ANALYSIS OF WATER RESOURCES PROBLEMS USING ELECTRONIC SPREADSHEETS

BY

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Over the last twenty years, comprehensive mathematical models have become very popular tools for solving water resources problems, including both quantitative and qualitative aspects. Many of these models however have become so unwieldy that practicing professionals do not use them. Instead, they continue to use the more traditional or simple models. Since these large models are often designed to be used in all parts of the world, they often become too general and/or too data intensive to be easily used by working professionals.

Electronic spreadsheets provide a means by which an engineer can prepare and analyze data, estimate model parameters, perform desk top calculations, and thoroughly document all of this work. If the expert could organize the preparation of the initial input data set for large models, or have a program that could both assist in arriving at reasonable parameter estimates and run small scale models, then the entire problem solving process could proceed much more efficiently.

This thesis presents a method of combining spreadsheets and comprehensive model analysis to provide a well documented system that can be used by the hydrologist to solve a variety of water resources problems. Included is a discussion of basic spreadsheet tools useful in creating knowledge bases, data handling capabilities, resource analysis, and site specific hydrologic models. A discussion of two case studies in which the ideas were applied is carried throughout the thesis. Finally, a working prototype of a spreadsheet-based expert system is presented, and additional spreadsheet tools and programs for future research are described.

Chairman

Chapter I

INTRODUCTION

Importance of Documentation in Problem Solving

Throughout the last twenty years, the fields of hydrology and environmental engineering have become more and more dependent on computers and comprehensive computer models. As the fields advance, the need for computers to perform the many complicated, lengthy and time consuming calculations for engineering design increases, but the time available for regulators and engineers to review these model outputs decreases. Although the many comprehensive models available to the engineer can handle a variety of hydrologic design problems, their use is still only marginally accepted.

Hydrologic problem solving involves several steps, each of which varies in its importance. Once the expert has determined the nature of the hydrologic problem, a suitable method of solution must be chosen. When dealing with regulatory agencies, the professional must often use the standard method prescribed by the agency, or be prepared to thoroughly justify his chosen alternative method. Often this becomes too tedious or lengthy a process for either the developer or the agency, and the sometimes more advanced method of solution chosen by the problem solver is ultimately compared to the standard simplistic method. If the regulatory agencies receive numerous permit applications, the permitter may not have the time or desire to check large hydrologic computer model input and output data sets, and will often reject these advanced results with the suggestion of using the simpler standard methods.

Large comprehensive computer models have become very popular with engineers for analyzing water resources problems, but such models have many disadvantages from a design viewpoint. The nature and quality of input data in hydrologic models varies greatly, and several techniques must be incorporated in order to prepare accurate and usable input data sets. Once all available necessary data are gathered, the expert must consider the accuracy and completeness of the values, and decide upon the appropriate method of input for the chosen model. All of the required data for a model are seldom available, so the professional must use his expertise to develop the needed data, both from his previous knowledge of data characteristics and from other available data sources. Since data may be missing both temporally (missing data points in a time series) and spatially (discontinued data stations or non-existent stations, as well as providing values for all points between data stations), an accurate system of providing these data points must be available. Each input parameter of the model must be justified, so the expert must have a reliable and clear method of explaining the input to regulatory agencies and other interested parties. Each professional may use a different method of determining any particular parameter in large models, so the explanation must be relayed to the permitter in very clear terms if the more advanced problem solving methods are to be used.

It is often advantageous for the engineer to use "desk top" analyses and simple models before delving into the much more complex main frame (and more recently, personal computer) surface and subsurface models, in order to prepare an initial data set and obtain a "feel" for the results. Sometimes this type of analysis alone may be a better alternative to using the large models, and can be more easily compared to the accepted design practice. Even if the currently accepted method is determined to be suitable, the input parameters and assumptions must be well documented in order to check the expert's results. This process can be achieved through the use of a variety of techniques that can be performed on an electronic spreadsheet.

Hydrologic Analysis and the Electronic Spreadsheet

The electronic spreadsheet is a general purpose computer program that is becoming a popular tool for many fields. Although originally designed as a business and management program, the spreadsheet has found dozens of uses throughout the sciences.

Appearing as a large matrix of compartments, or cells, the electronic spreadsheet can be thought of as a large electronic sheet of paper. Only a small part of the paper appears on the screen at a time, but any section of the paper can be accessed by a few simple keystrokes. The spreadsheet can perform many mathematical and statistical functions more quickly than a calculator, can be used as a simple word processor, and can rearrange, delete, and/or transfer data to work files, with the stroke of a key. Many spreadsheets now include very good graphical components, iterative procedures, and even a programming language that can be used to produce automated template programs. The electronic spreadsheet used in this thesis was Lotus 123, Release 1A (Lotus Development Corporation, 1983a), which includes all of the above features. Other electronic spreadsheets are available, ranging in price from $100 to $500.

As the popularity of the electronic spreadsheet grew, many uses of the programs have been discovered and presented in the literature. One periodical, LOTUS, is completely dedicated to presenting new ideas for spreadsheets, and for answering questions on LOTUS problems. Other periodicals in many different fields have now presented spreadsheet ideas that are very useful in several capacities (Johansson, 1985, Olsthoorn, 1985). One such article, by Olsthoorn (1985), on using the electronic spreadsheet as a groundwater modeling tool, was part of the inspiration for this thesis (see Chapter VI).

The electronic spreadsheet has many uses in the field of engineering because of its versatility in data handling and analysis. In hydrologic design, this analytical tool can be very useful in many areas: hydrologic model data preparation and calibration, local data analysis, parameter estimation, and comparisons of measured vs simulated responses. If the expert could organize the preparation of the initial input data set for large models, or have a program that could both provide assistance in arriving at reasonable parameter estimates and running small-scale models, the entire problem solving process could proceed much more efficiently. Such a computer system is the topic of this thesis.

Objectives

As my own experience has shown, the preparation, organization, and analysis of data to be used in water resources problem solving can be very difficult, time consuming, and at times, very frustrating. Attempting to prepare a large data set, as is required by most main frame computer models, from a small or scattered data set leads to many decisions concerning accuracy that must be determined by the expert. Small amounts of data must be extrapolated throughout the area to be analyzed, unmeasured parameters must be decided upon based on reasonable assumptions, and incomplete data sets must be completed. The purpose of this thesis is to present a method of combining spreadsheet analysis and comprehensive model analysis to provide a system that can be used by hydrologists to solve several water resources problems. The thesis is presented in the order in which the original ideas were developed, beginning with basic data handling and analysis, and ending with the use of Lotus-based hydrologic and design models. Used as an example throughout the thesis are two projects that were used to develop the ideas: 1) a study of the effects of the Cypress Creek and Cross Bar Wellfields (located north of Tampa, Florida) on the surrounding hydrologic system (Heaney et al., 1986); and 2) the development of a stormwater design computer program for the South Florida Water Management District.

Chapter II presents an introduction to spreadsheets and data handling, with emphasis on the knowledge base capabilities of the spreadsheet. The Cypress Creek study is used to illustrate how this simple yet effective method can be used in hydrologic problem solving.

Chapter III expands the ideas in the previous chapter to include data and parameter analysis for use in comprehensive hydrologic models.

Also presented are methods of performing basic analysis on the spreadsheet that may preclude the need for more comprehensive models.

Chapter IV presents a more advanced use of the analysis by creating hydrologic models on the spreadsheet, and linking the spreadsheet analysis process to the idea of expert systems; computer models that help the expert in analyzing and reasoning through a variety of problems.

Chapter V presents a working prototype of a spreadsheet-based expert system for designing stormwater systems in South Florida. The system includes local data bases and analysis, a continuous surface-subsurface water budget model, a flood routing model, and an interface to the Storm Water Management Model (SWMM).

Chapter VI is a presentation of some other more advanced spreadsheet analytical tools, that can be used in conjunction with the expert system analysis. Included is a brief discussion of numerical analysis, spatial data distribution, and a three-dimensional finite difference groundwater model; all done completely on a Lotus 123 spreadsheet.

Finally, Chapter VII presents conclusions, and several ideas for further research.

Chapter II

SPREADSHEETS AND DATA HANDLING

The electronic spreadsheet has become very popular in recent years for use in a variety of fields. Small businesses, for which the software was originally developed, have used the spreadsheets for numerous accounting and record keeping tasks, and have found their ease of use and low cost to be of tremendous benefit. Other fields have recently discovered many applications for the worksheets, and in turn, the spreadsheets have been developed to include a variety of options. Electronic spreadsheets have such a wide variety of options that, in a way, they can be considered another computer language, such as BASIC or FORTRAN. This chapter presents an introduction to spreadsheets and their data handling capabilities. Most of the methods presented were applied to a large hydrologic study in central Florida. The following chapter will present data analysis techniques as applied to the same study.

Literature Review

The history of the microcomputer, or personal computer, is a very short one. A brief outline of the history of microcomputer analysis is presented in Table II-1. Microcomputers first became available in kit form in 1974 when the Intel Corporation developed the first microprocessor, the 8008 (TM). For the first time, the enormous amount of

Table II-1. Time Line of Microcomputer Development.

Date	Event
Early 1940s	First computer developed.
Early 1970s	Computers found in most large businesses.
1974	Intel Corporation develops first microprocessor.
1977	Apple II released - first preassembled microcomputer.
1978	Tandy/Radio Shack releases TRS-80, with advanced microprocessing chip.
1978	VisiCalc released, first spreadsheet for microcomputer. Over 400,000 copies sold. Microcomputer industry booms.
1980	SuperCalc released. Spreadsheets advanced.
1983	Lotus 123 Release 1A released. Most popular software ever.
1984	Expert sytems for PC become available.
1985	Lotus 123 Release 2 released. Most powerful spreadsheet to date.

Source: LeBlond and Cobb, 1983.

electronic circuitry present in large main frame computers was condensed onto a single silicon chip. With this development, microcomputers first became available for the individual hobbyist.

In 1977, Steve Wozniak and Steve Jobs introduced the Apple II, the first preassembled microcomputer made available for the nontechnical user. The Apple II came complete with disk drive and a Disk Operating System (DOS), and introduced the general public to the use of computers for business and home use.

In the earlier years of microcomputers, prewritten software was not yet available, although many PC's came with the BASIC language installed or on disk. Microcomputer users were forced to be programming experts, and the BASIC language did not provide businesses and other users with a convenient method of problem solving. In 1978, VisiCalc, the first spreadsheet program for microcomputers, was released, and the microcomputer industry changed drastically. Created by Robert Frankston and Dan Bricklin (1978) at Harvard Business School, the VisiCalc program gave the businessman and analyst a powerful business tool that did not need to be shared with others. The program is a "visible calculator", and requires no previous programming knowledge (LeBlond and Cobb, 1983). Appearing as a matrix of 254 rows and 64 columns, VisiCalc allows calculations to be performed as if on a sheet of paper, and allows the user to easily understand all aspects of the model.

Personal computers became increasingly popular with the business world, and spreadsheets began to develop into more powerful analytical tools. In 1980, the Sorcim Corporation introduced SuperCalc, a larger spreadsheet that contained most of VisiCalc's features and more. This program is available for over 125 different microcomputers, and soon became one the most popular programs in the world. As the personal computers became more powerful and memory limitations expanded, the electronic spreadsheets became larger in size and in command options, while the price remained well under $500 for most software.

The new spreadsheet releases during the 1980s included Context Management Systems' Context MBA (TM), Multiplan (TM), and Lotus 123. Each program contains many new functions, including fully integrated graphics, data base management, and powerful mathematical capabilities.

Introduction to Lotus 123

One spreadsheet, Lotus 123, is the most popular of the electronic worksheets today. Developed by Mitchell Kapor, President of Lotus Development Corporation, and Jonathon Sachs, Vice President of Research and Development at Lotus, 123 is so named because it combines three programs in one: the electronic spreadsheet, business graphics, and data management programs (LeBlond and Cobb, 1983).

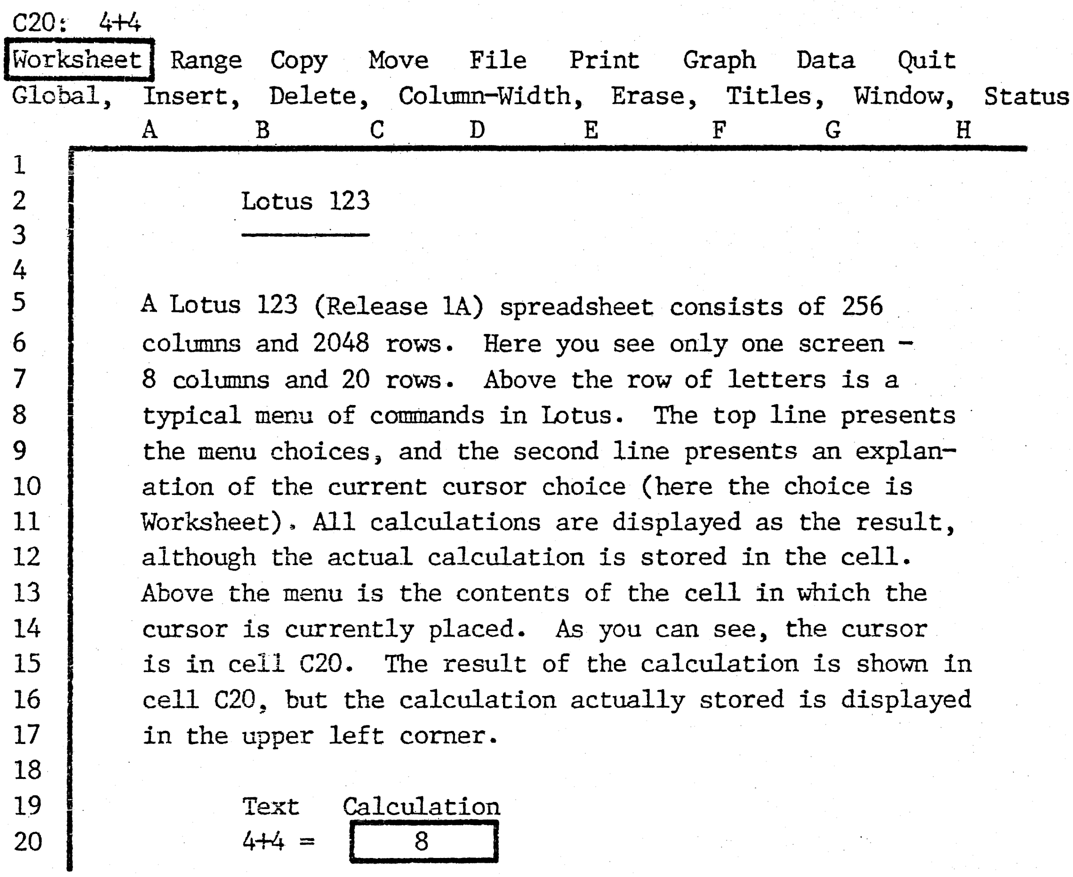
Like all spreadsheets, Lotus appears as a matrix of rows and columns, and can be considered to be a very large sheet of electronic paper. The user is able to add or erase calculations, text, or data in any block, or cell, at any time, and can import or export any part of the work and data to and from other software. The Lotus 123 data handling capabilities allow the user such an easy method of manipulation that many types of problems in many fields can be solved with little to no effort. Lotus 123 replaces the paper and pencil in numerical analysis, and provides a convenient method of analytical organization.

Besides the comprehensive manual that accompanies the software (Lotus Development Corporation, 1983b), several additional manuals have been written on the uses of Lotus 123 (LeBlond and Cobb, 1983, Anderson and Cobb, 1984, Ridington and Williams, 1985), and a monthly publication, LOTUS, is dedicated to advancing the use of the program. Although these many guides exist, Lotus 123 is almost self explanatory once a few basic concepts are understood.

The general framework of Lotus 123 (Release 1A) is shown in Figure II-1. Since the spreadsheet is so large, only a small portion of the total spreadsheet appears on the screen at a time. By using the arrow keys, the user may move the large cursor anywhere on the 254 by 2048 cell matrix (the most recent release, Release 2, contains 254 by 8192 cells), and can enter data, text, or calculations in any cell. By typing in a calculation (such as 2*2), the result of the calculation will appear in the cell (that is, 4). Although only the answer appears, the calculation is still stored in the cell, and can be seen in the upper left corner of the screen (when the cursor is in the correct cell).

Functions

Many of the basic functions in Lotus are presented in Tables II-2 and II-3. Most of Lotus's commands are invoked by striking the "/" key, upon which a branching menu of commands appears at the top of the screen. By using the /COPY command, the contents of this cell can be copied to any number of desired cells, or the /MOVE command will move



```
C20:  4+4
Worksheet  Range  Copy   Move   File   Print   Graph   Data   Quit
Global,  Insert,  Delete,  Column-Width,  Erase,  Titles,  Window,  Status
            A       B       C       D       E       F       G       H
 1
 2                  Lotus 123
 3                  ---------
 4
 5          A Lotus 123 (Release 1A) spreadsheet consists of 256
 6          columns and 2048 rows.  Here you see only one screen -
 7          8 columns and 20 rows.  Above the row of letters is a
 8          typical menu of commands in Lotus.  The top line presents
 9          the menu choices, and the second line presents an explan-
10          ation of the current cursor choice (here the choice is
11          Worksheet). All calculations are displayed as the result,
12          although the actual calculation is stored in the cell.
13          Above the menu is the contents of the cell in which the
14          cursor is currently placed.  As you can see, the cursor
15          is in cell C20.  The result of the calculation is shown in
16          cell C20, but the calculation actually stored is displayed
17          in the upper left corner.
18
19                  Text    Calculation
20                  4+4 =   |    8    |
```

Figure II-1. The Lotus 123 Spreadsheet.

Table II-2. Frequently Used Lotus 123 Release 1A Commands.

Commands	Uses
/Worksheet Commands	
Global Format	Worksheet number format
Global Column-Width	Set width of column
Global Recalculation	Formula recalculation procedures
Insert	Create row/columns
Delete	Eliminate rows/columns
/Range Commands	
Erase	Erase cell entries
Name	Maintain set of names for ranges
/Copy Command	Copy entries to new locations
/Move Command	Move entries to new locations
/File Commands	
Save or Retrieve	Store or restore data to/from disk
Combine	Incorporate stored files into current spreadsheet
Xtract	Save part of current spreadsheet onto disk
Import	Incorporate print file into spreadsheet
/Print Commands	Print to printer or ASCII file
/Graph Commands	All graphing options
/Data Commands	
Fill	Enter numbers into range
Sort	Sort data records
Query	Select data records from a data base

Source: Lotus 123 User's Manual, 1983b.

Table II-3. Frequently Used Lotus 123 Release 1A Functions.

Functions	Uses
@COS(x)	Cosine
@SIN(x)	Sine
@ASIN(x)	Arcsine
@RAND	Random number (0-1)
@SQRT(x)	Square root
@TRUE, @FALSE	1 (TRUE), 0 (FALSE)
@IF(cond,x,y)	x if cond is TRUE (non-zero) y if cond is FALSE (zero)
@IRR(guess,range)	Internal rate of return
@COUNT(list)	Numbers of values
@SUM(list)	Sum of values
@AVG(x)	Average value
@MIN(x)	Minimum value
@MAX(x)	Maximum value
@STD(x)	Standard deviation ("N" method)
@VAR(x)	Variance ("N" method)
@HLOOKUP(x,range,offset)	Table lookup with index row
@DCOUNT	Data base count

Source: Lotus 123 User's Manual, 1983b.

the cell's contents to any desired cell. If the equation needs to be changed, or if an error in text spelling occurs, the Edit commands allow any cell to be easily corrected. These three commands alone make Lotus 123 a very useful management and planning tool, and coupled with the dozens of other commands in the Lotus menu, make the spreadsheet a powerful tool for handling and analyzing data.

Data Handling Capabilities

Once a data set has been entered on a floppy disk, it is ready to be used by a Lotus 123 spreadsheet. Simply by importing the file into Lotus, the data are ready for analysis and manipulation, or, data entered directly to a Lotus spreadsheet may be copied to an ASCII file for use in other programs.

Part of a fairly large data set of monthly pan evaporation at a central Florida station is presented in Table II-4. This data set was entered directly onto the spreadsheet by hand, but the data can be imported from other floppy disk data sets in other formats, or with linkage to a large mainframe and sufficient memory, the data can be imported from large data sets on magnetic tape.

Once the data set is on the spreadsheet, it can be rearranged and analyzed. By using the /Data Sort command, the data may be sorted in order of any of the data points in the set; in the example, by evaporation amount, by month, and/or by year (Table II-4). The data set may be rearranged into any format for use in other programs or for easy analysis, partially deleted to dispose of unnecessary data points, or copied to any other points on the spreadsheet. A frequency analysis may

Table II-4. Monthly Lake Alfred Evaporation Data Analysis on Lotus 123.

Chronological Listing

Year	Month	Evaporation (inches)
75	1	3.58
75	2	4.08
75	3	6.44
75	4	7.22
75	5	8.05
75	6	7.40
75	7	6.97
75	8	7.22
75	9	6.02
75	10	5.36
75	11	3.87
75	12	2.86
76	1	3.10
76	2	4.34
76	3	6.25
76	4	7.13
76	5	7.90
76	6	0.40
76	7	7.55
76	8	7.75
76	9	6.40
76	10	5.45
76	11	3.18
76	12	2.50

Count	24.00
Minimum	0.40
Maximum	8.05
Mean	5.46
Standard Deviation	2.05

Data Sorted by Depth

Year	Month	Evaporation (inches)
76	6	0.40
76	12	2.50
75	12	2.86
76	1	3.10
76	11	3.18
75	1	3.58
75	11	3.87
75	2	4.08
76	2	4.34
75	10	5.36
76	10	5.45
75	9	6.02
76	3	6.25
76	9	6.40
75	3	6.44
75	7	6.97
76	4	7.13
75	4	7.22
75	8	7.22
75	6	7.40
76	7	7.55
76	8	7.75
76	5	7.90
75	5	8.05

be easily performed by using the /Data Distribution command, by which a designated portion of the data are placed into "bins," or data ranges, in order to count how many of each data range are found in the data set.

Graphics

It is usually advantageous for the expert to begin data analysis by acquiring a "feel" for the data, or being able to visualize what the compiled data actually look like as a set. This can be accomplished easily by using one of the many graphical options in Lotus 123.

By using a simple line plot, which is accomplished by just a few keystrokes, one can quickly visualize a set of data. In a time series, such as in Figure II-2, obvious trends and anomalies can easily be seen and further analyzed. Possible typographical errors in the data set, i.e., June 1976 in Figure II-2, can be spotted quickly through the use of line plots. Once the graph has been constructed, the user has immediate access to the graph by stroking the F10 key, and is able to return to the graph after each change in the data as a check. As an even quicker reference tool, the graphs may be printed for convenience when working with data on the screen.

Lotus also includes bar, stacked bar, and pie chart graphics, as well as an XY plot, which, unlike the line plot, sorts the X values in ascending order. In addition to regular data point plotting, the XY plot option may be used for crude but useful mapping techniques, which will be discussed below. All graphics may be saved within the file to be used at any time, or may be saved in a print file for later use.

By using all of the above Lotus techniques, as well as many other Lotus commands, it is easy to begin constructing a knowledge base for

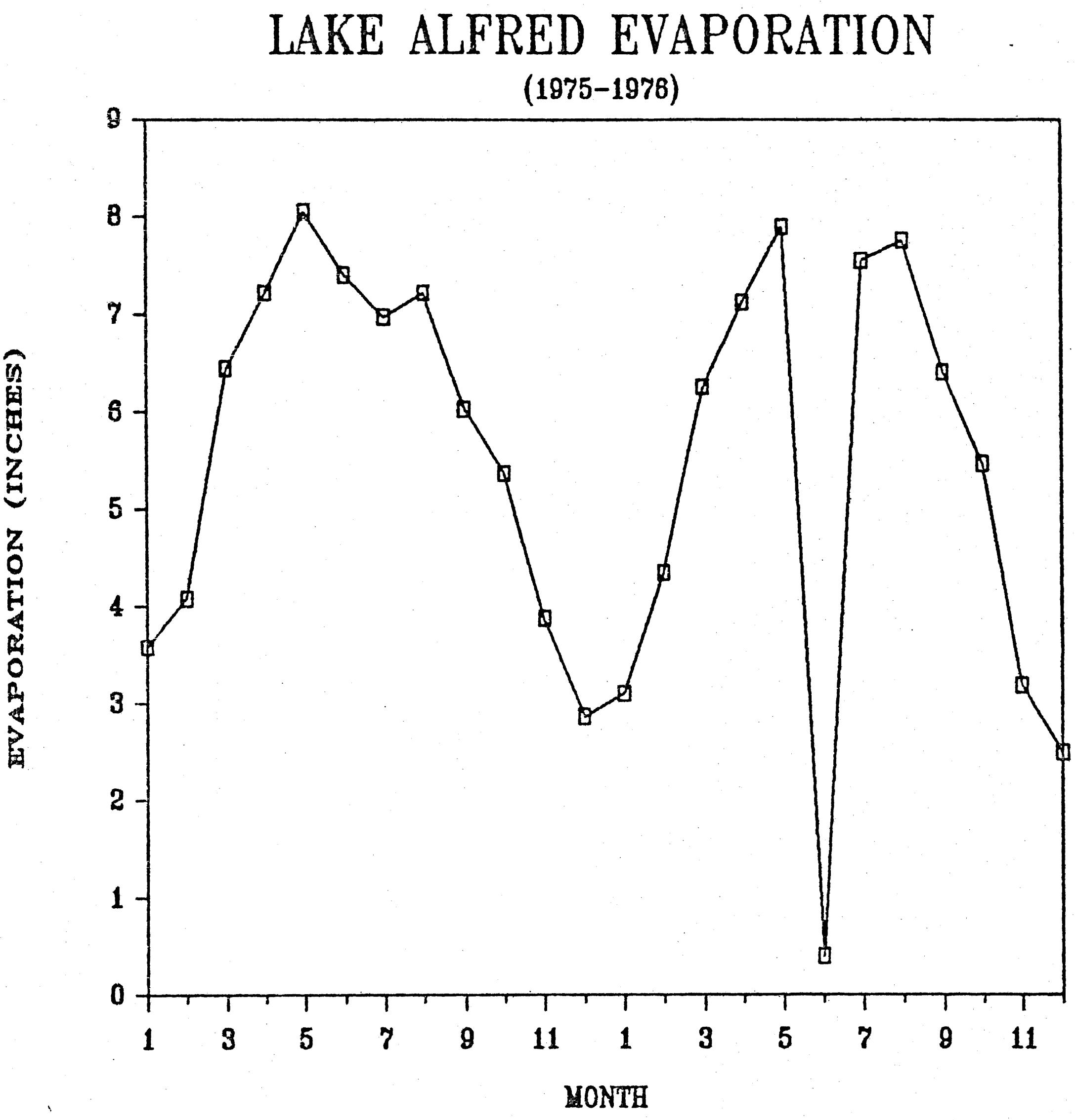


Figure II-2. Evaporation Time Series Presented on Lotus 123 Graphics.

any data analysis problem. If all of the pertinent data can be input, organized and documented within one spreadsheet, further analysis can be continued much more efficiently. As an example, the following is a presentation of a direct application of a Lotus knowledge base. This spreadsheet knowledge base was used to organize data during a University of Florida study of the effects of large drinking water supply wellfields on the surrounding hydrologic system (Heaney et al., 1986).

Knowledge Base Construction

When performing a hydrologic study, large amounts of data are required in order to evaluate each component of the water budget. Besides the obvious components of the hydrologic system such as precipitation, streamflow, evapotranspiration, and groundwater fluctuations and storage, other data used to further analyze changes must be considered. Such data include information on topography, land use, lake levels, soils, geology, and well pumping. When dealing with a fairly large study area, this data set can become unwieldy. Such was the case in the Cypress Creek study.

