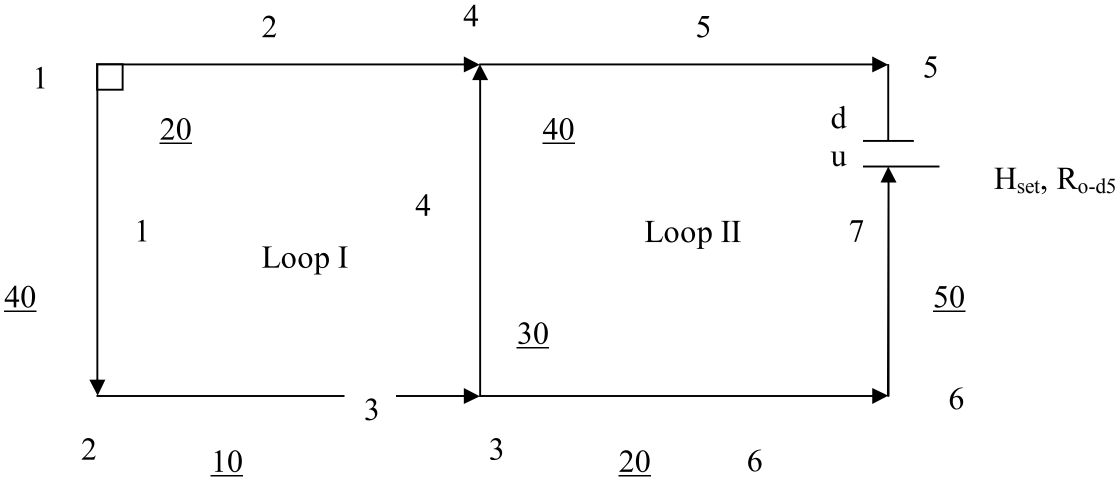
PRV in An External Pipe

The conditions prevail for PRV:

(1) HGL at downstream end d of the PRV remains H_{set}, a known and fixed value: d can be treated as source node (HGL=H_{set}). The single source network becomes now a two-source network with 1 and d. Note that HGL at upstream of PRV is unknown. Similarly, the resistance constant of PRV is variable and unknown.

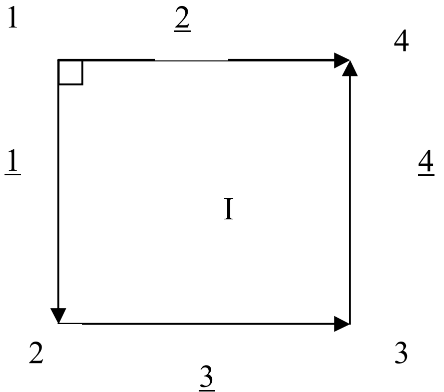
(2) Flow continuity must be maintained at PRV. Therefore, discharges in pipe segments 6-u and d-5 must be the same and equal to Q_7. In other words, a PRV can be replaced by

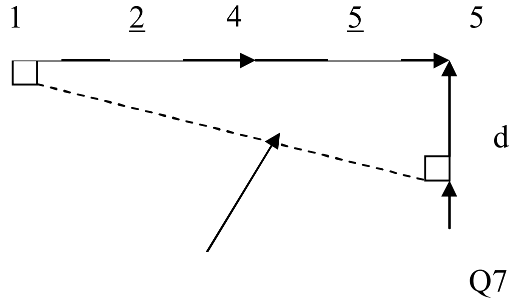
- a source node d with known HGL = H_{set} and inflow Q_7, and
- a sink node u with unknown head and outflow Q_7.



Q-Equations

The node flow continuity equations for nodes 2,3,4,5,6 and the head loss equation for loop I are written. However, the loop head loss equation for loop II is not applicable because of (1): The PRV is replaced by source and sink nodes, and a pseudo loop is formed.





$$F_7 = 20Q_2^n + 40Q_5^n - R_{o-d5}Q_7^n - 100 + H_{set} = 0$$

Thus, seven equations, seven unknowns: Q_1......Q_7

H-Equations

H-equations for the flow continuity at 2,3,4 remain unaffected by PRV:

$$F_1 = \left(\frac{100 - H_2}{40}\right)^{\frac{1}{n}} - \left(\frac{H_2 - H_3}{10}\right)^{\frac{1}{n}} - 0.3 = 0$$

$$F_2 = \left(\frac{H_2 - H_3}{10}\right)^{\frac{1}{n}} - \left(\frac{H_3 - H_4}{30}\right)^{\frac{1}{n}} - \left(\frac{H_3 - H_6}{20}\right)^{\frac{1}{n}} + 0.1 = 0$$

$$F_3 = \left(\frac{100 - H_4}{20}\right)^{\frac{1}{n}} - \left(\frac{H_3 - H_4}{30}\right)^{\frac{1}{n}} - \left(\frac{H_4 - H_5}{40}\right)^{\frac{1}{n}} - 0.2 = 0$$

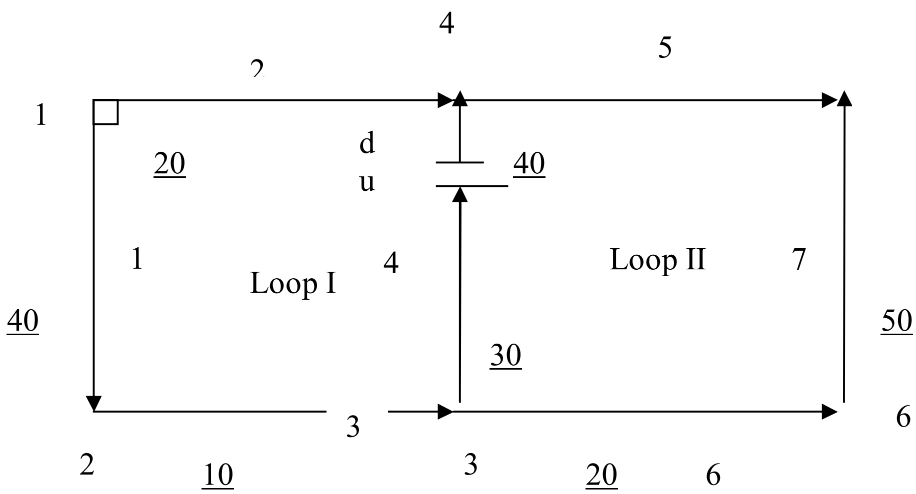
However, H-equations for nodes 5 and 6 modify to:

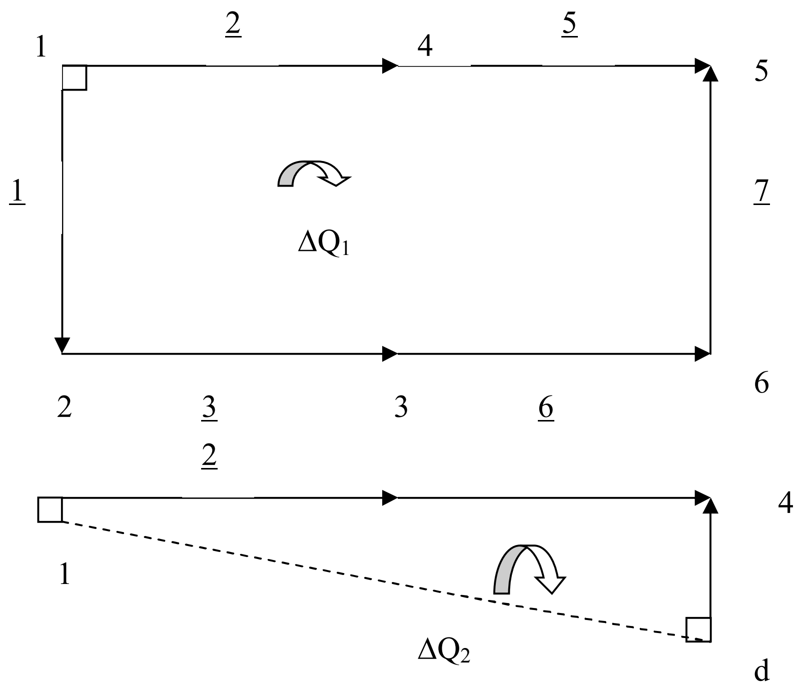
$$F_4 = \left(\frac{H_4 - H_5}{40}\right)^{\frac{1}{n}} - \left(\frac{H_{set} - H_5}{R_{o-d5}}\right)^{\frac{1}{n}} - 0.4 = 0$$

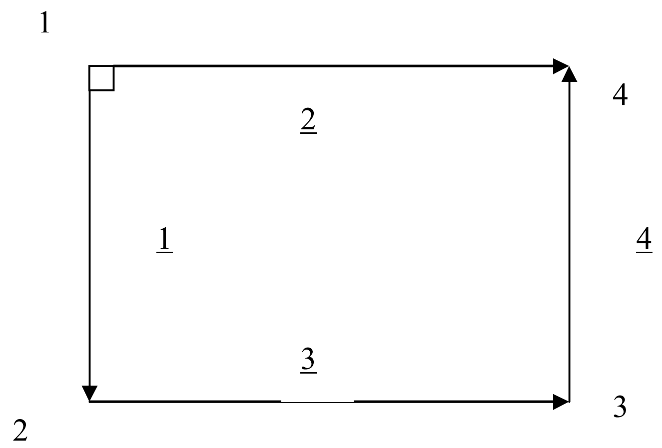
$$F_5 = \left(\frac{H_3 - H_6}{20}\right)^{\frac{1}{n}} - \left(\frac{H_{set} - H_5}{R_{o-d5}}\right)^{\frac{1}{n}} - 0.1 = 0$$

Note that, as H_u is not known, discharge in pipe segment 6-u can not be expressed in terms of H_u. Similarly, although H_d is known, the resistance coefficient of PRV is variable and therefore unknown. Therefore discharge in pipe segment 6-d can not be expressed in terms of H_{set}, H_5, R_{o-d5}. Therefore five equations, five unknowns.

PRV in an Internal Pipe







Q-Equations

Node-flow continuity equations for nodes 2,......6 give Q-equations.

$$F_1 = Q_1 - Q_3 - 0.3 = 0$$
$$F_2 = Q_{13} - Q_4 - Q_6 + 0.1 = 0$$
$$F_3 = Q_2 + Q_4 - Q_5 - 0.2 = 0$$
$$F_4 = Q_5 + Q_7 - 0.4 = 0$$
$$F_5 = Q_6 - Q_7 - 0.1 = 0$$

- for the overlapping loop:

$$F_6 = 20Q_2^n - 40Q_5^n - 50Q_7^n - 20Q_6^n - 10Q_3^n - 40Q_1^n = 0$$

- for the pseudo loop:

$$F_7 = 20Q_2^n - R_{o-d5}Q_4^n + H_{set} - 100 = 0$$

<u>H-Equations</u>

H-equations for the flow continuity at nodes 2,5,6:

$$F_1 = \left(\frac{100 - H_2}{40}\right)^{\frac{1}{n}} - \left(\frac{H_2 - H_3}{10}\right)^{\frac{1}{n}} - 0.3 = 0$$

$$F_2 = \left(\frac{H_4 - H_5}{40}\right)^{\frac{1}{n}} - \left(\frac{H_6 - H_5}{50}\right)^{\frac{1}{n}} - 0.4 = 0$$

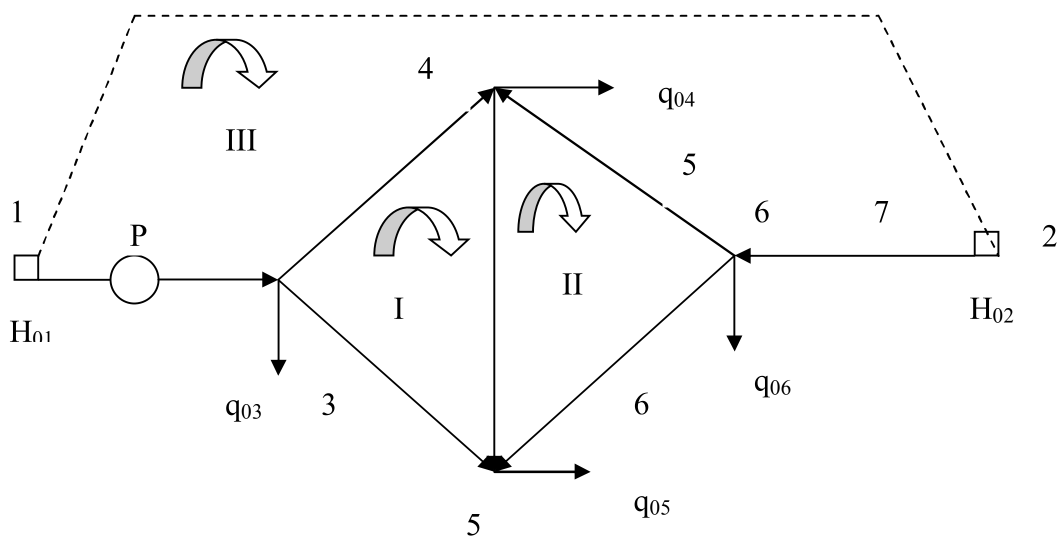
$$F_3 = \left(\frac{H_3 - H_6}{20}\right)^{\frac{1}{n}} - \left(\frac{H_6 - H_5}{50}\right)^{\frac{1}{n}} - 0.1 = 0$$

H-equations for nodes 3 and 4:

$$F_4 = \left(\frac{H_2 - H_3}{10}\right)^{\frac{1}{n}} - \left(\frac{H_{set} - H_4}{R_{o-d5}}\right)^{\frac{1}{n}} - \left(\frac{H_3 - H_6}{20}\right)^{\frac{1}{n}} + 0.1 = 0$$

$$F_5 = \left(\frac{100 - H_4}{20}\right)^{\frac{1}{n}} - \left(\frac{H_{set} - H_4}{R_{o-d5}}\right)^{\frac{1}{n}} - \left(\frac{H_4 - H_5}{40}\right)^{\frac{1}{n}} - 0.2 = 0$$

Inclusion of Pumps



Q-Equations

The network has seven pipes and therefore seven independent Q equations are necessary. Node flow continuity equations at nodes 3,4,5,6 and loop head loss equations for real loops I, II provide six equations. The seventh equation is available from the pseudo loop.

$$-R_{01}Q_1^{n} + h_p - R_{02}Q_2^n + R_{05}Q_5^n + R_{07}Q_7^n - H_{02} + H_{01} = 0 \qquad (25)$$

where h_p is head supplied by the pump.

Head-Discharge Relationship

h_p as a function of Q_p

It is common to use a relationship

$$h_p = AQ_p^2 + BQ_p + H_0 \qquad (26)$$

in which A, and H_o=constants, determined by fitting eqn(26) to three points taken from the expected working range of the pump head-discharge curve.

A more useful form of eqn (26) is,

$$h_p = AG_p^2 + \left(H_0 - \frac{B^2}{4A}\right) \qquad (27)$$

where

$$G_p = Q_p + \frac{B}{2A} \qquad (28)$$

A relationship of the form,

$$h_p = H_p - R_pQ_p^n \qquad (29)$$

is used also.

Shut off head (H_p)

Resistance constant of the pump (R_p)

Note that if previous equation (29) is used, all terms in equation (25) would be similar.

H-Equations

There are five unknowns, H_3,H_4,H_5,H_6 and h_p. The node flow continuity relationships at nodes 4,5,6 yield three equations.

For pipe 1:

$$H_{01} + h_p - H_3 = R_{01}Q_1^n \quad (30)$$

from which

$$Q_1 = \left(\frac{H_{01} + h_p - H_3}{R_{01}}\right)^{\frac{1}{n}} \quad (31)$$

Therefore, the node flow continuity relationship at node 3 would yield

$$\left(\frac{H_{01} + h_p - H_3}{R_{01}}\right)^{\frac{1}{n}} - \left(\frac{H_3 - H_4}{R_{02}}\right)^{\frac{1}{n}} - \left(\frac{H_3 - H_5}{R_{03}}\right)^{\frac{1}{n}} - q_{03} = 0 \quad (32)$$

Further as Q_1=Q_p, equation (31) and the equation related to head –discharge curve of the pump,

$$h_p = H_p - R_p Q_p{}^n \longrightarrow Q_p = \frac{1}{R_p{}^{\frac{1}{n}}}(H_p - h_p)^{\frac{1}{n}}$$

Then, from eqn (30) one gets,

$$H_{01} + H_{0p} - R_{0p}Q_1^n - H_3 = R_{01}Q_1{}^n \quad \text{or} \quad Q_1 = \left(\frac{H_{01} + H_{0p} - H_3}{R_{0p} + R_{01}}\right)^{\frac{1}{n}}$$

which modifies equation (32) to,

$$\left(\frac{H_{01} + H_{0p} - H_3}{R_{01} + R_{0p}}\right)^{\frac{1}{n}} - \left(\frac{H_3 - H_4}{R_{02}}\right)^{\frac{1}{n}} - \left(\frac{H_3 - H_5}{R_{03}}\right)^{\frac{1}{n}} - q_{03} = 0 \quad (33)$$

Thus, hp need not be taken as the fifth unknown parameter.

The unknown parameters are H_3,H_4,H_5,H_6 for which the three node flow continuity equations at node 4,5,6 and eqn (33).

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Chapter II: Metropolitan Ankara Water Supply System (North-8 Pressure Zone)

This chapter contains details of the work done in the Activity 1.1.7 (Collecting, reviewing, and analyzing data from full scale networks in the three countries, Jordan, UAE, and Turkey) in the project work-plan. The data collected is extensive and will suffice to carry out the remaining project activities.

Ankara is the second largest city of Turkey. Water treatment plant of Ankara (İvedik) supplies roughly 800 000 m3 of water per day (250 lt/day/capita). Its water distribution network consists of 37 pump stations and 73 tanks.

In this study, N8 (North-8) pressure zone, which is the zone at the end of the north line of Metropolitan Ankara Water Supply System, was chosen as the study area (Figure 1). It is laterally distributed on two adjacent hills, including Çiğdemtepe district of Yenimahalle county, and Şehit Kubilay, Sancaktepe and Yayla districts of Keçiören county. There are approximately 25000 people residing in these four districts. There is one storage tank, T53, and one pump station, P23. The pump system of P23 is composed of three parallel pumps which are used with a coordination to provide necessary water to feed the network. The tank T53 is rectangular in cross section with a height of 6.5 m and has a volume of 5000 m3. There is a main transmission line with a diameter of 500 mm between the pump and tank. The pipes of the system are ductile iron and the network is a grid type distribution system; pipes are ten years old.

Network Analysis

Network analysis has two components: a network solver that performs calculations and a data set that describes the related system. A data set, which should at least define the pipe network, system characteristics and water consumption rates, is required as an input for the network solver.

There are three primary types of data for network analysis: network data, operations data and consumption data. Network data describe the physical components of the water system. Operations data define the level at which facilities are operating and consumption data describe water demand. Network, operations and consumption data are essential to be able to execute the program and obtain a solution. This data group is also called as basic data. Some part of these data can be extracted from existing records: however the data that are related to consumption and roughness (C-values) should be measured, analyzed, calculated and distributed before analysis. The basic data should possess two important characteristics: completeness and accuracy. Completeness means that all relevant data should be included to avoid incomplete and erroneous results. Accuracy defines the correctness of the values used as data. Inaccurate data can lead to wrong conclusions and inappropriate recommendations. When data are limited, credibility and accuracy of the model may be questioned and therefore decisions based on such analysis are made with a lower degree of confidence. Judgements and experience become more important in the decision process when available data are limited (Cesario, 1995).

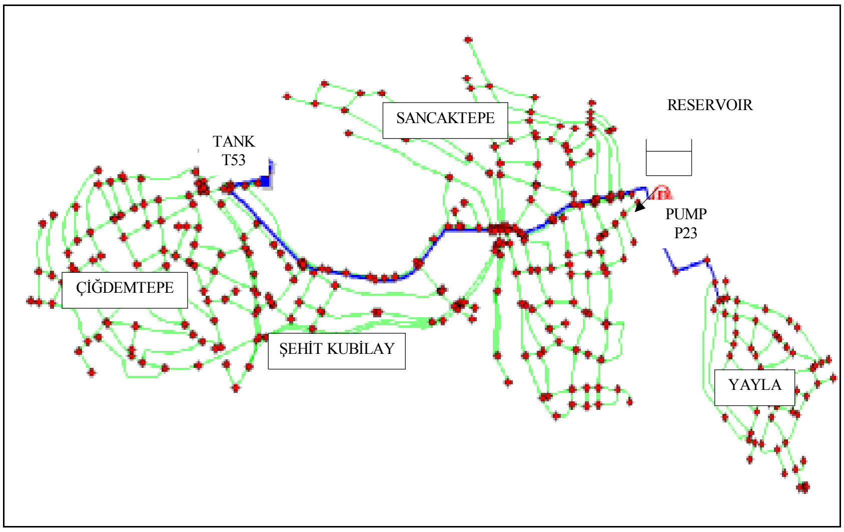


Figure 1. Water distribution network of N8 pressure zone.

Parameters Used in Network Analysis

Network data include pipe and node data and displayed in the form of a map (Figure 2).

