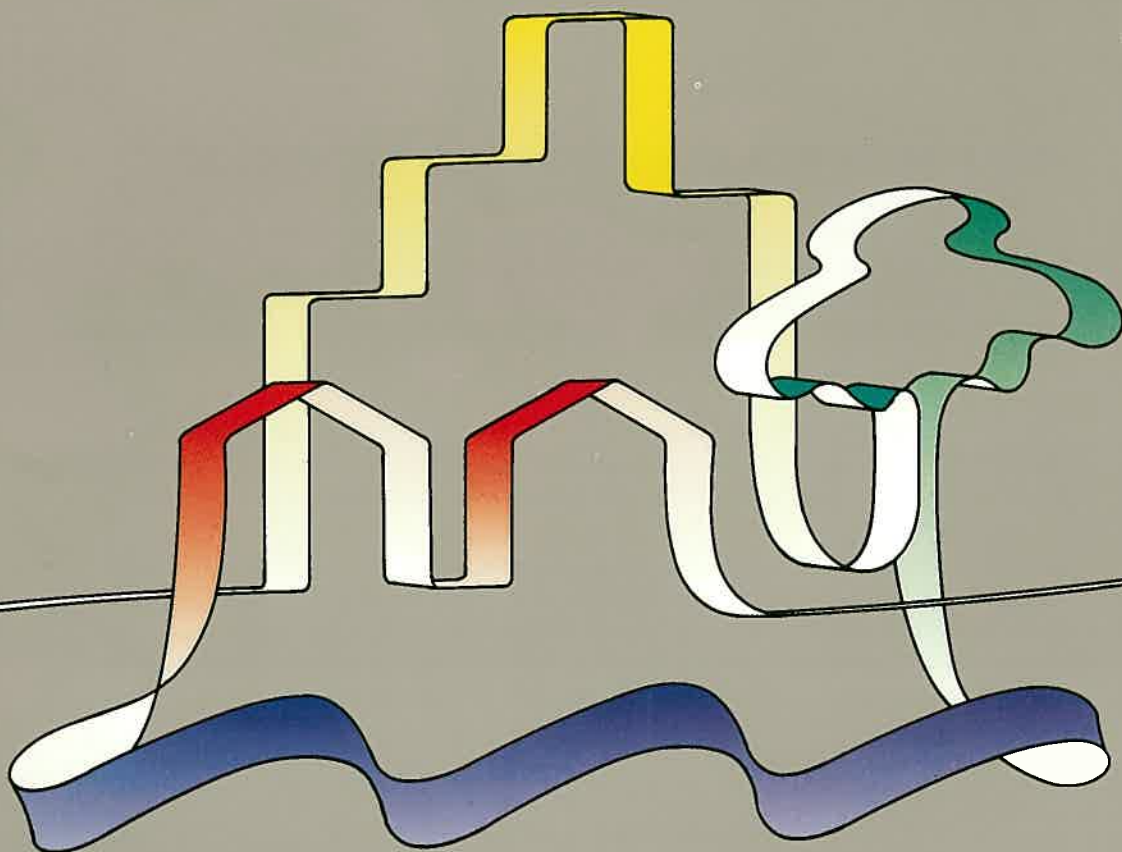




Urban Water Research Association of Australia

Graphical Interactive Pipe Network Analysis Program



Research Report No. 81

URBAN WATER RESEARCH ASSOCIATION OF AUSTRALIA

The Association was formed in 1986 following initiatives by the Australian Water Research Advisory Council and the Major Urban Water Authorities of Australia. The Association's primary role is to foster and promote a comprehensive, co-ordinated and cost-effective approach to urban water research within Australia, for both metropolitan and non-metropolitan areas.

The Association invites proposals for research work through its member authorities and allocates funding to approved projects on an annual basis. The actual research is undertaken by water authorities, research organisations, universities, consultants and government agencies.

The UWRAA Research Report series presents information resulting from research projects supported by the Association and is published as a record of the work undertaken and as a means of disseminating the research findings. The Association also encourages the presentation of findings by the researchers in professional journals and at conferences. The Association's reports are indexed on STREAMLINE, the national water data base.

For further details contact:

Executive Officer

Urban Water Research Association of Australia

C/- Melbourne Water

GPO Box 4342

Melbourne 3001

AUSTRALIA

Telephone: (03) 615 5816

Fax: (03) 615 4408

Urban Water Research Association of Australia

**Graphical Interactive Pipe
Network Analysis Program**

**B L Berghout
Hunter Water Corporation**

**Research Report No 81
July 1994**

© Urban Water Research Association of Australia, 1994

Published for the Urban Water Research Association of Australia by the Melbourne Water Corporation.

ISBN 1 875298 82 7

Cover design by Gregory R Smith

FOREWORD

This report is based on UWRAA Research Project No WS-56: 'Graphical Interactive pipe network analysis program (GIPNAP)' which was undertaken during the period July 1992-June 1994. Organisational responsibility for the project was as follows:

Sponsoring Authority : Hunter Water Corporation

Project Officer : Mr David McRae, Hunter Water Corporation

Research Agency : Hunter Water Corporation

Principal Researcher : Mr Brendan Berghout, Hunter Water Corporation

Review Panel : Dr Bob Wilson, Hunter Water Corporation
Mr Steve Weatherstone, Hunter Water Corporation

The project was funded by the Hunter Water Corporation and the Urban Water Research Association of Australia.

SYNOPSIS

This project report describes the development of an easy to use graphically driven computer program designed to solve for the pressures and flows in a water pipe network. The project involved the writing of a graphical interface for an existing pipe network analysis program and making some alterations to the existing program. The graphical interface and pipe network analysis program are both written in FORTRAN.

The original aim of the project was to develop a program which was sufficiently intuitive and interactive that it could be used in the training of basic principles in pipe network hydraulics to water authority field staff. The result is a program which not only fulfils these aims but is also a useful engineering tool for the design and analysis of small water pipe networks.

The mathematical approach used to solve the pipe network problem, description of the graphical interface and a users manual for GIPNAP, the resulting computer program, are contained in this report.

TABLE OF CONTENTS

| | | |
|-------|---|----|
| 1 | INTRODUCTION | 1 |
| 2 | DESCRIPTION OF GIPNAP | 2 |
| 2.1 | Overview of Pipe Network Hydraulics | 2 |
| 2.1.1 | Mathematical Theory | 2 |
| 2.1.2 | Formulation of Pipe network Problem as a Network Linear Program | 10 |
| 2.2 | Graphical Interface | 11 |
| 3 | DEVELOPMENT AND TESTING OF GIPNAP | 18 |
| 3.1 | Introduction | 18 |
| 3.2 | Tasks, Methods | 18 |
| 3.2.1 | Development of Input and Output Graphics | 18 |
| 3.2.2 | Modify Existing Pipe Network Analysis Program | 18 |
| 3.2.3 | User Manual | 18 |
| 3.3 | Testing Main Solving Algorithm | 19 |
| 3.4 | Trialling GIPNAP | 19 |
| 4 | APPLICATIONS FOR GIPNAP | 20 |
| 5 | ACKNOWLEDGMENTS | 21 |
| 6 | AVAILABILITY | 22 |
| 7 | REFERENCES | 23 |
| | APPENDIX A - GIPNAP USERS MANUAL | 24 |

LIST OF FIGURES

| | |
|---|----|
| Figure 2.1.....Network Topology | 3 |
| Figure 2.2.....Expanded Network Topology | 4 |
| Figure 2.3.....Legend for Network Topology Diagrams | 4 |
| Figure 2.4.....Content for Friction Element | 7 |
| Figure 2.5.....Content for Pump Element | 8 |
| Figure 2.6 (A).....Non-convex Pump Content | 8 |
| Figure 2.6 (B).....Approximation to Non-convex Pump Content | 8 |
| Figure 2.7.....Content for Water Entering Reservoir | 9 |
| Figure 2.8.....Content for Water Leaving Reservoir | 9 |
| Figure 2.9 (A).....Link from i to j | 10 |
| Figure 2.9 (B).....Arcs Representing Link from i to j | 10 |
| Figure 2.10.....Piecewise Linear Approximation of Cost Function | 11 |
| Figure 2.11.....Node Type and Data Input and Edit Screen | 13 |
| Figure 2.12.....Pump Information Screen | 13 |
| Figure 2.13.....Pipe Data Input and Edit Screen | 14 |
| Figure 2.14.....Small Pipe Network Consisting of a Reservoir, Pump and Demand Node | 14 |
| Figure 2.15.....Plan View of 'Solved' Network Showing Node Pressures and Pipe Flows | 15 |
| Figure 2.16.....Hydraulic Profile from Nodes 1 to 3 in Example Network | 16 |
| Figure 2.17.....Information for Node 3 Displayed in 'View' Mode | 17 |
| Figure 2.18.....A Screen from the 'View Summary' Option | 17 |

1. INTRODUCTION

In the mid 1980's the then Hunter District Water Board took on significant initiatives in the training of its Water Supply Distribution System Operators (Service Operators). These initiatives were prompted by work-place reforms which would see the multi-skilling of Service Operators. Prior to the implementation of these training programs, Service Operators learnt their "craft" on the job. They learnt about the concepts of water hammer, pressure, head loss, flushing, negative pressure and the like, often with some drama and expense. There were many misconceptions about water distribution system hydraulics.

In 1988, the staff training section of Hunter Water developed a scale model of a water distribution system. The model consisted of a network of pipes, valves, hydrants, tanks and pumping stations. Clear plastic piezometers were located strategic locations, so that pressure changes throughout the network could be clearly identified. The scale model has proven to be an extremely effective training aid for water distribution system hydraulics.

The concept of an interactive graphical computer driven simulation of a water distribution system was also considered as a training aid. Although not as tangible as a physical model, a computer model would have advantages in cost, physical size, availability and versatility of pipe network arrangement. Any pipe network could be modelled, including examples of real problems observed (through their work) by the trainees.

Berghout (1991) upgraded a water pipe network analysis program (Wong, 1985) as his Honours Year Project at the University of Newcastle. It could be used to solve for the pressures and flows throughout a pipe network given a particular set of demands and reservoir levels. This program provided the 'engine' which could be used to drive computer simulations of water pipe networks. It provided the basis for the development of GIPNAP, a graphical interactive pipe network analysis program, which can be used in the training of water authority field staff

The object of this project was:

To develop a pipe network analysis package with an interactive graphical interface which can be used in the training of water authority field staff.

2. DESCRIPTION OF GIPNAP

GIPNAP is a water pipe network analysis program. Water pipe networks are mostly used to distribute water throughout cities and towns. They consist of pipes, pumps, reservoirs, high level tanks and other special devices. Water pipe network analysis programs are used to determine:-

- the flow in each pipe, and
- the pressure at each pipe junction, valve or pump

for a given set of external demands. They are used in the design of new systems and for the amplification of existing systems. They are often used to identify problem areas (such as inadequate capacity pipes) in existing networks.

2.1 Overview of Pipe Network Hydraulics

2.1.1 Mathematical Theory

A solution to a pipe network problem is found when both the laws of continuity and conservation of energy are satisfied.

The law of continuity is satisfied when the flow into any node equals the flow out of that node. This can be expressed as:

$$Q_{in} - Q_{out} = r, \quad \text{for all nodes}$$

where Q_{out} is flow out of node
 Q_{in} is flow into node
 r is the external flow requirement at node

Conservation of energy requires the sum of head loss or head gain around any loop in the network to be zero.

These laws lead to a series of nonlinear simultaneous equations whose solution is pipe flow and head loss. One class of algorithms directly solves these equations. In contrast, Collins et al.(1976) have shown that the pipe network analysis problem is mathematically equivalent to a non-linear optimisation problem. This is the approach adopted in GIPNAP and is described in the following sections.

Figure 2.1 shows an example of a network topology. Some changes need to be made to the standard topology of a network for it to be modelled as an optimisation problem. These changes are outlined as follows.

1. As the flow in each link must be greater than or equal to zero, two way pipe elements are each modelled as two single direction links. Any flow in an undirected pipe will register as a positive flow in one of the unidirectional links.
2. To account for flow in to or out of a reservoir (a fixed head node), each reservoir is connected to a common ground node with a reference datum head of zero. The amount of water supplied at the ground node equals the sum of external requirements from nodes within the network.

An example network is shown in Figure 2.1. The expanded topology used in the optimisation problem model is shown in Figure 2.2. The legend for these diagrams is in Figure 2.3. Note that the flow direction for a pipe with a pump or reflux valve is known, so these are each modelled using one unidirectional link. Nodal demands r_n can be positive or negative.

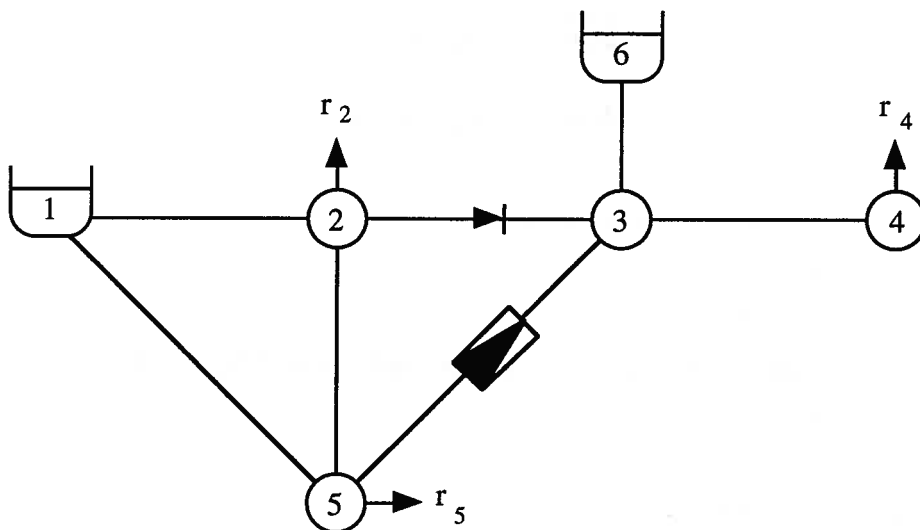


Figure 2.1 Network Topology

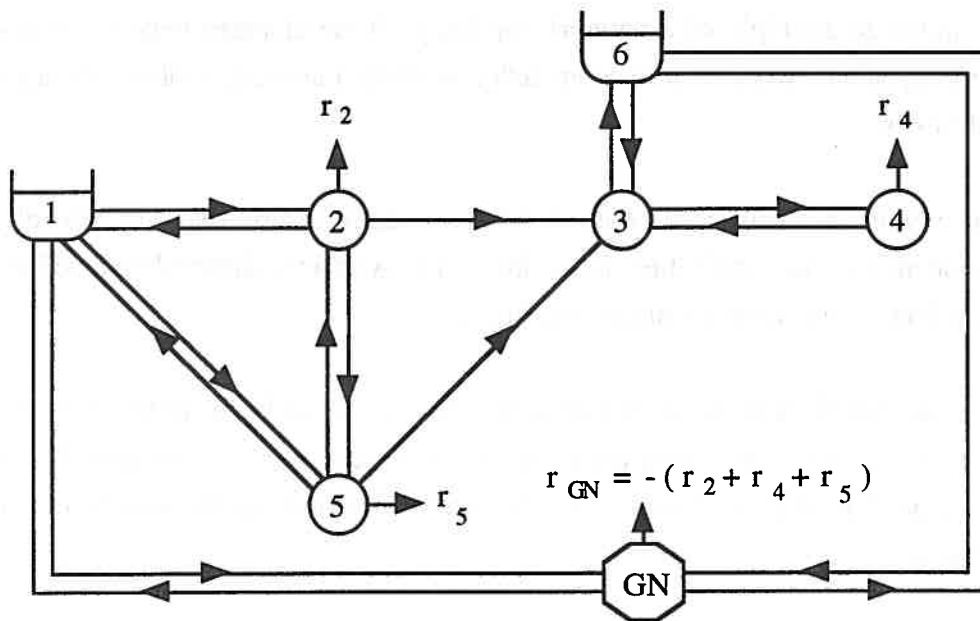


Figure 2.2 Expanded Network Topology

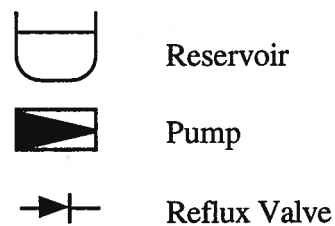


Figure 2.3 Legend for Network Topology Diagrams

Using the expanded network topology, the following definitions may be used to describe the pipe network analysis problem.

The network topology is defined by:

- a set of nodes N , and
- a set of ordered pairs of nodes E .

N includes junctions, points of external demand (or supply), reservoirs and the ground node. E includes pipes, pumps, valves, other appurtenances and other (frictionless) links.

Let Q_{ij} for each $(i,j) \in E$ denote the flow from node i to node j . Let H_n for each $n \in N$ denote the head at node n . Let H_n^* denote the head at fixed head nodes (reservoirs). Fixed head nodes are a sub-set of N .

The change in head between two nodes is given by

$$H_i - H_j = \phi_{ij}(Q_{ij}) \quad \text{for all } (i,j) \in E$$

where $\phi_{ij}(Q_{ij})$ is the relationship between energy loss or gain and flow for the element (i,j) . This relationship depends on the type of element linking nodes i and j . $\phi_{ij}(Q_{ij})$ must be continuous in any case and

$$\int_0^{Q_{ij}} \phi_{ij}(Q) dQ$$

convex over $Q_{ij} \geq 0$ for there to be a unique solution (Collins et al., 1976).

The formulation of the optimisation problem is:

Minimise

$$\sum_{(i,j) \in E} \left\{ \int_0^{Q_{ij}} \phi_{ij}(Q) dQ \right\} \quad (2.1)$$

subject to

$$\sum_{\{j:(n,j) \in E\}} Q_{nj} - \sum_{\{i:(i,n) \in E\}} Q_{in} = r_n, \quad \text{for all } n \in N$$

$$Q_{ij} \geq 0, \quad \text{for all } (i,j) \in E$$

where

E is set of ordered pairs of nodes,

N is set of nodes,

Q_{ij} denotes flow from node i to node j ,

r_n denotes flow requirements at node n ,

$\phi_{ij}(Q_{ij})$ is continuous over $Q_{ij} \geq 0$, and

$\int_0^{Q_{ij}} \phi_{ij}(Q) dQ$ is convex over $Q_{ij} \geq 0$ if a unique solution is to be reached.