The study area was the portion of the Cypress Creek Basin (CCB) located in Pasco County, in west-central Florida between U.S. Highway 41 to the west and Interstate 75 to the east (Figure II-3). The basin extends northward for about 14 miles from its outlet, just south of State Road 54. Cypress Creek runs north to south through the Cypress Creek Basin, draining 117 square miles of sandy ridges, flatwoods, hammocks, and swamps. Two areas within the Cypress Creek Basin were of

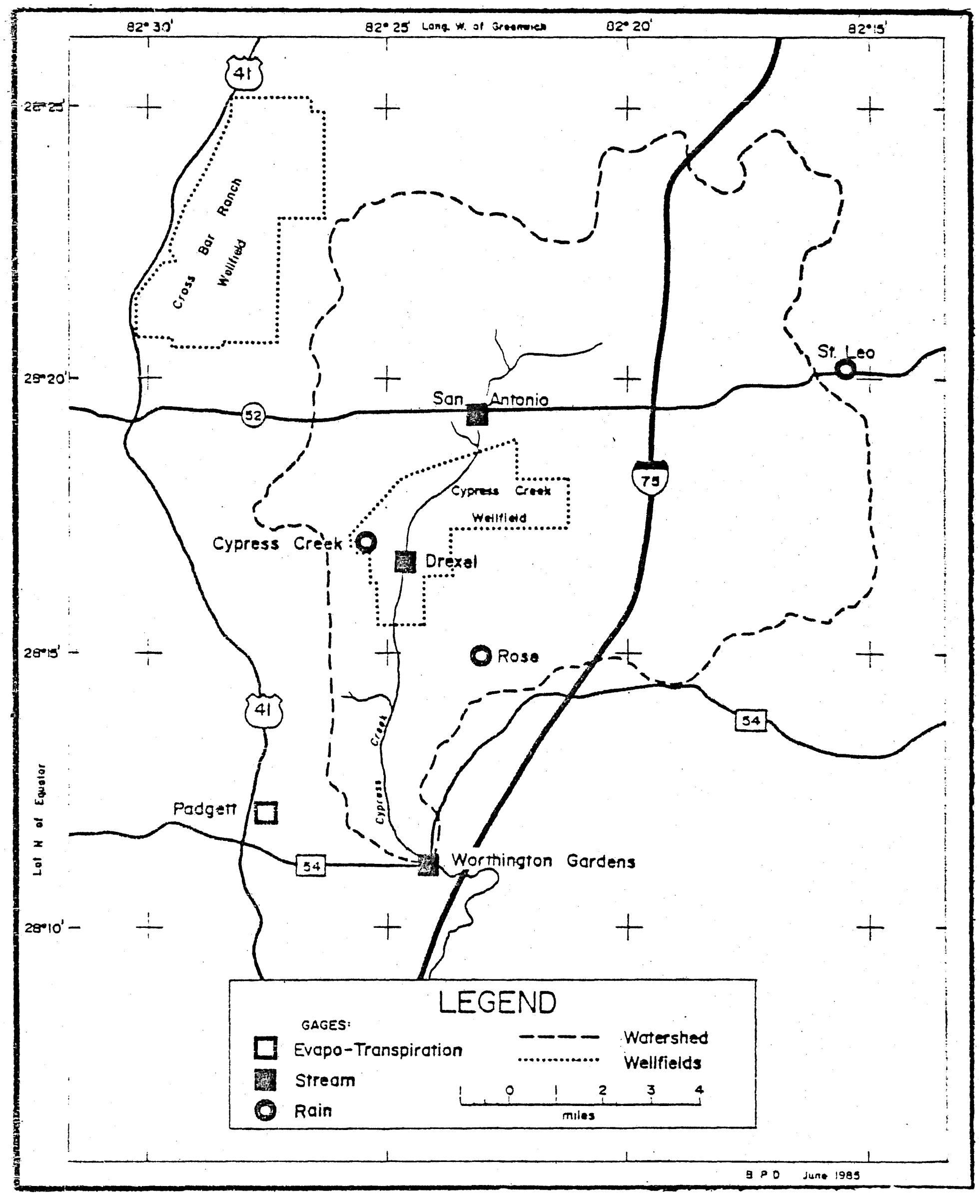


Figure II-3. Cypress Creek Basin, Oakes Pond Watershed, and Cypress Creek and Cross Bar Ranch Wellfields, North of Tampa, Florida (Heaney et al., 1986).

specific interest: the Oakes Pond Watershed (9.1 square miles), and the Cypress Creek Wellfield (7.9 square miles).

Although a fairly complete data base was collected on the study area, a method of organization was needed to permit efficient analysis and documentation on all work performed. Once primary analysis was performed on each parameter, and the expert began to acquire an understanding for the system, further analysis was needed. Since previous analysis was constantly being recalled, documentation of earlier steps was essential in order to avoid losing previous work. When dealing with very large data sets to be analyzed by several members of the research group, the need for organization became evident.

The knowledge base structure that was used for the Cypress Creek study is described below. Each parameter was considered separately and allotted a separate Lotus spreadsheet file.

Mapping

A spreadsheet-based map of the study area showing the location of each raingage to be used in the study is presented in Figure II-4. Through the use of a Lotus XY plot and data labeling, these crude but quite useful maps were constructed for each parameter file in the study. Such maps provide a quick reference for anyone using the file, and avoid the need to return to other printed maps during analysis.

By creating a list of X and Y coordinates (Table II-5) on the spreadsheet, any number of Z attributes may be assigned. In the case of Table II-5, which is a portion of the data used to create the previously presented raingage map, a 16 by 16 matrix was formed by entering a

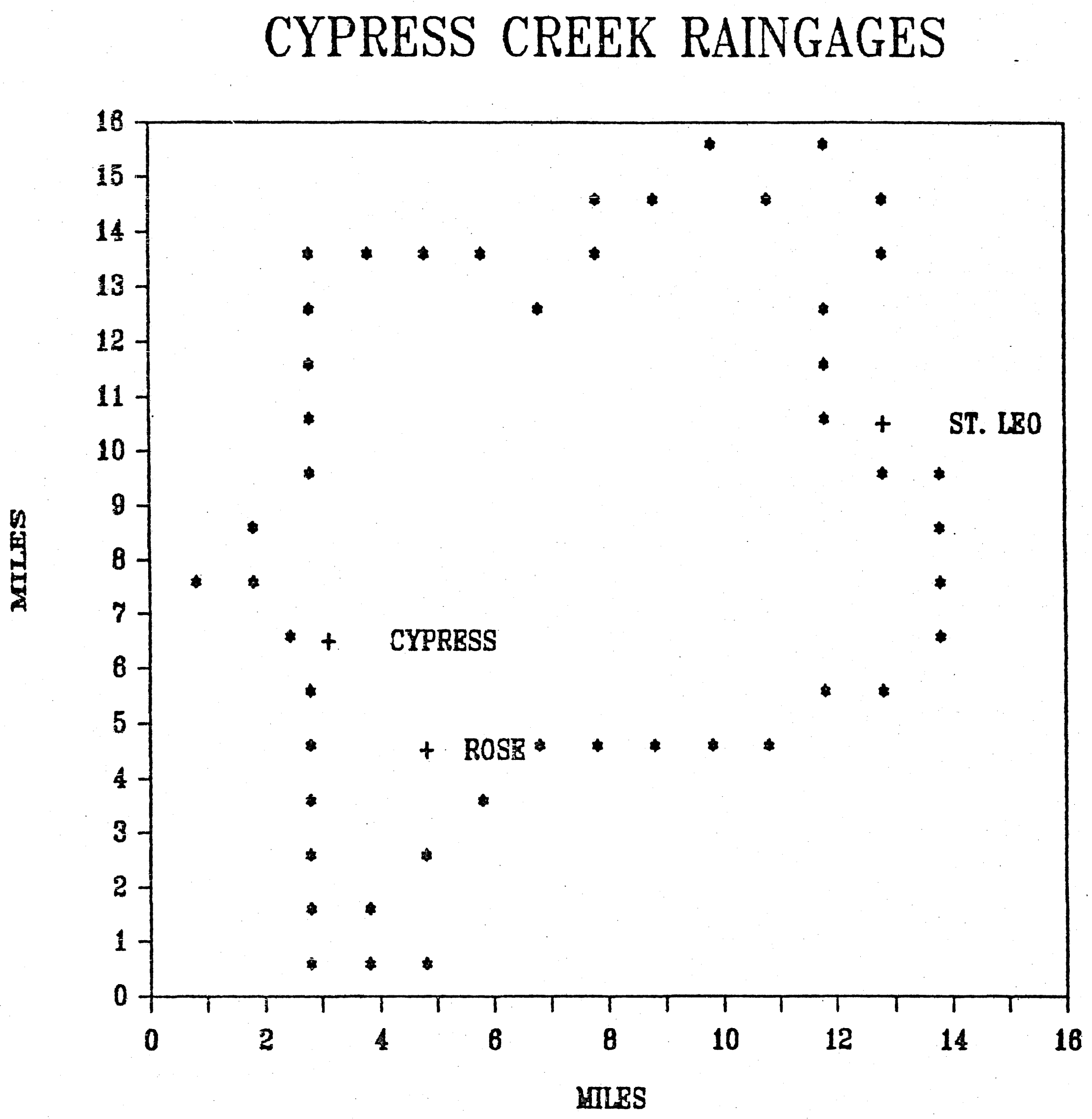


Figure II-4. Cypress Creek Basin Represented on Lotus 123 Map.

Table II-5. Portion of Rain Database for Cypress Creek Raingages, Presented on Lotus 123.

Coordinates (miles)		Attributes			
		Boundary	Perlnd	Gage	Elevation
X	Y	Z(1)	Z(2)	Z(3)	Z(4)
0.5	0.5				
1.5	0.5		1		
2.5	0.5	*	1	R	70
3.5	0.5	*	1	R	50
4.5	0.5	*	1	R	55
5.5	0.5				
6.5	0.5				
7.5	0.5				
8.5	0.5				
9.5	0.5				
10.5	0.5				
11.5	0.5				
12.5	0.5				
13.5	0.5				
14.5	0.5				
15.5	0.5				
0.5	1.5				
1.5	1.5				
2.5	1.5	*	1	R	75
3.5	1.5	*	1	R	50
4.5	1.5				
5.5	1.5				
6.5	1.5				
7.5	1.5				
8.5	1.5				
9.5	1.5				
10.5	1.5				
11.5	1.5				
12.5	1.5				
13.5	1.5				
14.5	1.5				
15.5	1.5				
0.5	2.5				
1.5	2.5				
2.5	2.5	*	1	R	50

Note: A Perlnd is a subcatchment used in the HSPF simulation model series of coordinates (X=.5 through 15.5, with corresponding Y values). Each cell of the matrix can represent any unit of area; in this case, each cell represents one square mile. Since the area of the watershed is 117 square miles, this matrix will easily accommodate the entire watershed. By using the /Copy command, it is unnecessary to type in all 256 values. The first 16 values may be entered through use of the /Data Fill command, by which any consecutive set of numbers may be entered instantly and automatically. The /Copy command may then be used to copy the original 16 to the desired amount of cells. Using this same technique for the Y values will create a 256 node matrix within a few minutes.

Since the Cypress Creek Basin is irregularly shaped and covers only 117 square miles, data labels were used to create a boundary for the watershed. By placing an asterisk (*) as the first attribute, Z(1) (in a column beside the X and Y values) for each square that lies on the watershed boundary, the basin is easily outlined on the graph (Figure II-5). Lotus graphics also allow a grid to overlay the map, in order to better visualize each block in the matrix (Figure II-6). Once the first map is constructed, it is very easy to alter the scale of the map by multiplying all X and Y coordinates by a scaling integer, as is seen in Figure II-7.

Each coordinate was specified as .5, 1.5, 2.5, etc. as opposed to integers in order to center the data labels within each cell on the map. If integers had been used, the data labels would have been placed at the grid nodes, where they could not be easily read. In this manner, several additional Z attributes can be created for each data point using

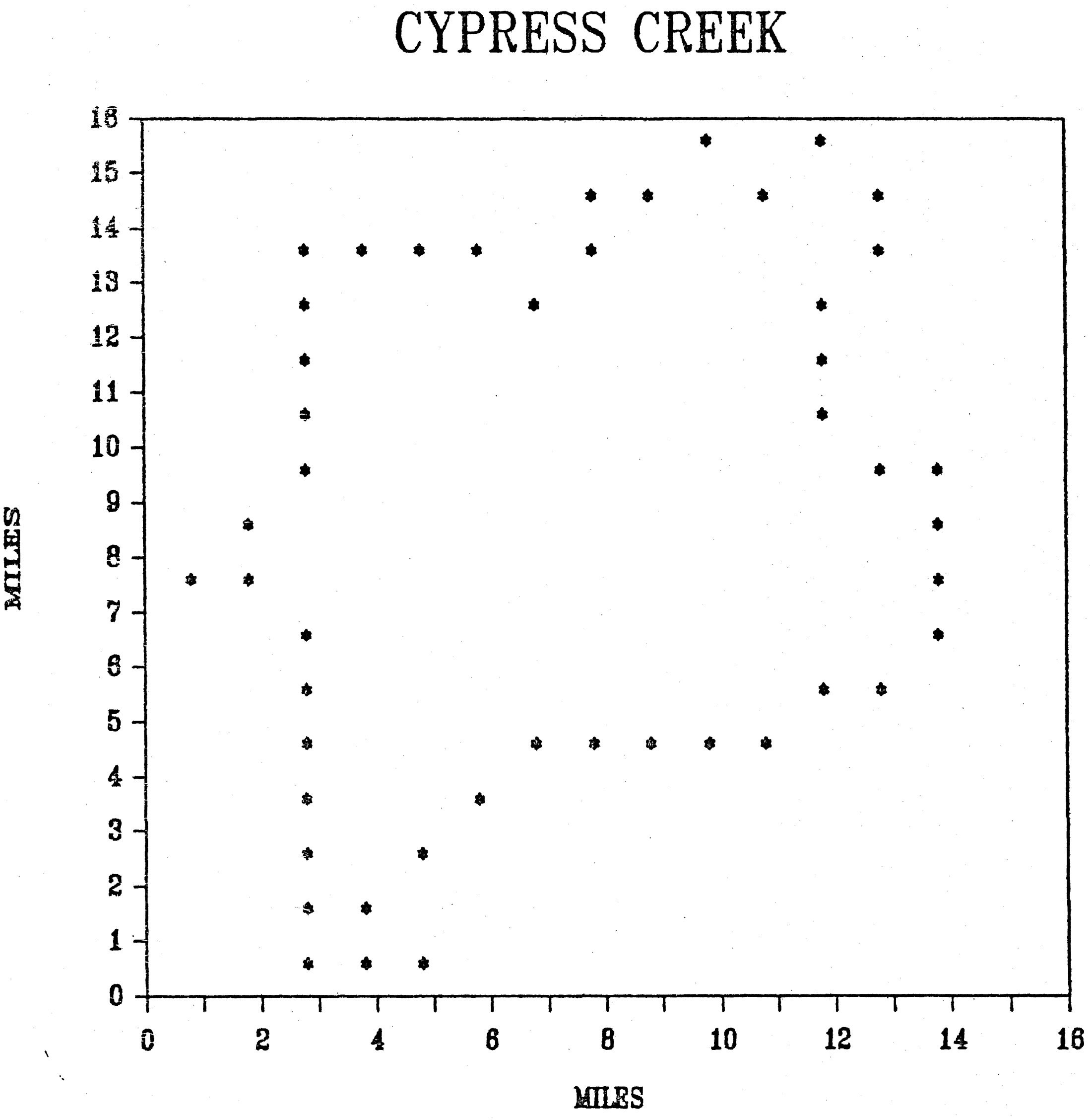


Figure II-5. Lotus Map Outline of Cypress Creek Basin.

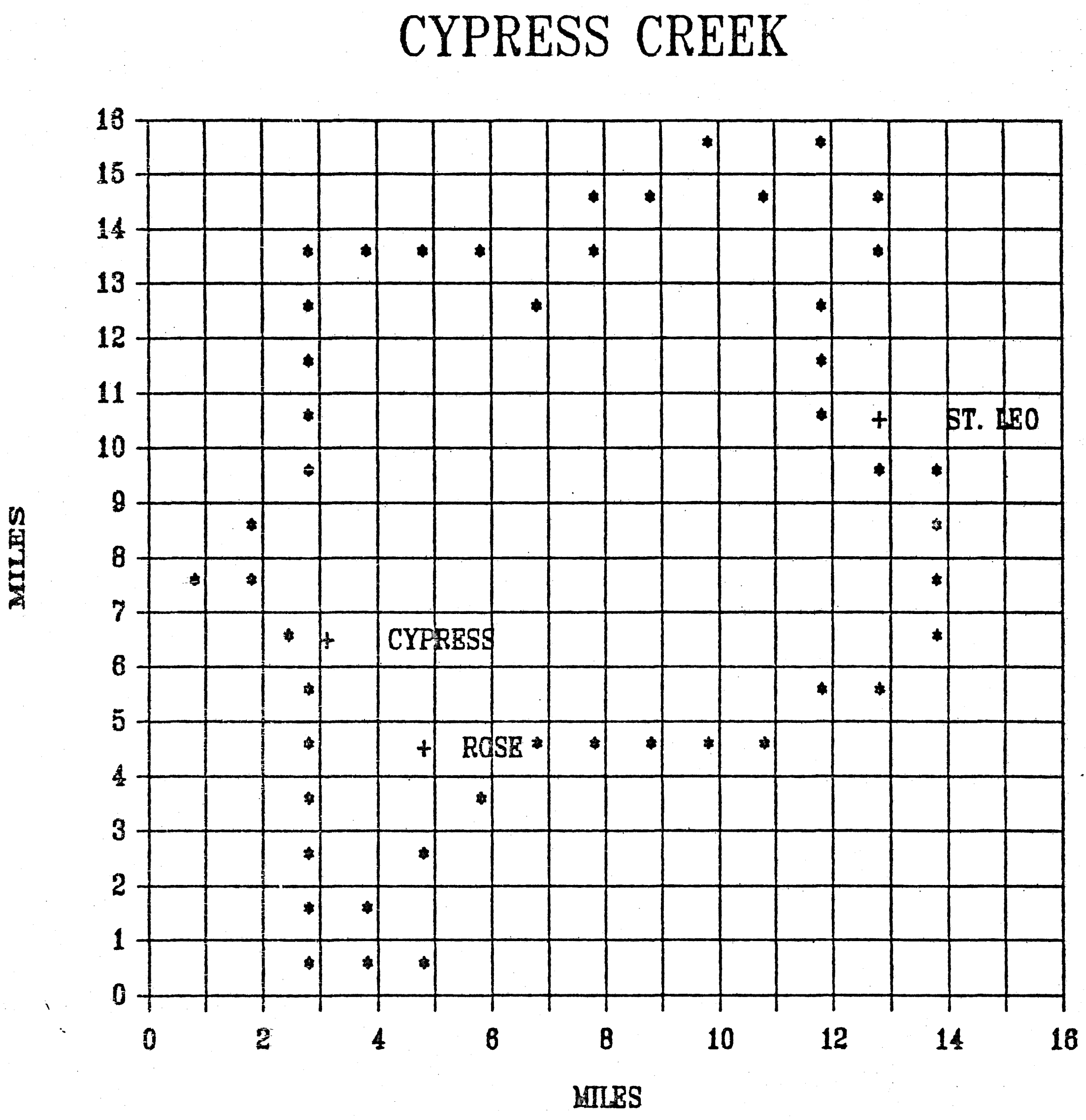


Figure II-6. Lotus Map of Cypress Creek with Vertical and Horizontal Gridding.

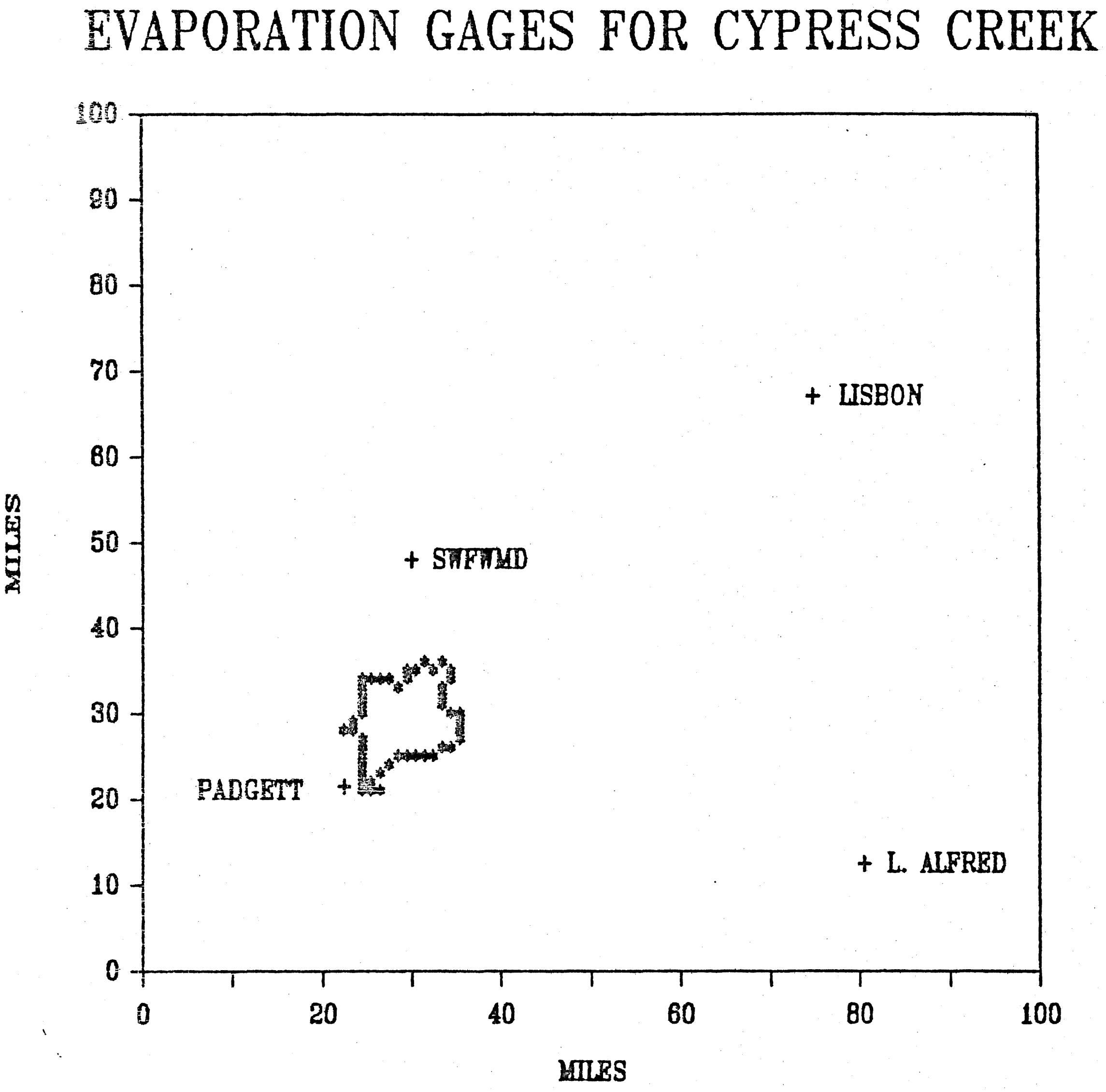
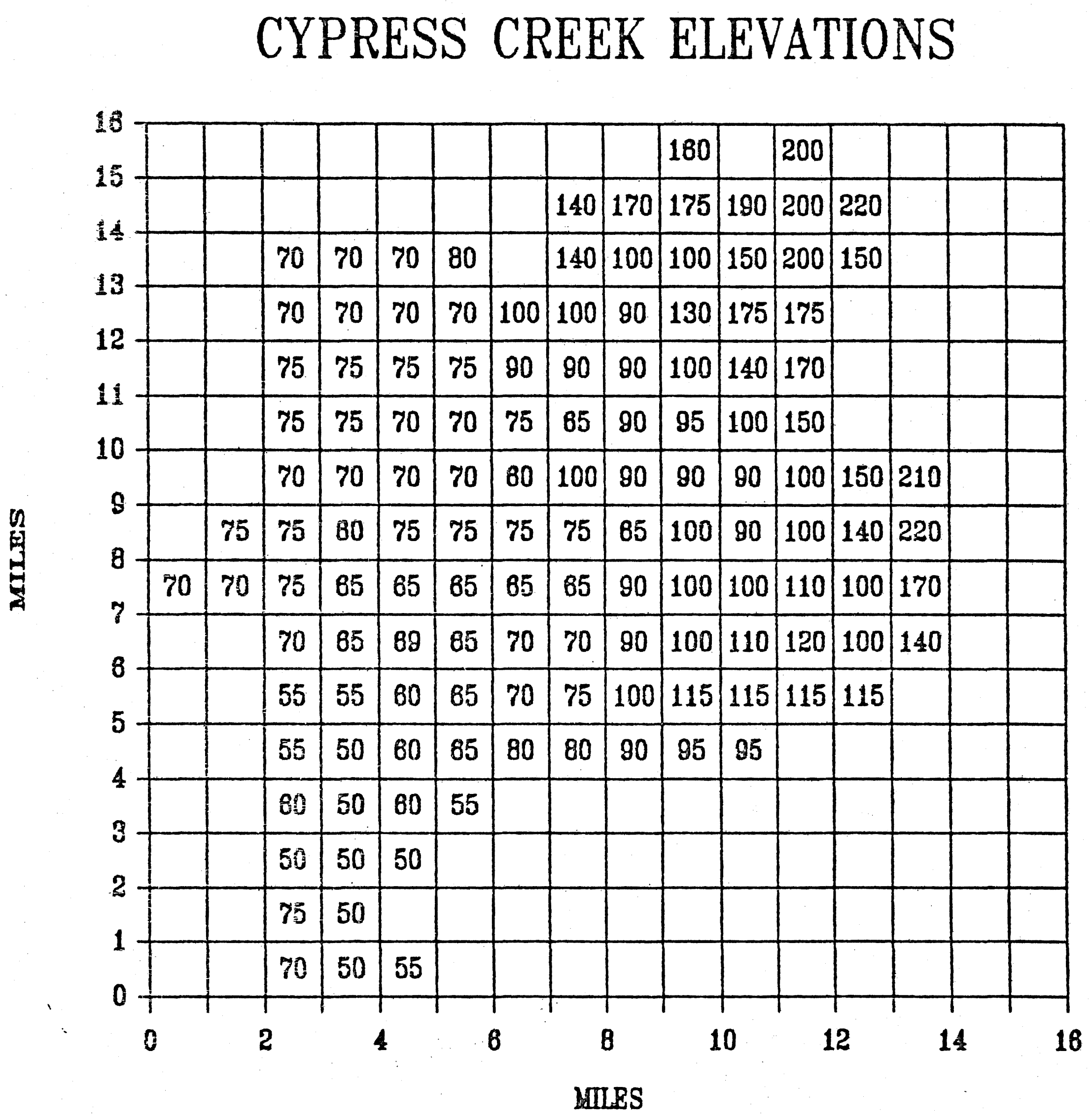


Figure II-7. Lotus Map of Evaporation Gages Located in the Cypress Creek Region.

the original X and Y coordinates. In the case of Figure II-4, the locations of the three raingage stations were added to the boundary asterisks. Such a map can easily be created for each parameter (evaporation, streamflow, well data, and geologic core stations for example), and saved with each parameter spreadsheet file.

In cases where a value can be assigned to each block on the map, such as average elevation or rainfall for each square mile, a column of Z attributes of these numbers is assigned to the X and Y coordinates. Each value will appear in the center of each block (Figure II-8), and will be changed automatically if the Z coordinates are altered on the spreadsheet. In Figure II-8, only elevation values within the Cypress Creek Basin boundaries were entered, so the values take on the shape of the watershed. These maps can also be included in each parameter spreadsheet file.

Once the XYZ map data set is entered to Lotus in the discussed format, more complex mapping programs can be easily used. Many contour mapping programs are available for the PC, each with a varying degree of sophistication. One such package, Golden Software's Golden Graphics (1985) allows the user to choose between two spatial distribution techniques: distance-weighting or kriging. By simply printing the XYZ coordinates from the spreadsheet to a print file, the data set is now ready for direct entry into the Golden Graphic map package. If a data point is not assigned to each X and Y coordinate, Golden Graphics will assign the Z value to each grid node through the use of one of its distribution techniques. These values can in turn be printed back to the spreadsheet file for future use. If a Z value is already assigned



									160		200				
							140	170	175	190	200	220			
		70	70	70	80		140	100	100	150	200	150			
		70	70	70	70	100	100	90	130	175	175				
		75	75	75	75	90	90	90	100	140	170				
		75	75	70	70	75	65	90	95	100	150				
		70	70	70	70	80	100	90	90	90	100	150	210		
	75	75	80	75	75	75	75	65	100	90	100	140	220		
70	70	75	65	65	65	65	65	90	100	100	110	100	170		
		70	65	69	65	70	70	90	100	110	120	100	140		
		55	55	60	65	70	75	100	115	115	115	115			
		55	50	60	65	80	80	90	95	95					
		60	50	60	55										
		50	50	50											
		75	50												
		70	50	55											

Figure II-8. Lotus Map of Mean Elevation (feet) per Square Mile in the Cypress Creek Basin.