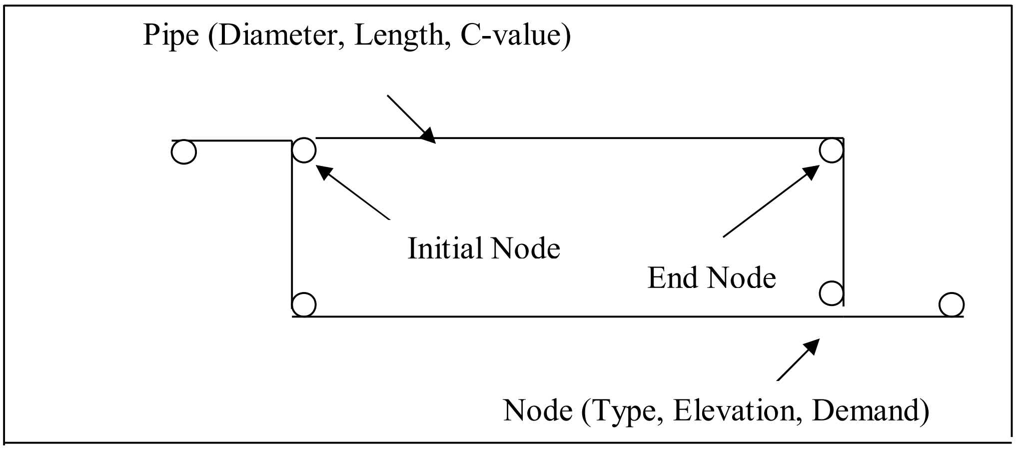


Figure 2. Pipe and node data

The minimum information, that pipe data should include, are initial and end node information, diameter, length and roughness coefficient of any pipe to execute a network analysis program.

Nodes represent either sources of supply or points of demand. Node data include node number, topographic elevation and demand information.

The network map for N8 pressure zone contains pipe network, pump station locations and tank locations. In addition to that information, their databases include attribute data like pipe code, length, diameter, topographic elevations and coordinates of junction nodes. The X and Y coordinates (geographic location) of nodes, which refer to distances away from north-south and west-east, are important to export the network maps from MapInfo to a hydraulic analysis program. The network map for N8 pressure zone will be sent with a format which can be used in MapInfo. The files with 'tab' extension can only be opened by using MapInfo. For that reason, the files that include the pipe characteristics, nodal information, pump and tank data will also be sent as word and Excel files.

As a note, MapInfo Professional, the world's leading software for mapping and geographic analysis, allows someone to better visualize and analyze data resulting in more effective business practices and decisions.

Prediction of pipe roughness cofficients constitutes an important part of hydraulic network analysis. The roughness coefficient refers to a value that defines the roughness of the interior of a pipe. Two common roughness coefficients are the Hazen-William's C-value and the Darcy-Weisbach's f-value. Although the Darcy-Weisbach's roughness term is generally considered more accurate and flexible, it is also more complicated and difficult to estimate; consequently, the Hazen-William's C-value is more commonly used in network modeling.

The numerical values of C range from 20 to 150. The higher C values indicate smoother pipe interior surfaces that mean greater carrying capacities for the pipes. Since the field estimations of C-factors is relatively difficult, generally the approximate literature values are used by using the material and age information for each pipe. The network of this particular study (N8) was reported to be completely reconstructed in 1992 with ductile iron pipes. Considering the age of pipes and the condition of the network, the C-roughness coefficient was assumed to be '130' for all pipes.

Operations data describe actual system characteristics at a given time. The appropriate values are selected as input into the model to define initial system conditions. For the network sent, the operations data for tank includes information about tank geometry and initial water levels. Operations data for pumps includes data for use in describing the pump-flow characteristics curve and the pressure at the entrance of the pump to make hydraulic analysis for certain working conditions. The data taken from SCADA (Supervisory Control and Data Acquisition) gives information about the water levels in the tanks and the pressure at the entrance and at the exit of the pumps; but does not include code number of working pumps. Since the pumping station ,P23, has three parallel pumps and any combination of these pumps can be operative (either as a single pump or as combinations of multiple pumps), it is necessary to know which pump or which combination of pumps is in operation at any moment. Therefore the necessary part of data was taken directly from the log books of the pump station, P23.

The initial tank elevation was calculated as the summation of tank bottom elevation and the average tank level which was computed by using data obtained from SCADA during the calculations of daily demand curves.

The tank bottom elevation and the topographic elevation of the pumping station are 1148.80 m and 1047.33 m respectively.

The initial tank elevation at a certain time was calculated as the summation of the tank bottom elevation and the tank level at this time. The HGL (hydraulic grade line) at the suction side of the pumping station was calculated by summing the topographic elevation and the pressure head at the suction side of the pumping station.

In computations ;

Initial Tank Elevation at time t = 1148.80 + Tank Level at time t
Reservoir Elevation = 1047.33 + Pressure Head at the suction side of the pumping station

Table 2 shows the essential data related to the Tank 53 (T53) for computation. T53 is rectangular type of tank with a volume of 5000 m3 and height of 6.5m.

Table 2. Tank characteristics of N8 Pressure Zone

Name	Max Elevation (m)	Min Elevation (m)	Base Area (m^2)	Base Elevation (m)	Tank Height (m)	Tank Volume (m^3)
T53	1155.30	1148.80	769.200	1148.80	6.50	5000

Table 3. Pump-Discharge Relations for 3 pumps of P23

Pump No:	SHUTOFF HEAD (m)	MIN.DIS. (lt/s)	HEAD2 (m)	DIS.2 (lt/s)	HEAD3 (m)	DIS.3 (lt/s)	HEAD4)	DIS.4 (lt/s)	HEAD5)	DIS.5 (lt/s)	HEAD6)	DIS.6 (lt/s)
3	55.20	0.00	54.00	22.00	53.00	29.00	52.00	31.00	50.00	33.30	47.50	36.00
2	54.20	0.00	53.00	13.00	52.00	21.00	51.10	28.00	50.00	30.00	48.20	32.00
1	55.20	0.00	55.00	3.00	54.50	16.00	54.00	23.00	53.50	27.00	53.00	29.00
			HEAD6)	DIS.6 (lt/s)	HEAD7)	DIS.7 (lt/s)	HEAD8)	DIS.8 (lt/s)	HEAD9 (m)	DIS.9 (lt/s)	HEAD10 (m)	DIS.10 (lt/s)
			47.50	36.00	46.40	38.00	44.60	40.00	43.30	42.00	42.00	44.00
			48.20	32.00	47.40	33.00	45.60	35.00	44.00	36.60	42.80	38.00
			53.00	29.00	52.00	32.00	49.90	36.00	46.00	41.70	41.30	46.00

The table above lists hows the head-discharge information for each pump yielding coordinates of ten points identifying the H-Q curves shown by Figure 3.

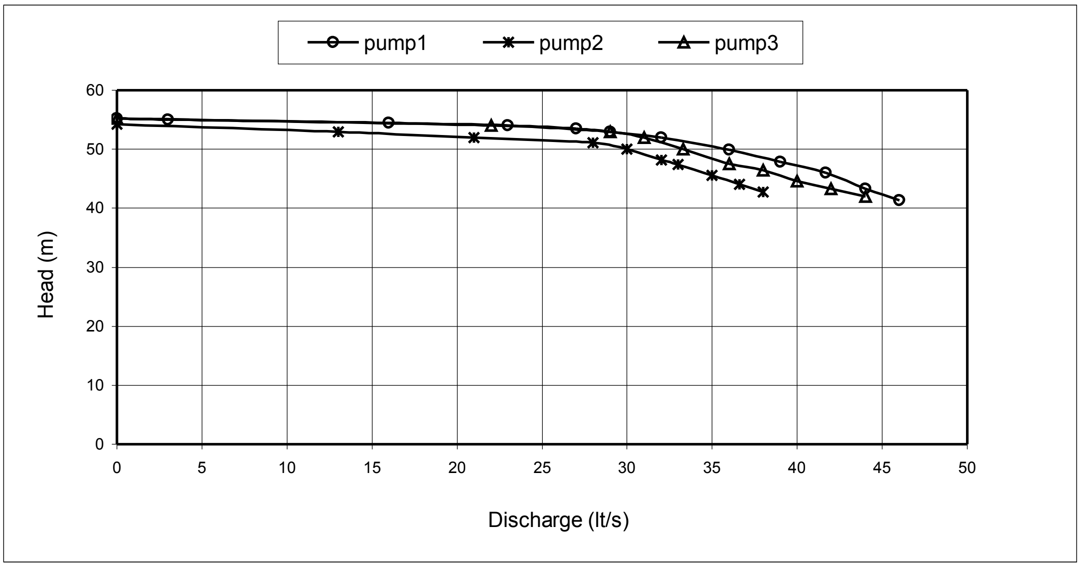


Figure 3. Pump curves used in analysis

The following data belong to the date: 1st of June ,2001. Head supplied by pump can be calculated by subtracting the pressures at the entrance of the pump from the pressures at the exit. Tank water levels corresponding to every hour of the day have also been provided.

Working Pumps on 01.06.2002

Pump 3 (P3) already has been working at time 00:00 and continued to work until 03:15. Then, pump 2 (P2) worked between the hours 05:00-22:00. Shortly, we can say that,
P1:..- 03:15 and P2: 05:00 - 22:00

Table 4. Operational Data

Time	Pressure at the entrance of the pump	Pressure at the exit of the pump	Water Level in Tank	Head Gaining From Pump
(hr)	(bar)	(bar)	(m)	(m)
00:00	6.15	10.47	2.7561	44.11
01:00	6.40	10.47	2.6844	41.51
02:00	6.31	10.47	2.6313	42.47
03:00	6.47	10.47	2.7406	40.84
04:00	5.79	10.33	2.8469	46.30
05:00	6.02	10.48	2.9516	45.53
06:00	6.02	10.48	3.0063	45.53
07:00	6.02	10.48	3.0609	45.53
08:00	5.89	10.48	3.0609	46.86
09:00	5.76	10.48	3.0609	48.13
10:00	5.76	10.48	3.0609	48.13
11:00	6.03	10.48	3.0609	45.39
12:00	5.99	10.48	2.9547	45.79
13:00	6.11	10.48	2.8438	44.57
14:00	6.11	10.48	2.7906	44.57
15:00	5.87	10.48	2.7375	47.01
16:00	6.26	10.48	2.7375	42.98
17:00	5.87	10.48	2.6844	46.96
18:00	5.75	10.48	2.6281	48.19
19:00	5.65	10.48	2.5719	49.26
20:00	5.65	10.48	2.5042	49.26
21:00	5.65	10.39	2.4063	48.42
22:00	5.38	10.36	2.4063	50.83
23:00	5.84	10.37	2.3516	46.25

Head gains from pump operation (in meters)=(Pressure at the exit of the pump-Pressure at the entrance of the pump)*10.198

The constant 10.198 is used to convert bar to the unit of meter.

This head value is used to quantify the pump discharge to the network by using the pump-discharge curve of the related pump. Once again, it is worth to emphasize that there are 3 pumps working in parallel in N8 pressure zone. Therefore one has to use the pump-discharge relation of active pump at that time.

Consumption Data

Consumption, also known as demand, is assigned to the nodes in a network model. Estimation of the consumption quantities and the distribution of consumption throughout the network is the most important and time-consuming part of the analysis. Correct estimation of the rates of water consumption at demand nodes is rather difficult; accurate estimation of nodal demands should be performed by detailed calibration studies (Walski, 1983).
Figure 3 shows the daily demand curve of N8 pressure zone for first of June, 2001 Table 4 gives the total consumption from N8 pressure zone for the date (01.06.2001) at every hour. These values are multiplied with nodal weights to find the demand value extracted from each node.

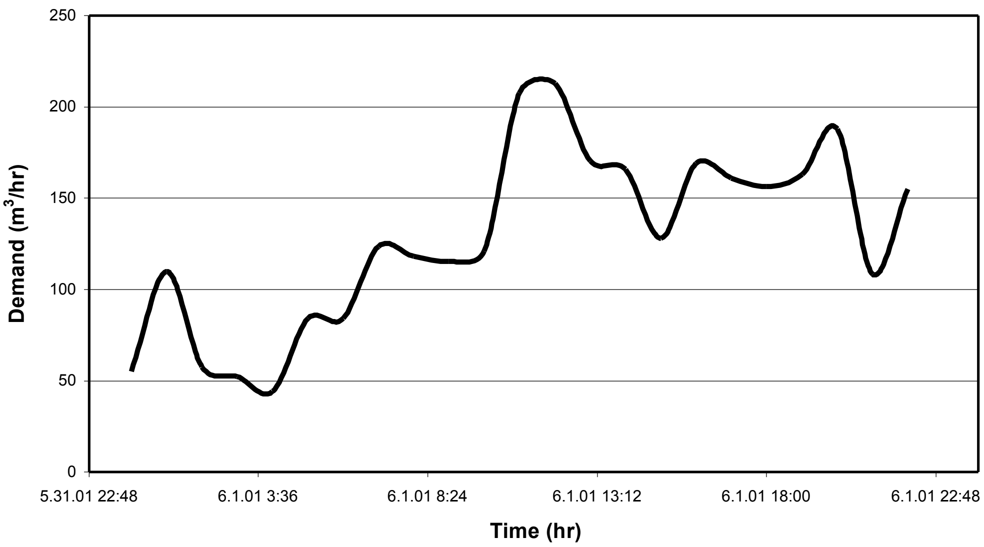


Figure 3. Daily demand curve for 1st of June, 2001

Table 4. Consumption rate in N8 pressure zone for 1st of June, 2001

Demand (m^3/hr)	Month, Day, Time (hr)
55.15	6.1.01 0:00
109.97	6.1.01 1:00
57.49	6.1.01 2:00
52.39	6.1.01 3:00
44.19	6.1.01 4:00
84.18	6.1.01 5:00
84.18	6.1.01 6:00
123.61	6.1.01 7:00
118.24	6.1.01 8:00
115.52	6.1.01 9:00
121.14	6.1.01 10:00
207.73	6.1.01 11:00
212.81	6.1.01 12:00
170.57	6.1.01 13:00
165.89	6.1.01 14:00
128.20	6.1.01 15:00
169.17	6.1.01 16:00
161.17	6.1.01 17:00
156.36	6.1.01 18:00
163.02	6.1.01 19:00
187.98	6.1.01 20:00
108.45	6.1.01 21:00
155.05	6.1.01 22:00
1870.60	6.1.01 23:00

One should note that exactly there is no water extraction from the main-line of N8 pressure zone. Therefore nodal weights concerning to this part of the network should be taken as zero.

Nodal demands can be found by using:

$q_i = Q * NW_i$, i : 1,2,.....,N where;
NW_i : nodal weight based on pipe lengths
q_i : demand extracted from each node
Q : amount of water consumed at a certain time.

Determination of Nodal Weights

The nodal weight of any node is the percent of demand consumed at that node which is calculated by dividing the summation of the half of the lengths of the pipes connected to the node, to the summation of the lengths of all pipes in the system. Knowing the nodal weight of each node, nodal demands can be calculated by multiplying them with the total consumption at a certain time, if the total demand of the network is known.

Table 5 shows the pipe characteristics and from node – to node information for each pipe. This data can also be used for sketching the network.

Table 5. Characteristics of Pipes in N8 Pressure Zone

Pipe No:	From Node	To Node	Length (m)	Diameter (cm)
1	11000	5026	10	50
2	11000	5025	10	50
3	11000	5024	10	50
4	5026	5023	10	50
5	5025	5023	10	50
6	5024	5023	10	50
7	3147	10000	175	50
8	5002	5014	279	50
9	5003	3147	374	50
10	5004	5002	174	50
11	5005	3212	21	50
12	5006	5017	41	50
13	3286	5019	95	50
14	5007	5018	123	50
15	5008	3286	80	50
16	5009	5020	47	50
17	5001	5022	188	50
18	5010	5021	34	50
19	5011	3232	94	30
20	5012	5011	161	30
21	5001	5012	281	30
22	3212	5016	20	50
23	5013	5015	327	50
24	5014	5003	11.3	50
25	5015	5004	14.3	50
26	5016	5013	13.6	50
27	5017	5005	9.6	50
28	5018	5006	8.3	50
29	5019	5007	8.7	50
30	5020	5008	10	50
31	5021	5009	10.1	50
32	5022	5010	11	50
33	5023	5001	44	50
1001	1	3009	124	15
1002	2	3	69	15
1003	3	3010	40	15
1004	3	3011	59	15
1005	3144	622	191.5	15
1006	100	130	109	10
1007	101	100	50	20
1008	102	101	112	10
1009	101	103	54	20
1010	103	104	27	20
1011	104	105	83	10
1012	105	589	160	10
1013	106	409	92	12.5
1014	107	106	115	12.5
1015	108	115	184	10
1016	109	3057	67	15
1017	109	420	46	15
1018	110	420	46	15
1019	111	110	99	15
1020	108	419	108	15
1021	100	419	56	15
1022	112	100	107	15
1023	113	112	74	15
1024	3205	3058	94	10
1025	115	3059	97	20
1026	115	116	73	20

1027	116	118	39	20
1028	116	117	70	10
1029	117	590	128	10
1030	118	105	81	12.5
1031	105	106	68	12.5
1032	104	118	97	20
1033	103	107	67	15
1034	107	119	61	15
1035	119	102	49	10
1036	120	119	89	15
1037	120	160	35	15
1038	121	3060	340	10
1039	122	145	90	10
1040	123	122	193	10
1041	124	123	46	10
1042	125	124	49	10
1043	125	3061	281	12.5
1044	126	3062	121	10
1045	127	128	80	10
1046	128	3063	88	10
1047	129	111	138	12.5
1048	129	130	61	12.5
1049	130	144	105	12.5
1050	131	144	78	12.5
1051	123	3064	137	10
1052	132	129	67	12.5
1053	132	133	149	12.5
1054	133	134	102	12.5
1055	134	440	45	12.5
1056	135	132	76	10
1057	136	135	118	10
1058	137	135	130	10
1059	138	109	268	15
1060	139	3065	106	10
1061	139	3066	84	10
1062	134	140	214	12.5
1063	140	141	47	12.5
1064	141	3067	32	12.5
1065	112	120	136	10
1066	112	127	51	10
1067	144	127	99	10
1068	145	137	32	10
1069	146	147	88	10
1070	147	140	88	10
1071	148	3068	220	10
1072	147	148	48	10
1073	149	148	54	10
1074	141	149	108	12.5
1075	149	3071	177	12.5
1076	160	159	50	20
1077	128	113	57	20
1078	128	126	39	20
1079	126	161	57	20
1080	161	131	26	20
1081	122	3064	100	20
1082	122	162	57	20
1083	162	3077	122	10
1084	162	121	58	20
1085	121	3078	55	20
1086	146	136	127	20
1087	136	133	83	20
1088	163	138	51	20
1089	138	164	86	20
1090	164	3079	348	12.5

1091	164	165	127	20
1092	165	591	236	25
1093	161	124	126	10
1094	408	410	61	15
1095	409	411	250	12.5
1096	410	3144	165.5	15
1097	411	3061	83	12.5
1098	412	3145	12	10
1099	413	1	23	10
1100	1	2	38	10
1101	588	3146	52	10
1102	415	416	40	10
1103	416	3147	27	10
1104	416	411	65	25
1105	111	108	14	15
1106	117	3149	48	10
1107	102	3150	29	10
1108	159	411	19	20
1109	160	113	115	20
1110	419	129	88	12.5
1111	110	132	237	10
1112	420	139	217	10
1113	452	649	104	12.5
1114	574	575	21	15
1115	575	576	47	15
1116	576	577	62	15
1117	578	579	78	15
1118	579	580	103	15
1119	580	581	102	15
1120	581	582	40	15
1121	582	583	56	15
1122	583	584	88	15
1123	584	585	65	15
1124	585	586	25	15
1125	586	587	77	15
1126	587	588	356	15
1127	588	3204	50	10
1128	589	409	151	25
1129	589	590	89	25
1130	590	591	95	25
1131	591	3205	186	10
1132	592	408	76	15
1133	593	592	67	15
1134	593	623	59	15
1135	594	3206	122	10
1136	595	575	258	10
1137	596	595	418	10
1138	599	3207	202	10
1139	602	3209	186	20
1140	578	595	180	10
1141	603	3210	58	10
1142	576	3211	111	10
1143	604	605	18	25
1144	605	606	223	25
1145	606	607	25	25
1146	607	608	101	25
1147	608	612	460	25
1148	609	610	66	10
1149	610	611	416	10
1150	611	594	275	10
1151	612	3213	213.5	25
1152	616	3215	468	15
1153	617	3216	230	10
1154	616	617	139	10

1155	604	616	42	15
1156	618	619	47	10
1157	619	620	62	10
1158	620	621	39	10
1159	621	622	101	10
1160	622	410	71	10
1161	623	3218	55	10
1162	618	625	122	12.5
1163	624	618	52	12.5
1164	625	626	88	10
1165	625	3218	8.5	10
1166	626	630	66	12.5
1167	627	630	120	12.5
1168	628	612	70	10
1169	629	631	109	12.5
1170	630	629	85	10
1171	587	624	28	12.5
1172	627	624	46	12.5
1173	631	627	90	12.5
1174	580	3221	136	10
1175	607	3222	76	10
1176	609	3223	66	10
1177	606	3224	60	10
1178	605	3225	225	10
1179	632	609	26	10
1180	634	635	45	10
1181	635	636	34	12.5
1182	636	638	84	10
1183	637	3226	77	10
1184	638	637	58	10
1185	639	638	80	10
1186	640	639	23	10
1187	637	1066	51	20
1188	641	633	129	20
1189	642	993	112	12.5
1190	643	644	26	12.5
1191	644	645	50	12.5
1192	645	452	40	12.5
1193	646	452	92	12.5
1194	647	652	62	10
1195	635	3227	89	10
1196	648	639	562	10
1197	648	647	55	20
1198	649	647	105	12.5
1199	649	3228	108	12.5
1200	650	3229	46	30
1201	650	651	22	30
1202	652	3230	152	20
1203	656	3232	550	12.5
1204	657	648	139	10
1205	651	648	54	25
1206	658	3233	61	10
1207	642	666	35	12.5
1208	666	3234	65	10
1209	666	640	30	12.5
1210	640	656	167	12.5
1211	645	3228	126	10
1212	766	770	141	10
1213	767	772	143	10
1214	768	602	140	12.5
1215	769	782	113	15
1216	770	767	72	15
1217	771	770	102	15
1218	771	3285	23	15