This can be re-expressed in as:

Minimise

$$\sum_{(i,j) \in E} \text{Content} \quad (2.2)$$

subject to

$$\sum_{(n,j) \in E} Q_{nj} - \sum_{(i,n) \in E} Q_{in} = r_n, \quad \text{for all } n \in N$$

$$Q_{ij} \geq 0, \quad \text{for all } (i,j) \in E$$

where 'content' is defined in as:

$$\text{Content} = \theta_{ij}(Q_{ij}) = \int_0^{Q_{ij}} \phi_{ij}(Q) dQ \quad (2.3)$$

As stated earlier, $\phi_{ij}(Q)$ must be continuous and $\theta_{ij}(Q_{ij})$ convex over $Q_{ij} \geq 0$

In this formulation of the optimisation problem, an energy loss is taken as being positive. The 'content' for various system elements is defined as follows:

i. Energy-Loss Element

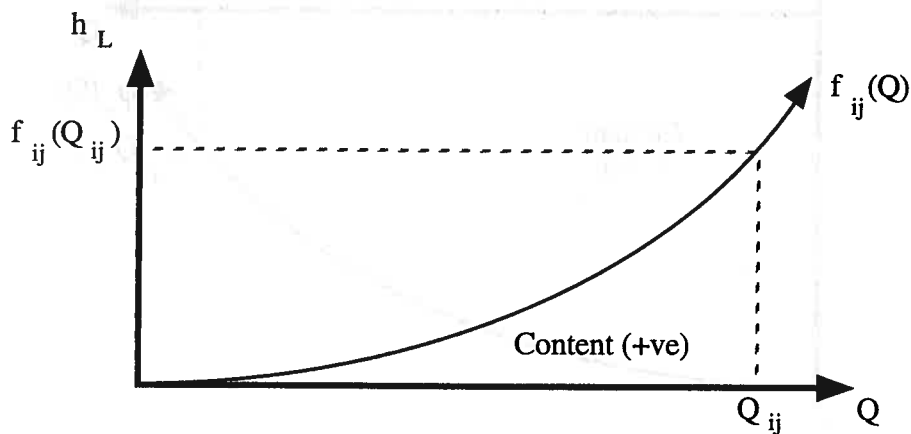
Any friction element is an energy loss element. This includes pipes, valves and junctions. The energy loss for these elements is generally expressed by:

$$h_L = \frac{kV^2}{2g} = \frac{8kQ^2}{\pi^2 D^4 g} \quad (2.4)$$

where

- k = minor loss coefficient for valves, junctions, etc.,
- k = $f \frac{L}{D}$ for pipes,
- f = pipe friction factor. It can be determined by a number of different methods including the Hazen-Williams or Colebrook equations,
- L = length of pipe,
- D = diameter of pipe,
- V = water velocity, and
- Q = water flow.

The content for an energy loss element is shown in Figure 2.4.



$$\text{Content} = \theta_{ij}(Q_{ij}) = \int_0^{Q_{ij}} f_{ij}(Q) dQ$$

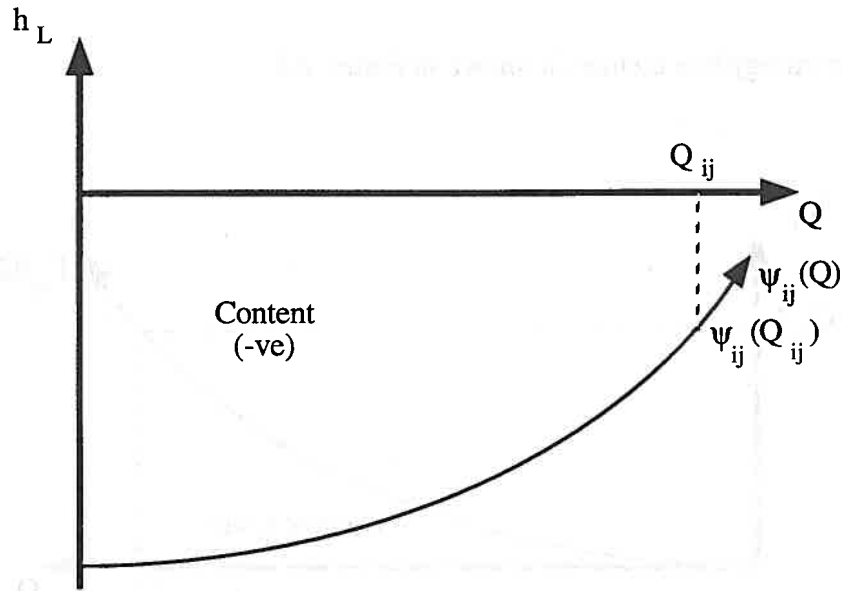
$$\text{where } f_{ij}(Q) = \frac{8kQ^2}{\pi^2 D^4 g}$$

Figure 2.4 Content for Friction Element

ii. Energy Gain Element

Pumps are energy gain elements assuming that water flows through them in the direction of pumping. This is assumed to be true for all pumps encountered (a reverse flow through a pump would have a large energy loss). Indeed, most networks are designed, through the use of reflux valves, so that reverse flow through pumps is not possible.

The content for an energy gain element is characterised in Figure 2.5.



$$\text{Content} = \theta_{ij}(Q_{ij}) = \int_0^{Q_{ij}} -\psi_{ij}(Q) dQ$$

where $\psi_{ij}(Q) =$ pump characteristic, which must be convex.

Figure 2.5 Content for Pump Element

If a pump content is not convex, as shown in Figure 2.6 (A), then the characteristic is approximated by the curve shown in Figure 2.6 (B). As with friction element head loss curves, the pump characteristic needs to be continuous and increasing to ensure the content function is convex and will lead to a unique optimal solution.

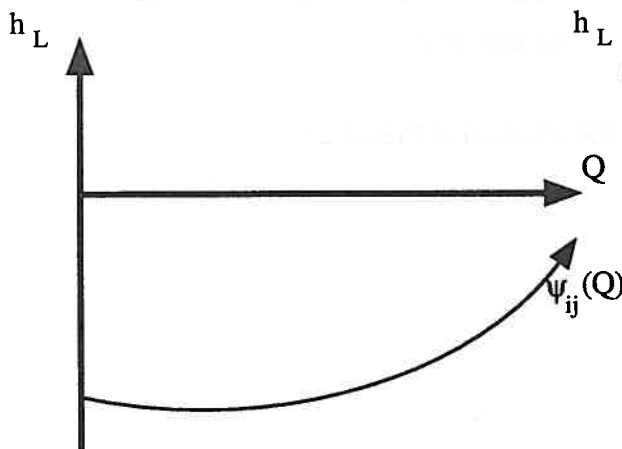


Figure 2.6 (A)

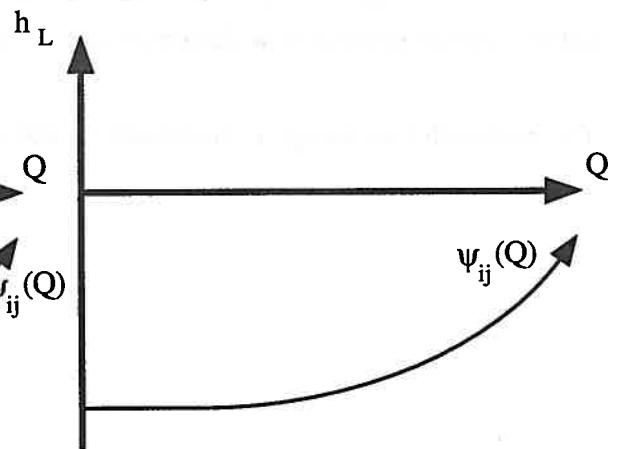
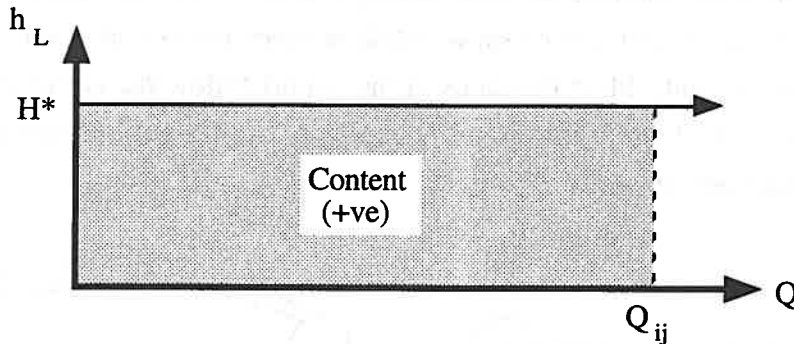


Figure 2.6 (B)

The Approximation (B) Used to Define a Pump with Non-Convex Content (A)

iii. Reservoirs

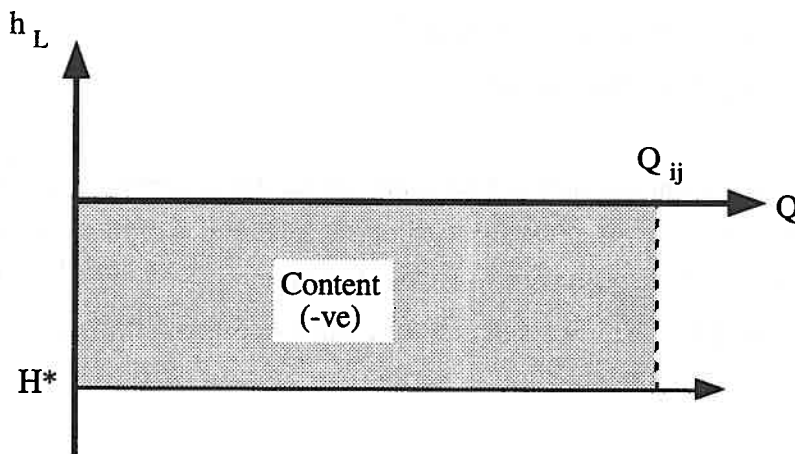
Reservoirs are special elements which provide water or receive water at a constant head. As water providers they can be seen as energy gain elements and as receivers they are energy loss elements. The energy gain or loss due to flow from or to reservoirs is costed by the content of the links between each reservoir and the ground node (g). The content of the reservoir to ground node link (receiving water) and vice versa (providing water) are shown in Figures 2.7 and 2.8 respectively.



$$\text{Content} = \theta_{ng}(Q_{ng}) = \int_0^{Q_{ng}} H^* dQ$$

where H^* = hydraulic head for reservoir n with datum at ground node g

Figure 2.7 Content for Water Entering Reservoir



$$\text{Content} = \theta_{gn}(Q_{gn}) = \int_0^{Q_{gn}} -H^* dQ$$

where H^* = hydraulic head for reservoir

Figure 2.8 Content for Water Leaving Reservoir

2.1.2 Formulation of Pipe network Problem as a Network Linear Program

The non-linear optimisation problem presented in the Section 2.1.1 can be solved using a network linear program if each non-linear cost function is approximated by a piece-wise linear cost function. Friction links and most pump links have non-linear cost functions. Links between reservoirs and the ground node have linear (constant) cost functions.

Links with non-linear cost functions are modelled by a series of arcs. Each arc has a set capacity and a linear cost function. Figure 2.9(A) shows a link between nodes i and j and 2.9(B) shows the arcs used to replace this link. Most diagrams in this report follow the convention that arcs are depicted by curved connections between nodes and links by straight line connections. Eqn 2.5 describes the arc cost function.



Figure 2.9(A)
Link from i to j

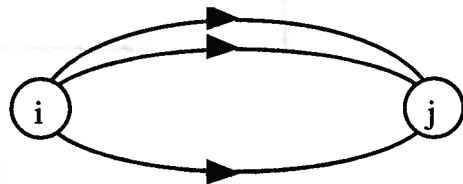


Figure 2.9(B)
Arcs representing link from i to j

$$\emptyset_{ij}^n(Q) = C_{ij}^n * Q_{ij}^n \quad (2.5)$$

where n is an arc from node i to node j ,

$\emptyset_{ij}^n(Q)$ is the cost function used in the optimisation problem (Eqn. 2.1),

C_{ij}^n is the cost for arc n , and

Q_{ij}^n is the flow in arc n .

The arc cost functions are chosen to build up a piecewise linear approximation to the link cost function. Figure 2.10 shows how the cost function of a typical link is represented by the linear cost functions of three arcs. For any convex link cost function, $C_{ij}^n < C_{ij}^{n+1}$. In Figure 2.10, $C_{ij}^1 < C_{ij}^2 < C_{ij}^3$. As arc 1 has the least cost, it will be filled to capacity before flow enters arc 2.

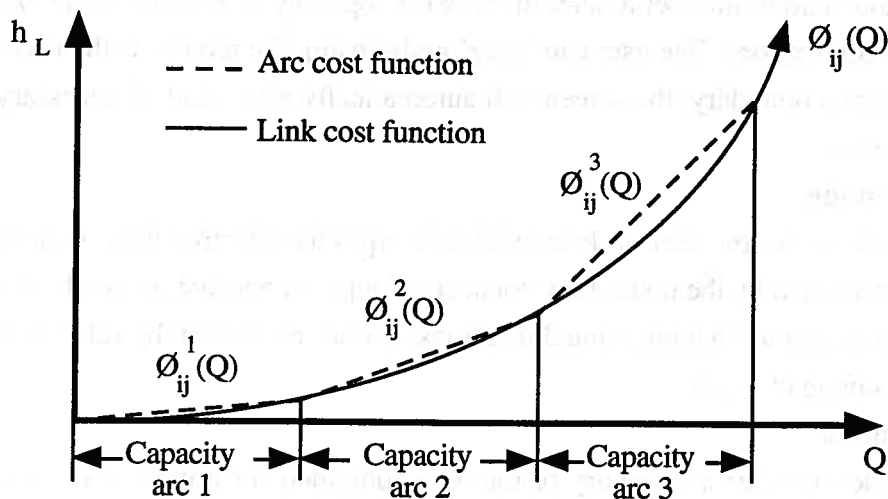


Figure 2.10 Piecewise Linear Approximation of Cost Function

Wong (1987) devised and implemented a very effective method for defining the arc costs and flow capacities. Put simply, the network is initially solved using a coarse piecewise linear approximation, which provides an estimate to the flow in each link. Hereafter, a finer piecewise linear approximation is only used in the vicinity of the expected flow. This is repeatedly refined and the network re-solved until an accurate solution is reached. Berghout (1991) extended and revised Wong's program to include nonlinear feedback devices such as pressure reducing valves.

2.2 Graphical Interface

The graphics developed for GIPNAP facilitate graphical data entry and result presentation.

Data entry/editing is controlled by the user through use of a mouse. The program responds to the mouse commands in accordance with the data entry/editing mode which the user has chosen. GIPNAP provides the following data entry/editing modes:

- **Add mode**

Nodes or pipes are added using the mouse. If the mouse is 'clicked' on an open space, then a new node is created. If clicked on an existing node, held down, and then released on another node, a connecting pipe is created. Pipe or node data is requested through a series of input screens, shown in Figures 2.11, 2.12 and 2.13, as each pipe or node is entered.

- **Edit mode**

Clicking on a node or pipe will allow the user to alter the data already entered for that node or pipe using the same input screens as used in 'Add' mode.

- **Move mode**

Move mode allows the user to alter the network topology by moving nodes without altering network connections. The user can 'drag' nodes using the mouse. If the user drags a node over a screen boundary, the screen will automatically scroll and, if necessary, expand the diagram size.

- **Delete mode**

This mode allows the user to delete nodes or pipes by selecting them with the mouse. As pipes are defined by the nodes they connect, all pipes connected to a node which is deleted will also be deleted. Unintentional deletions can be resurrected by reloading the network without saving changes.

- **View mode**

This mode provides a summary of the data contained for a pipe or node as selected. It differs from 'Edit' mode in that data is displayed in a small window without covering the plan view of the selection.

The user is also able to save, print the network or view a tabular summary of input data at any time during the network entering process.

Pipe networks are entered such that all devices (pumps, valves, etc) occur at nodes and are joined by connecting pipes. Node and pipe type are initially entered in 'Add' mode but can be later changed in 'Edit' mode. Node data and type are entered into the screen shown in Figure 2.11. For pump type nodes, pump curve data is required and is entered into the screen shown in Figure 2.12. The pipe data screen is shown in Figure 2.13.