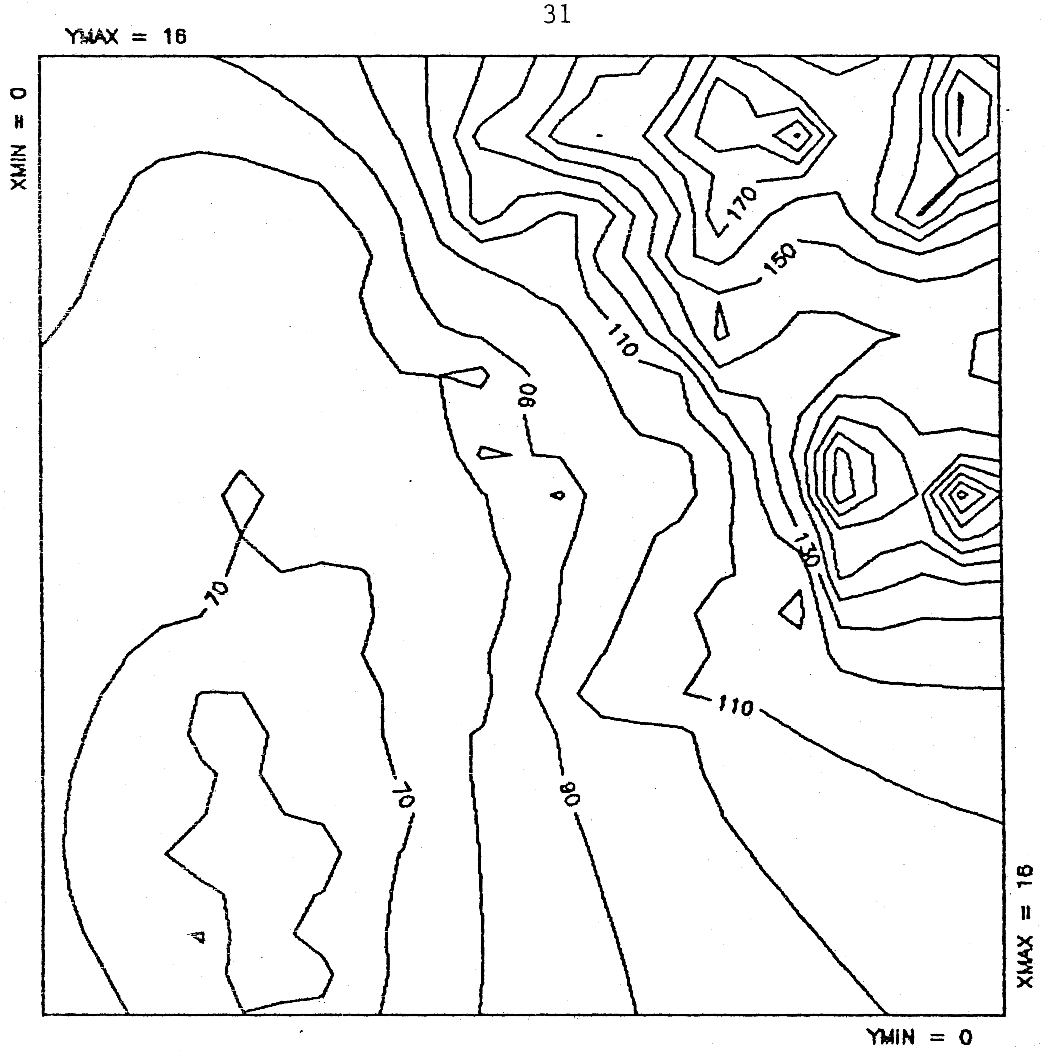
to each X and Y coordinate, Golden Graphics can be used solely to construct a contour map or a three dimensional surface map, as in Figures II-9 and II-10. Golden Software also markets programs that produce more sophisticated XY and line plots than Lotus graphics, and can also be used with Lotus 123 created data sets.

Other mapping software is available, but the spreadsheet can be used as a convenient analytical tool for all such software, and can easily be interfaced in the manner discussed above to many programs.

Data and Statistics

Data entered onto a Lotus file can be used in many ways, and are ready for manipulation at any time. Daily rainfall data entered onto a Lotus spreadsheet are presented on Table II-6. Preliminary statistics, such as a data point count, average, and standard deviation, are included with each parameter file. Besides containing selected annual, monthly, daily, and event data, each section is fully documented to inform the user where additional data can be found, as well as referencing the data included in the spreadsheet.

All data may be stored on a separate file and imported onto the worksheet as needed for preliminary analysis. By saving data files separately, the problem of memory limitations on any particular spreadsheet is avoided. Once a certain set of data is viewed and analyzed by the user, a new set of data can be imported from another data file and printed directly over the old data set, thus avoiding the need for large data sets. If is it desirable to save the work on the old data set, this too can be saved as a separate file, or printed for future reference.



CYPRESS CREEK

Figure II-9. Golden Software Contour Map of Cypress Creek Basin Topography.

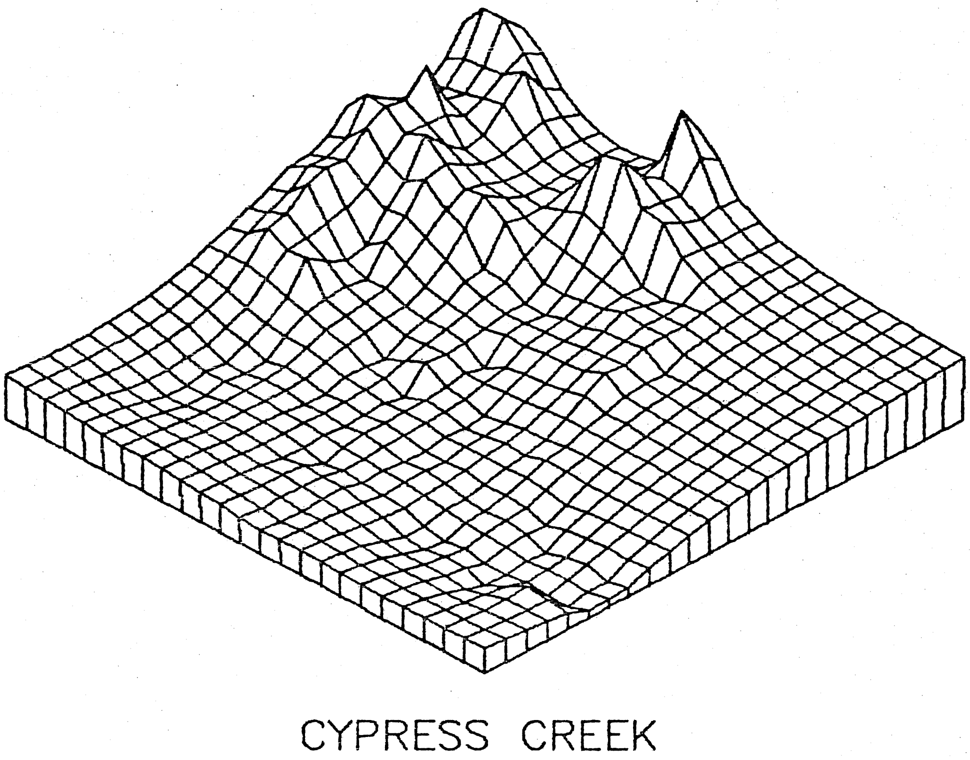


Figure II-10. Golden Software Surface Map of Cypress Creek Basin Topography.

Table II-6. Spreadsheet Presentation of Cypress Creek Precipitation for Water Year 1979.

Day	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
1			0.90					0.09				0.03
2				1.57					0.07		1.05	0.07
3											0.03	0.13
4						0.20				0.03	0.02	0.11
5	0.05		0.72		0.07	0.01					0.10	0.02
6					0.10	1.60					1.55	
7					0.55	0.36		0.80		0.58	0.15	
8						0.07		10.50		0.06	1.30	
9				0.70				0.46		0.01	0.01	
10			0.10									0.44
11			0.10								1.55	0.15
12			0.11	1.93						0.46	1.50	0.74
13				0.54						0.06	0.30	0.22
14	0.33								0.03	0.11		0.65
15								0.07		0.02		1.10
16										0.14	0.42	0.01
17										0.01	0.78	0.09
18										0.12	0.02	0.01
19										0.67	1.05	
20				0.10					0.03	0.03	0.54	0.10
21				0.50							0.01	0.64
22			0.08						0.28		0.08	0.26
23						0.66	0.04			0.61	0.24	2.00
24			1.10	0.72	1.10		0.04	2.25		0.10	1.45	1.00
25					1.70		0.25			0.01	0.01	0.45
26								0.01	0.02		0.15	0.64
27			0.15	0.04					2.30		0.14	0.34
28	0.45		1.75						0.24		0.01	0.30
29			0.40						0.03		0.01	0.64
30								0.36			0.76	0.02
31				0.15				0.01			0.17	
SUM	0.83	0	5.41	6.25	3.52	2.9	0.33	14.55	3	3.02	13.4	10.16
COUNT	3.00	0.00	10.00	9.00	5.00	6.00	3.00	9.00	8.00	16.00	27.00	25.00
MEAN	0.28	0.00	0.54	0.69	0.70	0.48	0.11	1.62	0.38	0.19	0.50	0.41
MAX	0.45	0.00	1.75	1.93	1.70	1.60	0.25	10.50	2.30	0.67	1.55	2.00
MIN	0.05	0.00	0.08	0.04	0.07	0.01	0.04	0.01	0.02	0.01	0.01	0.01
STD.VAR	0.17	0.00	0.54	0.62	0.62	0.54	0.10	3.21	0.73	0.23	0.55	0.45
COEF.VA	0.61	0.00	0.99	0.89	0.88	1.12	0.90	1.99	1.96	1.23	1.12	1.11

The Cypress Creek study was based on the analysis of several time series and the effects of other parameters on these series. As a result, the study became somewhat data intensive, and summary tables became very important in the parameter spreadsheet files. A rainfall data summary table for water year 1979 is presented in Table II-7. The rainfall data for the three raingages used in the study (Cypress Creek, Rose, and St. Leo) are compared, and a weighted sum (in this case, an average) of each month is presented. These summaries, included in each parameter file, provide a quick statistical analysis for the larger data sets.

As stated earlier, all data sets were documented within each parameter spreadsheet for easy acquisition in further analysis. Documentation was either placed beside the data, or was referenced as to where the documentation could be found elsewhere on the spreadsheet. Through the use of the GOTO command (Function key 5 on the PC keyboard) and Range names in Lotus 123, the user can gain immediate access to the documentation anywhere on the spreadsheet. By giving the documentation text a "Range" name, such as RAIN, the user only needs to strike the F5 key and type RAIN to move directly to that range, in this case, the text called RAIN. This technique allows the data base compiler to fully document all data without crowding with the data space. This process can be further advanced and streamlined through the use of the Lotus 123 programming language, known as macros. This process will be discussed in following chapters.

Table II-7. Summary of Daily Rainfall Statistics for Cypress Creek Spreadsheet Data Base.

Values are in inches

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
Sum												
Cypress	0.83	0.00	5.41	6.25	3.52	2.90	0.33	14.55	3.00	3.02	13.40	10.16
Rose	0.29	0.02	3.51	5.61	3.00	3.61	0.61	16.02	2.19	3.90	13.66	14.87
St. Leo	0.29	0.02	4.54	5.88	2.33	3.63	1.23	16.81	2.14	2.09	16.99	10.27
Average	0.47	0.01	4.49	5.91	2.95	3.38	0.72	15.79	2.44	3.00	14.68	11.77
Standard Deviation												
Cypress	0.17	0.00	0.54	0.62	0.62	0.54	0.10	3.21	0.73	0.23	0.55	0.45
Rose	0.07	0.00	0.31	0.26	0.74	0.89	0.21	4.10	0.42	0.38	0.70	0.57
St. Leo	0.07	0.00	0.53	0.56	0.54	0.66	0.40	3.42	0.59	0.21	0.69	0.37
Average	0.09	0.00	0.35	0.51	0.54	0.66	0.15	3.12	0.34	0.16	0.51	0.33

Annual Totals	
Cypress	63.37
Rose	67.29
St. Leo	66.22
Average	65.61

Conclusions

All of the above processes and techniques were used in the Cypress Creek study with much success, and can be adapted to a variety of needs and data handling problems. The result is a well referenced, documented, and accessible knowledge base that is very versatile and easily used in several analyses. A firm control of all data associated with the study area was the first (and very important) step in the analysis of the Cypress Creek Basin, and provided a framework for all further work on the project.

The spreadsheet provides a much more efficient method of compiling and analyzing data than hand analysis or conventional computer programs, and requires little to no knowledge of computer programming. Since all of the data and documentation may be stored on a few floppy disks, information may be easily transferred from one analyst to another, and may be used in a variety of computer programs.

Once the data have been fully analyzed, it is often necessary to run computer models in order to create simulated data where data are unavailable. Chapter III discusses how the electronic spreadsheet can be used to construct easy-to-understand hydrologic models, and how these models can be used to analyze local hydrologic phenomena.

CHAPTER III

DATA PREPARATION AND ANALYSIS

Choosing An Analytical Method

The first step in accomplishing a satisfactory result in hydrologic computer modeling is to decide upon the most suitable method of solving the given problem. The chosen method is selected based upon several criteria (Haan *et al.*, 1982): the needed accuracy of the prediction, the simplicity of the model or models considered, the consistency of the parameter estimates, the sensitivity to changes in the parameter values, and the amount of time and funding available for the problem solving method. In addition to these considerations, the expert must consider the data input required as compared to what is available, and the amount of experience with the particular model. In reality, the engineer may have to consider the amount of experience the permitting agencies have with analyzing the results of the proposed model, since the agency must ultimately judge the accuracy of its predictions. Once the method of problem solving is determined, data collection, preparation, and analysis can begin. Since the actual running, calibration, and results of the chosen model all depend on the accuracy of the initial input of data, this step certainly deserves a great deal of attention.

From the results of a national survey of private consulting firms and state agencies, Austin (1986) reports that the lack of accurate data sets, lack of time, and the lack of acceptance of large hydrologic computer models by decision makers are among the main reasons why modeling use is limited in water resources planning and design. Austin also found that if decision makers had a better understanding of computer models, use in design would be much more prevalent. The results of hydrologic computer models, of course, can only be as accurate as the input data set; thus data collection and preparation become highly important in the use of such models.

The Cypress Creek study began with the intent to use several hydrologic models to simulate the study area. Much of the time was consumed by data collection and parameter estimation for the models, all of which was done entirely by hand. Surface hydrology was simulated using the Hydrologic Simulation Program - Fortran (HSPF), which required a total input of 150 parameter estimates, and took several months to set up and run. Groundwater was to be simulated through use of the USGS McDonald and Harbaugh model (1984), which requires several thousand parameter estimates, but was abandoned after several weeks of preliminary work. Although several large modeling efforts were included in the study, later efforts were directed toward a comprehensive analysis of the local data. Spreadsheets ultimately became the main analytical tools in the project, and several techniques became very useful.

The use of electronic spreadsheet analysis cannot affect the initial collection of data, but does allow the expert to present all data analysis in a very organized fashion, and allows the reviewer to check all calculations and documentation involved in the data preparation process. Without such documentation and presentation of calculations, the reviewer does not know how the data analysis and model calibrations were performed, and cannot accurately judge the reliability of the results. Such an organized system would relieve the permitting agencies from much of the time and burden of trying to understand the workings of large computer models, and may eventually persuade agencies to use such computer models.

Data Preparation For Computer Models

Several methods of data analysis and preparation can be utilized. Methods of estimating missing values in time series are reviewed and discussed by several researchers (Foufoula-Georgiou, 1982, Kottegoda *et al.*, 1977), and will not be discussed further. Methods of distributing data spatially depend on the nature of the data, as well as the level of accuracy necessary for the particular problem. Special parameters for individual models must often be determined through the use of several model runs, or through the use of simpler analyses. The analyst needs to experiment with the data in order to achieve the best result, either before the model is run, throughout the calibration process, or both. Since it is strongly in the researcher's favor to compile a data set that is as accurate as possible the first time through (within the constraints of time and funding), a convenient way of arriving at this data set is needed. Several methods of data distribution, parameter estimation, and overall input organization can be accomplished through the use of the Lotus spreadsheet and some other useful microcomputer software.

Spatial Analysis and Data Distribution

Both main frame and personal computer software is available for contouring and data distribution of spatial data (Sampson, 1978, Golden Software, 1985), but such software offers a limited choice of distribution techniques, and can produce questionable results. Such software is very valuable when a particular type of data distribution is decided upon, and can be used in conjunction with spreadsheet analysis to develop data sets. The use of a particular distribution method, however, may be dependent upon the type of data in question. Several papers have been published concerning the use of each type of data distribution (Rouhani, 1985, Tabios and Salas, 1985, Creutin and Obled, 1982), but the judgment of the expert can often produce much better results when dealing with complex data sets, and only after several model runs and analyses of the results can an expert achieve a comfortable feeling for the accuracy of the input data (Daves, 1973).

Spatial distribution analysis on Lotus

The comparison of spatial analysis techniques can be performed quite easily on an electronic spreadsheet. Although more complicated distribution techniques, such as Universal Kriging, are better left to the available PC software, several data distributions for moderately sized study areas are possible on the spreadsheet. An example of a distance-weighted data distribution performed on the three raingages of the Cypress Creek study is presented in Table III-1. Several distance weighting formulas are available, such as $1/D^2$ and $1/D^3$, but here a more

Table III-1. Lotus Distance-weighting Spatial Distribution for Rainfall at Cypress Creek (Partial Listing).

Coordinates		Distance			Weighting			Sum	Weights			Weighted Values
1	2	3	4	5	6	7	8	9	10	11	12	13
X	Y	DROSE	DCYP	DLEO	ROSE	CYP	LEO	SUMDIST	WR	WC	WL	WEIGHT
0.5	0.5	5.66	6.32	15.62	4.10	3.06	0.00	7.16	0.57	0.43	0.00	2.3
1.5	0.5	5.00	6.08	14.87	5.87	3.46	0.00	9.33	0.63	0.37	0.00	2.3
2.5	0.5	4.47	6.00	14.14	7.99	3.61	0.00	11.59	0.69	0.31	0.00	2.3
3.5	0.5	4.12	6.08	13.45	9.92	3.46	0.00	13.38	0.74	0.26	0.00	2.3
4.5	0.5	4.00	6.32	12.81	10.75	3.06	0.00	13.81	0.78	0.22	0.00	2.3
5.5	0.5	4.12	6.71	12.21	9.92	2.54	0.00	12.46	0.80	0.20	0.00	2.3
6.5	0.5	4.47	7.21	11.66	7.99	1.99	0.00	9.98	0.80	0.20	0.00	2.3
7.5	0.5	5.00	7.81	11.18	5.87	1.51	0.00	7.37	0.80	0.20	0.00	2.3
8.5	0.5	5.66	8.49	10.77	4.10	1.10	0.00	5.20	0.79	0.21	0.00	2.3
9.5	0.5	6.40	9.22	10.44	2.80	0.79	0.00	3.58	0.78	0.22	0.00	2.3
10.5	0.5	7.21	10.00	10.20	1.89	0.55	0.00	2.43	0.78	0.22	0.00	2.3
11.5	0.5	8.06	10.82	10.05	1.26	0.00	0.00	1.26	1.00	0.00	0.00	2.4
12.5	0.5	8.94	11.66	10.00	0.83	0.00	0.52	1.35	0.62	0.00	0.38	2.0
13.5	0.5	9.85	12.53	10.05	0.54	0.00	0.00	0.54	1.00	0.00	0.00	2.4
14.5	0.5	10.77	13.42	10.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.4
15.5	0.5	11.70	14.32	10.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.4
0.5	1.5	5.00	5.39	15.00	5.87	4.97	0.00	10.84	0.54	0.46	0.00	2.2
1.5	1.5	4.24	5.10	14.21	9.20	5.81	0.00	15.01	0.61	0.39	0.00	2.3
2.5	1.5	3.61	5.00	13.45	14.03	6.14	0.00	20.18	0.70	0.30	0.00	2.3
3.5	1.5	3.16	5.10	12.73	19.46	5.81	0.00	25.27	0.77	0.23	0.00	2.3
4.5	1.5	3.00	5.39	12.04	22.13	4.97	0.00	27.10	0.82	0.18	0.00	2.3
5.5	1.5	3.16	5.83	11.40	19.46	3.93	0.00	23.39	0.83	0.17	0.00	2.4
6.5	1.5	3.61	6.40	10.82	14.03	2.95	0.00	16.98	0.83	0.17	0.00	2.4

Notes:

1. Columns 1 and 2 are the maps coordinates for each node.
2. Columns 3 through 5 are the distances between each grid node and each raingage, in miles.
3. Columns 6 through 8 are unnormalized weighting factors, computed by applying the weighting formula:
   ((1-(D/(1.1*DMAX)))^2)/((D/(1.1*DMAX))^2)
4. Column 9 is the sum of columns 6 through 8.
5. Columns 10 through 12 are the normalized weighting factors for each node.
6. Column 13, labeled WEIGHT, is the weighted rainfall estimation for each node.

Actual Gage Rainfall	inches
Rose	2.42
Cypress	2.03
St. Leo	1.25
Average	1.74

complicated formula developed for the Surface II (1976) main frame contouring software is used:

$$W = ((1-(D/(1.1*DMAX)))^2)/((D/(1.1*DMAX))^2) \qquad \text{(III-1)}$$

where

W = raingage weight,

D = distance from point to raingage, and,

DMAX = distance from point to furthest raingage.

The third through fifth columns, labeled DROSE, DCYP, and DLEO, are the distances in miles between each grid node on the map and each of the raingages. For instance, the Rose raingage is located at grid node X = 4.5 and Y = 4.5, which is found in cells A78 (X) and B78 (Y). The formula used to calculate the first value for DROSE (located in C10) would therefore be

$$(((A78-A10)^2) + ((B78-B10)^2))^{1/2} \qquad \text{(III-2)}$$

or the equivalent of

$$((X1-X2)^2 + (Y1-Y2)^2)^{1/2} \qquad \text{(III-3)}$$

This formula needs only to be entered into the first cell and copied into the remaining cells. Lotus automatically changes each formula's variables to fit the needs of each cell. For instance, if the formula A1+B2 (or the contents of cell A1 added to the contents of B2) were copied to the cell below, the formula would automatically be changed to

A2+B3. If the same formula was copied to the cell to the right, the formula would be changed to B1+C2, and so forth. Thus "calculation tables," such as Table III-1, may be constructed not only to perform calculations, but also to provide a useful reference table for review.

The sixth through eighth columns, labeled ROSE, CYP, and LEO, apply the weighting formula discussed above, to calculate an unnormalized weighting factor. The column labeled SUMDIST sums the three weighting factor columns. Each weighting factor is then normalized by dividing by the sum of the distances. Thus the columns labeled WR, WC, and WL are the actual weights for the raingage values for each cell in the study area. Finally, the amount of rainfall from each gage is multiplied by its corresponding weight, and this sum becomes the weighted rainfall amount for that cell (found in the column labeled WEIGHT).

The technique used to copy the formulas for the last calculation is somewhat different than the technique described above because the same cell, rainfall amount, must be multiplied throughout each pertaining column. In this case, a dollar sign ($) is placed in front of the cell variables that are to remain constant throughout the row or column. If a "$" is placed in front of the entire cell variable, i.e. $B10, the column part of the variable, or B, will remain constant throughout the copied row. If the "$" is placed only in front of the row number, i.e. B$10, the row part of the variable, or 10, will remain constant throughout the copied column. If the "$" is placed in front of both, i.e. B10, no matter where the variable is copied, both the row and column will remain constant. Lotus calls these "absolute cell addresses", and the variables with no "$" are called "relative cell addresses." Thus, the formula for the first weight value is

$$(J10*\$N\$3)+(K10*\$N\$4)+(L10*\$N\$5) \qquad (III-4)$$

where J10, K10, and L10 = Rose, Cypress, and St. Leo weights, and

N3, N4, and N5 = Rose, Cypress, and St. Leo rainfall

This formula copied to the cell below will be

$$(J11*\$N\$3)+(K11*\$N\$4)+(L11*\$N\$5) \qquad (III-5)$$

Each consecutive formula copied in the column will be changed similarly, avoiding the need to change each formula manually.

Although somewhat tedious in appearance, this method allows the user to follow through each calculation and make any necessary changes; unlike prepackaged data distribution software. This technique also allows the user to compare the results of several different distance weighting formulas very quickly. Besides distance-weighting spatial distribution, the user may select many other techniques, such as is presented in Table III-2. The distance-weighted results are compared to those of a polynomial fit, a nearest neighbor distribution, and an average of the three gages, as applied to one month of rainfall. Simple statistics can be applied to each data set in order to determine which distribution is more reasonable in accordance with the knowledge of the

Table III-2. Comparison of Spatial Distribution Techniques on Lotus 123 as Applied to the Cypress Creek Watershed for May, 1983.

	Coordinates			Weighted Values		
	X	Y	WEIGHT	POLY	NEAR	MEAN
	0.5	0.5	2.3	3.2	2.4	1.74
	1.5	0.5	2.3	3.2	2.4	1.74
	2.5	0.5	2.3	3.2	2.4	1.74
	3.5	0.5	2.3	3.2	2.4	1.74
	4.5	0.5	2.3	3.2	2.4	1.74
	5.5	0.5	2.3	3.2	2.4	1.74
	6.5	0.5	2.3	3.2	2.4	1.74
	7.5	0.5	2.3	3.2	2.4	1.74
	8.5	0.5	2.3	3.2	2.4	1.74
	9.5	0.5	2.3	3.2	2.4	1.74
	10.5	0.5	2.3	3.2	2.4	1.74
	11.5	0.5	2.4	3.2	2.4	1.74
	12.5	0.5	2.0	3.2	2.4	1.74
	13.5	0.5	2.4	3.2	2.4	1.74
	6.5	15.5	1.5	0.3	1.3	1.74
	7.5	15.5	1.4	0.3	1.3	1.74
	8.5	15.5	1.3	0.3	1.3	1.74
	9.5	15.5	1.3	0.3	1.3	1.74
	10.5	15.5	1.3	0.3	1.3	1.74
	11.5	15.5	1.3	0.3	1.3	1.74
	12.5	15.5	1.3	0.3	1.3	1.74
	13.5	15.5	1.3	0.3	1.3	1.74
	14.5	15.5	1.3	0.3	1.3	1.74
	15.5	15.5	1.3	0.3	1.3	1.74
Maximum			2.42	3.20	2.42	1.74
Minimum			1.25	0.27	1.25	1.74
Mean			1.81	1.74	1.77	1.74
Standard Deviation			0.42	0.90	0.51	0.00

Notes:

1. The column labeled WEIGHT applies the weighting formula in Table III-1.
2. The column labeled POLY applies the following polynomial: 3.3+2.8E-17X-.195Y
3. The column labeled NEAR applies the nearest neighbor method.
4. The column labeled MEAN is the average of the gage values.