1219	772	3286	35	12.5
1220	772	773	109	12.5
1221	773	774	47	12.5
1222	774	775	22	15
1223	775	776	58	15
1224	776	771	60	15
1225	773	3287	82	10
1226	777	769	114	10
1227	778	3288	57	15
1228	778	779	46	15
1229	780	781	51	15
1230	781	777	113	15
1231	777	783	128	15
1232	782	783	59	15
1233	775	3289	89	10
1234	784	774	116	10
1235	785	784	268	15
1236	779	1916	304	10
1237	1732	778	260	10
1238	789	3292	179	10
1239	790	825	80	10
1240	790	791	51	10
1241	791	819	145	10
1243	792	819	141	15
1244	792	793	58	15
1245	793	794	101	15
1246	794	795	37	20
1247	795	796	35	20
1248	796	3293	129	20
1249	794	797	66	20
1250	797	802	70	20
1251	798	781	170	12.5
1252	799	800	57	10
1253	800	820	104	10
1254	802	801	183	20
1255	803	802	23	20
1256	803	804	58	12.5
1257	804	836	50	12.5
1258	780	835	116	12.5
1259	805	3294	111	10
1260	806	834	134	12.5
1261	807	808	23	10
1262	808	791	91	10
1263	791	809	56	10
1264	809	800	47	10
1265	800	810	76	10
1266	810	3295	83	10
1267	813	823	55	12.5
1268	813	814	23	12.5
1269	814	789	53	12.5
1270	789	795	68	12.5
1271	815	814	126	10
1272	797	3297	139	12.5
1273	816	815	69	12.5
1274	815	793	92	12.5
1275	816	827	97	15
1276	818	827	59	15
1277	819	818	71	15
1278	820	821	53	20
1279	821	819	50	20
1280	820	3298	279	10
1281	822	3299	58	20
1282	823	822	108	20
1283	823	817	114	20

1284	817	824	188	20
1285	824	807	164	20
1286	825	807	89	20
1287	822	3300	23	10
1288	818	826	69	12.5
1289	827	3301	66	10
1290	801	792	89	12.5
1291	808	3302	154	10
1292	828	826	183	10
1293	829	809	63	10
1294	810	799	120	10
1295	799	829	42	10
1296	829	790	58	10
1297	834	803	89	12.5
1298	805	3307	86	10
1299	806	805	49	10
1300	835	806	53	10
1301	836	835	25	10
1302	602	766	43	20
1303	766	838	65	20
1304	837	3285	98	10
1305	838	837	63	10
1306	623	3213	100	15
1307	798	796	80	12.5
1308	804	798	48	12.5
1309	647	646	57	20
1310	646	657	38	20
1311	657	641	47	20
1312	641	636	223	10
1313	967	1000	58	12.5
1314	991	3403	13	10
1315	992	3404	11	10
1316	990	3405	64	10
1317	990	1002	112	10
1318	993	1002	116	10
1319	1000	3409	82	12.5
1320	1000	1015	72	12.5
1321	1001	1015	78	12.5
1322	1002	1001	122	12.5
1323	1004	3410	40	10
1324	1005	967	135	20
1325	1006	1005	62	12.5
1326	1006	643	62	12.5
1327	1001	1007	27	10
1328	1007	1008	84	10
1329	1008	1066	33	20
1330	1005	1012	43	20
1331	1012	1008	85	20
1332	1008	993	45	12.5
1333	1013	642	107	12.5
1334	1002	1013	46	12.5
1335	1013	3412	93	10
1336	1014	1007	79	10
1337	1015	1014	54	10
1338	1014	1012	65	10
1339	1016	644	174	10
1340	1017	1016	134	12.5
1341	1016	1018	36	12.5
1342	1018	1019	50	12.5
1343	1019	3228	24	12.5
1344	1004	1020	171	20
1345	1021	1020	50	20
1346	1021	3230	124	20
1347	1066	1006	103	10

1348	1732	3781	95	10
1349	1762	1796	71	10
1350	1762	1767	179	10
1351	1767	1911	69	10
1352	1777	3781	24	12.5
1353	1778	3789	119	10
1354	1796	1910	108	20
1355	1778	3781	31	12.5
1356	1778	3803	42	12.5
1357	1839	1762	110	10
1358	1762	3811	236	10
1359	1911	1839	118	10
1360	1911	1777	230	10
1361	1777	1916	23	10
1362	1913	3830	142	20
1363	1913	1910	36	20
1364	1914	776	71	10
1365	1915	3285	62	12.5
1366	1916	784	32	10
1367	1917	3832	83	10
1368	1918	1917	53	10
1369	1913	1918	57	10
1370	1919	1918	29	10
1371	1915	1914	117	10
1372	1917	1915	106	10
1373	1796	3835	46	20
1374	3145	413	4	10
1375	3225	632	12	10
1376	3146	415	9	10
1377	597	1754	259.72	15
1378	597	960	282.13	15
1379	960	3785	49.54	10
1380	1731	1746	106.95	15
1381	1745	1905	82.18	15
1382	1746	1745	145.09	15
1383	1745	1749	98.4	10
1384	960	1749	268.9	15
1385	1749	1731	117.29	15
1386	1750	1731	111.92	15
1387	1753	1755	61.49	10
1388	1754	3785	47.28	10
1389	1755	3785	98.1	10
1390	1753	1754	83.04	15
1391	1905	1753	98.25	15
1392	3207	597	91.8	10
1393	3232	650	68	30
1394	3064	131	5	20
1395	3218	3219	25.5	10
1396	631	3221	402	12.5
1397	3221	3222	5	12.5
1398	3222	3220	7	12.5
1399	577	603	12.5	15
1400	603	578	38	15
1401	159	412	11	10
1402	412	3076	25.5	10
1403	658	652	51.5	20
1404	651	658	17	20
1405	990	991	69.5	10
1406	991	992	12.5	10
1407	992	3402	10.5	10
1408	440	3163	89.83	12.5
1409	628	629	5.1	10
1410	783	3292	11.6	10
1411	3292	813	110.8	10

1412	782	3299	29.3	15
1413	3299	3209	13.5	15
1414	3209	599	10.5	15
1415	769	768	57.2	15
1416	768	767	4.8	15
1417	3298	820	127	20
1418	801	3298	8	20
1419	637	634	75.7	20
1420	634	633	15.8	20
1421	633	3226	57.2	10
1422	3226	643	8.8	10
1423	967	1017	18.1	20
1424	1017	1004	28.4	20
1425	817	828	18.7	15
1426	828	816	27.9	15
1427	3302	824	54.6	12.5
1428	826	3302	13.1	12.5
1429	1910	1919	67.4	12.5
1430	1919	1839	9	12.5
1431	3065	163	143.1	20
1432	133	3065	9.4	20
1433	779	785	55.9	15
1434	785	780	7.6	15
1435	3212	511	41	25
1436	511	604	16	25
1437	511	3300	18	10
1438	608	519	207	10
1439	628	520	207	10
1440	137	521	79	10
1441	3213	591	15	25

Node data that include node number, topographical elevation, X and Y coordinates of each node and their corresponding nodal weights can be seen in Table 6.

Table 6. Node data

Node No:	Elevation (m)	X (m)	Y (m)	Nodal Weight
1	1118.37	482751.10	4429439.13	0.0022410980
2	1113.28	482732.11	4429472.17	0.0012962026
3	1116.81	482780.48	4429520.83	0.0020351593
100	1129.99	482599.50	4429193.58	0.0039007220
101	1128.07	482644.91	4429172.29	0.0026166334
102	1125.20	482683.66	4429277.52	0.0023016682
103	1118.14	482694.44	4429151.05	0.0017928784
104	1113.76	482715.08	4429137.95	0.0025076070
105	1098.59	482791.22	4429116.25	0.0047487050
106	1101.36	482813.22	4429179.51	0.0033313619
107	1121.21	482714.04	4429215.12	0.0029437125
108	1118.94	482638.85	4429034.80	0.0037068973
109	1092.01	482746.54	4428867.69	0.0046154505
110	1104.48	482681.49	4428929.79	0.0046275646
111	1117.07	482644.63	4429021.97	0.0030406249
112	1128.17	482588.12	4429300.44	0.0044579680
113	1123.41	482579.70	4429374.30	0.0029800547
115	1090.82	482788.86	4428943.07	0.0042883714
116	1097.24	482762.97	4429010.84	0.0022047559
117	1087.76	482830.17	4429019.59	0.0029800547

118	1100.21	482750.06	4429047.62	0.0026287474
119	1119.73	482732.35	4429272.84	0.0024106946
120	1119.85	482711.47	4429356.46	0.0031496513
121	1100.53	482239.99	4429185.50	0.0054876617
122	1114.86	482325.83	4429255.80	0.0053301791
123	1108.40	482357.49	4429429.48	0.0045548803
124	1110.37	482402.73	4429439.13	0.0026772036
125	1109.76	482450.54	4429449.63	0.0039976343
126	1122.92	482490.10	4429344.42	0.0026287474
127	1127.57	482540.15	4429282.06	0.0027862300
128	1123.77	482525.20	4429360.22	0.0031981075
129	1120.41	482536.38	4429093.61	0.0042883714
130	1118.47	482502.48	4429144.11	0.0033313619
131	1120.01	482416.44	4429306.26	0.0013204307
132	1114.07	482489.58	4429045.94	0.0064083290
133	1097.16	482385.14	4428939.58	0.0041599625
134	1084.56	482313.45	4428867.53	0.0043731697
135	1109.73	482435.15	4429072.87	0.0039249501
136	1094.85	482337.37	4429007.50	0.0039734062
137	1106.20	482337.23	4429157.71	0.0029194844
138	1084.24	482522.40	4428793.72	0.0049061876
139	1102.88	482494.22	4428921.64	0.0049304157
140	1083.91	482178.43	4429001.90	0.0042278012
141	1079.55	482131.75	4429009.71	0.0022653261
144	1119.97	482451.94	4429236.52	0.0034161602
145	1110.40	482364.54	4429174.54	0.0014779133
146	1097.71	482267.36	4429113.88	0.0026045193
147	1093.11	482222.56	4429078.38	0.0027135457
148	1090.63	482181.68	4429103.54	0.0039007220
149	1081.59	482130.86	4429117.55	0.0041066607
159	1115.82	482740.85	4429402.39	0.0009691234
160	1118.21	482694.08	4429386.53	0.0024228087
161	1119.92	482439.20	4429318.71	0.0025318351
162	1107.06	482275.70	4429228.91	0.0028710283
163	1085.40	482478.59	4428819.56	0.0023513358
164	1080.91	482606.67	4428775.06	0.0067959784
165	1080.75	482732.03	4428784.07	0.0043973978
408	1090.41	482920.20	4429180.60	0.0016596239
409	1092.71	482903.07	4429200.97	0.0059722234
410	1097.02	482900.40	4429237.90	0.0036039279
411	1117.48	482760.16	4429402.55	0.0050515561
412	1116.32	482740.54	4429413.24	0.0005875311
413	1118.37	482755.23	4429419.73	0.0003270791
415	1129.66	482851.17	4429425.58	0.0005935881
416	1124.45	482823.72	4429413.16	0.0015990537
419	1128.67	482611.16	4429138.77	0.0030527389
420	1098.54	482709.15	4428894.82	0.0037432394
440	1079.97	482281.91	4428835.25	0.0016333364
452	1103.58	484975.60	4428844.30	0.0028589142
511	1094.87	483858.49	4429222.61	0.0009085532
519	1091.70	483411.73	4428974.77	0.0025076070
520	1091.70	483396.42	4428974.77	0.0025076070

521	1097.90	482270.20	4429115.75	0.0009570094
574	1094.31	483850.90	4429273.30	0.0002543949
575	1097.09	483830.20	4429273.50	0.0039491782
576	1105.49	483783.30	4429274.20	0.0026650895
577	1112.96	483721.80	4429277.20	0.0009024962
578	1118.09	483671.00	4429278.50	0.0035857568
579	1121.84	483615.30	4429232.20	0.0021926418
580	1123.67	483551.10	4429151.90	0.0041308888
581	1122.68	483469.40	4429099.60	0.0017201941
582	1123.47	483429.90	4429094.50	0.0011629481
583	1124.89	483373.80	4429098.40	0.0017444222
584	1125.73	483286.50	4429112.40	0.0018534486
585	1124.51	483222.40	4429125.20	0.0010902639
586	1123.23	483197.30	4429129.60	0.0012356324
587	1119.80	483124.70	4429153.90	0.0055845740
588	1137.56	482907.10	4429424.40	0.0055482319
589	1081.14	482938.90	4429054.67	0.0048456174
590	1074.85	482946.91	4428966.22	0.0037795815
591	1070.08	482949.20	4428871.60	0.0064446711
592	1085.43	482939.10	4429106.50	0.0017323082
593	1080.05	482950.40	4429040.10	0.0015263694
594	1070.34	482984.30	4428882.30	0.0048092752
595	1078.53	483675.80	4429453.40	0.0103696212
596	1064.65	483295.40	4429621.00	0.0050636702
597	1061.91	483750.90	4429523.30	0.0076760636
599	1092.26	483867.17	4429275.36	0.0025742342
602	1077.13	483866.50	4429461.50	0.0044700820
603	1114.32	483709.16	4429276.58	0.0013143737
604	1094.91	483852.10	4429208.00	0.0009206673
605	1094.44	483843.10	4429191.90	0.0056451442
606	1093.24	483714.60	4429010.10	0.0037311254
607	1094.37	483694.40	4428995.10	0.0024470368
608	1090.59	483611.20	4428938.90	0.0093035854
609	1091.54	483702.90	4428985.50	0.0019140188
610	1089.81	483651.90	4428943.30	0.0058389689
611	1078.70	483248.10	4428883.60	0.0083708040
612	1079.44	483161.60	4428912.50	0.0090067913
616	1092.50	483867.00	4429176.60	0.0078620142
617	1082.93	483856.10	4429046.00	0.0044700820
618	1103.75	483091.80	4429089.80	0.0026772036
619	1106.86	483070.20	4429131.10	0.0013204307
620	1110.58	483039.10	4429184.60	0.0012235184
621	1112.43	483014.60	4429214.30	0.0016959661
622	1115.71	482948.70	4429290.50	0.0044034548
623	1076.01	482956.50	4428981.70	0.0025924053
624	1115.85	483123.00	4429131.50	0.0015263694
625	1079.74	483010.20	4429000.10	0.0026469185
626	1080.39	483080.70	4428947.80	0.0018655627
627	1117.82	483164.90	4429112.30	0.0031011951
628	1092.81	483194.00	4428973.30	0.0034173716
629	1092.85	483189.50	4428975.70	0.0024119060
630	1092.14	483110.40	4429006.10	0.0032829058

631	1116.62	483243.80	4429068.80	0.0072805401
632	1090.69	483722.80	4429001.90	0.0004603336
633	1110.26	484970.33	4428736.39	0.0024470368
634	1110.67	484976.00	4428721.60	0.0016535669
635	1113.44	484949.20	4428685.70	0.0020351593
636	1109.19	484931.20	4428657.10	0.0041308888
637	1108.19	485026.30	4428669.90	0.0031702452
638	1107.31	485004.30	4428616.30	0.0026893176
639	1095.77	484974.90	4428542.20	0.0080558389
640	1092.07	484966.50	4428520.50	0.0026650895
641	1107.37	484871.80	4428816.60	0.0048335033
642	1092.87	485028.50	4428500.60	0.0030769670
643	1105.36	485035.10	4428747.70	0.0011726394
644	1104.78	485023.70	4428771.50	0.0030285108
645	1103.69	485001.40	4428815.70	0.0026166334
646	1102.04	484899.40	4428896.60	0.0022653261
647	1094.72	484899.90	4428953.30	0.0033798181
648	1091.72	484846.60	4428968.20	0.0098123752
649	1089.47	485002.80	4428944.70	0.0038401518
650	1084.82	484815.21	4429013.71	0.0016475099
651	1084.24	484836.23	4429020.28	0.0011266060
652	1084.47	484904.40	4429014.70	0.0032162785
656	1077.41	484843.60	4428597.70	0.0086857692
657	1104.62	484889.60	4428860.10	0.0027135457
658	1084.15	484853.13	4429021.28	0.0015687686
666	1092.54	484994.10	4428508.60	0.0015748256
766	1077.98	483867.00	4429504.50	0.0030163968
767	1098.48	484001.80	4429428.00	0.0026626667
768	1098.54	484000.90	4429423.30	0.0024470368
769	1097.98	483979.36	4429371.21	0.0034428111
770	1098.47	484007.00	4429499.60	0.0038159237
771	1103.82	483997.80	4429600.70	0.0022410980
772	1110.73	484141.20	4429394.10	0.0034767305
773	1108.82	484131.90	4429502.80	0.0028831423
774	1107.88	484120.70	4429548.80	0.0022410980
775	1107.58	484108.60	4429566.70	0.0020472733
776	1105.18	484057.15	4429593.58	0.0022895542
777	1112.87	484066.90	4429298.80	0.0043004854
778	1086.90	484323.60	4429381.30	0.0043973978
779	1095.94	484278.30	4429372.10	0.0049170902
780	1106.63	484215.40	4429362.70	0.0021151120
781	1112.24	484165.30	4429350.90	0.0040460905
782	1094.59	483920.50	4429275.20	0.0024385569
783	1099.68	483953.90	4429240.60	0.0024058490
784	1104.23	484204.60	4429620.30	0.0050394421
785	1105.49	484223.00	4429363.70	0.0040158054
789	1110.74	484056.80	4429128.80	0.0036342130
790	1081.28	484134.70	4428644.40	0.0022895542
791	1088.74	484133.00	4428695.60	0.0041551169
792	1115.01	484185.80	4428974.30	0.0034888445
793	1115.26	484141.80	4429006.60	0.0030406249
794	1119.53	484128.80	4429106.30	0.0024712648

795	1120.17	484123.30	4429143.30	0.0016959661
796	1120.28	484118.80	4429178.20	0.0029558266
797	1119.35	484194.30	4429106.70	0.0033313619
798	1119.09	484198.90	4429185.50	0.0036099849
799	1077.47	484233.50	4428643.60	0.0026529755
800	1089.07	484235.70	4428700.60	0.0034403883
801	1109.37	484266.00	4428934.60	0.0033919321
802	1113.20	484264.10	4429110.60	0.0033434760
803	1114.04	484256.20	4429131.70	0.0020593874
804	1114.11	484247.20	4429188.80	0.0018897907
805	1089.99	484338.20	4429320.60	0.0029800547
806	1100.78	484301.10	4429289.00	0.0028589142
807	1083.49	484022.80	4428666.50	0.0033434760
808	1085.97	484044.60	4428675.20	0.0032465636
809	1087.74	484189.00	4428700.60	0.0020109312
810	1090.42	484311.70	4428698.80	0.0033798181
813	1102.14	483981.20	4429121.20	0.0022871314
814	1104.16	484003.70	4429122.50	0.0024470368
815	1106.37	484049.60	4429005.80	0.0034767305
816	1101.06	483985.80	4428983.80	0.0023489130
817	1095.65	483944.90	4429002.40	0.0038849737
818	1104.86	484085.60	4428865.70	0.0024106946
819	1106.34	484149.80	4428839.40	0.0049304157
820	1102.17	484246.80	4428803.70	0.0068202065
821	1104.26	484197.20	4428822.60	0.0012477464
822	1094.86	483898.80	4429219.40	0.0022895542
823	1094.82	483926.10	4429114.60	0.0033555900
824	1089.43	483961.80	4428818.00	0.0049255701
825	1074.99	484077.70	4428601.10	0.0020472733
826	1099.46	484025.80	4428831.00	0.0032114329
827	1104.28	484050.10	4428912.20	0.0026893176
828	1098.56	483962.80	4428999.50	0.0027813844
829	1077.06	484192.00	4428637.70	0.0019745891
834	1104.99	484339.90	4429162.00	0.0027014317
835	1109.92	484260.00	4429255.10	0.0023501244
836	1113.04	484240.60	4429238.60	0.0009085532
837	1093.61	483903.10	4429589.00	0.0019503610
838	1080.21	483844.70	4429565.40	0.0015505975
960	1057.52	483509.68	4429593.30	0.0072753311
967	1079.58	485286.80	4428772.80	0.0025572745
990	1070.73	485201.40	4428411.50	0.0029739976
991	1058.28	485233.00	4428349.60	0.0011508341
992	1056.86	485245.70	4428350.60	0.0004118774
993	1101.45	485077.80	4428600.20	0.0033071338
1000	1075.12	485310.10	4428719.80	0.0025681772
1001	1081.60	485210.20	4428609.80	0.0027498878
1002	1085.82	485148.00	4428510.30	0.0047971612
1004	1075.60	485328.40	4428793.50	0.0029001020
1005	1093.94	485153.80	4428753.80	0.0029073704
1006	1101.14	485091.90	4428748.30	0.0027498878
1007	1086.35	485184.40	4428616.40	0.0023016682
1008	1099.79	485103.40	4428637.00	0.0029921687

