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ANALYSIS OF WATER SUPPLY PROBLEMS USING MICROCOMPUTERS

by

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OF THE UNIVERSITY OF FLORIDA IN
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ANALYSIS OF WATER SUPPLY PROBLEMS
USING MICROCOMPUTERS

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Improvements in the microcomputer and ever more sophisticated software packages allow a person to solve water supply problems today that could only be solved with larger computers previously. A solution to three water supply problems is sought through the use of the microcomputer and three software programs.

The first water supply problem deals with improving the knowledge base structure of a model which determines preliminary design and cost estimates for various potable water treatment processes. The second problem involves improving the efficiency in handling both input and output data associated with a model which analyzes flow in pipe networks. The third problem concerns the optimization of water distribution networks that include erroneous flows within the network.

An electronic spreadsheet is used throughout in solving the water supply problems. The spreadsheet effectively replaces hand calculation methods to solve these water supply problems that could not be solved using a microcomputer five years ago. A computer programming language called macro is used extensively within the spreadsheets to create programs for problem solution that are fast, flexible, and simple to use. Macros are written to create a menu system which allows even the novice to operate the programs while knowledge bases, help systems, and logical data handling capabilities are included for ease of operation.

CHAPTER I
INTRODUCTION

The microcomputer, combined with existing software, is becoming an increasingly powerful tool for solving environmental engineering problems. Until recently, when microcomputers began to be used, most automated computation was performed on large general-purpose computers, using remote terminals. The microcomputer offers the alternative of a small, inexpensive desk-top work station. The user can perform small tasks on microcomputers more efficiently and cost effectively than on large computers.

This is not to say that microcomputers will eventually replace large computers. The main-frame user may find it easier to use the microcomputer to more logically understand the problem at hand before delving into the larger computer. The most effective way of using the various sizes of available computers is to fit them to the tasks they are to perform instead of trying to perform all tasks on large, general-purpose computers. With improvements in the available software, microcomputers are able to solve ever more technical engineering problems.

The objective of this thesis is to demonstrate the ever expanding role of the microcomputer using existing software, more specifically the Lotus 123 electronic spreadsheet, to solve water distribution and treatment problems. Three software packages are used to solve three different water distribution and treatment problems. The software includes an electronic spreadsheet, a linear programming model, and a model for computer analysis of flow in pipe networks.

Chapter II gives a general background on electronic spreadsheets. Lotus 123, Release 2, is chosen as it is the most popular electronic spreadsheet available at this time. The explanation of the Lotus 123 spreadsheet will be brief as the reader is invited to read a thesis by Hancock (1986) for a description of the evolution of the microcomputer and use of the Lotus 123 electronic spreadsheet in water resources.

Chapter III applies Lotus 123 to create a decision support system for the preliminary design and cost estimation of municipal potable water treatment. A newly developed interactive program written in the BASIC computer language, called WATERMAID, already exists for this purpose. An attempt is made to improve upon the knowledge base structure of this program using Lotus 123.

Chapter IV demonstrates the capability and advantages of using Lotus 123 in a data management role. Lotus 123 is used to create a spreadsheet program for the pre- and postprocessing of data used in a model for computer analysis of flow in pipe networks. The majority of time spent in the use of existing pipe network models is in the processing of the initial data to be used in the model and the final output data. The pre- and postprocessors are designed to speed the data management process.

Chapter V applies existing methods used by chemical engineers in the optimization of erroneous flows in industrial process networks to the field of water distribution networks. Lotus 123 is used to demonstrate the methods, which are presently used on much larger computer systems, on the microcomputer. In addition, two linear programming methods to achieve this optimization process are introduced.

The summary and conclusions are found in Chapter VI. In addition, Chapter VI includes possibilities for further research in this area.

CHAPTER II
THE LOTUS 123 ELECTRONIC SPREADSHEET

Introduction

Electronic spreadsheets are one of the more popular software produced at this time and Lotus 123 is the most popular of the electronic spreadsheets. The Lotus 123 electronic spreadsheet can be described as a large matrix of cells, 254 columns by 8192 rows, and can be visualized as a large electronic piece of paper. Instead of using a writing instrument and a piece of paper to accomplish calculations, the Lotus 123 user uses the computer keyboard to make entries and views only a portion of the large electronic spreadsheet on the monitor. In other words, with the Lotus 123 spreadsheet, the engineer can put away the engineering paper, pencil, and hand held calculator.

The user of the Lotus 123 spreadsheet is able to employ a myriad of commands and functions which make the spreadsheet a very powerful and versatile tool for solving engineering problems (LeBlond and Cobb, 1985; Lotus Development Corporation, 1985; Gregory, 1986). Special mathematical, statistical, data management and logical functions can be accessed for use in the spreadsheet. Graphs can be produced from data involving X and Y coordinates. Even maps and figures can be produced using Lotus 123.

An important advantage of Lotus 123 is that the user does not need to learn a programming language. The spreadsheet can be used to duplicate many programs produced using a programming language such as BASIC or FORTRAN. Only a minimum of commands needs to be learned initially to get started.

One of the problems in using a conventional program, say written in the BASIC language, is that the user is working with a sort of "black box". In an interactive program the user is prompted to input certain data and when the program is executed, final computations are output. The user is normally not privy to what is going on inside the black box so the user does not clearly understand how the output is derived from the input.

Both calculations and text can be integrated into the spreadsheet. Using Lotus 123, all reference documentation in the form of equations, assumptions, data tables, graphs, maps, and figures can be included on the spreadsheet in an organized manner, thereby eliminating the black box. The documentation can be easily updated as advances in the knowledge base are made. Having the knowledge base integrated into the spreadsheet reduces the time and energy spent locating any required reference material and allows the user to quickly make intelligent decisions regarding parameter estimates that need to be input to the program.

Literature Review

The use of microcomputers and customized software programs in both the municipal sewer system (Calise et al., 1984; Cullen and Murrell, 1985) and potable water treatment and distribution systems (Harris, 1984; Koh & Maidment, 1984) provides a solution to the time consuming and tedious engineering problems of analysis, design and costing. In addition, engineering design is becoming more efficient as hand calculations are replaced by computer automated design.

Macros

The Lotus 123 user also has access to a programming language called macros (Ridington and Williams, 1985). A macro is a stored sequence of key strokes that would normally be manually entered to use Lotus' commands and functions. The macro is just an automation of physically pressing the desired set of key strokes. Also, custom tailored menus can be created using macros.

A macro can greatly simplify movement around the spreadsheet. Time can be saved using macros, but more importantly, an entire program written using the macro language can be included in a Lotus 123 spreadsheet. A program of this nature will allow a novice to use the spreadsheet just as a beginner uses an interactive program written in a more conventional programming language.

CHAPTER III
PRELIMINARY WATER TREATMENT DESIGN AND COST ESTIMATION

Introduction

Smith (1986) has written a personal computer program, called WATERMAID, in the BASIC computer language for the preliminary design of drinking water treatment process systems. The program calculates the expected contaminant removal performance and associated construction, operation, and maintenance costs of drinking water treatment systems consisting of various unit processes arranged in multiple configurations. The method presently used to estimate preliminary design, removal efficiency, and costs is hand calculation. The WATERMAID program is regarded as a significant improvement to this tedious calculation method. An attempt is made to improve upon the WATERMAID program with the use of Lotus 123 to provide a decision support system to accomplish the same goal.

Decision Support System

The goal of the decision support system is to create a program for solving a problem that would imitate the human logical process of reasoning (Johnson, 1986). The program provides a set of rules, logical steps, and any required knowledge bases.

The decision support program goal is to provide a system to carry an individual user through logical steps toward problem solution. Next, state of the art knowledge in the area of the problem must be provided to allow the user to enter intelligent input data to the program. Then, the expert system program must clearly show how the user inputs are used to calculate the output for completion of the problem solution. Lastly, the program must be easily updated as the knowledge base changes.

WATERMAID Program

WATERMAID is an acronym for Water-treatment Microcomputer Assisted Interactive Design. The program includes 25 separate water treatment processes that treat 55 contaminants. Design decisions are entered from the keyboard in response to screen prompts. The program allows the user to enter the raw water properties, cost factors, cost of various chemicals, and choose which treatment processes are desired. Minimal data and knowledge are provided to explain the required data inputs and how the output is determined. The technology used in sizing processes and estimating performance is the best currently available for preliminary design. The majority of the cost estimation data is taken from the EPA manual, Estimating Water Treatment Costs, Volume 2 (Gumerman et al., 1979).

Lotus 123 WTRMAID Program

A program called WTRMAID was written using Lotus 123 to overcome two major problem areas in the WATERMAID program, i.e., limited guidance on program inputs, and clearly demonstrating how program output is determined. The Lotus 123 WTRMAID program basically follows the format for the WATERMAID program except in a few areas which will be discussed.

WTRMAID Menu

The Lotus 123 WTRMAID program is menu driven. Figure 3-1 indicates where the various sections are located within the spreadsheet. Once the program begins, the user should only use the commands within the menu. No knowledge of the Lotus 123 commands and functions is required and it is best not to use them. The only keyboard knowledge that the user must have is the ability to use the direction keys to move the cursor within the spreadsheet, the Alt key, and the return key.

Striking the Alt and M keys together will access the menu. The initial menu shows eight basic commands: SECTIONS, PROCESS, HELP, GRAPH, DATA, EXECUTE, COPY, and QUIT. Using the direction keys, each command within the menu can be highlighted. Pressing return when that command is highlighted will either access a sub menu or initiate a macro.

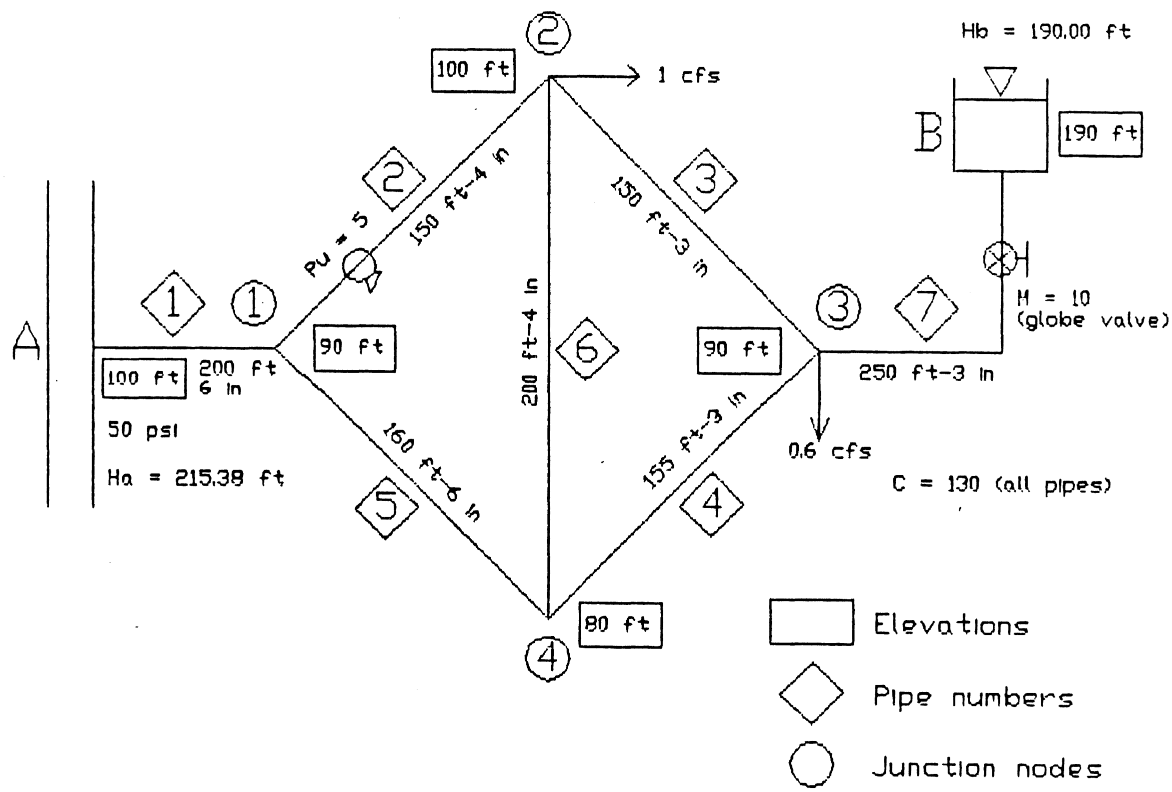


Figure 3-1. Spreadsheet Diagram of WTRMAID Program

Using the SECTIONS command will access a sub menu which lists seven additional commands: INTRODUCTION, TREATMENT, INFLUENT, COST, CHEMICALS, PROCESSES, and CONTAMINANT. Using any of these selections will move the cursor to that section within the spreadsheet. The INTRODUCTION is where the introductory message is contained. The TREATMENT section (Table 3-1) lists the 25 water treatment processes, the process abbreviation, and identifies the nomenclature for the influent stream and two possible effluent streams to each process.

Activating the INFLUENT section allows the user to access the section where 56 influent water property characteristics are listed (Table 3-2). The maximum contaminant levels specified in Environmental Protection Agency regulations are shown in the last column. Data are input or changed by moving the cursor between the brackets indicated as, [   ] and entering the desired number. The units are indicated next to each contaminant.

The COST section (Table 3-3) lists the cost indexes and cost factors used in the program. An individual can change any of the data as discussed above. The CHEMICALS section (Table 3-4) allows the user to input the cost of the chemicals used in the various water treatment processes. The CONTAMINANTS section (Table 3-5) indicates which processes may be used to remove specified contaminants.

Table 3-6 shows the PROCESS section where the stream/ process map is located. The process numbers are listed

Table 3-1. Treatment Process Section in WTRMAID Program.

Available water treatment processes:		Influent Stream	First Effluent Stream	Second Effluent Stream
1 Raw water pumping	RWP	water	water	none
2 Presedimentation	PRESED	water	water	sludge
3 Lime-soda ash softening	LIME	water	water	sludge
4 Rapid mixing (chemical addition)	RMIX	water	water	none
5 Flocculation	FLOC	water	water	none
6 Sedimentation	SED	water	water	sludge
7 Filtration	FILT	water	water	filtrate
8 Granular carbon adsorption	GAC	water	water	backwash
9 Reverse osmosis	RO	water	water	brine
10 Ion exchange	IONEX	water	water	brine
11 Basin air stripping	BSTRIP	water	water	none
12 Tower air stripping	TSTRIP	water	water	none
13 Disinfection with chlorine	KILL	water	water	none
14 Clear well storage	STOR	water	water	none
15 Finished water pumping	FWP	water	water	none
Sludge treatment and disposal processes:				
16 Gravity thickening	THICK	sludge	sludge	overflow
17 Sludge drying beds	BEDS	sludge	cake	filtrate
18 Vacuum filtration	VACF	sludge	cake	filtrate
19 Decanter centrifugation	CENT	sludge	cake	centrate
20 Filter press	FPRESS	sludge	cake	filtrate
21 Lime recalcination	RECALC	sludge	none	none
22 Sludge storage lagoons	LAGOON	sludge	none	none
23 Land disposal	LANDD	sludge	none	none
Fictitious processes:				
24 Stream mixer	MIX	Any two streams in/one out		
25 Stream splitter	SPLIT	Any one stream in/two out		

Table 3-2. Influent Water Properties Section in WTRMAID Program.

	Property	Influent	Stds
1	Average plant influent flow rate, mgd ------ =	[28]	NA
2	Design influent flow rate, mgd ------------- =	[40]	NA
3	Water temperature, degrees C --------------- =	[20]	NA
4	Raw water pH ------------------------------- =	[7.5]	NA
5	Turbidity, ntu ----------------------------- =	[50]	1.0
6	Color, pcu --------------------------------- =	[117]	NA
7	Coliform organisms, no./100 ml ------------- =	[100]	1.0
8	Total dissolved solids, mg/l --------------- =	[5000]	NA
9	Total suspended solids, mg/l --------------- =	[50]	NA
10	Volatile suspended solids, mg/l ------------ =	[5]	NA
11	Carbonate alkalinity, mg/l as CACO3 -------- =	[207]	NA
12	Non-carbonate alkalinity, mg/l as CACO3----- =	[0]	NA
13	Calcium ion Ca2+, mg/l --------------------- =	[110]	NA
14	Magnesium ion Mg2+, mg/l ------------------- =	[9.7]	NA
15	Sodium ion Na+, mg/l ----------------------- =	[50]	NA
16	Copper Cu2+, mg/l -------------------------- =	[0]	NA
17	Ferrous iron Fe2+, mg/l -------------------- =	[0]	NA
18	Ferric iron Fe3+, mg/l --------------------- =	[0.15]	NA
19	Bivalent manganese Mn2+, mg/l -------------- =	[0]	NA
20	Quadrivalent manganese Mn4+, mg/l ---------- =	[0]	NA
21	Chloride Cl-, mg/l ------------------------- =	[120]	NA
22	Sulfate ion (SO4)2-, mg/l ------------------ =	[107]	NA
23	Nitrate ion NO3-, mg/l --------------------- =	[105]	1 as N
24	Total organic carbon (TOC), mg/l ----------- =	[10]	NA
25	Nonpurgeable organic carbon (NPOC), mg/l --- =	[0]	NA
26	Pentavalent arsenic As5+, mg/l ------------- =	[0]	0.05
27	Trivalent arsenic As3+, mg/l --------------- =	[0]	0.05
28	Barium Ba2+, mg/l -------------------------- =	[0]	1.0
29	Cadmium Cd2+, mg/l ------------------------- =	[0]	0.01
30	Hexavalent chromium Cr6+, mg/l ------------- =	[0]	0.05

Table 3-2. continued.

	Property	Influent	Stds
31	Trivalent chromium Cr3+, mg/l --------------- =	[0]	0.05
32	Lead Pb2+, mg/l ----------------------------- =	[0]	0.05
33	Mercury Hg2+, mg/l -------------------------- =	[0]	0.002
34	Organic mercury, mg/l ----------------------- =	[0]	0.002
35	Quadravalent selenium Se4+, mg/l ------------ =	[0]	0.01
36	Hexavalent selenium Se6+, mg/l -------------- =	[0]	0.01
37	Silver Ag2+, mg/l --------------------------- =	[0]	0.05
38	Fluoride, mg/l ------------------------------ =	[0]	1.4-2.4
39	Endrin, mg/l -------------------------------- =	[0]	0.0002
40	Lindane, mg/l ------------------------------- =	[0]	0.004
41	Toxaphene, mg/l ----------------------------- =	[0]	0.005
42	2,4,D Insecticide, mg/l --------------------- =	[0]	0.10
43	2,4,5-TP (Silvex), mg/l --------------------- =	[0]	0.01
44	Methoxychlor, mg/l -------------------------- =	[0]	0.1
45	Gross alpha particle emission, pCi/l -------- =	[0]	15
46	Radium-226, pCi/l --------------------------- =	[0]	5
47	Radium-228, pCi/l --------------------------- =	[0]	5
48	THM formation precursors THMFP, micro-gm/l-- =	[0]	100
49	InstTHM CHCl3, micro-gm/l ------------------ =	[0]	100
50	InstTHM CHBrCl2, micro-gm/l ---------------- =	[0]	100
51	InstTHM CHBr2Cl, micro-gm/l ---------------- =	[0]	100
52	InstTHM CHBr3, micro-gm/l ------------------ =	[0]	100
53	Aluminum hydroxide AlOH3, mg/l ------------- =	[0]	NA
54	Ferric hydroxide FeOH3, mg/l --------------- =	[0]	NA
55	Calcium carbonate CaCO3, mg/l -------------- =	[0]	NA
56	Magnesium hydroxide MgOH2, mg/l ------------ =	[0]	NA

Table 3-3. Cost Factors Section in WTRMAID Program.

Cost indexes	
ENR construction cost index	265.38
Producer price index	199.7
Capital cost factors, % of construction cost	
Engineering cost (%)	10
Sitework, interface piping (%)	5
Subsurface considerations (%)	0
Standby power (%)	0
Amortization factors	
Amortization period (years)	20
Annual interest rate (%)	7
Land cost ($/acre)	2000
Unit cost factors	
Labor ($/hr)	10
Electricity ($/kwh)	0.03
Diesel fuel ($/gal)	0.45
Natural gas ($/cu ft)	0.0013

Table 3-4. Cost of Chemicals Section in WTRMAID Program.

1	Dry granular alum, $/ton	235
2	Liquid alum, $/ton equivalent dry alum	70
3	Quick lime CAO, $/ton	31.25
4	Slaked lime CA(OH)2, $/ton	32.5
5	Sodium hydroxide NAOH, $/ton	200
6	Soda ash NA2CO3, $/ton	150
7	Ferric sulfate FE2(SO4)3+7H2O, $/ton	118
8	Ferrous sulfate FESO4+7H2O, $/ton	115
9	Sulfuric acid H2SO4 66 Baume, $/ton	65
10	Hydrochloric acid HCL 20 Baume, $/ton	70
11	Anion exchange resin, $/cu ft	170
12	Cation exchange resin, $/cu ft	65
13	Salt NACL, $/ton	30
14	Liquid chlorine, $/ton	300
15	Powdered activated carbon, $/lb	0.35
16	Granular activated carbon, $/lb	0.5
17	Polyelectrolyte, $/lb	2
18	Aqua ammonia, $/ton	210
19	Potassium permanganate KMNO4, $/lb	3.62
20	Liquid carbon dioxide CO2, $/lb	0.05

Table 3-5. Contaminant Section in WTRMAID Program.

Contaminant:	MIX	RWP	PRESED	LIME	RMIX	FLOC	SED	FILT	GAC	RO	IONEX	BSTRIP	TSTRIP	STOR	KILL	FWP
PH	*	-	-	*	*	-	-	-	-	*	-	-	-	-	*	-
TURBIDITY	-	-	*	-	-	-	*	*	*	*	-	-	-	-	-	-
COLOR	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-
COLIFORMS	-	-	-	-	-	-	-	-	-	*	-	-	-	-	*	-
TDS	-	-	*	-	-	-	*	*	*	*	*	-	-	-	-	-
TSS	-	-	*	-	-	-	*	*	*	*	*	-	-	-	-	-
VSS	-	-	-	-	-	-	-	-	-	*	*	-	-	-	-	-
C-ALK	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-
NC-ALK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CALCIUM	-	-	-	-	-	-	-	-	-	*	*	-	-	-	-	-
MAGNESIUM	-	-	-	-	-	-	-	-	-	*	*	-	-	-	-	-
SODIUM	-	-	-	-	-	-	-	-	-	*	*	-	-	-	-	-
COPPER	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-
IRON II	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-
IRON III	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-
MANGANESE II	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-
MANGANESE IV	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-
CHLORIDE	-	-	-	-	-	-	-	-	-	*	*	-	-	-	-	-
SULFATE	-	-	-	-	-	-	-	-	-	*	*	-	-	-	-	-
NITRATE	-	-	-	-	-	-	-	-	-	*	*	-	-	-	-	-
TOC	-	-	-	-	-	-	-	-	*	*	-	-	-	-	-	-
NPOC	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-
ARSENIC V	-	-	-	-	-	-	*	-	-	*	-	-	-	-	-	-
ARSENIC III	-	-	-	-	-	-	*	-	-	*	-	-	-	-	-	-
BARIUM	-	-	-	-	-	-	*	-	-	*	-	-	-	-	-	-
CADMIUM	-	-	-	-	-	-	*	-	-	*	-	-	-	-	-	-

Table 3-5. Continued.

Contaminant:	MIX	RWP	PRESED	LIME	RMIX	FLOC	SED	FILT	GAC	RO	IONEX	BSTRIP	TSTRIP	STOR	KILL	FWP
CHROMIUM VI	-	-	-	-	-	-	*	-	-	*	-	-	-	-	-	-
CHROMIUM III	-	-	-	-	-	-	*	-	-	*	-	-	-	-	-	-
LEAD	-	-	-	-	-	-	*	-	-	*	-	-	-	-	-	-
MERCURY	-	-	-	-	-	-	*	-	-	*	-	-	-	-	-	-
ORG MERCURY	-	-	-	-	-	-	*	-	-	-	-	-	-	-	-	-
SELENIUM IV	-	-	-	-	-	-	*	-	-	*	-	-	-	-	-	-
SELENIUM VI	-	-	-	-	-	-	*	-	-	*	-	-	-	-	-	-
SILVER	-	-	-	-	-	-	*	-	-	*	-	-	-	-	-	-
FLUORIDE	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-
ENDRINE	-	-	-	-	-	-	-	-	*	*	-	-	-	-	-	-
LINDANE	-	-	-	-	-	-	-	-	*	*	-	-	-	-	-	-
TOXAPHENE	-	-	-	-	-	-	-	-	*	*	-	-	-	-	-	-
2-4-D	-	-	-	-	-	-	-	-	*	*	-	-	-	-	-	-
SILVEX	-	-	-	-	-	-	-	-	*	*	-	-	-	-	-	-
METHOXYCHLOR	-	-	-	-	-	-	-	-	*	*	-	-	-	-	-	-
ALPHA RAYS	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-
RADIUM-226	-	-	-	-	-	-	*	-	-	*	-	-	-	-	-	-
RADIUM-228	-	-	-	-	-	-	*	-	-	*	-	-	-	-	-	-
THMFP	-	-	-	-	-	-	*	-	-	*	-	*	*	*	*	-
CHCl3	-	-	*	-	*	*	*	-	*	-	-	*	*	*	*	-
CHBrCl2	-	-	*	-	*	*	*	-	*	-	-	*	*	*	*	-
CHBr2Cl	-	-	*	-	*	*	*	-	*	-	-	*	*	*	*	-
CHBr3	-	-	*	-	*	*	*	-	*	-	-	*	*	*	*	-
AlOH3	-	-	*	*	*	-	*	*	*	*	-	-	-	-	-	-
FeOH3	-	-	*	*	*	-	*	*	*	*	-	-	-	-	-	-
CaCO3	-	-	*	*	*	-	*	*	*	*	-	-	-	-	-	-
MgOH2	-	-	*	*	*	-	*	*	*	*	-	-	-	-	-	-

Table 3-7. Stream/Process Map Section in WTRMAID Program.

Loop Mark	User Process Number	Process Name	First Stream In	Second Stream In	First Stream Out	Second Stream Out
	1	RWP				
	2	PRESED				
	3	LIME				
	4	RMIX	4	0	5	0
	5	FLOC	5	0	6	0
	6	SED				
	7	FILT				
	8	GAC				
	9	RO				
	10	IONEX				
	11	BSTRIP				
	12	TSTRIP				
	13	KILL				
	14	STOR				
	15	FWP				
	16	THICK				
	17	BEDS				
	18	VACF				
	19	CENT				
	20	FPRESS				
	21	RECALC				
	22	LAGOON				
	23	LANDD				
	24	MIX				
	25	SPLIT				

along with the abbreviated process name. The user must indicate which processes are desired. In addition, the user identifies which process the effluent proceeds to. This is the most difficult section to be input. A simple example is given in the following paragraph.

If only two processes are identified, e.g., rapid mixing and flocculation, a 4 must be placed in the First Stream In column to the right of RMIX. This identifies that the raw influent will enter the rapid mixing process first. By placing a 5 in the First Stream Out column the user identifies that the effluent is to proceed to the flocculation process. Since there is no second stream in or out, zeroes are placed in those columns. The same procedure is applied to the second process, flocculation. The number 5 is placed in the First Stream In column, to the right of FLOC and a 6 is entered in the First Stream Out column. The 6 identifies that the effluent from the flocculation process will proceed to the sedimentation process.

The next item on the main menu is PROCESS. Highlighting PROCESS and pressing return will provide a sub menu that lists the various processes. At this time only two processes are listed for test purposes, FLOCCULATION and RAPID MIXING. There are two PROCESS commands, one located within the main menu and one located within the sub menu of the SECTIONS command. After the user has provided all the initial data inputs within the various sections listed within the SECTIONS command, each process identified in the

PROCESS section within the SECTION sub menu must be located by the user within the PROCESS command of the main menu.