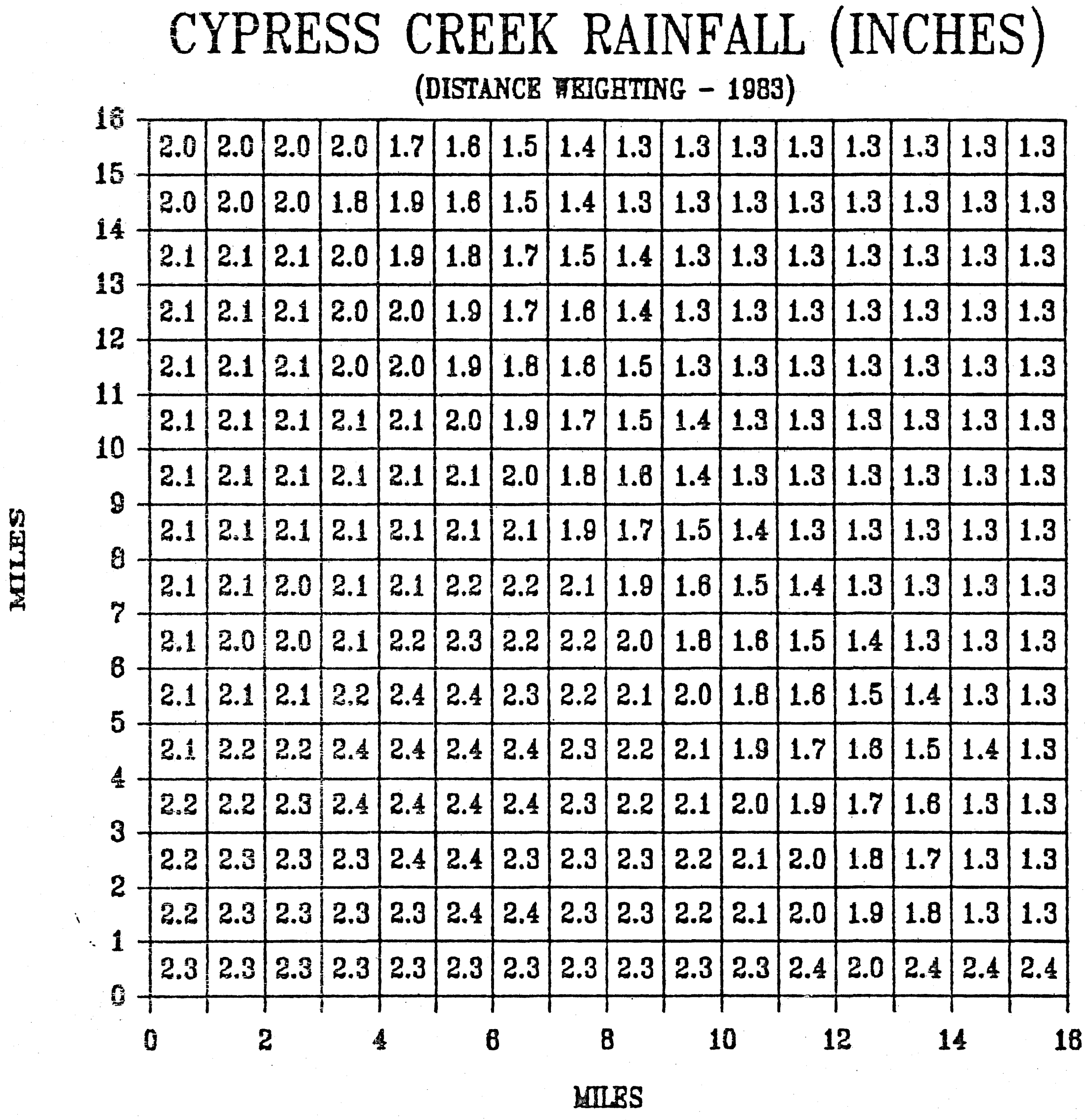
Gage Values:	Rose	2.42
	Cypress	2.03
	St.Leo	1.25
	Average	1.74

study area. Each type of distribution can also be mapped, as seen in Figure III-1. This type of analysis displays all of the data distributions on one spreadsheet, and allows the expert to acquire a feel for the data sets (see Appendix A for a more detailed discussion of spatial analysis comparisons on 123).

Other Useful Software

Contouring software currently available is less cumbersome to use than the spreadsheet technique for a pre-specified distribution system, and can be used in conjunction with large simulation models. Many models, such as finite difference groundwater models, require large data sets with a data point for every area unit in the simulation. When simulating very large areas, data sets consisting of hundreds of data points for each model parameter are not uncommon. The time necessary to determine, organize and enter this data set can take most of the modeling effort, and is surely a good reason to seek other analytical techniques rather than using these large models. Through the use of contouring programs and spreadsheets, this data entry process can be reduced to a small fraction of the original time.

By entering the matrix size and known data points, software such as Golden Graphics will distribute the data, produce a contour map or three dimensional surface for inspection, and produce a data set with a data point in each matrix cell that can be used directly in many models; all within a few minutes. This technique was used with much success for groundwater modeling during the Cypress Creek study, and was used both on the PC (using Golden Graphics) and on the main frame computer (using Surface II). When used on a PC, the output data set can be imported to



CYPRESS CREEK RAINFALL (INCHES)

(DISTANCE WEIGHTING - 1983)

2.0	2.0	2.0	2.0	1.7	1.6	1.5	1.4	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
2.0	2.0	2.0	1.8	1.9	1.6	1.5	1.4	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
2.1	2.1	2.1	2.0	1.9	1.8	1.7	1.5	1.4	1.3	1.3	1.3	1.3	1.3	1.3	1.3
2.1	2.1	2.1	2.0	2.0	1.9	1.7	1.6	1.4	1.3	1.3	1.3	1.3	1.3	1.3	1.3
2.1	2.1	2.1	2.0	2.0	1.9	1.8	1.6	1.5	1.3	1.3	1.3	1.3	1.3	1.3	1.3
2.1	2.1	2.1	2.1	2.1	2.0	1.9	1.7	1.5	1.4	1.3	1.3	1.3	1.3	1.3	1.3
2.1	2.1	2.1	2.1	2.1	2.1	2.0	1.8	1.6	1.4	1.3	1.3	1.3	1.3	1.3	1.3
2.1	2.1	2.1	2.1	2.1	2.1	2.1	1.9	1.7	1.5	1.4	1.3	1.3	1.3	1.3	1.3
2.1	2.1	2.0	2.1	2.1	2.2	2.2	2.1	1.9	1.6	1.5	1.4	1.3	1.3	1.3	1.3
2.1	2.0	2.0	2.1	2.2	2.3	2.2	2.2	2.0	1.8	1.6	1.5	1.4	1.3	1.3	1.3
2.1	2.1	2.1	2.2	2.4	2.4	2.3	2.2	2.1	2.0	1.8	1.6	1.5	1.4	1.3	1.3
2.1	2.2	2.2	2.4	2.4	2.4	2.4	2.3	2.2	2.1	1.9	1.7	1.6	1.5	1.4	1.3
2.2	2.2	2.3	2.4	2.4	2.4	2.4	2.3	2.2	2.1	2.0	1.9	1.7	1.6	1.3	1.3
2.2	2.3	2.3	2.3	2.4	2.4	2.3	2.3	2.3	2.2	2.1	2.0	1.8	1.7	1.3	1.3
2.2	2.3	2.3	2.3	2.3	2.4	2.4	2.3	2.3	2.2	2.1	2.0	1.9	1.8	1.3	1.3
2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.4	2.0	2.4	2.4	2.4

Figure III-1. Lotus Map of Cypress Creek Basin Rainfall Distributed by a Distance Weighting Technique.

a Lotus spreadsheet for analysis or comparison with other techniques. Visual inspection of the data, summary statistics and maps can be accomplished, and data entry is almost foregone.

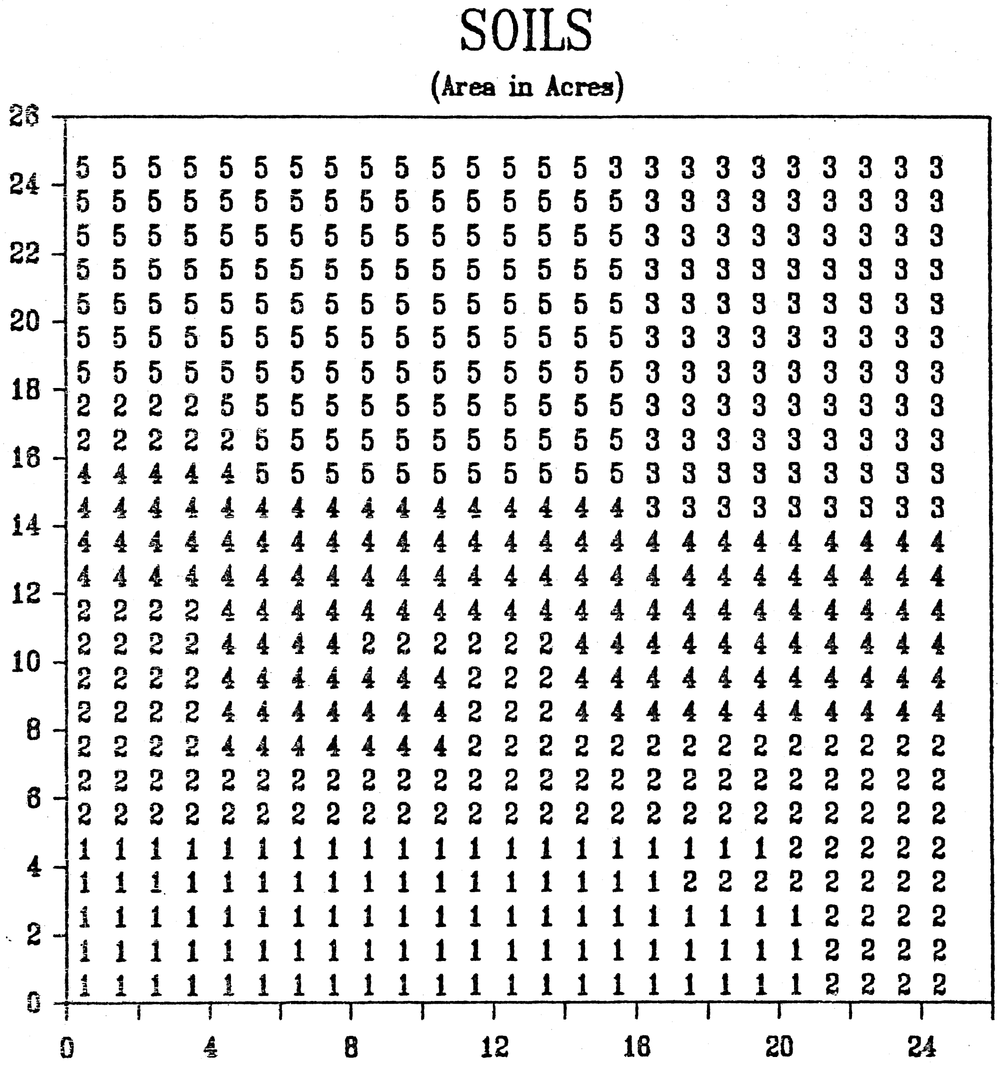
Parameter Estimation

Much of the early modeling work in the Cypress Creek study consisted of parameter estimation, most of which was accomplished with pencil and paper. Only after several model runs and expert consultations did the total list of parameters become complete. As expertise was gained in the use of spreadsheets, several methods were developed to use Lotus 123 for the estimation of parameters for hydrologic computer models.

Soil characteristics

Many hydrologic models require an average soil type or characteristic, such as storage capacity, infiltration rate, or hydraulic conductivity. The expert must usually make a guess at these parameters by inspecting soils maps or soil surveys. Through the use of the mapping techniques described in Chapter II and some simple calculations, this process can be easily automated on a spreadsheet. A spreadsheet soils map of an imaginary subdivision is shown in Figure III-2. Each cell represents one acre, and the number within the cell is the soil type for each cell. The data set is entered exactly as described in Chapter II, with each number (1-5) representing a different soil type.

Part of the data for the map is presented in Table III-3, exactly as it appears on the spreadsheet. Beside the data, four "bins", one for each soil type, are set up in order to use the /Data Distribution



5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	3	3	3	3	3	3	3	3	3	3
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	3	3	3	3	3	3	3	3	3
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	3	3	3	3	3	3	3	3	3
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	3	3	3	3	3	3	3	3	3
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	3	3	3	3	3	3	3	3	3
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	3	3	3	3	3	3	3	3	3
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	3	3	3	3	3	3	3	3	3
2	2	2	2	5	5	5	5	5	5	5	5	5	5	5	5	3	3	3	3	3	3	3	3	3
2	2	2	2	2	5	5	5	5	5	5	5	5	5	5	5	3	3	3	3	3	3	3	3	3
4	4	4	4	4	5	5	5	5	5	5	5	5	5	5	5	3	3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
2	2	2	2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
2	2	2	2	4	4	4	4	2	2	2	2	2	2	4	4	4	4	4	4	4	4	4	4	4
2	2	2	2	4	4	4	4	4	4	4	2	2	2	4	4	4	4	4	4	4	4	4	4	4
2	2	2	2	4	4	4	4	4	4	4	2	2	2	4	4	4	4	4	4	4	4	4	4	4
2	2	2	2	4	4	4	4	4	4	4	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2

Figure III-2. Lotus Map of Soils in a Hypothetical Subdivision.

Table III-3. Mapping Data for Hypothetical Soils of Example Subdivision.

X	Y	Soil Type
0.5	0.5	1
1.5	0.5	1
2.5	0.5	1
3.5	0.5	1
4.5	0.5	1
5.5	0.5	1
6.5	0.5	1
7.5	0.5	1
8.5	0.5	1
9.5	0.5	1
10.5	0.5	1
11.5	0.5	1
12.5	0.5	1
13.5	0.5	1
14.5	0.5	1
15.5	0.5	1
16.5	0.5	1
17.5	0.5	1
18.5	0.5	1
19.5	0.5	1
20.5	0.5	1
21.5	0.5	2
22.5	0.5	2
23.5	0.5	2
24.5	0.5	2
0.5	1.5	1
1.5	1.5	1
2.5	1.5	1
3.5	1.5	1
15.5	24.5	3
16.5	24.5	3
17.5	24.5	3
18.5	24.5	3
19.5	24.5	3
20.5	24.5	3
21.5	24.5	3
22.5	24.5	3
23.5	24.5	3
24.5	24.5	3

Soil Types

Type	Map #	Acres
Downs	1	100
Hancock	2	130
Ink	3	100
Miles	4	150
Potter	5	145
Total		625

command to count the number of cells for each soil type. When this command is invoked, Lotus will ask for the range of data to be distributed, and then for the range of bins. With the touch of the return key, the data will instantly be distributed among the bins, and will appear in the column to the right of the bins (as is seen in Table III-3). Thus, the acreage of each soil type is obtained very quickly.

Once this is accomplished, a calculation table can be constructed to calculate several soil parameters, as is presented in Table III-4. Each soil name is listed, along with the map group number, high water months, and minimum and maximum depths to the water table, as determined from previous field work. Characteristic storage capacity (or any other soil parameter), extracted from soil data or from field tests, is listed next. The data distribution is now used to determine the proportion of the entire area that each soil type occupies, and each soil parameter is weighted by this proportion. An area-weighted mean for each soil parameter can be achieved by simply averaging the weighted parameters. As many parameters as are needed can be added to the table, or parameters may be changed, and the table will automatically calculate all new values. This method not only provides a fast and convenient way of accurately calculating area-weighted parameters for computer models, but also presents an easily understood table of calculations and a map for the parameters that can be used by reviewers or for later reanalysis.

Rainfall frequency analysis

The /Data commands may be used for several other analyses, including rainfall frequency analysis. By sorting hourly rainfall data in descending order, as in Table III-5, and applying a plotting position

Table III-4. Calculation Table for Soil Charactersitics in the Example Study Area.

Soil Type	Group	High Water Months	Depth to Water table feet min	Depth to Water table feet max	Storage Capacity in/in	Infiltration Rate in/hr
Downs	5	Jun-Nov	3	5	0.06	1.30
Hancock	11	Jun-Feb	4	6	0.12	1.80
Ink	9	Jun-Oct	2	5	0.07	2.80
Miles	8	Jun-Oct	4	7	0.07	1.10
Potter	7	Jul-Oct	4	7	0.12	0.80
Area-weighted mean			3.4	6	0.09	1.56

Soil Type	Group	Area Acres	Proportion of area	weighted min. depth,ft	weighted storage cap.,in.	weighted infiltration rate,in/hr
Downs	5	100	0.160	0.480	0.010	0.208
Hancock	11	130	0.208	0.832	0.025	0.374
Ink	9	100	0.160	0.320	0.011	0.448
Miles	8	150	0.240	0.960	0.017	0.264
Potter	7	145	0.232	0.928	0.028	0.186
Area-weighted mean		625		3.520	0.090	1.480

Table III-5. Spreadsheet Calculation of Rainfall Event Frequency at St. Leo, Florida.

Rank	Date	Volume	Duration		Since > .2 inches		T
		inches	hours	days	hours	days	years
1	09/03/50	15.79	78	3.25	64	2.67	36.0
2	04/12/53	10.80	17	0.71	124	5.17	18.0
3	03/16/60	8.95	54	2.25	6	0.25	12.0
4	06/24/74	8.50	26	1.08	202	8.42	9.0
5	07/28/60	7.51	33	1.38	16	0.67	7.2
6	09/10/60	6.51	32	1.33	***	***	6.0
7	11/15/51	6.40	20	0.83	305	12.71	5.1
8	03/15/60	6.33	14	0.58	87	3.63	4.5
9	10/18/44	6.01	23	0.96	708	29.50	4.0
10	09/09/64	5.84	33	1.38	134	5.58	3.6
11	03/15/59	5.79	66	2.75	79	3.29	3.3
12	02/07/71	5.68	18	0.75	42	1.75	3.0
13	06/18/72	5.50	25	1.04	91	3.79	2.8
14	08/27/49	5.34	27	1.13	127	5.29	2.6
15	06/03/54	5.31	27	1.13	345	14.38	2.4
16	05/14/76	5.30	25	1.04	119	4.96	2.3
17	09/27/49	5.28	6	0.25	22	0.92	2.1
18	12/09/69	5.15	31	1.29	41	1.71	2.0
19	06/30/64	4.70	4	0.17	40	1.67	1.9
20	09/17/47	4.64	47	1.96	94	3.92	1.8
21	08/11/49	4.62	24	1.00	7	0.29	1.7
22	05/27/63	4.35	5	0.21	23	0.96	1.6
23	07/26/54	4.32	9	0.38	48	2.00	1.6
24	06/26/74	4.30	3	0.13	6	0.25	1.5
25	07/17/59	4.25	4	0.17	70	2.92	1.4
26	11/09/63	4.20	21	0.88	87	3.63	1.4
27	09/17/51	4.18	51	2.13	473	19.71	1.3
28	03/12/51	4.17	9	0.38	785	32.71	1.3
29	02/02/70	4.13	32	1.33	425	17.71	1.2
30	08/11/65	3.85	8	0.33	89	3.71	1.2

Note: T is the recurrence interval, (n+1)/m.
n is equal to number of annual values.
m is equal to rank of descending order.

formula, a graph of recurrence intervals may easily be constructed. Although others are available, the plotting position used in this example is (Viessman et al., 1977):

$$T = n+1/m \tag{III-6}$$

where T = recurrence interval, years,

n = the number of annual values, and,

m = the rank of descending values (largest = 1)

The last column contains the plotting position formula, where n is equal to the sum of column one and m is equal to the values in column one. By plotting column three versus the last column, a rainfall-recurrence interval plot is created for the local data. By also plotting accepted design storms on the same graph, as shown in Figure III-3, the local data may be compared to the design storms. If the actual rainfall values are plotted as data labels, the comparisons can be more easily accomplished, although the lack of space may allow the inclusion of only a few values, as is seen in Figure III-3.

Volume-duration curves may also be constructed using the same data. An example of a volume duration curve constructed using the data from Table III-5 and an XY plot is seen in Figure III-4. A bar graph, such as Figure III-5, can also be constructed to visualize the rainfall data. These graphs are simple to prepare, and their construction is very helpful for all data involved in the parameter estimations.

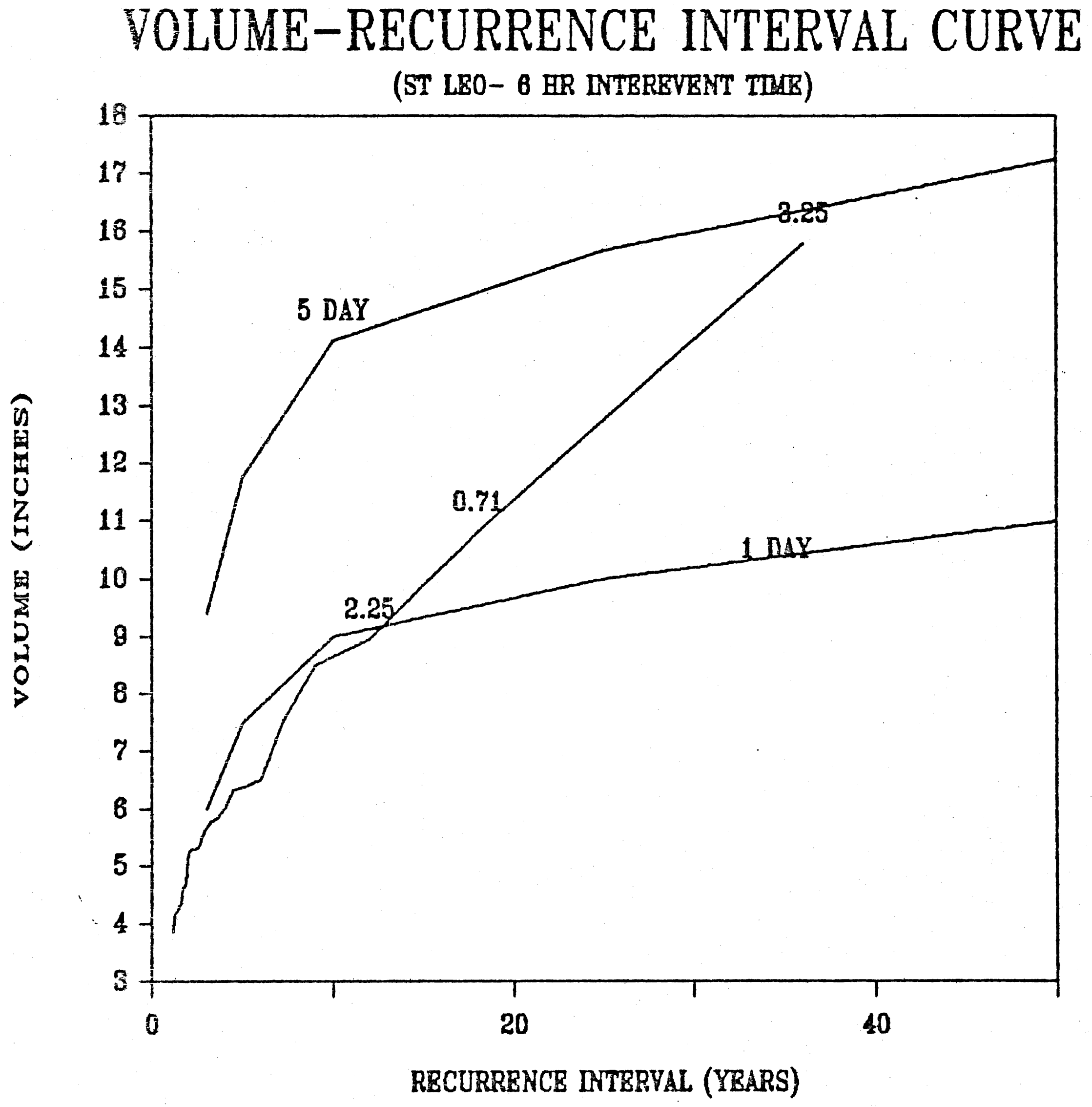


Figure III-3. Volume-Recurrence Interval of St. Leo, Florida Rainfall Events, Using Top 30 Events, 1944-1979.

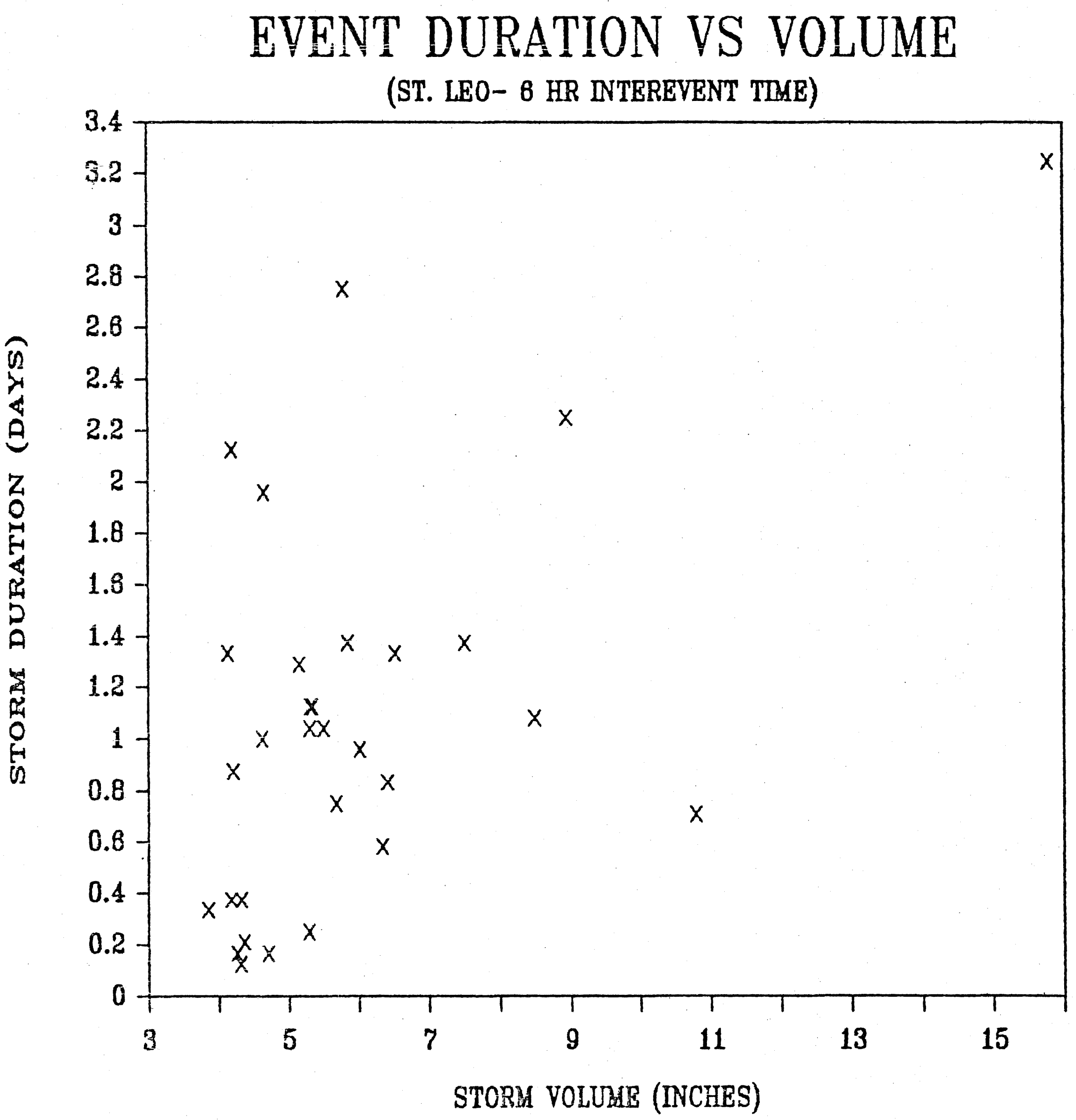


Figure III-4. Rainfall Event Duration Versus Volume at St. Leo, Florida, Using Top 30 Events, 1944-1979.

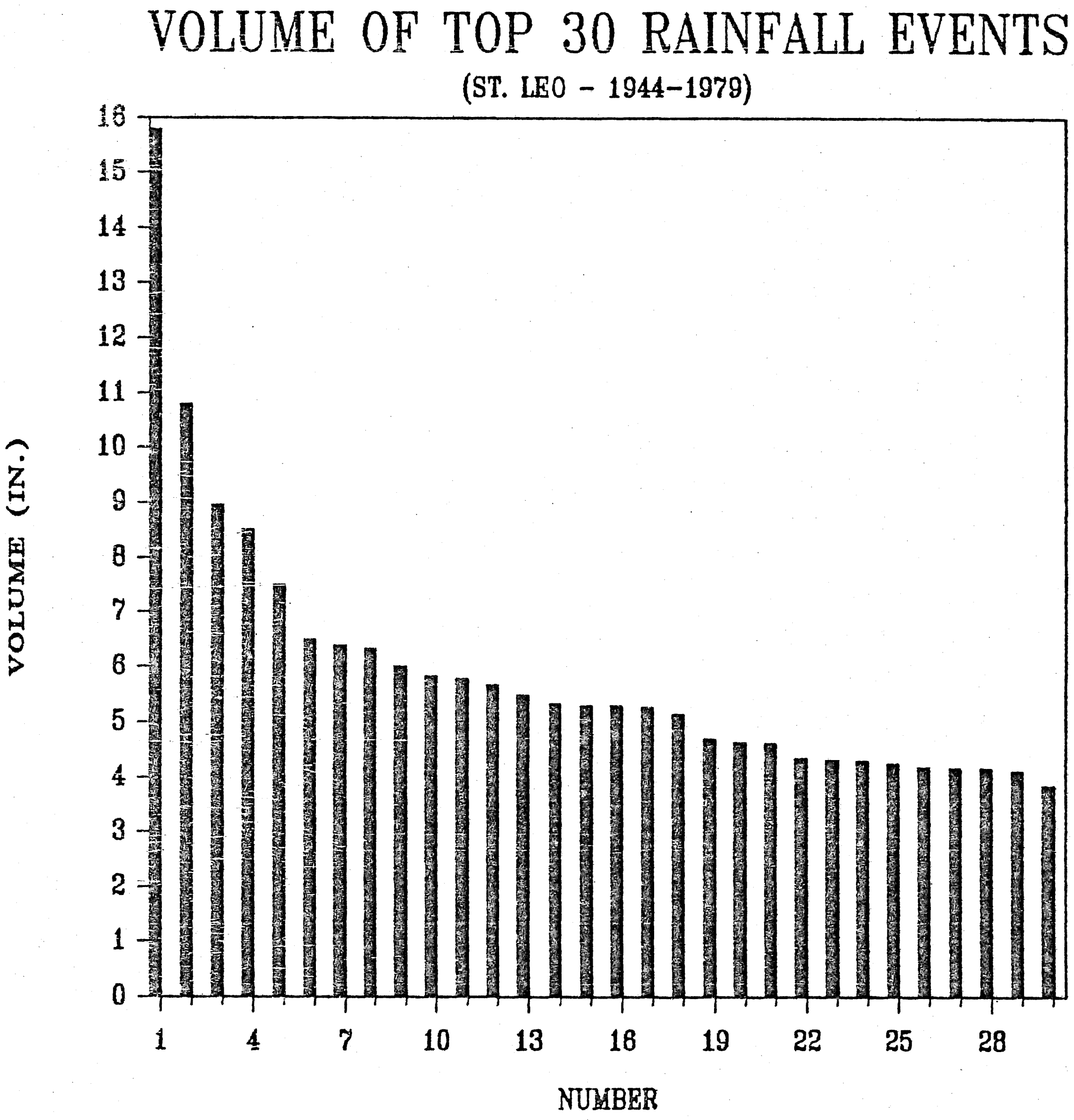


Figure III-5. Volume of Top 30 Rainfall Events at St. Leo, Florida, 1944-1979.