1012	1095.41	485143.30	4428711.60	0.0023380104
1013	1087.29	485110.10	4428484.70	0.0029800547
1014	1086.80	485205.40	4428692.90	0.0023985806
1015	1077.97	485255.90	4428673.40	0.0024712648
1016	1086.71	485185.60	4428827.70	0.0041672309
1017	1079.24	485302.69	4428781.54	0.0021865848
1018	1087.22	485157.50	4428849.60	0.0010418077
1019	1087.28	485118.00	4428879.60	0.0008964392
1020	1075.97	485212.20	4428917.50	0.0026772036
1021	1077.12	485169.10	4428943.40	0.0021078435
1066	1103.63	485071.70	4428647.50	0.0022653261
1731	1041.36	483169.93	4429763.09	0.0040722568
1732	1094.98	484272.90	4429633.50	0.0043004854
1745	1037.68	483339.65	4429812.76	0.0039451805
1746	1031.05	483202.83	4429859.97	0.0030532235
1749	1047.62	483282.58	4429733.18	0.0058703443
1750	1036.69	483064.37	4429797.41	0.0013558037
1753	1040.20	483488.28	4429742.23	0.0029410474
1754	1042.98	483545.99	4429682.56	0.0047249615
1755	1047.17	483444.92	4429698.62	0.0019332802
1762	1089.99	483826.32	4429848.85	0.0072199699
1767	1085.10	483993.39	4429793.09	0.0030042828
1777	1102.82	484201.86	4429668.99	0.0033555900
1778	1090.91	484206.91	4429724.03	0.0023258963
1796	1087.47	483756.63	4429838.23	0.0027256598
1839	1090.01	483864.16	4429745.71	0.0028710283
1905	1040.03	483420.76	4429813.59	0.0021857368
1910	1086.12	483788.81	4429734.91	0.0025609088
1911	1100.08	483980.57	4429725.23	0.0050515561
1913	1085.21	483800.31	4429700.78	0.0028468002
1914	1104.75	484089.81	4429656.57	0.0022774401
1915	1102.51	483976.12	4429682.04	0.0034525024
1916	1103.78	484216.33	4429650.51	0.0043489416
1917	1090.20	483871.80	4429665.60	0.0029315985
1918	1089.53	483855.57	4429716.10	0.0016838520
1919	1090.03	483855.17	4429745.18	0.0012768201
3009	1135.50	482865.72	4429486.50	0.0015021414
3010	1110.47	482751.91	4429548.70	0.0004845617
3011	1114.76	482823.44	4429560.81	0.0007147285
3057	1084.93	482794.71	4428841.39	0.0008116409
3058	1075.52	482833.46	4428790.43	0.0011387200
3059	1083.68	482816.11	4428850.30	0.0011750622
3060	1094.47	482357.21	4429476.07	0.0041187748
3061	1110.34	482718.84	4429473.94	0.0044095118
3062	1107.96	482446.98	4429457.58	0.0014657992
3063	1111.45	482516.51	4429445.78	0.0010660358
3064	1120.01	482413.23	4429304.02	0.0029315985
3065	1096.69	482390.63	4428931.99	0.0031314802
3066	1088.13	482479.20	4428838.92	0.0010175796
3067	1074.75	482099.81	4429013.08	0.0003876493
3068	1086.31	482184.89	4429318.47	0.0026650895
3071	1077.96	482147.17	4429290.49	0.0021441857

3076	1114.98	482728.20	4429435.25	0.0003089081
3077	1102.17	482269.04	4429349.96	0.0014779133
3078	1099.15	482254.90	4429133.83	0.0006662723
3079	1088.97	482353.08	4428885.41	0.0042156871
3144	1114.82	482815.80	4429358.71	0.0043247135
3145	1117.83	482751.55	4429418.46	0.0001938247
3146	1129.06	482857.26	4429419.63	0.0007389566
3147	1124.67	482845.48	4429406.54	0.0069776890
3149	1086.12	482867.96	4429049.23	0.0005814740
3150	1127.24	482654.93	4429280.31	0.0003513072
3163	1068.28	482331.00	4428760.20	0.0010882045
3204	1145.57	482955.90	4429434.60	0.0006057021
3205	1066.07	482870.70	4428705.50	0.0033919321
3206	1067.08	482922.10	4428778.90	0.0014779133
3207	1073.31	483823.20	4429466.70	0.0035591059
3209	1092.15	483877.73	4429275.68	0.0025439491
3210	1109.62	483693.00	4429331.80	0.0007026145
3211	1098.90	483732.50	4429362.80	0.0013446588
3212	1092.75	483865.91	4429262.19	0.0009933515
3213	1070.19	482960.30	4428881.70	0.0039794633
3215	1064.62	483897.40	4428725.30	0.0056693723
3216	1065.95	483857.30	4428817.00	0.0027862300
3218	1079.99	483005.10	4429006.60	0.0010781498
3219	1081.67	482994.29	4429029.84	0.0003089081
3220	1106.33	483650.78	4429052.86	0.0000847983
3221	1106.40	483639.77	4429048.18	0.0065779256
3222	1106.28	483644.70	4429049.50	0.0010660358
3223	1074.71	483758.60	4428949.80	0.0007995268
3224	1078.92	483770.40	4428987.10	0.0007268426
3225	1090.29	483731.60	4429010.00	0.0028710283
3226	1106.05	485026.93	4428744.73	0.0017323082
3227	1109.03	484876.20	4428736.20	0.0010781498
3228	1087.55	485098.30	4428893.30	0.0031254232
3229	1084.65	484789.10	4428982.40	0.0005572460
3230	1083.31	485052.70	4428982.80	0.0033434760
3232	1075.45	484797.01	4429079.10	0.0086251990
3233	1074.22	484850.90	4429082.10	0.0007389566
3234	1078.90	484970.30	4428448.50	0.0007874128
3285	1105.15	483994.40	4429623.40	0.0022168699
3286	1113.05	484140.30	4429359.60	0.0025439491
3287	1103.72	484203.70	4429535.70	0.0009933515
3288	1076.33	484379.40	4429393.50	0.0006905004
3289	1104.62	484146.50	4429647.50	0.0010781498
3292	1099.97	483955.70	4429229.10	0.0036511727
3293	1116.74	484102.40	4429305.70	0.0015627116
3294	1092.74	484390.00	4429222.70	0.0013446588
3295	1077.64	484368.60	4428655.10	0.0010054656
3297	1114.32	484199.40	4428967.60	0.0016838520
3298	1109.03	484265.68	4428926.64	0.0050152140
3299	1091.99	483891.20	4429276.50	0.0012210955
3300	1094.85	483875.40	4429217.80	0.0004966757
3301	1109.22	484111.80	4428935.10	0.0007995268

3302	1097.66	484015.27	4428823.24	0.0026856834
3307	1071.32	484411.70	4429365.40	0.0010418077
3402	1054.96	485250.43	4428341.32	0.0001271974
3403	1058.65	485220.40	4428347.90	0.0001574825
3404	1055.68	485256.10	4428352.50	0.0001332544
3405	1067.43	485239.70	4428443.20	0.0007752987
3409	1069.96	485390.40	4428737.90	0.0009933515
3410	1070.66	485367.00	4428804.00	0.0004845617
3412	1068.02	485143.50	4428397.50	0.0011266060
3781	1098.43	484203.34	4429693.20	0.0018171065
3785	1048.14	483524.07	4429640.67	0.0023612693
3789	1094.31	484288.18	4429642.48	0.0014415711
3803	1079.95	484211.08	4429765.83	0.0005087898
3811	1059.45	483744.12	4430069.91	0.0028589142
3830	1080.23	483844.71	4429565.42	0.0017201941
3832	1093.63	483903.14	4429589.03	0.0010054656
3835	1085.63	483742.24	4429881.45	0.0005572460
5001	1073.24	484475.93	4429367.34	0.0000000000
5002	1124.06	483397.39	4429087.19	0.0000000000
5003	1119.50	483115.82	4429149.26	0.0000000000
5004	1122.94	483553.97	4429136.24	0.0000000000
5005	1098.24	483886.99	4429262.87	0.0000000000
5006	1100.20	483936.40	4429257.15	0.0000000000
5007	1111.30	484053.98	4429303.39	0.0000000000
5008	1108.04	484218.87	4429375.10	0.0000000000
5009	1097.76	484275.04	4429384.04	0.0000000000
5010	1089.76	484318.08	4429392.89	0.0000000000
5011	1076.74	484756.78	4429159.12	0.0000000000
5012	1088.37	484600.89	4429117.27	0.0000000000
5013	1101.08	483831.93	4429263.09	0.0000000000
5014	1118.81	483125.89	4429144.25	0.0000000000
5015	1123.64	483562.93	4429147.37	0.0000000000
5016	1099.43	483845.51	4429262.73	0.0000000000
5017	1098.24	483896.65	4429263.19	0.0000000000
5018	1100.79	483944.10	4429254.12	0.0000000000
5019	1111.81	484060.80	4429308.79	0.0000000000
5020	1106.57	484228.88	4429376.65	0.0000000000
5021	1095.91	484284.78	4429386.05	0.0000000000
5022	1087.62	484328.62	4429395.11	0.0000000000
5023	1075.02	482989.99	4429468.50	0.0000000000
5024	1047.33	484526.69	4429367.91	0.0000000000
5025	1047.33	484517.31	4429364.07	0.0000000000
5026	1047.33	484504.33	4429360.49	0.0000000000
10000	1148.80	482990.00	4429480.92	0.0000000000
11000	1047.33	484524.97	4429345.16	0.0000000000

The network map of N8 pressure zone was sent in a format that can be used in MapInfo. However, the network has been separated into grids and copied as doc files that can be opened as Word Document (Figure 4). This enables the redrawing of the network in any other format by looking at the shape of it using the data, covering node and pipe characteristics. Further, the necessary data to run a hydraulic analysis program can be found in this report.

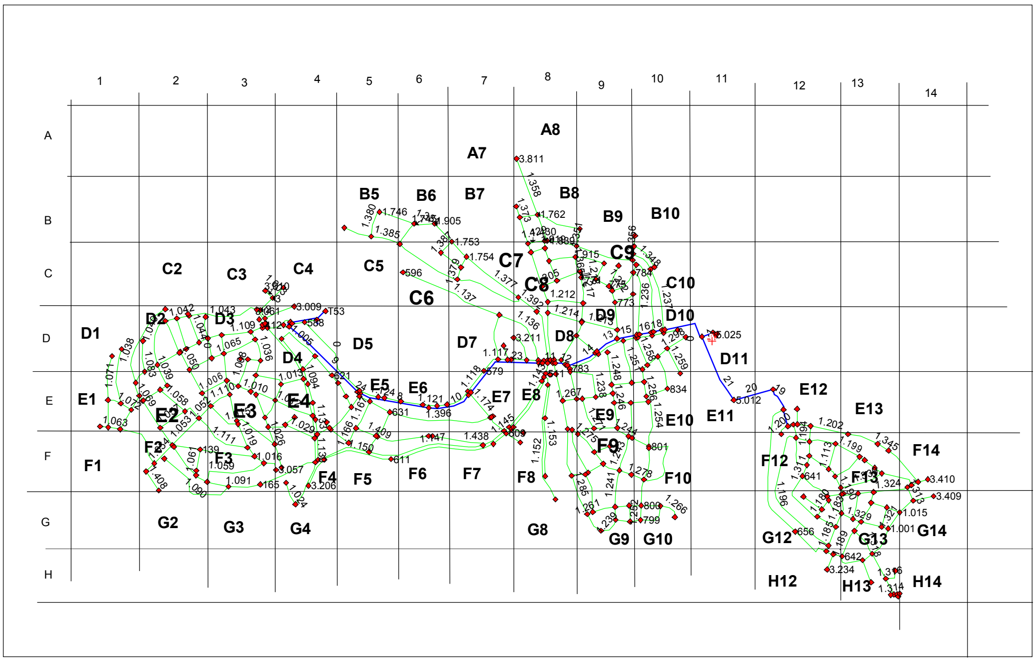


Figure 4. N8 pressure zone with grids

References

1) Cesario, L., Modeling, Analysis and Design of Water Distribution Systems, U.S.A, AWWA, 1995.
2) Özkan, T., Determination of Leakages in a Water Distribution Network Using SCADA Data , M.Sc. Thesis, METU, Dept. of Civil Eng., 2001.

Chapter III: The Cluster Details

As part of the project, a cluster computer has been installed in JUST. The cluster is nopw up and running. It costs of an 8-port optical switch that connects Pentuim 4 PC via fiber optic cables that are capable of transferring giga bits of data at a second rate. In this section of the report we summeraize the details iof this cluster. Also we will outline the installation details.

Myrinet Components

In order to setup any cluster, one must proceed through many steps, starting from understanding the concept of computer clusters, moving through the process of "plugging" all the underlying hardware together, and ending with installing the proper drivers and the various software that will control the operation of the cluster.

We have used Myricom Inc. products to setup our cluster. Generally speaking, those products can be categorized into hardware and software which will explain next what is behind each of them.

Hardware Products

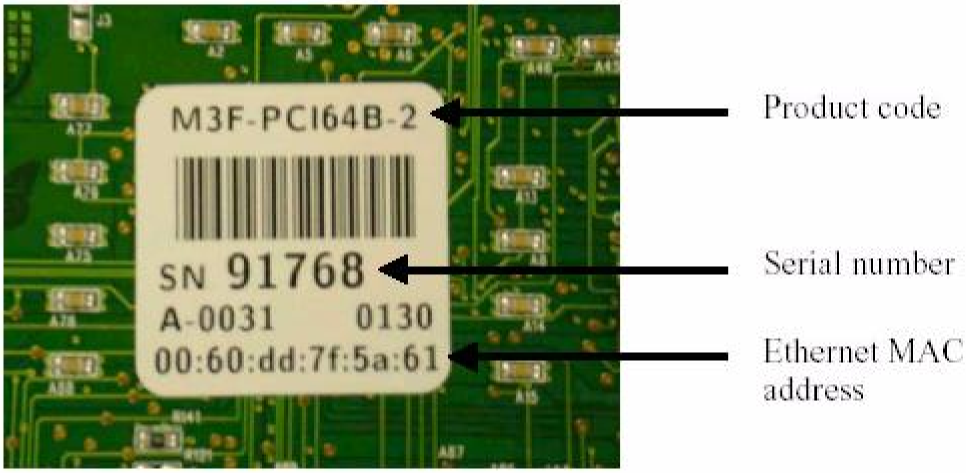
Our cluster is constructed from 3 components (in addition to the PC's used for processing): Thes the PCI Interfaces, the switch, and the cables.

Myrinet/PCI Host Interfaces: These are the Interfaces at the "desktop" end… each PC connected to the cluster should have one of these cards connected to its motherboard through the (PCI Bus).
The PCI Bus is a bus standard, well known for its reliability, and the high performance it can reach. It simply connects the interfaces card to the CPU.

When talking about the Host interfaces, we have many choices; one can use the traditional serial cards, the new fiber cards, or some special cards to support MAN/LAN applications. We choose the fiber cards for its extraordinary performance. Our interfaces are: M3F-PCI64B-2, they have a Myrinet-Fiber ports, has the "PCI Short Card" form factor, is of the 64B type (Myricom LANai 9 RISC processor operating at 133MHz), and has 2MB of local memory. The figure below shows how these interfaces looks like:

PCI short card (PCI64B, fiber connector)

Identification on each Myrinet/PCI interface: A label similar to that below appears on any Myrinet/PCI interface. This label contains the product code, the serial number, and the Ethernet MAC address.



The label on a Myrinet/PCI interface

The installation Process for the M3F-PCI64B-2 is done through the following steps:

Step 1: Power off the host to which you will be installing the card(s). Remove the exterior covering of the machine, and locate the PCI slot(s).

Step 2: Insert the Myrinet/PCI interface into a PCI slot. (As shown below)

Step 3: Secure the card in place with a locking screw (if applicable), replace the exterior cover of the host, and attach the Fiber cable between the card and the switch

Step 4: Power on the host and check that the card is detected by the host operating system.

This step is dependent on the operating system in use, in our case; we use the Linux operating system, this is the method for checking that the card is detected:

Issue the command **/sbin/lspci**, which will return all devices attached to the PCI bus.

```
[susan@athlon2 ~]# /sbin/lspci
00:00.0 Host bridge: Advanced Micro Devices [AMD] AMD-751 [Irongate] System Cont
roller (rev 23)
00:01.0 PCI bridge: Advanced Micro Devices [AMD] AMD-751 [Irongate] AGP Bridge (
rev 01)
00:07.0 ISA bridge: Advanced Micro Devices [AMD] AMD-756 [Viper] ISA (rev 01)
00:07.1 IDE interface: Advanced Micro Devices [AMD] AMD-756 [Viper] IDE (rev 03)
00:07.3 Bridge: Advanced Micro Devices [AMD] AMD-756 [Viper] ACPI (rev 03)
00:0f.0 Display controller: Texas Instruments TVP4020 [Permedia 2] (rev 01)
00:12.0 Ethernet controller: Lite-On Communications Inc LNE100TX (rev 20)
00:13.0 Multimedia audio controller: ESS Technology ES1969 Solo-1 Audiodrive (re
v 02)
00:14.0 Non-VGA unclassified device: MYRICOM Inc.: Unknown device 8043 (rev 03)
[susan@athlon2 ~]#
```

If the output you receive is similar to that above, namely you see the "MYRICOM Inc" entry, the Myrinet/PCI interface has been correctly detected

Myrinet Switch (M3-E16): Typically, a switch is a device that provides bridging functionality, it normally has a buffer for each link to which it is connected. When it receives a packet, it stores the packet in the buffer of receiving link and checks the address to find the outgoing link, if the outgoing link is free (no chance of collision), the switch send this frame to that particular link.
The installation of Myrinet switches is very easy, all what you have to do is to switch the power **ON**, and to connect the PCI/Host interfaces with the switch port (through a fiber cable in our case), it is hot swappable, you can plug the fiber in the switch while it is running, and the switch will detect it correctly.

Myrinet Fiber Cables: Although all Myrinet links carry packets in the same format at the Data Link level, Myrinet has five different Physical level (PHY) implementations over four different types of cables (Serial, Fiber, SAN, LAN). It is important to understand the characteristics of the types of cables used at your site, and how to install them. All Myrinet cables may be plugged or unplugged with the component power on. In our cluster, we have used the Fiber cable. Fiber is the preferred Myrinet PHY for several reasons:

- The fiber cables are small, light, flexible, and easy to install.
- The fiber cables and connectors exhibit exceptionally high reliability.
- Myrinet-Fiber cables may be up to 200m in length.
- Myrinet-Fiber components and cables operate within Class A limits for the emission of electromagnetic interference (EMI).

Myricom ships Fiber components with a dust plug in each port. It is recommended that the dust plug be left in place in unused switch ports. The fiber cable is shipped with dust caps on the ends of the fibers. To install the fiber cable, we just removed the dust plug and dust caps, and inserted the fiber-end connector.

Software Products:

Myricom supplies and supports Myrinet software (low-level firmware and a choice of middleware) for a variety of operating systems and processors. At present, the following middleware's are available: MPICH-GM, VI-GM, Sockets-GM, and PVM-GM.

The first Myrinet software package that must be installed is GM, the low-level message-passing system for Myrinet. GM includes a driver, Myrinet-interface control program, a network mapping program, and the GM API, library, and header files. We will discuss next the GM software installation on the Linux operating system:

GM installation is performed in 4 easy steps:

1. Configuring and compiling GM. First, we downloaded the GM from Myricom website, the URL is:

ftp://comrade@ftp.myri.com/pub/GM/gm-1.6.3_Linux.tar.gz

Then, we issue the command to unzip the file: gunzip -c gm-1.6.3_Linux.tar.gz | tar xvf –

Then, we run the configuration script for the Linux OS:
cdgm-1.6.3_Linux
./configure --with-linux=<linux-source-dir>
make

2. Installing the GM driver. After we selected the installation directory path <install_path> (we choose it to be /GM). Next, we issued the command to install the GM middleware:

cd binary
./GM_INSTALL <install_path>

you must start the driver (On each machine to install/copy the driver on that machine):
su root

<install_path>/sbin/gm_install_drivers
/etc/init.d/gm start

Green "link" LEDs have been illuminated on interfaces and ports on the line cards when the hardware is connected through a cable to an operating component and the GM firmware has been loaded.

Also, a yellow "LANai" LED has illuminated on the faceplate of the Myrinet PCI/Host interface. The yellow "LANai" LED is controlled by the LANai processor, and will pulse like a heartbeat while the GM MCP/firmware is running, and will pulse faster when there is more packet-sending activity (including sending acknowledge packets in reply to packets received.)

3. Run the GM mapper

cd <install_path>/sbin/
su root
./mapper ../etc/gm/map_once.args

The GM mapper is ONLY run on one node in the cluster (mapper node), and any subsequent invocations of the mapper should be done on this node only. The GM mapper must be run before any communication over Myrinet can occur.

4- Testing/Validation

Once the GM software is properly installed on all hosts/nodes in your cluster, we have validated our Myrinet installation by performing a sequence of tests. These test are provided by the Myrinet, we perform them all, and the results were identical to what is mentioned in the installation manual of the GM software

Message Passing Interface (MPI)

MPI is a library specification for message passing, proposed as a standard by a broadly based committee of vendors, implementers, and users. MPICH is a portable implementation of MPI, developed by Argonne National Laboratory. MPICH is designed to be highly portable and is currently used by a large number of providers of MPI implementations. MPICH-GM is a port of MPICH on top of GM (ch_gm) and is supported by Myricom.