Initiating the FLOCCULATION or RAPID MIXING commands will produce the data input section for that process. The two process input sections are located in Table 3-7. The required input data are entered within the spaces provided. A help information code is provided at each process input section. The code is in the form H#. For example, the help code H3 can be accessed by the user to provide knowledge on how to enter appropriate data in the rapid mixing process input section.

Knowledge Bases

Within the program, knowledge bases are provided in the form of a help system, graphs, and data tables. These knowledge bases can be accessed by using the HELP, GRAPH, or DATA commands in the main menu. Activating any of these three commands will produce sub menus in the form GRAPH 1-8, GRAPH 9-10, etc. GRAPH could be replaced with DATA or H for help. The knowledge bases are numbered starting with the number 1.

Menus created by the Lotus 123 programmer will only provide up to eight commands per menu. Therefore the graphs are listed in the sub menu as GRAPH 1-8, etc. Entering the GRAPH 1-8 command will produce an additional sub menu that will list GRAPH 1, GRAPH 2, . . . , GRAPH 8. Using the direction keys to highlight a specific graph will produce

Table 3-7. Flocculation Process Data Input Section in TRMAID Program.

```
Input:  H1

ENTER THE DESIRED VELOCITY GRADIENT -------------- = [      50 ] 1/sec
ENTER THE DESIRED DETENTION TIME ----------------- = [      45 ] min
END OF FLOCCULATION DATA INPUT

Rapid Mixing Process Data Input Section in WTRMAID Program

Input:  H3

ENTER THE DESIRED VELOCITY GRADIENT -------------- = [     600 ] 1/sec
ENTER THE DESIRED DETENTION TIME ----------------- = [      45 ] min
IDENTIFY WHICH COAGULANT IS DESIRED: ------------- = [       2 ]
   ENTER 1 FOR DRY ALUM, Al2(SO4)3+18.3H2O
   ENTER 2 FOR LIQUID ALUM, (SPECIFY DOSE AS DRY ALUM EQUIVALENT)
   ENTER 3 FOR FERRIC SULFATE, Fe2(SO4)3+3H2O
   ENTER 4 FOR FERROUS SULFATE & DISSOLVED OXYGEN, FeSO4+7H2O & O2
   ENTER 5 FOR NONE OF THE ABOVE
SPECIFY THE COAGULANT DOSE ----------------------- = [      40 ] mg/l
ENTER POLYMER DOSE IF POLYMER IS DESIRED --------- = [    0.25 ] mg/l

AT THIS POINT PRESS ALT AND Z KEYS AT SAME TIME.
pH reduced from        7.5     to       7.12 by coagulant addition
Operational pH range for   alum                is    5.5-7.8
Optimum pH for turbidity removal is 6.8
Optimum pH for color removal is 5.6

IF YOU WANT TO RAISE OR LOWER PH BY CHEMICAL ADDITION ENTER THE DESIRED
   PH AFTER CHEMICAL ADDITION -------------------- = [     7.5 ]
IDENTIFY WHICH CHEMICAL TO USE IF RAISING WATER PH = [       2 ]
   ENTER 1 FOR QUICK LIME, CaO
   ENTER 2 FOR SODIUM HYDROXIDE, NaOH
   ENTER 3 FOR SODA ASH, Na2CO3
END OF RAPID MIXING DATA INPUT
```

that graph on the screen. Pressing return after reviewing the data will return the user back to the appropriate place in the spreadsheet. Representative examples of the help system are included in Appendix A.

Execution

The EXECUTE command initiates a macro that creates the output for the processes identified by the user. Then, the user is prompted by several beeps during this macro to identify whether the WTRMAID file should be updated with the user's input, whether a file copy of the output should be made, and/or whether a printed copy of the output is desired. An example of the executed output for the two processes, rapid mixing and flocculation, is given in Appendix B. Once the output is completed, additional help codes in the output data identify where the knowledge base for each process is located within the HELP command in the main menu. These knowledge bases include graphs, data tables, and all calculations used to determine the output data.

The COPY command allows the user to update the WTRMAID program at any time. This may be desired if the user does not enter all input data during one sitting. The QUIT command within the WTRMAID main menu terminates the WTRMAID program.

Spreadsheet Protection

The spreadsheet is protected using the Lotus 123 spreadsheet, global, protection, and enable commands. Only those cell locations where user input is allowed are unprotected using the Lotus 123 range and unprotect commands. The diskette containing the WTRMAID program is not protected as the macro is written so that the program can be continually updated with the user's input.

Macros

The two macros in the WTRMAID program are located within Appendix C. The large macro initiated with the use of the Alt and M keys consists of the main menu, seven sub menus, and numerous sub macros. The largest sub macro located within this macro is associated with the EXECUTE command. The execute macro accomplishes the difficult task of identifying which processes are to be included in the final output and the proper order to execute each process.

The data and sort commands are used to process the stream/process map (Table 3-6) input by the user, and unused processes are eliminated. The next step is to execute the output for each process in order of occurrence. This is accomplished using Lotus 123 @if functions and macro branch statements. A subroutine is written to produce the output data for each process. If statements are used to determine the order of the processes.

Each process subroutine calculates the output data with the Lotus 123 copy command. The copy command recalculates only the applicable section within each process. This method is quicker than recalculating the entire spreadsheet during the execution of each process and results in reduced execution time for the entire program. The spreadsheet can then be placed in the recalculation manual mode which allows for data to be input at the fastest speed possible, i.e., the spreadsheet is not recalculated each time the return key is pressed when entering data.

Each process subroutine calculates the proper changes to the influent water and reflects the changes in the effluent stream. Only the changes to the stream vector are printed during the execution of each process. The initial stream vector is the data on the 56 influent water properties input by the user. An example in the rapid mixing process is that total suspended solids are increased by addition of a coagulating chemical. The increase in total suspended solids is reflected in the program output data. After the changes to the stream vector are determined the subroutine then accepts the input data to calculate the preliminary design and cost estimates.

The second macro, located within the rapid mixing program, is initiated by pressing the Alt and Z keys at the same time. This macro initiates an iteration process for determining the reduction in influent water pH after the addition of a coagulating chemical. The iteration process is found in Appendix D. The macro is required so that the spreadsheet can be kept in the manual recalculation mode. As previously mentioned, if the spreadsheet is in the normal mode of automatic recalculation, data entry would be very slow as the spreadsheet is recalculated each time data is entered.

Calculations

Design calculations within the WTRMAID program are fairly simple and are given in the respective help sections. Experienced Lotus 123 users can verify the calculations by reviewing the equation formulas located within each cell where output data are located. An experienced Lotus 123 user can easily change the required calculations as the best available technology changes with time.

The cost calculations can be fairly complex. The construction cost for the flocculation basin is given in detail in the help system (Appendix A), and all other cost equations follow the same format. Within Gumerman et al., cost data are given in tables and reflected in 3 cycle by 4 cycle logarithmic graphs. To perform the cost calculations within both the WATERMAID and WTRMAID programs, log-log polynomial least squares fits are given for the data listed in Gumerman et al. In the case of the flocculation basin, three curves are given for three different velocity gradient values. If input data for the velocity gradient are entered which do not exactly equal one of the velocity gradient values, then log-log interpolation is conducted to determine the cost of construction.

Data Tables and Graphs

An advantage of the WTRMAID program is that the data tables and graphs found within Gumerman et al. can be input into the spreadsheet as knowledge bases. The data table for the flocculation basin cost of construction is listed as DATA 1 (Table 3-8) and can be accessed using the DATA command in the main menu. The graph are named GRAPH 1 and can be located using the GRAPH command in the main menu.

GRAPH 1 is given in Figure 3-2 and was produced with guidance from a paper written by Fine (1987). The data required to produce the log-log graph is listed in Appendix E. An X range and three Y ranges are required to produce the logarithmic graph, and an extensive amount of data. But, once the initial time is spent to produce the graph, changes to the plotted data are achieved very quickly and easily.

Conclusions

The WTRMAID program may appear complicated, but it is in fact very simple to use, even for a person not familiar with Lotus 123. Even though only two water treatment processes are incorporated into the WTRMAID program at this time, they are sufficient to run a comparison with the WATERMAID program. Data can be entered into the WTRMAID program just as quickly as with the WATERMAID program.

The user has more control over the WTRMAID program. A case in point is the input of the stream/process map. In the WATERMAID program the creation of the stream/process map

Table 3-8. Data Table 1 in WTRMAID Program.

Data table 1:

AFTER VIEWING TABLE PRESS RETURN

Construction cost for flocculation - Horizontal Paddle System, G = 20

	Total Basin Volume (ft^3)					
Cost Category	1800	10000	25500	100000	500000	1000000
Excavation and Sitework	470	2550	4290	99700	40080	77640
Manufactured Equipment	12140	28240	31420	54500	118350	232730
Concrete	1400	7610	12740	29770	120280	232960
Steel	2360	12550	20440	46500	175290	339510
Labor	7080	20220	28110	69940	187360	373420
Elec. and Instrumentation	6980	28320	28320	28320	141610	283220
SUBTOTAL	30430	99490	125320	239000	782970	1539480
Misc. and Contingency	4560	14920	18800	35850	117450	230920
TOTAL	34990	114410	144120	274850	900420	1770400

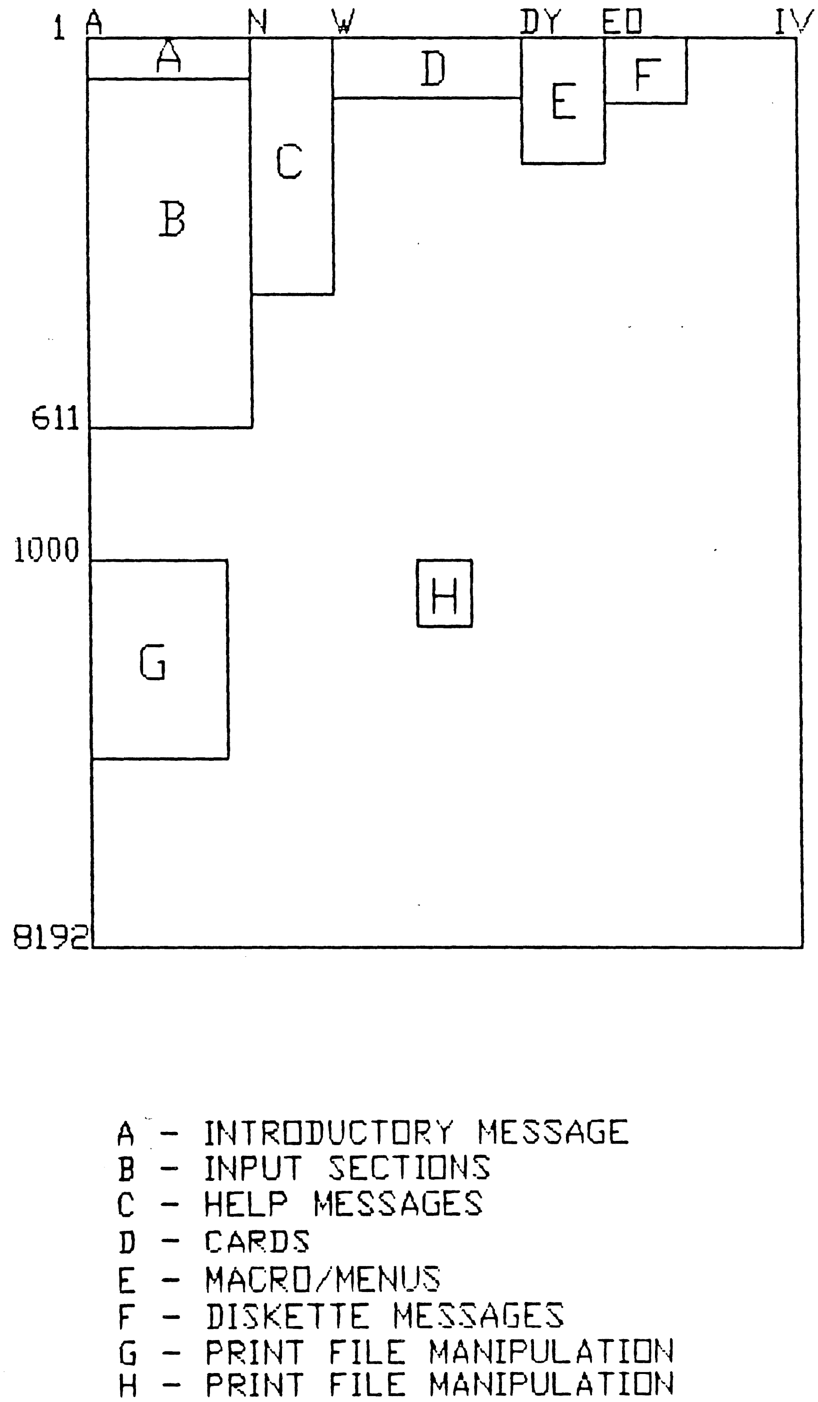


Figure 3-2. Modified Iterative Measurement Test

can be a difficult task since an individual is not able to view the possible process selections and their abbreviations when inputting data in this section. With the WTRMAID program the user is given this information.

The WTRMAID program is more flexible, allowing the user to move freely to any section at any time. If a person is inputting data in the rapid mixing process section and remembers that the chemical cost for the coagulant was not updated, that person can move to the chemical cost section, update the cost of the coagulant, and then return to the rapid mixing input section. It is recognized that both programs could be rewritten to exactly copy the other in the form of logical sequence of data input and output, except in the area of data base knowledge.

Lotus 123 provides the powerful ability to have the best available technology located right within the spreadsheet in the form of tables, equations, graphs, and even figures and maps can be duplicated using the Lotus 123 graph commands. All calculations can be documented to allow for convenient checking by anyone trying to understand the program.

The macro in the WTRMAID program, while producing the same output as the WATERMAID program, requires much less programming. The rapid mix process requires seven pages of BASIC programming while less than a page of macro programming accomplishes the same result. Less programming will make eventual improvements and modifications of the program a relatively easy matter.

CHAPTER IV
PRE- AND POSTPROCESSORS FOR A HYDRAULIC PIPE NETWORK ANALYSIS MODEL

Introduction

Wood (1980) has developed a popular program in FORTRAN IV, G level, for computer analysis of flow in pipe networks. Wood's model was chosen because it is the most widely used program to assist in the analysis of surcharged flow in pipe networks and as a tool for future capacity expansion of the network (Cesario, 1984).

Much of the time involved with modeling, such as with Wood's model, is spent in handling the required data prior to data input and in handling the output. Any means of streamlining the data handling process eases the time and complexities involved with model use.

Several methods exist to enter input data into Wood's model. An interactive input data program (INPUTF), provided within Wood's program, can be used for the initial input of data. Word processors like Word Perfect or Word Star can be used to make changes but may be complicated by the addition of hidden characters which can cause errors during program execution. Also, changes can be made using the line editor (EDLIN) which is provided on the DOS disk for the IBM personal computer and similar computers, or the IBM PC Personal Editor.

The major drawback with the INPUTF program is the time required to input data, and the INPUTF program will only compile the data which are input during the initial use of the INPUTF program. If all of the data cannot be entered during the initial data input session, then the user is not able to reenter the INPUTF program to complete the input of data. There is a method to use the INPUTF program to partially enter the entire data set but the remaining data entered at a later time, or corrections, would have to be entered using another editing method.

Lotus 123 Pre- and Postprocessors

A Lotus 123 program was written to increase the speed at which data can be entered for application with Wood's hydraulic network program, and to create a program which does not require all data to be input during the initial data input session. This program preprocesses the hydraulic network data into a format which is recognized by Wood's hydraulic network analysis program. The program is quick and does not require all data to be input at one time. Previous work has been conducted by Miles and Heaney (1986) in producing similar data handling processors for a storm water management model.

Lotus 123 can also be used as a postprocessor. A postprocessing program was written which receives the output file from Wood's program and formats the data into a Lotus 123 spreadsheet. Once the data are formatted, a multitude of data management functions can be used to analyze the output data.

Computer Analysis of Flow in Pipe Networks

Pipe network equations for steady state analysis have been expressed through loop or nodal equations. Wood's program uses loop equations which have demonstrated superior convergence (Wood, 1980; Viessman and Hammer, 1985). Loop equations express mass continuity and conservation of energy for the discharge in each pipe section. The number of pipe sections is determined from the following:

$$p = j + l + f - 1 \qquad (4.1)$$

where

p = number of pipe sections,

j = number of junction nodes,

l = number of primary loops, and

f = number of fixed grade nodes.

A junction node is described as a point where either two or more pipes meet, flow is gained or lost from the system, or a change in pipe diameter occurs. A fixed grade node is any point where the hydraulic grade line is known which is usually a connection to a storage tank or reservoir, or a known pressure at any source or discharge point. Primary loops are defined as a closed pipe circuit where all pipes are open. As an example, Figure 4-1 details a hydraulic pipe network with 7 pipes, 4 junction nodes,

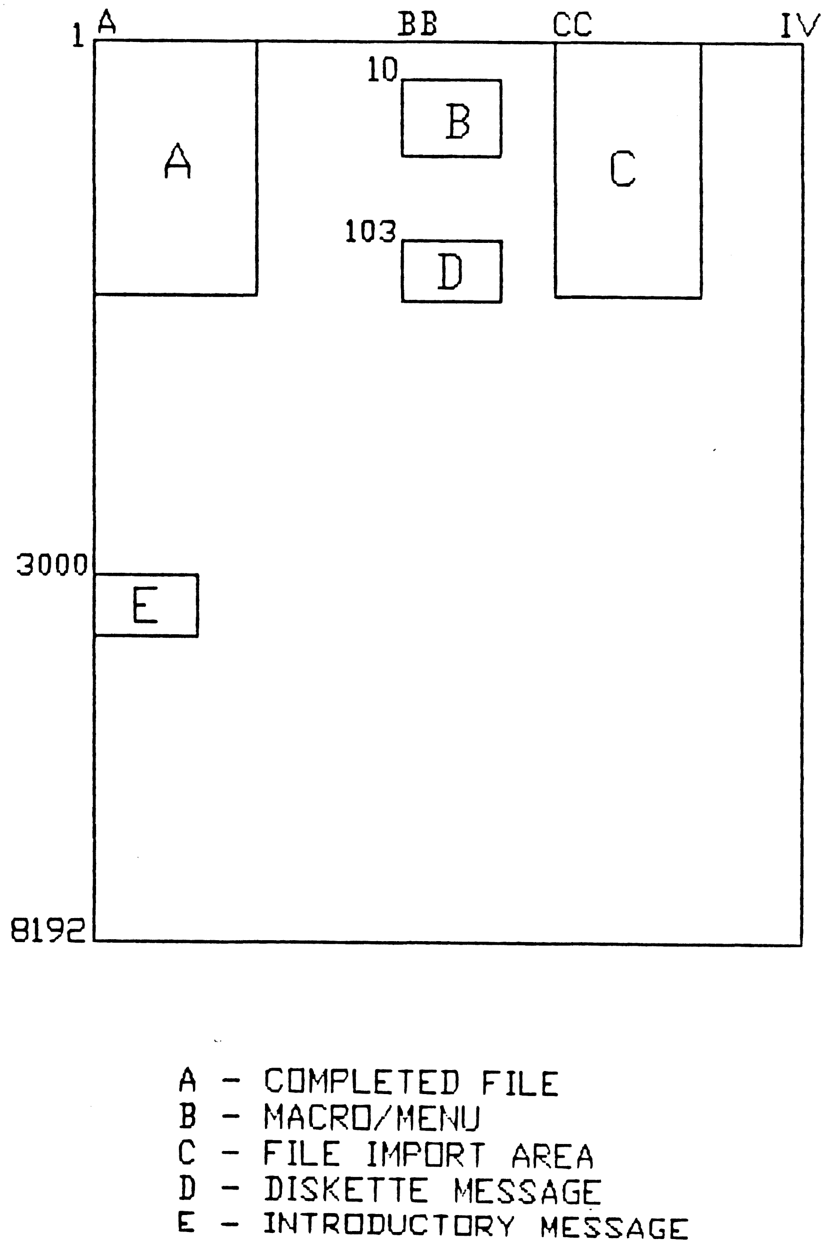


Figure 4-1. Water Distribution Network

2 fixed grade notes, and 2 primary loops (Viessman and Hammer, 1985).

Mass Continuity and Energy Conservation Equations

Equation 1 also provides the basis for a set of hydraulic equations which described the pipe network. A set of p equations can be formed, which include j mass continuity equations, l loop energy conservation equations, and f - 1 fixed grade node energy conservation equations. Continuity of mass is expressed for each junction node as:

$$\sum Qin - \sum Qout = Qe \qquad \text{(j equations)} \quad (4.2)$$

where

Qe = the external inflow or demand,

Qin = inflow, and

Qout = demand

Energy conservation at each primary loop is expressed as follows:

$$\Sigma h_l = \Sigma E_p \qquad \text{(l equations)} \quad (4.3)$$

where

h_l = energy loss in each pipe (including minor loss) and

E_p = energy input into the fluid by a pump.

For f fixed grade nodes, f - 1 conservation of energy equations can be written for paths of pipe sections between each set of two different fixed nodes as follows:

$$\Sigma dE = \Sigma h_l - \Sigma E_p \qquad \text{(f-1 equations)} \quad (4.4)$$

where

dE = the difference in total grade between the two fixed grade nodes.

As stated above, the energy loss, h_l, includes minor losses. Therefore the equation for the energy loss in the pipe is:

$$h_l = h_{lp} + h_{lm} \tag{4.5}$$

where

h_{lp} = the line loss in the pipe, and

h_{lm} = the minor loss in the pipe.

The line loss expressed in terms of the flow rate is given by:

$$h_{lp} = K_p*Q^n \tag{4.6}$$

where

K_p = the pipe line constant which is a function of the length, diameter, and roughness or friction factor of the pipe,

Q = the flow rate, and

n = an exponent.

The values of K_p and n depend on the energy loss expression used for the analysis. For the Hazen Williams equation:

$$K_p = X*L/(C^{1.852}*D^{4.87}) \tag{4.7}$$

where

X = a constant which depends on the units used and has a value of 4.73 for english units and 10.69 for SI units,

L = pipe length,

C = the roughness coefficient, and

D = pipe diameter,

and the value of n in equation 4.6 is 1.852.

The equation for the minor loss within a pipe section is:

$$h_{lm} = K_m * Q^2 \tag{4.8}$$

where K_m is a function of the sum of the minor loss coefficients for the fittings in the pipe section and the pipe diameter as follows:

$$K_m = .02517 * \ /D^4 \tag{4.9}$$

where

m = the sum of the minor loss coefficients for the fittings in the pipe section.

The energy input to a fluid by a pump, E_p, described by the useful power or by operating data as follows:

$$E_p = Z/Q \tag{4.10}$$

and

$$E_p = A + B*Q + C*Q^2$$

respectively where A, B and C are constant. The term Z is a function of the useful power of the pump and the specific gravity of the fluid and is:

$$Z = 8.814*P_u/S \text{ (English units)} \tag{4.11}$$

or

$$Z = .10197*P_u/S \text{ (SI units)}$$

where

P_u = the useful power of the pump, and

S = the specific gravity of the liquid.

Utilizing equations 4.5 through 4.11, the energy equations (equations 4.3 and 4.4) can be rewritten as:

$$dE = \Sigma(K_p*Q^n + K_m*Q^2) - \Sigma(Z/Q) \qquad (4.12)$$

and

$$dE = \Sigma(K_p*Q^n + K_m*Q^2) - \Sigma(A + B*Q + C*Q^2)$$

The continuity of mass equation (equation 4.2) and conservation of energy equations (equations 4.3 and 4.4) form a set of P simultaneous equations in terms of unknown flow rates which are called the loop equations. There is no direct solution of these equations since the energy equations are nonlinear. The most reliable and efficient algorithm, the linear method, was chosen for Wood's program (Viessman & Hammer, 1985).

The Linear Method

The linear method involves linearizing the energy equations in terms of an approximate flow rate in each pipe. The algorithm makes use of gradient methods to handle the non-linear flow rate, Q, terms in the energy equations (equation 4.12). The right hand side of equation 4.12 is the grade difference across a pipe section carrying a flow rate Q. This can be expressed as a function of Q as follows:

$$f(Q) = K_p*Q^n + K_m*Q^2 - Z/Q \qquad (4.13)$$

or

$$f(Q) = K_p*Q^n + K_m*Q^2 - (A + B*Q + C*Q^2)$$

The grade difference in a pipe section based on $Q = Q_1$ is:

$$H_1 = f(Q_1) = K_p*Q_1{}^n + K_m*Q_1{}^2 - Z/Q_1 \qquad (4.14)$$

or

$$H_1 = K_p*Q_1{}^n + K_m*Q_1{}^2 - (A + B*Q_1 + C*Q_1{}^2)$$

and the gradient evaluated at $Q = Q_1$ is:

$$G_i = f'(Q_i) = n*K_p*Q_i{}^{n-1} + 2*K_m*Q_i + Z/Q_i{}^2 \qquad (4.15)$$

or

$$G_1 = n*K_p*Q^{n-1} + 2*K_m*Q_1 - (B + 2*C*Q_1)$$

The non-linear energy equations (equation 4.12) are now linearized by taking the derivative of the variables in equation 4.14 or 4.15 with respect to the flow rate and evaluating them at $Q = Q_1$ using the following approximation:

$$f(Q) = f(Q_1) + f'(Q_1)*(Q-Q_1) \qquad (4.16)$$

When this relationship is applied to the energy equations (equation 4.12) the following linearized equation results:

$$dE = \Sigma H_1 + \Sigma G_1*(Q-Q_1) \qquad (4.17)$$

or

$$G_1*Q = (G_1*Q_1 - H_1) + dE$$

Equation 4.17 is now used to formulate the l + f - 1 energy equations in addition to the j continuity equations which form the set of p simultaneous equations.

Routine matrix procedures are used to solve the set of p simultaneous equations after an arbitrary flow rate for each pipe is picked. New flow rates are determined which are then used for the second trial. Trials are repeated until the change in flow from one trial to the next is negligible. Since the procedure simultaneously solves for the flow in each pipe, convergence is rapid and usually only requires from four to eight trials.

Solution of the Linear Method Using Lotus 123

Table 4-1 (Viessman & Hammer, 1985) lists the physical characteristics for the same hydraulic network shown in Figure 4-1. The values for K_p, K_m and Z are demonstrated in Table 4-2 for each pipe section, using equations 4.7, 4.9, and 4.11 respectively. In Table 4-3, the values for Q_1, G_1, and H_1 are determined for each pipe. The initial value for Q is calculated from an assumed pipe velocity of 1 foot per second. Table 4-4 demonstrates how equation 4.17 is determined for each conservation of energy equation, loop 1, loop 2, and path AB.

Table 4-1. Physical Characteristics for Pipes in Figure 4-1.

Pipe	Length L (ft)	Diameter D (in)	Area A (ft^2)	Roughness Coef C
1	200	6	0.785	130
2	150	4	0.349	130
3	150	3	0.196	130
4	155	3	0.196	130
5	160	6	0.785	130
6	200	4	0.349	130
7	250	3	0.196	130

Table 4-2. Calculation of Kp, Km, and Z for Pipes in Figure 4-1.

Kp=X*L/(C^1.852*D^4.87)	X =	4.73			
Km=.02517*M/D^4	M =	10			
Z=8.814*Pu/S	Pu =	5	S =	1	

Pipe	Kp	Km	Z
1	3.36	0	0
2	18.18	0	44.07
3	73.78	0	0
4	76.24	0	0
5	2.69	0	0
6	24.24	0	0
7	122.97	64.44	0

Table 4-3. Calculation of Qi, Hi, and Gi for Pipes in Figure 4-1.