Water budgets

A water budget can easily be determined by using a calculation table similar to that used for determining soil parameters. A spreadsheet-based annual water budget for the Cypress Creek study area is found in Table III-6. Since the precipitation, evapotranspiration, runoff, and well elevations are known, it is possible to calculate the change of storage (difference in consecutive well elevations) and the residual. The residual is calculated by the water budget equation

$$RL = P - ET - R - DS \tag{III-7}$$

where RL = residual (in.),

P = precipitation (in.),

ET = evapotranspiration (in.),

R = runoff (in.), and,

DS = change of storage (in.)

The change of storage is based on the assumption that the soil storage is equal to .1 inch of water per inch of soil. In this case, deep (artesian) well data were used to calculate the change of storage (whereas shallow well, or non-artesian well data would have been preferable), so the DS term is a very rough estimate. This table, all done automatically on a Lotus spreadsheet, was used to estimate the leakance in the area, which is represented by the residual. The leakance is the amount of water that seeps through the confining bed of the surficial aquifer and into the deep artesian aquifer. These calculations also assisted in the conclusion that evapotranspiration is the dominant loss

Table III-6. Approximate Water Budget for Upper Cypress Creek Basin, 1966-1983.

Notes	(1)		(3)		(4)		(5)		(6)	(7)	
Symbol	P	P	ET	ET	R	R	H	DH	DS	RL	RL
	Rain	5 point moving average	E-T	5 point moving average	Runoff	5 point moving average	Well Elev.	Delta H	Delta S	Residual	5 point moving average
Year	inch		inch		inch		feet	feet	inch	inch	
65							76.68				
66	53.46		41.02		11.07		76.70	0.02	0.02	1.35	
67	43.47		43.68		3.95		75.07	-1.63	-1.96	-2.20	
68	46.31	52.38	42.06	41.96	1.98	6.56	74.58	-0.49	-0.59	2.86	3.83
69	65.75	52.15	40.96	42.39	7.91	5.14	76.07	1.49	1.79	15.09	4.76
70	52.93	53.51	42.09	42.07	7.91	4.51	76.78	0.71	0.85	2.08	7.00
71	52.27	55.93	43.14	42.15	3.95	4.59	76.13	-0.65	-0.78	5.96	9.08
72	50.31	54.83	42.11	42.46	0.79	5.06	74.78	-1.35	-1.62	9.03	7.39
73	58.38	54.22	42.44	42.56	2.37	4.27	75.04	0.26	0.31	13.26	7.82
74	60.27	53.19	42.52	42.17	10.28	4.06	75.76	0.72	0.86	6.61	7.24
75	49.87	53.06	42.60	42.25	3.95	4.36	74.98	-0.78	-0.94	4.26	6.76
76	47.14	51.54	41.19	42.35	2.93	4.69	74.94	-0.04	-0.05	3.07	4.78
77	49.66	52.87	42.52	41.90	2.25	4.23	73.50	-1.44	-1.73	6.62	7.25
78	50.75	51.51	42.92	41.52	4.03	3.71	73.86	0.36	0.43	3.37	6.76
79	66.95	52.65	40.26	42.19	7.99	3.17	73.64	-0.22	-0.26	18.96	8.51
80	43.04	57.21	40.72	41.71	1.34	5.30	72.97	-0.67	-0.80	1.78	9.92
81	52.87	62.24	44.54	40.52	0.24	7.24	69.86	-3.11	-3.73	11.82	14.08
82	72.45		40.12		12.89		74.69	4.83	5.80	13.64	
83	75.89		36.95		13.76		75.52	0.83	1.00	24.18	
Mean	55.10		41.77		5.53					7.87	
Std Dev	9.32		1.63		4.15					6.76	
CV	0.17		0.04		0.75					0.86	

Notes:

1. St. Leo raingage.
2. Lisbon evaporation through 1979. Then, average of Padgett and SWFWMD.
3. ET= .72*E
4. Runoff at San Antonio based on a drainage area of 47 square miles.
5. Average of wells 5 and 7.
6. Change in storage based on 0.1 inch of water per inch of soil.
7. RL = P-ET-R-DS

CV= coefficient of variation (standard deviation/mean).

term of the water budget, and provided information about the mean, standard deviation, and coefficient of variation (standard deviation divided by the mean) for the data. Once again, this table provides not only an easy means to calculate a water budget, but provides a reference for outside parties that may review the work.

Time series analysis

Another use for line graphs in parameter estimation is the construction of moving average plots. Moving averages are used to filter out the short-term variability in order to identify the long-term trends in time series. Such graphs, before and after averaging, are presented in Figures III-6 and III-7. The graphs represent the water budget for the Cypress Creek study area in Table III-6. Every five points in the time series are averaged in order to reduce the short term variability, although varying amounts of points may be averaged until the trends are clearly visible.

The column after each column of data consists of averaging calculations of the five surrounding data points to the left. Once one of these calculations is entered, the formula may be copied to the entire column, and the formulas will be changed automatically for each cell. For instance, the first rainfall moving average value of 52.38 is the sum of the rainfall values of 53.46, 43.47, 46.31, 65.75, and 52.93 divided by five. If the rain data column is column B, the moving average column is column C, and the first row of data is row 10 (the row for year 1966), the formula for the first moving average point (in cell C12) will be

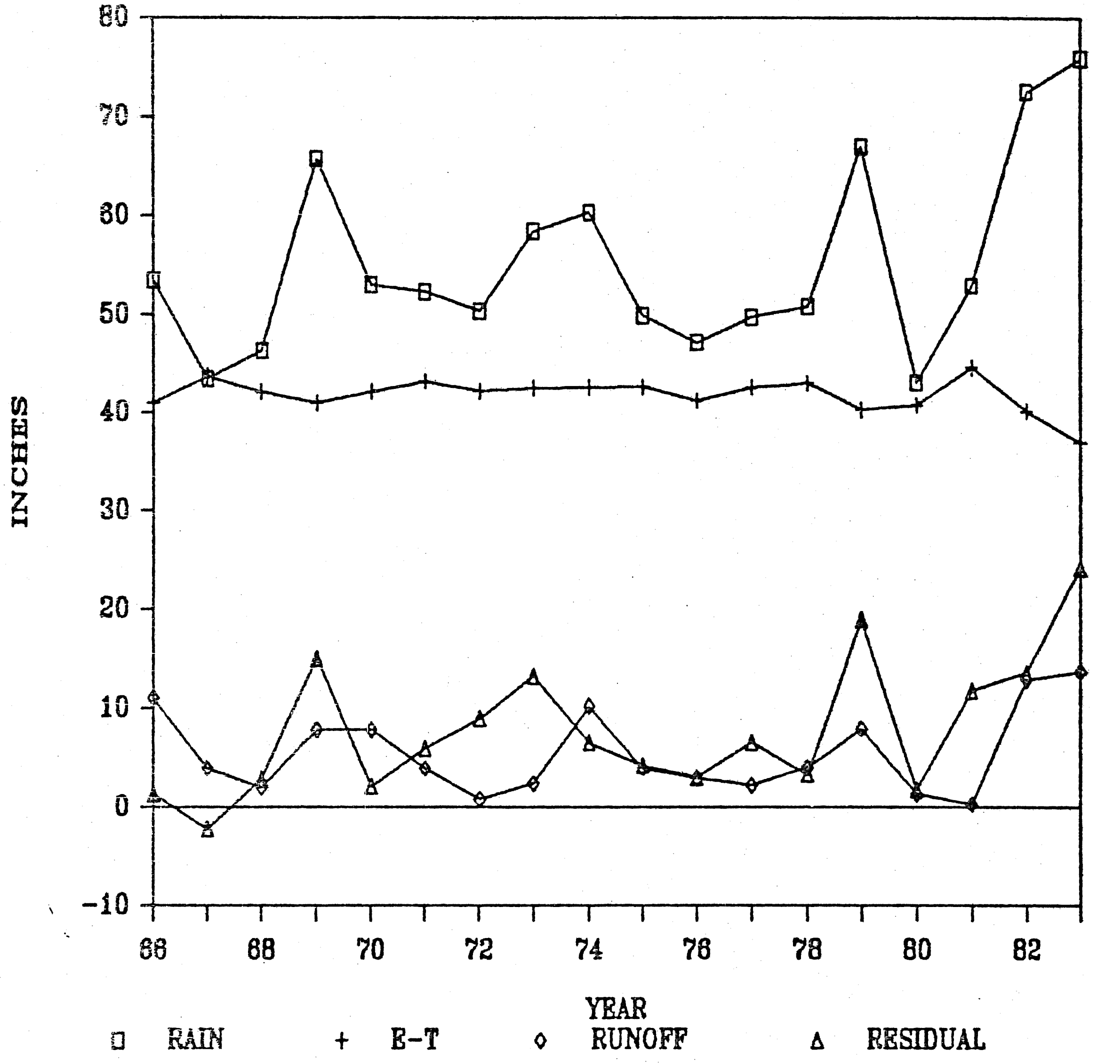


Figure III-6. Water Budget of Cypress: 1968-1983.

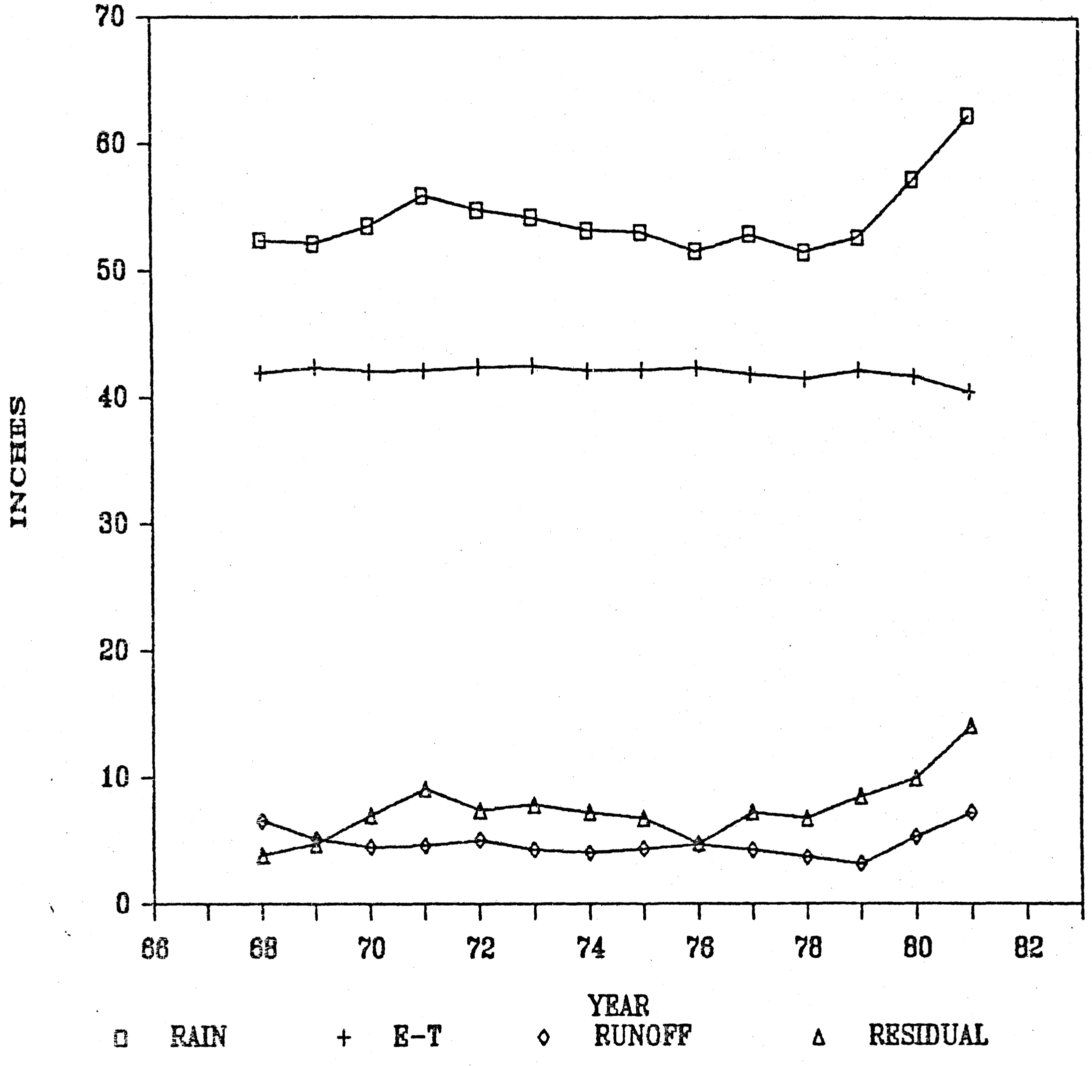


Figure III-7. Five Point Moving Average of Water Budget, Cypress Creek: 1968-1983.

(B10+B11+B12+B13+B14)/5 (III-8)

or, in more compact form,

@SUM(B10..B14)/5 (III-9)

When this formula is copied to the cell below, the formula will automatically change to

@SUM(B11..B15)/5 (III-10)

When copied to the entire column, this formula will be changed accordingly for each cell.

This plot shows that evapotranspiration and the residual outflow are relatively stable over time, while precipitation has increased in the early 1980s and runoff declined slightly through 1980. Such plots can be valuable in analyzing time series before using computer models.

Conclusions

The data analysis techniques presented above are only a few of the spreadsheet methods that are possible in hydrologic problem solving. Through the use of such techniques, an organized method of pre-modeling data analysis and parameter estimation may be accomplished, and a determination may be made as to whether large scale computer models are necessary. In the case of the Cypress Creek study, analytical techniques such as those described above proved more relevant than the larger computer models, and were used for arriving at many of the conclusions of the study. Although many of the techniques appear very simple, they are an analysis of actual local data, and can allow the hydrologist to use his/her expertise effectively.

The computational methods presented in this chapter can be regarded as subroutines of the larger analysis. If these techniques are interconnected, a simple model is formed. The following chapter will present methods of accomplishing more comprehensive spreadsheet modeling by applying these techniques to a larger scope of relationships. Through the use of spreadsheets, it is almost possible to duplicate larger main frame models, and present them in the easy to understand format that the spreadsheet provides.

CHAPTER IV

SPREADSHEET MODELING

Since the development of the computer, various attempts have been made to mathematically simulate many aspects of science and society. Although today's comprehensive main frame computer models often appear to be "black boxes" that produce volumes of answers when fed volumes of data, they are merely the automation of calculations that could be done entirely with a pencil and a pad of paper. Performing these numerous and complex calculations on paper would take several magnitudes more time than a computer would require, but the problem solver would gain a clear understanding of the processes needed to solve the problem. This in turn would provide a better understanding of the results, and may produce a higher level of assurance concerning the reliability of these results. The time needed for this type of analysis is too great, however, and the cost of this technique in most cases, far outweighs its advantages.

Although comprehensive hydrologic computer models provide a valuable service when dealing with comprehensive problems, the expert often finds it advantageous to use smaller models to better understand the nature of the given problem. Often the problem may be solved through the sole use of these smaller computer models, or even by "desk-top" analysis alone. The large models do provide many options, but local conditions sometimes require special consideration for accurate modeling, and the expert may be forced to develop his own model, or be satisfied with the results of the "generic" comprehensive models. Instead of developing these models on paper, and eventually developing computer code, it is possible to develop these models on "electronic paper", and eliminate the need for further computer programming. The development of hydrologic models on an electronic spreadsheet is the subject of this chapter. Although just a few models are presented in the following chapters, these ideas may be applied to a variety of hydrologic problems (or adapted to many other fields).

Model Development

Hydrologic model development usually consists of four stages: conceptualization, formulation, programming, and testing (McCuen and Snyder, 1986). Although conceptualization, the process of visualizing a problem and devising a solution, requires the most effort of the four, formulation of the model, programming, and testing the model may take many hours of effort, and require expertise in computer languages and concepts. The electronic spreadsheet allows the hydrologist to test a variety of formulations in little time, requires no knowledge of computer languages (although the special commands in 123, called macros, could be considered a computer language), and allows many convenient testing procedures. The models created on a spreadsheet are not "black boxes", for all formulations, equations, assumptions, and even documentation are presented, and changes to the structure of the model can be made at any time.

Linking Documentation with Calculations

Documentation, listing of assumptions, or any other explanatory remarks are valuable in hydrologic analysis. Since hydrologic analysis requires many expert judgments when complete data sets are not available, these judgments should be clearly presented within the analysis. Experts may make different assumptions in the design of hydrologic systems requiring regulatory agency approval, so step by step explanations can prove beneficial in the presentation of such designs.

One of the biggest advantages of Lotus 123 (or any other electronic spreadsheet) is the ability to combine calculations and text within the same page (one screen of the spreadsheet). Table IV-1 presents a simple spreadsheet calculation of an SCS curve number, used for estimating direct runoff. Each step is explained as it is performed, and each calculation may be examined when viewed on a microcomputer. The explanations include assumptions, references to named graphs (those graphs stored within the spreadsheet file and accessed by the /Graph Name Use command), and any other notes clarifying the calculation steps. By using a GO TO command in Lotus 123, several pages of explanation or references may be supplied for each set of calculations. When the pages of text are given a Range Name in Lotus, these sections of the spreadsheet may be accessed immediately by striking the F5 function key, and typing in the range name. The text will then immediately appear on the screen, and if the calculations are also given a range name, the user may return in the same manner. This procedure allows the user to move about even large spreadsheets quickly, and adds to the versatility of

Table IV-1. Soil Storage Calculations on Lotus 123.

Antecedent conditions		Comments
a. Depth to groundwater table, feet	3.5	average
b. Inches of soil storage	8.8	
c. In of compacted soil storage	6.6	8.8*0.75
% of max.. soil storage	75	
d. Ground storage,acre feet	233	(6.6/12)*423
Total perviousness, acres	423	previous work
Inches of computed soil storage	6.6	
e. Ground storage over entire area,S,inches	4.5	(233/625)*12
land area,acres	625	
ground storage,acre feet	233	
f. Find Curve number	69	CN=1000/(10+S)

spreadsheet use. As an added benefit, one page of the spreadsheet may be reserved as a list, or table of contents, of all range names incorporated into the spreadsheet, such as is seen in Table IV-2.

Lotus Modeling

All of the above procedures may be combined to create a variety of hydrologic models that can be easily designed, used, and understood by experts or beginners. These Lotus models are not only beneficial to the engineer or researcher, but can also be used as a learning tool for those just entering the field.

Lotus runoff model

A spreadsheet model for computing overland runoff using the SCS (Soil Conservation Service) method is presented in Table IV-3. All information and data needed to run the model are shown on one screen. The model runs automatically when the rainfall data and parameters are entered in the proper cells. Three parameters, the 25 year rainfall, the ground storage, and the acreage of the watershed, are entered into the three alloted cells, and are included in the calculations. These three parameters are arrived at by other means (the ground storage parameter was calculated through use of the model in Table IV-1), and can be changed at any time. If the parameters are changed, all of the calculations will automatically change accordingly. The rainfall ratio is based on a study of rainfall distributions in South Florida (SFWMD, 1981).

Each of the last four columns in the model contains a set of equations, created by entering the general equation for each column into

Table IV-2. Example of Table of Contents for Range Names.

Topic	Range name
Table of Contents	TOC
A. Land Use	land
1.Map of study area	
B. Soil Storage Calculations	soilcal
1.Soils map	
2.Topographic map	
3.Antecedent conditions	ante
4.Water Table Depth	soilst
5.Soil area	soilarea
C. Water Storage	waterst
1.Stage-volume relation	stage
2.Volume-stage relation	vol
D. Outflow Rate	Qout
E. Minimum Floor Elevation	floor
1.Design rains	rain
F. Stage-outflow	stageQ
G. Flow Routing	qroute
1.120 hr rain distribution	rdist120
H. Water Quality	QQual
1.24 hr rain distribution	rdist24
I. Dollar Valuation	value$
J. Daily Operation	day
1.Well Stage Data	

Table IV-3. Lotus Model of the SCS Runoff Method.

	Column					
	N	O	P	Q	R	S
Row	Sum Time Hours	Rain Ratio	Sum Rain inch	Sum Runoff inch	Sum Runoff ac-ft	Runoff cfs
	0	0				
133	24	0.146	1.46	0.06	3	2
134	48	0.359	3.59	1.02	53	25
135	58	0.572	5.72	2.51	131	94
136	59	0.628	6.28	2.95	153	276
137	59.5	0.678	6.78	3.35	174	507
138	59.75	0.828	8.28	4.60	240	3167
139	60	1.015	10.15	6.24	325	4136
140	60.5	1.088	10.88	6.90	359	828
141	61	1.126	11.26	7.25	377	434
142	62	1.177	11.77	7.71	402	293
143	72	1.359	13.59	9.39	489	106
144	96	1.472	14.72	10.45	544	28
145	120	1.568	15.68	11.36	592	24
146	144	1.568	15.68	11.36	592	0
147	168	1.568	15.68	11.36	592	0
148	192	1.568	15.68	11.36	592	0
149	216	1.568	15.68	11.36	592	0
150	240	1.568	15.68	11.36	592	0

25 yr, 24 hr rain, inches = 10
Ground storage, S, inches = 4.5
Acreage = 625

the first cell of each column, and simply copying down each column. Column P multiplies each step in the rain ratio by the 25 year, one day rain (10 inches), which is entered below the calculation table. The cumulative distribution of rainfall is given as a ratio to the total 24-hour rainfall depth. The total five day rainfall in the case of Table IV-3 is 15.68 inches. Column Q computes the runoff using the following equation:

$$\text{Column Q} = (\text{Column P} - 0.2S)^2/(\text{Column P} / 0.8S) \qquad \text{(IV-1)}$$

where S = ground storage (in.).

The ground storage parameter is also found at the bottom of the calculation table. As an example, if the first term of column P was in cell P133 of the spreadsheet, and the S term was in cell Q153, the contents of the first cell in column Q (found in cell Q133 of Table IV-3) would be as follows:

(P133-0.2*Q153)^2/(P133+0.8*Q153) (IV-2)

The $ is placed in front of the Q153 (S) term in order to keep the term constant when copied throughout the column (see Chapter 3). Since the terms are represented as cell addresses, the result of this calculation will automatically change when the contents of the included cell addresses change.

Column R simply converts the runoff sum in inches to acre-feet by multiplying column Q by the total acreage and dividing by 12 (total acreage is contained in the last parameter cell at the base of the table). Finally, the runoff in cubic feet per second is calculated in Column S by the following equation:

$$\text{Column S} = ((\text{Column N, term n})-(\text{Column N, term n-1})*43560)/ \\ ((\text{Column R, term n})-(\text{Column R, term n-1})*3600) \qquad \text{(IV-3)}$$

When converted to spreadsheet terms, the equation in the first cell of column S (S133) is the following:

$$((R133-R132)*43560)/((N133-N132)*3600) \qquad \text{(IV-4)}$$

By copying this equation throughout the column of the calculation table, a hydrograph of the study area for the 10 inch, 25 year storm is formed. By creating a line graph of runoff in cfs (column S) versus the sum of time in hours (Column N), the hydrograph can be visualized, as is presented in Figure IV-1. The graph can be given a Name in Lotus 123, and when stored with the file, the hydrograph will be automatically changed with any changes in the calculation table.

Lotus flood routing model

A model that can be used in conjunction with the above model is presented in Table IV-4. This calculation table is designed for flood routing of the runoff just calculated, through use of a variation of the modified Puls method, as is described in the South Florida Water Management District Permitting Information Manual for surface water system designs (1984). All parameters and assumptions are specified in the

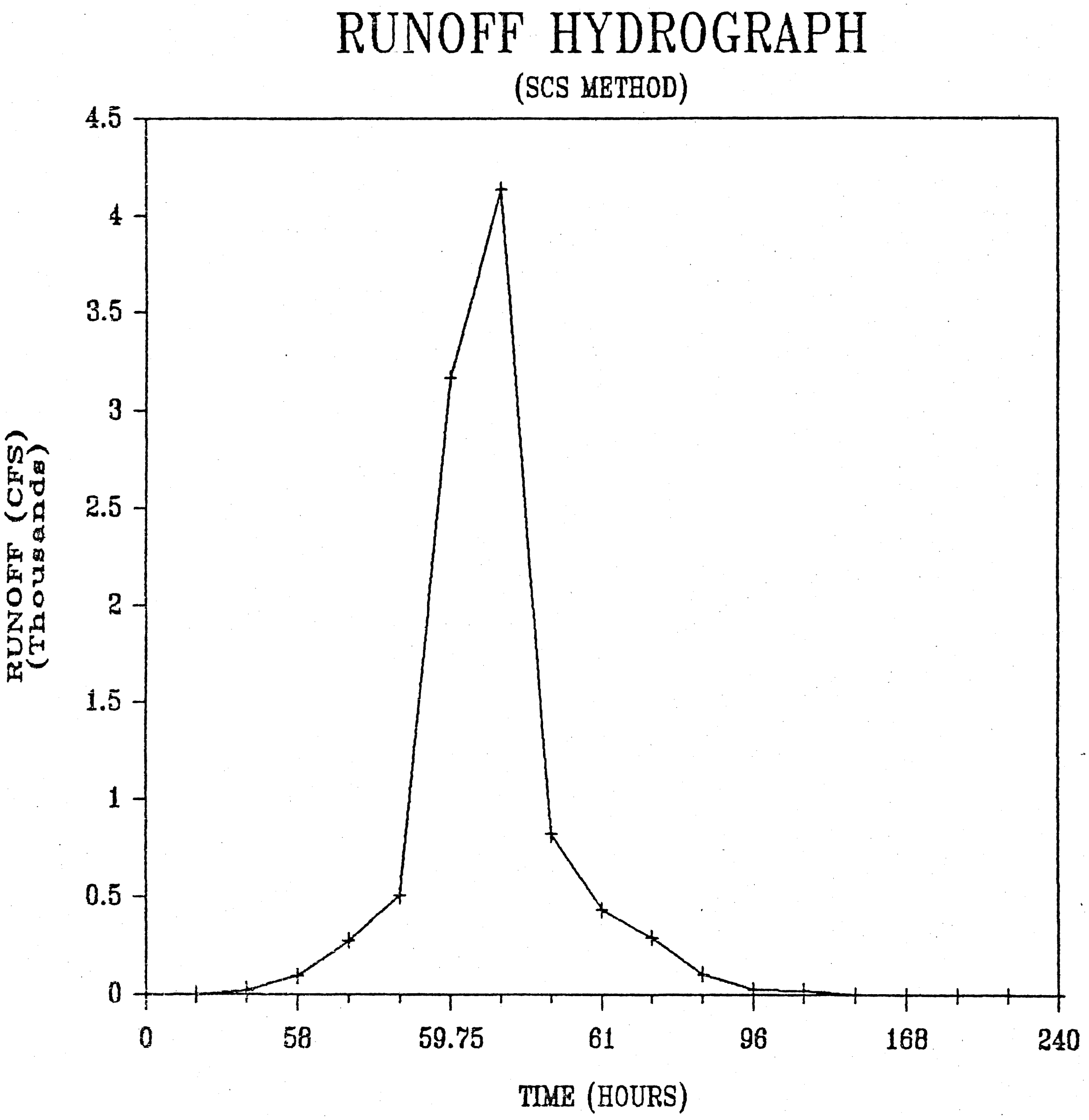


Figure IV-1. Runoff Hydrograph of the Hypothetical Subdivision Using the SCS Method on a Lotus 123 Spreadsheet.