Linux operating System:

Linux looks and feels much like any other UNIX system; indeed, UNIX compatibility has been a major design goal of the Linux project. However, Linux is much younger than most UNIX systems. Its development began in 1991, when a Finnish student, Linus Torvalds, wrote and christened Linux, a small but self-contained kernel for the 80386 processor, the first true 32-bit processor in Intel's range of PC-Compatible CPU's.

In theory, anybody can install a Linux system by fetching the latest revisions of the necessary system components from the ftp sites and compiling them. In Linux's early days, this operation was often precisely the one that a Linux user had to carry out. As Linux has matured, however, various individuals and groups have attempts to make this job less painful by providing a standard, precompiled set of packages for easy installation.

These collections, or distributions, include much more than just the basic Linux system. They typically include extra system installations and management utilities, as well as precompiled and ready to install packages of many of the UNIX tools, such as servers, web browsers, text processing and editing tools, and even games!!

We have chosen to install Linux Redhat 8.0, as we stated above, we installed the precompiled distribution, and install it on all the PC's that form the cluster, the installation process is very easy, wizard driven, all the options are displayed on the monitor, and all what you have to do is to choose the options that suit your needs.

Chapter IV: The Web-based Solution

The project in JUST has developed an efficient system that is accessible from within a web browser such as the Internet Explorer. In this chapter we give the details on the system.

Linear System

We used a well-known method for solving a set of linear equations; this method is called (Gaussian Elimination with scaled partial pivoting), maybe it will be difficult to explain the theory behind this method, or to start drawing the algorithm we used to solve the equations! So, we prefer the learn-by-example methodology for this section of our report. We will give a numerical example, with a step-by-step working solution. Let our system be as follow:

3	1	2	9	|	5
2	1	2	1	|	- 2
6	1	1	8	|	2
-3	1	2	0	|	2

Pivot Scale: [9, 2, 8, 3]
Pivot Order [1, 2, 3, 4]

Determine the pivot row by taking the row corresponding to the largest of [3/9, 2/2, 6/8, 3/3]. Row 2 is the pivot row that will be used to eliminate the first variable from equations 1,3, and 4. The multipliers are: [3/2,X,6/2,3/2] and the result of the elimination is:

0	-1/2	-1	15/2	|	8
2	1	2	1	|	- 2
0	-2	-5	5	|	8
0	3/2	5	5/2	|	-1

Pivot Order [2, 1, 3, 4]

Determine the next pivot by taking the row corresponding to the largest of [[(1/2)/9], X,2/8,[(3/2)/4]] = [1/18, X, 1/4, 3/8]. Row 4 is the pivot row that will be used to eliminate the second variable from equations 1 and 3. The multipliers are: [1/3,X,4/3,X] and the result of the elimination is:

0	0	2/3	25/3	|	23/3
2	1	2	1	|	- 2
0	0	5/3	25/3	|	20/3
0	3/2	5	5/2	|	-1

Pivot Order [2, 4, 3, 1]

Determine the next pivot as the row corresponding to the largest of [2/27, X, 5/24, X]. Row 3 is the pivot row that will be used to eliminate the third variable from equation 1. The multiplier is: [2/5,X,X,X] and the result of the elimination is:

0	0	0	5	|	5
2	1	2	1	|	- 2
0	0	5/3	25/3	|	20/3
0	3/2	5	5/2	|	-1

Pivot Order [2, 4, 3, 1]

Back Substitution

The pivot order determines the order in which equations will be solved. The equations are taken in the reverse of the pivot order.

5z1 = 5 => z=1

Continue the same way; solving the next three simple equations will yield:

Y = -1, X = 1 ,and W = -1

Nonlinear Equations

Some of the equations involved in pipe network analysis are nonlinear. Since there is no direct method available for their solution, these aquations are first linearized and then solved. Naturally, the solution is approximate. Therefore it should be corrected and an iterative procedure should be continued until satisfactory accuracy is reached.

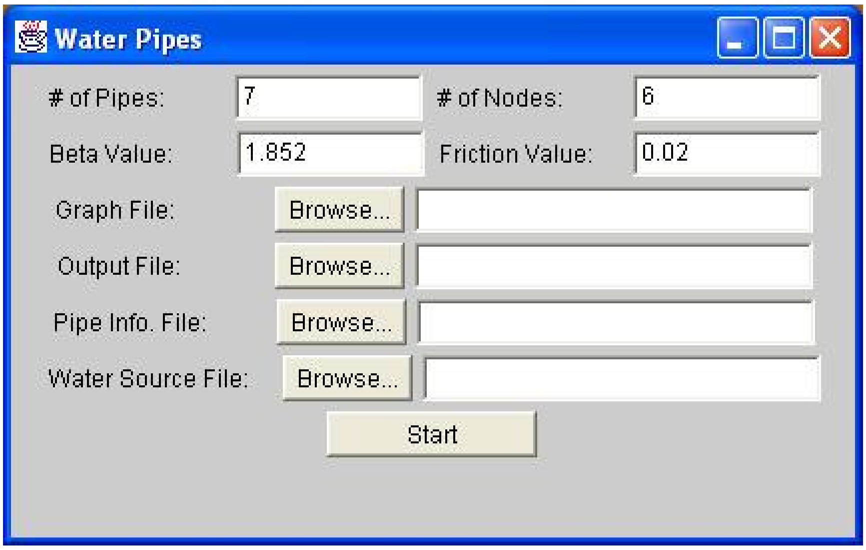
The nonlinearity in the equations for pipe network analysis is uniform and simple: the variables are raised to the same, nonunity exponent (n=2 in Darcy-Weisbach; n=1.852 for Hazen-Williams). This is a helpful feature and the nonlinear term can be easily linearized by merging a part of the nonlinear term into the pipe resistance term.

In order to undertsand the theory of the Linerization, you should refer to the (Linear Theory Method, Prepared by Civil Engineering Group (CEG), METU – ATILIM UNIVERSITY, PART III, September, 2002).

For now, we will explain how our system works with this type of equations. We will show in details how to operate the program, how to get the data in and out, and how to use all the functionality provided by the system.

The Main Screen

When you run the program, you will see the following screen:



From this screen, you enter all the data needed to run the program. We will now explain each field in details:

- # of pipes: Enter the number of pipes that the graph contains. Be aware, no negative values are accepted.

- # of Nodes: Enter the number of pipes that the graph contains. Be aware, no negative values are accepted.

- Beta value: this value takes one of two values, eithere n=2 (Darcy-Weisbach) or n=1.852 (Hazen-Williams).

- Friction Value: The value represents the friction of the pipes, thois value will be considered for ALL the pipes in the system.

- Graph file: The place where you specify the path of the Graph file (explained later)

- Output file: The place where you specify the path of the Output file (explained later)
- Pipe Info file: The place where you specify the path of the Pipe Info file (explained later)

- Water Source file: The place where you specify the path of the Water Source file (explained later)

Input Format

We have three input files in our system; we will explain here each one in details:

Graph File: This file contains a table that represents the water pipes in terms of numbers, these numbers represents the direction of the pipes between two nodes. So, if we have two nodes, we can represent the pipe between them using three values:

- 0: No pipe at all
- 1: Pipe in clockwise direction
- -1: Pipe in counterclockwise direction.

See this snapshot:

	A	B	C	D	E	F
1	0	0	-1	-1	0	0
2	0	0	1	-1	0	-1
3	1	-1	0	0	0	0
4	1	1	0	0	-1	0
5	0	0	0	1	0	1
6	0	1	0	0	-1	0
7						

For example, the above table tells us that a pipe in clockwise direction exists between nodes 3 and 1, a pipe in counterclockwise direction exists between nodes 3 and 2, and no connection at all between nodes 3 and 4.

So, you have only to map the water pipes graph you want to analyze, into the format described above. And then you enter the file location in the system main screen.

Pipe Information File

This file contains useful information about the pipes. We are concerned about the pipes length and diameter, and this is the place where we define these values. This is how this file looks like:

	A	B	C	D
1	0	2	7.737814	0.2
2	0	3	3.868907	0.2
3	2	1	1.934453	0.2
4	1	3	5.803361	0.2
5	3	4	7.737814	0.2
6	1	5	3.868907	0.2
7	5	4	9.672268	0.2
8				

- The numbers (1 to 7) represents the pipe number.
- Column A and B represents the nodes that the pipe resides in between. A is the (From) node, and B is the (To) node. So, pipe 3 resides from node 2 to node 1.
- Column C represents the length of the pipe
- Column D represents the diameter of the pipe.

Water Source File: This file represents the water source data. The value could have a positive sign (source) or a negative sign (sink).

	A
1	100
2	95
3	-0.3
4	-0.2
5	-0.4
6	-0.1
7	

Remember that we have 6 nodes in our example. Node 1 is a source (100) and node 3 sinks (0.3)

Starting the Program

In order to run the programs, you should first fill all the information needed in the main screen described above. Fill the file paths, and then, press the Start button. The results will be output to the "results.cvs" file, this file exists In the location you specify in the main screen. This is a snapshot of the output file:

	A
1	0.325163
2	0.471974
3	0.025163
4	-0.02233
5	0.249643
6	0.250357
7	0.150357
8	

Each row indicated the value of a variable in the final result vector, so, in our system, this is the solution of the system:

X1 = 0.325163
X2 = 0.471974
X3 = 0.025163
X4 = -0.02233
X5 = 0.249643
X6 = 0.250357
X7 = 0.150357

This is all what you need! The system is so user friendly, the GUI is simple and easy to understand. And the input/output is well formatted in files.

Chapter V: The Project Website

After we finished all the work assigned to us in this phase, we started to think about a professional way to view it. Apart from all the reports we have written, the need for a full-available resource that contain our job has emerged. We concluded that the best idea that meets our criteria is to develop a ***website*** that contains all what we did in the last 10 months, so, we started.

Our website is simple, we gave it a professional look, and we used a template that targets Projects-website. It is easy to navigate through it, and to retrieve all the needed information from it.

In this report, we will talk about the website. We will explain the contents of each page, providing snapshots and comments about it.

The Website Address and Hosting

The website address is:

http://www.cis.just.edu.jo/undp

just paste this address in your internet browser, and you will be routed to our website

Website Authentication

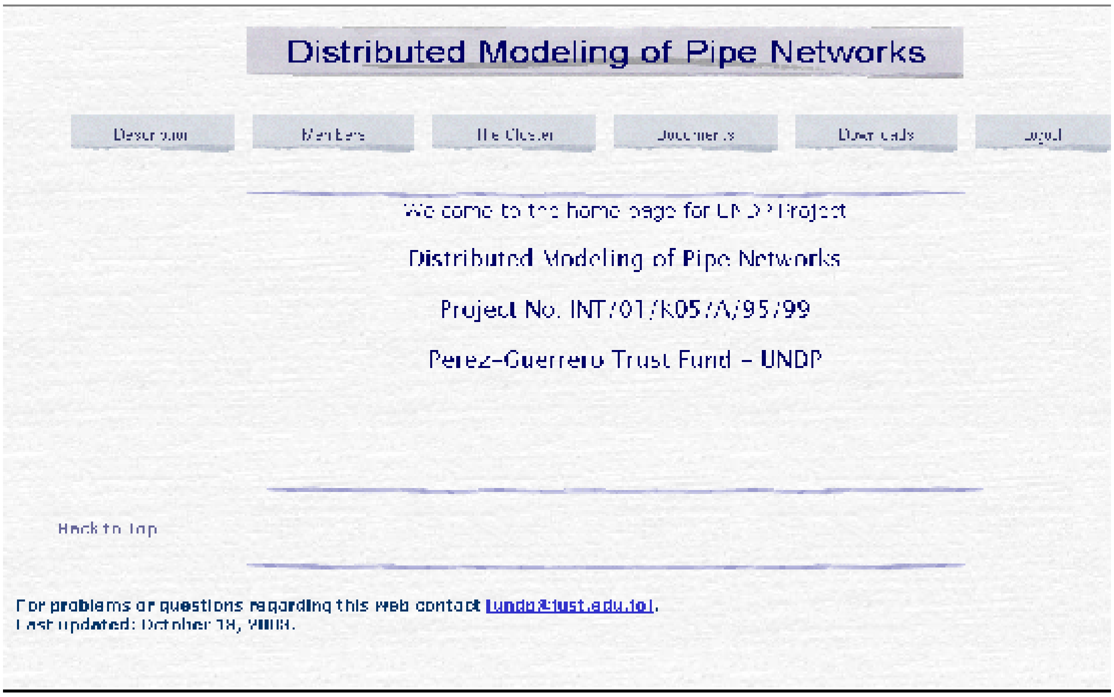
The website is authenticated through a user name and a password. Whenever you are prompted to enter a username/password, please use the following:

Username: root
Password: unproject

Website Contents

Home page:

The home page is the main page in the website, you will be directed to this page once you enter the proper username/password



Description Page

This page contains all the needed information about the scope of the project. It is an overview about the problem domain, solution, used technology, and all other related information that is related to the project. Use it to draw the Top-level vision about the project.

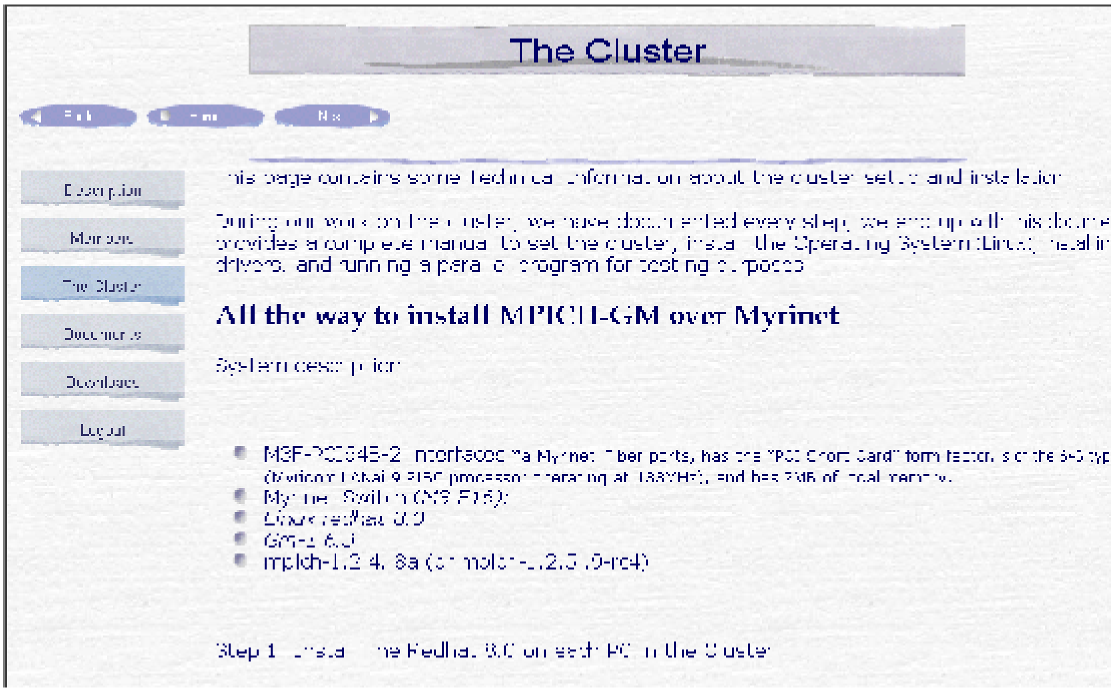
Members:

This page provides information about the members of the project. Either the civil Engineering group or the programmer group.

Simply, it is a list of names; each name is a link to the project member's CV. Click the link to open the CV, or right-click it, and choose (***Save Target As***) to save it to your local hard drive.

<u>The cluster:</u>

This page describes the cluster that we build in this project. It provides information about the hardware used to build this structure, the software installed upon it (operating system, drivers, parallel programming tools), and a step-by-step walk through about the process of building such a cluster.



<u>Documents:</u>

This page contains all the documents written on behalf of this project, this include: the document written by the civil engineering group, and the ones written be the programming group. In addition, you will find extra documents that are related to the project.

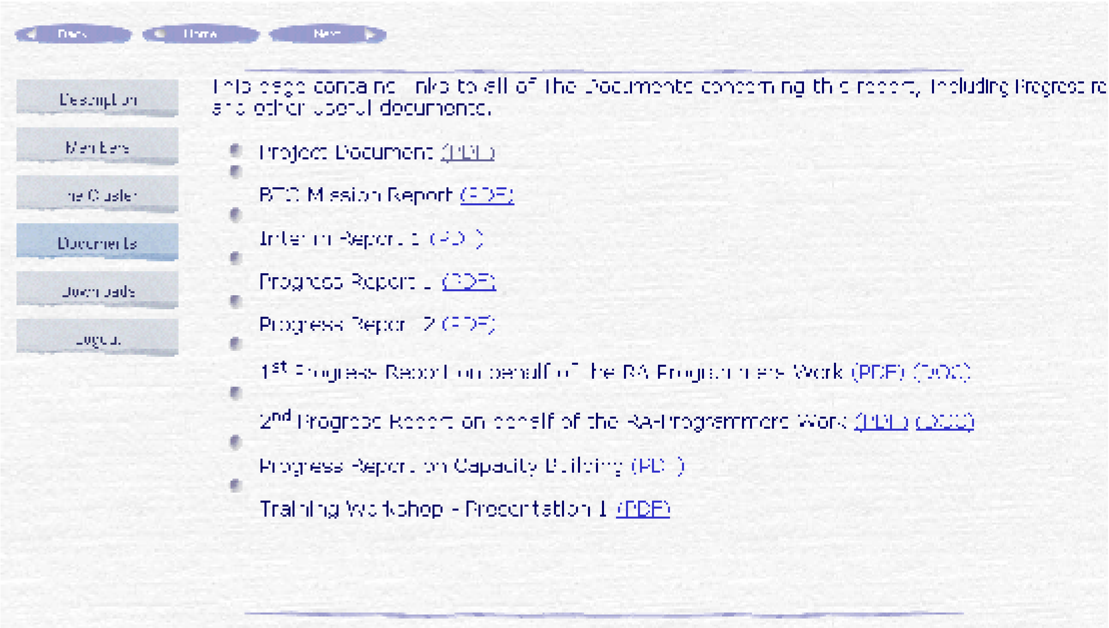
Simply, it is a list of names; each name is a link to the document. Click the link to open the document, or right-click it, and choose (***Save Target As***) to save it to your local hard drive.

You will find the documents in two formats, doc and pdf formats.

This is the list of documents in this page:

- Project Document (PDF)
- BTO Mission Report (PDF)
- Interim Report 1 (PDF)
- Progress Report 1 (PDF)
- Progress Report 2 (PDF)
- 1st Progress Report on behalf of the RA-Programmers Work (PDF) (DOC)
- 2nd Progress Report on behalf of the RA-Programmers Work (PDF) (DOC)
- Progress Report on Capacity Building (PDF)
- Training Workshop - Presentation 1 (PDF)

This is a snapshot of the page:



Downloads:

This page contains all the programs that we wrote through our work on this project. It permits the viewer to download the code, in addition to a link to the java platform download page (needed to run the java program).

This is the list of the available downloads:

- Ankara Pipe Network data
- Visual Basic Code
- Java Program
- Java Platform download page (needed to run the Java Program)

And this is a snapshot of the page:

Logout:

By clicking this link, you will logout the current session. If you want to re-enter the website, you must enter the correct username/password. This link provides the needed security to protect the site. Please be sure to click it before closing your browser.

Chapter VI: The Modeling Algorithms

The System

The algorithms that will be presented in this section apply to a number of known iterative methods for solving [A]$\vec{x} = \vec{b}$ including Jacobi, Gauss-Seidel, and Successive Over-relaxation methods. Combining the two systems of equations in (1) and (3) will end up with the system given in (4).

$$\begin{bmatrix} a_{1,1} & a_{1,2} & \cdots & a_{1,M} \\ a_{2,1} & a_{2,2} & \cdots & a_{2,M} \\ \vdots & \vdots & \ddots & \vdots \\ a_{N,1} & a_{N,2} & \cdots & a_{N,M} \\ \delta_{1,1}\xi(f_1^{(k)}) & \delta_{1,2}\xi(f_2^{(k)}) & \cdots & \delta_{1,M}\xi(f_M^{(k)}) \\ \delta_{2,1}\xi(f_1^{(k)}) & \delta_{2,2}\xi(f_2^{(k)}) & \cdots & \delta_{2,M}\xi(f_M^{(k)}) \\ \vdots & \vdots & \ddots & \vdots \\ \delta_{\Omega,1}\xi(f_1^{(k)}) & \delta_{\Omega,2}\xi(f_2^{(k)}) & \cdots & \delta_{\Omega,M}\xi(f_M^{(k)}) \end{bmatrix} \begin{bmatrix} f_1^{(k+1)} \\ f_2^{(k+1)} \\ \\ \vdots \\ \\ f_M^{(k+1)} \end{bmatrix} = \begin{bmatrix} -l_1 \\ l_2 \\ \vdots \\ l_N \\ 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix} \quad (4)$$

In the following section we present row-mapping function that maps rows from the above system of equations to hosts in the cluster. This mapping function will then be used in developing parallel algorithms for solving the system on a cluster environment.

Mapping System Rows to Hosts

Denote by Υ_i the i[th] row in the system of equations in (4), $1 \le i \le N+\Omega$. Υ_i consists of the i[th] row in the coefficient matrix, the i[th] value in the unknown vector (the flow f_i in q_i), and the i[th] value in the known vector (the load value l_i at node n_i if $i \le N$ or zero if $i > N$). The row Υ_i is called light row if $i \le N$ and heavy row otherwise.