Qi is based on a velocity of 1 ft/sec, Q=V*A, V=1 therefore

Q=A

Gi = 1.852*Kp^.852 + 2*Km*Qi + Z/Qi^2

Hi = Kp*Qi^1.852 + Km*Qi^2 - Z/Qi

Pipe	Qi	Hi	Gi
1	0.785	2.151	5.072
2	0.349	-123.7	375.415
3	0.196	3.620	34.140
4	0.196	3.740	35.278
5	0.785	1.721	4.057
6	0.349	3.451	18.308
7	0.196	8.517	82.204

Table 4-4. Calculation of Summation of Gi*Qi.

sum Gi*Qi = sum (Gi*Qi - Hi) + dE

	Pipe No. and Sign	Gi		Qi		Gi*Qi	Hi	dE
Loop 1	2+	375.415	*	0.349	=	131.044	123.663	
	6+	18.308	*	0.349	=	6.391	-3.451	0
	5-	4.057	*	0.785	=	-3.187	1.721	
						134.248	121.933	
				sum Gi*Qi = sum (Gi*Qi - Hi) + dE =				256.181
Loop 2	6-	18.308	*	0.349	=	-6.391	3.451	
	3+	34.140	*	0.196	=	6.703	-3.620	0
	4-	35.278	*	0.196	=	-6.927	3.740	
						-6.614	3.571	
				sum Gi*Qi = sum (Gi*Qi - Hi) + dE =				-3.043
PATH AB	1+	5.072	*	0.785	=	3.983	-2.151	
	2+	375.415	*	0.349	=	131.044	123.66	25.38
	3+	34.140	*	0.196	=	6.703	-3.620	
	7+	82.204	*	0.196	=	16.141	-8.52	
						157.871	109.376	
				sum Gi*Qi = sum (Gi*Qi - Hi) + dE =				292.627

Solving a Set of Simultaneous Equations Using Matrix Techniques

A matrix (Table 4-5) is now developed so that the seven equations (p=j+1+f-1 or 4+2+2-1=7) and seven unknowns (Q1, Q2, . . . , Q7) can be solved simultaneously. There are j = 4 mass continuity equations (equation 4.2). Anequation is included for each junction node. For example, the mass balance for junction node 4 is Q4 - Q5 - Q6 = 0. Notice that the right hand side (RHS) of this equation is the external inflow or demand, which at this junction node is always equal to zero. The energy conservation equation for loop 2 (equation 4.17) is 34.14*Q3 - 35.28*Q4) - 18.31*Q6 = -3.04. The negative sign indicates that the flow in pipe four is moving in a counter clockwise direction. The right hand side of the equation is equal to the value determined in Table 4-4.

The seven by seven matrix is solved in Lotus by inverting the left hand side (LHS), and post-multiplying this inverse by the right hand side vector to determine the new Q values. The matrix procedures are also shown in Table 4-5. The new values for Q1 through Q7 are now used to update Table 4-3 and the entire process is repeated to determine another set of Q values. The iterative process stops when the change in Q values is within an established tolerance. Tables 4-6, 4-7, 4-8, and 4-9 show the second, third, fourth, and fifth iterations for this hydraulic network. The final Q values are Q1=1.73, Q2=1.37, Q3=0.37, Q4=0.36, Q5=0.001, and Q7=0.132. Table 4-10 is the output

Table 4-5. Matrix for Solving Simultaneous Equations.

	LHS							
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	RHS
PATH AB	5.07	375.41	34.14	0.00	0.00	0.00	82.20	292.63
LOOP 1	0.00	375.41	0.00	0.00	-4.06	18.31	0.00	256.18
LOOP 2	0.00	0.00	34.14	-35.28	0.00	-18.31	0.00	-3.04
JUNC 1	-1.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00
JUNC 2	0.00	-1.00	1.00	0.00	0.00	1.00	0.00	-1.00
JUNC 3	0.00	0.00	-1.00	-1.00	0.00	0.00	1.00	-0.60
JUNC 4	0.00	0.00	0.00	1.00	-1.00	-1.00	0.00	0.00

LHS^-1								RHS
0.01	-0.01	-0.01	-0.95	-0.86	-0.73	-0.92		292.63
0.00	0.00	0.00	0.00	-0.04	-0.02	-0.01		256.18
0.00	0.00	0.01	0.02	0.26	-0.30	0.03		-3.04
0.01	-0.01	-0.01	0.03	-0.11	-0.43	0.05	*	0.00
0.01	-0.01	-0.01	0.04	-0.81	-0.71	-0.91		-1.00
0.00	0.01	-0.01	-0.02	0.70	0.28	-0.04		-0.60
0.01	-0.01	-0.01	0.05	0.14	0.27	0.08		0.00

= new Q values =

	Q
1.7051	1
0.7162	2
0.1896	3
0.5155	4
0.9890	5
-0.4735	6
0.1051	7

LHS		RHS
292.63		292.63
256.18		256.18
-3.04		-3.04
0.00	=	0.00
-1.00		-1.00
-0.60		-0.60
0.00		0.00

Table 4-6. Second Iteration of Linear Method.

Qi is based on a velocity of 1 ft/sec, Q=V*A, V=1 therefore Q=A
Gi = 1.852*Kp^.852 + 2*Km*Qi + Z/Qi^2
Hi = Kp*Qi^1.852 + Km*Qi^2 - Z/Qi

	Qi	Hi	Gi
1	1.7051	9.039	9.817
2	0.7162	-51.7	111.252
3	0.1896	3.394	33.144
4	0.5155	22.348	80.290
5	0.9890	2.637	4.938
6	0.4735	6.069	23.738
7	0.1051	2.610	46.969

sum Gi*Qi = sum (Gi*Qi - Hi) + dE

	Pipe No. and Sign	Gi		Qi		Gi*Qi	Hi	dE
Loop 1	2+	111.252	*	0.716	=	79.676	51.740	
	6+	23.738	*	0.473	=	11.239	-6.069	0
	5-	4.938	*	0.989	=	-4.883	2.637	
						86.0316	48.3082	
				sum Gi*Qi = sum (Gi*Qi - Hi) + dE =				134.339
Loop 2	6-	23.738	*	0.473	=	-11.239	6.069	
	3+	33.144	*	0.190	=	6.286	-3.394	0
	4-	80.290	*	0.515	=	-41.389	22.348	
						-46.343	25.023	
				sum Gi*Qi = sum (Gi*Qi - Hi) + dE =				-21.320

Table 4-6. Continued.

PATH AB	1+	9.817	*	1.705	=	16.740	-9.039	
	2+	111.252	*	0.716	=	79.676	51.74	25.38
	3+	33.144	*	0.190	=	6.286	-3.394	
	7+	46.969	*	0.105	=	4.938	-2.61	

						107.639	36.6979	

sum Gi*Qi = sum (Gi*Qi - Hi) + dE = 169.717

	Q1	Q2	Q3	LHS Q4	Q5	Q6	Q7	RHS
PATH AB	9.82	111.25	33.14	0.00	0.00	0.00	46.97	169.72
LOOP 1	0.00	111.25	0.00	0.00	-4.94	23.74	0.00	134.34
LOOP 2	0.00	0.00	33.14	-80.29	0.00	-23.74	0.00	-21.32
JUNC 1	-1.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00
JUNC 2	0.00	-1.00	1.00	0.00	0.00	1.00	0.00	-1.00
JUNC 3	0.00	0.00	-1.00	-1.00	0.00	0.00	1.00	-0.60
JUNC 4	0.00	0.00	0.00	1.00	-1.00	-1.00	0.00	0.00

			LHS^-1					RHS
0.01	-0.01	0.00	-0.89	-0.73	-0.51	-0.85		169.72
0.00	0.01	0.00	0.01	-0.14	-0.07	-0.02		134.34
0.01	0.00	0.00	0.06	0.31	-0.31	0.09		-21.32
0.00	0.00	-0.01	0.04	-0.04	-0.20	0.07	*	0.00
0.01	-0.02	0.00	0.09	-0.58	-0.44	-0.83		-1.00
-0.01	0.01	0.00	-0.05	0.55	0.24	-0.10		-0.60
0.01	-0.01	0.00	0.11	0.27	0.49	0.15		0.00

Table 4-6. Continued.

= new Q values =

	Q
1.7064	1
1.2408	2
0.2997	3
0.4067	4
0.4656	5
-0.0589	6
0.1064	7

LHS		RHS
169.72		169.72
134.34		134.34
-21.32		-21.32
0.00	=	0.00
-1.00		-1.00
-0.60		-0.60
0.00		0.00

Table 4-7. Third Iteration of Linear Method.

Qi is based on a velocity of 1 ft/sec, Q=V*A, V=1 therefore Q=A
Gi = 1.852*Kp^.852 + 2*Km*Qi + Z/Qi^2
Hi = Kp*Qi^1.852 + Km*Qi^2 - Z/Qi

	Qi	Hi	Gi
1	1.7064	9.051	9.823
2	1.2408	-8.4	69.081
3	0.2997	7.921	48.947
4	0.4067	14.405	65.602
5	0.4656	0.653	2.599
6	0.0589	0.128	4.021
7	0.1064	2.667	47.454

sum Gi*Qi = sum (Gi*Qi - Hi) + dE

	Pipe No. and Sign	Gi		Qi		Gi*Qi	Hi	dE
Loop 1	2+	69.081	*	1.241	=	85.714	8.415	
	6+	4.021	*	0.059	=	0.237	-0.128	0
	5-	2.599	*	0.466	=	-1.210	0.653	
						84.7409	8.94027	
	sum Gi*Qi = sum (Gi*Qi - Hi) + dE =							93.6812
Loop 2	6-	4.021	*	0.059	=	-0.237	0.128	
	3+	48.947	*	0.300	=	14.669	-7.921	0
	4-	65.602	*	0.407	=	-26.678	14.405	
						-12.246	6.612	
	sum Gi*Qi = sum (Gi*Qi - Hi) + dE =							-5.634

Table 4-7. Continued.

PATH AB	1+	9.823	*	1.706	=	16.762	-9.051	
	2+	69.081	*	1.241	=	85.714	8.41	25.38
	3+	48.947	*	0.300	=	14.669	-7.921	
	7+	47.454	*	0.106	=	5.047	-2.67	
						----------	----------	
						122.191	-11.223	

sum Gi*Qi = sum (Gi*Qi - Hi) + dE = 136.348

	LHS Q1	Q2	Q3	Q4	Q5	Q6	Q7	RHS
PATH AB	9.82	69.08	48.95	0.00	0.00	0.00	47.45	136.35
LOOP 1	0.00	69.08	0.00	0.00	-2.60	4.02	0.00	93.68
LOOP 2	0.00	0.00	48.95	-65.60	0.00	-4.02	0.00	-5.63
JUNC 1	-1.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00
JUNC 2	0.00	-1.00	1.00	0.00	0.00	1.00	0.00	-1.00
JUNC 3	0.00	0.00	-1.00	-1.00	0.00	0.00	1.00	-0.60
JUNC 4	0.00	0.00	0.00	1.00	-1.00	-1.00	0.00	0.00

LHS^-1

								RHS
0.01	-0.01	-0.01	-0.89	-0.84	-0.53	-0.86		136.35
0.00	0.01	0.00	0.01	-0.08	-0.03	-0.03		93.68
0.01	-0.01	0.01	0.06	0.12	-0.30	0.08		-5.63
0.01	-0.01	-0.01	0.05	0.04	-0.24	0.06	*	0.00
0.01	-0.02	-0.01	0.10	-0.76	-0.50	-0.84		-1.00
-0.01	0.02	-0.01	-0.05	0.80	0.26	-0.10		-0.60
0.01	-0.01	-0.01	0.11	0.16	0.47	0.14		0.00

Table 4-7. Continued.

				Q
			1.7358	1
			1.3700	2
			0.3721	3
=	new Q values	=	0.3637	4
			0.3658	5
			-0.0021	6
			0.1358	7

LHS		RHS
136.35		136.35
93.68		93.68
-5.63		-5.63
0.00	=	0.00
-1.00		-1.00
-0.60		-0.60
0.00		0.00

Table 4-8. Fourth Iteration of Linear Method.

Qi is based on a velocity of 1 ft/sec, Q=V*A, V=1 therefore Q=A
Gi = 1.852*Kp^.852 + 2*Km*Qi + Z/Qi^2
Hi = Kp*Qi^1.852 + Km*Qi^2 - Z/Qi

	Qi	Hi	Gi
1	1.7358	9.342	9.967
2	1.3700	0.4	67.499
3	0.3721	11.827	58.861
4	0.3637	11.711	59.642
5	0.3658	0.418	2.116
6	0.0021	0.000	0.238
7	0.1358	4.234	59.052

sum Gi*Qi = sum (Gi*Qi - Hi) + dE

	Pipe No. and Sign	Gi		Qi		Gi*Qi	Hi	dE
Loop 1	2+	67.499	*	1.370	=	92.473	-0.393	
	6+	0.238	*	0.002	=	0.001	0.000	0
	5-	2.116	*	0.366	=	-0.774	0.418	
						91.6990	0.02421	

sum Gi*Qi = sum (Gi*Qi - Hi) + dE = 91.7232

Table 4-8. Continued.

Loop 2	6-	0.238	*	0.002	=	-0.001	0.000	
	3+	58.861	*	0.372	=	21.903	-11.827	0
	4-	59.642	*	0.364	=	-21.689	11.711	
						----------	----------	
						0.213	-0.115	

sum Gi*Qi = sum (Gi*Qi - Hi) + dE = 0.098

PATH AB	1+	9.967	*	1.736	=	17.301	-9.342	
	2+	67.499	*	1.370	=	92.473	-0.39	25.38
	3+	58.861	*	0.372	=	21.903	-11.827	
	7+	59.052	*	0.136	=	8.018	-4.23	
						----------	----------	
						139.694	-25.796	

sum Gi*Qi = sum (Gi*Qi - Hi) + dE = 139.278

				LHS				
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	RHS
PATH AB	9.97	67.50	58.86	0.00	0.00	0.00	59.05	139.28
LOOP 1	0.00	67.50	0.00	0.00	-2.12	0.24	0.00	91.72
LOOP 2	0.00	0.00	58.86	-59.64	0.00	-0.24	0.00	0.10
JUNC 1	-1.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00
JUNC 2	0.00	-1.00	1.00	0.00	0.00	1.00	0.00	-1.00
JUNC 3	0.00	0.00	-1.00	-1.00	0.00	0.00	1.00	-0.60
JUNC 4	0.00	0.00	0.00	1.00	-1.00	-1.00	0.00	0.00

Table 4-8. Continued.

			LHS^-1					RHS
0.01	-0.01	0.00	-0.90	-0.88	-0.59	-0.88		139.28
0.00	0.01	0.00	0.00	-0.03	-0.02	-0.03		91.72
0.00	0.00	0.01	0.05	0.06	-0.29	0.06		0.10
0.00	0.00	-0.01	0.05	0.06	-0.29	0.06	*	0.00
0.01	-0.02	0.00	0.10	-0.85	-0.57	-0.85		-1.00
0.00	0.02	-0.01	-0.05	0.91	0.28	-0.09		-0.60
0.01	-0.01	0.00	0.10	0.12	0.41	0.12		0.00

				Q
			1.7320	1
			1.3702	2
			0.3692	3
=	new Q values	=	0.3627	4
			0.3618	5
			0.0010	6
			0.1320	7

LHS		RHS
139.28		139.28
91.72		91.72
0.10		0.10
0.00	=	0.00
-1.00		-1.00
-0.60		-0.60
0.00		0.00

Table 4-9. Fifth and Final Iteration of Linear Method.

Qi is based on a velocity of 1 ft/sec, Q=V*A, V=1 therefore Q=A
Gi = 1.852*Kp^.852 + 2*Km*Qi + Z/Qi^2
Hi = Kp*Qi^1.852 + Km*Qi^2 - Z/Qi

	Qi	Hi	Gi
1	1.7320	9.304	9.949
2	1.3702	0.4	67.497
3	0.3692	11.657	58.471
4	0.3627	11.657	59.514
5	0.3618	0.409	2.096
6	0.0010	0.000	0.123
7	0.1320	4.013	57.569

sum Gi*Qi = sum (Gi*Qi - Hi) + dE

	Pipe No. and Sign	Gi		Qi		Gi*Qi	Hi	dE
Loop 1	2+	67.497	*	1.370	=	92.486	-0.409	
	6+	0.123	*	0.001	=	0.000	0.000	0
	5-	2.096	*	0.362	=	-0.758	0.409	
						91.7281	-0.0000	

sum Gi*Qi = sum (Gi*Qi - Hi) + dE = 91.7280

Table 4-9. Continued.

Loop 2	6-	0.123	*	0.001	=	0.000	0.000	
	3+	58.471	*	0.369	=	21.589	-11.657	0
	4-	59.514	*	0.363	=	-21.589	11.657	
						----------	----------	
						0.001	0.000	

sum Gi*Qi = sum (Gi*Qi - Hi) + dE = 0.000

PATH AB	1+	9.949	*	1.732	=	17.231	-9.304	
	2+	67.497	*	1.370	=	92.486	-0.41	25.38
	3+	58.471	*	0.369	=	21.589	-11.657	
	7+	57.569	*	0.132	=	7.598	-4.01	
						----------	----------	
						138.904	-25.383	

sum Gi*Qi = sum (Gi*Qi - Hi) + dE = 138.900

				LHS				
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	RHS
PATH AB	9.95	67.50	58.47	0.00	0.00	0.00	57.57	138.90
LOOP 1	0.00	67.50	0.00	0.00	-2.10	0.12	0.00	91.73
LOOP 2	0.00	0.00	58.47	-59.51	0.00	-0.12	0.00	0.00
JUNC 1	-1.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00
JUNC 2	0.00	-1.00	1.00	0.00	0.00	1.00	0.00	-1.00
JUNC 3	0.00	0.00	-1.00	-1.00	0.00	0.00	1.00	-0.60
JUNC 4	0.00	0.00	0.00	1.00	-1.00	-1.00	0.00	0.00

Table 4-9. Continued.

LHS^-1

								RHS
0.01	-0.01	-0.01	-0.90	-0.88	-0.58	-0.88		138.90
0.00	0.01	0.00	0.00	-0.03	-0.02	-0.03		91.73
0.01	0.00	0.01	0.05	0.06	-0.29	0.06		0.00
0.01	0.00	-0.01	0.05	0.06	-0.29	0.06	*	0.00
0.01	-0.02	0.00	0.10	-0.85	-0.56	-0.85		-1.00
0.00	0.02	-0.01	-0.05	0.91	0.27	-0.09		-0.60
0.01	-0.01	-0.01	0.10	0.12	0.42	0.12		0.00

				Q
			1.7319	1
			1.3702	2
			0.3692	3
=	new Q values	=	0.3627	4
			0.3617	5
			0.0010	6
			0.1319	7

LHS		RHS
138.90		138.90
91.73		91.73
0.00		0.00
0.00	=	0.00
-1.00		-1.00
-0.60		-0.60
0.00		0.00

Table 4-10. Wood's Model Solution to Pipe Network in Figure 4-1.

FLOWRATE IS EXPRESSED IN CFS AND PRESSURE IN PSIG

A SUMMARY OF THE ORIGINAL DATA FOLLOWS

PIPE NO.	NODE NOS.		LENGTH (FEET)	DIAMETER (INCHES)	ROUGHNESS	MINOR LOSS K	FIXED GRADE
1	0	1	200.0	6.0	130.0	.00	215.38
2	1	2	150.0	4.0	130.0	.00	
THERE IS A PUMP IN LINE 2 WITH USEFUL POWER = 5.00							
3	2	3	150.0	3.0	130.0	.00	
4	4	3	155.0	3.0	130.0	.00	
5	1	4	160.0	6.0	130.0	.00	
6	2	4	200.0	4.0	130.0	.00	
7	3	0	250.0	3.0	130.0	10.00	190.00

JUNCTION NUMBER	DEMAND	ELEVATION	CONNECTING PIPES		
1	.00	90.00	1	2	5
2	1.00	100.00	2	3	6
3	.60	90.00	3	4	7
4	.00	80.00	4	5	6

OUTPUT SELECTION: ALL RESULTS ARE OUTPUT EACH PERIOD

THIS SYSTEM HAS 7 PIPES WITH 4 JUNCTIONS , 2 LOOPS AND 2 FGNS

THE RESULTS ARE OBTAINED AFTER 5 TRIALS WITH AN ACCURACY = .00062

FILL THIS SECTION |
WITH ANY INPUT YOU DESIRE |
TO DESCRIBE YOUR HYDRAULIC NETWORK PROGRAM |

Table 4-10. Continued.

PIPE NO.	NODE NOS.		FLOWRATE	HEAD LOSS	PUMP HEAD	MINOR LOSS	VELOCITY	HL/1000
1	0	1	1.73	9.30	.00	.00	8.82	46.52
2	1	2	1.37	32.57	32.16	.00	15.70	217.15
3	2	3	.37	11.66	.00	.00	7.52	77.71
4	4	3	.36	11.66	.00	.00	7.39	75.20
5	1	4	.36	.41	.00	.00	1.84	2.56
6	2	4	.00	.00	.00	.00	.01	.00
7	3	0	.13	2.89	.00	1.12	2.69	11.56

JUNCTION NUMBER	DEMAND	GRADE LINE	ELEVATION	PRESSURE
1	.00	206.08	90.00	50.30
2	1.00	205.67	100.00	45.79
3	.60	194.01	90.00	45.07
4	.00	205.67	80.00	54.46

THE NET SYSTEM DEMAND = 1.60

SUMMARY OF INFLOWS(+) AND OUTFLOWS(-) FROM FIXED GRADE NODES

PIPE NUMBER	FLOWRATE
1	1.73
7	-.13

THE NET FLOW INTO THE SYSTEM FROM FIXED GRADE NODES = 1.73
THE NET FLOW OUT OF THE SYSTEM INTO FIXED GRADE NODES = -.13

file from Wood's program for the same network showing the solution of the same flow rate for each pipe. The solutions are the same.

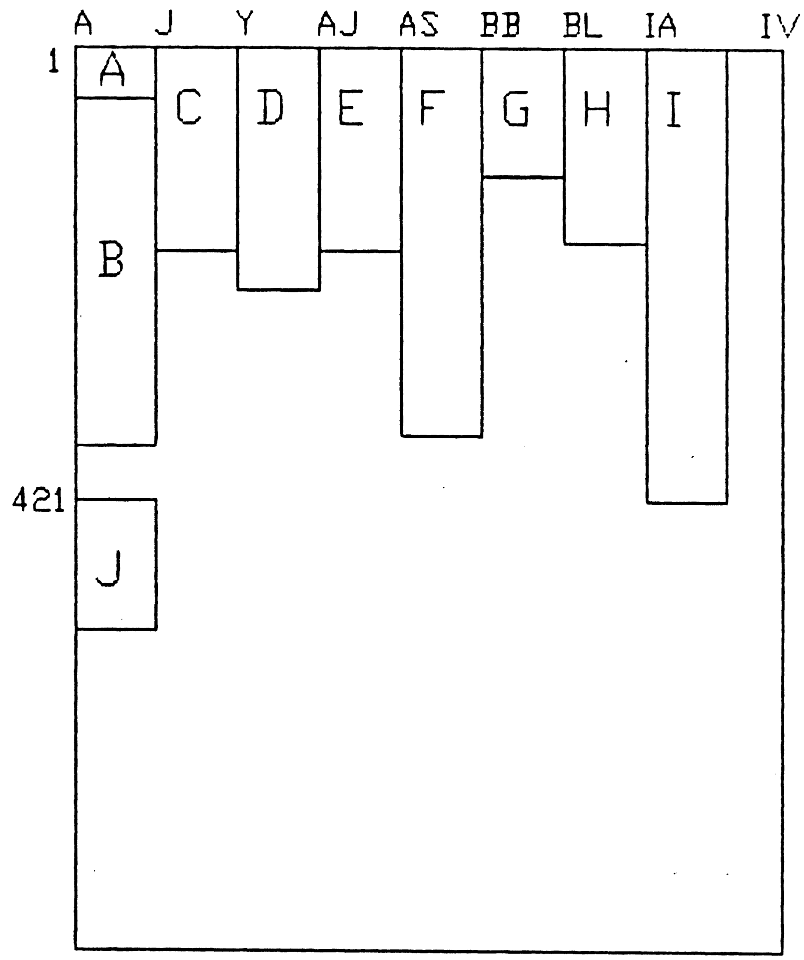
Additional Features in Wood's Model

The program features an extended period simulation. A steady state analysis is carried out as outlined above for a specific set of conditions and time periods. The computed flows into and out of the storage tanks are then used to project the change in tank water levels over the next time interval. A new steady state solution is then carried out with the new water levels.

Analysis of a surcharged storm sewer systems is possible with the program. In one application the flooded inlets to the storm sewer system are modeled as storage tanks. The amount of water entering the inlet detention tank can be determined from the runoff hydrograph. The program determines how high the water rises at the inlet detention basins and how the sewer system will handle the flow. The program runs until the inlet pools have emptied. In a second application, the program can determine the height to which water will rise in manholes, when the manholes are input as junction nodes.

Lotus 123 Preprocessor

The Lotus 123 spreadsheet which contains Wood's Hydraulic Network preprocessor is listed as file 123WOODS.WK1. Figure 4-2 shows how the program is laid out



A - INTRODUCTORY MESSAGE
B - SECTIONS
C - MACRO
D - LOG GRAPH
E - FLOC PROCESS
F - RAPID MIXING PROCESS
G - DATA TABLES
H - CONTAMINANT SECTION
I - OUTPUT AREA
J - PROCESS SORTING AREA

Figure 4-2. Spreadsheet Diagram of Wood's Model Preprocessor within the spreadsheet. A separate area within the spreadsheet contains the input sections, help messages, cards, macros and menus, diskette messages, and two areas for manipulation of the cards.

At this time the preprocessor will accept a network containing up to 100 pipes, 100 junction nodes, 100 pumps, and 32 pressure regulating valves. The program can be easily expanded to 1000 pipes, 1000 junction nodes, and 1000 pumps which are the maximum inputs for Wood's program.

Menu

The Lotus 123 preprocessor spreadsheet is menu driven. Pressing the alt and M keys at the same time will activate the menu at the top of the screen. The first command listed is SECTIONS. If return is pressed while SECTIONS is highlighted a new menu will appear listing each section. Pressing return at a particular highlighted section will cause that section to appear on the screen.

The sections are where data are input. Blank forms are provided with Wood's program for collecting input data. The sections within the spreadsheet are designed to look as much like these forms as possible. This is done so that persons already using Wood's program would be familiar with the sections in the Lotus 123 preprocessor. Appendix G includes a copy of each section where data can be input.

Spreadsheet Protection

The spreadsheet is protected so that data can only be entered within the proper cells in each section. This is achieved using the Lotus 123 spreadsheet, global, protection, and enable commands. Only those cells where data are to be input are unprotected using the range and unprotect commands. Cells where data are to be input are defined by brackets or by columns. The cursor must be moved so that it is located between the brackets or within the column designated to enter data. Question marks are located within cells where data must be entered or Wood's program will not run due to insufficient data.

Error and Help Messages

Error and help messages are included at the data entry locations. If a number is entered that is not within the range of acceptable values the word ERROR will appear next to the data entry point. This is achieved using the Lotus 123 @if function to check the data being entered. For further assistance, a help menu is provided. Next to each data entry location there is an alpha-numeric in the form H1, H2, H3 . . . . H31. This alpha-numeric can be used in conjunction with the help menu for additional explanation and guidance. Pressing the alt and M keys to access the main menu. Then move the cursor to highlight the word HELP and press return to produce the help menu.

Help Menu

The help menu lists the section name. The section name may be further divided by the help number if there are more than eight help alpha-numerics within that section (a user written menu in Lotus 123 can only contain up to eight commands). Highlighting a specific section within the help menu produces a menu of all the help numbers located within that section. Then, highlighting a particular help number provides the desired help message. Appendix H lists the help messages. Pressing the return key after reading the help message returns the user to the proper data input section.