Table IV-4. Lotus Model of the Puls Flood Routing Method.

```
                                    Column
       A     B      C      D       E      F      G        H        I        J

    5 Stage-outflow relationship.                    Flow routing through system.
    6 Minimum weir crest, ft.=  11.9                 Basis:
    7 Assume a max. stage, ft.= 15.5                 25 year rain, inches=             10
    8 Max. discharge rate, cfs,   132 @ H= 3.6       Ground storage, S, inches=        4.5
    9 Discharge formula.                             Acreage=                          625
   10             Q=K*h^1.5                          Rain distribution, see sub-file
   11 Thus, K=Q/h^1.5=          19.33                SCS runoff,R=(P-.2*S^2)/(P+.8*S)
   12                                                Weir elevation, ft=              11.9
   13                                                Weir equation, Q=K*h^1.5
   14                                                        K=                      19.33
   15                                                Stage-volume relationship
   16                                                Volume-stage relationship
   17
   18
   19  Sum          Sum       Sum                          Sum   Stored
   20 Time  Rain   Rain      Runoff       Outflow        Outflow Volume    Stage
 R 21 Hours Ratio  inch    inch ac-ft    cfs   ac-ft      ac-ft   ac-ft      Ft
 O 22     0     0                                                            11
 W 23    24 0.146   1.46  0.06     3      0     0.0        0.0       3    11.06
   24    48 0.359   3.59  1.02    53      0     0.0        0.0      53    11.95
   25    58 0.572   5.72  2.51   131     11     9.2        9.2     131    13.23
   26    59 0.628   6.28  2.95   153     33     2.7       11.9     144    13.42
   27  59.5 0.678   6.78  3.35   174     41     1.7       13.6     162    13.67
   28 59.75 0.828   8.28  4.60   240     62     1.3       14.8     226    14.46
   29    60 1.015  10.15  6.24   325     98     2.0       16.9     310    15.24
   30  60.5 1.088  10.88  6.90   359    121     5.0       21.9     343    15.37
   31    61 1.126  11.26  7.25   377    126     5.2       27.1     356    15.42
   32    62 1.177  11.77  7.71   402    130    10.7       37.8     375    15.50
   33    72 1.359  13.59  9.39   489    140   116.1      153.9     451    15.81
   34    96 1.472  14.72 10.45   544    142   282.1      436.0     390    15.56
   35   120 1.568  15.68 11.36   592     84   167.2      603.2     156    13.58
   36   144 1.568  15.68 11.36   592      5     9.3      612.5       0    11.00
   37   168 1.568  15.68 11.36   592      0     0.0      612.5       0    11.00
   38   192 1.568  15.68 11.36   592      0     0.0      612.5       0    11.00
   39   216 1.568  15.68 11.36   592      0     0.0      612.5       0    11.00
   40   240 1.568  15.68 11.36   592      0     0.0      612.5       0    11.00
```

area above the calculation table. The discharge formula at the weir, the weir equation, and the SCS runoff equation are also presented on the screen. The discharge equation is determined by the regulatory agencies in the area of the development. This discharge relationship for the weir is used within the flood routing procedure. As is evident from the following description, the model uses an iterative process, which can be easily accomplished using Lotus 123.

Columns A through E are exactly the same as those in the runoff model presented above. They need not be included in this model if the two are on the same spreadsheet; instead, the results of the runoff model may be recalled from another section of the spreadsheet. For demonstration purposes, the runoff model will be included in this model.

Columns F and G calculate the outflow at the weir both in cubic feet per second and acre-feet. Column F uses the weir equation presented at the top of the page by averaging the present stage with the previous stage:

$$Q = K*(((S_t+S_{t-1})/2)-WE)^{1.5} \qquad \text{(IV-5)}$$

where

Q = outflow at weir, cfs,

K = weir coefficient,

S_t = present stage, feet,

S_{t-1} = stage in previous time step, feet, and,

WE = weir elevation, feet.

The outflow in acre-feet is calculated as the minimum of the outflow calculated by the previous column converted to acre-feet, or the stored volume calculated by the previous time step. This is accomplished through use of the @MIN function (@MIN(a,b)), and is represented as follows:

$$\text{@MIN(F35*(A35-A34)*3600/43560,I34)} \qquad \text{(IV-6)}$$

where F35 = location of outflow in time step t, cfs,

A35-A34 = location of time sum at time step t minus location of time sum at time step t-1, hours, and,

I34 = location of stored volume in time step t-1, acre-feet.

As always, the locations represent the actual values found in those locations.

Column H is calculated by adding the summed outflow of the previous time step to the outflow of the current time step (Column H, Row t-1 plus Column G, Row t). The stored volume is calculated as the maximum of zero or the result of the following equation:

$$SV_t = SV_{t-1} - Q_{t-1} + SR_t - SR_{t-1} \qquad \text{(IV-7)}$$

where SV_t = stored volume at time step t, ac-ft,

SV_{t-1} = stored volume at time step t-1, ac-ft,

Q_{t-1} = outflow at time step t-1, ac-ft,

SR_t = sum runoff at time step t, ac-ft, and,

SR_{t-1} = sum runoff at time step t-1, ac-ft.

Finally, the last column, stage, is calculated by using the @LOOKUP command. The volume-stage relationship table to be used in this model is presented in Table IV-5. This table is determined previous to

Table IV-5. Volume-Stage Relationship for the Hypothetical Subdivision.

	R	S	T	U	V	W
346			Sum			
347			Storage	Stage		
348			acre-ft	feet		
349			0	11		
350			100	12.8		
351			200	14.2		
352			300	15.2		
353			400	15.6		
354			500	16		
355			600	16.2		
356			700	16.5		
357			800	16.7		
358			900	17		
359			1000	17		
360						
361						
362						

running the model, by use of other calculations or by design. The table is located elsewhere on the same spreadsheet as the model. Since stage is a function of storage, the stage can be interpolated by calculating the stored volume, as we have done in Column I, and consulting the table. The @VLOOKUP function can help in this process by automatically looking up the corresponding stage value in the table when given the storage value. Lotus also has an @HLOOKUP command to be used for looking up a value from a row.

The @VLOOKUP command is specified as follows:

$$\text{@VLOOKUP}(x,\text{range},\text{offset}) \tag{IV-8}$$

where x = cell address of known value,

range = range where table is found, and

offset = number of columns to the right of the x range to look.

For the case of Table IV-5, the command used to find the corresponding value for a storage of 100 acre-feet would be

$$\text{@VLOOKUP}(100,\text{T349..U359},1) \tag{IV-9}$$

meaning the value is 100, the range of the table is between cells T349 and U359, and the corresponding value is found one column over.

In the case where a number between two values is supplied, such as a storage of 118 for the example above, the supplied value is rounded to the nearest value found in the table. In order to avoid this error and be able to interpolate between values, the following complex equation was used in Column H:

```
@VLOOKUP(SV,range,1)+(@VLOOKUP(SV+100,range,1)
-@VLOOKUP(SV,range,1))*(SV/100-@INT((SV/100)))        (IV-10)
```

where SV = stored volume, ac-ft.

The @INT command simply produces the integer of the term within the parentheses. Therefore, this equation looks up the two neighboring values, interpolates between the two by a linear increment, and produces a result. Alternatively, a function could be fit to the data. Lotus 123 Release 2 allows a regression to be performed, but this procedure will not be discussed in this thesis.

Despite appearing a bit complex, this model can be used many times for several study areas, and produces results instantly. As in the runoff model, the product is the outflow hydrograph seen in Figure IV-2. Since the model is displayed completely before the user and operates so quickly, many runs may be performed within minutes, and parameters may be changed with instant results. These models may all be contained within one spreadsheet, and be may interconnected to produce more complex models. Although Lotus allows existing models to be constructed on the spreadsheet, such as the two discussed earlier, it also provides an excellent means to develop new models. The following is an example of a model that was developed and used in the Cypress Creek study.

Spreadsheet Modeling Case Study

The HSPF model has been used in the Cypress Creek study to analyze the surface hydrology and to perform a simplified analysis of the groundwater system (Hicks, 1985). However, HSPF cannot analyze the

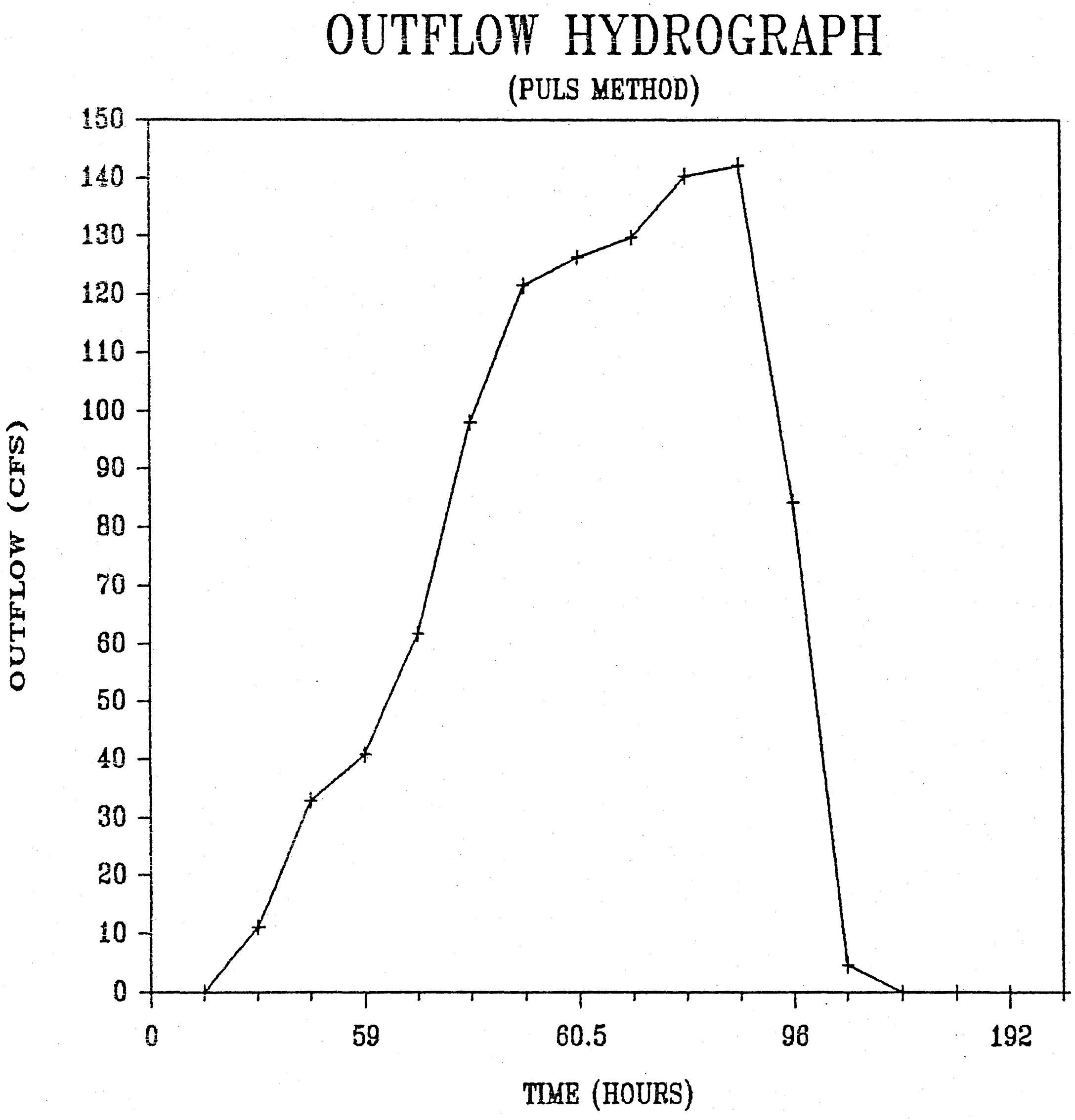


Figure IV-2. Outflow Hydrograph of the Hypothetical Subdivision Using the Puls Method on a Lotus 123 Spreadsheet.

behavior of the shallow aquifer when the water table falls below the streambed. Since streamflow is primarily a function of the height of the watertable in many parts of Florida, this becomes a serious problem. HSPF also does not incorporate the impact of pumpage.

Available groundwater models do not run on a continuous basis. Thus, they are unable to output the necessary time series information on well stages over several months or years. Development of a comprehensive surface-groundwater model which can run continuously would be a major effort and was well beyond the available resources for this study. This model would be very large because of its need to anticipate all possible configurations of surface and groundwater systems as well as types of problems ranging from flood to drought analysis.

Fortunately, for a specific study area and problem, the required complexity of the model can be reduced significantly by examining the local data. Also, the particular problem can be diagnosed by formulating and testing specific hypotheses regarding the anticipated behavior of the system. This approach was utilized in the Cypress Creek study. The knowledge base construction and data analysis techniques presented in the previous sections provided excellent insight as to the more important aspects of the problem. Also, the results of the HSPF and groundwater simulations gave a good indication of which components of the hydrologic cycle are more important for the study area and the specific problem.

A Continuous Surface-Groundwater Model

Using Lotus 123, a daily surface-groundwater model for upper and middle Cypress Creek was developed for the year 1979 (although any year of data could be input to the model). Longer periods of time may be modeled, but the constraints of incomplete data sets and possibly insufficient computer memory make one year a convenient period. This model used daily data for rainfall and evaporation. Depth-dependent relationships were included for both evapotranspiration and streamflow. The model keeps track of the water table and can handle the case where it falls below the streambed. The model is calibrated against both streamflow and water table levels.

Cypress Creek was divided into two sections for modeling purposes, determined by the major subcatchments in the watershed (Figure IV-3). After several HSPF simulations it was determined that a portion of the northwest subcatchment should be excluded, making the total drainage area above the San Antonio streamgage equal to 47.4 square miles. The spreadsheet simulation was run for upper Cypress Creek Basin (above the San Antonio streamgage) and the portion of the basin between the San Antonio and the Drexel streamgages. These two areas were determined to be those sections of the creek where the effects of pumping could be most easily detected.

Spreadsheet Simulation of the Upper Cypress Creek Basin

The daily water budget equation for the area is

$$dS/dt = (P-ET-Q-L)/(12*K) \qquad \text{(IV-11)}$$

where dS/dt = daily change in the shallow water table, ft of soil,

P = rainfall, inches of water,

ET = evapo-transpiration, inches of water,

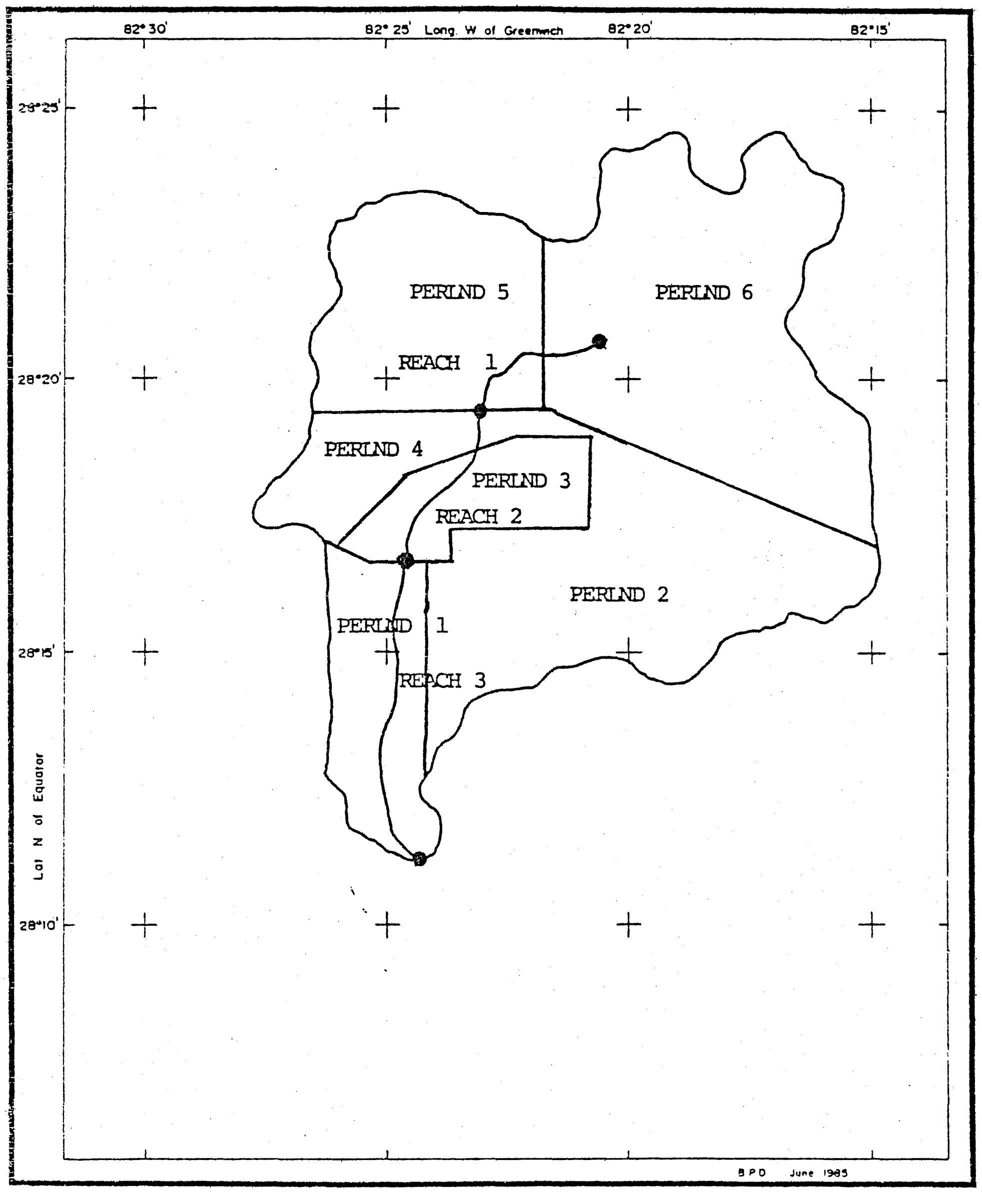


Figure IV-3. Major Subcatchments of the Cypress Creek Basin, Defined as PERLNDs for HSPF (Hicks, 1985).

Q = streamflow, inches of water,

L = leakance to lower aquifer, inches of water, and,

K = inches of water per inch of soil.

The spreadsheet model estimates the water table elevation at the end of each time step as a function of each of the above sources and sinks. Thus, all inputs and outputs of water in inches are converted to feet of change of the groundwater in the soil.

The calculation table is formatted so that the calculations can be easily followed by the user. All of the assumptions and parameters used in the model are input below the calculation table. Also below the table are a set of summary statistics for the simulation, a continuity check, and a presentation of the contributions of each water budget component. As in all Lotus models, these calculations are performed almost instantaneously when the data are input to the columns.

Precipitation and evaporation

The results of the daily Lotus simulation for Cypress Creek above the San Antonio streamgage are summarized in Table IV-6. The detailed results are presented in Appendix B. Calendar year 1979 was selected because data are available, it is within the period when pumping was underway, and it is a fairly normal year from a hydrologic viewpoint. The rain is estimated as a weighted average of the St Leo and the Cypress Creek gages, i.e.,

$$P = a*P(1)+(1-a)*P(2) \qquad \text{(IV-12)}$$

Table IV-6. Summary of Lotus Simulation of Cypress Creek Above San Antonio: 1979.

	Precipitation Cypress Creek inches	Saint Leo inches	Weighted Mean inches	Evap inches	E-T inches	Calc Streamflow cfs	Calc Streamflow inches	Calc Head inches	Meas Flow cfs	Meas Head inches
TOTAL	61.06	66.89	63.975	60.07	45.1	10051	7.87		10140	
MEAN					0.12	27.54		68.39	27.78	68.48
MAX					0.42	205.7		74.89	500	72.71
MIN					0	0		62.01	0	65.64
STANDARD DEVIATION					0.07	44.51		2.84	58.47	1.77

KEY ASSUMPTIONS:

1.E-T=(ETMAX-ETRATE*(GRDEL-WTEL))*E	GRDEL	74
	ETMAX	1
	ETRATE	0.04
2.DRAINAGE AREA, SQUARE MILES =		47.4
3.STORAGE COEF. =		0.085
4.DISCHARGE-HEAD RELATIONSHIP = K*H^B	K=	3.3
	B=	2
5.ELEVATION FOR WHICH BASE FLOW = 0, FEET		67
6.LEAKANCE, IN/YR		8.2
7.WEIGHTS OF RAIN GAGES	CYPRESS CRK	0.5
	ST LEO	0.5

CONTINUITY CHECK: dS/dT = (P-ET-Q-L)   PERCENT CONTRIBUTIONS

P=		63.975 IN.	INFLOWS	
ET=		45.169 IN.		
Q=		7.886 IN.	P=	100%
L=		8.200 IN.		
			OUTFLOWS	
dS/dT=	CALC	2.719 IN.	ET=	73.74%
	MEAS	2.611 IN.	Q=	12.87%
			L=	13.39%

This weighting factor, a, is used as a calibration parameter. By comparison, the HSPF simulations were done using a single gage. The evaporation is the daily evaporation from the Lisbon station, located approxiamately 60 miles from the study area. In HSPF, the mean monthly evaporation was used. Evapotranspiration is estimated as a function of evaporation and water table elevation, i.e.,

$$ET = (ETmax-n*(Hgrd-Hwt))*E \qquad (IV-13)$$

where ET = evapotranspiration, inches of water,

ETmax = maximum ET rate, inches per day,

n = reduction in ET rate per unit decrease in head,

Hgrd = ground elevation,feet,

Hwt = water table elevation,feet, and

E = pan evaporation rate, inches per day.

ETmax, n, and Hgrd are used as calibration parameters.

Streamflow

The discharge in Cypress Creek is approximated by fitting a power function of the form:

$$Q = a*H^b \qquad (IV-14)$$

where Q = estimated flow in cfs,

H = estimated water table elevation at well 4, feet, and,

a,b = parameters.

The calculated flow in cfs is converted to inches/day over the catchment.

Pumpage and well elevations

Pumpage is represented in the model as a change in leakance. As pumpage in the artesian aquifer changes, a proportional change in leakance may occur in the pumping vicinity. If the change does occur, the surficial water table will be affected, and change the outcome of the model.

The model was calibrated with water level data from well 4, located just north of the Cypress Creek Wellfield. A map presenting the locations of all the observation wells in the study area is shown in Figure IV-4.

The model estimates the daily flow and stage for the year. The power of the spreadsheet approach is apparent during the calibration. The key assumptions and calibration parameters are shown at the bottom of the table. All of the equations in the table are expressed in terms of the calibration parameters. Thus, the new result is calculated immediately once the revised parameter estimates are inserted. The final estimates are shown in the table. All of these values fall within the expected range. The most sensitive assumption is the weighting on the rain gages.

Results

The results are quite good. The estimated mean flow of 27.5 cfs agrees closely with the measured flow of 27.8 cfs. Similarly, the estimated mean stage of 68.4 feet is very close to the measured stage of 68.5 feet, and the continuity check is very good. Figures IV-5 and IV-6 show the simulated vs. measured flows and stages respectively. The fit

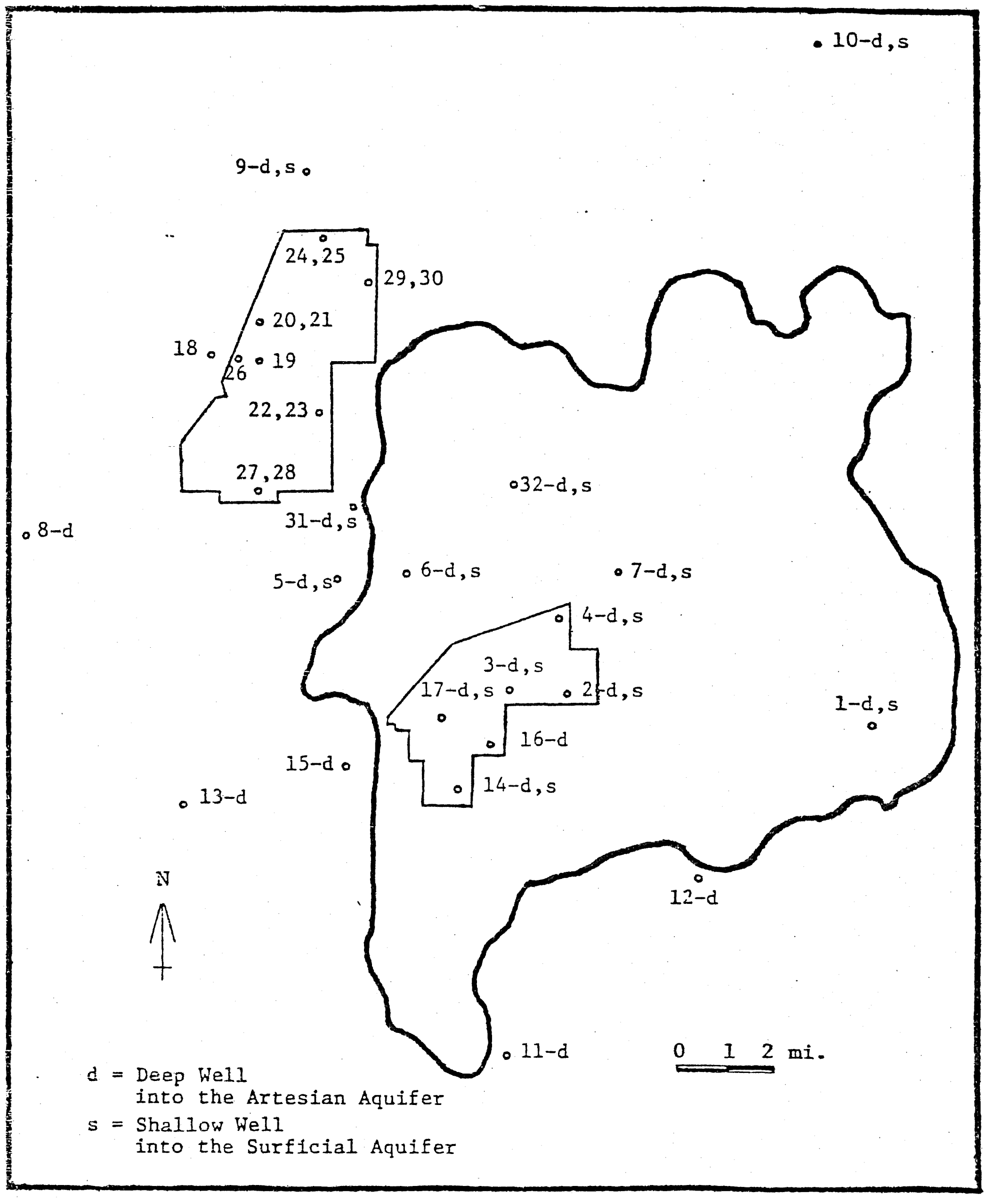


Figure IV-4. Location of Deep and Shallow Observation Wells in the Cypress Creek Region. (Heaney et al., 1986).