Let P denote the number of hosts in the cluster, and let $\pi_1, \pi_2, \ldots, \pi_P$ denote the individual hosts. An intuitive workload distribution function would be to assign (N+Ω)/P rows to each host in the cluster. However, the workload involved in calculating the flow values is not uniform. In order to achieve a fair distribution, the workload ratio between light and heavy rows should be accounted for. Let $\lambda_{1,\cdots,N}$ denote the amount of arithmetic workload involved in updating each element in Υ_i, $1 \le i \le N$, and also let $\lambda_{N+1,\cdots,N+\Omega}$ denote the amount of arithmetic workload involved in updating each element in Υ_i, $N+1 \le i \le N+\Omega$. The workload ratio γ between light and heavy rows is given by

$$\gamma = \frac{\lambda_{N+1,\cdots,N+\Omega}}{\lambda_{1,\cdots,N}}.$$

The ratio γ can be utilized to achieve a balanced workload distribution among the available hosts in the cluster. Given a system of N+Ω equations and a cluster of P hosts, a balanced workload distribution can be achieved by assigning Φ(N,Ω,P) light rows or Ψ(N,Ω,P) heavy rows to each host, where

$$\Phi(N,\Omega,P) = \frac{N+\gamma\Omega}{P} \quad \text{and} \quad \Psi(N,\Omega,P) = \frac{N+\gamma\Omega}{\gamma P}.$$

To simplify the expressions, we shall refer to $\Phi(N,\Omega,P)$ and $\Psi(N,\Omega,P)$ by the symbols Φ and Ψ, respectively. In the following definition we present a balanced workload distribution function.

Definition 1: Let $\aleph : \Re \rightarrow \Pi$ be a function that maps rows from $\Re = \{\Upsilon_i \mid 1 \le i \le N+\Omega\}$ to hosts in $\Pi = \{\pi_i \mid 1 \le i \le P\}$. This function is given by

$$\aleph(\Upsilon_i) = \begin{cases} \pi_{\lfloor i/\Phi \rfloor} & \text{if } 1 \le i \le N \\ \pi_{\lceil N/\Phi \rceil + \lfloor (i-N)/\psi \rfloor} & \text{if } N+1 \le i \le N+\Omega \end{cases}$$

The function $\aleph$ evenly distributes the workload among the P hosts in the cluster such that each host deals with either light rows or heavy rows. The function $\aleph$ assigns to the host π_i the set of light rows $\{\Upsilon_j \mid (i-1)\Phi+1 \le j \le i\Phi\}$ if $i \le \frac{N}{\Phi}$, or the set of heavy rows $\{\Upsilon_j \mid N+(i-\frac{N}{\Phi}-1)\Psi+1 \le j \le (i-\frac{N}{\Phi})\Psi\}$ if $i > \frac{N}{\Phi}$. Let us denote by ρ_i the set of rows assigned to π_i. Also, let us denote by υ_i the set of unknown values (the flow values) associated with ρ_i.

Similar distribution functions that assign mixture of light and heavy rows to a single host can also be developed in order achieve even more balanced workload distribution. However, such functions would involve the analysis and complicate parallel code development for the algorithms. In the following we present parallel algorithms for the system given in (4) that is independent of workload distribution function.

Distributed Iterative Algorithms

In this section we present distributed algorithms for solving the system in (4) on a cluster environment consisting of P hosts. The term task (or process) refers to an instance of a program running on a host computer. We assume that tasks on same or different hosts can communicate with each other. Any task can initiate/terminate children sub-tasks not necessarily on the same host. These assumptions are among the groundwork of today's cluster computing technology. Two popular examples are PVM [1, 13] and MPI [5].

In our parallel setup for solving the system of equations in (4), a control task π_C initiates all other computing tasks $\pi_1, \pi_2, \ldots, \pi_P$. The control task then sends ρ_i to π_i, $1 \le i \le P$, and blocks until computing tasks send back their results. When the convergence criterion is met, π_C signals computing tasks for termination and sending back their final results. Another approach of doing this is to let each host evaluate the convergence criterion. In this way the termination condition will be rather distributed.

Upon receiving ρ_i, a computing task π_i computes and broadcasts υ_i to all tasks. It then initiates blocking receive to get υ_j from π_j, $1 \le i \le P$ and $i \ne j$, followed by non-blocking receive to get the termination flag from π_C. Figures 2 and 3 outline the algorithms for the control task and the computing tasks.

It should be noticed that the algorithms in Figures 2 and 3 are independent on workload distribution functions. The function $\aleph$ is used by the proposed algorithms to determine the set ρ_i (and implicitly υ_i). Hence, the proposed algorithms are general in the sense that the workload distribution function is not integrated into the algorithms; hence allowing the algorithms to operate under various workload distribution functions with minimal modification effort.

Control task π_C

1. Initiate π_i for $1 \le i \le P$
2. Send ρ_i to π_i for $1 \le i \le P$
3. Set done to false
4. Repeat steps 5 to 7 until done is true
5. Receive υ_i from π_i $1 \le i \le P$
6. Assess convergence(done)
7. Send done to π_i for $1 \le i \le P$

Figure 2: Algorithm for the control task.

Computing Task π_i

1. Receive ρ_i from π_C
2. Set done to false
3. Repeat steps 4 to 7 until done is true
4. Compute υ_i
5. Send υ_i to π_C and π_j for $1 \le j \le P$ and $j \ne i$
6. Receive υ_j from π_j for $1 \le j \le P$ and $j \ne i$
7. Receive done from π_C

Figure 3: Algorithm for computing tasks.

The fourth step in the computing task π_i consists of two sub-steps: First linearization then solution. At the k^{th} iteration, the $(k-1)^{st}$ solution vector is substituted into the non-linear sub-systems in Equations (3). The resulting linear system when combined as shown in Equation (4) is then solved using any method for solving systems of linear equations; however iterative methods require less communication overhead which is vital in cluster computing based on shared networking infrastructure. The methods Jacobi, Gauss Seidel, and Successive Over-relaxation among other methods are all applicable.

Performance Analyses

The hosts executing algorithms for the control task π_C and the computing task π_i perform the following sub-tasks in the given order:

- π_C communicates $(N+\Omega)M$ matrix elements to π_i, $1 \le i \le P$.
- π_i computes υ_i, $1 \le i \le P$.
- π_i broadcasts υ_i to all hosts, $1 \le i \le P$.
- π_C assesses convergence and broadcasts a one bit signal to π_i, $1 \le i \le P$.

The first sub-task is executed only once, however, depending on the underplaying cluster setup, there may be no need to communicate ρ_i from π_C to π_i, $1 \le i \le P$, in the presence of network file system. In such system all hosts can access shared input files simultaneously in order to read the relevant rows.

The broadcasting cost needed to exchange υ_i's between all hosts in the cluster can be estimated using a common model for measuring the cost of communicating a message of dimension m in a network with latency λ and unit transmission cost of   , which is given by $\lambda +$ m [3]. With this model broadcasting υ_i's between all hosts in the cluster costs $\lambda P +$ M and broadcasting the convergence signal costs $\lambda +$ for each iteration. Hence, a one iteration communication cost in both π_C and π_i is $\lambda(P+1)+$ $(M+1)$.

Computing the set of values υ_i, $1 \le i \le P$, can be done in parallel. By virtue of the function $\aleph$ which evenly distributes the workload among the P hosts in the cluster, it will take an order of $(N+\gamma\Omega)M/\gamma P$ time steps to compute the vector $\vec{f}$. Notice that the workload ratio between light and heavy rows (γ) is does not affect the computing time complexity. Also, assessing the convergence can be done in a variety of methods, which costs no more than $O(M)$ time steps, and therefore the computing time for the two algorithms of Figures 2 and 3 is proportional to $(N+\gamma\Omega)M/\gamma P$.

Experimentation

The proposed algorithms for solving the nonlinear system in Equation (4) given in the previous section have been implemented on a typical academic installation of a cluster computer consisting of eight Pentium hosts running Linux. Hosts are hocked using 100 Mbps Ethernet segments. The algorithms in Figures 2 and 3 have been implemented using PVM as a parallel programming environment [13]. The experiments have been repeated on various pipe network sizes, light rows to heavy rows ratio, and using cluster computers of 2, 4, and 8 hosts. Figures 4, 5 and 6 show the results of these experiments.

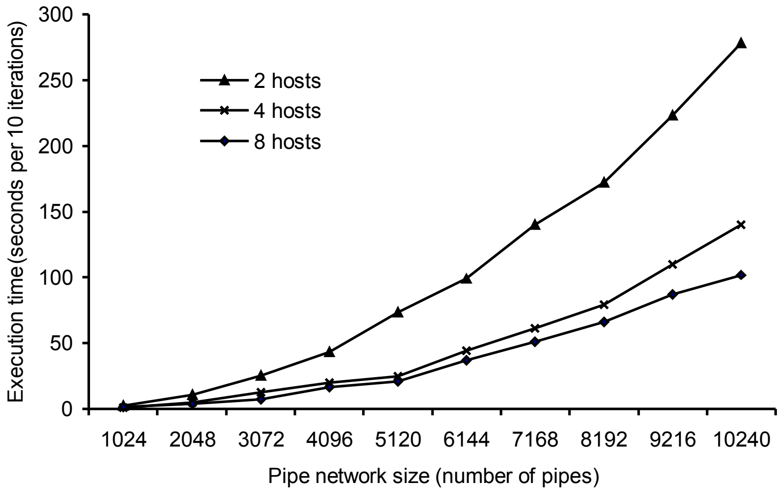


Figure 4: Real execution time when quarter of the system are light rows.

The first experiment is given in Figure 4 which shows the real execution for the proposed cluster algorithm for analyzing pipe networks of size ranging from 1,024 up to 10,240 pipes. In this experiment light rows constitute only quarter of the system and the other three quarters are heavy rows. Here we assume that workload ratio between heavy and light rows is 5 (i.e. heavy rows cost five times more than light rows in terms of computing time). This ratio depends on the choice of how the factor α_j is evaluated. The assumed number is a rough estimate based on the number of arithmetic operations in Hazen-Williams formula.

Figure 4 suggests that involving more hosts into the cluster ends up in a faster solution; however the speedup gain slows down for larger number of hosts which is attributed to the expected dominance of communication overhead over the gain in computation speedup. Two more experiments have also been conducted using equal number of heavy and light rows, Figure 5, and then using more light rows (three quarters of the system) than heavy rows, Figure 6. Of course the algorithms run faster with "lighter" systems. The trend of increased speedup for larger clusters continues with lighter systems as well.

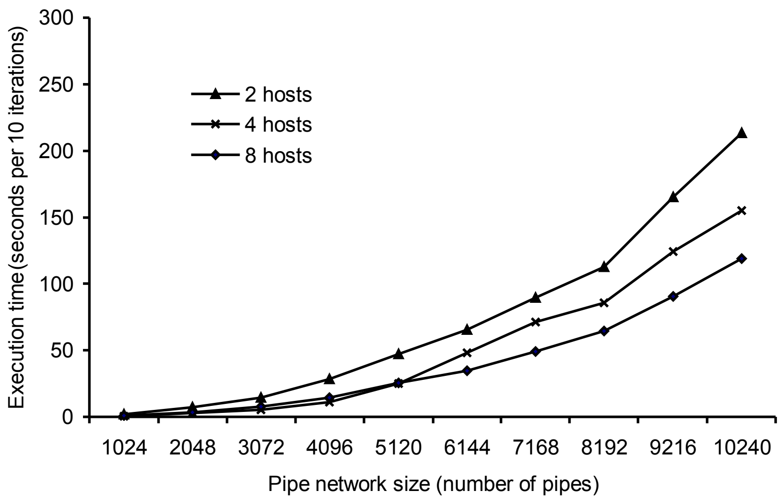


Figure 5: Real execution time when half of the system are light rows.

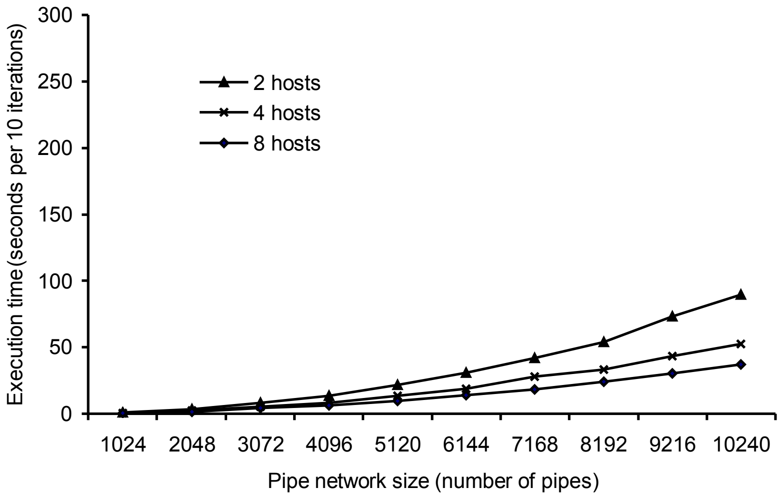


Figure 6: Real execution time when three quarters of the system are light rows.

Conclusions

This study led to the conclusion that cluster computing offers a low-cost alternative for analyzing large-scale pipe networks for distributing natural resources such as water, oil, gas, air-conditioning, compressed air systems among others. The proposed algorithms utilize idle cycles of any number of hosts connected by general purpose network to achieve fast solutions that would otherwise require expensive parallel computers. Experimental results on a cluster of eight hosts connect via Ethernet segments have been conducted to verify this observation. The proposed approachis useful in at least two ways, first it can be used to model large-scale pipe networks, second it provides additional evidences that cluster computing is an appealing technology that goes inline with today's market forces, yet provides wide avenue for research in high-performance parallel computing.

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Chapter VII: The Consultant Inputs

Two consultants have been invited to serve the project. The consultants are Dr. Nuri Merzi from Middle East Technical University and Dr. Khaled Day from Sultan Qaboos University. Dr Merzi's inputs are outlined in previous sections. Below we summarize Dr. Day's inputs.

Introduction

Dr. Khaled Day from Sultan Qaboos University, Oman, has collaborated with the investigators of the "Distributed Modeling of Pipe Networks" project (Project No: INT/ 01/ K05/ A/ 95/ 00, Perez-Guerrero Trust Fund – UNDP) from Jordan University of Science and Technology (JUST) during the two periods from 29 May to 6 June and from 12 to 19 June 2003 as a research consultant for performing the following duties:

- Assessing the Myrinet cluster setup in JUST campus, the core infrastructure for web-based long lasting computing environment for pipe network design and analysis.
- Assessing the developed parallel programming environment for the cluster.
- Formulating parallel algorithms based on linear methods for pipe network analysis.
- Helping the ITG – JUST developing MPI/PVM parallel code for pipe network analysis.
- Giving a seminar to the faculty and students in JUST campus presenting research findings in cluster computing as a core technology for this project. The seminar should emphasize the assessment component to pin-point the areas of possible improvement for the installed cluster environment and also for the developed parallel methods of solution for pipe network modeling.
- Writing and submitting a technical report outlining the overall design assessment for both the cluster infrastructure and for the developed methods of solution.
- This document is a technical report prepared by the research consultant with regard to the above list of tasks.

The Myrinet Cluster Setup at JUST

A cluster is a collection of nodes that are interconnected via some network technology. Each of these nodes can be a single or multiprocessor system (PCs, Workstations, or SMPs) with memory, I/O facilities, and an operating system. Cluster computers may also be called as: poor-man's supercomputers, COW (Cluster Of Workstations), and NOW (Networks of Workstations). The experimental cluster computing environment at Jordan University of Science and Technology is based on Myrinet networking equipment interconnecting Linux workstations.

The following Myrinet hardware is used:

- M3F-PCI64B-2 interface cards
- M3-E16 Myrinet Switch
- Myrinet Fiber Cables

This hardware setup provides an adequate basis for a cluster computing system.

The Parallel Programming Environment

The following software components have been successfully installed and tested on the JUST cluster nodes:

- GM driver
- Myrinet-interface control program
- GM mapper
- GM API, library, and header files
- Message Passing Interface, MPI (MPICH-GM implementation)
- Linux Redhat 8.0 operating system

The hardware and software installations offer high-speed communication capability between cluster nodes and is adequate for supporting efficient cluster-based parallel computing.

Parallel Algorithms for Pipe Network Analysis

The project investigators have developed a linear system of equations for modeling flow in pipe networks. Parallel algorithms for solving this system in a cluster-computing environment are obtained. A method has been designed for mapping computing tasks to cluster nodes. This mapping is then used in developing parallel algorithms for solving the system on a cluster environment consisting of P hosts. A master/slave approach is used where a control task initiates all other computing tasks. The control (master) task sends data to the computing tasks (slaves) and blocks until computing tasks send back their results. When the convergence criterion is met, the master task signals computing tasks for termination and sending back their final results.

Upon receiving its data a slave performs its computation task and broadcasts the result to all tasks. It then initiates blocking receive to get the of the other slaves, followed by non-blocking receive to get the termination flag from the control task. Figures 2 and 3 outline the algorithms for the control task and the computing tasks.

The algorithms given below are independent on workload distribution functions. Hence, the proposed algorithms are general in the sense that the workload distribution function is not integrated into the algorithms; hence allowing the algorithms to operate under various workload distribution functions with minimal modification effort.

Control task π_C

1. Initiate π_i for $1 \leq i \leq P$
2. Send ρ_i to π_i for $1 \leq i \leq P$
3. Set done to false
4. Repeat steps *5* to *7* until done is true
5. Receive υ_i from π_i $1 \leq i \leq P$
6. Assess convergence*(*done*)*
7. Send done to π_i for $1 \leq i \leq P$

Computing Task π_i

1. Receive ρ_i from π_C
2. Set done to false
3. Repeat steps *4* to *7* until done is true
4. Compute υ_i
5. Send υ_i to π_C and π_j for $1 \leq j \leq P$ *and* $j \neq i$
6. Receive υ_j from π_j for $1 \leq j \leq P$ *and* $j \neq i$
7. Receive done from π_C

The tasks on same or different hosts can communicate with each other. Any task can initiate/terminate children sub-tasks not necessarily on the same host. These communication and synchronization operations can be achieved using message passing primitives available in MPI.

MPI Communication for the Pipe Network Algorithms

MPI primitives can be used to implement the communication and synchronization operations embedded in the algorithms of figures 2 and 3. The table 1 illustrates the basic MPI functions.

Table1: Basic MPI Functions

Function call	Function job
MPI.INIT ()	Initiate an MPI computation.
MPI.FINALIZE ()	Terminate a computation.
MPI.COMM_SIZE ()	Determine number of processes.
MPI.COMM_RANK ()	Determine my process identifier.
MPI.SEND ()	Send a message.
MPI.RECV ()	Receive a message

There are two types of communication in MPI:

- Point-to-Point Communication

The elementary communication operation in MPI is point-to-point communication that is direct communication between two processors, one of which sends and the other receives. Point-to-point communication in MPI is “two-sided”, meaning that both an explicit send and an explicit receive are required. Data are not transferred without the participation of both processors.

In a generic send or receive, a message consisting of some block of data is transferred between processors. A message consists of an envelope, indicating the source and destination processors, and a body, containing the actual data to be sent.

MPI uses three pieces of information to characterize the message body in a flexible way:

1. Buffer: the starting location in memory where outgoing data is to be found (for a send) or incoming data is to be stored (for a receive).
2. Datatype: the type of the data to be sent. In the simplest cases this is an elementary type such as float/ REAL, int/ INTEGER, etc.
3. Count: the number of items of type datatype to be sent.

The two main types of point-to-point communication functions are blocking and non-blocking communication. This depends on whether the return from the send/ receive function signals the availability of the send/ receive buffers for reuse by the application. This is illustrated in Figure 1.

- Collective Communication

In addition to point-to-point communications between individual pairs of processors, MPI includes routines for performing collective communications. These routines allow larger groups of processors to communicate in various ways, for example, one-to-several or several-to-one see Figure 2. The main advantages of using the collective communication routines over building the equivalent out of point-to-point communications are:

- The possibility of error is significantly reduced. One line of code – the call to the collective routine – typically replaces several point-to-point calls.
- The source code is much more readable, thus simplifying code debugging and maintenance.
- Optimized forms of the collective routines are often faster than the equivalent operation expressed in terms of point-to-point routines.

Examples of collective communications include broadcast operations, gather and scatter operations and reduction operations.

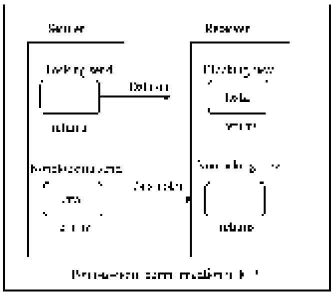
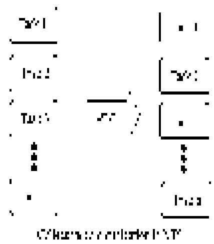
 

Figure 1: Point-to-Point communication   Figure 2: Collective communication

∗ MPI_Bcast ( )

Broadcasts (sends) a message from the process with rank “root” to all other processes in the group. A graphic representation of the MPI_Bcast is shown below :

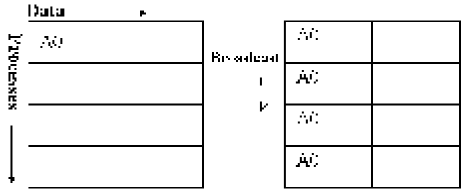


Figure 3: MPI BroadCast Primitive

The syntax of MPI_Bcast is :

MPI.COMM_WORLD.Bcast(Object buffer,int offset,int count,Datatype datatype,int root).