Additional Program Features

Actually, two files are required for the preprocessor to work. The second file is listed as BLANK.WK1. This file contains the card section. The card section is only combined into the 123WOODS.WK1 spreadsheet for preprocessing purposes after all input data are entered. The card section is removed for a very good reason; to speed up the time required to recalculate the spreadsheet after each input is made. Recalculation of the spreadsheet is desired so that error messages can appear as data are entered.

Since the BLANK.WK1 file is combined into the 123WOODS.WK1 file the diskette cannot be write-protected. To protect the diskette containing the 123WOODS.WK1 spreadsheet as much as possible, diskette messages are included. If followed, these messages will ensure that the diskette containing the two preprocessing files is removed and replaced with the user's diskette prior to saving any data.

A copy of the data which has been entered can be saved at any time using the COPY command within the main menu. The saved data file can then be input back into the preprocessor at a future time so that more data can be entered or changed. The command within the main menu which combines the saved file into the preprocessor is CHANGES.

Once the input of all data is completed, the user can instruct the preprocessor to manipulate the data into a form which will be accepted by Wood's program. The COMPILE command within the main menu is used for this purpose. The input data are moved to the respective card sections. In each card section the data are placed in the proper format and in the proper location (Appendix I). Each piece of data is formatted to the required number of decimal places and the decimal point is located at the exact location required in that row. This system is exactly that which was required when cards were keypunched so that data could be input into the computer. Data are formatted and the location set by using the Lotus 123 range, format, fixed and spreadsheet, column, set commands.

Each card section is then formatted into a print file, using the printer and file commands. This is done to maintain the different data format and location integrity for each card. The print files are then imported back into the preprocessor where the cards are manipulated into the proper order. Finally, a completed print file is produced which is in the proper format to be accepted by Wood's program and the preprocessing program is terminated. Table 4-11 contains data for the network in Figure 4-1 which have been preprocessed by Lotus 123. It is important to remember that the completed file is in the format, filename.PRN because it is a print file. Saving the file as filename.WK1 creates a file which will not be recognized by Wood's program.

Macro

The menu system and all of the commands within the menu are accomplished with one macro which is initiated by pressing the alt and M keys. A copy of the macro which includes two subroutines and nine separate menus is listed in Appendix J. Some of the macro is hidden due to overlapping cells. The entire macro can be viewed on the monitor screen by placing the cursor on each hidden cell to view the cell contents. The macro initially introduces the main menu. Subsequent menu selections either introduce sub menus or a completion of the macro.

All of the available options within the system data section are functional. These various input options are fully explained within the help menu. The output option data section is not functional. The output data section is used to limit the amount of output data. Since the post-processor is written to accept all output data from Wood's program the output section is disregarded. Also, the

```
0   0    7    4    0    0    0    0    0  0.000000  0.00000 0.00000000
FILL THIS SECTION                                                          |
WITH ANY INPUT YOU DESIRE                                                  |
TO DESCRIBE YOUR HYDRAULIC NETWORK PROGRAM                                 |
0   0    1   200.00       6.00    130.00      0.00      0.00    215.38
0   1    2   150.00       4.00    130.00      0.00      5.00      0.00
0   2    3   150.00       3.00    130.00      0.00      0.00      0.00
0   4    3   155.00       3.00    130.00      0.00      0.00      0.00
0   1    4   160.00       6.00    130.00      0.00      0.00      0.00
0   2    4   200.00       4.00    130.00      0.00      0.00      0.00
0   3    0   250.00       3.00    130.00     10.00      0.00    190.00
      0.00      90.00    1    0    0    0    0    0    0    0    0    0
      1.00     100.00    2    0    0    0    0    0    0    0    0    0
      0.60      90.00    3    0    0    0    0    0    0    0    0    0
      0.00      80.00    4    0    0    0    0    0    0    0    0    0
 0
    0    0    0    0    0    0
  -2.000
      3      2    3      150.0    3.0      130.0         .00
      4      4    3      155.0    3.0      130.0         .00
      5      1    4      160.0    6.0      130.0         .00
      6      4    2      200.0    4.0      130.0         .00
      7      3    0      250.0    3.0      130.0       10.00        190.
```

Table 4-11. Preprocessed Input Data Ready for Wood's Model.

extended period simulation is not included in the preprocessor at this time.

Lotus 123 Postprocessor

The postprocessor is a much simpler program than the preprocessor. The spreadsheet layout is demonstrated in Figure 4-3. The postprocessor accepts the output data file from Wood's program as an import file into Lotus 123, and separates the data under proper headings.

As mentioned earlier, the data introduced to Wood's program are in the format of a print file, filename.PRN. When Wood's program is executed, by typing KYPIPEF, the program asks the user to identify the input file. The input file name is of the format filename.PRN. Wood's program also asks the user to name the output file. It is important to name the output file name with the same .PRN suffix. Since the postprocessor is importing a file produced from another program the file must be in the form filename.PRN to be listed in the postprocessor for import.

Menu

The postprocessor file name is WOODS123.WK1. The program is menu driven. The menu is accessed by pressing the alt and M keys at the same time. There are four options. The IMPORT command is used to import the output file from Wood's program and manipulate the file into a workable Lotus 123 spreadsheet. The COPY command creates

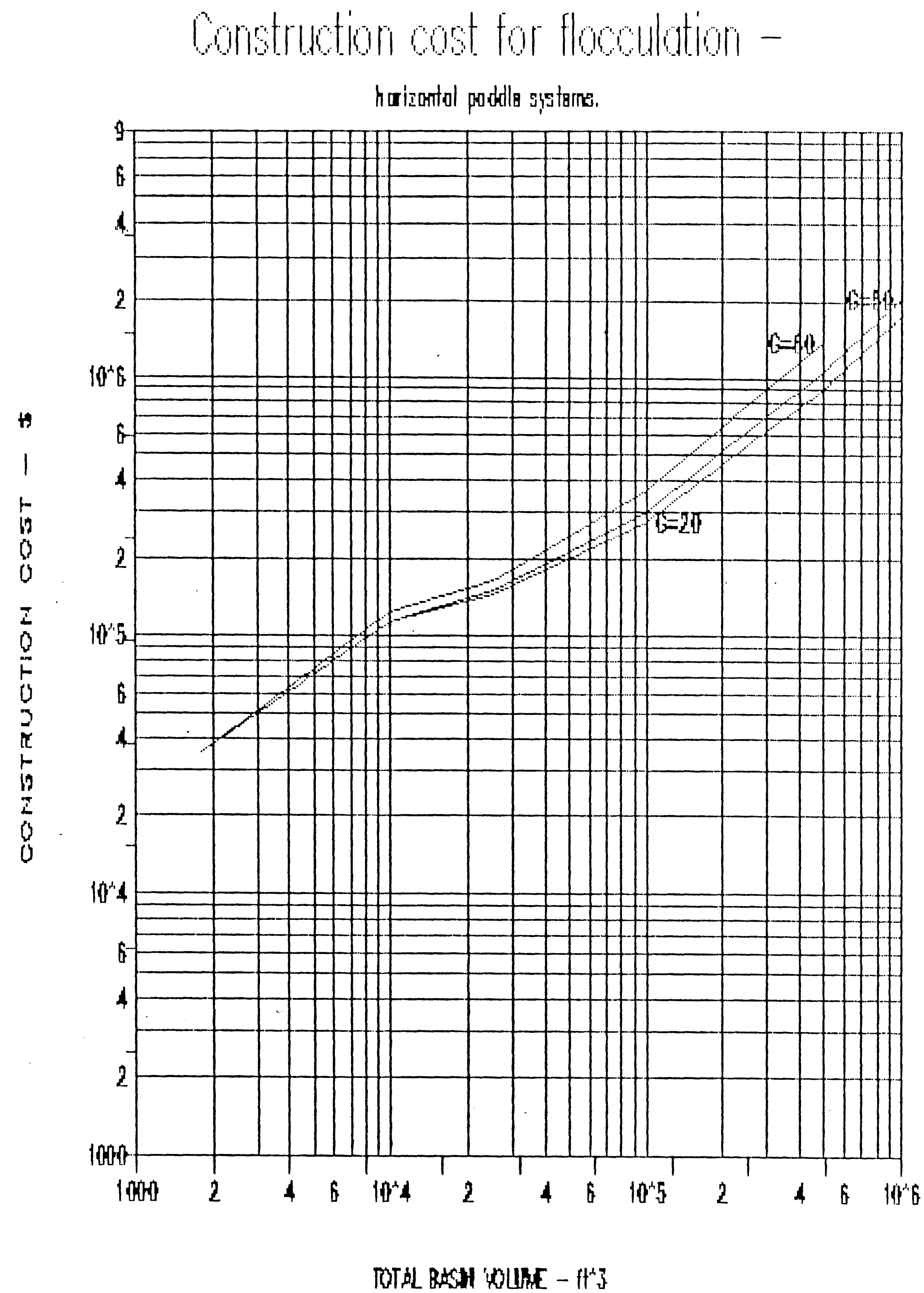


Figure 4-3. Spreadsheet Diagram of Wood's Model Postprocessor

a saved file of the spreadsheet. The HELP command returns to the introductory message and the QUIT command terminates the program.

Additional Features

The postprocessor diskette can be write-protected. The user is directed to remove the diskette after the program file is retrieved. The macro (Appendix J) involves one menu, with the IMPORT command being the only command which involves a macro continuation of more than one line. Again, some of the macro is hidden due to cell overlap.

Table 4-12 shows a copy of the postprocessed output data, seen earlier in Table 4-10, for the hydraulic pipe network shown in Figure 4-1. The data in Table 4-10 were imported into Lotus 123 using the file, import, and text commands. Table 4-10 is Wood's output file. The data in this file cannot be effectively manipulated using further Lotus 123 commands and functions. Using the postprocessor, the output file from Wood's program is imported using the file, import, and numbers command. The numbers are then placed under the proper headings so that the output data can be recognized. The data are now in a usable format so that they can be manipulated by Lotus commands and functions, especially the data management commands.

The Lotus 123 data management commands can be very useful in identifying pipes with certain characteristics. For example, pipes which have pressures, flows, head loss, or velocities above or below a critical value of interest to

Table 4-14. Postprocessed Output Data From Wood's Model.

PIPE NUMBER	NODE	NUMBER	FLOW RATE	HEAD LOSS	PUMP HEAD	MINOR LOSS	VELOCITY	HL/1000
1	0	1	1.73	9.3	0	0	8.82	46.52
2	1	2	1.37	32.57	32.16	0	15.7	217.15
3	2	3	0.37	11.66	0	0	7.52	77.71
4	4	3	0.36	11.66	0	0	7.39	75.2
5	1	4	0.36	0.41	0	0	1.84	2.56
6	2	4	0	0	0	0	0.01	0
7	3	0	0.13	2.89	0	1.12	2.69	11.56

JUNCTION NUMBER	DEMAND	GRADE LINE	ELE-VATION	PRESSURE
1	0	206.08	90	50.3
2	1	205.67	100	45.79
3	0.6	194.01	90	45.07
4	0	205.67	80	54.46

THE NET SYSTEM DEMAND = 1.6

SUMMARY OF INFLOWS(+) AND OUTFLOWS(-) FROM FIXED GRADE NODES

PIPE NUMBER	FLOW RATE
1	1.73
7	-0.13

THE NET FLOW INTO THE SYSTEM FROM FIXED GRADE NODES = 1.73
THE NET FLOW OUT OF THE SYSTEM INTO FIXED GRADE NODES = -0.13

the user could be separately identified. Macros can be easily written to automate this process.

Conclusions

The Lotus 123 preprocessor for use with the Computer Analysis of Flow in Pipe Networks model is an effective tool. The preprocessor eliminates the two major problems associated with the data input program within Wood's model. The preprocessor allows the user to partially input data, save the file, and return at a later time to continue data entry. This is especially valuable when large pipe networks are being entered for use in Wood's model.

Secondly, entering data in the preprocessor is quicker than using Wood's input program. Data for the Kanapaha force main network in Gainesville, Florida which contains 54 pipes, 45 nodes, and 13 pumps took one and a half hours to enter using Wood's input program and 30 minutes to enter using the preprocessor. Compiling the input data in Wood's input program is quicker. It takes Wood's program about a minute versus up to eight minutes to preprocess the input data in the preprocessor. But the overall time spent in completing a file ready for use with Wood's model is still much shorter using the Lotus 123 preprocessor.

The Lotus 123 preprocessor has a very definite advantage in that the help system is included within the preprocessing program. For an individual using Wood's model for the first time, the preprocessor provides quick help as opposed to having to search through the user's manual provided with Wood's model.

The Lotus 123 postprocessor is very quick, taking less than two minutes to format the output data from Wood's model. Upon completion, the output data are in a form ready to be further processed using the Lotus 123 data management commands.

Most of the time spent using hydraulic network analysis models is in the formulation of data for input into the model and evaluation of the output data. Lotus 123 can be effective in streamlining these processes.

CHAPTER V
OPTIMAL ADJUSTMENTS IN ERRONEOUS HYDRAULIC NETWORK FLOWS

Introduction

When modeling a hydraulic flow network it is imperative that the actual quantity of flow in each pipe be known. The required result is that the sum of the inflows to any node equals the sum of the outflows from that node. Thus conservation of mass is upheld when the following condition is met at each node:

$$\text{Inputs} - \text{Outputs} = 0 \tag{5.1}$$

The measurement of flow taken within a pipe may contain a random or even a gross error due to the inadequacies of the instrument and techniques used to measure the flow. Random errors are unassociated with those measurements which do not equal the true value of the flow but are within the error of the instrument used to measure the flow. Gross errors are associated with those measurements well outside the instrument's normal standard deviation.

Errors may not be detected while flow measurements are being taken. Flow measurements must be taken during as static a time period as possible. Pipe flow measurements are usually taken at night when flow values are at their minimum. All measurements must be taken quickly during as short a time interval as possible.

Once the flow data are collected, and if errors are detected, a determination must be made to either remeasure the pipe flows or to artificially balance the hydraulic pipe network. Several methods can be used to balance the flows within a hydraulic network.

Much research has been accomplished within the chemical engineering field concerning the balancing of erroneous flows within industrial process plants and will be reviewed later. Flow measurements are received via telemetered data readings. These readings are then used within computer programs that regulate the operation and efficiency of the process plant. Erroneous data in this type of computerized operation can lead to inefficient plant operation and scrapping of the computerized monitoring system.

Least Errors Squared Network Optimization

The majority of existing computer programs are written with a subroutine to balance the faulty network. A consistent mass balance of the data is achieved by means of a constrained linear least errors squared procedure. In mathematical form the problem is to minimize the sum of the normalized errors squared:

$$\min \phi(X_i) = \Sigma_i (1/\sigma_i^2)(X_i - X_i^*)^2 \qquad (5.2)$$

subject to the constraints imposed by j linear nodal balance equations of the form:

$$\tau_j(X_i) = \Sigma_i a_{ij} X_i = 0 \qquad (5.3)$$

where

X_i = the ith corrected measurement,

X_i^* = the ith observed measurement,

σ_i^2 = the error variance of the ith measurement,

τ_j = the balance constraint for the jth node, and

a_{ij} = the coefficient of X_i in the jth balance equation (+1 for an input flow and -1 for an output flow).

To determine the X_i values for his nonlinear objective function the method of Lagrange multipliers (Heenan and Serth, 1986) is used to form the following set of simultaneous equations:

$$d/dX_i[\phi(X_i) + {}_j r_j \ {}_j(X_i)] = 0 \text{ and} \qquad (5.4)$$

$$d/dr_j[\phi(X_i) + {}_j r_j \ {}_j(X_i)] = {}_j(X_i) = 0 \qquad (5.5)$$

which can then be solved.

Optimization of the Network Using Lotus 123

Figure 5-1 depicts a steam system for a methanol plant (Heenan and Serth, 1986). The network involves 10 nodes and 25 streams. All unconnected streams flow into or out of the environment, which could be shown as another node, but for simplicity of the diagram the node is not shown. Table 5-1 gives the stream number, the true or actual stream flow rate, and the observed flow rate. The observed flow rate is the measurement received within the telemetry data and

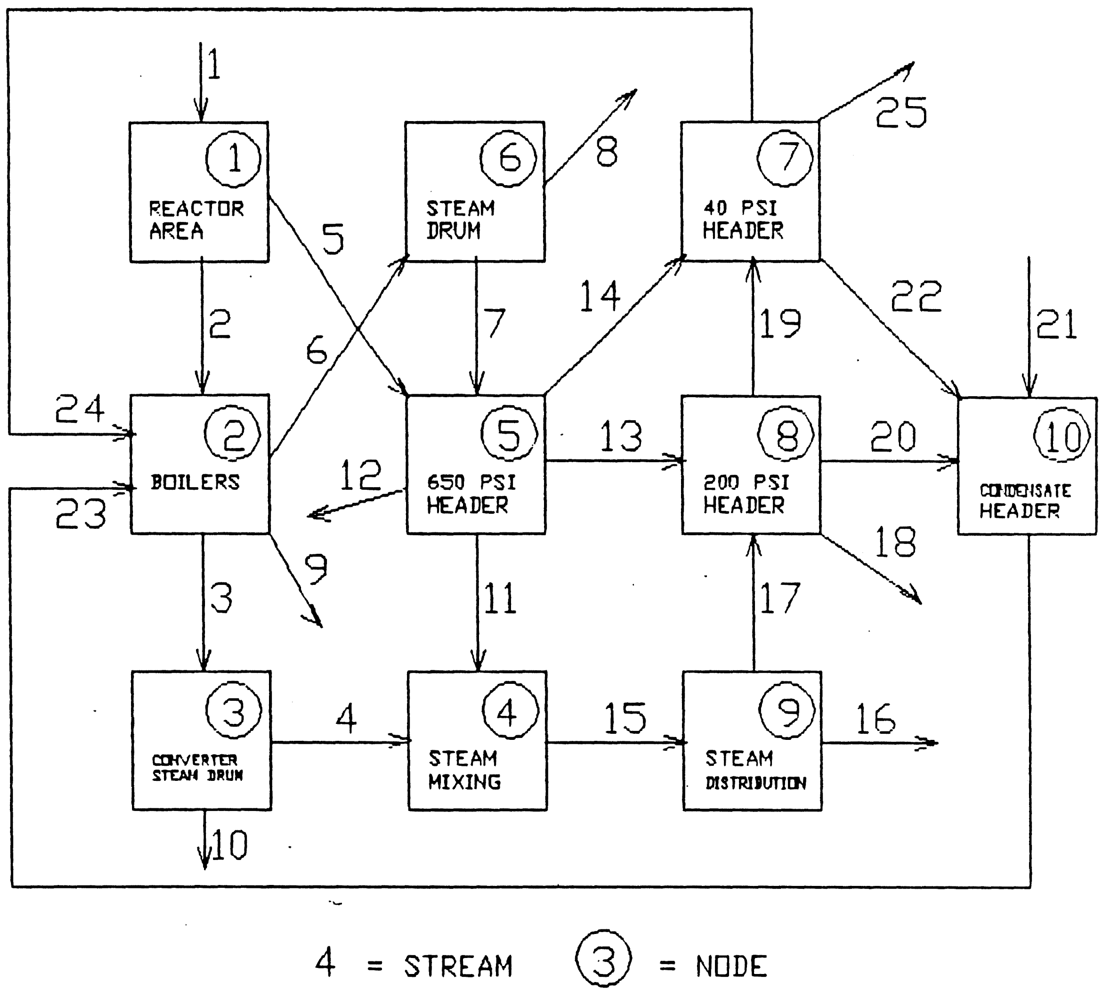


Figure 5-1. Methanol Steam Plant Network

Table 5-1. True and Observed Flow Rate Measurements for Methanol Plant.

Stream	True Flow Rate	Observed Flow Rate
1	296.6	289.94
2	50.6	85.41
3	117.2	113.86
4	115.3	120.81
5	246	241.81
6	244.8	248.39
7	243	245.53
8	1.8	1.79
9	4.7	4.55
10	1.9	1.89
11	84.7	83.09
12	70.2	71.3
13	132	67.9
14	202.1	203.55
15	200	202.19
16	188	90.07
17	12	12.31
18	102.6	104.31
19	35.7	35.52
20	5.7	5.48
21	264.6	274.32
22	37.1	37.49
23	307.4	298.31
24	8.7	8.33
25	192	193.42

subject to the measurement errors of the measuring instrument. Tables 5-2 and 5-3 demonstrate the objective function using equation 5.2, subject to the nodal constraints using equation 5.3.

The Lagrange multipliers are introduced in Table 5-4. The multiplier is indicated by the letter r. To solve this set of nonlinear equations, partial derivatives are taken using equations 4 and 5 as demonstrated in Table 5-5. This set of 36 equations and 36 unknowns can be solved using routine matrix procedures. The matrix is given in Table 5-6.

Lotus 123 simplifies the solution of this matrix through the use of the data, matrix, inversion and data, matrix, multiply commands. The left hand side of the matrix is inverted and then multiplied by the right hand side. The solution is given in Table 5-7. The new reconciled flow rates are given along with the true and observed flow rates. Lotus 123 is also used as a check to ensure that each nodal constraint equation is balanced, i.e., that the sum of the inflows minus the sum of the outflows equals zero.

Network Optimization Using Linear Programming

Two additional strategies for optimally adjusting erroneous hydraulic network flows have been introduced. They are the methods of minimizing the sum of the absolute values of the errors:

$$\text{Min } \sum_i |e_i| \tag{5.6}$$

Table 5-2. Minimizing the Sum of the Normalized Errors Squared.

```
Objective function:   Min   (Xi-Xi*)^2/oi^2   for each i

         Minimize  Z=( X 1 - 289. )^2 /   7.415 ^2 +
                     ( X 2 - 85.4 )^2 /   1.265 ^2 +
                     ( X 3 - 113. )^2 /   2.930 ^2 +
                     ( X 4 - 120. )^2 /   2.883 ^2 +
                     ( X 5 - 241. )^2 /   6.150 ^2 +
                     ( X 6 - 248. )^2 /   6.120 ^2 +
                     ( X 7 - 245. )^2 /   6.075 ^2 +
                     ( X 8 - 1.79 )^2 /   0.045 ^2 +
                     ( X 9 - 4.55 )^2 /   0.118 ^2 +
                     ( X10 - 1.89 )^2 /   0.048 ^2 +
                     ( X11 - 83.0 )^2 /   2.118 ^2 +
                     ( X12 - 71.3 )^2 /   1.755 ^2 +
                     ( X13 - 67.9 )^2 /   3.300 ^2 +
                     ( X14 - 203. )^2 /   5.053 ^2 +
                     ( X15 - 202. )^2 /   5.000 ^2 +
                     ( X16 - 90.0 )^2 /   4.700 ^2 +
                     ( X17 - 12.3 )^2 /   0.300 ^2 +
                     ( X18 - 104. )^2 /   2.565 ^2 +
                     ( X19 - 35.5 )^2 /   0.893 ^2 +
                     ( X20 - 5.48 )^2 /   0.143 ^2 +
                     ( X21 - 274. )^2 /   6.615 ^2 +
                     ( X22 - 37.4 )^2 /   0.928 ^2 +
                     ( X23 - 298. )^2 /   7.685 ^2 +
                     ( X24 - 8.33 )^2 /   0.218 ^2 +
                     ( X25 - 193. )^2 /   4.800 ^2

         subject to:    X1-X2-X5 = 0
                        X2+X23+X24-X3-X6-X9 = 0
                        X3-X4-X10 = 0
                        X4+X11-X15 = 0
                        X5+X7-X11-X12-X13-X14 = 0
                        X6-X7-X8 = 0
                        X14+X19-X22-X24-X25 = 0
                        X13+X17-X18-X19-X20 = 0
                        X15-X16-X17 = 0
                        X20+X21+X22-X23 = 0
                        X8+X9+X10+X12+X16+X18+X25-X1-X21 = 0
```

Table 5-3. Minimizing the Sum of the Normalized Errors Squared.

Minimize Z=

0.02	X 1	^2	-10.55	X 1	+ 1528.95	+
0.62	X 2	^2	-106.75	X 2	+ 4558.65	+
0.12	X 3	^2	-26.53	X 3	+ 1510.10	+
0.12	X 4	^2	-29.08	X 4	+ 1756.58	+
0.03	X 5	^2	-12.79	X 5	+ 1545.96	+
0.03	X 6	^2	-13.26	X 6	+ 1647.27	+
0.03	X 7	^2	-13.31	X 7	+ 1633.49	+
493.83	X 8	^2	-1767.90	X 8	+ 1582.27	+
72.43	X 9	^2	-659.12	X 9	+ 1499.50	+
443.21	X10	^2	-1675.35	X10	+ 1583.20	+
0.22	X11	^2	-37.06	X11	+ 1539.75	+
0.32	X12	^2	-46.30	X12	+ 1650.54	+
0.09	X13	^2	-12.47	X13	+ 423.36	+
0.04	X14	^2	-15.95	X14	+ 1623.04	+
0.04	X15	^2	-16.18	X15	+ 1635.23	+
0.05	X16	^2	-8.15	X16	+ 367.25	+
11.11	X17	^2	-273.56	X17	+ 1683.73	+
0.15	X18	^2	-31.71	X18	+ 1653.78	+
1.26	X19	^2	-89.18	X19	+ 1583.91	+
49.25	X20	^2	-539.74	X20	+ 1478.87	+
0.02	X21	^2	-12.54	X21	+ 1719.71	+
1.16	X22	^2	-87.16	X22	+ 1633.82	+
0.02	X23	^2	-10.10	X23	+ 1506.77	+
21.14	X24	^2	-352.17	X24	+ 1466.80	+
0.04	X25	^2	-16.79	X25	+ 1623.75	

subject to:

X1-X2-X5 = 0
X2+X23+X24-X3-X6-X9 = 0
X3-X4-X10 = 0
X4+X11-X15 = 0
X5+X7-X11-X12-X13-X14 = 0
X6-X7-X8 = 0
X14+X19-X22-X24-X25 = 0
X13+X17-X18-X19-X20 = 0
X15-X16-X17 = 0
X20+X21+X22-X23 = 0
X8+X9+X10+X12+X16+X18+X25-X1-X21 = 0

Table 5-4. Introduction of Lagrange multipliers.

```
   0.02 X 1 ^2    -10.55 X 1  + 1528.95 +
   0.62 X 2 ^2   -106.75 X 2  + 4558.65 +
   0.12 X 3 ^2    -26.53 X 3  + 1510.10 +
   0.12 X 4 ^2    -29.08 X 4  + 1756.58 +
   0.03 X 5 ^2    -12.79 X 5  + 1545.96 +
   0.03 X 6 ^2    -13.26 X 6  + 1647.27 +
   0.03 X 7 ^2    -13.31 X 7  + 1633.49 +
 493.83 X 8 ^2  -1767.90 X 8  + 1582.27 +
  72.43 X 9 ^2   -659.12 X 9  + 1499.50 +
 443.21 X10 ^2  -1675.35 X10  + 1583.20 +
   0.22 X11 ^2    -37.06 X11  + 1539.75 +
   0.32 X12 ^2    -46.30 X12  + 1650.54 +
   0.09 X13 ^2    -12.47 X13  +  423.36 +
   0.04 X14 ^2    -15.95 X14  + 1623.04 +
   0.04 X15 ^2    -16.18 X15  + 1635.23 +
   0.05 X16 ^2     -8.15 X16  +  367.25 +
  11.11 X17 ^2   -273.56 X17  + 1683.73 +
   0.15 X18 ^2    -31.71 X18  + 1653.78 +
   1.26 X19 ^2    -89.18 X19  + 1583.91 +
  49.25 X20 ^2   -539.74 X20  + 1478.87 +
   0.02 X21 ^2    -12.54 X21  + 1719.71 +
   1.16 X22 ^2    -87.16 X22  + 1633.82 +
   0.02 X23 ^2    -10.10 X23  + 1506.77 +
  21.14 X24 ^2   -352.17 X24  + 1466.80 +
   0.04 X25 ^2    -16.79 X25  + 1623.75 +
r1*(X1-X2-X5) +
r2*(X2+X23+X24-X3-X6-X9) +
r3*(X3-X4-X10) +
r4*(X4+X11-X15) +
r5*(X5+X7-X11-X12-X13-X14) +
r6*(X6-X7-X8) +
r7*(X14+X19-X22-X24-X25) +
r8*(X13+X17-X18-X19-X20) +
r9*(X15-X16-X17) +
r10*(X20+X21+X22-X23) +
r11*(X8+X9+X10+X12+X16+X18+X25-X1-X21)
```

Table 5-5. Partial Derivatives.

dL/dX 1	=	0.04	X 1	-10.55	+r1-r11
dL/dX 2	=	1.25	X 2	-106.75	-r1+r2
dL/dX 3	=	0.23	X 3	-26.53	-r2+r3
dL/dX 4	=	0.24	X 4	-29.08	-r3+r4
dL/dX 5	=	0.05	X 5	-12.79	-r1+r5
dL/dX 6	=	0.05	X 6	-13.26	-r2+r6
dL/dX 7	=	0.05	X 7	-13.31	+r5-r6
dL/dX 8	=	987.65	X 8	-1767.90	-r6+r11
dL/dX 9	=	144.86	X 9	-659.12	-r2+r11
dL/dX10	=	886.43	X10	-1675.35	-r3+r11
dL/dX11	=	0.45	X11	-37.06	+r4-r5
dL/dX12	=	0.65	X12	-46.30	-r5+r11
dL/dX13	=	0.18	X13	-12.47	-r5+r8
dL/dX14	=	0.08	X14	-15.95	-r5+r7
dL/dX15	=	0.08	X15	-16.18	-r4+r9
dL/dX16	=	0.09	X16	-8.15	-r9+r11
dL/dX17	=	22.22	X17	-273.56	+r8-r9
dL/dX18	=	0.30	X18	-31.71	-r8+r11
dL/dX19	=	2.51	X19	-89.18	+r7-r8
dL/dX20	=	98.49	X20	-539.74	-r8+r10
dL/dX21	=	0.05	X21	-12.54	+r10-r11
dL/dX22	=	2.32	X22	-87.16	-r7+r10
dL/dX23	=	0.03	X23	-10.10	+r2-r10
dL/dX24	=	42.28	X24	-352.17	+r2-r7
dL/dX25	=	0.09	X25	-16.79	-r7+r11
dL/dr 1	=X1-X2-X5				
dL/dr 2	=X2+X23+X24-X3-X6-X9				
dL/dr 3	=X3-X4-X10				
dL/dr 4	=X4+X11-X15				
dL/dr 5	=X5+X7-X11-X12-X13-X14				
dL/dr 6	=X6-X7-X8				
dL/dr 7	=X14+X19-X22-X24-X25				
dL/dr 8	=X13+X17-X18-X19-X20				
dL/dr 9	=X15-X16-X17				
dL/dr10	=X20+X21+X22-X23				
dL/dr11	=X8+X9+X10+X12+X16+X18+X25-X1-X21				

Table 5-6. Matrix for Solving Simultaneous Equations.