Quit Return

2. Node Data

Node number: 23 Node name: 30

Coordinates: X - 444 Y - 194

Enter node elevation (in metres above datum): .0000

Select node type:

- J - pipe junction or demand point
Enter node demand (in megalitres per day) : -.000000E+00
- R - reservoir
Enter reservoir head (in metres above datum):
- P - pump
- U - pressure reducing valve (PRV)
Enter PRV set pressure (in metres above datum):
- U - pressure sustaining valve (PSU)
Enter PSU set pressure (in metres above datum):
- U - stop valve (SU)
Enter percent open (0 - shut; 100 - open):
- U - reflux valve
- L - other minor loss element

For any valve or other minor loss element, enter Head Loss Coefficient (HLC)
In the case of valves, enter "fully open" HLC:

Figure 2.11 Node Type and Data Input and Edit Screen

Quit Cancel Add

4. Pump Details

Pump characteristic number: 2 Node number: 23

Select pump type:

- Constant Rotation Pump (defined using pump characteristic equation)
Enter coefficients for pump characteristic equation:

$$H = \boxed{-5.346} * Q^2 + \boxed{7.057} * Q + \boxed{55.951}$$
 where units for Q are megalitres per day and H is metres
- Constant Rotation Pump (defined using head vs flow data)

| H (m) | Q (ML/d) | H (m) | Q (ML/d) | H (m) | Q (ML/d) |
|---------|------------|---------|------------|---------|------------|
| 1. | | 2. | | 3. | |
| 4. | | 5. | | 6. | |
| 7. | | 8. | | 9. | |
| 10. | | 11. | | 12. | |
| 13. | | 14. | | 15. | |

Figure 2.12 Pump Information Screen

Quit Return

3. Pipe Data

Pipe name: From-node: 22 To-node: 23
 (Pipe 1 of 1 pipes) From-node: 23 To-node: 22

Pipe length (in metres):

Pipe internal diameter and roughness:
 STANDARD PIPE

| nominal pipe size (mm) | DICL (class K9) | CICL |
|------------------------|-------------------------------|-------------------------------|
| 100 | <input type="radio"/> (103.7) | <input type="radio"/> (93.5) |
| 150 | <input type="radio"/> (158.7) | <input type="radio"/> (145.8) |
| 200 | <input type="radio"/> (209.4) | <input type="radio"/> (191.3) |
| 250 | <input type="radio"/> (262.4) | <input type="radio"/> (243.1) |
| 300 | <input type="radio"/> (317.0) | <input type="radio"/> (293.6) |
| 375 | <input type="radio"/> (396.4) | <input type="radio"/> (371.4) |
| 500 | <input type="radio"/> (528.3) | <input type="radio"/> (500.9) |
| 600 | <input type="radio"/> (627.2) | <input type="radio"/> (597.7) |
| 750 | <input type="radio"/> (783.4) | |

USER DEFINED PIPE:
 diameter (in mm): roughness (in mm):

Minor losses (k) to be included with pipe head loss:

where head loss = $k * v^2 / (2 * g)$

Figure 2.13 Pipe Data Input and Edit Screen

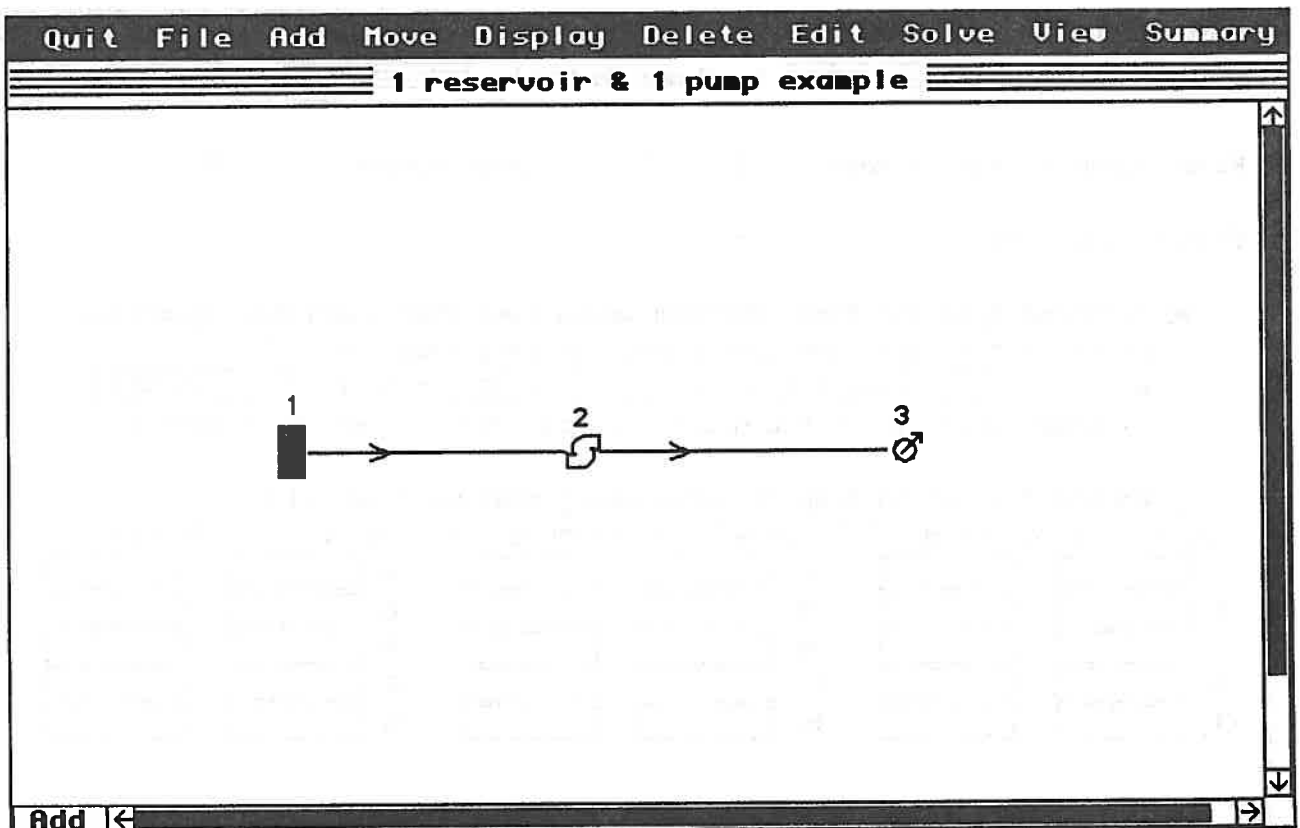


Figure 2.14 Small Pipe Network Consisting of a Reservoir, Pump and Demand Node.

A variety of result formats are available. The following descriptions of output options refer to output from the network shown in Figure 2.14.

GIPNAP output display options are listed below:

- A display of node pressures and pipe flows on the original network diagram, with arrows on each pipe to indicate flow direction. This gives the user an overview of major flow lines and pressure distribution. A pressure range can be specified so that nodes with too high or too low a pressure will flash. An example of the plan view output display is shown in Figure 2.15.
- A long section of pipe elevation and hydraulic grade line can be displayed for a series of selected nodes, as shown in Figure 2.16. The long section gives the user immediate feedback on the contributions by each component on a flow path to head loss. Independence of hydraulic grade line from ground elevation is clearly shown on the long section displays. The nodes in Figure 2.16 all have zero elevation, which has led to an invisible elevation profile.

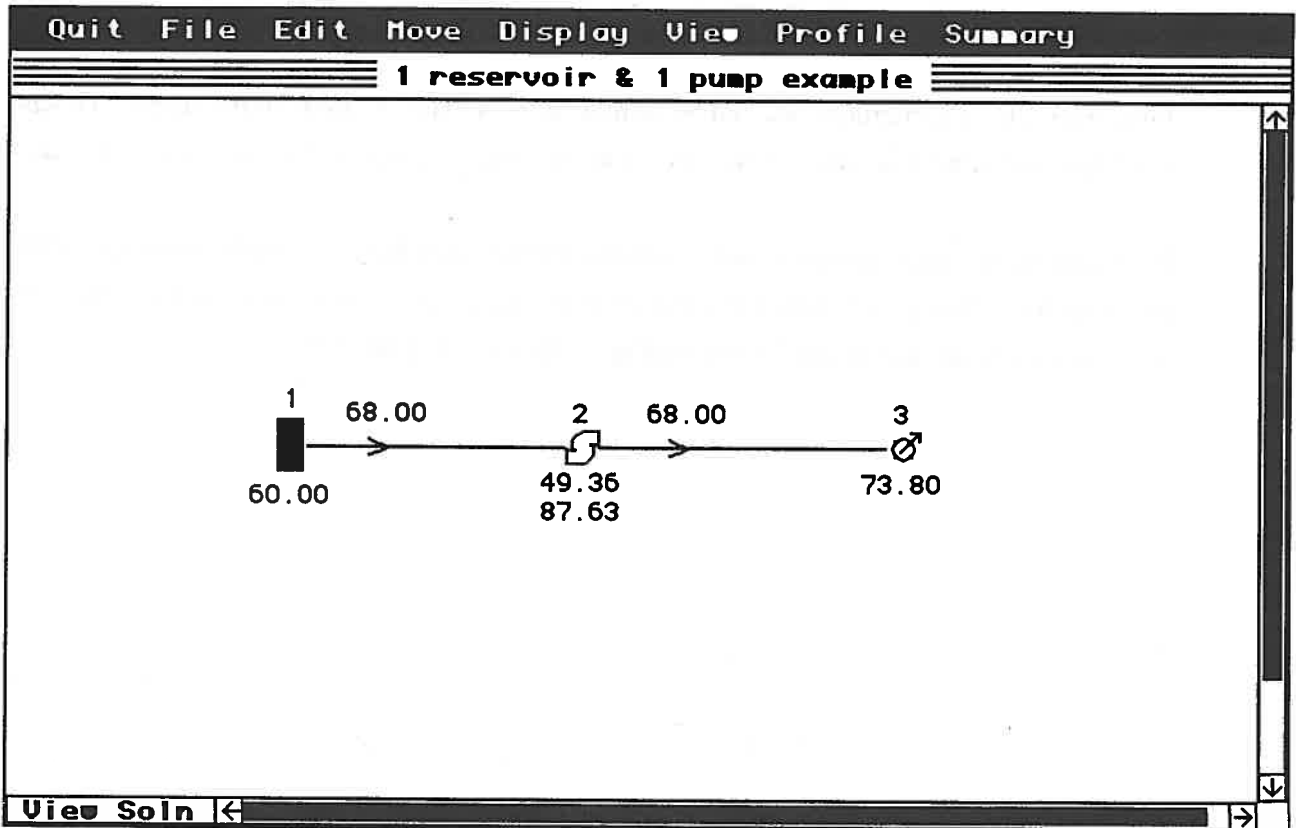


Figure 2.15 Plan View of 'Solved' Network Showing Node Pressures and Pipe Flows

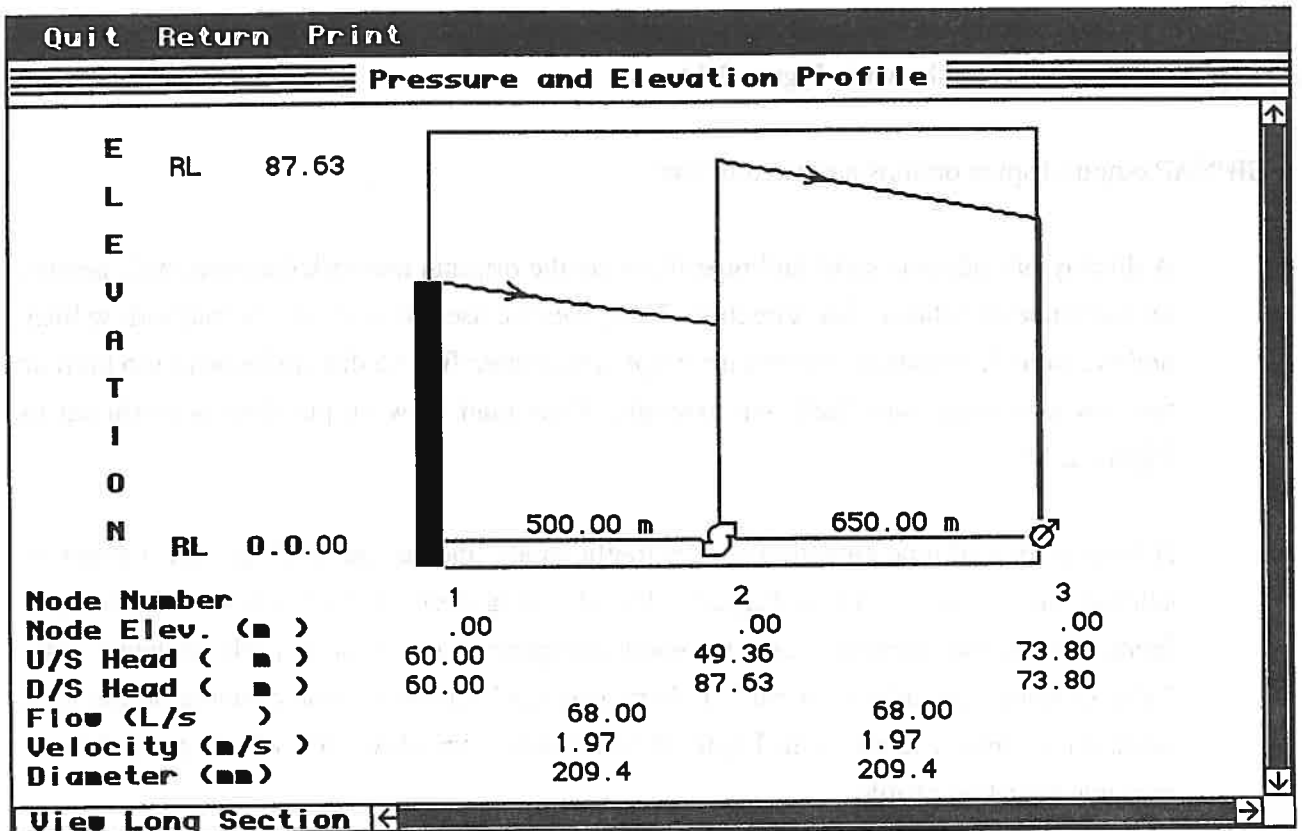


Figure 2.16 Hydraulic Profile from Nodes 1 to 3 for Example Network

- Information for a particular node can be displayed in an extra window on the screen. This is useful for checking that data was actually entered correctly. Figure 2.17 shows this display.
- Input and output data can be viewed in tabular format. This format is useful to people who are used to working with data files and wish to see all network information at once. A single screen from the tabular format display is shown in Figure 2.18.

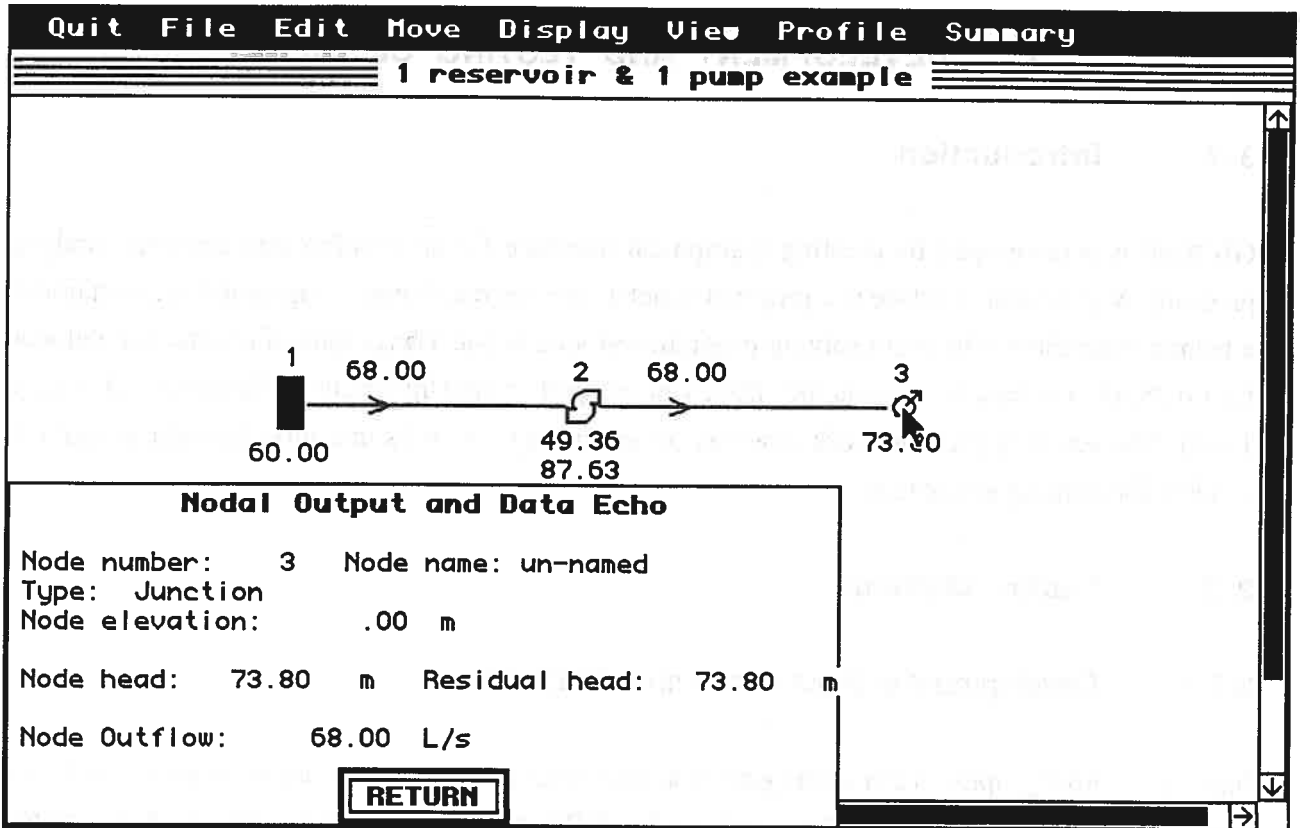


Figure 2.17 Information for Node 3 Displayed in 'View' Mode

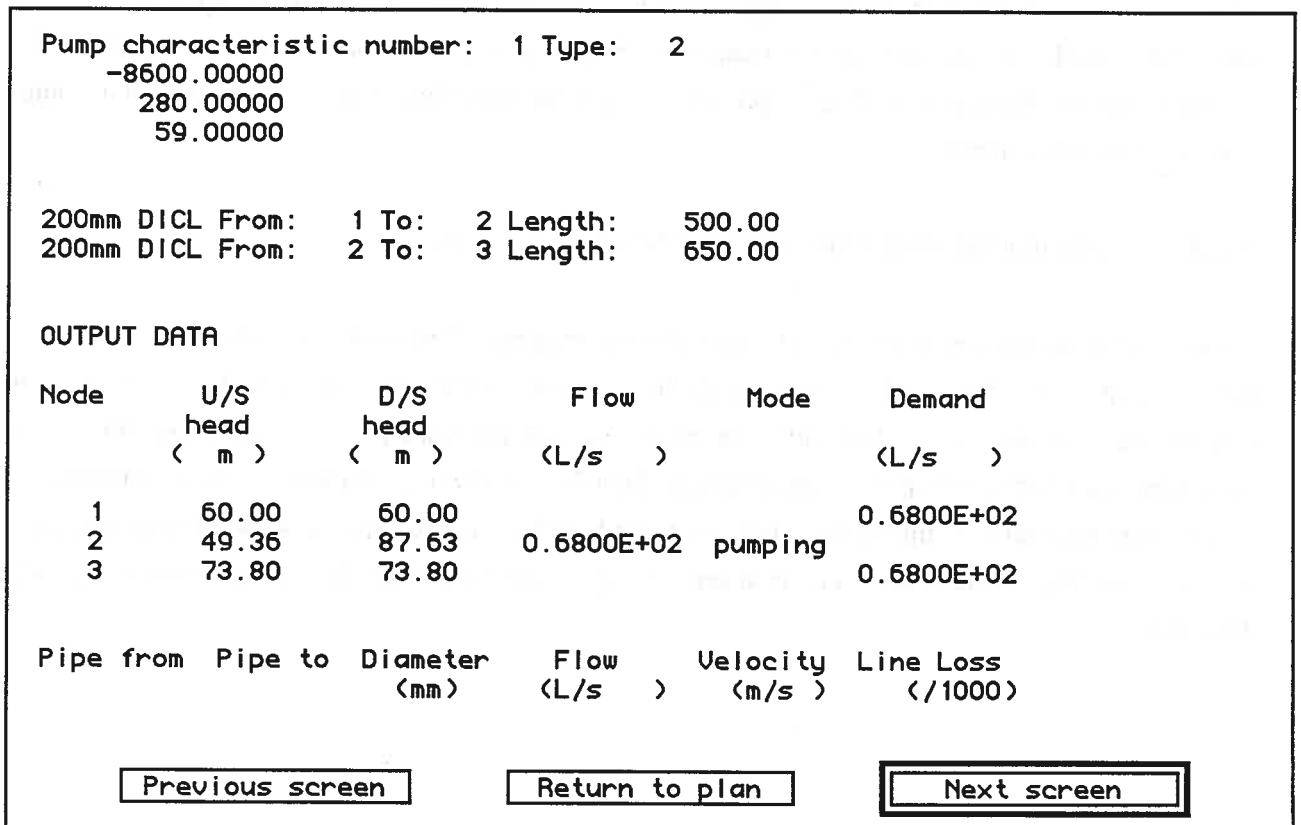


Figure 2.18 A Screen from the 'View Summary' Option

3. DEVELOPMENT AND TESTING OF GIPNAP

3.1 Introduction

GIPNAP was developed by creating a graphical interface for an existing pipe network analysis program. A graphical interface is a program which translates data from a graphical representation to a format readable by the main solving program and vice versa. The graphical interface developed for GIPNAP was based on a graphics library developed at the University of Newcastle (Kuczera, 1993). The existing pipe network analysis program also needed some modification to make it suitable for training applications.