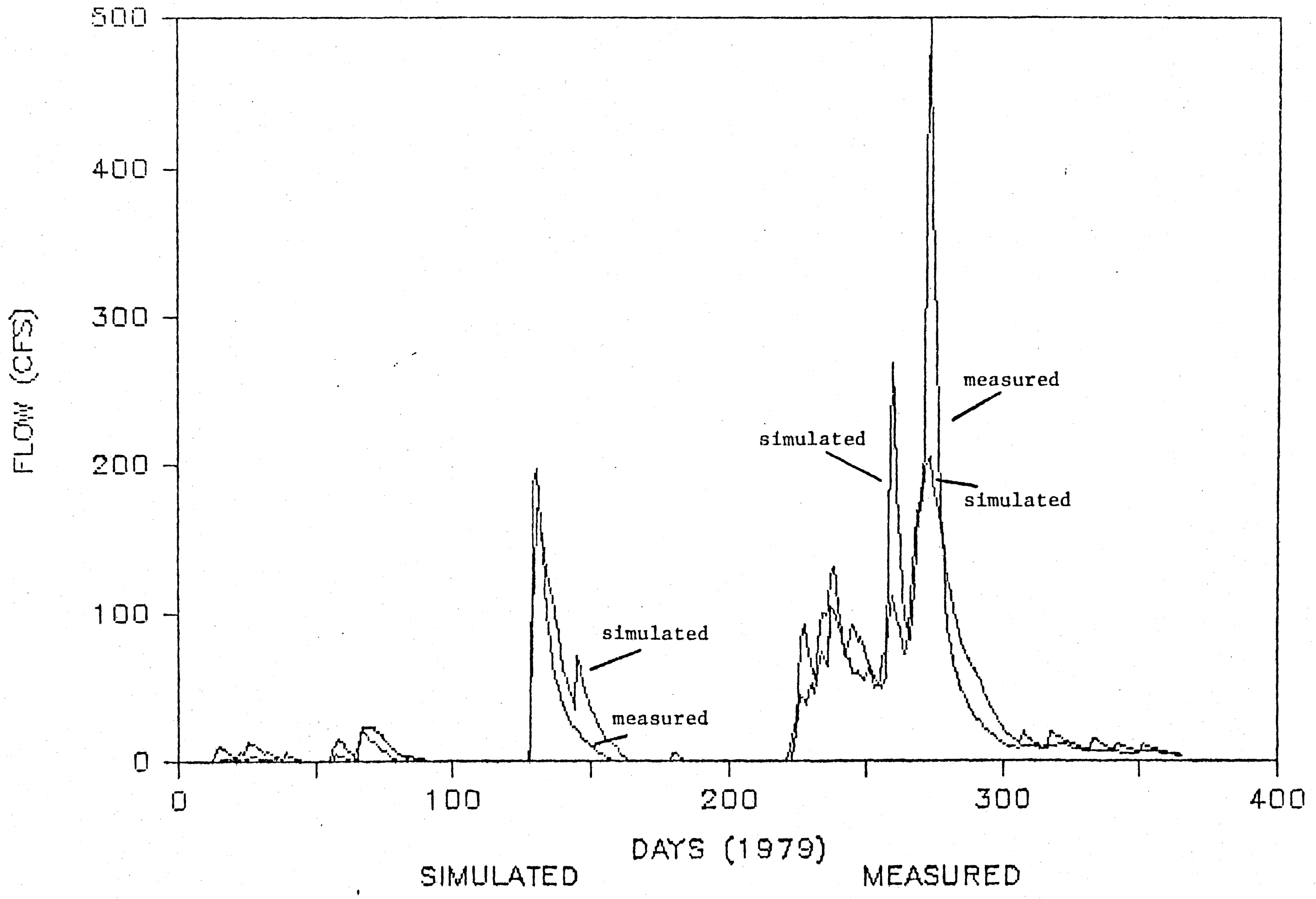


Figure IV-5. Simulated vs Measured Flows at San Antonio (Heaney et al., 1986).

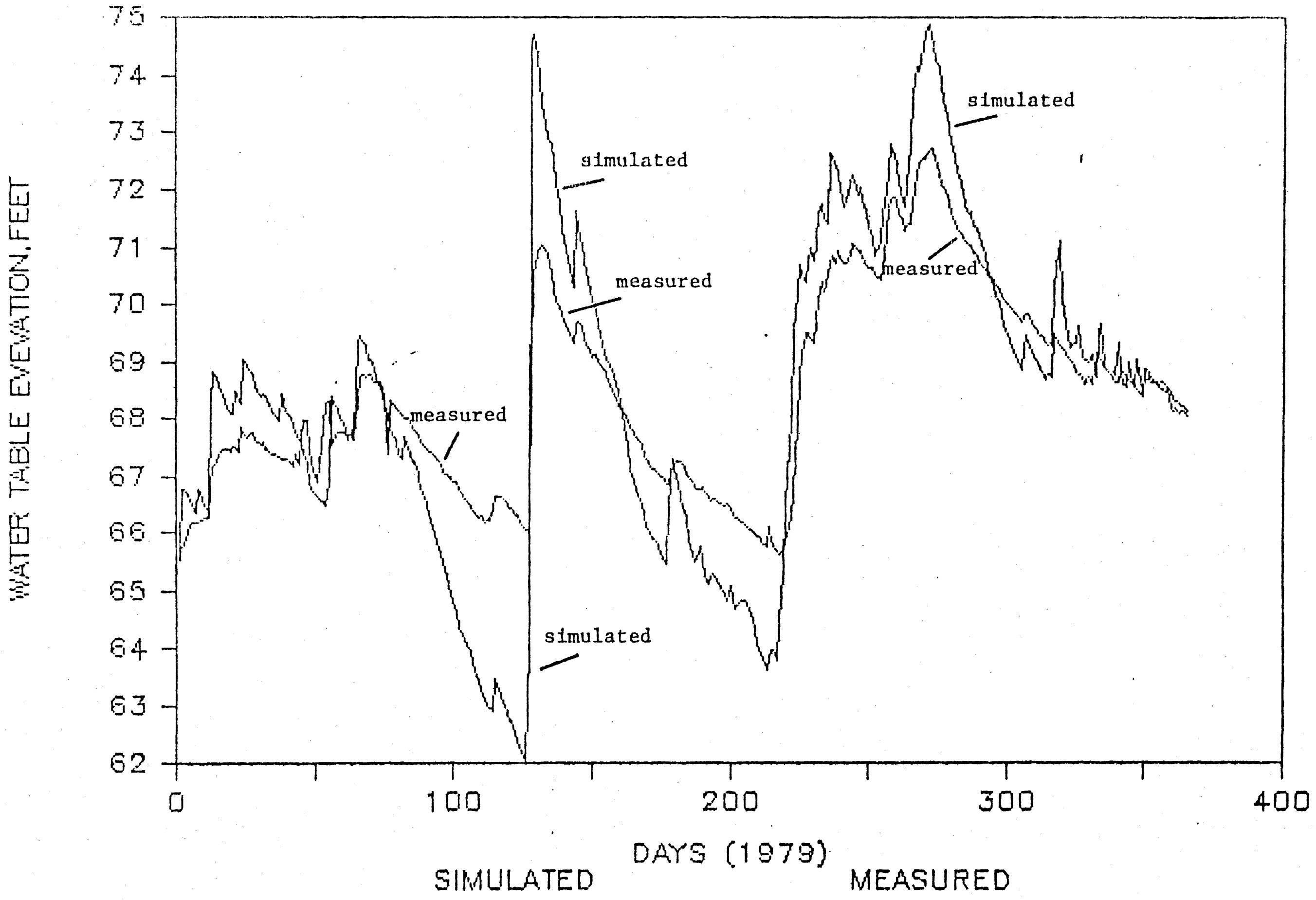


Figure IV-6. Simulated vs Measured Heads at Well 4 (Heaney et al., 1986).

is very good. The most important loss term is ET. It is over three times as large as the runoff, the next largest item in the water budget. The model was calibrated to fit well for the normal range of flows. Thus, simulated high flows may differ significantly from the measured high flows.

This model is able to track the movement of the water table below the stream bed; this was a limitation of HSPF. Of course, this model can be criticized for not explicitly tracking some parts of the hydrologic cycle. The potentiometric head is not analyzed. However, the analysis of the well data indicated clearly that the potentiometric head is highly correlated with the water table. Also, the unsaturated zone is not analyzed explicitly. However, since no good information about the relationship between the unsaturated zone and runoff and ET exists, its effect can be included in the other terms of the water budget.

Cypress Creek Between San Antonio and Drexel

The simulation of Cypress Creek between San Antonio and Drexel appeared to be much more complex than the upstream reach for several reasons. First, this reach contains the Cypress Creek Wellfield. Second, it receives runoff from the upper reach. Third, it contains a large area of wetlands.

Calibration

The rainfall and evaporation estimates were prepared in the same manner as for the upstream reach. Early efforts to calibrate the model against the stage in well 3 (located within the Cypress Creek Wellfield, see Figure IV-4) proved futile because the stages in the well changed drastically for no apparent reason. It was concluded that this rapid change was due to turning pumps on and off in the well field. Although well 4 is located at an elevation approximately 7 to 10 feet higher than the Drexel area, it appears to be less affected by the wellfield pumps, and was used for the calibration. Thus, the simulated heads will be eight feet below the measured heads. Next, an attempt was made to derive a stage-discharge relationship for this reach. However, no reasonable approximation could be found. Thus, the measured upstream and downstream discharges were used as input data to see how significant they might be. The model was calibrated by predicting well levels. The results indicate that streamflow is relatively unimportant in the water budget for this reach. Our best guess is that the inflow passes through this reach in a day or two. This conclusion is based on analyzing storm hydrographs at San Antonio and Drexel (see Figure IV-7).

Results

The results of the simulation of heads for the year 1979 are summarized in Table IV-7 and Figure IV-8. The detailed simulation is shown in Appendix C. The means of the heads agree within 0.4 feet and the standard deviations of the heads are very close, i.e., 1.8 vs. 1.77. The calculated leakance rate was 22.3 inches per year.

Overall, the results for both the flows and heads at San Antonio and the heads at Drexel are good. The most sensitive calibration parameters for both simulations are the leakance, storage coefficient, and the rain gage weighting factors.

The leakance above San Antonio was 8.5 inches per year while the leakance in the middle reach was 22.3 inches. Leakance is more im-

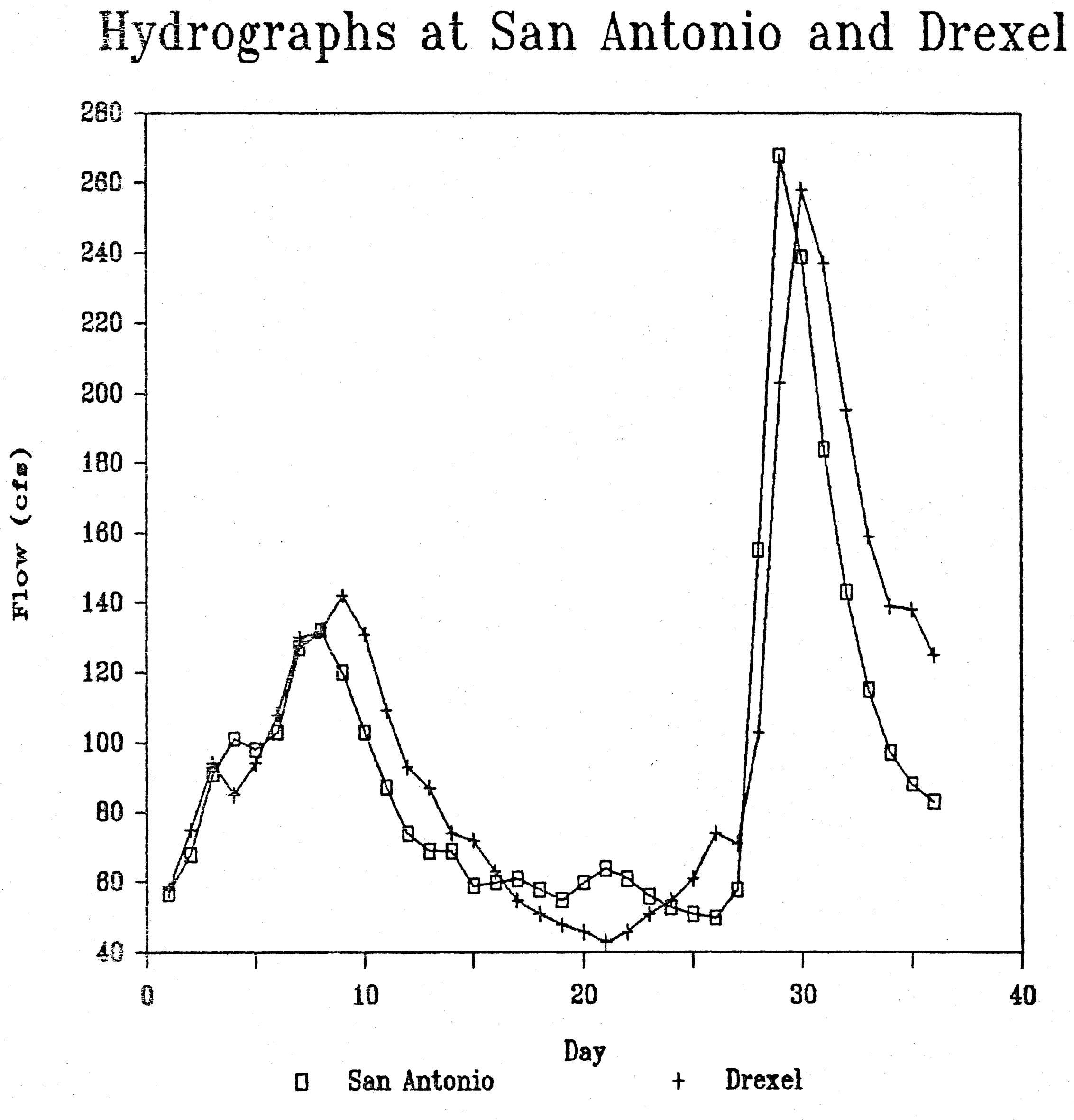


Figure IV-7. Hydrographs at San Antonio and Drexel (Heaney et al., 1986).

Table IV-7. Summary of Lotus Simulation of Cypress Creek Between San Antonio and Drexel: 1979.

	Precipitation Weighted Mean	Cypress Creek	Saint Leo	Evap	E-T	Leakance	Well # 4 Head Calc	Meas
TOTAL	64.0	61.1	66.9	60.1	41.8	22.33		
MEAN							58.1	68.5
MAX							62.13	72.71
MIN							53.91	65.64
STD DEV							1.80	1.77

KEY ASSUMPTIONS:

1.ET=(ETMAX-ETRATE*(GRDEL-WTEL))*E	GRDEL	68
	ETMAX	1
	ETRATE	0.03
3.STORAGE COEF.=		0.15
4.MAXIMUM LEAKANCE		70
6.INDICATOR RAIN GAGE WEIGHTS	Cypress	0.5
	St. Leo	0.5

CONTINUITY CHECK: dS/dT=(P-ET-Q-L)

P= 63.975 IN.
ET= 41.819 IN.
L= 22.331 IN.

dS/dT= -0.175 IN.
-0.084

PERCENT CONTRIBUTIONS

INFLOWS

P= 100%

OUTFLOWS

ET= 65.19%
L= 34.81%

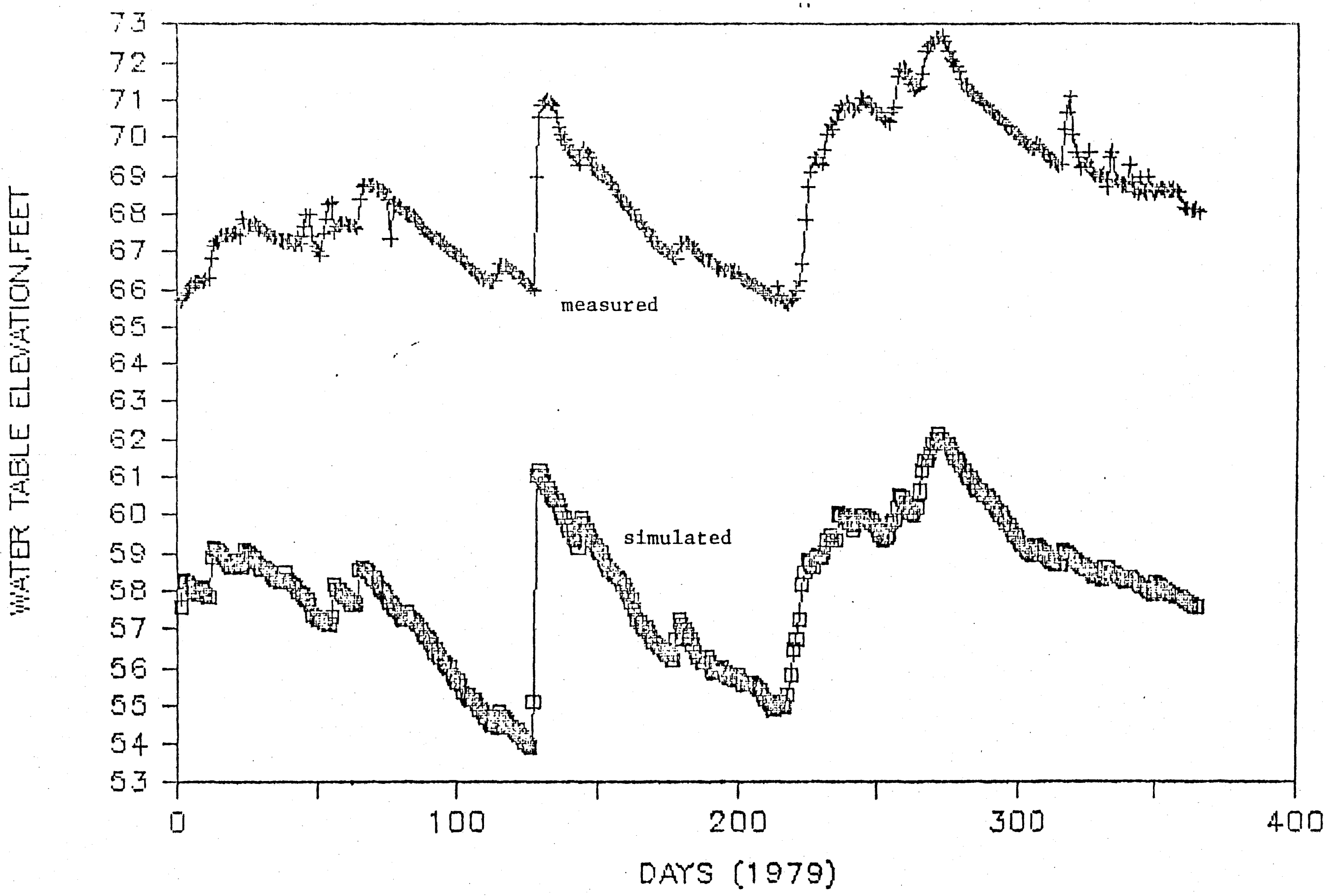


Figure IV-8. Simulated vs Measured Head at Drexel -- Well 4 (Heaney, et al., 1986).

portant at Drexel than at San Antonio because of the pumpage. The evapo-transpiration was higher for the upstream vs. the middle reach, i.e., 45.1 inches vs. 41.8 inches. The lowered groundwater table would be expected to reduce ET. A lower storage capacity (.085) was used in the upper reach than in the lower reach (.15). This difference is consistent with the soils of the two areas. The same rain gage weights were used for the two areas.

Conclusions

The results of these simulations are instructive in two ways. First, they indicate that sets of plausible parameter estimates can be found for this study area such that a good simulation of the surface-groundwater hydrology can be obtained. Secondly, it is also apparent that this solution is not unique. Many other combinations of parameter estimates could have provided similar or even better solutions. Thus, it is important not to take these results too literally. The main area of uncertainty is in the evapo-transpiration estimates and the associated estimates of leakance, especially in the San Antonio to Drexel reach where it is possible to reduce the ET and increase the leakance and still get a plausible result.

While it is possible to develop a very large surface-groundwater model that could give much improved temporal and spatial information, it appears to be more beneficial to use a spreadsheet analysis approach to conform to the local problem. The basic idea is to focus the effort on those components of the hydrologic cycle that are most important for this area and this problem. Also, the sophistication of the modeling should depend on the available data. It is counterproductive to use a sophisticated model with a weak data base. Lastly, it is very desirable to use models that can be understood and used by technical people who are not computer experts.

This model does sensitivity analysis very well. The user only has to change the assumed parameter estimate(s) and the new answer is automatically recalculated in about ten seconds. Thus, it is possible to run a few hundred test cases in a single day. These tests can be run by the experts who are most knowledgeable about the technical aspects of the problem. The sensitivity analysis shows the limits of accuracy that are achievable, and it is possible to get reasonable calibrations with numerous plausible assumptions regarding the parameter estimates.

Automation Using Macros

Lotus modeling can be very easy when compared to modeling in BASIC or FORTRAN, but as the spreadsheet begins to become very large, getting about and performing calculations may become confusing. Through the use of a simple programming feature in Lotus 123, several small programs, called keyboard macros, may be included in the spreadsheet to perform many operations automatically.

A macro is a stored sequence of keystrokes, that may be placed in a reserved section of the spreadsheet (although they may be placed anywhere on the spreadsheet, no other work should be done in the macro area). Each macro is identified by the symbol \ (not to be confused with /), followed by one of the letter keys, A-Z. When the macro is run, by stroking the Alt and corresponding letter keys simultaneously, the computer automatically types the keystrokes in the macro. This not only saves the time of striking several keys repeatedly, but allows the expert to write "programs", defined as a series of keystrokes, that can be used by others.

An example of a simple macro is the following:

`/GNUrain~`

This macro represents the command to retrieve and view the named graph RAIN. If one was to perform this procedure manually, it would be accomplished by stroking the / key followed by the menu choices Graph, Name, and Use. The user may either move the cursor to each choice, or may simply strike the first letter of each choice. A list of the named graphs would then appear, and the user would choose RAIN, and stroke the return key. The GNU in the macro represents the three menu choices (by the first letters of each), the "rain" is the graph choice, and the ~ is the macro symbol for the return key. Thus the user has the choice of either striking the letters seen in the macro, or simply simultaneously depressing the Alt and the corresponding macro letter. When lengthy series of keystrokes are incorporated into macros, the Alt-letter procedure proves to be the much shorter path.

Several macro commands are available that represent Lotus functions, many of which are presented in Table IV-8. These commands assist in automation and simplification of the macros. By mastering the use of macros, Lotus may be customized to the individual needs, and the need to purchase "template" software for Lotus, which are nothing more than a collection of macros that can be constructed by the user, will be eliminated. Several books are available on the many uses of macros

Table IV-8. Special Key Indicators and Commands Used in Lotus Macros.

Key Indicators	Key
~	Return
{Down}	Down arrow
{Right}	Right arrow
{End}	End
{PgDn}	PgDn
{Edit}	F2 Function
{Graph}	F10 Function
{GoTo}	F5 Function
{Esc}	Escape
{?}	Pause for input until the Return key is pressed

Command	Function
/XIcondition~	If-Then
/XGlocation~	GoTo
/XClocation~	Call subroutine
/XR	Return from subroutine
/XQ	Quit macro execution
/XMlocation~	Process a user-defined menu
/XLmessage~location~	Display a message in the control panel, accept a label entry (/XL) or number entry (/XN), a place entry in a cell
/XNmessage~location~	

(Riddington and Williams, 1985, LeBlond and Cobb, 1983), which will aid in the construction and design of the miniature programs. Although one of the advantages of Lotus 123 is the elimination of the need for computer programming, Lotus macros create the option to include simple yet powerful programming when there is a need.

The variety of macros that may be constructed is almost limitless. Thus, it is nearly impossible to present all of the macros that have been used throughout the past hydrologic studies. Once the Lotus user understands the workings of macros, their construction is not difficult. A list of a few of the more useful macros in the past hydrologic analyses is presented in Table IV-9.

Conclusions

Spreadsheet modeling can be used to solve a variety of water resources problems, and has proven to be successful in a large hydrologic study. The models can be fully documented on the spreadsheet, and allow the user to understand each of the processes included in the models. These advantages allow the expert to make more accurate judgments about model parameter estimates since all of the calculations are plainly presented on the spreadsheet.

The programming option in Lotus 123, known as macros, allows complete automation of most of the modeling procedures, and makes the creation of spreadsheet versions of main frame simulation models possible. The comprehensive or simple spreadsheet models allow the expert to organize ideas, estimation techniques, and references in the modeling

Table IV-9. Useful Lotus Macros in Hydrologic Modeling.

Macro	Uses
/xmA2~ AREA Shows area {goto} Area~	The /xmA2~ command is used to produce the menu at cell A2. The menu, which begins with choice AREA is below (at A2). Other choices may be placed directly to the right of the first. Directly below is the description of the choice, and below the description is the command executed when AREA is chosen. (see Appendix D)
/gnuRAIN~q~	This macro recalls a graph named RAIN. The three letters represent /Graph Name Use. Many macros may be created by using the first letters of the commands.
/{home}{up}{left}{up}	This macro, when given the range name \0, will automatically return the spreadsheet to home and beep three times to alert the user that the spreadsheet is ready. This is useful for large files that require time to boot.
/cz42~note~	This simple macro copies the contents of cell z42 to the cell range named note. This macro may be included in other larger macros to prompt the user at different stages of large programs.
/reHELP~ /fcce{?}~	This macro will first erase the range HELP and copy a help file into that range. The {?} command will pause for the user to type in the name, and will resume the macro when the user strikes the return key.

process, while providing an excellent learning tool for the beginning modeler.

Such modeling procedures may be combined into larger systems for a variety of water resources problems. The following chapter discusses a comprehensive hydrologic design model that was constructed for use in South Florida. Several macros, adapted to many of the models previously discussed, are presented.

CHAPTER V

STORMWATER EXPERT SYSTEM

The spreadsheet modeling concepts discussed in the previous chapters can be used separately for several hydrologic analyses, but can also be used in a more powerful way. When combined, these techniques can become the building blocks of easy-to-understand comprehensive models that provide documentation, references, and suggestions. The following chapter describes a prototype of such a model, originally designed to help design stormwater systems in South Florida. The model is based on the current model used by the South Florida Water Management District, but expands on many of the procedures in the model. The product is a program that combines the calculating power of a conventional computer program and the advisory power of the "expert system".

The Expert System

As previously discussed, it is often advantageous for the engineer to use "desk top" analyses and simple models before delving into the much more complex main frame (and more recently, personal computer) surface and subsurface models, in order to prepare an initial data set and "feel" for the results. Sometimes this type of analysis alone may be a better alternative to using the large models, and can be more easily explained to the regulatory agencies. Even if the agency accepted method is determined to be suitable, the input parameters and assumptions must be well documented in order for the agency to check the expert's result.

Much can be learned from hydrologic texts and manuals, but obtaining the information contained in such sources can take months of research. Also, since each individual gathers different experiences and has a different educational background, it is often necessary to consult with several individuals with varying types of expertise before a particular part of a complex hydrologic problem can be solved. This ability to consult with other experts is often very costly or impossible, and may be the cause of many modeling problems. If an engineer had every expert in a particular topic available at his fingertips, and could consult with them at every stumbling block, as well as present his thinking to the other experts (and to himself) in a clear and logical manner, water resources problem solving would be a much simpler process. If, in addition to the above, the engineer had easy access to any section of a water resources design manual at any point in time, problem solving would be further expediated. Of course, this is quite impossible, but with the use of a computerized "expert system", we can come close.

Expert systems are computerized design aids that can be developed for almost any problem. They are a systematic method of incorporating expert suggestions, reasoning, and ideas within a computer program in order to provide the user with helpful information. The expert system also provides an organized train of thought which helps the user progress much more smoothly through any particular problem.

Expert systems are a direct product of the concept of artificial intelligence. The idea is to create a computer program that could in a sense think, or imitate the human logical process of reasoning. Such a system usually has a set of rules, logical steps, and knowledge bases. By progressing systematically through the steps of reasoning, the computer can help the user solve a problem, using a previously input knowledge base. This knowledge base can be modified at any time, and the logic can also be changed as needed. Thus the user has the benefit of an organized method of approach to a problem, as well as the help of other experts' knowledge.

Such systems have been created for other fields, such as medicine, manufacturing, chemistry, and geology (see below). A fully developed expert system can be used to diagnose disease in humans or faulty mechanisms in an automobiles engine. Simply by receiving a set of answers to step by step questions, a computer can determine the logical answer to many problems, either by a series of IF THEN statements, or by some other logical progression.

In hydrology, this type of logical tool could be very useful in many areas: hydrologic model data preparation and calibration, local data analysis, parameter estimation, and theory versus actuality comparisons to name a few. If the expert could organize the the initial input data set for large models, or have a program that could assist in arriving at reasonable parameters and small scale models, the entire problem solving process would proceed much more smoothly and quickly.

Literature Review

The field of artificial intelligence (AI) has existed almost as long as the field of computers. As early as the late 1950s, computer scientists have sought to create a combination of computer hardware and software that could imitate the brain, and recreate the mystery of human reasoning. Although the quest continues with some members of the computer sciences field, most have begun to abandon the ominous task of developing software to recreate the human brain for more field specific software that can interact with an expert in that field to help solve specific types of problems.

The most promising branch of AI by far is the recent development of the expert system. Expert systems were first experimented with in the mid to late 60s, and have been brought to a much wider use in the 80s. With the coming of the personal computer (PC} in recent years, the expert system approach to artificial intelligence has become very popular, and the success of the several new special-purpose computer software packages has added to the "expert system revolution".