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16	X17	X18	X19	X20	X21	X22	X23	X24	X25	r1	r2	r3	r4	r5	r6	r7	r8	r9	r10	r11		RHS
X1	0.03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	-1	=	10.54668
X2	0	1.24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	1	0	0	0	0	0	0	0	0	0	=	106.7474
X3	0	0	0.23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	1	0	0	0	0	0	0	0	0	=	26.52564
X4	0	0	0	0.24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	1	0	0	0	0	0	0	0	=	29.07998
X5	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	1	0	0	0	0	0	0	=	12.78656
X6	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	1	0	0	0	0	0	=	13.26359
X7	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	0	0	0	0	=	13.30583
X8	0	0	0	0	0	0	0	987.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	1	=	1767.901
X9	0	0	0	0	0	0	0	0	144.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	1	=	659.1217
X10	0	0	0	0	0	0	0	0	0	886.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	1	=	1675.346
X11	0	0	0	0	0	0	0	0	0	0	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	0	0	0	0	0	=	37.06226
X12	0	0	0	0	0	0	0	0	0	0	0	0.64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	1	=	46.29832
X13	0	0	0	0	0	0	0	0	0	0	0	0	0.18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	1	0	0	0	=	12.47015
X14	0	0	0	0	0	0	0	0	0	0	0	0	0	0.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	1	0	0	0	0	=	15.94734
X15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.08	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	1	0	0	=	16.1752
X16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.09	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	1	=	8.154821
X17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	0	=	273.5555
X18	0	0	0	0	0	X0	0	0	0	0	0	0	0	0	0	0	0	0.30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	1	=	31.70890
X19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.51	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	0	0	=	89.18390
X20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	98.4	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	1	0	=	539.7353
XX1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	=	12.53798
X22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.32	0	0	0	0	0	0	0	0	0	-1	0	0	1	0	=	87.16007
X23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0	0	0	1	0	0	0	0	0	0	0	-1	0	=	10.10206
X24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	42.2	0	0	1	0	0	0	0	-1	0		0	0	=	352.1733
X25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.08	0	0	0	0	0	0	-1	0	0	0	1	=	16.78993

Table 5-6. Continued.

r1	1	-1	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	=	0
r2	0	1	-1	0	0	-1	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	=	0
r3	0	0	1	-1	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	=	0
r4	0	0	0	1	0	0	0	0	0	0	1	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	=	0
r5	0	0	0	0	1	0	1	0	0	0	-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	=	0
r6	0	0	0	0	0	1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	=	0
r7	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	-1	0	-1	-1	0	0	0	0	0	0	0	0	0	0	0	=	0
r8	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	=	0
r9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	=	0
r10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	=	0
r11	-1	0	0	0	0	0	0	1	1	1	0	1	0	0	0	1	0	1	0	0	-1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	=	0

Table 5-7. Matrix Solution; Reconciled Flow Rates.

The left hand side of the matrix is inverted and multiplied by the right hand side of the matrix to create the new reconciled flow rates. In addition, the nodal equations are checked for accuracy.

Stream	True Flow Rate	Reconciled Flow Rate	Observed Flow Rate
1	296.6	296.54	289.94
2	50.6	83.43	85.41
3	117.2	111.17	113.86
4	115.3	109.28	120.81
5	246	213.11	241.81
6	244.8	256.77	248.39
7	243	254.98	245.53
8	1.8	1.79	1.79
9	4.7	4.57	4.55
10	1.9	1.89	1.89
11	84.7	73.31	83.09
12	70.2	73.27	71.3
13	132	108.98	67.9
14	202.1	212.54	203.55
15	200	182.59	202.19
16	188	169.67	90.07
17	12	12.92	12.31
18	102.6	83.70	104.31
19	35.7	32.80	35.52
20	5.7	5.40	5.48
21	264.6	238.36	274.32
22	37.1	37.03	37.49
23	307.4	280.79	298.31
24	8.7	8.29	8.33
25	192	200.02	193.42

Node	Equation	Balance
1	X1-X2-X5 =	5.68E-14
2	X2+X23+X24-X3-X6-X9 =	7.99E-14
3	X3-X4-X10 =	3.46E-14
4	X4+X11-X15 =	0
5	X5+X7-X11-X12-X13-X14 =	2.84E-14
6	X6-X7-X8 =	1.82E-14
7	X14+X19-X22-X24-X25 =	-2.66E-14
8	X13+X17-X18-X19-X20 =	-8.88E-15
9	X15-X16-X17 =	2.66E-14
10	X20+X21+X22-X23 =	-2.49E-14
11	X8+X9+X10+X12+X16+X18+X25-X1-X21 =	-1.84E-13

where

$$e_i = X_i - X_i^*$$

and minimizing the maximum error of any stream:

$$\text{Min Max } e_i \qquad (5.7)$$

The above strategies are solved using linear programming procedures (Bradley et al., 1977; Hillier and Lieberman, 1967; Schrage, 1984). At this point a new wastewater distribution network (Figure 5-2) is introduced with a tableau more familiar to linear programming procedures (Table 5-8). Only those flows which connect two nodes exist and are known as arcs. An arc is numbered according to the direction of flow and the nodes which it connects. For example, the arc X2625 indicates the arc is between nodes 26 and 25, and the direction of flow is from node 26 to node 25. The flows into or out of the environment have been removed and their values are now located within the parentheses at their respective nodes. Notice that in the tableau (Table 5-8) the 16 nodes are listed vertically on the left, the arcs are listed horizontally across the top, and the flows entering or leaving the network are listed horizontally with their respective nodes on the right hand side.

There are three types of nodes (Bradley et al., 1977; Hillier and Lieberman, 1967). A source node supplies water to the network. In the network the source nodes are nodes 27, 32, 35, 38, 41, and 43. Sink nodes are those nodes

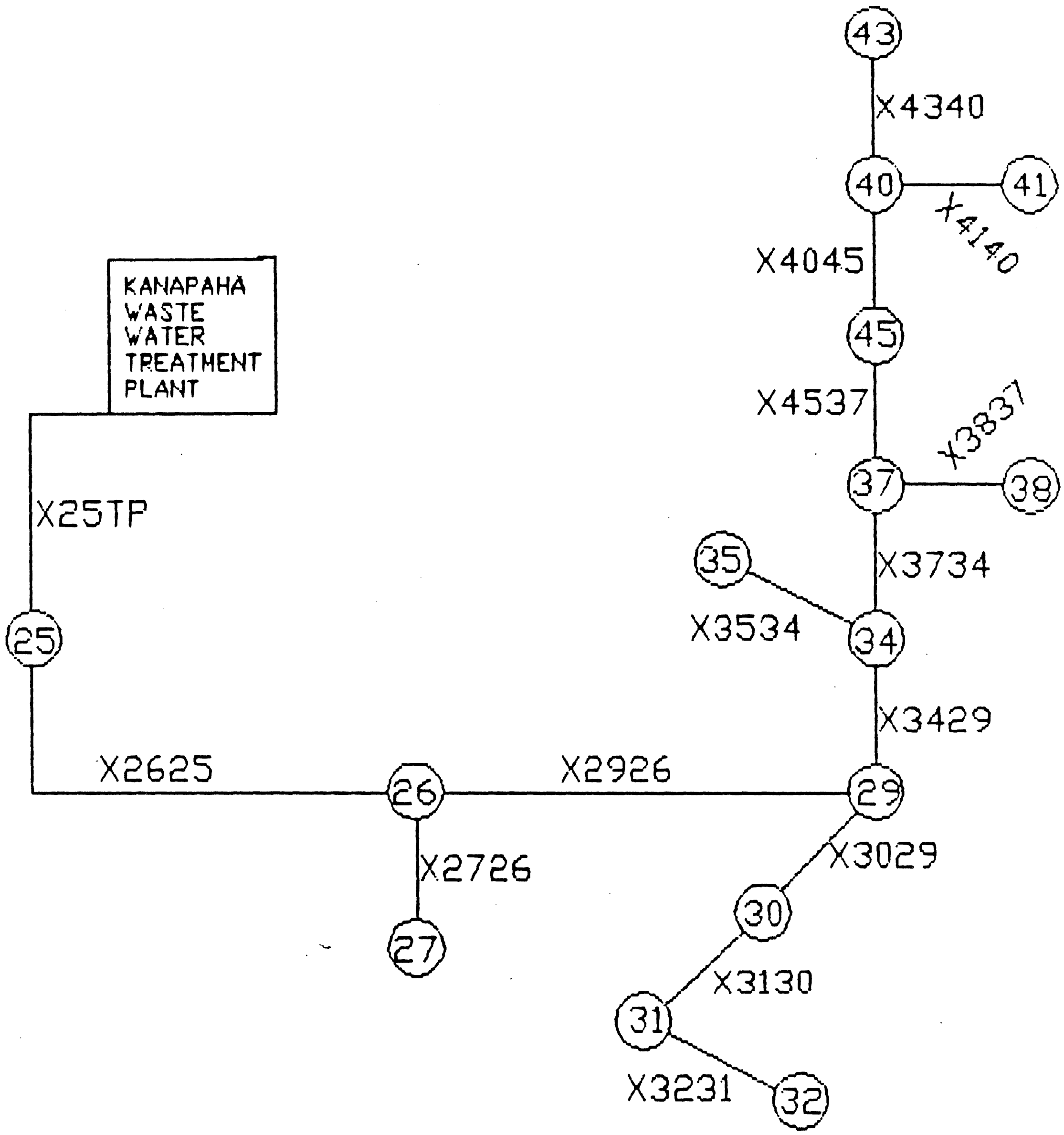


Figure 5-2. Waste Water Collection Network

Table 5-8. Linear Programming Formulation.

	Actual Stream Values															
	1000	1000	300	700	50	50	50	650	150	500	200	300	100	200	300	
Stream	X25TP	X2625	X2726	X2926	X3029	X3130	X3231	X3429	X3534	X3734	X3837	X4045	X4140	X4340	X4537	RHS
Node 25	1	-1														0
Node 26		1	-1	-1												0
Node 27			1													300
Node 29				1	-1			-1								0
Node 30					1	-1										0
Node 31						1	-1									0
Node 32							1									50
Node 34								1	-1	-1						0
Node 35									1							150
Node 37										1	-1				-1	0
Node 38											1					200
Node 40												1	-1	-1		0
Node 41													1			100
Node 43														1		200
Node 45												-1			1	0
Node TP	-1															-1000

where water is in demand. The demand node is the waste water treatment plant node TP. The last type of node is a trans-shipment node where there is no net supply or demand. In this network, nodes 25, 26, 29, 30, 31, 34, 37, 45, and 40 are transshipment nodes.

The 10 equations that are depicted within the tableau are the flow balance equations at each node. Each equation satisfies the conservation of flow law:

(Flow out of node)-(Flow into node)=Net supply (5.8)

Within the tableau, a 1 indicates flow out of a node and a -1 indicates flow into a node. As an example, at node 25, the balance equation is:

$$X25TP - X2625 = 0 \tag{5.9}$$

A positive right hand side indicates that water is supplied to the network at that node. A quick check will verify that each stream is listed in two equations within the tableau, once as an input and once as an output.

Comparison of the Three Network Optimization Strategies

All three optimization strategies: minimizing the sum of the normalized errors squared, minimizing the sum of the absolute value of the errors, and minimizing the maximum error were tested on the waste water treatment network. Each method was tested using five sets of data. The five data sets contain no gross errors (Table 5-9). All errors are random, which is defined as within a standard deviation of 5% of the actual or true stream flow values. Random

Table 5-9. Random Error Test Cases.

Comparison of three optimization strategies on five test cases which include only random errors.

Stream	Actual Flow Rate	Observed Flow Rate Test 1	Test 2	Test 3	Test 4	Test 5
X4340	200	196.25	198.04	201.91	196.77	198.13
X4140	100	99.64	95.7	101.98	100.57	102.35
X4045	300	314.67	286.35	306.09	314.37	313.17
X4537	300	288.48	304.89	308.79	304.1	285.15
X3837	200	199.05	202.39	206.86	196.8	204.55
X3734	500	503.85	482.77	488.44	475.51	512.8
X3534	150	142.63	153.53	154.41	142.74	157.31
X3429	650	674.74	660.51	662.03	648.64	648.59
X3231	50	51.91	48.82	51.87	50.7	49.38
X3130	50	52.12	48.81	47.84	51.38	48.07
X3029	50	51.95	51.58	49.49	50.95	48.91
X2926	700	678.49	724.45	723.01	681.94	684.82
X2726	300	310.06	292.01	286.37	296.17	307.37
X2625	1000	958.2	993.87	973.5	967.38	1046.88
X25TP	1000	980.59	965.12	1000.57	969.43	1024.85

errors are imposed on the actual flow data set using the random number generator in Lotus 123.

Least Errors Squared Analysis

Table 5-10 gives the objective function and constraints for minimizing the sum of the normalized errors squared on the first data set. The method of solution is similar to the methanol network discussed previously. Tables 5-11 and 5-12 display the objective function and constraints, using the strategies of minimizing the sum of the absolute value of the errors and minimizing the maximum error, respectively, on the first data set.

Least Absolute Value Analysis

To solve the problem of minimizing the sum of the absolute value of the errors using linear programming (Table 5-11), the errors, e_i, are defined as $U_i - V_i$. This is required since linear programming is designed for variables constrained to be non negative. The objective function and constraints are defined in the following form (Schrage, 1984):

$$\text{Min } \Sigma_i (U_i + V_i) \quad (5.10)$$

subject to

$$U_i - V_i + X_i = X_i^* \text{ for all } i, \text{ and} \quad (5.11)$$

$$\Sigma_i a_{ij} X_i = 0 \text{ for each node.} \quad (5.12)$$

Equation 5.11 represents the constraint that the error, $U_i - V_i$, plus the corrected or reconciled flow, X_i, equals the

Table 5-10. Minimizing the Sum of the Normalized Errors Squared.

Minimize

$$
\begin{aligned}
Z = {} & (X4340 - 196.25)^2 / 10^2 + \\
& (X4140 - 99.64)^2 / 5^2 + \\
& (X4045 - 314.67)^2 / 15^2 + \\
& (X4537 - 288.48)^2 / 15^2 + \\
& (X3837 - 199.05)^2 / 10^2 + \\
& (X3734 - 503.85)^2 / 25^2 + \\
& (X3534 - 142.63)^2 / 7.5^2 + \\
& (X3429 - 674.74)^2 / 32.5^2 + \\
& (X3231 - 51.91)^2 / 2.5^2 + \\
& (X3130 - 52.12)^2 / 2.5^2 + \\
& (X3029 - 51.95)^2 / 2.5^2 + \\
& (X2926 - 678.49)^2 / 35^2 + \\
& (X2726 - 310.06)^2 / 15^2 + \\
& (X2625 - 958.2)^2 / 50^2 + \\
& (X25TP - 980.59)^2 / 50^2
\end{aligned}
$$

subject to:

$$
\begin{aligned}
& X4340+X4140-X4045 = 0 \\
& X4045-X4537 = 0 \\
& X4537+X3837-X3734 = 0 \\
& X3734+X3534-X3429 = 0 \\
& X3231-X3130 = 0 \\
& X3130-X3029 = 0 \\
& X3429+X3029-X2926 = 0 \\
& X2926+X2726-X2625 = 0 \\
& X2625-X25TP = 0 \\
& X4340+X4140+X3837+X3534+X3231+X2726-X25TP = 0
\end{aligned}
$$

Table 5-11. Minimizing the Sum of the Absolute Values of of the Errors

```
MIN     U1 + V1 + U2 + V2 + U3 + V3 + U4 + V4 + U5 + V5 + U6
+ V6 + U7 + V7 + U8 + V8 + U9 + V9 + U10 + V10 + U11 + V11 +
U12 + V12 + U13 + V13 + U14 + V14 + U15 + V15

SUBJECT TO
          2)   U1 - V1 + X4340 =    196.25
          3)   U2 - V2 + X4140 =     99.64
          4)   U3 - V3 + X4045 =    314.67
          5)   U4 - V4 + X4537 =    288.48
          6)   U5 - V5 + X3837 =    199.05
          7)   U6 - V6 + X3734 =    503.85
          8)   U7 - V7 + X3534 =    142.63
          9)   U8 - V8 + X3429 =    674.74
         10)   U9 - V9 + X3231 =     51.91
         11)   U10 - V10 + X3130 =     52.12
         12)   U11 - V11 + X3029 =     51.95
         13)   U12 - V12 + X2926 =    678.49
         14)   U13 - V13 + X2726 =    310.06
         15)   U14 - V14 + X2625 =    958.2
         16)   U15 - V15 + X25TP =    980.59
         17)   X4340 + X4140 - X4045 =     0
         18)   X4045 - X4537 =    0
         19)   X4537 + X3837 - X3734 =     0
         20)   X3734 + X3534 - X3429 =     0
         21)   X3231 - X3130 =    0
  --More--
          6)   U5 - V5 + X3837 =   199.05
          7)   U6 - V6 + X3734 =   503.85
          8)   U7 - V7 + X3534 =   142.63
          9)   U8 - V8 + X3429 =   674.74
         10)   U9 - V9 + X3231 =     51.91
         11)   U10 - V10 + X3130 =     52.12
         12)   U11 - V11 + X3029 =     51.95
         13)   U12 - V12 + X2926 =    678.49
         14)   U13 - V13 + X2726 =    310.06
         15)   U14 - V14 + X2625 =    958.2
         16)   U15 - V15 + X25TP =    980.59
         17)   X4340 + X4140 - X4045 =     0
         18)   X4045 - X4537 =     0
         19)   X4537 + X3837 - X3429 =     0
         20)   X3734 + X3534 - X3429 =     0
         21)   X3231 - X3130 =     0
  --More--
         22)   X3130 - X3029 =     0
         23)   X3429 + X3029 - X2926 =     0
         24)   X2926 + X2726 - X2625 =     0
         25)   X2625 - X26TP =     0
         26)   X4340 + X4140 + X3837 + X3534 + X3231 + X2726
               - X25TP = 0
  END
```

Table 5-12. Minimizing the Maximum Error

```
MIN   Z

SUBJECT TO
          2)   U1 - V1 + X4340 =    196.25
          3)   U2 - V2 + X4140 =     99.64
          4)   U3 - V3 + X4045 =    314.67
          5)   U4 - V4 + X4537 =    288.48
          6)   U5 - V5 + X3837 =    199.05
          7)   U6 - V6 + X3734 =    503.85
          8)   U7 - V7 + X3534 =    142.63
          9)   U8 - V8 + X3429 =    674.74
         10)   U9 - V9 + X3231 =     51.91
         11)   U10 - V10 + X3130 =     52.12
         12)   U11 - V11 + X3029 =     51.95
         13)   U12 - V12 + X2926 =    678.49
         14)   U13 - V13 + X2726 =    310.06
         15)   U14 - V14 + X2625 =    958.2
         16)   U15 - V15 + X25TP =    980.59
         17)   Z - U1 - V1 >=   0
         18)   Z - U2 - V2 >=   0
         19)   Z - U3 - V3 >=   0
         20)   Z - U4 - V4 >=   0
         21)   Z - U5 - V5 >=   0
         22)   Z - U6 - V6 >=   0
         23)   Z - U7 - V7 >=   0
  --More--
         21)   Z - U5 - V5 >=   0
         22)   Z - U6 - V6 >=   0
         23)   Z - U7 - V7 >=   0
  --More--
         24)   Z - U8 - V8 >=     0
         25)   Z - U9 - V9 >=     0
         26)   Z - U10 - V10 >=     0
         27)   Z - U11 - V11 >=     0
         28)   Z - U12 - V12 >=     0
         29)   Z - U13 - V13 >=     0
         30)   Z - U14 - V14 >=     0
         31)   Z - U15 - V15 >=     0
         32)   X4340 + X4140 - X4045 =    0
         33)   X4045 - X4537 =    0
         34)   X4537 + X3837 - X3734 =    0
         35)   X3734 + X3534 - X3429 =    0
         36)   X3231 - X3130 =    0
         37)   X3130 - X3029 =    0
         38)   X3429 + X3029 - X2926 =    0
         39)   X2926 + X2726 - X2625 =    0
         40)   X2625 - X25TP =    0
         41)   X4340 + X4140 + X3837 + X3534 + X3231 + 2726
              - X25TP = 0
  END
```

observed flow, X_i^*. Equation 12 is the nodal constraint equation where the sum of inflows minus outflows must equal zero.

At this point, it is assumed that neither the flows on the left or right hand side of each equation are known to be correct. If the external supply into and demand out of the network was known, an optimal balance of the streams on the left hand side of each node equation could be solved for.

Minimizing the Maximum Error

In using a linear program (Schrage, 1984), minimizing the maximum error is expressed as follows (Table 5-12):

$$\text{Min } Z \tag{5.13}$$

subject to

$$U_i+V_i+X_i = X_i^* \text{ for all } i, \tag{5.14}$$

$$Z-U_i-V_i >= 0, \text{ for all } i, \text{ and} \tag{5.15}$$

$${}_{i}a_{ij}X_i = 0 \text{ for each node.} \tag{5.16}$$

In equation 5.13, Z represents the maximum error. Equation 5.15 represents the constraint that $Z >= U_i + V_i$. If the constraint sets 5.14, 5.15, and 5.16 are met, then the least maximum error solution will be found when Z is minimized.

The above three methods used for the optimization of erroneous flows within the waste water network were continued on the next four data sets. In comparing the results, the summation of the deviation between each true flow rate and the corrected or reconciled flow rate is calculated (Table 5-13). Minimizing the sum of the normalized errors squared proved to be the best method in all but one test case.

With this limited amount of test cases the least error squared analysis would seem to be the best method to use in the optimization of erroneous data, if the data contain only random errors. But what if the data sets contain gross errors?

Optimization of Networks Involving Gross Errors

The three network optimization techniques are now used in three test cases of the network where approximately 20% of the streams received gross errors, i.e. the observed value is greater than the standard deviation of 5% (Table 5-14). The rest of the streams contain random errors. Lotus 123 was used with the random number function to create the data sets.

When gross errors are imposed, minimizing the sum of the absolute value of the errors is the best technique to use in the optimization of data which contain gross errors. Table 5-15 indicates the results. This method proved to be best in each test when a comparison of the sum of the deviations between true and reconciled data was made.

Gross Error Detection Algorythms

Five algorithms are currently being used in the detection of gross errors, removing them, and optimally adjusting the rest of the flows which are assumed to include

Table 5-13. Random Error Test Results.

TEST 1

Reconciled flow rates: LS	LAV	MINMAX	Sum of deviation between true and reconciled flow rates: LS	LAV	MINMAX
198.88	196.25	195.35	1.12	3.75	4.65
100.30	99.64	99.64	0.30	0.36	0.36
299.18	295.89	294.99	0.82	4.11	5.01
299.18	295.89	294.99	0.82	4.11	5.01
199.56	199.05	199.05	0.44	0.95	0.95
498.74	494.94	494.04	1.26	5.06	5.96
142.46	131.64	161.02	7.54	18.36	11.02
641.20	626.58	655.06	8.80	23.42	5.06
51.92	51.91	32.44	1.92	1.91	17.56
51.92	51.91	32.44	1.92	1.91	17.56
51.92	51.91	32.44	1.92	1.91	17.56
693.12	678.49	687.50	6.88	21.51	12.50
304.91	302.10	290.38	4.91	2.10	9.62
998.03	980.59	977.88	1.97	19.41	22.12
998.03	980.59	977.88	1.97	19.41	22.12
		sum =	42.59	128.28	157.06

Table 5-13. Continued.

TEST 2

Reconciled flow rates: LS	LAV	MINMAX		Sum of deviation between true and reconciled flow rates: LS	LAV	MINMAX
198.68	198.04	198.04		1.32	1.96	1.96
95.86	95.70	89.74		4.14	4.30	10.26
294.54	293.74	287.78		5.46	6.26	12.22
294.54	293.74	287.78		5.46	6.26	12.22
202.06	202.39	202.39		2.06	2.39	2.39
496.60	496.13	490.17		3.40	3.87	9.83
154.59	156.91	168.36		4.59	6.91	18.36
651.19	653.04	658.53		1.19	3.04	8.53
49.76	48.82	48.81		0.24	1.18	1.19
49.76	48.82	48.81		0.24	1.18	1.19
49.76	48.82	48.81		0.24	1.18	1.19
700.95	701.86	707.34		0.95	1.86	7.34
289.96	292.01	274.90		10.04	7.99	25.10
990.91	993.87	982.23		9.09	6.13	17.77
990.91	993.87	982.23		9.09	6.13	17.77
			sum =	57.55	60.64	147.32

Table 5-13. Continued.