3.2 Tasks, Methods

3.2.1 Development of Input and Output Graphics

Input and output graphics refer to the graphical data input and result presentation routines. A major hurdle in the development of the graphics for GIPNAP was the development of a panning technique. Panning is required for network diagrams which are larger than the computer screen and allow the user to move around the diagram using a set of scroll bars. The panning developed for GIPNAP includes innovations which make it both very easy to use and refresh quickly when the screen is moved. Most of the other graphics developments were based on similar existing graphics routines (Kuczera, 1993).

3.2.2 Modify Existing Pipe Network Analysis Program

Some modifications had to be made to the existing program (Berghout, 1991) to make it suitable for a graphical interface and to training applications. For example, valves and pumps are now considered at nodes rather than between nodes, so that pressure profiles can accurately show instantaneous jumps or drops in water pressure. Development of the graphical interface produced a much easier program testing facility than existed when the original pipe network analysis program was written. This led to the detection and fixing of problems which had not been originally detected.

3.2.3 User Manual

A User Manual has been produced for GIPNAP. It contains a description of each option available in GIPNAP. Generally users will find GIPNAP to be fairly self-explanatory, but will be able to reference the manual if they need some additional information. The Users manual is included in Appendix A.

3.3 Testing Main Solving Algorithm

The program has been extensively tested for ability to converge to a correct solution for a wide range of small network problems. The results for most trials were checked by hand for conservation of mass at nodes and for conservation of energy around network loops while some were checked against solutions obtained using WATSYS. The development of the graphics interface made testing of the solving routines very easy, with inconsistencies, such as head loss for zero flow, standing out clearly.

3.4 Trialling GIPNAP

GIPNAP has been trialled within the Hunter Water Corporation. It has been used for various applications, including a bore-line pumping model. As a result of trialling, GIPNAP has been adopted as a primary tool for doing available pressure calculations for fire flows, a calculation which involves analysing a small network in which water is supplied by a point (or points) of known pressure on a much larger network. Prior to using GIPNAP, this calculation was performed by hand and generally only took into account head loss along the most obvious flow path. GIPNAP has been successfully used by staff who have only a general knowledge in pipe network analysis and computer modelling.

Use as a training aid has been limited. Most likely it will be used as a demonstration aid and given to trainees as an assignment.

4. APPLICATIONS FOR GIPNAP

GIPNAP is designed as an easy to use pipe network analysis program. It can be used to analyse networks containing the following appurtenances:

- pipes
- reservoirs
- stop valves
- pressure reducing valves
- pressure sustaining valves
- reflux (check) valves
- pumps
- minor loss elements

This type of program is useful for a wide range of applications, including personnel training and design and analysis of pipe networks for urban water supply, pumped sewerage, irrigation, plumbing, etc. The maximum size of network that can be solved by GIPNAP depends on available computer memory. For example, on IBM compatibles, GIPNAP requires approximately 600kb of RAM to solve a network with up to 120 pipes and nodes.

5. ACKNOWLEDGMENTS

The development of GIPNAP has been made possible by a number of organisations and individuals.

Funding has been provided by Hunter Water Corporation and Urban Water Research Association of Australia. Hunter Water's contribution was greatly increased to enable the project to be completed when it was realised that my original cost estimate was flawed. I thank them for this important vote of confidence in the project.

The University of Newcastle, through Dr. George Kuczera, provided the time and knowledge (and FORTRAN graphics library) which enabled me to develop the graphics used in GIPNAP. A special thanks to George for his continued support and enthusiasm.

At Hunter Water, I thank Steve Weatherstone for his suggestions, ideas and reviews of features of the program. His background in the development of staff training is reflected in GIPNAP's suitability to staff training. Also, I thank Dr. Bob Wilson for his ready source of technical data.

Systems Investigation, Hunter Water, provided the use of WATSYS for the purpose of making comparative checks on the results produced by GIPNAP, and the computing facilities used in the development of GIPNAP.

The research staff and review panel for this project are listed below:

Research Staff: Brendan Berghout, Hunter Water Corporation

Review Panel: Dr. Bob Wilson, Hunter Water Corporation
 Steve Weatherstone, Hunter Water Corporation

6. AVAILABILITY

A Demonstration Version of GIPNAP is available from the Urban Water Research Association of Australia on request. This version can analyse a network of up to 15 nodes and runs on IBM compatible personal computers with a 386 (or later) cpu.

The full version of the program, which can analyse a network containing up to 500 nodes, is available for purchase through the Hunter Water Corporation. The full version also runs on IBM compatible personal computers with a 386 (or later) cpu and requires approximately 1.5 Megabytes of RAM.

7. REFERENCES

1. Balfour, A., and Marwick, D. H. (1979). Programming in Standard Fortran 77. Heinemann Educational Books Limited.
2. Berghout, B. L. (1991). Modelling Pressure Reducing Valves in Water Distribution Systems. Project Report, Department of Civil Engineering and Surveying, University of Newcastle.
3. Chandrashekar, M. (1980). Extended Set of Components in Pipe Networks. Journal of the Hydraulics Division, ASCE, Vol. 106, No. HY1, 133-149.
4. Collins, M. A., et al. (1976). Solving the Pipe Network Analysis Problem Using Optimisation Techniques. Technical Report IEOR 76008, School of Engineering and Applied Science, Southern Methodist University, Dallas, Texas.
5. Collins, M. A. (1979). Pitfalls in Pipe Network Analysis Techniques. 1979 ASCE Convention Atlanta.
6. Collins, M. A., et al. (1979). Multiple Operating Points in Complex Pump Networks. Journal of the Hydraulics Division, ASCE, Vol. 105, No. HY3, 229-244.
7. Jeppson, R. W., and Davis, A. L. (1976). Pressure Reducing Valves in Pipe Network Analyses. Journal of the Hydraulics Division, ASCE, Vol. 102, No. HY7, 987-1001.
8. Kuczera, G. (1993). A Portable FORTRAN Graphics Interface Applied to Model Calibration and Headworks Simulation Software. Proc. 2nd Australasian Conf. on Computing for the Water Industry Melbourne, 235-240
9. Streeter, V. L., and Wylie, E. B. (1981). Fluid Mechanics - First SI Metric Edition. McGraw-Hill Ryerson Limited.
10. Wong Yen Nyen, P. (1987) Simulation Of Piped Water Distribution Systems. Project Report, Department of Civil Engineering and Surveying, University of Newcastle.

GIPNAP

USER MANUAL

June, 1994

Urban Water Research Association of Australia

CONTENTS

| | |
|--|----------|
| CHAPTER 1 - INTRODUCTION | 1 |
| 1.1.....Introduction | 1 |
| 1.2.....An Overview of Pipe Network Analysis | 1 |
| 1.3.....System Requirements for GIPNAP | 2 |
| 1.4.....Installation Instructions for GIPNAP | 2 |
| 1.5.....Symbols Used by GIPNAP | 3 |
| CHAPTER 2 - OPENING, CREATING AND COPYING NETWORK FILES | 4 |
| 2.1.....Starting the Program | 4 |
| 2.2.....Show Network | 5 |
| 2.2.1.....View an Existing Network File | 5 |
| 2.2.2.....Creating a New Network File | 6 |
| 2.2.3.....Copying an Existing Network to a New Network File | 6 |
| 2.3.....Show Limits | 8 |
| CHAPTER 3 - INPUT OF PIPE NETWORK DATA | 9 |
| 3.1.....Setting Up and Solving Pipe Network Problems | 9 |
| 3.2.....File Menu | 10 |
| 3.2.1.....Save | 10 |
| 3.2.2.....Open network | 10 |
| 3.2.3.....Print | 11 |
| 3.3.....Add Mode | 12 |
| 3.3.1.....Node Details | 14 |
| 3.3.1.1.....Junction or Demand Point | 15 |
| 3.3.1.2.....Reservoir | 15 |
| 3.3.1.3.....Pump | 16 |
| 3.3.1.4.....Pressure Reducing Valve (PRV) | 17 |
| 3.3.1.5.....Pressure Sustaining Valve (PSV) | 18 |
| 3.3.1.6.....Stop Valve | 19 |
| 3.3.1.7.....Reflux Valve | 19 |
| 3.3.1.8.....Other Minor Loss Element | 20 |
| 3.3.2.....Pipe Details | 20 |
| 3.4.....Move mode | 21 |
| 3.5.....Display Menu | 23 |
| 3.5.1.....Set units | 24 |
| 3.5.2.....Head Alert | 25 |

| | | |
|--------|--------------------------|----|
| 3.5.3 | Info layout | 25 |
| 3.6 | Delete Mode | 25 |
| 3.6.1 | Deleting Nodes | 25 |
| 3.6.2 | Deleting Pipes | 25 |
| 3.7 | Edit Mode | 26 |
| 3.7.1 | Editing Nodes | 26 |
| 3.7.2 | Editing Pipes | 26 |
| 3.8 | Solve | 26 |
| 3.9 | View Mode | 27 |
| 3.10 | Summary | 27 |
| 3.10.1 | Create Summary Data File | 27 |
| 3.10.2 | View Summary | 28 |

CHAPTER 4 - OUTPUT OF RESULTS 29

| | | |
|-------|--|----|
| 4.1 | Viewing Solutions to Pipe Network Problems | 29 |
| 4.2 | File | 32 |
| 4.3 | Edit | 32 |
| 4.4 | Move | 32 |
| 4.5 | Print Network | 32 |
| 4.6 | View Mode | 32 |
| 4.7 | Profile | 33 |
| 4.7.1 | View Profile | 33 |
| 4.7.2 | Return | 33 |
| 4.9 | Summary | 33 |

CHAPTER 5 - EXAMPLE NETWORK FILES 34

| | | |
|-----|-------------------------|----|
| 5.1 | Example 1 - BURWOOD.NET | 34 |
| 5.2 | Example 2 - NCLE.NET | 34 |

CHAPTER 6 - TYPICAL VALUES AND CONVERSION FACTORS 35

| | | |
|-------|-------------------------|----|
| 6.1 | Conversion Factors | 35 |
| 6.1.1 | Flow | 35 |
| 6.1.2 | Velocity | 35 |
| 6.1.3 | Volume | 35 |
| 6.1.4 | Length | 35 |
| 6.2 | Head Loss Data | 36 |
| 6.2.1 | Pipes (wall roughness) | 36 |
| 6.2.2 | Fittings (minor losses) | 38 |

DISCLAIMER

While every attempt has been made to ensure that GIPNAP produces correct results or appropriate error messages for all configurations, errors may still occur. The author, Hunter Water Corporation, Urban Water Research Association of Australia and The University of Newcastle disclaim jointly and severally any liability, consequential or otherwise, arising from use of GIPNAP and material in this manual.

Accordingly it is recommended that the user carry out a comparative check of results using another technique or calculation.

COPYRIGHT

The GIPNAP manual and software are copyrighted with all rights reserved.

FEEDBACK

Any feedback regarding the use of GIPNAP and this manual, such as program errors or inconsistencies would be greatly appreciated. Please address correspondence to:

Brendan Berghout
Department of Civil Engineering & Surveying
University of Newcastle
Callaghan NSW 2308
AUSTRALIA

CHAPTER 1 - INTRODUCTION

1.1 Introduction

This is the reference manual for GIPNAP, a Graphical Interactive Pipe Network Analysis Program. It contains information about the processes involved in modelling piped water networks using GIPNAP. Chapter 5 contains a description of Example network files included with the program. Chapter 6 contains tables of accepted values and conversion factors useful in pipe network analyses.

GIPNAP was developed to provide an effective and simple means of demonstrating the performance of small pipe networks. It can be used for training of water supply operations personnel, design of small systems and analysis of system performance.

1.2 An Overview of Pipe Network Analysis

Pipe network analysis involves the determination of the flows and pressure throughout a pipe network given a particular demand and supply scenario. The pipe networks referred to in these problems are those which convey liquids (such as oil or water) or gases (such as natural gas). The fluid being conveyed is under pressure, and has no free surface as in open channel (phreatic) flow. Sewerage reticulation problems cannot be solved by pipe network analyses.

The solution of a pipe network problem is very similar to the solution of electrical circuit problems. A solution is found when it meets the following conditions:

- i. The algebraic sum of head losses around each closed loop in the network must be zero.
- ii. Flow into each junction must equal flow out of the junction.
- iii. The proper relation between head loss and discharge must be maintained in each pipe.

Pipe network analyses are a routine part of the design and operation of piped water distribution systems, so a tool which can perform these analyses is very useful. The types of situations GIPNAP can be used for is discussed in detail in Chapter 5.

GIPNAP has been written specifically for the analysis of water pipe networks, but could be modified relatively easily for the analysis of gas or other fluid pipe networks in which consideration of fluid compressibility is not required.

1.3 System Requirements for GIPNAP

Macintosh

RAM 800kb for GIPNAP + System requirements - ie, 2 Megabytes minimum

CPU 68020/68881 or 68030/68882 preferred
68000 version is available, but can be slow

System System 6.0 or later required

IBM Compatibles

RAM Approximately 1 Megabyte extended memory is required.

CPU 386 or better

1.4 Installation Instructions for GIPNAP

Macintosh

Copy the files GIPNAP, GIPNAP.MEN and the example network files into an appropriate folder. Network files must be stored in the same folder as the program to enable them to be located by the program.

IBM Compatibles

1. Create the directory C:\GIPNAP
2. Copy all files from the diskette to C:\GIPNAP
(example network files, *.NET, are optional)
3. If wishing to run from Windows, add following line to C:\WINDOWS\SYSTEM.INI file (on the next line immediately below [386Enh]):
DEVICE=C:\GIPNAP\DOSXNT.386
4. Reboot machine
GIPNAP can now be run from FILEMANAGER or DOSPROMPT in Windows.











Notes:

You can store network files in a 'working' directory (eg. C:\NETFILES) if you wish. To do this, you need to specify path as well as file name when opening files. (Eg. the appropriate name for the file BB.NET would be C:\NETFILES\BB.NET)

This version of GIPNAP can only be run on 386 or 486 (or later) IBM compatible computers.

1.5 Symbols Used by GIPNAP

The following symbols are used by GIPNAP:

| | | | |
|--|---------------------------|---|------------------------|
|  | Junction with demand |  | Pump |
|  | Junction |  | Stop valve |
|  | Reservoir |  | Reflux valve |
|  | Pressure reducing valve |  | Minor loss element |
|  | Pressure sustaining valve |  | Pipe from node to node |

CHAPTER 2 - OPENING, CREATING AND COPYING NETWORK FILES

2.1 Starting the Program

GIPNAP is executed using the standard procedure for the computer being used. On Macintosh this is done by double clicking the mouse on the GIPNAP icon; on IBM by double clicking GIPNAP icon in File Manager (under Windows) or typing GIPNAP at the DOS Prompt when in the appropriate directory; on Apollo or SUN by typing GIPNAP when in the appropriate directory.

When GIPNAP is executed, the screen shown in Figure 2.1 appears.

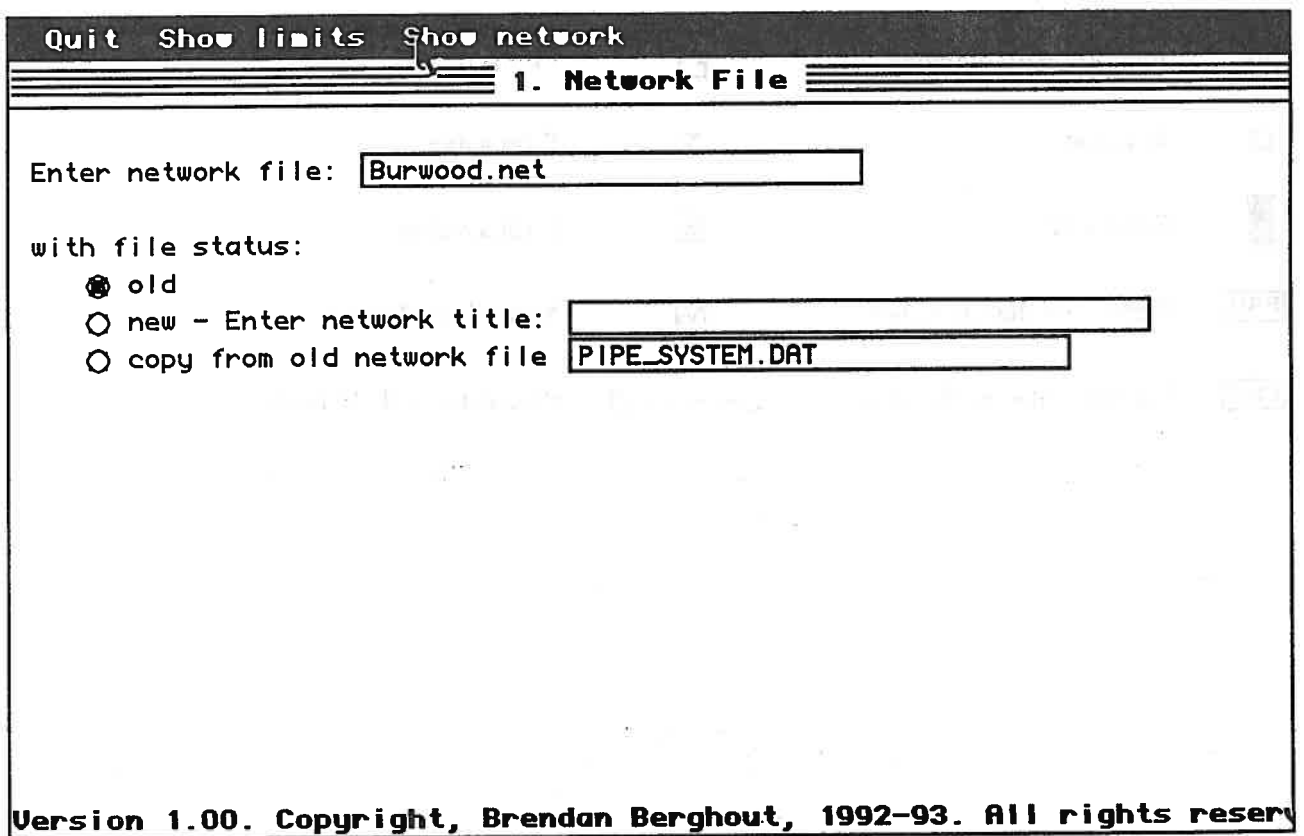


Figure 2.1 - Network File Selection Screen (on Macintosh)

The following options are available:

- i. Show network - new or existing. Refer to Section 2.2
- ii. Show limits (of program) - See Section 2.3

Notes:

- The file GIPNAP.MEN must be in the same directory or folder as GIPNAP.EXE for GIPNAP to run.