Buffer	buffer array
Offset	initial offset in buffer
Count	number of items in buffer
datatype	datatype of each item in buffer
Root	rank of broadcast root

∗ MPI_Allreduce

Applies a reduction operation and places the result in all tasks in the group.
Its syntax is :
MPI.COMM_WORLD.Allreduce(Object sendbuf ,int sendoffet,Object recvbuf,int recvoffset,int count,Datatype datatype,Op op)

sendbuf	send buffer array
sendoffset	initial offset in send buffer
recvbuf	receive buffer array
recvoffset	initial offset in receive buffer
Count	number of items in send buffer
datatype	data type of each item in send buffer
Op	reduce operation

∗ MPI_Alltoall

In MPI_Alltoall each process sends distinct data to each receiver. The jth block from processor I is received by processor j and stored in ith block. A graphic representation of the MPI_Alltoall is shown below :

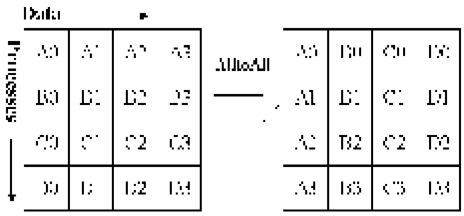


Figure 4 : MPI All-To-All Primivte

The syntax of MPI_Alltoall is :

MPI.COMM_WORLD.Alltoall(Object sendbuf, int sendoffset , int sendcounts , Datatype sendtype ,Object recvbuf,int recvoffset,int recvcount,Datatype recvtype)

Sendbuf	send buffer array
Sendoffset	initial offset in send buffer
Sendcount	number of items sent to each process
Sendtype	datatype of send buffer items
Recvbuf	receive buffer array
Recvoffset	initial offset in receive buffer
Recvcount	number of items received from any process
Recvtype	datatype of receive buffer items

* MPI_Alltoallv

MPI_Alltoallv is the vector version of MPI_Alltoall. MPI_Alltoallv extends the functionality of MPI_Alltoall by changing the receive count from an integer to an integer array and providing a new argument displs(array). MPI_Alltoallv allows a varying count of data from each processor.
The syntax of MPI_Alltoallv is :

MPI.COMM_WORLD.Alltoallv(Object sendbuf , int sendoffset, int [ ] sendcount , int sdispls, Datatype sendtype, Object recvbuf, int recvoffset, int [ ] recvcount, int [ ] rdispls, Datatype recvtype)

Sendbuf	send buffer array
Sendoffset	initial offset in send buffer
Sendcounts	number of items sent to each process
Sdispls	displacements from which to take outgoing data
Sendtype	datatype of each item in send buffer
Recvbuf	receive buffer array
Recvoffset	initial offset in receive buffer
Recvcounts	number of elements received from each process
Rdispls	displacements at which tp place incoming data
Recvtype	datatype of each item in receive buffer

Cluster Computing Seminar

Dr Khaled Day has given a seminar titled Cluster Computing on 5th June 2003 at Jordan University of Science and Technology. The following is a list of the presented topics:

- How to run applications faster
- Multiple computers

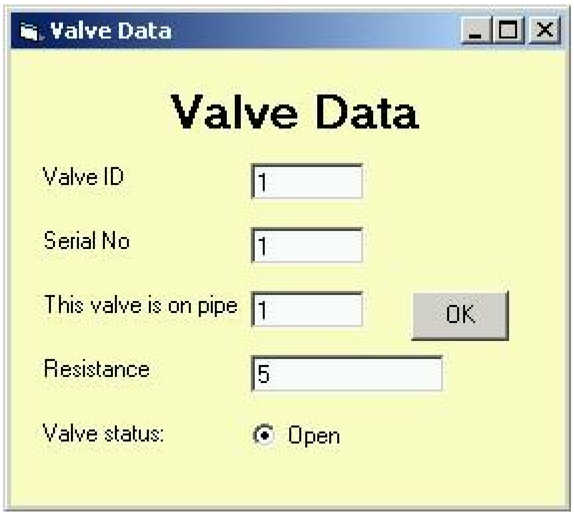
- Cluster computers: definition and motivation
- Parallel computing in the past and now
- Cluster setup at Sultan Qaboos University
- Parallel and distributed processing research group at Sultan Qaboos University
- Message passing computing
- Programming in a cluster computing environment
- Message passing parallel programming software tools for clusters
- Basics of message-passing programming using user-level message passing libraries
- Single Program Multiple Data Model (SPMD)
- Multiple Program Multiple Data Model (MPMD)
- Basic “point-to-point” send and receive
- Synchronous versus asynchronous message passing
- Group message passing (broadcast, scatter, gather, reduce)
- Parallel Virtual Machine (PVM)
- Message Passing Interface (MPI)
- A first cluster-based parallel programming example: Parallel Bucket Sort
- A second cluster-based parallel programming example: autocorrelation matrix
- Performance evaluation of cluster-based parallel programs.

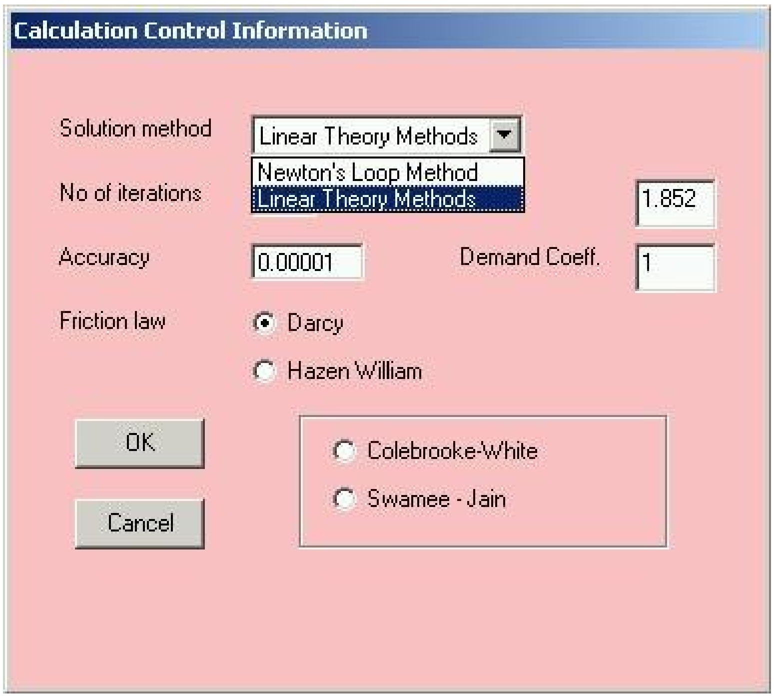
Conclusion

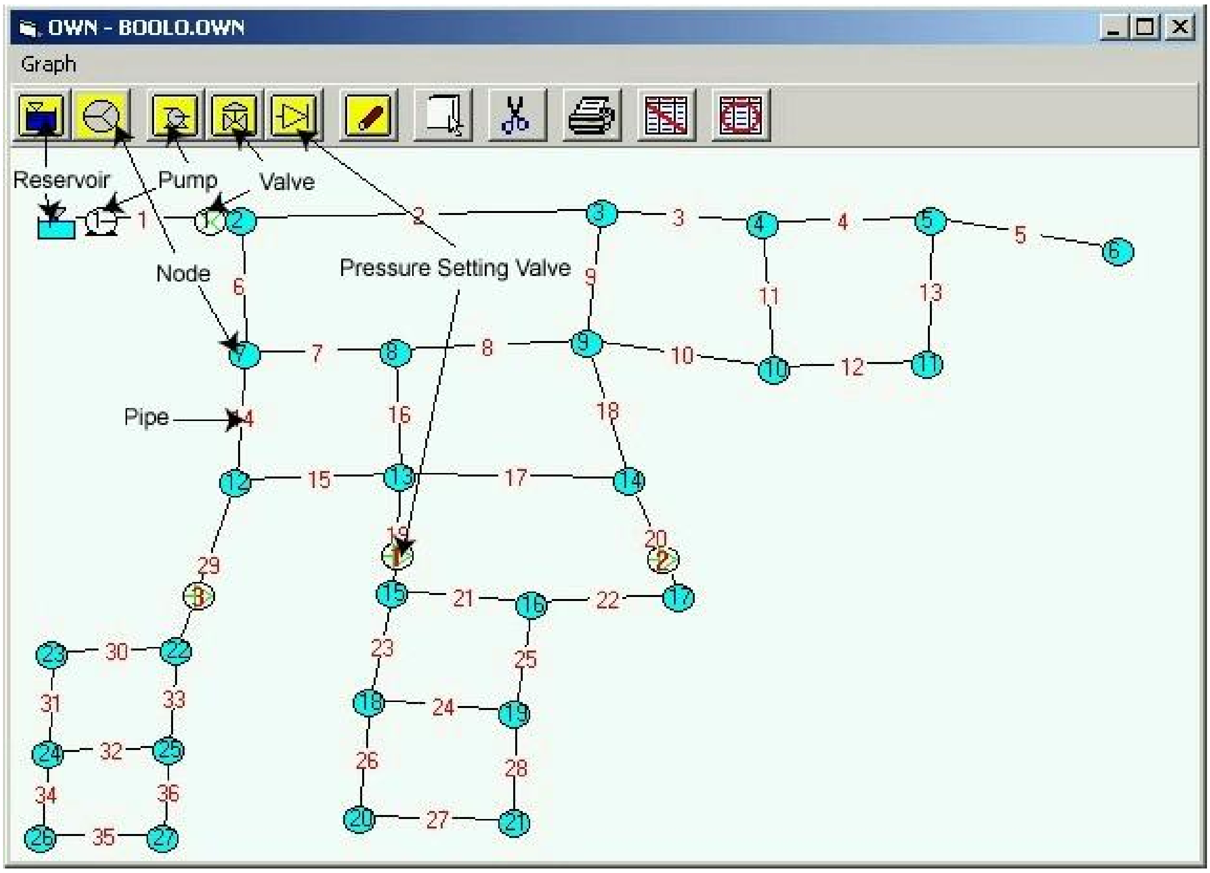
In this project cluster computing solutions for pipe network modeling and analysis have been developed. A high-performance cluster using Myrinet hardware and software and Linux Redhat 8.0 operating system has been setup at JUST university. Algorithms for pipe network analysis have been proposed using MPI for inter-node communication. Experimental results on the cluster have been conducted. The proposed solution has allowed to model large-scale pipe networks and has provided additional evidence that cluster computing is an affordable technology for high-performance parallel computing.

Chapter VIII: The Visual Basic Programs

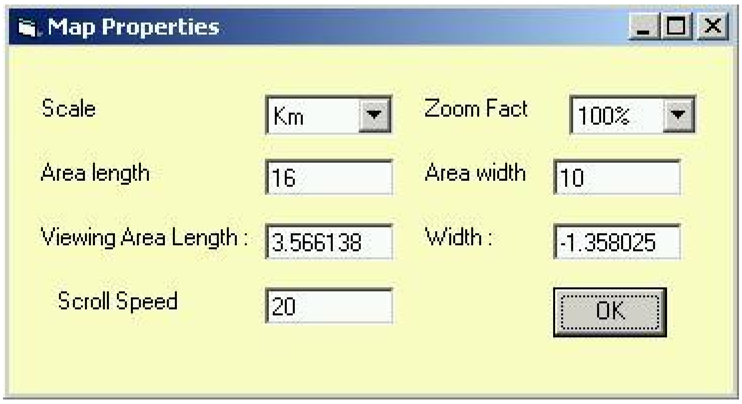
The project team in UAE has developed a VB system with graphical user interfaces (GUI) for solving the pipe system. The VB programs are downloadable from the project website. We list below a number of screenshots from the developed programs



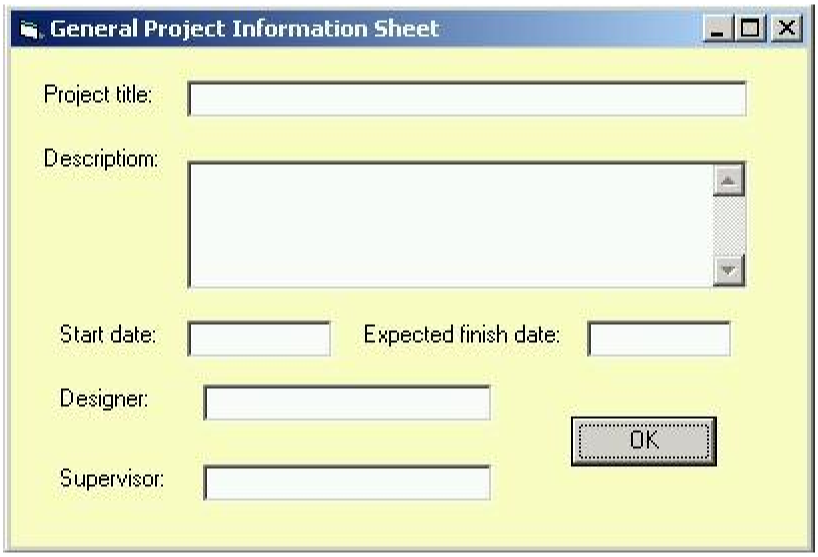


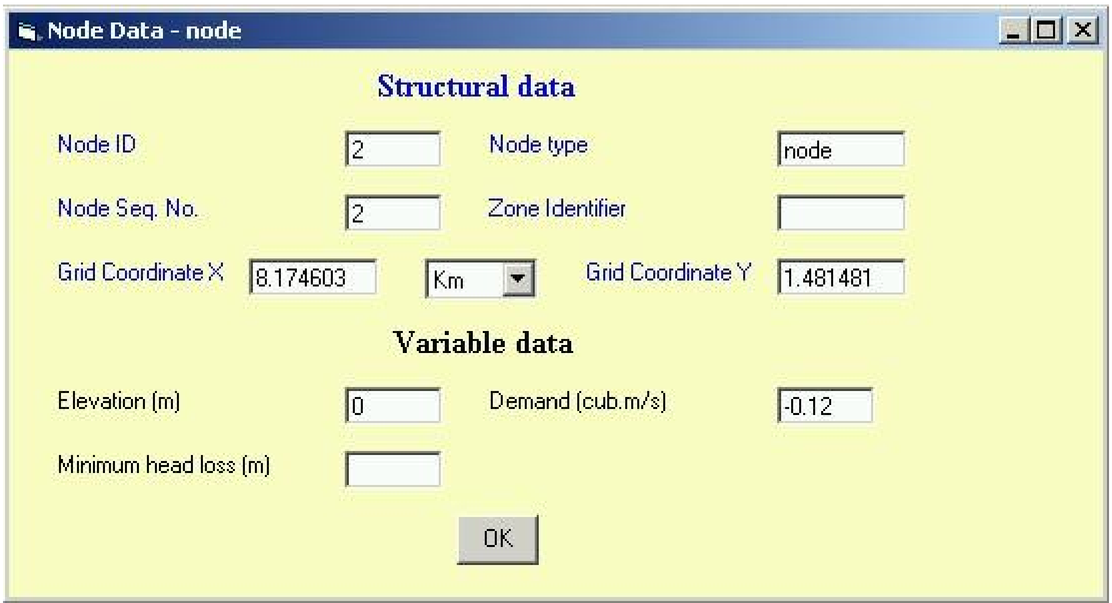


OWN - BOOLO.OWN
Graph
Reservoir
Pump
Valve
Node
Pressure Setting Valve
Pipe



Map Properties
Scale
Km
Zoom Fact
100%
Area length
16
Area width
10
Viewing Area Length :
3.566138
Width :
-1.358025
Scroll Speed
20
OK


General Project Information Sheet
Project title:
Descriptiom:
Start date:
Expected finish date:
Designer:
OK
Supervisor:


Node Data - node
Structural data
Node ID
2
Node type
node
Node Seq. No.
2
Zone Identifier
Grid Coordinate X
8.174603
Km
Grid Coordinate Y
1.481481
Variable data
Elevation (m)
0
Demand (cub.m/s)
-0.12
Minimum head loss (m)
OK

Pipes Results

Project: boulos   Printed on: 18/10/2003 12:14:12 AM

Node ID	X-Coord	Y-Coord	Type	Zone	Demand(m^3/s)	Elevation(m)	Hyd.grade(m)	Pressure
1	0.61	1.65	reservoir		0	210	210.00	
2	3.20	1.65	node		-0.12	0	279.09	2,7
3	8.17	1.48	node		-0.12	0	273.42	2,6
4	10.40	1.74	node		-0.06	0	271.51	2,6
5	12.75	1.65	node		-0.06	0	271.02	2,6
6	15.32	2.33	node		-0.06	0	270.73	2,6
7	3.25	4.61	node		-0.12	0	274.03	2,6
8	5.32	4.57	node		-0.12	0	272.86	2,6
9	7.96	4.36	node		-0.12	0	272.77	2,6
9	10.56	4.95	node		-0.06	0	271.50	2,6
11	12.70	4.83	node		-0.06	0	271.08	2,6
12	3.12	7.45	node		-0.12	0	272.64	2,6
13	5.40	7.32	node		-0.12	0	272.53	2,6
14	8.54	7.41	node		-0.12	0	272.50	2,6
15	5.29	9.90	node		-0.06	0	226.80	2,2
16	7.22	10.16	node		-0.06	0	226.60	2,2
17	9.26	9.99	node		-0.06	0	228.13	2,2
18	4.97	12.32	node		-0.06	0	225.79	2,2

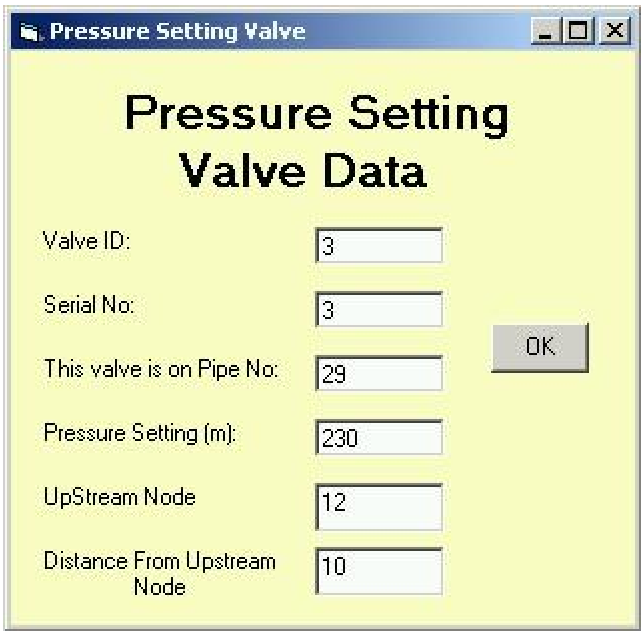
Close Form   Print

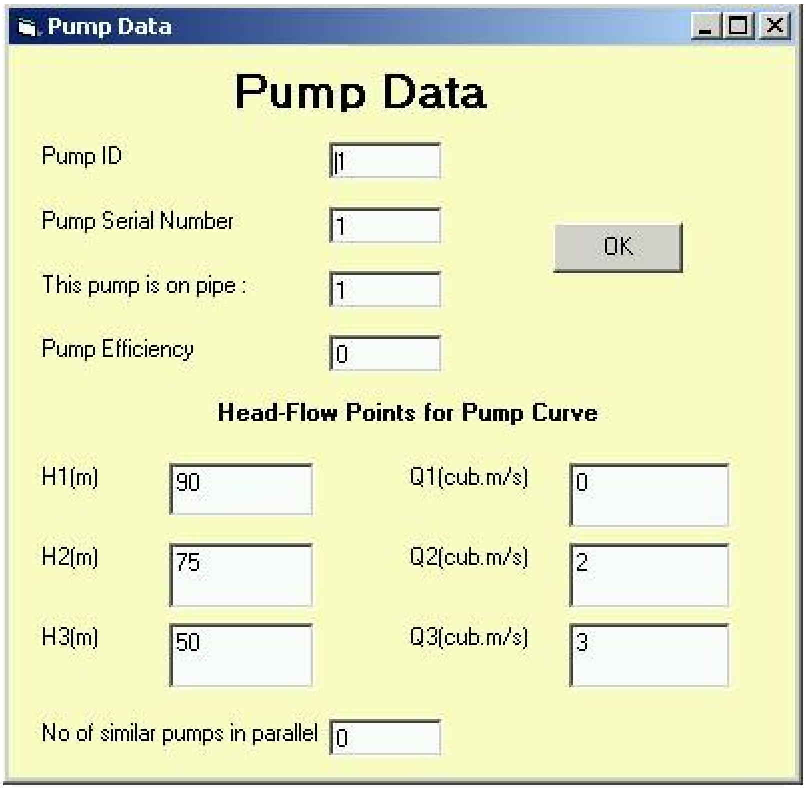
Pipes Results

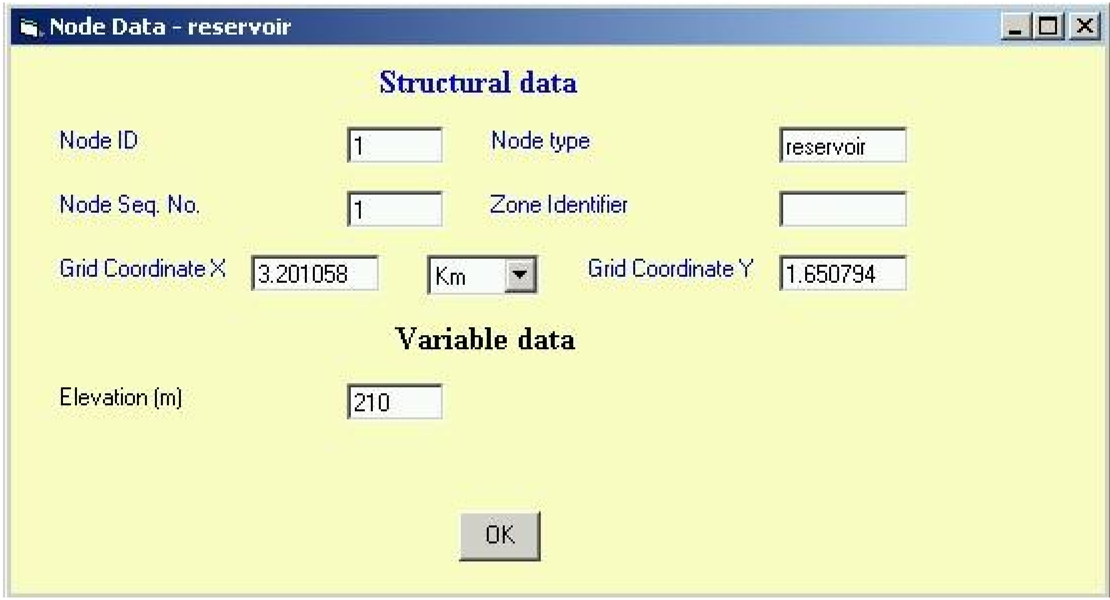
Project: boulos   Printed on: 18/10/2003 12:13:17 AM