TEST 3

Reconciled flow rates: LS	LAV	MINMAX		Sum of deviation between true and reconciled flow rates: LS	LAV	MINMAX
201.98	201.91	188.37		1.98	1.91	11.63
102.00	101.98	106.88		2.00	1.98	6.88
303.98	303.89	295.25		3.98	3.89	4.75
303.98	303.89	295.25		3.98	3.89	4.75
203.86	203.73	206.72		3.86	3.73	6.72
507.84	507.62	501.97		7.84	7.62	1.97
154.47	154.41	167.94		4.47	4.41	17.94
662.30	662.03	669.92		12.30	12.03	19.92
49.74	51.87	39.55		0.26	1.87	10.45
49.74	51.87	39.55		0.26	1.87	10.45
49.74	51.87	39.55		0.26	1.87	10.45
712.04	713.90	709.47		12.04	13.90	9.47
284.64	286.37	277.56		15.36	13.63	22.44
996.67	1000.27	987.03		3.33	0.27	12.97
996.67	1000.27	987.03		3.33	0.27	12.97
			sum =	75.25	73.14	163.76

Table 5-13. Continued.

TEST 4

Reconciled flow rates: LS	LAV	MINMAX		Sum of deviation between true and reconciled flow rates: LS	LAV	MINMAX
200.09	196.77	190.03		0.09	3.23	9.97
101.40	100.57	112.46		1.40	0.57	12.46
301.49	297.34	302.48		1.49	2.66	2.48
301.49	297.34	302.48		1.49	2.66	2.48
193.23	190.91	184.91		6.77	9.09	15.09
494.71	488.25	487.40		5.29	11.75	12.60
142.46	142.74	154.63		7.54	7.26	4.63
637.17	630.99	642.02		12.83	19.01	7.98
50.98	50.95	39.49		0.98	0.95	10.51
50.98	50.95	39.49		0.98	0.95	10.51
50.98	50.95	39.49		0.98	0.95	10.51
688.15	681.94	681.52		11.85	18.06	18.48
293.74	287.49	284.28		6.26	12.51	15.72
981.89	969.43	965.80		18.11	30.57	34.20
981.89	969.43	965.80		18.11	30.57	34.20
			sum =	94.14	150.79	201.82

Table 5-13. Continued.

TEST 5

Reconciled flow rates: LS	LAV	MINMAX		Sum of deviation between true and reconciled flow rates: LS	LAV	MINMAX
197.43	198.13	216.36		2.57	1.87	16.36
102.17	102.35	84.12		2.17	2.35	15.88
299.60	300.48	300.48		0.40	0.48	0.48
299.60	300.48	300.48		0.40	0.48	0.48
204.24	204.55	196.35		4.24	4.55	3.65
503.84	505.03	496.83		3.84	5.03	3.17
156.33	143.56	157.31		6.33	6.44	7.31
660.17	648.59	654.14		10.17	1.41	4.14
48.77	48.91	48.91		1.23	1.09	1.09
48.77	48.91	48.91		1.23	1.09	1.09
48.77	48.91	48.91		1.23	1.09	1.09
708.95	697.50	703.05		8.95	2.50	3.05
310.35	327.35	325.60		10.35	27.35	25.60
1019.30	1024.85	1028.65		19.30	24.85	28.65
1019.30	1024.85	1028.65		19.30	24.85	28.65
			sum =	91.71	105.43	140.69

Results:

Test	LS	LAV	MINMAX
1	42.59	128.28	157.06
2	57.55	60.64	147.32
3	75.25	73.14	163.76
4	94.14	150.79	201.82
5	91.71	105.43	140.69
sum =	361.24	518.28	810.65

Table 5-14. Gross Error Test Cases.

Comparison of three optimization strategies on three test cases which include approximately 20% gross errors.

Stream	Actual Flow Rate	Observed Flow Rate Test 1	Test 2	Test 3
X4340	200	192.69	196.2	191.25
X4140	100	102.52	98.5	137.01
X4045	300	297.59	289.52	448.85
X4537	300	311.89	58.53	314.13
X3837	200	193.12	205.76	206.4
X3734	500	891	295.98	516.85
X3534	150	147.26	142.88	148.16
X3429	650	645.74	669.28	674.24
X3231	50	48.1	70.65	51.09
X3130	50	34.8	48.63	51.95
X3029	50	51.58	49.63	47.68
X2926	700	692.94	707.68	729.37
X2726	300	93.65	496.98	290.67
X2625	1000	999.13	1006.15	974.18
X25TP	1000	1044.18	1684.8	975.1

Table 5-15. Gross Error Test Results.

TEST 1

Reconciled flow rates:			Sum of the deviation between true and reconciled flow rates:		
LS	LAV	MINMAX	LS	LAV	MINMAX
220.15	192.69	195.07	20.15	7.31	4.93
109.39	112.67	235.95	9.39	12.67	135.95
329.54	305.36	431.02	29.54	5.36	131.02
329.54	305.36	431.02	29.54	5.36	131.02
242.63	193.12	326.55	42.63	6.88	126.55
572.17	498.48	757.57	72.17	1.52	257.57
146.41	147.26	21.60	3.59	2.74	128.40
718.58	645.74	779.17	68.58	4.26	129.17
44.94	48.10	37.93	5.06	1.90	12.07
44.94	48.10	37.93	5.06	1.90	12.07
44.94	48.10	37.93	5.06	1.90	12.07
763.52	693.84	817.10	63.52	6.16	117.10
118.74	305.29	93.65	181.26	5.29	206.35
882.26	999.13	910.75	117.74	0.87	89.25
882.26	999.13	910.75	117.74	0.87	89.25
		sum =	771.02	64.99	1582.77

Table 5-15. Continued.

TEST 2

Reconciled flow rates:			Sum of the deviation between true and reconciled flow rates:		
LS	LAV	MINMAX	LS	LAV	MINMAX
146.17	191.02	0.00	53.83	8.98	200.00
85.99	98.50	58.53	14.01	1.50	41.47
232.17	289.52	58.53	67.83	10.48	241.47
232.17	289.52	58.53	67.83	10.48	241.47
207.41	205.76	435.62	7.41	5.76	235.62
439.58	495.28	494.15	60.42	4.72	5.85
156.73	162.77	482.20	6.73	12.77	332.20
596.31	685.05	976.35	53.69	35.05	326.35
56.67	49.63	70.65	6.67	0.37	20.65
56.67	49.63	70.65	6.67	0.37	20.65
56.67	49.63	70.65	6.67	0.37	20.65
652.98	707.68	1047.00	47.02	7.68	347.00
526.80	496.98	298.47	226.80	196.98	1.53
1179.79	1204.66	1345.47	179.79	204.66	345.47
1179.79	1204.66	1345.47	179.79	204.66	345.47
		sum =	985.17	704.83	2725.85

Table 5-15. Continued.

TEST 3

Reconciled flow rates: LS	LAV	MINMAX		Sum of the deviation between true and reconciled flow rates: LS	LAV	MINMAX
208.55	191.25	191.25		8.55	8.75	8.75
141.33	137.01	190.24		41.33	37.01	90.24
349.88	328.26	381.49		49.88	28.26	81.49
349.88	328.26	381.49		49.88	28.26	81.49
195.60	197.82	202.72		4.40	2.18	2.72
545.48	526.08	584.21		45.48	26.08	84.21
144.66	148.16	145.16		5.34	1.84	4.84
690.15	674.24	729.37		40.15	24.24	79.37
50.14	51.09	0.00		0.14	1.09	50.00
50.14	51.09	0.00		0.14	1.09	50.00
50.14	51.09	0.00		0.14	1.09	50.00
740.29	725.33	729.37		40.29	25.33	29.37
282.08	249.77	223.31		17.92	50.23	76.69
1022.37	975.10	952.68		22.37	24.90	47.32
1022.37	975.10	952.68		22.37	24.90	47.32
			sum =	348.39	285.25	783.81

Results:

Test	LS	LAV	MINMAX
1	771.02	64.99	1582.77
2	985.17	704.83	2725.85
3	348.39	285.25	783.81
sum =	2104.58	1055.07	5092.43

random errors. The algorithms have so far been described for use in industrial processes, especially chemical, but can also prove to be of value in the optimization of potable and waste water hydraulic flow networks.

Measurement Test

The measurement test is the most straightforward of the algorithms (Mah and Tamhane, 1982; Iordaache et al., 1985). A statistical test is used to determine if there are any gross errors. The test for gross errors is based on the assumption that random errors are normally distributed. After the data have been adjusted using the least error squared analysis, a set of residuals is calculated:

$$e_i = X_i - X_i^* \qquad (5.17)$$

The residuals are then tested to determine if any are gross errors, known as outliers. For a 95% confidence level an outlier is defined as

$$-1.96. > e_i/\sigma_{ei} > 1.96 \qquad (5.18)$$

The general method is to detect which of the measurements include gross errors. These measurements are removed and replaced with more realistic values. Now, the network is assumed to contain only random errors and the flows within the network can be optimally adjusted and balanced so that each node satisfies the condition of equation 5.1.

In the measurement test, all outliers are removed by a process called nodal aggregation. The stream which has been determined to be a gross error is removed from the data set temporarily by combining the inflows and the outflows of the two nodes, which the stream flows between, into one. The least squared error analysis is reapplied to the new set of data where outliers have been removed. The removed streams are easily determined from the new set of X_i values.

Modified Iterative Measurement Test

The second algorithm is the modified iterative measurement test (Serth and Heenan, 1986). This test is similar to the measurement test. Once the initial least squared error analysis is applied, the residuals calculated, and the outliers identified, only the worst outlier is removed via nodal aggregation and the least squared error analysis applied. The new data set is then perused for unrealistic flow rates, such as negative flow rates, or grossly large positive ones. If unrealistic flow rates are present, the outlier is put back in and the cycle is applied to the next largest outlier until there are no more outliers among the remaining residuals.

Pseudonodes Test

The pseudonodes test is the third algorithm (Mah et al., 1976). Here, nodes are statistically tested for imbalances. A nodal imbalance which has been statistically normalized is defined as

$$\delta_j = \Sigma_i a_{ij} X_i / \sigma_j \qquad (5.19)$$

where

$$\sigma_j = (\Sigma_i \sigma_i^2)^{.5} \quad (5.20)$$

An outlier is a nodal imbalance which contains at least one gross error and is defined by:

$$-1.96>\delta_j>1.96 \quad (5.21)$$

Each node is tested successively. If the nodal imbalance is not an outlier, its respective streams are assumed to contain no gross errors and the streams are removed from further consideration. Next, this procedure is contained for aggregates of two nodes, called pseudonodes, then aggregates of three nodes and so forth until no greater number of aggregates can be formed. The streams that have not been eliminated at the end of this procedure are assumed to contain gross errors. These streams can then be replaced through the method of nodal aggregation and least squared error analysis as discussed in the measurement test.

<u>Combinatorial Test</u>

The combinatorial test is the forth algorithm (Serth and Heenan, 1986). This method is similar to the pseudonode test in that each individual node is tested for nodal imbalances. The search is conducted for combinations of gross errors which can explain the observed pattern of imbalances. In other words, each single stream is assumed to contain a gross error to see if that stream by itself will cause the nodal imbalance. If no individual stream can explain the nodal imbalances, then combinations of two streams are tested, then combinations of three streams, and so forth until no larger combination is possible. A very large number of combinations is possible for even a small number of streams.

Screened Combinatorial Test

The last algorithm is the screened combinatorial test (Serth and Heenan, 1986). This method involves both the pseudonode and combinatorial tests. The pseudonode test is used to screen the initial data to identify the streams which contain gross errors. The combinatorial test is then applied to the reduced data which includes only those streams identified to have gross errors.

Comparison of the Five Algorithms

The five algorithms were used to test 100 sets of data (Heenan and Serth, 1986). A random number generator was used to introduce both random and gross errors to a completely balanced original set of streams within a network. Twenty percent of the flows were given gross errors. The modified iterative measurement and the screened combinatorial tests were the most accurate in identifying approximately 80% of the gross errors, with the least number of erroneous identifications, while reducing the total error within the network by greater than 60%. Due to the better efficiency, the modified iterative measurement test was the method of choice (Heenan and Serth, 1986).

Solving the Modified Iterative Measurement Test Using Lotus 123

Lotus 123 can be used to demonstrate the modified iterative measurement test as applied to the waste water network. The instrument measurement standard deviation is assumed to be 5% of the true value for each stream. The third test case for data used in the optimization of a network involving gross errors (Table 5-14) is used for this example. In this data set, the observed stream reading for X4045 contains a gross error which deviates by greater than 5% from the true or actual flow rate. The streams involve random errors and deviate from the actual flow rate by less than or equal to 5%.

The observed flow rates are initially balanced by minimizing the sum of the normalized errors squared through the use of Lagrange multipliers. Table 5-16 gives the initial observed flow rates and the reconciled flow rates. Next, the 95% confidence level statistical test is applied to identify the possible gross errors using equations 5.19, 5.20, and 5.21 as shown in Table 5-16. Two gross errors are determined after this initial optimization process and statistical check.

Stream X4045 is the worst outlier. The value is removed from the data set. Stream X4045 is eliminated from the original data set through nodal aggregation by combining nodes 40 and 45 (Figure 5-3), the least error squared analysis is repeated, and a new value is determined for stream X4045 to be included in the original observed flow

Table 5-16. Modified Iterative Measurement Test.

				Statistical test				
Stream	True Flow Rate	Recon-ciled Flow Rate	Observed Flow Rate	ei= Xi-Xi*	(sigma)ei =true* 5%	ei/ (sigma)ei	Gross Error	Worst Outlier
X4340	200	208.55	191.25	17.30	10	1.73	NO	
X4140	100	141.33	137.01	4.32	5	0.86	NO	
X4045	300	349.88	448.85	-98.97	15	-6.60	YES	*
X4537	300	349.88	314.13	35.75	15	2.38	YES	
X3837	200	195.60	206.40	-10.80	10	-1.08	NO	
X3734	500	545.48	516.85	28.63	25	1.15	NO	
X3536	150	144.66	148.16	-3.50	7.5	-0.47	NO	
X3429	650	690.15	674.24	15.91	32.5	0.49	NO	
X3231	50	50.14	51.09	-0.95	2.5	-0.38	NO	
X3130	50	50.14	51.95	-1.81	2.5	-0.72	NO	
X3029	50	50.14	47.68	2.46	2.5	0.98	NO	
X2926	700	740.29	729.37	10.92	35	0.31	NO	
X2726	300	282.08	290.67	-8.59	15	-0.57	NO	
X2625	1000	1022.37	974.18	48.19	50	0.96	NO	
X25TP	1000	1022.37	975.10	47.27	50	0.95	NO	

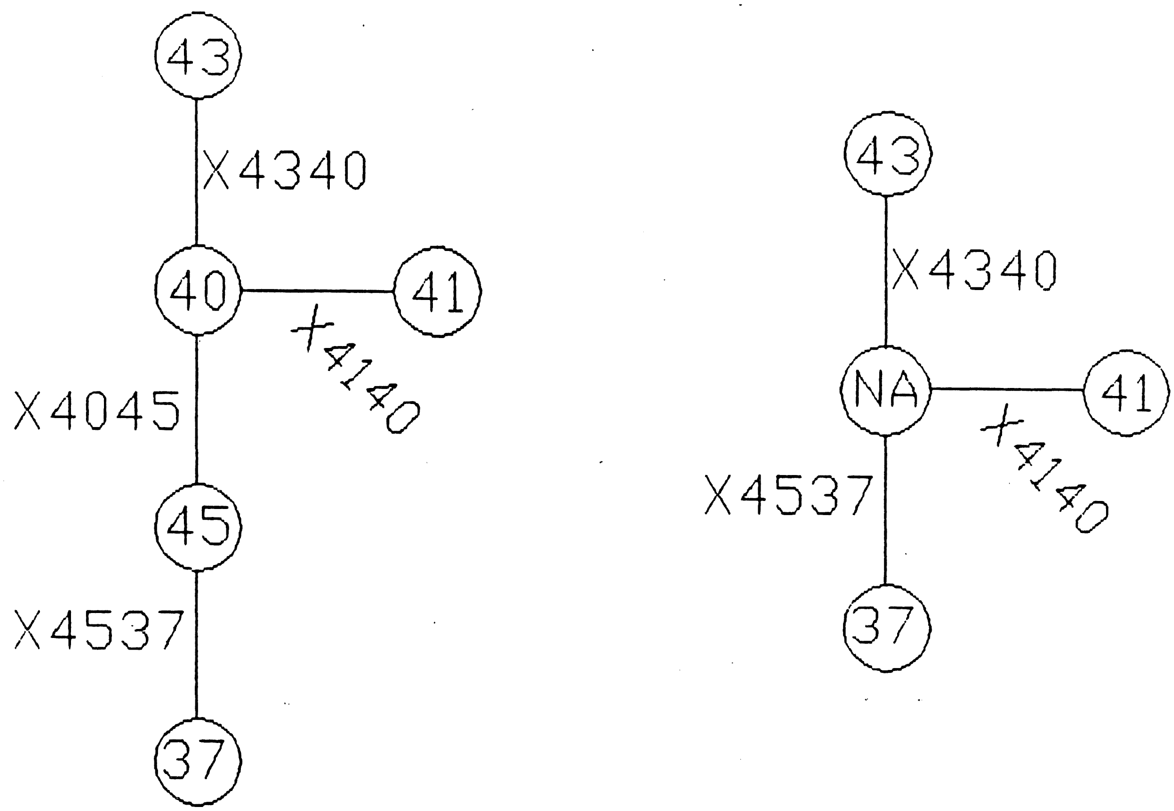


Figure 5-3. Nodal Aggregate to Eliminate Stream X4045

rates as shown in Table 5-17. The new value for stream X4045 is equal to stream X4537 or the sum of X4340 and X4140 which equals 320.88. The statistical test is conducted and no gross errors are identified. If additional gross errors were identified, the same procedure would be iterated until no gross errors are identified after the statistical test.

A final least errors squared analysis is now repeated using the original data set except for the value 320.88 which replaces the original observed flow rate for stream X4045. The final reconciled flow rates are given in Table 5-18.

Comparison of Network Optimization With and Without Error Detection

A comparison between the reconciled values with and without error detection can now be made for this single test case. The use of the modified iterative measurement test reduced the total sum of the deviation between the actual flow rates and the reconciled flow rates by approximately 100% over the use of least errors squared optimization without error detection (Table 5-19). The total deviation is reduced from 348.39 to 174.30 through the use of the modified iterative measurement test.

Conclusions

The conventional use of least errors squared analysis and five algorithms, of which the modified iterative measurement test was discussed in detail, in the industrial process area have been demonstrated for use in the

Table 5-17. Modified Iterative Measurement Test.

Stream	True Flow Rate	Reconciled Flow Rate	Observed Flow Rate	Statistical test: ei= Xi-Xi*	(sigma)ei =true* 5%	ei/ (sigma)ei	Gross Error	Worst Outlier
X4340	200	185.35	191.25	-5.90	10	-0.59	NO	
X4140	100	135.53	137.01	-1.48	5	-0.30	NO	
X4045	300	320.88	320.88	0.00	15	0.00	NO	
X4537	300	320.88	314.13	6.75	15	0.45	NO	
X3837	200	203.50	206.40	-2.90	10	-0.29	NO	
X3734	500	524.38	516.85	7.53	25	0.30	NO	
X3536	150	147.21	148.16	-0.95	7.5	-0.13	NO	
X3429	650	671.59	674.24	-2.65	32.5	-0.08	NO	
X3231	50	50.20	51.09	-0.89	2.5	-0.36	NO	
X3130	50	50.20	51.95	-1.75	2.5	-0.70	NO	
X3029	50	50.20	47.68	2.52	2.5	1.01	NO	
X2926	700	721.79	729.37	-7.58	35	-0.22	NO	
X2726	300	284.90	290.67	-5.77	15	-0.38	NO	
X2625	1000	1006.69	974.18	32.51	50	0.65	NO	
X25TP	1000	1006.69	975.10	31.59	50	0.63	NO	

Table 5-18. Modified Iterative Measurement Test.

Stream	True Flow Rate	Reconciled Flow Rate	Observed Flow Rate	Statistical test: ei= Xi-Xi*	(sigma)ei =true* 5%	ei/ (sigma)ei	Gross Error	Worst Outlier
X4340	200	181.56	191.25	-9.69	10	-0.97	NO	
X4140	100	134.59	137.01	-2.42	5	-0.48	NO	
X4045	300	316.15	316.15	0.00	15	0.00	NO	
X4537	300	316.15	314.13	2.02	15	0.13	NO	
X3837	200	204.79	206.40	-1.61	10	-0.16	NO	
X3734	500	520.94	516.85	4.09	25	0.16	NO	
X3536	150	147.62	148.16	-0.54	7.5	-0.07	NO	
X3429	650	668.56	674.24	-5.68	32.5	-0.17	NO	
X3231	50	50.21	51.09	-0.88	2.5	-0.35	NO	
X3130	50	50.21	51.95	-1.74	2.5	-0.70	NO	
X3029	50	50.21	47.68	2.53	2.5	1.01	NO	
X2926	700	718.77	729.37	-10.60	35	-0.30	NO	
X2726	300	285.36	290.67	-5.31	15	-0.35	NO	
X2625	1000	1004.13	974.18	29.95	50	0.60	NO	
X25TP	1000	1004.13	975.10	29.03	50	0.58	NO	

Table 5-19. Comparison With and Without Error Detection.

Stream	Observed Flow Rate	Reconciled Values: With Error Detection	Reconciled Values: Without Error Detection	True Flow Rate	Deviation Between True and Reconciled Flow Rates: With Error Detection	Deviation Between True and Reconciled Flow Rates: Without Error Detection
X4340	191.25	181.56	208.55	200	18.44	8.55
X4140	137.01	134.59	141.33	100	34.59	41.33
X4045	316.15	316.15	349.88	300	16.15	49.88
X4537	314.13	316.15	349.88	300	16.15	49.88
X3837	206.40	204.79	195.60	200	4.79	4.40
X3734	516.85	520.94	545.48	500	20.94	45.48
X3536	148.16	147.62	144.66	150	2.38	5.34
X3429	674.24	668.56	690.15	650	18.56	40.15
X3231	51.09	50.21	50.14	50	0.21	0.14
X3130	51.95	50.21	50.14	50	0.21	0.14
X3029	47.68	50.21	50.14	50	0.21	0.14
X2926	729.37	718.77	740.29	700	18.77	40.29
X2726	290.67	285.36	282.08	300	14.64	17.92
X2625	974.18	1004.13	1022.37	1000	4.13	22.37
X25TP	975.10	1004.13	1022.37	1000	4.13	22.37
				Sum =	174.30	348.39

optimization of erroneous flows within a water distribution network. Two additional methods for the optimization of a network involving linear programming procedures were introduced, minimizing the sum of absolute value of the errors and minimizing the maximum error.

If all the errors are random, the method of minimizing the sum of the errors squared was demonstrated to be the most effective in minimizing the sum of the deviations between actual and reconciled flow rates. When gross errors are introduced, the method of minimizing the sum of the absolute values of the errors was demonstrated to be the method of choice. Also, use of gross error detection in the modified iterative measurement test proves to reduce the total error as demonstrated here and in prior research.

An interesting area for further research, for use when gross errors are present, is the application of minimizing the sum of the absolute value of the errors within the modified iterative measurement test. Since this method was demonstrated to be the best of the network optimization methods when gross errors are present in the data set, the use of this method in the modified iterative measurement test may provide an even better result in reducing the deviation between true and reconciled flow values.

The statistical test used within the modified iterative measurement test assumes that the errors are normally distributed. Although this may not be the case, the method has demonstrated to reduce the overall error when a network is optimally balanced (Serth and Heenan, 1986).

CHAPTER VI
SUMMARY AND CONCLUSIONS

Objectives

Use of microcomputers and ever more sophisticated software packages are allowing a person to solve water supply problems today that could only be solved with larger computers previously. In this thesis, three different water supply problems are solved. The first problem deals with improving the knowledge base structure of a model which determines preliminary design and cost for treating drinking water with various water treatment processes.

The second problem involves improving the efficiency in handling both input and output data of a model which analyzes flow in pipe networks. The last water supply problem concerns the optimization of water distribution networks that include erroneous flows.

Electronic Spreadsheets

Throughout this thesis, Lotus 123 release 2 is used as the mainstay to solve water supply problems. Lotus 123 effectively replaces calculation by hand and automates the problem solving process. Included in Lotus 123 are a myriad of commands and functions which make the spreadsheet a very powerful and versatile tool for solving engineering problems.

In this thesis, the macro programming language and the matrix functions are used extensively. Matrix inversion and multiplication commands are extremely helpful in the solution of large sets of simultaneous equations. The matrix commands are used in chapter V in the optimization of erroneous network flows.

Decision Support System

The decision support system provides a framework for solving a problem. In chapter III, the problem is to determine the preliminary design and cost for various potable water treatment processes. A Lotus 123 spreadsheet supplies the system of rules, logical steps, and knowledge bases to solve the problem. Within the spreadsheet, the required information for solving the problem is grouped together within logical sections, i.e., chemical costs, cost factors, influent water properties, and desired treatment process sections. A macro menu system allows easy movement around the spreadsheet and help messages for any problem areas.

Lotus 123 excels in creating the knowledge base. Data tables, graphs, figures, maps, and equations can be included within the spreadsheet to document how the problem is solved. The use of logarithmic graphs is of special significance in providing water treatment cost estimates. The knowledge base within the spreadsheet is easily updated as the state of the art solution to the problem changes.

Data Handling

In chapter IV, a Lotus 123 spreadsheet is created to pre- and postprocess data for use in a model which analyses flow in a pipe network. Most of the time involved with using this model or any other model is spent creating and manipulating the data base. The spreadsheet can effectively streamline data handling. Various functions provided by Lotus 123, plus a macro incorporating the functions, creates a very fast program which reduces data handling time. The preprocessor can cut the data handling time by fifty percent when used as opposed to the data input system provided by the hydraulic network analysis model.

Another advantage in using the spreadsheet pre- and postprocessors is with the help support system. As many help messages as required can be included within the spreadsheet. This allows one to stay within the processing program and find needed assistance instead of searching through a user's manual.

Spreadsheet Modeling

The Lotus 123 macro language is used in chapters III and IV to create program to solve two different problems. The macro designed for the water treatment model is simple to use and involves much less programming language than the water treatment model written in the BASIC language. Macro capabilities in handling data and providing knowledge bases are extensive, as discussed throughout this thesis.

A spreadsheet model run by a menu system created by macros is simple to use. The macro speeds up any process in the spreadsheet whether it is movement around the spreadsheet or data handling.

Conclusions

In this thesis, three software programs are used with a microcomputer to solve three different water supply problems. Ten years ago, none of these problems could be solved with a microcomputer. Advances in software capabilities and microcomputer execution speed are allowing for the solution of ever move complicated engineering problems.

The majority the this thesis deals with the Lotus 123 electronic spreadsheet. The electronic spreadsheet can be a powerful tool in solving water supply problems. Lotus 123 spreadsheets are designed to determine preliminary design and cost estimates for various potable water treatment processes (chapter III), to process data input into and output from a pipe network flow analysis model (chapter IV), and in the optimization of erroneous flows within a network by using matrix procedures to solve simultaneous equations (chapter V). A person using the spreadsheet can combine various commands and functions within a macro to create a program that is fast, flexible, and easy to use.

The Lindo software program is used in chapter V in the optimization of erroneous network flows using linear programming. Minimizing the sum of the least absolute value of the errors and minimizing the maximum error are used in the optimization of the network. Although limited testing is done, the method of minimizing the sum of the least absolute value of the errors demonstrated the best efficiency when the data included gross errors. Linear programming and the use of the Lindo program is again an example of a powerful program for use in the solution of water supply problems that was not available ten years ago.

Suggestions for Additional Investigations

In chapter V, several algorithms are discussed for the optimization of a network which includes gross errors. The method of choice is the modified iterative measurement test which uses the method of minimizing the sum of the errors squared. The method of using linear programming to minimize the sum of the absolute value of the errors seems to demonstrate superior efficiency when gross errors are included in the data set. Further study is warranted for use of this method within the modified iterative measurement test to determine if a more efficient program can be created.