2.2 Show Network

This command enables the user to view an existing network or to create a new one. It can also be used to copy an existing network to a new file. If a network is already loaded in memory, then the show network command will close it and replace it with the selected network.

2.2.1 View an Existing Network File

To access an existing network, follow these steps:

1. Type the name of the existing network in the top box:

Enter network file:

2. Select file status of 'old':

with file status:

- old
- new - Enter network title:
- copy from old network file

3. Click on the option 'Show network' in the menu bar.

Notes:

- 'Network title' and 'Copy from file' boxes are not used when viewing an existing network, so it does not matter what information is displayed in these boxes.
- On IBM compatibles, filenames are limited to 8 characters plus a 3 character extension. Eg, TOWNCNTR.NET

2.2.2 Creating a New Network File

To create a new network, follow these steps:

1. Type the name of the network you wish to create in the top box:

Enter network file:

2. Select file status of 'new':

with file status:

old

new - Enter network title:

copy from old network file

3. Enter a title for the new network in the 'Network title' box, adjacent to the file status:

new - Enter network title:

4. Click on the option 'Show network' in the menu bar.
5. Nominate the preferred unit system at the 'Set units' screen, as described in Section 3.5.1.

Notes:

- 'Copy from file' box is not used when creating a new network, so it does not matter what information is displayed in this box.
- Don't forget to change the file status to 'old' next time you wish to view the network you have just created.
- On IBM compatibles, filenames are limited to 8 characters plus a 3 character extension. Eg, TOWNCNTR.NET

2.2.3 Copying an Existing Network to a New Network File

This option enables the user to create a new network file with the information from an existing network file. This feature can be used to make experimental changes to a network without losing the original information.

To copy an existing network to a new network file, follow these steps:

1. Enter the name of the network file you wish to create (COPY TO) in the top box:

Enter network file:

2. Select file status of 'copy':

with file status:

old

new - Enter network title:

copy from old network file

3. Enter the name of the existing file you wish to copy from in the 'Copy from file' box, adjacent to the file status:

copy from old network file

4. Click on the option 'Show network' in the menu bar.

Notes:

- 'Network title' box is not used when copying an existing network to a new network file, so it does not matter what information is displayed in this box.
- Don't forget to change the file status to 'old' next time you wish to view the network you have just created.
- On IBM compatibles, filenames are limited to 8 characters plus a 3 character extension. Eg, TOWNCNTR.NET

2.3 Show Limits

This option allows the user to check on the maximum number of nodes (and special nodes) and links which the program has been configured to analyse. If a network is already loaded, the 'Show limits' option will also display the current number of nodes and links in the network. The 'Show limits' display is shown in Figure 2.2.

| Quit Return | |
|---|-----|
| GIPNAP Limits | |
| Number of nodes in current network..... | 10 |
| Maximum number of nodes allowed..... | 250 |
| Number of links in current network..... | 10 |
| Maximum number of links allowed..... | 250 |
| Maximum number of pumps allowed..... | 10 |
| Maximum number of prvs and psvs (combined) allowed..... | 5 |

Figure 2.2 - 'Show limits' information screen

CHAPTER 3 - INPUT OF PIPE NETWORK DATA

3.1 Setting Up and Solving Pipe Network Problems

Pipe network components are entered as nodes and pipes. New components are added by selecting 'Add' mode from the top menu bar. The menu bar for unsolved networks is shown in Figure 3.1. Add mode is discussed in Section 3.3. **Nodes must be entered before the pipes connecting them can be entered.**



Figure 3.1 Main menu bar for unsolved networks.

Node elements include valves (including stop, pressure reducing and pressure sustaining), junctions, demand points, reservoirs, pumps, and other minor loss elements. The entry of node elements is discussed in Section 3.3.1.

Pipe elements make up the connections between the nodes. Pipe elements are discussed in Section 3.3.2.

Once created, pipe network components can be edited (Section 3.7), deleted (Section 3.6) or moved (Section 3.4) by selecting the appropriate mode from the top menu bar and then selecting the component with the mouse.

Other features available before (and after) solving include:

Main menu:

- View mode, in which the input details of a component are displayed when it is selected using the mouse (Section 3.9)
- Summary option will produce a text file of the input data, which can be browsed from within GIPNAP (Section 3.10)

File menu (3.2):

- Save network file (Section 3.2.1)
- View a different network file (and close current file) (Section 3.2.2)
- Print option to create a postscript file of the network diagram (Section 3.2.3)
- Show Limits (of program) (Section 3.2.4)

Display menu (3.5):

- Set units for data input and output (Section 3.5.1)
- Set head alert - alarm to indicate nodes which have a pressure outside or inside a selected pressure range once the network is solved (Section 3.5.2)
- Set the information to be displayed for each node or pipe (Section 3.5.3)
- Zoom - to view entire network on one screen or to adjust node spacing (Section 3.5.4)

Once a complete network has been entered, it can be solved by selecting the 'Solve' option from the top menu bar. This is discussed in Section 3.8. After solving, a new menu bar will appear with the options for viewing the results. These options are discussed in Chapter 4.

3.2 File Menu

When 'File' is selected from the main menu, the menu shown in Figure 3.2 is displayed. The options available from the File menu are:

- Save network file (Section 3.2.1)
- View a different network file (and close current file) (Section 3.2.2)
- Print option to create a postscript file of the network diagram (Section 3.2.3)
- Show Limits (of program) (Section 2.3)



Return Save Open network Print Show limits

Figure 3.2 File menu

3.2.1 Save

This option allows the user to save a network. It is wise to save a network frequently while entering it, to avoid data loss if the system crashes (for whatever reason). When the user 'Solves' a network, the network file is automatically saved. The user is prompted to save the network when quitting or closing by opening another network file.

3.2.2 Open network

This option is used to open a different network, as discussed in Chapter 2. When a network file is opened, the file currently in memory is closed and replaced by the selected file. The user is prompted to save the current file if it is being closed.

3.2.3 Print

The print command allows the user to create a postscript file of the network diagram. Node head and pipe flow labels will be printed on each node or pipe as they appear on the screen. A postscript file will be formed for each page of the picture and will have a name similar to 'Postfle.001.'

Macintosh

The postscript file created by the print command needs to be dumped to a printer using another program, which can be running simultaneously to GIPNAP if using multifinder. The program SendPS can be used to dump the postscript files to a laser printer, but appears to work only for 'old' Macintosh laser printers.

Alternatively, screen dumps can be made using 'Shift' '⌘' '3' keys simultaneously. This will create a 'MacPaint©' file in the main directory which can be printed using a variety of drawing packages including MacPaint©, Canvas© and MacDrawPro©. Remember to put the mouse to the side of the diagram, as it will show up on the screen dump. Most of the example diagrams in this manual were created using screen dumps.

IBM Compatible

The user can elect to have the postscript file dumped directly to a printer, if the computer is connected to a postscript printer. In this case, the user has to specify the correct syntax for a DOS print command. The user is referred to their DOS manual (and/or network manual for networked printers) for the correct print syntax.

In some instances, the initial print command opens the connection to a printer, with subsequent commands assuming the same connection. In these situations, the user can select the 'special first print' option. Note that the 'special first print' option should only be required for the first picture printed after the computer has been switched on, if at all.

3.3 Add Mode

Add mode is used to add new network components to a new or existing network. Edit mode (Section 3.7) should be selected if you wish to change the details of a network component.

Node elements and pipes are entered using Add mode, depending on the instructions given by the user through the way the mouse is used.

If the mouse is clicked (single click) in an open area of the screen, then a node is created. An example of node entry is shown in Figure 3.3. The user then has to enter the details for the node, as discussed in Section 3.3.1. The user can choose to 'Cancel' the node just entered by selecting 'Cancel' from the menu bar shown in Figure 3.5.

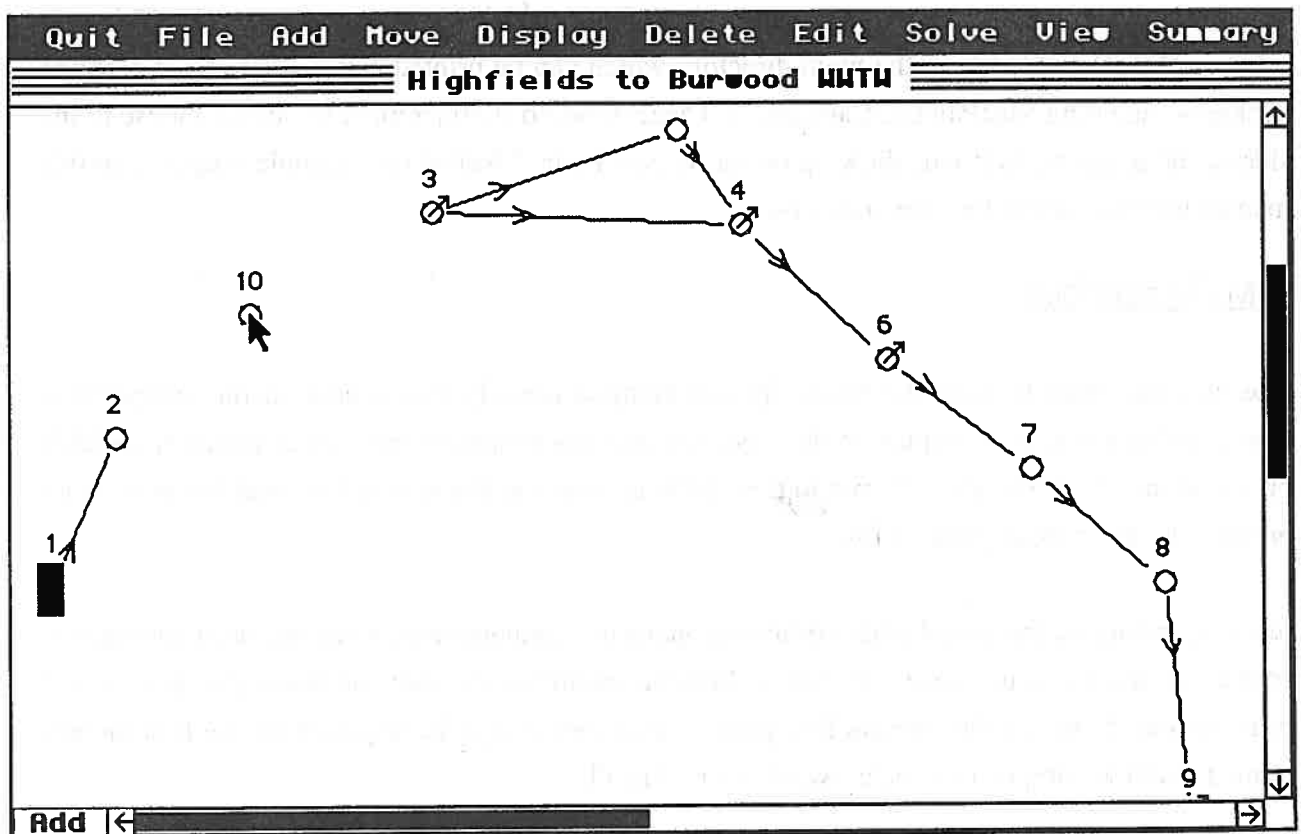


Figure 3.3 Entering a node (Node 10) by single click of mouse in an open area. Note the current mode (Add) displayed in box at bottom left of screen.

If the mouse is depressed on a node, moved onto another node and then released (you will see a 'rubber band' representing the pipe you are creating), then a pipe is created, as shown in Figure 3.4. As with node creation, details are required for the pipe (Section 3.3.2) and the user has the option to 'Cancel' the new pipe. If the destination node of the pipe is not visible on the portion of network shown on the screen, then the screen will automatically scroll as the screen borders are 'bumped.'

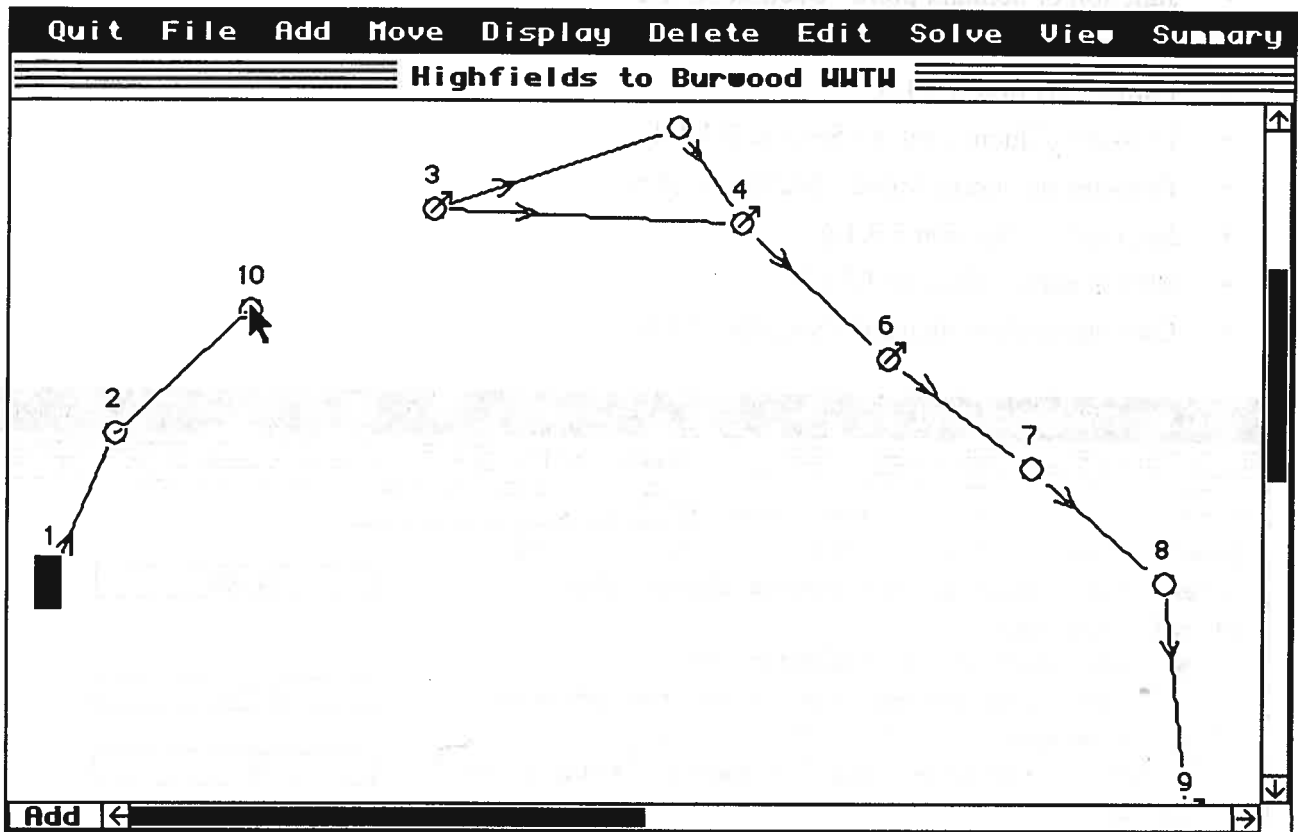


Figure 3.4 Entering a pipe (Node 2 to Node 10) by clicking of mouse in Node 2 and dragging. Note the current mode (Add) displayed in box at bottom left of screen.

Pipe direction is not important, unless the pipe is leading to or from a special valve or pump node. The flow direction through special valves (prv, reflux, psv) and pumps is set by the direction of the arrows on the pipes connected to them. This direction can be reversed, if incorrectly entered, in 'Edit' mode.

3.3.1 Node Details

Node details are required when nodes are being entered or edited. The screen for entering node details is shown in Figure 3.5 and is fairly self-explanatory. Node types and the details required are given in the following sections:

- Junction or demand point - Section 3.3.1.1
- Reservoir - Section 3.3.1.2
- Pump - Section 3.3.1.3
- Pressure reducing valve - Section 3.3.1.4
- Pressure sustaining valve - Section 3.3.1.5
- Stop valve - Section 3.3.1.6
- Reflux valve - Section 3.3.1.7
- Other minor loss element - Section 3.3.1.8

| Quit Cancel Add | |
|---|----------------|
| 2. Node Data | |
| Node number: | 4 |
| Node name: | Fifth St. |
| Coordinates: | X - 137 Y - 52 |
| Enter node elevation (in metres above datum): | 52.00 |
| Select node type: | |
| <input checked="" type="radio"/> Pipe junction or demand point | |
| Enter node demand (in litres per second): | 2.50 |
| <input type="radio"/> Reservoir | |
| Enter reservoir head (in metres above datum): | .00 |
| <input type="radio"/> Pump | |
| <input type="radio"/> Pressure reducing valve (PRU) | |
| Enter PRU set pressure (in metres above datum): | .00 |
| <input type="radio"/> Pressure sustaining valve (PSU) | |
| Enter PSU set pressure (in metres above datum): | .00 |
| <input type="radio"/> Stop valve - Enter % open (0 - shut; 100 - open): | 100.000 |
| <input type="radio"/> Reflux valve | |
| <input type="radio"/> Other minor loss element | |
| For any valve or other minor loss element, enter Head Loss Coefficient (HLC) where $HL = HLC * Q * Q$ (Q in cubic metres per second, HL in metres) (In the case of valves, enter "fully open" HLC): | |
| | .0000 |

Figure 3.5 Node Details Screen

3.3.1.1 Junction or Demand Point

Junction nodes are used at pipe intersections or demand points. Any number of pipes can enter or exit a junction node. An external demand or supply (negative demand) can be entered at a junction node.

The following information is required to describe a junction or demand node:

- **Node name.** If no name is provided, name will default to 'un-named'
- **Node elevation.** Node elevation is used to compute the residual pressure at a node. If a profile of pipe elevation is required, then node elevation should be provided. Node elevation will default to 0.0 if no elevation is provided.
- **Node demand.** Node demand (in the set units) is only required at points of local demand or supply. Node demand will default to 0.0, if no entry is made. When a node is acting as a demand or supply point, an arrow 'out' or 'in', respectively, is displayed as shown in Figure 3.6.