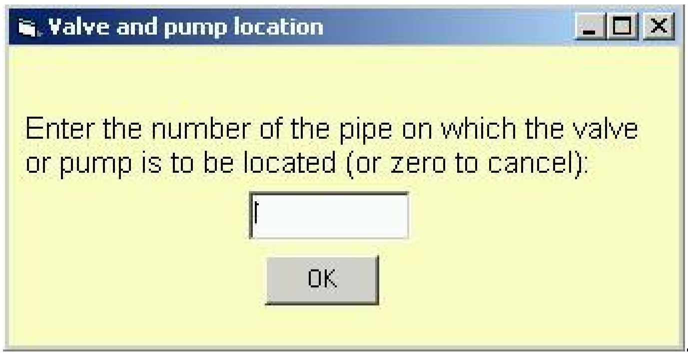
Pipe	Start Node	End Node	Diameter(m)	Length(m)	HW Coeff.	Hd-loss(m)	Flowrate(L/s)	Velocity(
1	1	2	1	600	120	3.42	2,040.00	
2	2	3	0.7	1300	120	5.67	691.70	
3	3	4	0.4	400	120	1.90	166.34	
4	4	5	0.4	300	120	0.50	94.05	
5	5	6	0.4	400	120	0.29	60.00	
6	2	7	0.7	400	120	5.06	1,228.30	
7	7	8	0.7	500	120	1.18	495.21	
8	8	9	0.7	800	120	0.09	96.55	
9	3	9	0.7	400	120	0.65	405.37	
10	9	10	0.4	400	120	1.27	133.66	
11	4	10	0.4	400	120	0.02	12.29	
12	10	11	0.4	300	120	0.42	85.95	
13	11	5	0.4	400	120	0.06	25.95	
14	7	12	0.7	400	120	1.40	613.09	
15	12	13	0.7	500	120	0.10	133.09	
16	8	13	0.7	400	120	0.32	278.66	
17	13	14	0.7	800	120	0.03	51.68	
18	9	14	0.7	400	120	0.26	248.25	

Close Form   Print


Pressure Setting Valve
Pressure Setting
Valve Data
Valve ID:
3
Serial No:
3
This valve is on Pipe No:
29
Pressure Setting (m):
230
UpStream Node
12
Distance From Upstream Node
10
OK


Pump Data
Pump Data
Pump ID
1
Pump Serial Number
1
This pump is on pipe :
1
Pump Efficiency
0
OK
Head-Flow Points for Pump Curve
H1(m)
90
Q1(cub.m/s)
0
H2(m)
75
Q2(cub.m/s)
2
H3(m)
50
Q3(cub.m/s)
3
No of similar pumps in parallel
0


Node Data - reservoir
Structural data
Node ID
1
Node type
reservoir
Node Seq. No.
1
Zone Identifier
Grid Coordinate X
3.201058
Km
Grid Coordinate Y
1.650794
Variable data
Elevation (m)
210
OK


Valve and pump location
Enter the number of the pipe on which the valve or pump is to be located (or zero to cancel):
OK

Chapter IX: Partially Satisfied Networks

Usual network models assume fixed nodal demands and they obtain associated nodal pressures and pipe discharges. The deficiency of these models is that they are not capable of determining partially satisfied demands at certain nodes due to insufficient pressures lower than the preset minimum required pressure. The assumption that nodal consumptions are fixed irrespective the network pressures, is reasonable for the design period during which pressures are above the minimum required pressure. However, during the lifetime of the network, one or more of the following situations may arise:

(1) Actual nodal demands are more than the predicted design demands due to an unpredicted growth over the entire area. Consequently, the system becomes inadequate even during the design period.

(2) Even though the overall growth is well predicted, it may be unbalanced, causing the system to be deficient in some zones and higher than adequate in others.

(3) The consumptions at some nodes are higher than the design ones, due to installation of pumps, illegal usage of water or excessive leakage; this situation, would create a deficiency at some parts of the network.

(4) The distribution system is used beyond its design period and therefore becomes deficient.
(5) Some pipes or pumps are closed for maintenance which will cause deficiency at some nodes.

That's why classical network equations should be should be solved in such a way that nodal demands should be treated as "adjustable" depending on the nodal pressure. This will help a lot to solve problems emerging in developing countries where water is scarce and demands are satisfied partially.

Chapter X: Back to Office Mission Report 1

General Information

	MISSION INFORMATION	COMMENTS
b) Dates of Mission	July 19 – 26, 2002	
c) Reasons for Mission	Training and initiating the project activities	
d) Cost of Mission and Source	USD 3,119.50	Travel costs for 2 members of the project team.

Objectives of the Mission

The project team met for the first time in Ankara during the period 19 – 26 July 2002 to achieve a number of predefined tasks and initiate the planed activities. The project team members have been divided into two groups each with well-defined set of tasks to be accomplished as described in the tables shown below. The first group is the Information Technology Group (ITG) lead by Dr. Abdel-Elah Al-Ayyoub (Jordan University of Science and Technology), Dr. Ali Yazici (Atilim University), and Dr. Saad Harous (Sharjah University). The ITG members are the project principal investigators. The second group is the Civil Engineering Group (CEG) which is contains training professionals who give capacity building and training services to the ITG and its related sub-groups as well as to the project beneficiaries. Currently the CEG includes Dr. Nuri Merzi and Ms. Tülay Özkan (Middle East Technical University), and Dr. Selçuk Soyupak (Atilim University). See the Chapteres for these scholar's CVs.

Methodology of Mission

The mission set a number of milestones for the different project activities. Literature surveys have already been done and the two groups (ITG and CEG) have agreed on their lists of tasks to be achieved in the times specified. The computational model that will be employed have been discussed and a report has been written.

Key Issues, Processes, Outcomes

The CEG explained the various aspects related to targeted models for analyzing water distribution systems. The meeting was conducted on a formal capacity building training sessions and the following conclusions were reached.

1) The CEG presented a range of known methods for modeling water distribution systems. Initially they gave a brief introduction on the theoretical foundation surrounding the problem of water distribution. Next, the CEG went into more details concerning relevant parameters such as pressure reducing vales, water quality among other aspects.
2) After explaining the problem complexities and summarizing some solution methods, the recommendation reached by the two groups (ITG and CEG) is to use linear theory combined with graph theoretic approach for better performance on cluster computing environments.
3) The CEG will transmit the theoretical models for the solution of pipe network systems strictly for meaningful scenarios and cases. The CEG will then train the ITG on how these models work and more importantly how these models can be transformed into working algorithms from which the targeted computer programs are produced.

4) Since the ITG will be developing the computer programs for the final product, extensive training sessions for ITG and its related sub-groups at the three universities (Jordan University of Science and Technology, Atilim University, and Sharjah University) will be conducted by the CEG and its sub-groups. These training sessions will include online demonstration on existing commercial systems for water network distribution systems, seminars and workshops for presenting developed models for the targeted system. These demonstrations, seminars, and workshops will be organized on either the ITG or the CEG main sites (JUST or METU).
5) The CEG discussed the various options for data acquisition for the purpose of testing the planned system for water distribution. The CEG explained the format of the data which can be obtained from the Metropolitan Ankara Network System (SCADA and GIS facilities).
6) The CEG elucidated the implementation mysteries associated with pipe network factors such as pressure reducing valves, water quality, tank levels, etc. These factors can easily lead to erroneous results if treated superficially. Hence, the ITG deems further capacity building workshops for its sub-groups as a vital issue for correct implementation of the targeted system.

Tasks Completed During Mission

The table below summarizes tasks achieved in and after this mission. The table covers the period from June to September 2002. The last column indicates the status of the activity as listed in the original work-plan.

Activities related to the mission	Status
1.1.1. Activity: Hosting PM & PCIs in JUST-Jordan & Atilim-Turkey	DONE
1.1.2. Activity: Installing personal desktop publishing needs (laptops, printers, scanners, CD writers, etc)	Specifications submitted
1.1.3. Activity: Literature survey on steady state analysis of pipe networks	DONE
1.1.4. Activity: Development of computational algorithms and testing considering numerical and parallel computing aspects	DONE
1.1.5. Activity: Testing the developed algorithms utilizing the data from a full scale network that is part of Metropolitan Ankara Network System utilizing SCADA and GIS facilities	DONE

Description of Lessons Learned, Observations, Recommendations

The team needs to make another meeting early next year to discuss the implementation of the proposed models and to see a first prototype of the system in terms of hardware and software. The following recommendations have been made:

1) linear algebra is the best choice for implementing the system for pipe network modeling.

2) A cluster of 8 nodes will be installed in the first sage and then another 4 nodes will be added at a later stage.

3) High speed optical switches will be used as a backbone for the system area network.

4) The system can be implemented in any freeware message passing system .

5) A web-based front end will developed to make the system accessible form anywhere.

Next Steps, Follow-up, Actors & Timeline

The tables below show the milestones for the project activities and their related outcome. The tables are separated by groups, though there are some dependencies on the group activities.

ITG's Responsibilities

Project Intervention		Deadline	Indicators
ITG.1	Literature survey on parallel solutions for the steady state analysis of pipe networks	End of August 2002	Interim Report
ITG2.	Installing and the cluster computing systems SW&HW	End of September 2002	Interim Report
ITG3.	Submitting original receipts against payments for the QFR	Mid October 2002	
ITG4.	Developing parallel algorithms for CGE's models	End of October 2002	
ITG5.	Compilation of data from real networks in Amman and Sharjah WA and AWEA.	End of November 2002	Interim Report
ITG 6.	Based on the Ankara network, the developed parallel methodologies will be test against various networks obtained from different combinations of hydraulic accessories (or different scenarios).	End of December 2002	Interim Report
ITG7.	Follow-up project proposal which will include the comparing the compiled data from the 3 countries using the developed methodologies.	End of March 2003	Proposal Draft and letter of endorsement from the relevant agency

CEG's Responsibilities

Project Intervention		Deadline	Indicators
CEG.1	Literature survey on steady state analysis of pipe networks	End of August 2002	Interim Report
CEG.2	Development of computational models	End of September 2002	Interim Report
CEG.3	2nd Training Session: Training on the developed models, examples, and tutorials	Mid October 2002	
CEG.4	Submitting original receipts against payments for the QFR	Mid October 2002	
CEG.5	Data Compilation from a real network of around 250 pipes Ankara network.	Mid November 2002	Interim Report
CEG.6	Based on the Ankara network, the developed methodologies will be test against various networks obtained from different combinations of hydraulic accessories (or different scenarios).	End of December 2002	Interim Report
CEG.7	Follow-up project proposal which will include the comparing the compiled	End of March 2003	Proposal Draft and letter of endorsement

	data from the 3 countries using the developed methodologies.	from the relevant agency

Attendees/Delegates

The ITG group selected Dr. Nuri Merzi and Ms. Tülay Özkan (Middle East Technical University), and Dr. Selçuk Soyupak (Atilim University) to serve in the its CEG for their well-recognized achievements in the area of resource distribution networks. Below is a brief biography for the above mentioned academics. The full CV's are attached to this report.

Professor Merzi is working for the Water Resources Laboratories in the Department of Civil Engineering at Middle East Technical University. He received his Ph.D. degree in Civil Engineering in 1986 from FPF Lausanne – Switzerland. He also received his M.S. and B.S. degrees in 1981 and 1978, respectively, from Middle East Technical University where is now is now a faculty member since 1989. Professor Merzi served a scientific visitor in Canada Centre for Inland Waters – Canada during the years 1986 - 1989. He received a number of research grants from major funding agencies to support several projects dealing with water resources. Recent examples directing the project entitled "Hydraulic Modeling of Ankara Water Distribution Network" and the project entitled "Rehabilitation of Water Distribution Networks" which are both accomplished this year. Professor Merzi has supervised and currently supervising several graduate theses in the area of water distribution networks. He and his graduate students are involved in issues related to water such as identifying efficient pump combinations, determination of leakages, integration of SCADA with GIS for water quality modeling, and hydraulic modeling of water distribution networks. Professor Merzi has published a number of scientific papers and technical articles and also he has been providing training services for Ankara Water and Sewerage Administration on Hydraulic Modeling of Ankara Water Distribution Network for over 5 years.

Professor Selçuk Soyupak is working for the Civil Engineering Department at the Atilim University – Turkey. He obtained his Ph.D. degree in Civil Engineering - Water Resources in 1979 from the University of Waterloo – Canada. He also obtained his M.Sc. in 1973 in Environmental Engineering and the B.Sc. 1971 in Civil Engineering from Middle East Technical University Ankara – Turkey. He worked for Atilim, METU, and Waterloo for over 30 years teaching and researching in the areas of environmental engineering and specifically in water resources. Professor Soyupak has leaded and coordinated a number of projects and served in the consulting boards for many projects in the areas of water supply and distribution systems. Few examples on these projects include "Şanlıurfa and Harran Plains On-Farm and Village Development" for Su-Yapı Mühendislik ve Müşavirlik and "Erzurum Water Supply Project" for Parmaş. Professor Soyupak has been doing training and teaching in the area of water resources and offered a number of on-line (on the Internet) courses on Water Supply Engineering. He also organized a number of international conferences on the topic water resources management and published many papers in the same field.

Chapter XI: Back to Office Mission Report 2

General Information

	MISSION INFORMATION	COMMENTS
a) Dates of Mission	July 28 – August 3, 2003	
b) Reasons for Mission	Finalizing the project and discussion future follow-up work	
c) Cost of Mission and Source	USD 1091.5 – Activity 1.1.1	Travel costs for 1 member of the project team.

Objectives of the Mission

The project teams (ITG and CEG) met for the second time in Ankara – METU campus during the period from July 28 to August 5, 2003 to finalize the project and further discuss follow-up as future project. The two teams agreed on the material that the final report should contain and also the website contents. The project team finally assessed the quality of the produced deliverables which are:

1) The progress reports.

2) The developed computer programs.

3) The project website.

Another main objective for the visit was to tackle technical problems with the produced computer programs. The CEG suggested a number of solutions to these problems as will be detailed later on this report.

Methodology of Mission

A series of regular meetings took place during this period, most of which were technical meetings. The two groups discussed the known systems WaterCad and EPANet as tools to aid is validating the results produced by our programs. The purpose is to locate bugs in the developed programs by comparing the produced numerical results with those produced by commercially available systems.

The ITG and CEG groups have agreed to continue comparing results for the following two reasons: Locate and fix bugs and also to investigate the speed of the produced programs.
The project team members agreed to publish these findings in a conference proceeding next year. The same results will also be included in an intermediate report or part of the final report that will be submitted to the UNDP late September 2003.

Key Issues, Processes, outcomes

The key issues and lessons learned during the first phase of the project are summarized in the following list:

- The problem of modeling static pipe networks with known and fixed loads turn out to be easy to solve.

- To satisfy certain requirements and demands on a pipe network, partially satisfied network methods should be used. This is a computationally intensive problem that cannot be solved using commercially available systems. The project team feels that this is a problem that should be addressed in future work. The importance of this problem can be better explained if we consider the following scenario: The inhabitance of a certain region benefiting from a certain pipe network complains about the lack of sufficient pressure. To sort out the problem, we can increase the pressure from the nearing pump; however that might have side effects of on the parts of the network that might not have problem in the first place. In this situation the study of partially satisfied networks will help.

- The CEG briefed the project team on the partially satisfied networks.

- The CEG group will develop a report summarizing how these methods (partially satisfied networks) will be employed in the follow-up project. This document will be ready by the end of September 2003. The UNDP will be informed on the outcome of the report; though it is not part of the deliverables.

Tasks Completed During Mission

The progress reports have been reviewed for the last time and approved. The material for the final report has been discussed and agreed up on. Related tasks have been distributed.
The table below summarizes tasks achieved during this mission. The last two columns indicate the status of the activity and its relevance to the mission. Activity numbering follows the same numbering as appeared in the project work-plan.

Activity	Status	Relevance to this mission
3.1.1. activity: Parallel program development, testing and verification on optical san based cluster computing system	PM – JUST DONE	This mission addressed some technical programming issues for this activity.
3.1.2. activity: Testing the parallel algorithms utilizing the data from SCADA and GIS facilities	PCI-(Atilim & METU) In progress	The collected data have been reviewed.
3.1.3. activity: Performance assessment and comparison of developed parallel algorithms as compared to conventional methods	PCI-(Atilim & METU) In progress	The approach of assessing and maintaining the produced code has been defined and agreed upon.
3.1.4. activity: Hosting research consultants (from SQU - Oman) and/or PM/PC's in JUST – Jordan to discuss the obtained solutions and agree on further design issues.	PM – JUST DONE	The external consultant report has been reviewed and its technical concerns regarding our approach have been addressed.
4.1.2. activity: Design and implementation of the system interface screens	PCI-Sharjah DONE	The produced Visual Basic interfaces have been tested.
4.1.3. activity: Testing, debugging and verification	PCI-Sharjah In progress	A testing method has been defined and the testing tasks has been distributed to the team members.
5.1.1. activity: Project website	PM – JUST In progress	The outline for the site contents has been defined. The implementation will start soon.
5.1.4. activity: Project outcomes presentation and dissemination	PM – JUST In progress	The main findings will be published in a conference paper that will appear in the 2nd phase of the project.

Description of Lessons Learned, Observations, Recommendations

The main lesson learned in the first phase of the project is related to the complexity of the problem when large dynamic pipe networks are involved. The practical situations unfortunately are full of these challenges which make modeling rather complex.
The added complexity manifests itself in the required mathematical models and the amount of computation time imposed on the computer system. Therefore, the project team recommends using a computational cluster with larger number of hosts (recall that JUST's cluster contains only 4 hosts).
The team will keep on developing the needed models that will be implemented on JUSTs cluster or elsewhere. The good news is that JUST has decided to upgrade their cluster to include up to 32 hosts which makes it a strong candidate to host the future modeling environment.

Next Steps, Follow-up, Actors and Timeline

The team decided that Dr. Abdel-Elah Al-Ayyoub and his team in Jordan organize a workshop to handle the programming tasks and submit a running system for evaluation before the end of August 2003. The sessions of this workshop should cover the following main items:

1. Practical methods of solution for linear methods with emphasis on Gauss Jordan and Gauss–Haurd.
2. Implementation on implementation on single processor machines using web enabled language.
3. Linearization of pipe model systems: How linearize the pipe equations so Gauss Jordan and Gauss – Haurd can be applied on the resulting linear systems.
4. Implementation of the linearization processes using web enabled.
5. Web interface to the Java programs.
6. Website development and contents discussion.

The workshop will start on 17 August and will conclude no later than 26 August 2003.

Chapter XII: The Workshop

The final workshop was help at Jordan university of Science and Technology during the periods from 17 to 26 August 2003.. The main speaker was Dr. Mohamed Towaiq who trained the project sub teams on some numerical solution for systems of pipe equations. The training workshop also included other session on website development. The table below is an excerpt for the workshop program

2nd Workshop: The Final Deliverables

Day – Date	Session – Time	Moderator	Intervention
Day 1 – 17 Aug	Session 1: 9 – 10 am Session 2: 11 – 12 am	Dr. M. Towaiq Dr. M. Towaiq	Linear systems – GJ. Linear systems – GH.
Day 2 – 19 Aug	Session 3: 9 – 10 am Session 4: 11 – 12 am	Dr. M. Towaiq Dr. M. Towaiq	GJ and GH implementation on single processor machines using web enabled language (e.g. Java).
Day 3 – 21 Aug	Session 5: 9 – 10 am Session 6: 11 – 12 am	Dr. M. Towaiq Dr. M. Towaiq	Linearization of pipe model systems: How linearize the pipe equations so GJ and GH can be applied on the resulting linear systems.
Day 4 – 24 Aug	Session 7: 9 – 10 am Session 8: 11 – 12 am	Dr. M. Towaiq Dr. M. Towaiq	Implementation of the linearization processes using web enabled language (e.g. Java).
Day 5 – 26 Aug	Session 9: 9 – 10 am Session 10: 11 – 12 am	Dr. A. Al-Ayyoub Dr. B. Mahafzah	Web interface to the Java programs. Website development and contents discussion.