In chapter IV, the postprocessor accepts data from Wood's model and places the data into the Lotus 123 spreadsheet. Additional macros could be written to test the output data for certain characteristics. Important among these characteristics would be to determine which pipes involved velocities that are too low or too high, critical pressures, and abnormal head loss.

APPENDIX A
HELP SECTIONS IN WTRMAID PROGRAM

Flocculation Input Help Section in WTRMAID Program

PRESS RETURN TO RETURN TO PROCESS DATA INPUT AREA

Velocity gradient - The velocity gradient for flocculation is a measure of the mechanical energy supplied to the process. The optimum range for the velocity gradient has been found to be 30-60 feet per second per foot, or 1/sec.

Detention time - The Ten State Standards recommended minimum flocculating detention time is 30 minutes.

Flocculation Output Help Section in WTRMAID Program

Operational flow - The average influent flow rate identified in the influent water properties section.

Basin volume - The basin volume is determined by:

$$V = Q1 \cdot (10^{6}) \cdot DET \cdot (\text{day}/1440\ \text{min}) \cdot (\text{ft}^{3}/7.48\ \text{gal}) \cdot Q2/Q1$$

where V = basin volume (ft^3),
$Q1$ = operational flow (mgd),
DET = detention time (min), and
$Q2$ = design flow (mgd).

Absolute water viscosity - The viscosity is determined by:

$$MU = 3.513 \cdot 10^{-5}/\exp(.0249 \cdot T)$$

where MU = absolute water viscosity ($\text{lb} \cdot \text{sec}/\text{ft}^2$) and
T = temperature in degrees C given in the influent water properties section.

Flocculation horsepower - The power is determined by:

$$P = G^{2} \cdot V \cdot MU/(500\ \text{ft} \cdot \text{lb}/\text{sec}/\text{hp})/.6$$

where P = horsepower (hp),
G = velocity gradient (1/sec), and
V = basin volume (ft^3).

Cost equations - Gumerman gives construction cost as a function of basin volume for three G values: 20, 50, and 80 feet/sec/foot, or 1/sec.
The graph name is GRAPH 1.
The data name is DATA 1.

These data were fit with three third degree log-log polynomials and a log-log interpolation is used to find the cost for G values within the 20-80 G range. Operation and maintenance cost given by Gumerman were functions only of basin volume except for electrical process energy.

Electrical process energy (kwh/yr) was computed as follows:

```
   Elec process energy = V*EXP(2.0395*LN(G)-7.7562
where    V = basin volume (ft^3), and
         G = velocity gradient (1/sec).
```

The cost of constructing the flocculation basin if G=50 is computed as follows:

```
      Cost = EXP(10.016+.82679*LN(Z)-.11751*
             LN(Z)^2+.013467*LN(Z)^3)
where    Z = V/1000, and
         V = basin volume (ft^3)
If G>50 then:
      Cost = A*G^B
where    B = (TEMP3-TEMP2)/LN(80/50)
         A = EXP(TEMP2)/50^B
         TEMP2 = 10.016+.82679*LN(Z)-.11751*
                 LN(Z)^2+.013467*LN(Z)^3
         TEMP3 = 9.995298+.89577*LN(Z)-.11777*
                 LN(Z)^2+.013929*LN(Z)^3
If G<50 then:
      Cost = A*G^B
where    B = (TEMP2-TEMP1)/LN(50/20)
         A = EXP(TEMP2)/50^B
         TEMP1 = 9.9914+.8824199*LN(Z)-.14313*
                 LN(Z)^2+.015593*LN(Z)^3
         TEMP2 = 10.016+.82679*LN(Z)-.11751*
                 LN(Z)^2+.013467*LN(Z)^3
```

In each of the above three cost equations, The total construction cost is determined by:

```
   Constr cost = cost*CCI/265.38
where      CCI = engineer construction cost index.
```

Rapid Mixing Input Help Section in WTRMAID Program

PRESS RETURN TO RETURN TO PROCESS DATA INPUT AREA

Velocity gradient - The rapid mix velocity gradient should be 300-900 feet per second per foot, or 1/sec.

Detention time - The range of recommended rapid mix detention time is 10-30 seconds. Ten State Standards set the maximum detention time at 30 seconds.

Choice of coagulant and dose - All four of the chemicals reduces the alkalinity and pH of the water being treated. For example, each mole of dry alum, liquid alum (expressed as dry alum), or ferric sulfate added reduces alkalinity of the water by 6 equivalents and each mole of ferrous sulfate added reduces alkalinity by 2 equivalents. If molecular weights of the chemicals are taken as 671.5 for alum, 454 for ferric sulfate and 278 for ferrous sulfate, the corresponding reduction in alkalinity as mg/l CaCO3 per mg/l chemical added are .45 for alum, .66 for ferric sulfate, and .36 for ferrous sulfate.

Also, the concentration of precipitate, aluminum or ferric hydroxide, is computed. For alum and ferric sulfate two moles of precipitate are produced per mole of chemical added. For ferrous sulfate one mole of Fe(OH)3 is produced per mole of chemical added. For example, .23 mg/l of Al(OH)3 is produced for each mg/l of alum added, .47 mg/l of Fe(OH)3 is produced for each mg/l of ferric sulfate added, and .385 mg/l of Fe(OH)3 is produced for each mg/l of ferrous sulfate added.

A choice of none of the above is given if only polymer is to be used as the coagulant.

Polymer - Polyelectrolytes (Polymers) can be used as a coagulant aid. The dose should be roughly proportional to the raw turbidity. Usual dose is .1-.5 mg/l. For 100 turbidity: 1 mg/l.

PH change - As mentioned above under coagulant choice and dose, addition of each coagulant lowers the pH of the water. In order to compute the pH after addition of the coagulating chemical, the dissolved carbonate CT=CO3+HCO3+H2CO3 is computed from pH and alkalinity before chemical addition. The value of CT found is stored as TARGET. Next, the reduced alkalinity resulting from chemical addition is found. Half interval iteration is then used to find the pH corresponding to the original CT and the new alkalinity. This iterative procedure is located in DATA 2.

Desired pH after chemical addition - Enter the pH desired after addition of the coagulant. The new pH, PHNEW is then used to calculate the dose of pH changing chemical required to achieve this new pH.

Choice of pH changing chemical - If PHNEW is less than the pH after coagulant addition, sulfuric acid is used to lower the pH. Otherwise, three chemicals are allowed for raising the pH: quick lime (CaO), sodium hydroxide (NaOH), and soda ash (Na2CO3).

Rapid Mixing Output Help Section in WTRMAID Program

Operational flow - The average influent flow rate identified in the influent water properties section.

Chemical dose for pH adjustment - Since CT and PHNEW are known for each chemical except soda ash, the required change in alkalinity (DALK, eq/l) is found and the required chemical dose (mg/l) computed. For example, one mole/l of CaO increases alkalinity by 2 equivalents. Thus, the dose of CaO required in mg/l is DALK*500*56.08 when DALK is expressed as eq/l. Similarly, the required dose of NaOH is DALK* 4000. If DALK is negative the dose of H2SO4 (mg/l) is -DALK*500*98.07.

If soda ash is selected for pH adjustment, both CT and alkalinity are increased. In this case, DALK is computed as follows where HPLUS is hydrogen ion concentration (mol/l), ALK is alkalinity (eq/l), OH is hydroxide ion (mol/l), and KA1 and KA2 are the two dissociation constants for carbonic acid.

```
      B = 1 + KA2/HPLUS + HPLUS/KA1
   DALK = (CT/B+2*KA2*CT/HPLUS/B+OH-HPLUS-ALK)/
          (11/2/B-KA2/HPLUS/B)
```

The calculations are found in DATA 3.

Mixing volume - The basin volume is determined by:

```
   V = Q1*(10^6)*DET*(day/86400 sec)*(ft^3/7.48 gal)*Q2/Q1
where      V = basin volume (ft^3),
          Q1 = operational flow (mgd),
         DET = detention time (sec), and
          Q2 = design flow (mgd).
```

Absolute water viscosity - The viscosity is determined by:

```
        MU = 3.513*10^-5/EXP(.0249*T)
where   MU = absolute water viscosity (lb*sec/ft^2) and
         T = temperature in degrees C given in the influent
             water properties section.
```

Mixing horsepower - The power is determined by:

$$P = G^2 \cdot V \cdot MU/(500\ ft \cdot lb/sec/hp)/.6$$

where P = horsepower (hp),
G = velocity gradient (1/sec), and
V = basin volume (ft^3).

Cost equations - Log-log polynomial least squares fits were found between V and construction cost for G values for 300, 600, and 900. Log-log interpolation was used to find construction cost for G values other than those given but within the 300-900 range. Estimates for labor, and materials were made from polynomial fits of data from Gumerman. Process electrical energy is computed from V and G.

Construction costs for chemical feed systems were given by maximum delivery rate, lb/hr. The required feed rate was computed and the cost of the feeding installation was estimated from polynomial fits of the cost data. Liquid sulfuric acid (93.14% H_2SO_4) with a density of 15.3 lb/gal was used and feeder cost was estimated with polynomial fits of the cost data. Construction cost for feeding ferric sulfate, ferrous sulfate, and quick lime was handled in a similar way.

The costs for ferric and ferrous sulfate differed only by the dry chemical density: 80 lb/ft^3 for ferric sulfate, and 64 lb/ft^3 for ferrous sulfate. Density of soda ash can vary widely. For example, light soda ash density is 35-46 lb/ft^3 and dense soda ash density is 68-78 lb/ft^3. Soda ash density is assumed to have an average value of 60 lb/ft^3. With this assumption soda ash feeder cost was found.

The annual cost for chemicals is computed using unit costs found within the chemical costs section.

APPENDIX B
EXECUTED OUTPUT FROM EXAMPLE WTRMAID PROGRAM

WTRMAID PROGRAM EXECUTION OUTPUT:

Stream/Process map:

Loop Mark	User Process Number	Process Name	First Stream In	Second Stream In	First Stream Out	Second Stream Out
	4	RMIX	4	0	5	0
	5	FLOC	5	0	6	0

Initial stream vector:

	Input Stream 1	Input Stream 2	Output Stream 1	Output Stream 2
MGD	28	0	28	0
DEGC	20	0	20	0
PH	7.5	0	7.5	0
TURBIDITY	50	0	50	0
COLOR	117	0	117	0
COLIFORMS	100	0	100	0
TDS	5000	0	5000	0
TSS	50	0	50	0
VSS	5	0	5	0
C-ALK	207	0	207	0
NC-ALK	0	0	0	0
CALCIUM	110	0	110	0
MAGNESIUM	9.7	0	9.7	0
SODIUM	50	0	50	0
COPPER	0	0	0	0
IRON II	0	0	0	0
IRON IV	0.15	0	0.15	0
MANGANESE II	0	0	0	0
MANGANESE IV	0	0	0	0
CHLORIDE	120	0	120	0
SULFATE	107	0	107	0
NITRATE	105	0	105	0
TOC	10	0	10	0
NPOC	0	0	0	0
ARSENIC V	0	0	0	0
ARSENIC III	0	0	0	0
BARIUM	0	0	0	0
CADMIUM	0	0	0	0

CHROMIUM VI	0	0	0	0
CHROMIUM III	0	0	0	0
LEAD	0	0	0	0
MERCURY	0	0	0	0
ORG MERCURY	0	0	0	0
SELENIUM IV	0	0	0	0
SELENIUM VI	0	0	0	0
SILVER	0	0	0	0
FLUORIDE	0	0	0	0
ENDRINE	0	0	0	0
LINDANE	0	0	0	0
TOXAPHENE	0	0	0	0
2-4-D	0	0	0	0
SILVEX	0	0	0	0
METHOXYCHLOR	0	0	0	0
ALPHA RAYS	0	0	0	0
RADIUM-226	0	0	0	0
RADIUM-228	0	0	0	0
THMFP	0	0	0	0
CHCl3	0	0	0	0
CHBrCl2	0	0	0	0
CHBr2Cl	0	0	0	0
CHBr3	0	0	0	0
AlOH3	0	0	0	0
FeOH3	0	0	0	0
CaCO3	0	0	0	0
MgOH2	0	0	0	0

Rapid mixing process:

Input: H3

```
ENTER THE DESIRED VELOCITY GRADIENT ---- = [     600 ] 1/sec
ENTER THE DESIRED DETENTION TIME ------- = [      45 ] min
IDENTIFY WHICH COAGULANT IS DESIRED: --- = [       2 ]
   ENTER 1 FOR DRY ALUM, Al2(SO4)3+18.3H2O
   ENTER 2 FOR LIQUID ALUM, (SPECIFY DOSE AS DRY ALUM
EQUIVALENT)
   ENTER 3 FOR FERRIC SULFATE, Fe2(SO4)3+3H2O
   ENTER 4 FOR FERROUS SULFATE & DISSOLVED OXYGEN,
FeSO4+7H2O & O2
   ENTER 5 FOR NONE OF THE ABOVE
SPECIFY THE COAGULANT DOSE ------------- = [      40 ] mg/l
ENTER POLYMER DOSE IF POLYMER IS
DESIRED -------------------------------- = [    0.25 ] mg/l
```

AT THIS POINT PRESS ALT AND Z KEYS AT SAME TIME.
pH reduced from 7.5 to 7.12 by coagulant addition Operational pH range for alum is 5.5-7.8
Optimum pH for turbidity removal is 6.8
Optimum pH for color removal is 5.6

IF YOU WANT TO RAISE OR LOWER PH BY CHEMICAL ADDITION ENTER THE DESIRED
PH AFTER CHEMICAL ADDITION ------------- = [7.5]
IDENTIFY WHICH CHEMICAL TO USE IF RAISING
WATER PH = [2]
ENTER 1 FOR QUICK LIME, CaO
ENTER 2 FOR SODIUM HYDROXIDE, NaOH
ENTER 3 FOR SODA ASH, Na2CO3

END OF RAPID MIXING DATA INPUT

Changes incurred to stream vector by rapid mix process:

	Input Stream 1	Input Stream 2	Output Stream 1	Output Stream 2
PH	7.5	0	7.5	0
TSS	50	0	60.4	0
AlOH3	0	0	10.4	0
FeOH3	0	0	0	0

Rapid mixing output: H4

Operational flow =	28 mgd
Chemical dose for pH adjustment =	14.08012 mg/l Sodium hydroxide
Mixing volume =	2785.212 ft^3
Absolute water viscosity =	2.14E-05 lb*sec/ft^2
Mixing horsepower =	55.60316 hp

Construction cost, dollars		
Rapid mix basin		44823.14
Liquid alum		73963.67
Sodium hydroxide		46677.80
Polymer		23208.29
	Total	188672.9

Labor, man-hours/year		
Rapid mix basin		496.7706
Liquid alum		38.90171
Sodium hydroxide		124
Polymer		206.3215
	Total	865.9938

Maintenance & materials, dollars/year		
Rapid mix basin		52.35399
Liquid alum		98.76775
Sodium hydroxide		263.6736
Polymer		264.1615
	Total	678.9570

Process electrical energy, kwh/year

Rapid mix basin		254355.1
Liquid alum		5029.013
Sodium hydroxide		3270
Polymer		17300
	Total	279954.1

Building electrical energy, kwh/year

Liquid alum		100666.3
Sodium hydroxide		23309.22
Polymer		9025.687
	Total	133001.2

Chemical cost, dollars/year

Liquid alum		119185.6
Sodium hydroxide		119867.7
Polymer		42566.3
	Total	281619.6

Total costs:

Construction cost =	188672.9	$
Labor =	865.9938	man*hr/yr
Maintenance materials =	678.9570	$/yr
Process electrical energy =	279954.1	kw*hr/yr
Building energy =	133001.2	kw*hr/yr
Diesel fuel =	0	gal/yr
Natural gas =	0	10^6 ft^3/yr
Chemicals =	281619.6	$/yr

END OF RAPID MIXING DATA OUTPUT

Flocculation process:

Input: H1

ENTER THE DESIRED VELOCITY GRADIENT -- = [50] 1/sec
ENTER THE DESIRED DETENTION TIME ----- = [45] min

END OF FLOCCULATION DATA INPUT

Flocculation output: H2

Operational flow =	28	mgd
Basin volume =	167112.2	ft^3
Absolute water viscosity =	2.14E-05	lb*sec/ft^2
Flocculation horsepower =	29.73217	hp

Total costs:

```
Construction cost =          431624.1 $
Labor =                      950.8302 man*hr/yr
Maintenance materials =      6231.588 $/yr
Process electrical energy =136009.0 kw*hr/yr
Building energy =                   0 kw*hr/yr
Diesel fuel =                       0 gal/yr
Natural gas =                       0 10^6 ft^3/yr
Chemicals =                         0 $/yr
```

The effluent water properties are the same as the influent water properties.

END OF FLOCCULATION DATA OUTPUT

END OF WTRMAID PROGRAM

APPENDIX C
MACROS IN WTRMAID PROGRAM

Main Macro in WTRMAID Program

```
\m
{menucall menu}
SECTIONS PROCESS  HELP     GRAPH    DATA     EXECUTE  COPY     QUIT
Moves curMoves theProvides Use to caUse to caUpdates tUpdates tTerminates the program.
{menucall{menucall{menucall{menucall{menucall{branch e{home}/fd/qy
                                                       {quit}
{menucall sections}
INTRODUCTTREATMENTINFLUENT COST     CHEMICALSPROCESS  CONTAMINANTS
Moves theMoves theMoves theMoves theMoves theMoves theTable that shows which processes affect which
{goto}int{goto}tre{goto}pro{goto}cos{goto}che{goto}pro{goto}contam~
{quit}   {quit}   {quit}   {quit}   {quit}   {quit}   {quit}

{menucall process}
FLOCULATIRAPID MIXETC
Moves theMoves the cursor to the rapid mixing process section.
{goto}flo{goto}rpmix~
{quit}   {quit}

{menucall help}
H1-8     H9-16
Help messHelp messages 9 through 16.
{menucall help1}

{menucall help1}
H1       H2       H3       H4       H5       H6       H7       H8
Moves curMoves curMoves curMoves curMoves curMoves curMoves curMoves cursor to help message 8.
{goto}1~ {goto}2~ {goto}3~ {goto}4~ {goto}5~ {goto}6~ {goto}7~ {goto}8~
{?}      {quit}   {?}      {quit}
{goto}floc~       {goto}rpmix~
{quit}            {quit}

{menucall graph}
GRAPHS 1-GRAPHS 9-16
Graphs 1 Graphs 9 through 16.
{menucall graph1}

{menucall graph1}
GRAPH 1  GRAPH 2  GRAPH 3  GRAPH 4  GRAPH 5  GRAPH 6  GRAPH 7  GRAPH 8
View of gView of gView of gView of gView of gView of gView of gView of graph 8.
/gnu1~
q
```

```
{goto}grph1~
{quit}

{menucall data}
DATA 1    DATA 2    DATA 3    DATA 4    DATA 5    DATA 6    DATA 7    DATA 8
View of dView of dView of dView of dView of dView of dView of dView of data 8.
{goto}dat{goto}dat{goto}data3~
{?}       {?}       {?}
{goto}grp{goto}3~ {goto}4~
{quit}    {quit}    {quit}
                                                          Macro description
{branch exec}
/wgpd/reia4.ih1000~{home}/fdb:~                           clears ouput area
{beep}{getlabel "Do you want a file copy of your input? (Y or Nsaves file before execution
{if j55="y"}/wgpe/fswtrmaid~r~/wgpd                                "
{goto}ia5~                                                produces copy of stream/process map
/rv{esc}a287.g311~a425~                                            "
/dsda425.g449~pd425~a~g                                            "
{goto}d424~{end}{down}{left 3}/m{end}{right}{end}{right}           "
{end}{down}~a425~                                                  "
{goto}d425~{end}{down}{down}/re{left 2}{end}{down}~                "
{goto}ia5~/rv{esc}a421.g441~~{goto}ib1000~{end}{up}{down 2}{left}  "
Initial stream vector:{down 2}                            inserts label
/rv{esc}a342.f398~~{goto}ia1000~{end}{up}{down 2}         inserts initial stream vector
{if d425=4}{branch rpmixsub}                              branch to subroutine
{if f425=5}{branch flocsub}                               branch to subroutine
END OF WTRMAID PROGRAM{down}{goto}ia1~                    saves output file
{beep}{getlabel "Do you want a file copy of your output? (Y or produces extract output file
{if j69="y"}/fxv{esc}{?}~ia1.ih1000~                               "
{beep}{getlabel "Do you want a printed copy of your output? (Y produces printed copy of output
{if j71="y"}{goto}ia1000~{end}{up}/ppr{bs}.{left}{end}{up}{right 8}~agq   "
{goto}ia1~                                                moves cursor to top of output
/wgpe{quit}                                               enable protection

{branch rpmixsub}                                         rapid mix subroutine
/c{esc}as1.az332~as1~                                     recalculates rapid mix program
/rv{esc}as1.az29~~{goto}ia1000~{end}{up}{down 2}          inserts mix input data
Changes incurred to stream vector by rapid mix process:{down 2}inserts label
{let e346,av329}~{let e395,av330}~{let e396,av331}~{let e351,avinserts stream vector changes
/rv{esc}a342.f342~~{down}
/rv{esc}a343.f343~~{down}                                          "
/rv{esc}a346.f346~~{down}                                          "
/rv{esc}a351.f351~~{down}                                          "
/rv{esc}a395.f395~~{down}                                          "
/rv{esc}a396.f396~~{down 2}                                        "
/rv{esc}as61.az120~~{goto}ia1000~{end}{up}{down 2}        inserts m        "
{branch back}                                             return

{branch flocsub}                                          floc subroutine
/c{esc}aj1.aq108~aj1~                                     recalculates floc program
/rv{esc}aj1.aq8~~{goto}ia1000~{end}{up}{down 2}           inserts floc input data
/rv{esc}aj41.aq62~~{goto}ia1000~{end}{up}{down 2}         inserts floc output data
{branch back1}                                            return
```

Iteration Macro in WTRMAID Program

```
\z
/wgpd{goto}as17~/cas17.az215~~{goto}as1~
{if ay7<5}{let aw17,at215}~/wgpe{quit}
/wgpe{quit}
```

APPENDIX D
PH ITERATION CALCULATION IN RAPID MIX PROCESS OF WTRMAID PROGRAM

```
     PH =       7.5  HPLUS = 0.000000
    ALK =       207     OH = 0.000000
    ALK =   0.00414   HCO3 = 0.004127
     KW =   1.0E-14    CO3 = 0.000006
    KA1 = 0.000000  H2CO3 = 0.000293
    KA2 =   4.7E-11     CT = 0.004426

 TARGET = 0.004426

   PMAX =       7.5   DOSE =        40      PH =      5.25  HPLUS = 0.000005
   PMIN =         3 MOLDOSE =0.000059                           OH = 0.000000
  PHOLD =       7.5    ALK = 0.003782    ALK = 0.003782   HCO3 = 0.003788
     PH =      5.25                       KW =   1.0E-14    CO3 = 0.000000
                                         KA1 = 0.000000  H2CO3 = 0.047870
                                         KA2 =   4.7E-11     CT = 0.051658

    DEV = 0.047231                        PH =     6.375  HPLUS = 0.000000
   PMAX =       7.5                                          OH = 0.000000
   PMIN =      5.25                      ALK = 0.003782   HCO3 = 0.003782
    ABS =      2.25                       KW =   1.0E-14    CO3 = 0.000000
  PHOLD =      5.25                      KA1 = 0.000000  H2CO3 = 0.003584
     PH =     6.375                      KA2 =   4.7E-11     CT =  7.4E-03

    DEV = 0.002939                        PH =    6.9375  HPLUS = 0.000000
   PMAX =       7.5                                          OH = 0.000000
   PMIN =     6.375                      ALK = 0.003782   HCO3 = 0.003779
    ABS =     1.125                       KW =   1.0E-14    CO3 = 0.000001
  PHOLD =     6.375                      KA1 = 0.000000  H2CO3 = 0.000980
     PH =    6.9375                      KA2 =   4.7E-11     CT =  4.8E-03

    DEV = 0.000334                        PH =   7.21875  HPLUS = 0.000000
   PMAX =       7.5                                          OH = 0.000000
   PMIN =    6.9375                      ALK = 0.003782   HCO3 = 0.003776
    ABS =    0.5625                       KW =   1.0E-14    CO3 = 0.000002
  PHOLD =    6.9375                      KA1 = 0.000000  H2CO3 = 0.000512
     PH =   7.21875                      KA2 =   4.7E-11     CT =  4.3E-03
```

```
   DEV = -0.00013             PH = 7.078125  HPLUS = 0.000000
  PMAX =  7.21875                               OH = 0.000000
  PMIN =   6.9375            ALK = 0.003782   HCO3 = 0.003778
   ABS =  0.28125             KW =  1.0E-14    CO3 = 0.000002
 PHOLD =  7.21875            KA1 = 0.000000  H2CO3 = 0.000709
    PH = 7.078125            KA2 =  4.7E-11     CT =  4.5E-03

   DEV = 0.000062             PH = 7.148437  HPLUS = 0.000000
  PMAX =  7.21875                               OH = 0.000000
  PMIN = 7.078125            ALK = 0.003782   HCO3 = 0.003777
   ABS = 0.140625             KW =  1.0E-14    CO3 = 0.000002
 PHOLD = 7.078125            KA1 = 0.000000  H2CO3 = 0.000603
    PH = 7.148437            KA2 =  4.7E-11     CT =  4.4E-03

   DEV = -0.00004             PH = 7.113281  HPLUS = 0.000000
  PMAX = 7.148437                               OH = 0.000000
  PMIN = 7.078125            ALK = 0.003782   HCO3 = 0.003777
   ABS = 0.070312             KW =  1.0E-14    CO3 = 0.000002
 PHOLD = 7.148437            KA1 = 0.000000  H2CO3 = 0.000654
    PH = 7.113281            KA2 =  4.7E-11     CT =  4.4E-03

   DEV = 0.000007             PH = 7.130859  HPLUS = 0.000000
  PMAX = 7.148437                               OH = 0.000000
  PMIN = 7.113281            ALK = 0.003782   HCO3 = 0.003777
   ABS = 0.035156             KW =  1.0E-14    CO3 = 0.000002
 PHOLD = 7.113281            KA1 = 0.000000  H2CO3 = 0.000628
    PH = 7.130859            KA2 =  4.7E-11     CT =  4.4E-03

   DEV = -0.00001             PH = 7.122070  HPLUS = 0.000000
  PMAX = 7.130859                               OH = 0.000000
  PMIN = 7.113281            ALK = 0.003782   HCO3 = 0.003777
   ABS = 0.017578             KW =  1.0E-14    CO3 = 0.000002
 PHOLD = 7.130859            KA1 = 0.000000  H2CO3 = 0.000640
    PH = 7.122070            KA2 =  4.7E-11     CT =  4.4E-03

   DEV = -0.00000
   ABS = 0.008789
    PH = 7.122070
```

APPENDIX E
DATA REQUIRED TO PRODUCE LOGARITHMIC GRAPH IN WTRMAID PROGRAM

Log graph:

					X Labels		Y Labels		Label
			X	A	A below	B	B left	C	C right
Scale	Trans X	Trans Y							
			0	0		0	1000		
1000	0	0	1	0		0			
2000	0.100343	0.076128							
3000	0.159040	0.120660	0	0.076128		0.076128	2		
4000	0.200686	0.152256	1	0.076128		0.076128			
5000	0.232990	0.176764							
6000	0.259383	0.196789	0	0.120660		0.120660			
7000	0.281699	0.213719	1	0.120660		0.120660			
8000	0.301029	0.228385							
9000	0.318080	0.241321	0	0.152256		0.152256	4		
10000	0.333333	0.252893	1	0.152256		0.152256			
20000	0.433676	0.329021							
30000	0.492373	0.373553	0	0.176764		0.176764			
40000	0.534019	0.405149	1	0.176764		0.176764			
50000	0.566323	0.429657							
60000	0.592717	0.449682	0	0.196789		0.196789	6		
70000	0.615032	0.466612	1	0.196789		0.196789			
80000	0.634363	0.481278							
90000	0.651414	0.494214	0	0.213719		0.213719			
100000	0.666666	0.505786	1	0.213719		0.213719			
200000	0.767009	0.581914							
300000	0.825707	0.626446	0	0.228385		0.228385			
400000	0.867353	0.658043	1	0.228385		0.228385			
500000	0.899656	0.682550							
600000	0.926050	0.702575	0	0.241321		0.241321			
700000	0.948366	0.719505	1	0.241321		0.241321			
800000	0.967696	0.734171							
900000	0.984747	0.747107	0	0.252893		0.252893	10^4		
1000000	1	0.758679	1	0.252893		0.252893			
2000000		0.834807							
3000000		0.87934	0	0.329021		0.329021	2		
4000000		0.910936	1	0.329021		0.329021			
5000000		0.935444							
6000000		0.955468	0	0.373553		0.373553			
7000000		0.972398	1	0.373553		0.373553			
8000000		0.987064							
9000000		1.000000	0	0.405149		0.405149	4		
			1	0.405149		0.405149			

	0 0.429657	0.429657
1 0.429657	0.429657	
0 0.449682	0.449682	6
1 0.449682	0.449682	
0 0.466612	0.466612	
1 0.466612	0.466612	
0 0.481278	0.481278	
1 0.481278	0.481278	
0 0.494214	0.494214	
1 0.494214	0.494214	
0 0.505786	0.505786	10^5
1 0.505786	0.505786	
0 0.581914	0.581914	2
1 0.581914	0.581914	
0 0.626446	0.626446	
1 0.626446	0.626446	
0 0.658043	0.658043	4
1 0.658043	0.658043	
0 0.682550	0.682550	
1 0.682550	0.682550	
0 0.702575	0.702575	6
1 0.702575	0.702575	
0 0.719505	0.719505	
1 0.719505	0.719505	
0 0.734171	0.734171	
1 0.734171	0.734171	
0 0.747107	0.747107	
1 0.747107	0.747107	
0 0.758679	0.758679	10^6
1 0.758679	0.758679	
0 0.834807	0.834807	2
1 0.834807	0.834807	
0 0.87934	0.87934	
1 0.87934	0.87934	
0 0.910936	0.910936	4
1 0.910936	0.910936	

```
              0 0.935444          0.935444
       1 0.935444          0.935444

       0 0.955468          0.955468       6
       1 0.955468          0.955468

       0 0.972398          0.972398
       1 0.972398          0.972398

       0 0.987064          0.987064
       1 0.987064          0.987064

       0         1                1       9
       1         1                1

       0         0     1000
       0         1

0.100343         0        2
0.100343         1

0.159040         0
0.159040         1

0.200686         0        4
0.200686         1

0.232990         0
0.232990         1

0.259383         0        6
0.259383         1

0.281699         0
0.281699         1

0.301029         0
0.301029         1

0.318080         0
0.318080         1

0.333333         0     10^4
0.333333         1

0.433676         0        2
0.433676         1

0.492373         0
0.492373         1

0.534019         0        4
0.534019         1
```

0.566323	0	
0.566323	1	
0.592717	0	6
0.592717	1	
0.615032	0	
0.615032	1	
0.634363	0	
0.634363	1	
0.651414	0	
0.651414	1	
0.666666	0	10^5
0.666666	1	
0.767009	0	2
0.767009	1	
0.825707	0	
0.825707	1	
0.867353	0	4
0.867353	1	
0.899656	0	
0.899656	1	
0.926050	0	6
0.926050	1	
0.948366	0	
0.948366	1	
0.967696	0	
0.967696	1	
0.984747	0	
0.984747	1	
1	0	10^6
1	1	

X	Y			
G = 20				
1800	34990	0.085090	0.390452	
10000	114410	0.333333	0.520571	
25000	144120	0.465980	0.545926	
100000	274850	0.666666	0.616830	G=20
500000	900420	0.899656	0.747158	
1000000	1770400	1	0.821414	
G = 50				

1800	34990	0.085090	0.390452	
10000	114420	0.333333	0.520580	
25000	150210	0.465980	0.550472	
100000	304080	0.666666	0.627930	
500000	1057150	0.899656	0.764783	
1000000	2077750	1	0.838996	G=50
G = 80				
1800	34990	0.085090	0.390452	
10000	123540	0.333333	0.529003	
25000	163900	0.465980	0.560051	
100000	368570	0.666666	0.649055	
500000	1373620	0.899656	0.793544	G=80

APPENDIX F
INPUT SECTIONS IN SPREADSHEET PREPROCESSOR FOR WOOD'S MODEL

1. SYSTEM DATA

```
*Simulation type key (1 for EPS) ----------------- = [        ] H1
Flow identification code ------------------------- = [        ] H2
        (0=CFS, 1=GPM, 2=MGD, 3=SI)
Number of pipes ---------------------------------- = [   ?    ] H3
Number of junction nodes ------------------------- = [   ?    ] H4
Number of PRV's ---------------------------------- = [        ] H5
*Data check -------------------------------------- = [        ] H6
*Suppress input summary -------------------------- = [        ] H7
*Geometric verification -------------------------- = [        ] H8
*Maximum number of trials (default=20) ----------- = [        ] H9
*Relative accuracy (default=.005) ---------------- = [        ] H10
*Specific gravity (default=1.0) ------------------ = [        ] H11
*Kinematic viscosity (default=Hazen Williams Equ.) = [        ] H12
*Non consecutive pipe numbering ------------------ = [        ] H13

        *Omit this data to use program defaults
```

2. LABEL (three lines)   H14

```
------------------------------------------------------------------------
FILL THIS SECTION                                                      |
WITH ANY INPUT YOU DESIRE                                              |
TO DESCRIBE YOUR HYDRAULIC NETWORK PROGRAM                             |
------------------------------------------------------------------------
```

3. PRV DATA (omit if there are no PRV's)   H15

```
                                    PRV #1        PRV #2        PRV #3        PRV #4
Junction node number ----------- = [      ]      [      ]      [      ]      [
Downstream pipe number --------- = [      ]      [      ]      [      ]      [
Grade maintained by PRV -------- = [      ]      [      ]      [      ]      [

                                    PRV #5        PRV #6        PRV #7        PRV #8
Junction node number ----------- = [      ]      [      ]      [      ]      [
Downstream pipe number --------- = [      ]      [      ]      [      ]      [
Grade maintained by PRV -------- = [      ]      [      ]      [      ]      [
```

	PRV #9	PRV #10	PRV #11	PRV #12
Junction node number ----------- =	[ ]	[ ]	[ ]	[
Downstream pipe number --------- =	[ ]	[ ]	[ ]	[
Grade maintained by PRV -------- =	[ ]	[ ]	[ ]	[

	PRV #13	PRV #14	PRV #15	PRV #16
Junction node number ----------- =	[ ]	[ ]	[ ]	[ ]
Downstream pipe number --------- =	[ ]	[ ]	[ ]	[ ]
Grade maintained by PRV -------- =	[ ]	[ ]	[ ]	[ ]

	PRV #17	PRV #18	PRV #19	PRV #20
Junction node number ----------- =	[ ]	[ ]	[ ]	[ ]
Downstream pipe number --------- =	[ ]	[ ]	[ ]	[ ]
Grade maintained by PRV -------- =	[ ]	[ ]	[ ]	[ ]

	PRV #21	PRV #22	PRV #23	PRV #24
Junction node number ----------- =	[ ]	[ ]	[ ]	[ ]
Downstream pipe number --------- =	[ ]	[ ]	[ ]	[ ]
Grade maintained by PRV -------- =	[ ]	[ ]	[ ]	[ ]

	PRV #25	PRV #26	PRV #27	PRV #28
Junction node number ----------- =	[ ]	[ ]	[ ]	[ ]
Downstream pipe number --------- =	[ ]	[ ]	[ ]	[ ]
Grade maintained by PRV -------- =	[ ]	[ ]	[ ]	[ ]

	PRV #29	PRV #30	PRV #31	PRV #32
Junction node number ----------- =	[ ]	[ ]	[ ]	[ ]
Downstream pipe number --------- =	[ ]	[ ]	[ ]	[ ]
Grade maintained by PRV -------- =	[ ]	[ ]	[ ]	[ ]

4. PIPE DATA

Pipe Number	H16 Pipeline Status Code	H17 Node Number 1	H18 Node Number 2	H19 Length	H20 Diameter	H21 Rough-ness	H22 Sum of Minor Loss Coef's	H23 Pump Data	H24 FGN HGL	H25 Pipe Number
1		?	?	?	?	?				1
2										2
3										3
4										4
5										5
.										.
.										.
.										.

5. PUMP DATA

Total number of pumps ---------- = [ ] H26

Pump Number	Cutoff Head 1st Point	H27 Discharge 1st Point	Head 2nd Point	Discharge 2nd Point	Head 3rd Point	Discharge 3rd Point
1		0				
2		0				
3		0				
4		0				
5		0				
.						
.						
.						

6. JUNCTION DATA

H28 Demand	H29 Ele-vation	H30 Junction Node Number	H31 Pipes connecting this junction node Pipe #1	Pipe #2	Pipe #3	Pipe #4	Pipe #5
		1					
		2					
		3					
		4					
		5					
		.					
		.					
		.					

8. OUTPUT OPTION DATA

Output selection --------------------------------- = [ ]
Number of juncts. for max-min pressure summary --- = [ ]
Input next two items for limited output only
Number of pipes for limited output --------------- = [ ]
Number of junction nodes for limited output ------ = [ ]
Key for geometric data --------------------------- = [ ]
Changes incorporated prior to first run ---------- = [ ]

END OF ALL DATA ---------------------------------- = [-2]

APPENDIX G
HELP MESSAGES IN PREPROCESSOR FOR WOOD'S MODEL

1. Simulation Type Key

Leave blank to run a regular simulation. Input the number 1 to run an extended period simulation.

2. Flow Identification Code

Leave blank for cubic feet per second.
Input the number 1 for gallons per minute.
Input the number 2 for million gallons per day.
Input the number 3 for liters per second.

3. Number of Pipes

Input the number of pipes in your network.

4. Number of Junction Nodes

Input the number of junction nodes in your network.

5. Number of PRV's

Input the number of pressure regulating valves in your network. Leave blank if there are no pressure regulating valves in your network.

6. Data Check

This option will allow the computer to read and check all the input data including changes but suppresses the actual analysis.

Output pertaining to the original data and changes is obtained and can be used for checking. This option is useful for checking physical data by hand before going to the expense of the analysis and is obtained at a fraction of the cost. It is also very useful for checking a number of changes before they are actually processed.

Input the number 1 to engage this option. Leave blank if this option is not desired.

7. Suppress Input Summary

A complete summary of input data for pipelines and junctions is normally output. However, this output can be redundant and lengthy and may be suppressed using this option.

Input the number 1 to engage this option. Leave blank if this option is not desired.

8. Geometric Verification

The input data summary includes a list of pipes connecting at each junction node which can be checked by the user against system geometry and, if verified, will assure that the input data for connecting nodes is correct. An option is available for computer verification of this data. If this option is used the computer will check pipes connecting junction nodes generated using the input data for this purpose. A successful check of this data will assure that the system is geometrically correctly input. A successful verification will produce a verifying message while an unsuccessful verification will produce a message identifying this error and the junction node where it occurred and will suppress the analysis until this discrepancy is removed.

Input the number 1 to engage this option. In addition, the within the junction section, the connecting pipes at each junction node must be input in ascending numerical order. Leave blank if this option is not desired.

9. Maximum Number of Trials

This limit is set at 20 unless a different limit is specified as the ninth number. It is unlikely that this limit will ever be reached, but it is imposed to guard against an unforeseen convergence problem (this conceivably could be caused by a check valve or a pump operating extremely close to its boundary condition).

Leave blank for default setting or input the number of trials you desire.

10. Relative Accuracy

This parameter determines when the solution is acceptable. It is defined as the total (absolute) change in flowrate in the pipes from the previous trial divided by the total (absolute) flowrate and is set at 0.005 unless this option is employed to change this value. It is unlikely that the user will want to exercise this option and change the relative accuracy and such a change is not recommended.

Leave blank for the default setting. Input another value to change the relative accuracy.

11. Specific Gravity

Unless specified by the user, water is assumed to be the liquid being transported.

Leave blank if the default setting is desired. Input a different specific gravity (ratio of liquid density to water density) if required.

12. Kinematic Viscosity

The default setting keys the use of the Hazen Williams head loss equation, which is appropriate for water distribution systems. For liquids (and for water, if desired) the Darcy Weisbach equation should be used.

Leave blank for the default setting. If the Darcy Weisbach equation is desired, input the value for the kinematic viscosity (in feet squared per second or meters squared per second for SI units). If this option is used, the pipe roughness for the expression must be input for the roughness within the pipe data section with the units of millifeet or millimeters for SI units.

13. Non Consecutive Pipe Numbering

Non consecutive numbering junction nodes is always acceptable. However, it is assumed that the pipes are numbered one to p, where p equals the total number of pipes, and the data is input in this order unless this option is employed.

Leave blank if consecutive numbering is used. Input the number 1 if you input pipes in a non consecutive order. In addition the pipes must be numbered in an ascending order. No alphabetic information is allowed.

14. Label

Whatever is typed within this space appears as a problem identification heading for the computer output.

15. PRV Data

Omit this section if pressure regulating valves are not within your network. Note that for each PRV, the location of the PRV is defined by a junction node at the PRV and the pipe downstream from the PRV. In addition, the grade which the PRV is set to maintain, in feet or meters, is required. A total of 32 PRV's can be input.

16. Pipeline Status Code

Leave blank if there is no check valve in the pipe.

Input the number 1 if there is a check valve in the pipe.

Input the number 2 if the pipe is closed.

17. Node Number 1 and Node Number 2

Input the two junction nodes which the pipe connects. If the direction of flow is known, input the junction node number which the water is leaving as node number 1 and input the junction node which the water flows into as node number 2.

18. Node Number 1 and Node Number 2

Input the two junction nodes which the pipe connects. If the direction of flow is known, input the junction node number which the water is leaving as node number 1 and input the junction node which the water flows into as node number 2.

19. Length

Input the length of the pipe in feet or meters depending on the units you have chose.

20. Diameter

Input the inside diameter of the pipe in inches or centimeters depending the units you have chosen.

21. Roughness

Input the Hazen Williams roughness coefficient if the Hazen Williams head loss equation is being used. If the Darcy Weisbach head loss relationship is being used, then the pipe roughness in millifeet or millimeters is input here.

22. Sum of Minor Loss Coefficients

Input the sum of the minor loss coefficients for this pipe.

23. Pump Data

Leave blank if no pump is in the line.

Input the number -1 if a pump is in the line and you desire to enter three pump operating data points within the pump section.

If you desire to enter the useful horsepower input by the pump, enter this value directly.

24. FGN HGL

Leave blank if the pipe does not connect to a fixed grade node.

If the pipe connects to a fixed grade node, input the value of the total grade (elevation + pressure head) in feet or meters.

25. Pipe Number

Leave blank for consecutive numbering, 1,2,3...,p.

If non consecutive numbering is used, input pipe number. Pipes must be in ascending order and no alphabetic information is allowed.

26. Total Number of Pumps

Leave blank if no pumps are within the network. Otherwise input the total number of pumps within the network.

27. Pump Data

This data is supplied only for pumps described by operating data. This option is keyed by a -1 for the pump data within the pipe data section. The head in feet or meters and the discharge in the flow units specified are included for three operating points. The first pump operating data point must be the cutoff head and discharge, the second point at an intermediate point of normal operation, and the third point at the extreme end of normal pump operation. The pump data must be input in the same order as the pumps were listed in the pipe data section.

28. Demand

Leave blank if there is no external demand at the node. If there is an external demand at the junction node, input the value in the flow units specified. The value is positive for an outflow and negative for inflow.

29. Elevation

Leave blank if you do not desire the pressure at this node in the output data. Input the elevation in feet or meters if pressure output data is desired.

30. Junction Node Number

Input the node number for this junction. The junction nodes are already numbered in this column but they can be replaced by any number desired.

31. Pipes Connecting This Junction Node

Leave blank if you do not desire a geometric verification. If you asked for a geometric verification within the system data section, you must complete this section. Enter the number for each pipe connecting the junction node in ascending order.

32. Output Option Data

Leave this section blank. This section is for limiting the amount of output data and for an extended period simulation. These cards have not been input into the Lotus 123 preprocessor at this time.

33. End of all Data

An input of -2 indicates that all input has been completed.

APPENDIX H
DATA CARDS IN SPREADSHEET PREPROCESSOR
FOR WOOD'S MODEL

1. SYSTEM DATA

```
         10        20        30        40        50        60        70
1234567890123456789012345678901234567890123456789012345678901234567890123456789O

0   0 ?    ?       0    0    0    0    0  0.000000  0.00000 0.00000000    0    0
```

3. PRV DATA

```
         10        20        30        40        50        60        70
12345678901234567890123456789012345678901234567890123456789012345678901234567890

    0    0    0.00      0    0    0.00      0    0    0.00      0    0     0.00
    0    0    0.00      0    0    0.00      0    0    0.00      0    0     0.00
    0    0    0.00      0    0    0.00      0    0    0.00      0    0     0.00
    0    0    0.00      0    0    0.00      0    0    0.00      0    0     0.00
    0    0    0.00      0    0    0.00      0    0    0.00      0    0     0.00
```

4. PIPELINE DATA

```
         10        20        30        40        50        60        70
12345678901234567890123456789012345678901234567890123456789012345678901234567890

0 ?   ?    ?        ?         ?               0.00      0.00      0.00         1
0   0    0     0.00      0.00      0.00      0.00      0.00      0.00          2
0   0    0     0.00      0.00      0.00      0.00      0.00      0.00          3
0   0    0     0.00      0.00      0.00      0.00      0.00      0.00          4
0   0    0     0.00      0.00      0.00      0.00      0.00      0.00          5
```

5. PUMP DATA

```
         10        20        30        40        50        60        70
1234567890123456789012345678901234567890123456789012345678901234567890123456789

      0.00      0.00      0.00      0.00      0.00      0.00
      0.00      0.00      0.00      0.00      0.00      0.00
      0.00      0.00      0.00      0.00      0.00      0.00
      0.00      0.00      0.00      0.00      0.00      0.00
      0.00      0.00      0.00      0.00      0.00      0.00
```

6. JUNCTION DATA

```
         10        20        30        40        50        60        70
1234567890123456789012345678901234567890123456789012345678901234567890123456789

      0.00      0.00   1    0    0    0    0    0    0    0    0    0    0
      0.00      0.00   2    0    0    0    0    0    0    0    0    0    0
      0.00      0.00   3    0    0    0    0    0    0    0    0    0    0
      0.00      0.00   4    0    0    0    0    0    0    0    0    0    0
      0.00      0.00   5    0    0    0    0    0    0    0    0    0    0
```

7. BLANK LINE

```
 0
```

8. OUTPUT OPTION DATA

```
         10        20        30        40        50        60        70
1234567890123456789012345678901234567890123456789012345678901234567890123456789

    0    0    0    0    0    0
```

END OF CHANGES - END OF ALL DATA

```
         10        20        30        40        50        60        70
1234567890123456789012345678901234567890123456789012345678901234567890123456789

  -2.000
```

APPENDIX I
MACROS IN SPREADSHEET PRE- AND POSTPROCESSORS FOR WOOD'S MODEL

Macro in Preprocessor

```
\m
{menucall menu}
SECTIONS COMPILE  COPY     HELP     QUIT     CHANGES
Moves theInitiatesMakes a cProvides Ends progCopies existing file onto this diskette so that change
{menucall{branch c{goto}eol{menucall/qy      {goto}exl~{?}~{home}/wgpd/fcce{?}~{goto}fgl~{?}~{home}

{menucall sections}
SYSTEM   LABEL    PRV      PIPE     PUMP     JUNCTION OUTPUT
Moves theMoves theMoves theMoves theMoves theMoves theMoves the cursor to this section.
{goto}sys{goto}lab{goto}prv{goto}pip{goto}pum{goto}jun{goto}output~
{quit}   {quit}   {quit}   {quit}   {quit}   {quit}   {quit}

{menucall help}
SYSTEM 1-SYSTEM 9-LABEL    PRV      PIPE 16-2PIPE 24-2PUMP     JUNCTION OUTPUT
Provides Provides Provides Provides Provides Provides Provides Provides Provides help in this secti
{menucall{menucall{goto}14~{goto}15~{menucall{menucall{menucall{menucall{menucall system}
                  {?}      {?}
                  {goto}lab{goto}prv~
                  {quit}   {quit}

{menucall sys}
1        2        3        4        5        6        7        8
Provides Provides Provides Provides Provides Provides Provides Provides further explanation of this
{goto}1~ {goto}2~ {goto}3~ {goto}4~ {goto}5~ {goto}6~ {goto}7~ {goto}8~
{?}      {?}      {?}      {?}      {?}      {?}      {?}      {?}
{goto}sys{goto}sys{goto}sys{goto}sys{goto}sys{goto}sys{goto}sys{goto}system~
{quit}   {quit}   {quit}   {quit}   {quit}   {quit}   {2quit}  {quit}

{menucall sys1}
9        10       11       12       13
Provides Provides Provides Provides Provides further explanation of this data entry point.
{goto}9~ {goto}10~{goto}11~{goto}12~{goto}13~
{?}      {?}      {?}      {?}      {?}
{goto}sys{goto}sys{goto}sys{goto}sys{goto}system~
{quit}   {quit}   {quit}   {quit}   {quit}
```

```
          {menucall pip}
16       17       18       19       20       21       22       23
Provides Provides Provides Provides Provides Provides Provides Provides further explanation of this
{goto}16~{goto}17~{goto}18~{goto}19~{goto}20~{goto}21~{goto}21~{goto}23~
{?}      {?}      {?}      {?}      {?}      {?}      {?}      {?}

{goto}pip{goto}pip{goto}pip{goto}pip{goto}pip{goto}pip{goto}pip{goto}pipe~
{quit}   {quit}   {quit}   {quit}   {quit}   {quit}   {quit}   {quit}

{menucall pip1}
24       25
Provides Provides further explanation of this data entry point.
{goto}24~{goto}25~
{?}      {?}
{goto}pip{goto}pipe~
{quit}   {quit}

{menucall pup}
26       27
Provides Provides further explanation of this data entry point.
{goto}26~{goto}27~
{?}      {?}
{goto}pum{goto}pump~
{quit}   {quit}

{menucall jun}
28       29       30       31
Provides Provides Provides Provides further explanation of this data entry point.
{goto}28~{goto}29~{goto}30~{goto}31~
{?}      {?}      {?}      {?}
{goto}jun{goto}jun{goto}jun{goto}junction~
{quit}   {quit}   {quit}   {quit}
                                                            macro description
{branch compile}
/wgpd                                                       disable protection
/fdb:~{goto}w1~/fcceblank~/wgra{goto}g26~{edit}~            combines file BLANK
/pfsystem~rrw6.aj6~oml0~mt0~ouqgq                           creates system print file
/pflabel~rra63.h65~oml0~mt0~ouqgq                           creates label print file
{goto}cr6~{end}{right}{down g28}                            creates prv file
/re{end}{left}{end}{down}~                                            "
/pfprv~rrcr6.dc13~oml0~mt0~ouqgq                                      "
{goto}al6~{end}{right}{down g26}                            moves pipe file
/re{end}{left}{end}{down}~                                            "
{goto}al6~/rv{end}{right}{end}{down}~al1000~                          "
{goto}as1000~                                                         "
{if e323>0}{for ef13,1,g26,1,mac_rtn}                {if @cellinserts blank rows
/pfpipe~rral1000.au1100~oml0~mt0~ouqgq               {down}{recreates pipe print file
{goto}aw6~{end}{right}{down e323}                           creates pump print file
/re{end}{left}{end}{down}~                                            "
/pfpump~rraw6.bb105~oml0~mt0~ouqgq                                    "
```

```
          {goto}bg6~{end}{right}{down g27}                   creates junction print file
/re{end}{left}{end}{down}~                                       "
/pfjunction~rrbg6.bs105~oml0~mt0~ouqgq                           "
/pfoutput~rrbu6.ce6~oml0~mt0~ouqgq                     creates output print file
/pfend~rrch6.cm6~oml0~mt0~ouqgq                        creates end print file
/pfblank~rrbu11~oml0~mt0~ouqgq                         creates blank print file
{goto}a700~                                            moves cursor
/fitsystem~{down}{goto}a701~                           imports system print file
/fitlabel~{goto}a704~                                  imports label print file

{if g28>0}/fitprv~{goto}a1000~{end}{up}{down}          imports prv print file if it exists
/fitpipe~                                              imports pipe print file
{goto}a1000~{end}{up}{down}                            moves cursor
{if e323>0}/fitpump~{goto}a1000~{end}{up}{down}        imports pump file if it exists
/fitjunction~{end}{down}{down}                         imports juntion print file
/fitblank~{down}                                       imports blank print file
/fitoutput~{down}                                      imports output print file
/fitend~                                               imports end print file
{if e323>0}{goto}a700~{down g26+e323+3+g28+e323}       inserts pump file data within pipe f
{for eg36,1,e323,1,sub_rtn}                   /m~{end}{up}{up}~{       "
{if e323>0}{down}/wdr{end}{down}{up}~         {return} deletes b       "
{goto}eo1~{?}~/pf{?}~ra700.m1000~oml0~mt0~ouqgq        saves file
/qy                                                    quit
```

Macro in Postprocessor

```
\m      {menucall menu}

IMPORT   COPY     HELP     QUIT
InitiatesProduces An explanTerminates the program.
{branch i/fdb:~/fs/rnchere~/qy
                                              macro description
{branch import}
/wgpd{goto}bb100~{?}~{goto}cc1~/fin{?}~       imports file to postprocess
{goto}cc2000~{end}{up}{up}/c{down}~ak1~       configures net flow data
{end}{up}{end}{up}/c{end}{down}{right}~v6~    configures fixed grade node summary data
{end}{up}/c~t1~                               configures net system demand figure
{end}{up}{end}{up}/c{end}{down}{end}{right}~k4~   configures data
{end}{up}{end}{up}/c{end}{down}{end}{right}~a4~   configures flow and velocity data
{goto}a2000~{end}{up}{down 3}/ck1.o100~~      configures data
{goto}a2000~{end}{up}{down 3}/cq1.t1~~        configures net system demand figure
{goto}a2000~{end}{up}{down 3}/cv1.w100~~      configures fixed grade node summary data
{goto}a2000~{end}{up}{down 3}/cad1.ak2~~      configures net flow data
/rek1.ak100~/recc1.cz2000~                    clears spreadsheet
{goto}a4~/wdr~{home}                          return to home
{quit}                                        quit
```

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BIOGRAPHICAL SKETCH

Captain Michael A. Moore was born on January 17, 1955, in Jacksonville, Florida, to Rear Admiral and Mrs. V. W. Moore, Jr. He attended numerous public schools in conjunction with his father's assignments with the U.S. Navy and graduated from Camp Zama American High School in Japan. He enrolled in the Army Reserve Officer Training Corps program at the University of California, Santa Barbara, and received his commission and a Bachelor of Arts degree in environmental science in 1978.

He has served tours at the Air Defense Artillery Basic Officer Course at Fort Bliss, Texas, with the Second Battalion, 67th Air Defense Artillery in Germany, at the Engineer Officer Advanced Course at Fort Belvoir, Virginia, and with the 14th Engineer Battalion (Combat, Corps) at Fort Ord, California. In 1985 he was assigned to the University of Florida, Gainesville, and entered the Department of Environmental Engineering Sciences graduate program with a concentration in water resource analysis. He received a Master of Science degree in August, 1987. His next assignment will be with the Middle East-Africa Project Office, U.S. Army Corps of Engineers with duty station in Cairo, Egypt.