Figure 3.6 - Demand(1) and Supply(2) Nodes

3.3.1.2 Reservoir

Reservoir nodes are treated as fixed head nodes which behave as an infinite source or sink. Every network requires at least one reservoir to act as a water source.

The following information is required to describe a reservoir node:

- **Node name.** If no name is provided, name will default to 'un-named'
- **Node elevation.** Node elevation is used to compute the residual pressure at a node. If a profile of pipe elevation is required, then node elevation should be provided. Node elevation will default to 0.0 if no elevation is provided.
- **Reservoir head** or top water level (in metres above datum) is required at all reservoir nodes.

3.3.1.3 Pump

When a pump node is selected, the user has to select one of the ten pump curves, using the screen shown in Figure 3.7. These may or may not already be defined. If not already defined, the user has to provide a pump curve - either as a series of coordinates on the curve or as a parabolic equation. The user also has the option of editing an already defined pump curve. Pump curve information is provide through the screen shown in Figure 3.8.

Each pump curve can be used at as many pump locations as the user wishes.

```
Quit Cancel Select Pump Edit Pump
===== 5. Pump Selection =====
Pump at node: 42
Select a pump for this node:
○ Pump 1 (defined)
● Pump 2 (defined)
○ Pump 3 (defined)
○ Pump 4 (defined)
○ Pump 5 (undefined)
○ Pump 6 (undefined)
○ Pump 7 (undefined)
○ Pump 8 (undefined)
○ Pump 9 (undefined)
○ Pump 10 (undefined)
```

Figure 3.7 - Pump Curve Selection Screen

The following information is required to describe a pump node:

Node details screen:

- **Node name.** If no name is provided, name will default to 'un-named'
- **Node elevation.** Node elevation is used to compute the residual pressure at a node. If a profile of pipe elevation is required, then node elevation should be provided. Node elevation will default to 0.0 if no elevation is provided.

The following information is required to describe a PRV:

- **Node name.** If no name is provided, name will default to 'un-named'
- **Node elevation.** Node elevation is used to compute the residual pressure at a node. If a profile of pipe elevation is required, then node elevation should be provided. Node elevation will default to 0.0 if no elevation is provided.
- **PRV set pressure.** The PRV set pressure is the set downstream head (in metres above datum) for the pressure reducing valve.
- **Valve Head Loss Coefficient (HLC).** The valve HLC is the fully open head loss coefficient for the valve. It is calculated using the relationship $h_L = HLC * Q^2$ where Q is flow in m³/s and h_L is head loss across the valve in metres. Refer to Chapter 6 for recommended values of HLC.

3.3.1.5 Pressure Sustaining Valve (PSV)

Pressure sustaining valves are used to maintain pressure upstream of the valve at a nominated head. They work by throttling flow so that the pressure upstream is kept at the set pressure. Note that there should be at least one reservoir downstream of each PSV in a network, so that demands can be met even when the PSV is fully shut.

The following information is required to describe a PSV:

- **Node name.** If no name is provided, name will default to 'un-named'
- **Node elevation.** Node elevation is used to compute the residual pressure at a node. If a profile of pipe elevation is required, then node elevation should be provided. Node elevation will default to 0.0 if no elevation is provided.
- **PSV set pressure.** The PRV set pressure is the set upstream head (in metres above datum) for the pressure sustaining valve.
- **Valve Head Loss Coefficient (HLC).** The valve HLC is the fully open head loss coefficient for the valve. It is calculated using the relationship $h_L = HLC * Q^2$ where Q is flow in m³/s and h_L is head loss across the valve in metres. Refer to Chapter 6 for recommended values of HLC.

3.3.1.6 Stop Valve

Stop Valve nodes have been entered primarily as a training tool. A stop valve can only be used to stop flow through a particular part in a network where there are alternative flow routes.

The following information is required to describe a stop valve:

- **Node name.** If no name is provided, name will default to 'un-named'
- **Node elevation.** Node elevation is used to compute the residual pressure at a node. If a profile of pipe elevation is required, then node elevation should be provided. Node elevation will default to 0.0 if no elevation is provided.
- **Percent open.** The percent open represents the amount of restriction applied at the stop valve. Stop valves are operated within the program by making an adjustment on the valve HLC, so it is **important to enter a HLC value** for these valves.
- **Valve Head Loss Coefficient (HLC).** The valve HLC is the fully open head loss coefficient for the valve. It is calculated using the relationship $h_L = HLC * Q^2$ where Q is flow in m³/s and h_L is head loss across the valve in metres. Refer to Chapter 6 for recommended values of HLC.

3.3.1.7 Reflux Valve

A reflux valve is a uni-directional flow device. It is the water pipe equivalent of an electrical diode. Other names for a reflux valve include check valve, non-return valve and flap valve.

The following information is required to describe a reflux valve:

- **Node name.** If no name is provided, name will default to 'un-named'
- **Node elevation.** Node elevation is used to compute the residual pressure at a node. If a profile of pipe elevation is required, then node elevation should be provided. Node elevation will default to 0.0 if no elevation is provided.
- **Valve Head Loss Coefficient (HLC).** The reflux valve HLC is the head loss coefficient in the permissible flow direction. It is calculated using the relationship $h_L = HLC * Q^2$ where Q is flow in m³/s and h_L is head loss across the valve in metres. Refer to Chapter 6 for recommended values of HLC.

3.3.1.8 Other Minor Loss Element

A minor loss element is a restriction to flow other than pipe friction. Minor losses include valves, junctions, sudden expansions or contractions and other appurtenances. GIPNAP can model the effect of a minor loss element if its head loss characteristics can be described by $h_L = HLC * Q^2$.

The following information is required to describe a minor loss element:

- **Node name.** If no name is provided, name will default to 'un-named'
- **Node elevation.** Node elevation is used to compute the residual pressure at a node. If a profile of pipe elevation is required, then node elevation should be provided. Node elevation will default to 0.0 if no elevation is provided.
- **Valve Head Loss Coefficient (HLC).** The valve HLC is the head loss coefficient for the minor loss element. It is calculated using the relationship $h_L = HLC * Q^2$ where Q is flow in m³/s and h_L is head loss across the valve in metres. Refer to Chapter 6 for recommended values of HLC.

3.3.2 Pipe Details

When a pipe is created or edited, the Pipe Details are entered using the screen shown in Figure 3.9.

The details required for each pipe include:

- **Pipe name.** If no name is provided, name will default to 'un-named'
- **Pipe length.** All pipes must be given a pipe length.
- **Diameter and Wall roughness.** Diameter and wall roughness can be entered manually or by selecting a standard pipe. Standard pipes include a range of ductile iron cement lined (DICL) and cast iron cement lined (CICL) pipes. If entering a non-standard pipe manually, be careful to select the 'USER DEFINED PIPE' button, otherwise the diameter and roughness values for the pipe will be lost.

Quit Return

3. Pipe Data

Pipe name: From-node: 43 To-node: 42
(Pipe 1 of 1 pipes) From-node: 42 To-node: 43

Pipe length (in metres):

Pipe internal diameter and roughness:
STANDARD PIPE

| nominal pipe size (mm) | DICL (class K9) | CICL |
|------------------------|-------------------------------|-------------------------------|
| 100 | <input type="radio"/> (103.7) | <input type="radio"/> (93.5) |
| 150 | <input type="radio"/> (158.7) | <input type="radio"/> (145.8) |
| 200 | <input type="radio"/> (209.4) | <input type="radio"/> (191.3) |
| 250 | <input type="radio"/> (262.4) | <input type="radio"/> (243.1) |
| 300 | <input type="radio"/> (317.0) | <input type="radio"/> (293.6) |
| 375 | <input type="radio"/> (396.4) | <input type="radio"/> (371.4) |
| 500 | <input type="radio"/> (528.3) | <input type="radio"/> (500.9) |
| 600 | <input type="radio"/> (627.2) | <input type="radio"/> (597.7) |
| 750 | <input type="radio"/> (783.4) | |

USER DEFINED PIPE:
diameter (in mm): roughness (in mm):

Minor losses (k) to be included with pipe head loss:

where head loss = $k * v^2 / (2 * g)$

Figure 3.9 Pipe Details Screen

3.4 Move mode

Move mode allows the user to move nodes. All network connections are maintained when nodes are moved. Nodes can be moved in the following ways:

1. Moving single nodes

A single node can be moved using the following procedure illustrated in Figure 3.10.

- Depress the mouse button on the node to be moved and don't release (Frame 2).
- Move the mouse to the new location for the node keeping the mouse button depressed (Frames 3 to 5).
- Release the mouse button (Frame 6).

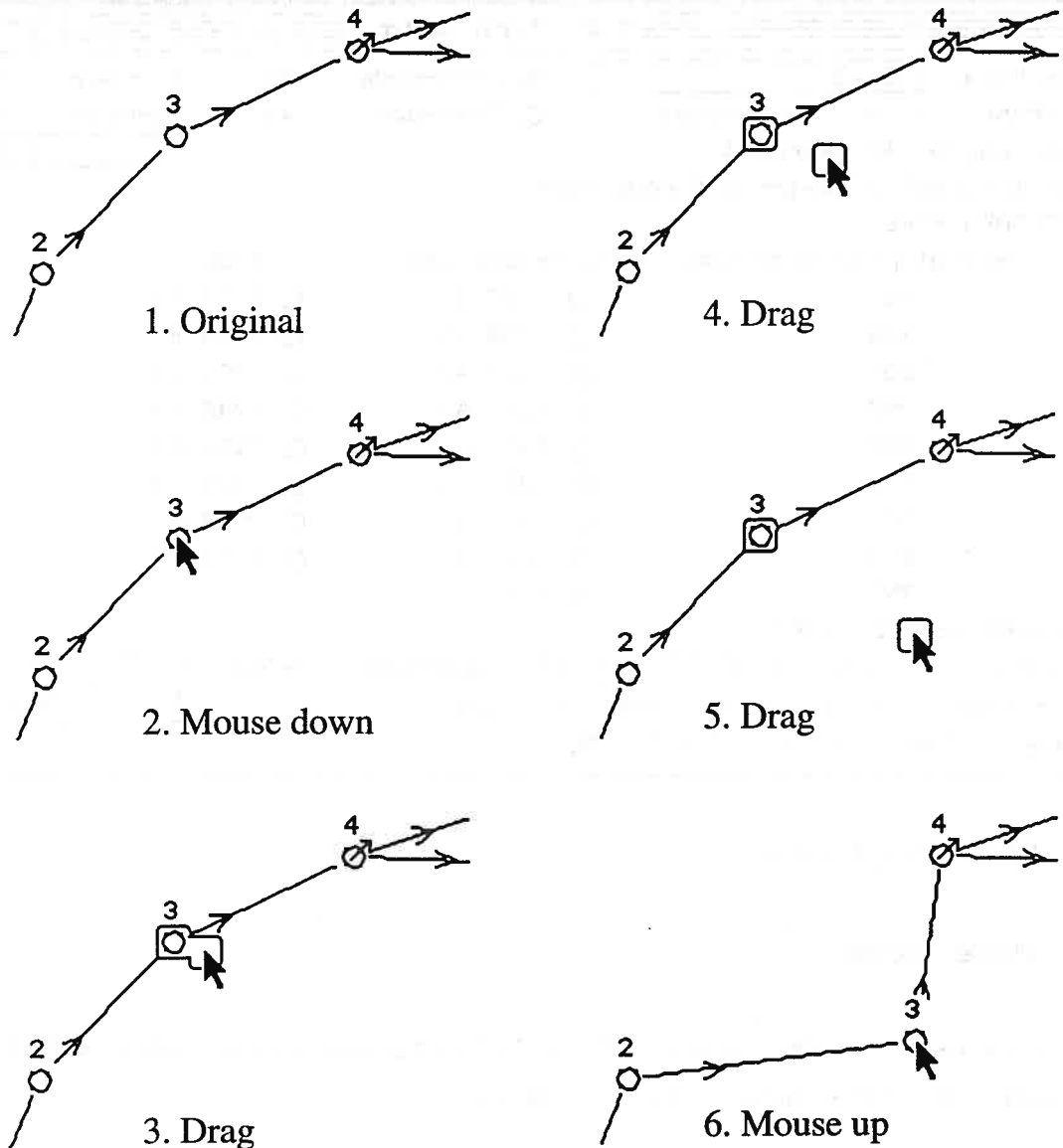


Figure 3.10 Moving a single node

2. Moving groups of nodes

A group of nodes can be moved using the following procedure, as illustrated in Figure 3.11.

- Depress the mouse in a vacant area at the top left corner of an imaginary rectangle containing the group of nodes (Frame 1).
- Slide the mouse to the bottom right of the imaginary rectangle while keeping the mouse button depressed.
- Release the mouse and the nodes in the rectangle will be selected (Frame 2).

- Depress the mouse in the imaginary rectangle and move it as for a single node. All nodes selected will automatically follow.

Notes:

- If moving a node beyond the edge of the screen, just bump the edge with the mouse and the screen will automatically scroll.
- The picture size can be enlarged (not magnified) by trying to move a node or nodes beyond the edge of the screen when the scroll bar is already at its limit.

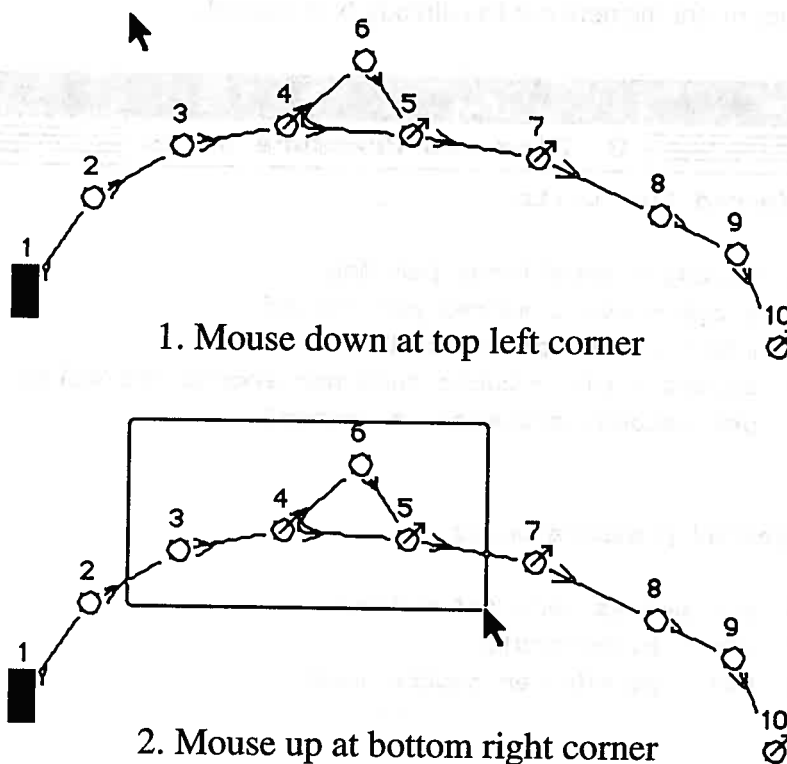


Figure 3.11 Selecting a group of nodes to be moved

3.5 Display Menu

The 'Display menu' is activated by selecting 'Display' from the main menu. The Display menu is shown in Figure 3.12. Options available from the Display menu are:

- Set units for data input and output (Section 3.5.1)
- Set head alert - alarm to indicate nodes outside or inside a set pressure range once network is solved (Section 3.5.2)

- Info layout - set the information to be displayed for each node or pipe (Section 3.5.3)
- Zoom - to view entire network on one screen or to adjust node spacing (Section 3.5.4)

Return Set units Head alert Info layout Zoom

Figure 3.12 Display menu

3.5.1 Set units

This option allows the user to change the pressure and flow units used in data input and display. The screen used is shown in Figure 3.13. Pressure and flow units can be changed at any time, regardless of whether or not the network has already been solved.

Quit Return

8. Flow and Pressure Units

Select preferred flow units:

- ML/day - megalitres per day
- m³/s - cubic metres per second
- L/s - litres per second
- cusecs - cfs - cubic feet per second (velocity in feet per second, diameter in inches)

Select preferred pressure units:

- m - metres head (of water)
- kPa - kilopascals
- PSI - pounds per square inch

Figure 3.13 Pressure and Flow Units Screen

3.5.2 Head Alert

The head alert option can be used to highlight areas within a system which have high or low pressure. Any nodes which have an upstream or downstream residual head outside or within a set pressure range can be set to flash. The user also has the option of having no nodes flash (suppress head alert).

3.5.3 Info layout

The Info layout options allow the user to choose which information is displayed at each node and pipe. Information is displayed in the same order (top to bottom) as it is shown on the Info layout screen, but without blanks for the un-used fields. Both upstream and downstream heads are shown at valve and pump station nodes when head information (absolute or residual) is requested.

3.6 Delete Mode

Delete mode is used to delete network components. Delete mode should be used with extreme caution, as an 'undo' option is not available. It is often a good idea to 'Save' (by selecting 'File' and then 'Save') before deleting nodes or pipes as it is much easier to delete information than it is to create it.

Deleting nodes is discussed in Section 3.6.1, and pipes in Section 3.6.2.

3.6.1 Deleting Nodes

Nodes are deleted by clicking the mouse (once) on the node to be deleted when in 'Delete mode.' **All pipes immediately connected to the node being deleted will also be deleted.**

3.6.2 Deleting Pipes

Pipes are deleted by clicking the mouse (once) on the pipe to be deleted when in 'Delete mode.' Care should be taken when deleting pipes which are near each other, as the wrong pipe may accidentally be deleted.

3.7 Edit Mode

Edit mode is used to modify the information already entered for nodes or pipes. Network components are edited using the same information screens as when the nodes were created.

3.7.1 Editing Nodes

Nodes are edited by clicking the mouse (once) on the node to be edited when in 'Edit mode.' Refer to Section 3.3.1 for node information details.

3.7.2 Editing Pipes

Pipes are edited by clicking the mouse (once) on the pipe to be deleted when in 'Edit mode.' Refer to Section 3.3.2 for pipe information details.

3.8 Solve

The solve command is used to analyse the pipe network. When the network is being analysed, all data is automatically saved (ie, all changes made since opening the network file will be saved). Once solved, the solution (pipe flow, node pressure, etc) becomes available and can be viewed as discussed in Chapter 4.

Networks cannot be solved unless the following criteria are satisfied:

- All nodes must be connected to each other by a pipe network - there cannot be any unconnected parts lying around.
- A network must contain at least one reservoir.
- If PRVs or pumps are used, there must be at least one reservoir connected to the upstream side of each PRV or pump.
- If PSVs are used, there must be at least one reservoir connected to the downstream side of each PSV.
- Stop valves should not be closed if they isolate demands from supply - the program **must** meet a demand, which is impossible if there is no supply. It is OK, however, to shut stop valves if alternate supply paths exist.
- Demands downstream of a pump should not exceed the pump capacity - if they do an error message will appear and the solution provided will be invalid.

Notes:

- GIPNAP can detect and point to the cause for some unfeasible network solutions. If there is insufficient supply to a node, this could be caused by too high a nodal demand or by a constriction in the network. Studying which nodes have been starved of water could point to the cause of the constriction. Common causes of constrictions include incorrect use of PRVs, PSVs or pump curves.

3.9 View Mode

View mode allows the user to quickly check the data at a node or pipe. If a solution has been reached, pressure and flow data is also displayed. Information on a component is displayed by clicking the mouse once on the component. Information is displayed in a window not covering the component being checked. The information window is closed by hitting the 'Return' key or by clicking in the 'Return' box.

3.10 Summary

The summary option produces a tabular summary of input node and pipe information. If the network has been solved, a summary of the solution for each node and pipe is also produced. Two options are available: Create summary data file (Section 3.10.1) and View summary (Section 3.10.2).

3.10.1 Create Summary Data File

This option creates a text format data file of the summary. The data file can be viewed and printed using a text editor or word processor. The summary file has the same name as the network file, but has the suffix '.SUM'.

3.10.2 View Summary

This option allows the user to view the summary from within GIPNAP. The user can scroll through the file using the 'Previous screen' or 'Next screen' options. An example screen from 'View summary' for a solved network is shown in Figure 4.1(d). The summary file is arranged in the following order:

- Node data
- Pump characteristics
- Pipe data
- Node output data (if solved)
- Pipe output data (if solved)

Note: The same text format data file as the 'Create Summary Data File' option produces is also created by the 'View summary' option.

CHAPTER 4 - OUTPUT OF RESULTS

4.1 Viewing Solutions to Pipe Network Problems

Once a pipe network has been solved, various options are available for viewing the solution. If a file is in a 'solved' state, the top menu bar will have different options to those available in an 'unsolved' state, as shown by Figures 4.1(a) and 4.1(b).

The plan view of a solved network has flags on each node showing upstream and downstream pressure and also on each pipe showing pipe flow. A summary of output display options is shown in Figure 4.1.

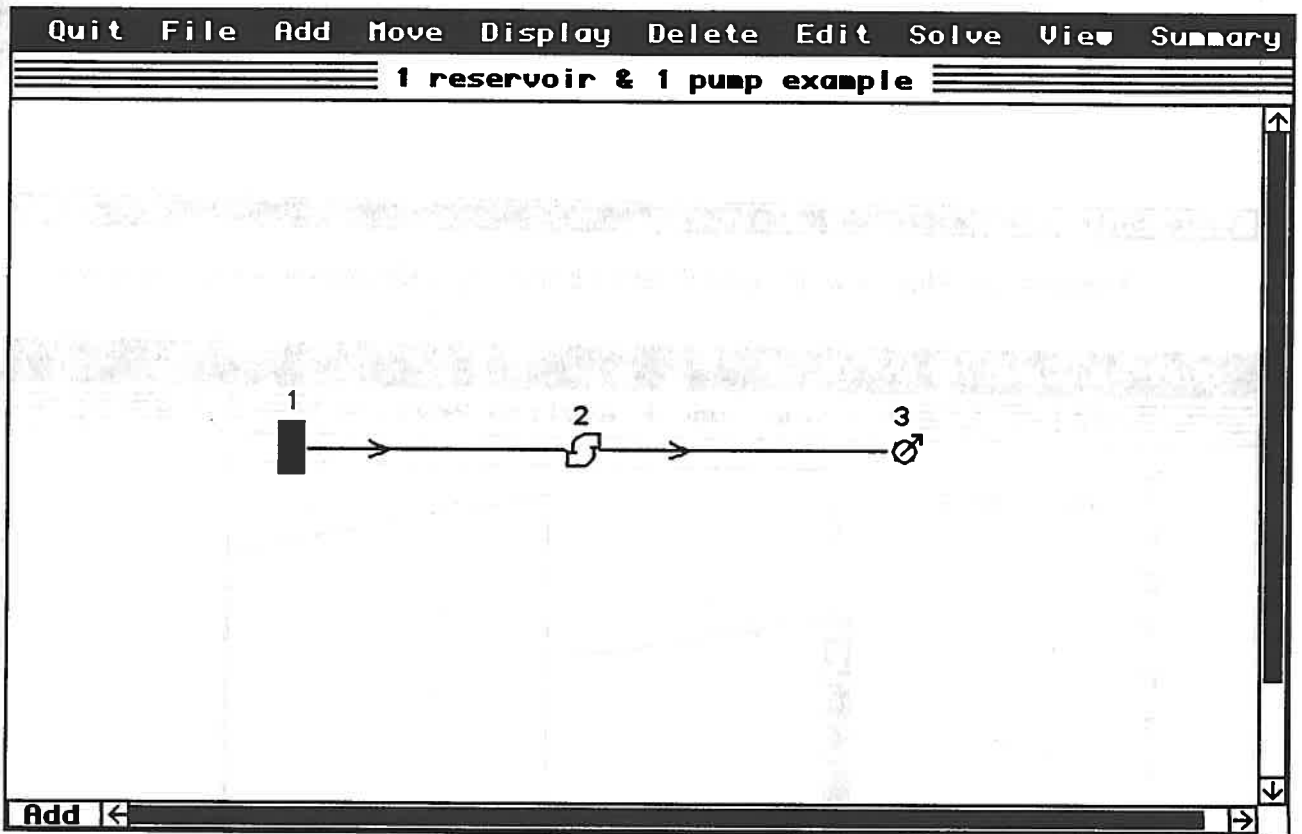


Figure 4.1(a) 'Unsolved' pipe network

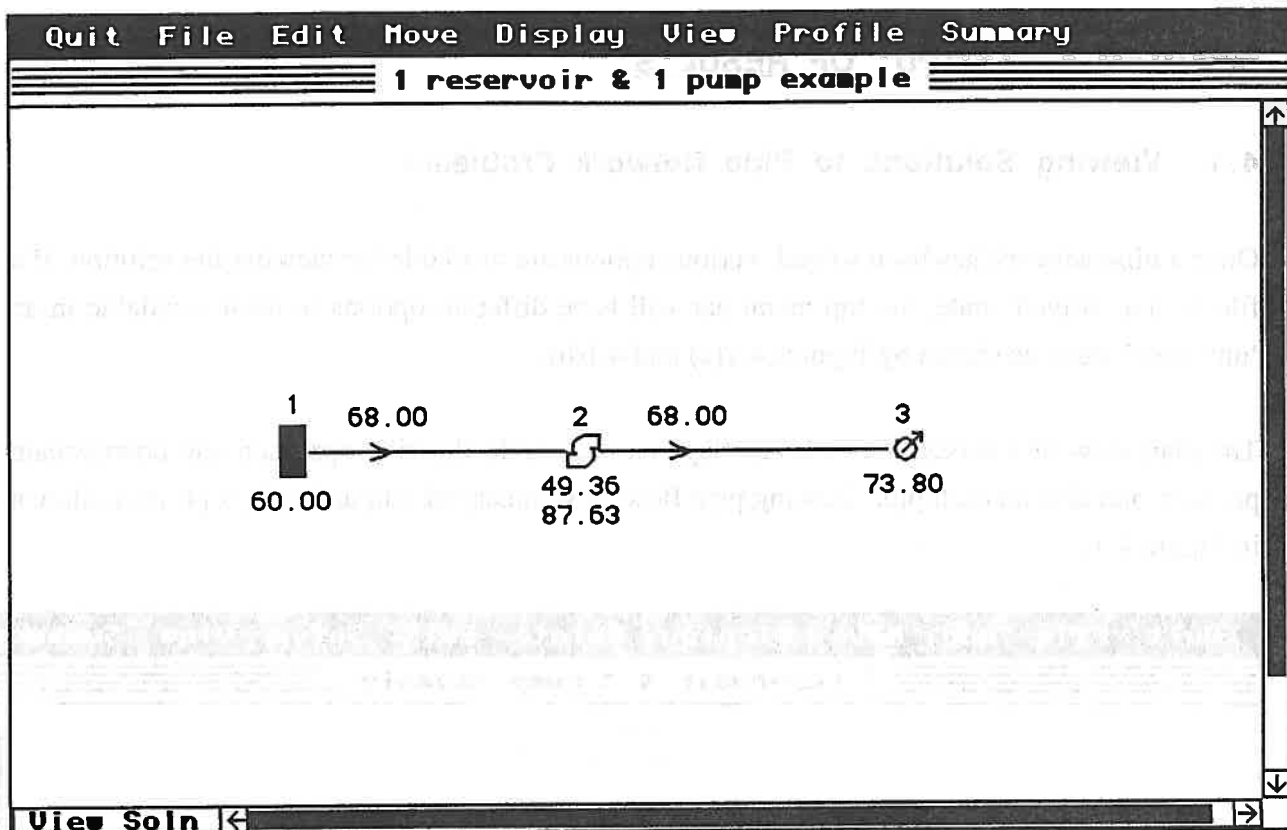


Figure 4.1(b) Plan view of 'solved' network showing node pressures and pipe flows

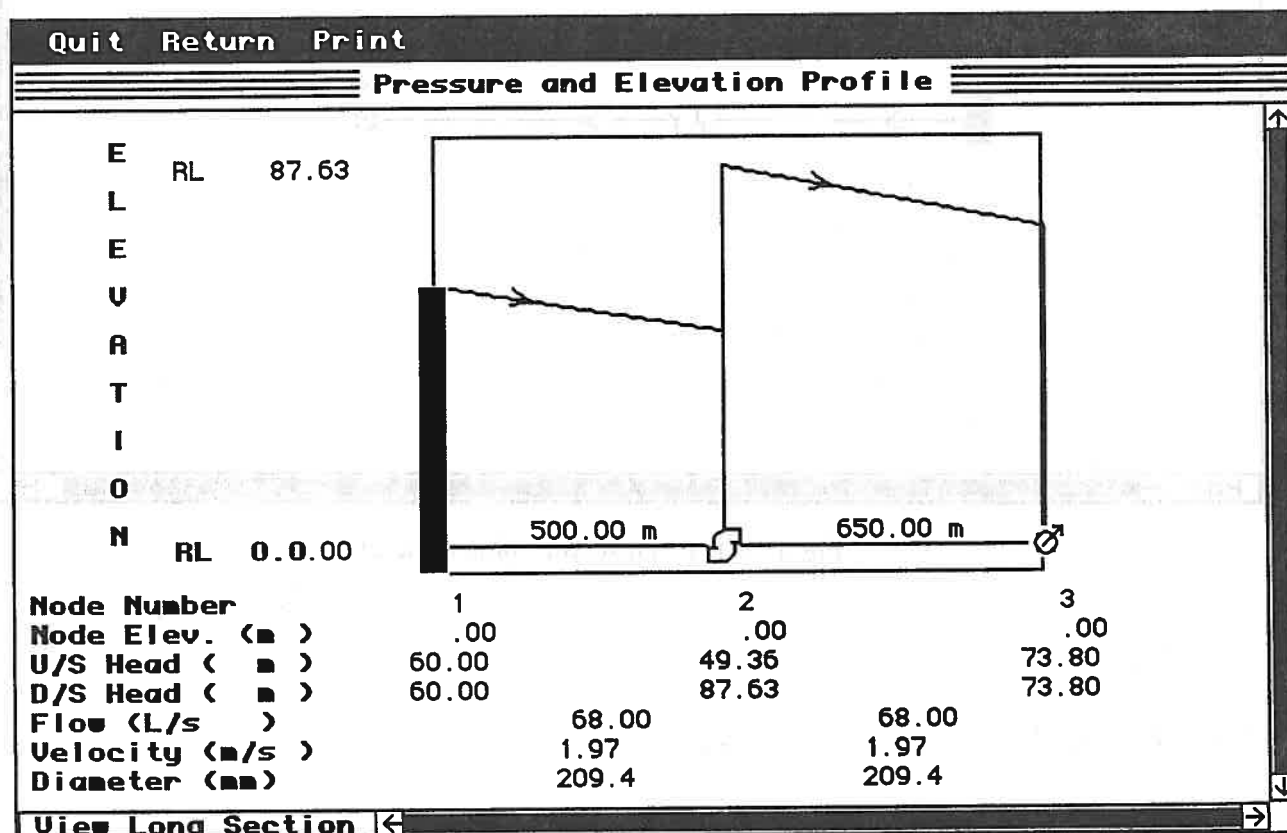


Figure 4.1(c) Hydraulic profile from nodes 1 to 3 of solution

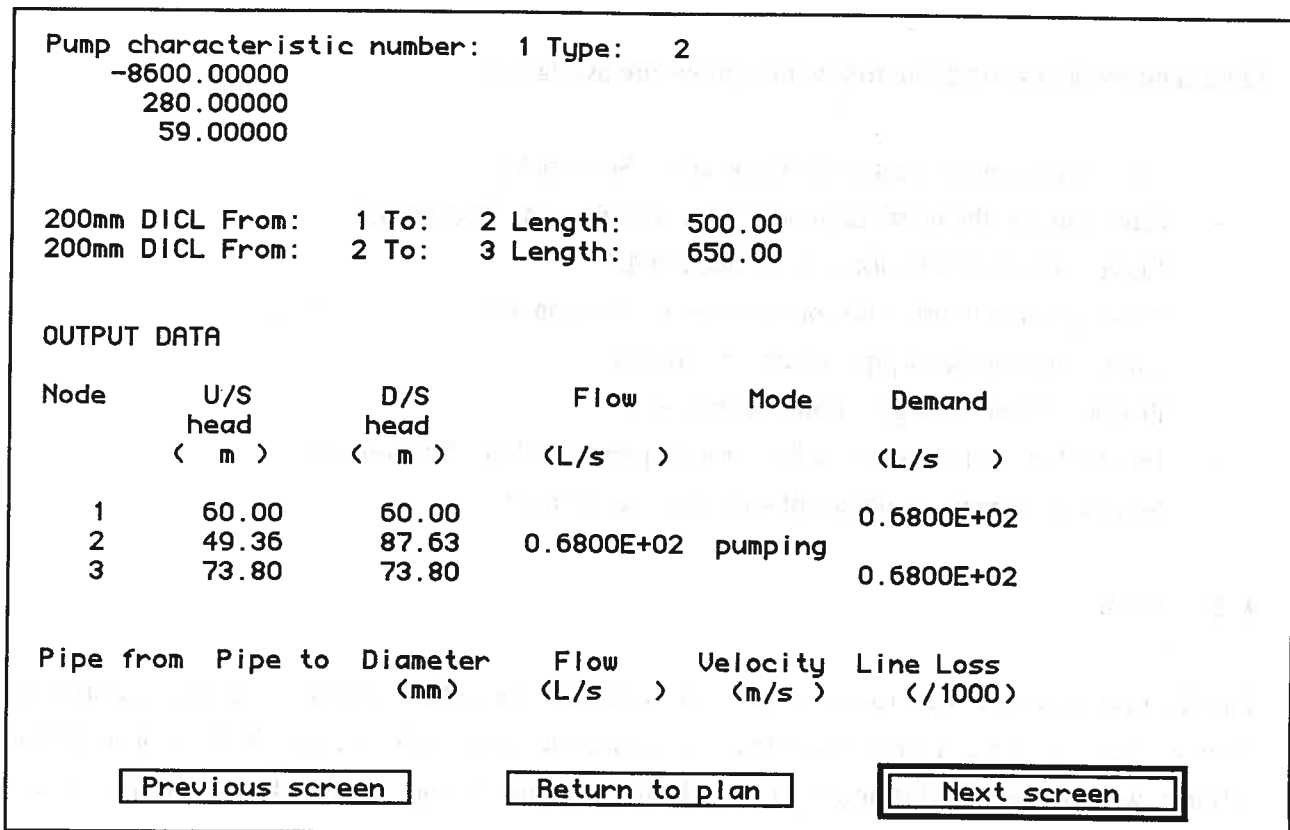


Figure 4.1(d) One screen from 'View Summary' option

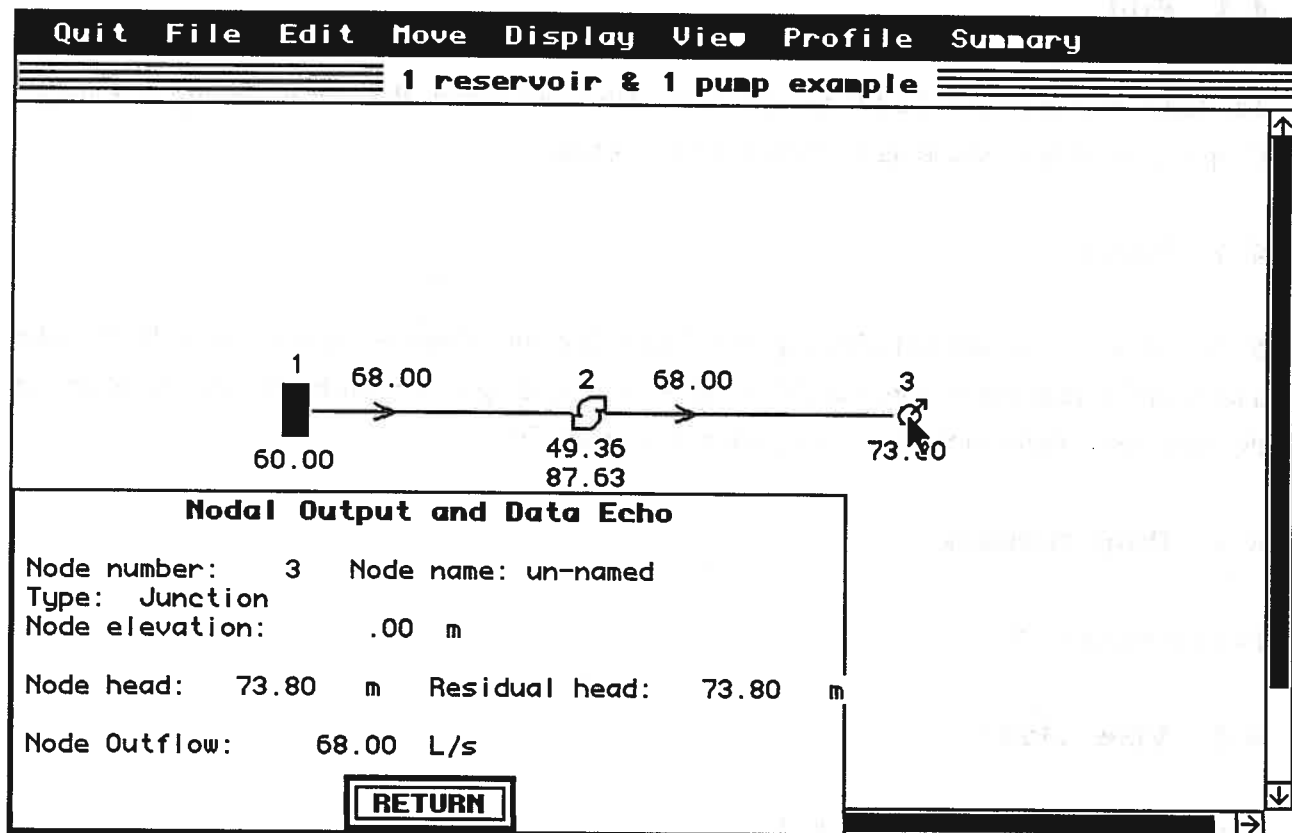


Figure 4.1(e) Information on node 3 displayed in 'View' mode by selecting with mouse

Once a network is solved, the following options are available:

- File - select another network file or save - Section 4.2
- Edit - change the network node or pipe information - Section 4.3
- Move - alter the network layout - Section 4.4
- Print - print network with solution labels - Section 4.5
- View - view node or pipe details - Section 4.6
- Profile - create a long section - Section 4.7
- Head Alert - set or suppress low or high pressure alert - Section 4.8
- Summary - create summary of solution - Section 4.9

4.2 File

The file option can be used to save a network or to select a different network. These features are discussed in Chapter 2. Don't forget that changes made to the network layout since opening (or solving) will not be saved if another network file is opened before saving changes to the current file.

4.3 Edit

The 'Edit' option reverts the file to 'unsolved' status, and allows the user to modify it. Refer to Chapter 3 for details on adding to or editing the network.

4.4 Move

Nodes can be moved without affecting the solution. It is sometimes useful to move nodes to make a long section diagram is more readable (Node spacing in long sections is based on their spacing in the plan view). Refer to Section 3.4 for node moving details.

4.5 Print Network

Refer to Section 3.5

4.6 View Mode

Refer to Section 3.9 and Figure 4.1(e)

4.7 Profile

The profile option allows the user to create a long section of hydraulic grade line and node elevation along a selected flow path.

Nodes are selected by clicking the mouse on nodes in the same sequence as the user wishes to display on the long section. Any first node can be selected, but each subsequent node must connect to the previous node by a single pipe. Up to 15 nodes can be selected for a long section.

Spacing of nodes on the long section diagram is based on their spacing on the plan view, so care should be taken with the plan view arrangement in producing a readable long section. Node 1, then node 2, then node 3 were selected in Figure 4.1(b) to produce the profile in Figure 4.1(c).

4.7.1 View Profile

'View profile' displays the long section along the selected flow path. The line with arrows on it represents the hydraulic grade line. The elevation profile is a plain line with the network components on it. If elevations have been set to zero, the elevation profile will appear as a straight line along the bottom of the diagram, as in Figure 4.1(c).

4.7.2 Return

'Return' returns the user to the plan view diagram.

4.9 Summary

Refer to Section 3.10

CHAPTER 5 - EXAMPLE NETWORK FILES

Two example network files have been included with GIPNAP. Both networks represent information from real life networks in the Newcastle area.

5.1 Example 1 - BURWOOD.NET

BURWOOD.NET is a small network in which there is basically one flow path. A long section of the solution reveals a low pressure problem at nodes 7 and 9. This problem can be remedied by replacing the pipe between nodes 5 and 7 with a larger diameter pipe (eg. 150mm DI1CL).

5.2 Example 2 - NCLE.NET (not available with demonstration version)

NCLE.NET is a network consisting of approximately 43 nodes, 55 pipes, 1 reservoir and 1 pump station. The pump station keeps the area under consideration pressurized. Demands on each node reflect peak Summer water usage in the network area.

CHAPTER 6 - TYPICAL VALUES AND CONVERSION FACTORS

6.1 Conversion Factors

6.1.1 Flow

| | |
|---|---|
| 1 L/s = 0.001 m ³ /s 1 ML/day = 11.57 L/s 1 L/s = 0.0353 ft ³ /s 1 L/s = 13.198 g.p.m. | 1 m ³ /s = 1000 L/s 1 L/s = 0.0864 ML/day 1 ft ³ /s = 28.3 L/s 1 g.p.m. = 0.0758 L/s |
|---|---|

Table 6.1 - Flow conversion factors

6.1.2 Velocity

| | |
|--------------------|---------------------|
| 1 m/s = 3.281 ft/s | 1 ft/s = 0.3048 m/s |
|--------------------|---------------------|

Table 6.2 - Velocity conversion factors

6.1.3 Volume

| | |
|--|--|
| 1 m ³ = 1000L 1 ML = 1 * 10 ⁶ L 1 L = 0.220 gal 1 m ³ = 35.315 ft ³ 1 m ³ = 1.308 yd ³ | 1 L = 0.001m ³ 1L = 1 * 10 ⁻⁶ ML 1 gal = 4.5461 L 1 ft ³ = 0.0283 m ³ 1 yd ³ = 0.7646m ³ |
|--|--|

Table 6.3 - Volume conversion factors

6.1.4 Length

| | |
|---|--|
| 1 m = 3.281 ft 1 m = 1.094 yd 1000m = 0.6214 mile | 1 ft = 0.3048 m 1 yd = 0.914 m 1 mile = 1609 m |
|---|--|

Table 6.4 - Length conversion factors

6.2 Head Loss Data

6.2.1 Pipes (wall roughness)

Background

GIPNAP uses the Colebrook formulation to solve for pipe friction factor. It does this using a fixed point iteration scheme. The Colebrook formulation (Eqn. 5.10.7, 'Fluid Mechanics', Streeter & Wylie) is reproduced in Eqn. 6.1 and the pipe head loss equation in Eqn. 6.3.

$$\frac{1}{\sqrt{f}} = -0.86 \ln\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{R\sqrt{f}}\right) \quad (6.1)$$

where f = friction factor
 ε = pipe wall roughness (m)
 D = pipe diameter (m)
 R = Reynolds number - Eqn. 6.2

$$R = \frac{VD}{\nu} \quad (6.2)$$

where V = flow velocity (m/s)
 D = pipe diameter (m)
 ν = kinematic viscosity = $1 * 10^{-6}$ at 20°C

$$h_L = f \frac{LV^2}{D2g} \quad (6.3)$$

where

h_L = pipe head loss

f = friction factor (from Eqn. 6.1)

L = pipe length (m)

V = flow velocity (m/s)

D = pipe diameter (m)

g = gravity constant = 9.806m/s/s

GIPNAP only requires the following information to calculate pipe head losses:

- pipe wall roughness - see Table 6.5
- pipe diameter
- pipe length

Pipe Wall Roughness

Values for pipe wall roughness are provided in Table 6.5. They have been reproduced from Figure 5.32, 'Fluid Mechanics', Streeter & Wylie

| Pipe Wall Material | Roughness (ϵ) in mm |
|----------------------------------|--------------------------------|
| Riveted steel | 0.9 - 9.0 |
| Concrete | 0.3 - 3.0 |
| (DICL, CICL pipes) | (0.3) |
| Wood stave | 0.18 - 0.9 |
| Cast iron | 0.25 |
| Galvanised iron | 0.15 |
| Asphalted cast iron | 0.12 |
| Commercial steel or wrought iron | 0.046 |
| Drawn tubing | 0.0015 |

Table 6.5 - Accepted values for pipe wall roughness

6.2.2 Fittings (minor losses)

Minor loss are the losses incurred at fittings and junctions throughout a water pipe network. Minor losses are calculated by GIPNAP using a head loss coefficient (HLC) in accordance with the equation:

$$h_L = \text{HLC} * Q^2 \quad (6.4)$$

where h_L = head loss for minor loss element

HLC = GIPNAP minor loss head loss coefficient

Q = Flow through minor loss element

In many texts minor losses are calculated using a K factor where:

$$h_L = \frac{KV^2}{2g} \quad (6.5)$$

where K = diameter independent head loss coefficient

V = velocity of flow through minor loss element

g = gravity constant (= 9.806m/s/s on earth)

Equating Eqns. 6.5 and 6.6, HLC can be expressed in terms of K and D:

$$\text{HLC} = \frac{8K}{g\pi^2 D^4} \quad (6.6)$$

or

$$\text{HLC} = \frac{0.08266 K}{D^4} \quad (6.7)$$

where D = diameter of minor loss element (in m)

K = diameter independent head loss coefficient

As HLC is not independent of diameter, K factors are quoted in Table 6.6 of head loss coefficients. The user must convert these values to HLC factors using Eqn. 6.7. See Example 6.1.

Example 6.1 - Calculating HLC for standard 100mm diameter gate valve

$$D = 0.1\text{m}$$

$$K = 0.20 \quad (\text{from Table 6.6})$$

$$\begin{aligned} \text{Hence HLC} &= 0.08266 * 0.20 / 0.1^4 \\ &= 165.3 \end{aligned}$$

| Component | Coefficient K |
|--|---------------|
| Angle valve (open) | 5.00 |
| Cock valve (open) | 0.01 |
| Gate valve (open) | 0.20 |
| Globe valve (open) | 10.00 |
| Swing reflux or check (open) | 2.50 |
| Close return bend | 2.20 |
| Standard tee | 1.80 |
| Standard elbow | 0.90 |
| Medium sweep elbow | 0.75 |
| Long sweep elbow | 0.60 |
| <u>Entrance losses</u> | |
| Square | 0.5 |
| Rounded | 0.01 - 0.05 |
| Re-entrant | 0.8 - 1.0 |
| Remember: HLC = $\frac{0.08266 K}{D^4}$ | |

Table 6.6 - Accepted K values for selected appurtenances

UWRAA RESEARCH REPORTS

| Report Number | Title | Author | Report Number | Title | Author |
|---------------|--|---|---------------|---|---|
| 1 | Trickling filter – solids contact process: Pilot plant studies. | M. Laginestra | 21 | Management and display of dam surveillance data | D. M. Stirling G. L. Benwell A. B. Murnane |
| 2 | A model of water pricing for Melbourne, Sydney and Perth | P. B. Dixon P. M. Norman | 22 | Evaluation and demonstration facilities for primary sensors | J. A. Lanaway M. Cavey |
| 3 | Taste generation associated with chloramination | M. Kerslake | 23 | Modelling and design of reservoir aeration destratification systems | D. P. Lewis J. C. Patterson J. Imberger R. P. Wright S. G. Schadlow |
| 4 | Bacterial regrowth in water supplies | K. Power L. A. Nagy | 24 | Modelling optimum conditions for reservoir destratification using mechanical mixers | R. M. A. Velzeboer J. A. Cugley J. C. Patterson |
| 5 | Leakage management: Assessing the effect of pressure reduction on losses from water distribution systems | B. Horvath | 25 | Methods for detection of <i>Giardia</i> and <i>Cryptosporidium</i> in water: A preliminary assessment | C. A. Bee P. E. Christy B. E. Robinson |
| 6 | Improving communication with the public on water industry policy issues | B. E. Nancarrow G. J. Syme | 26 | Toxic cyanobacteria in water supplies: Analytical techniques | D. J. Flett B. C. Nicholson |
| 7 | Water use efficiency of domestic appliances | I. J. Beith D. J. Horton | 27 | Tracing toxic discharges to sewers by analysis of biofilms | D. Oliver T. Watson |
| 8 | Pilot plant study of fermentation units to increase degradable COD fraction in sewage. | P. J. Bliss D. Barnes P. R. Evans I. Law | 28 | Electronic meter reading: Link between water meter and house | P. J. Reid J. S. Renwick M. F. Prior |
| 9 | Artificial destratification of water storages in Australia. | T. F. McAuliffe R. S. Rosich | 29 | Identification of common noxious cyanobacteria: Part 1 – Nostocales | P. Baker |
| 10 | Taste thresholds of mono-chloramine and chlorine in water | R. O'Halloran C. Veres | 30 | Forecasting water demand using weather data | M. N. Viswanathan |
| 11 | Chromatographic analysis of chloramines using electro-chemical detection | R. O'Halloran Hai Lin Ge P. Spizziri | 31 | Effects of controls on water consumption | M. N. Viswanathan |
| 12 | Glass reinforced plastic bore casing for large diameter and deep bores | R. Bowyer | 32 | Biological removal of iron from groundwater: Preliminary studies | M. N. Viswanathan |
| 13 | A guide to improving communication with the public on water industry policy issues | B. E. Nancarrow G. J. Syme | 33 | Statistical modelling of water main failures | E. Tsui G. Judd |
| 14 | Fouling and cleaning of fine bubble ceramic dome diffusers | K. J. Hartley | 34 | Stratification, mixing and water quality in Darwin water supply reservoirs | R. Lukatelich D. Robertson K. Boland J. Imberger J. Patterson |
| 15 | Chloramination of Water Supplies | P. M. Thomas (ed) | 35 | Performance auditing in the Australian urban water industry | S. O'Kane I. Parry D. Blunden D. Herring |
| 16 | The 1988 Australian Winter Storms Experiment: Report on aircraft observations | J. B. Jensen | 36 | Microbiological studies on enhanced removal of phosphates from sewage | R. C. Bayly J. W. May G. Vasiliadis G. N. Rees |
| 17 | Pipeline assets: Life cycle economic life | R. Vass management and M. Anderson R. Lewis D. Samson | 37 | Magnetite and microwaves in sewage effluent treatment | D. R. Dixon A. J. Ware |
| 18 | Development of empirical model for tradewaste discharges to small treatment plants | Camp Scott Furphy | 38 | Polymer based electrode for the selective detection of dichloramine | Y. Lin G. G. Wallace |
| 19 | PRELIM users guide (Amended): Australian Version | Camp Scott Furphy | 39 | Current cost asset valuation: Methodology | J. Dyke |
| 20 | Chemical regeneration of activated carbon: Preliminary studies | G. Newcombe | | | |

UWRAA RESEARCH REPORTS

| Report Number | Title | Author | Report Number | Title | Author |
|---------------|--|--|---------------|---|--|
| 40 | Community analysis of household water pressure satisfaction | G. J. Syme B. E. Nancarrow B. J. Bishop P. VanderWal | 59 | Electronic household water meter: Investigation into a cost effective design | Z. Balazic A. Leong |
| 41 | Assessment of coagulants for water treatment | C. Donati | 60 | Domestic greywater reuse: Preliminary evaluation | B. Jeppesen |
| 42 | Coagulants for water treatment: A generic guide | ACWQR | 61 | Chemical regeneration of activated carbon: A feasibility study | G. Newcombe |
| 43 | Optimal prices for urban water: A general equilibrium model applied to Melbourne | P.B. Dixon D.J. Baker | 62 | Tracing toxic discharges to sewers by analysis of biofilms (Stage 2) | W. H. Lock |
| 44 | Applications of the Streaming Current Detector in water treatment | W. Barron D. R. Dixon M. Pascoe | 63 | Production of Jerusalem artichoke hybrids under irrigation using urban wastewater | M. Parameswaran |
| 45 | Sydney coastal stormwater study | W. G. Rowlands et.al. | 64 | Control of pitting corrosion of copper tubes in potable waters | R. J. Taylor P. H. Cannington |
| 46 | Identification of common noxious cyanobacteria: Part 2 – Chroococcales and Oscillatoriales | P. Baker | 65 | Measurement of Total Factor Productivity in major water utilities: Melbourne case study | I. Manning E. Molyneux |
| 47 | Levelling using the Global Positioning System | A. P. Armstrong P. A. Collier F. J. Leahy | 66 | Assimilable organic carbon as a measure of bacterial growth potential in water supplies | K. C. Tapang M. Drikas L. E. Bennett |
| 48 | Allocation of sewerage costs to customer segments | R. Hood P. Geary | 67 | Simultaneous peak water demands in residential areas | J. Henstridge G. J. Syme B. E. Nancarrow |
| 49 | Impact of urban lawns on nutrient contamination of an unconfined aquifer | M. L. Sharma D. E. Herne P. G. Kin J. D. M. Byrne | 68 | Installation damage: Effect on lifetimes of uPVC pipes subjected to cyclic pressure | L. S. Burn |
| 50 | Early warning system for hazardous substances in sewage | R. O'Halloran B. A. Sexton N. H. Pilkington | 69 | Safety aspects of the design of roadways as floodways | R. J. Keller B. Mitsch |
| 51 | Management model for trade waste discharges to small treatment plants (including PRELIM VERSION 4.0 Users Guide) | Camp Scott Furphy | 70 | Regional development implications of wastewater reuse: Werribee case study | D. Hunter W. Smith L. Nagy P. Jacob |
| 52 | Automatic meter reading: Link between meters and billing centre (Combined utilities trial) | B. Phey A. Leong Z. Balazic | 71 | Treatment of electroplating wastes using new-generation membrane technology | A. G. Fane Y. R. Shen |
| 53 | Prediction of perceived odour strength and type from composition of sewage odour mixtures | D. G. Laing A. Eddy D. J. Best | 72 | Stochastic economic approach to headworks augmentation timing | G. Kuczera W. S. Ng |
| 54 | Tracer studies using bacteriophage to predict the fate of viruses in the marine community: Preliminary assessments | B. J. Richardson A. L. Charlton S. Currie P. Ashton I. Lowther | 73 | Domestic greywater reuse: Overseas practice and its applicability to Australia | B. Jeppesen D. Solley |
| 55 | Development of a water quality analyser suitable for unattended use in rivers and streams | G. W. Skyring I. A. Johns J. A. Cugley | 74 | Decision support systems for the water industry: An Object-Oriented approach | J. M. Edwards |
| 56 | Enhancement of nitrification in wastewater lagoons | P. M. Gross | 75 | Chemical characterisation and olfactometric measurement of odours from sewage treatment process units | R. Kaye N. Mulhem D. Stone |
| 57 | Identification of critical water supply assets | PPK Consultants | 76 | Utilisation of sewage sludge for minesite rehabilitation: Rix's Creek Mine Trial | C. P. Phillips |
| 58 | Water in Our Environment: Education Project | H. Breidahl D. Cliffe H. Henderson | 77 | A benchmarking methodology for the Australian water industry | I.R.C. Eggleton |
| | | | 78 | Water quality effects of aeration/destratification at Harding Reservoir, W.A. | R.S. Rosich T.A. McAuliffe |

UWRAA RESEARCH REPORTS

| Report Number | Title | Author | Report Number | Title | Author |
|---------------|---|------------------------------|---------------|-------|--------|
| 79 | Heavy metals and organics in domestic wastewater | W. H. Lock | | | |
| 80 | Effluent reuse: Land and wet weather storage requirements | J. M. Anderson T. J. Ruge | | | |