One of the first expert systems developed was the system known as MYCIN (Shortcliffe, 1976). MYCIN is a rule-based medical consultation system that is able to relay its reasoning to the user. While MYCIN is used specifically for diagnosing bacterial infections and infectious blood diseases, it has spurred the development of several other systems to be used for other types of medical problems, such as PUFF (Kunz, 1978), for pulmonary disorders, ONCOCIN (Shortcliffe, et al. 1981), for cancer, and MOLGEN (Friedland, 1979; Stefik, 1980), for molecular genetics. Since its development, this expert system has been used at the Stanford Medical Center, and has proven to be successful (Van Horn, 1986).

The MYCIN system contains the knowledge of some of the world's foremost experts in the field, and allows the user to access this knowledge at any time. By using a series of interactive queries, the system is able to converse with the user in English, rather than terse computer jargon, and explain its reasoning at any step. Unlike its human counterparts, the computer is able to process a vast amount of information and questioning without ever missing a step or forgetting a question.

Unlike MYCIN, which still remains in the laboratory as a research tool, many expert systems have been developed to the point where they are commercially available and used extensively in the field. The expert system known as R1 (McDermott, 1980) is used by the Digital Equipment Corporation (DEC) to configure large VAX computer systems for its customers. R1 does not use an interactive procedure like many other expert systems, but rather arranges the knowledge fed to it by the user into the best feasible configuration for the customers' needs through the use of about 500 rules. These rules are the product of DEC's many years of expertise in VAX configuration, and allow the work to be done in a fraction of the time it would normally require.

Within the last ten years, expert systems have become a valuable to for the scientist and engineer, both in research and in professional business. DENDRAL (Buchanan and Feigenbaum, 1978), a computer program that has been developed over the last 20 years, is such an expert system designed for mass spectral analysis. By producing a rather large list of possible identities of any particular chemical's mass spectrum, and then using a system of comparisons and tests, DENDRAL is able to identify a compound in a fraction of the time it would take an expert. DENDRAL's "generate and test" variety of logical progression is yet another type of expert system that is possible (as compared to the "arrangement" technique of R1 or the "user interaction" technique of MYCIN).

PROSPECTOR (Duda et al., 1978), a geological system used to locate ore deposits, was developed by SRI International in San Francisco. It has helped locate a valuable molybdenum deposit valued at $100,000,000. Like MYCIN, PROSPECTOR uses an interactive session with the trained expert in order to deduce whether a proposed site contains a commercially valuable quantity of mineable ore, and can give the user a value, based on a scale from -5 to 5, of what the certainty is of each step and final conclusion. PROSPECTOR uses a reasoning mechanism known as backward chaining, which primarily evaluates the certainty of a given hypothesis. In other words, the system begins with the answer, and evaluates whether or not the questions leading to that answer are in agreement. Since the system's knowledge base and "inference engine", or logical processing mechanism, are completely separate, the PROSPECTOR system can be adapted to almost any of field by just changing the knowledge base.

Subsequently, SRI International developed HYDRO (Gaschnig et al., 1981), a prototype water resources expert system that uses the original inference mechanism of PROSPECTOR. First designed to help the expert determine parameters for the Hydrocomp HSPF simulation model used for watershed simulation, HYDRO determines values for each parameter by giving the user a menu of answers for each question asked by the program. The user enters a choice along with a value of certainty (again from -5 to 5), and the system deduces a parameter value and supplies its value of certainty. HYDRO is an extension of the PROSPECTOR system since it is encoded with judgmental processes which involve numerical computations. The knowledge base is provided primarily by an expert hydrologist with much experience with the use of HSPF.

At first, the HYDRO expert system appears to be a useful method for calibrating HSPF. Since the system contains the knowledge of a hydrologist with much experience with HSPF, estimation of the many parameters should be measier and more accurate, and the entire modeling process can be expediated.

Upon inspection of the HYDRO system, however, most of its questions are factual, and actually require little judgment at all. A typical example of one of HYDRO's queries is as follows:

> What is the soil type in the area under consideration?
> The choices are:
> 1) exposed rock or other impervious surfaces
> 2) extremely tight clays
> 3) clay/silt
> 4) fine to medium silt
> 5) medium to coarse silt or fine-grained sand
> 6) coarse sand or gravel or soil of volcanic origin

In order to answer such a question, the expert needs a knowledge base; in this example, a soils map of the study area. The user once again finds himself searching through printed data, making assumptions and calculating averages, and trying to fit the answer to one of the choices presented in the menu. Since this question needs a factual answer, the expert system does help in solving the problem, but merely attempts to organize the thought process in determining the answer. The expert needs a system of creating the knowledge base for solving the problem—something the HYDRO program does not provide.

Unfortunately, all of the above expert systems require main frame computers with large allotments of memory, have almost no calculation abilities, and often require answers from menus that may not pertain to the expert's particular area of interest. Research now includes providing expert systems for personal computer use, and expert system "shells" and programming packages (e.g., Expert-Ease, 1983, Turbo Prolog, 1986), that allow the user to develop his own expert system for any field.

Expert Systems and the Electronic Worksheet

The link between the electronic worksheet and the expert system has not been fully established. LOTUS magazine (Streblo, 1986) reports that Lotus 123 has been used in a small way to help handle data for expert systems, but with the merging of expert system theory and electronic spreadsheet data analysis and maneuverability, the development of a very useful and interesting method of water resources problem solving is possible.

Upon reviewing the methodology required for stormwater system design in the South Florida Water Management District (SFWMD), it appeared that the process could easily be performed entirely on an electronic spreadsheet. If the process could be combined with the expert systems philosophy, a very powerful analytical tool could be created. The following is a description of the development and structure of such a program. Although the program was originally designed specifically for use in the SFWMD, it has been generalized for use in any geographic area, and includes several other design options. The system's features include local data bases and analysis, a continuous surface-subsurface water budget model, a flood routing model, and an interface to the EPA Storm Water Management Model (SWMM).

Expert System Development for South Florida

Since the South Florida Water Management District was given the authority to regulate all waters within the district (Chapter 373, Florida Statutes, Florida Water Resources Act of 1972), it has had the responsibility to regulate all development and utilization of all water resources in the District. In accordance with the Act, several guidelines and design criteria have been established for such developments. The permitting program for surface water management systems is described in the Permit Information Manual, Volume IV (SFWMD, 1984), and is the basis of the expert system presented herein.

The manual describes several design techniques and criteria that must be observed in storm water management developments, many of which pertain to systems discharging into the many canals in South Florida. These techniques include rainfall analysis, ground storage analysis, runoff calculations, and flood routing.

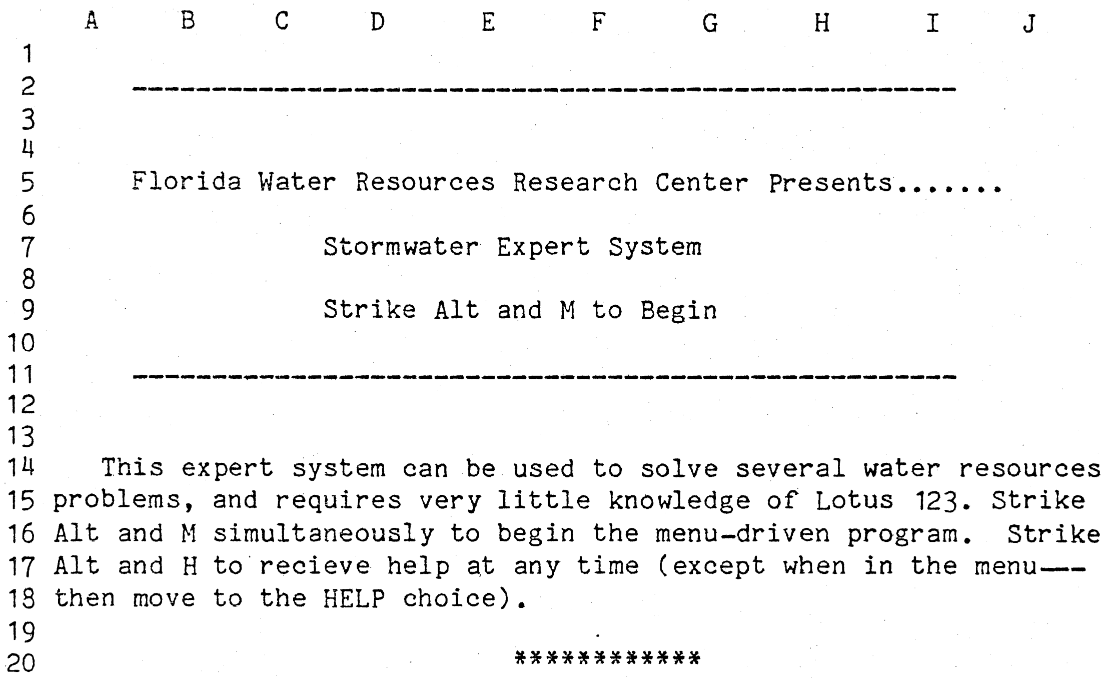
When originally released, the techniques were described entirely in the manual, but have recently been made available on floppy disk for use in microcomputers. This program, entitled RC4 (SFWMD, 1985), is a "black box" type of model, where the user feeds in some information, and the computer produces the results. Among other parameters, the model asks for information on ground storage, design rainfall, project area size, and termination discharge, and then produces a hydrograph of the discharge. The user can use the SCS method, the Santa Barbara method, or the mass routing method for the runoff. The program attempts to simplify the process of design and to insure that all engineers use a consistent method of design, but the "black box" procedure gives the user no control over the processes if unsatisfactory results occur, and requires no basis or documentation for the input data.

As an alternative to this program, a more comprehensive and visual version of the model can be constructed on an electronic spreadsheet. The program is completely menu driven, documented, referenced, and can be modified to meet any users needs.

The Stormwater Expert System

Main Menu

The introductory screen of the Stormwater Expert System (SWES) appears in Figure V-1. The file has been given the name AUTO123 so that the program is automatically booted when the Lotus 123 program is booted. The operations macro name, \0, is assigned to a macro that starts the program immediately upon entering the system file. The introductory page presents the title and gives initial instructions on operating the program.



```
     A    B    C    D     E     F     G     H     I    J
 1
 2      ----------------------------------------------------
 3
 4
 5      Florida Water Resources Research Center Presents.......
 6
 7                  Stormwater Expert System
 8
 9                  Strike Alt and M to Begin
10
11      ----------------------------------------------------
12
13
14    This expert system can be used to solve several water resources
15 problems, and requires very little knowledge of Lotus 123. Strike
16 Alt and M simultaneously to begin the menu-driven program.  Strike
17 Alt and H to recieve help at any time (except when in the menu---
18 then move to the HELP choice).
19
20                           ************
```

Figure V-1. Introductory Page for the Stormwater Expert System on Lotus 123.

When the M macro is implemented (by simultaneously depressing the Alt and M keys), the table of contents seen in Table V-1 will appear. The table of contents is divided into two segments—a data and knowledge base at the top, and the design models at the bottom. By moving the cursor to the letter in front of any category in either section and stroking the return key, a menu for that letter will appear at the top of the screen, as seen in Figure V-2. Here the letter A was chosen, and the subcategories of that letter appear in the menu. These menus are exactly like the menus used by the Lotus program, with a topic name on the top line and an explanation for each at the bottom, except that these menus may be created by the user through the use of the /XM macro command. This technique is described in Appendix D. By moving the cursor to the desired choice and stroking the return key once again, the segment of the spreadsheet containing the chosen model or data base instantly appears on the screen. The model or data base may be inspected or changed, and by striking Alt-M once again, the table of contents again appears instantly. The procedure of using the table of contents and menus is a very efficient way of moving about the large spreadsheet, and allows protection options that will be discussed below.

Program Features

Many of the models and analytical techniques described in previous chapters are included in the SWES program. Although the actual data and size of each of the models will change with the study area, the copy, move, and erase commands make the expansion or reduction of each of the models and data set an easy process.

Table V-1. Table of Contents for the Stormwater Expert System.

MOVE CURSOR TO PART LETTER, HIT RETURN TO CHOOSE CATEGORY, AND THEN CHOOSE FROM MENU.

Part	Table of Contents	Knowledge Base			
I.	Description of the Study Area				
A	Data Set	Study Area	Soils	Land Use	Topo
B	Rainfall	Rainfall General Stats	Design Storm Conditions	Storm Frequency Analysis	
C	Runoff	Design Conditions	Soil Infiltration	Imperviousness	Initial Abstraction
D	Ground Water	Design Conditions	Well Data	Well Data Graph	Leakance
II.	Design of Stormwater Management System				
E	Stage-Area-Volume	Stage-Area	Stage-Volume		
F	Design Storm(s)	Default Value	120 hr Rain	24 hr Rain	Frequency Analysis
G	Runoff Estimation	SCS Method	Unit Hydrograph	SWMM	DABRO
H	Stage Discharge Relation		Storage Routing		
I	Benefit Cost Analysis	Flood Damages	Control Costs	Optimal Design	

```
S20:                                                            CMD MENU
AREA  GRID  LANDMAP  LANDDATA  TOPO DATA  SOILS MAP  SOILDATA
Map of the study area
        S        T        U        V        W        X        Y

19  MOVE CURSOR TO PART LETTER, HIT RETURN TO CHOOSE
             CATEGORY, AND THEN CHOOSE FROM MENU.
21  --------------------------------------------------
22           Table
23           of
24  Part     Contents          Knowledge Base
25  ---------------------------------------------------
26  I.   Description of the Study Area
27  ---------------------------------------------------
28      A    Data     Study    Soils    Land     Topo
29           Set      Area              Use
30  ---------------------------------------------------
31      B    Rainfall Rainfall Design   Storm
32                    General  Storm    Frequency
33                    Stats    Condi-   Analysis
34                             tions
35  ---------------------------------------------------
36      C    Runoff   Design   Soil     Imper-   Initial
37                    Condi-   Infil-   vious-   Abstrac-
38                    tions    tration  ness     tion
```

Figure V-2. Example Menu of the Stormwater Expert System.

The prototype was initially set up using a hypothetical 625 acre subdivision as the study area (Figure V-3). This subdivision is similar to the example used in a past edition of the SFWMD Permit Information Manual (SFWMD, 1984).

Knowledge base

Maps and data. The first line of the table of contents contains several data bases and maps. A map presenting the general locations of the regional data stations is seen under the choice "Study Area" (Figure V-4). This map is created exactly like those discussed in Chapter II, and provides a basis for the user to choose the appropriate data gages for each analysis. A macro automatically calls the map when the choice, Study Area, is made (using the macro given as an example in Chapter IV), and presents the legend seen in Table V-2 upon striking the return key. Striking the return key one more time returns the user to the main menu. Maps of the soils, land use, and topography are also included in the menu, and are recalled in the same manner. The actual data base for each map can also be recalled for inspection or correction. Since the user may add to or rearrange these menus, additional maps may be included for presentation of other characteristics. In addition, data sets such as topography may be exported to ASCII files to create surface or contour maps with Golden Graphics, as is seen in Figure V-5.

Design criteria and parameter estimation. The Rainfall, Runoff, and Ground Water selections contain design storms, parameter calculations (as previously described), additional data sets, and graphs.

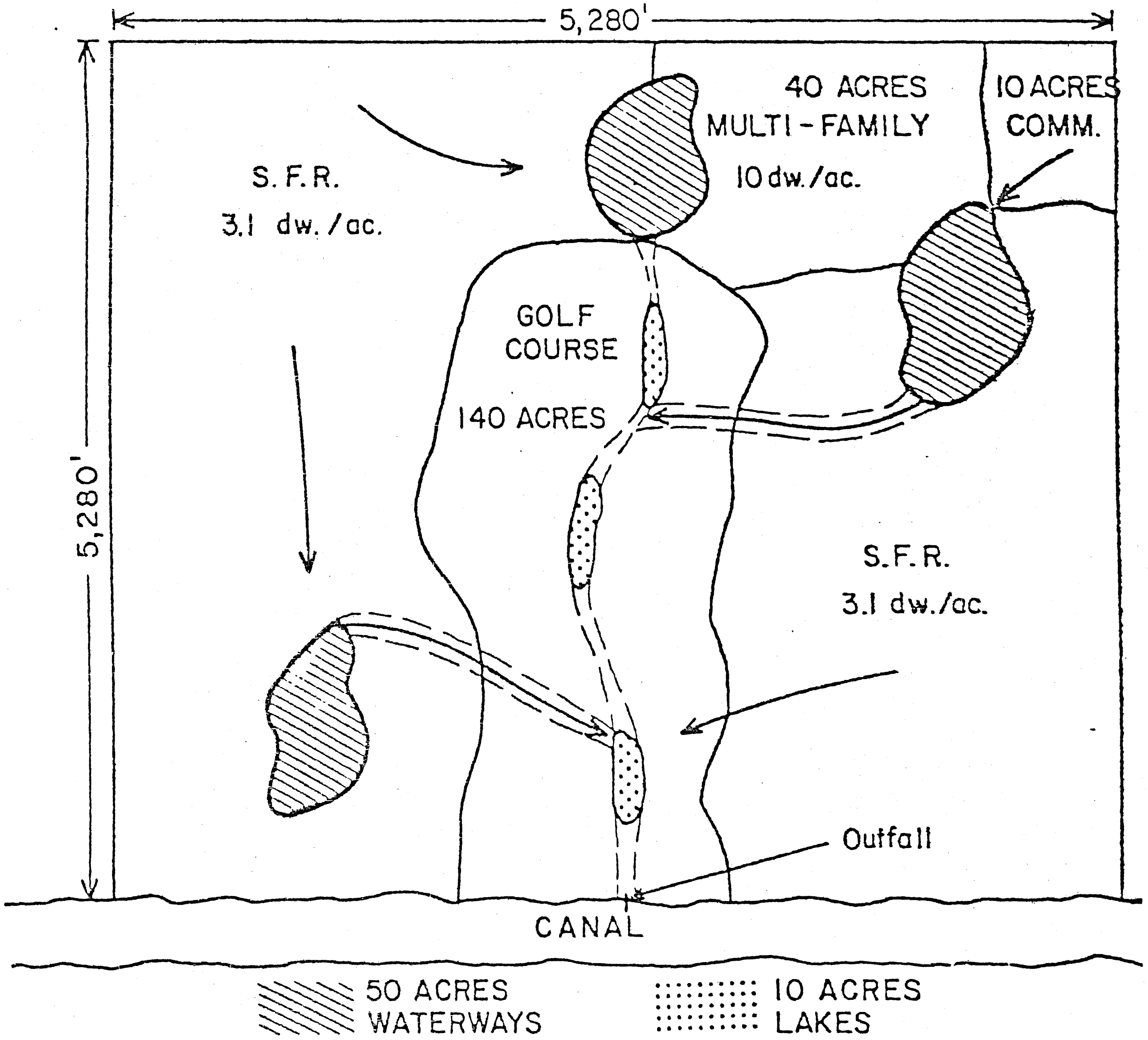


Figure V-3. Hypothetical 625 Acre Subdivision (SFWMD, 1984).

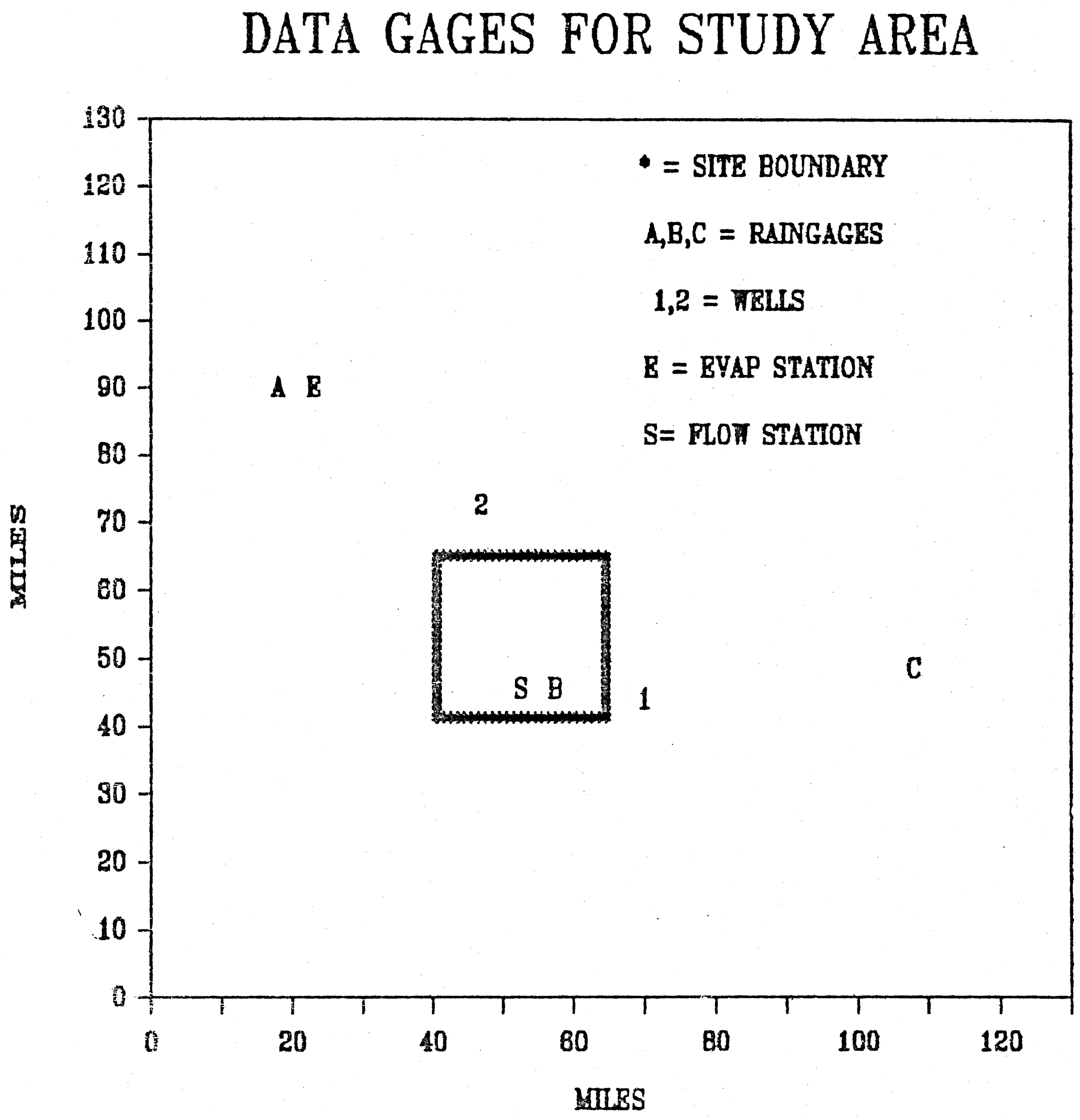


Figure V-4. Lotus Map of Data Gages in Hypothetical Subdivision Region.

Table V-2. Legend for Lotus Map of Example Study Area.

DATA STATIONS IN THE AREA

Site	Location	Parameter	Period	Comments
A	WESTEND	Rain	1956-1978	DAILY WITH MISSING DATA
B	ST. LEO	Rain	1931-1986	DAILY AND HOURLY
C	OUTLAND	Rain	1970-1986	DAILY AND HOURLY
1	Mr.Jones	Well Elevation	1968-1979	SHALLOW
2	Golf course	Well Elevation	1968-1979	DEEP AND SHALLOW
S	CANAL	Streamflow	1970-1986	MISSING DATA
E	WESTEND	Evaporation	1960-1978	MISSING DATA

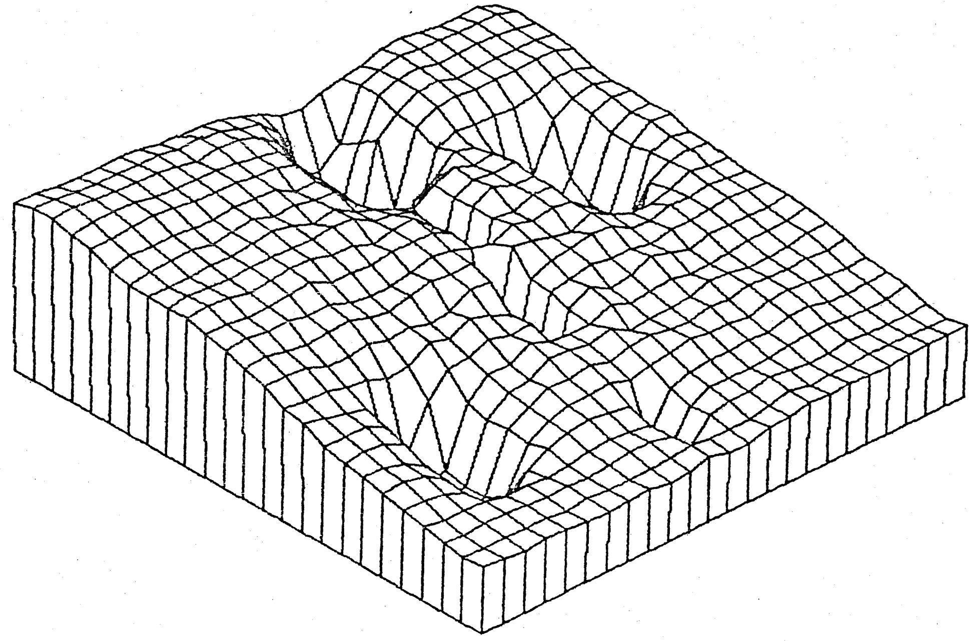


Figure V-5. Golden Software Topographical Map of the Hypothetical Subdivision.

Analysis includes area weighted infiltration rates and other soil parameters, rainfall frequency, and well data analysis.

Help files and manuals. Pertinent sections of the Permit Information Manual are available at the stroke of a key, such as is seen in Table V-3. If necessary, the entire manual could be added to a section of the spreadsheet, or different spreadsheet file, and be accessed at any time. By adding the manual directly to the spreadsheet, the user needs nothing but the spreadsheet for the complete analysis and no longer needs to thumb through the pages of a manual.

These spreadsheet expert systems could require a relatively sizeable amount of memory, depending on the organization of the models and data bases on the spreadsheet. This expert system requires almost 300K of memory, which will of course increase or decrease depending on the user's needs. Although the Release 2 version of Lotus 123 uses memory space much more efficiently than its predecessor, it is still wise to carefully construct such expert systems as to minimize memory requirements. Since large manuals may require a great deal of spreadsheet memory, the use of "Help" files may be a better alternative.

Customized help files similar to those in the Lotus program and other software may be developed for the spreadsheet expert system through the use of macros. If each section or topic of the reference manual is stored on a separate spreadsheet file and a list of the files is presented on the expert system spreadsheet, these files may be recalled at any time when the user needs assistance. By reserving a blank set of pages at least as large as the largest help file, each file may be printed in the blank space when it is chosen from the list of help

Table V-3. Section of Surface Water Management Design Criteria on a Spreadsheet.

1. General

The design of surface water management systems to meet local criteria and District criteria as specified in Rule 16K-4035, Basis of Review", requires the consideration of some basic hydrologic and hydraulic principles. More specific data and methodology will be presented herein on: rainfall depth
rainfall dist.

A. Depth

1. Selection of Design Event

The depth of rainfall in inches for a specific return frequency and storm duration is the most basic parameter needed in the design and analysis of a storm water management system. The design event (return frequency storm) is determined either from local criteria of from the "Basis of Review" document. For unregulated watercourses the following chart is a summary of the criteria specified in the "Basis of Review" document.

SIZE (acres)	FREQUENCY	DURATION
A≤100	10 Year	24 Hours
100<A<640	10 Year	5 Days
A≥640	25 Year	5 Days

2. Determination of Rainfall Amount

Once we have determined the design frequency and duration we can use Figures 8 through 17 for estimating the appropriate rainfall depth.
(see manual)

Source: SFWMD, 1984.

files. Once the user has read the text and is ready to return to other work, the text will be erased from the working spreadsheet but remains available for future use. The blank area is now ready for another help file to be printed at any time.

The list of some of the help files used in this expert system appears in Table V-4, and is recalled through use of the main menu. As in the main menu, the user moves the cursor to the desired letter and strokes the return key. The macro then moves the cursor to the reserved help section, recalls the appropriate file, and prints it in the alloted space through use of the /File Combine command. Since the entire spreadsheet outside of the blank help area is protected, there is no risk of importing help files that are too large and will destroy other sections of the system. In the event that a particular help file is too large to combine onto the working spreadsheet, the working spreadsheet may be saved and exitted, and the new help file may be recalled through use of macros. In this case, a macro would have to be added to the help file to return to the working spreadsheet file after review, since once a file is exitted, all macros implemented in that file will end.

Any text available on a word processor file, such as Wordstar or Word Perfect, may be imported into a Lotus file, eliminating the need to enter the text through the keyboard. Such help files reduce the need for printed manuals, and allow immediate access to any desired section.

Design calculations and models

Design characteristics.

The first choices of the design and modeling segment concern the stage-volume and the stage-area rela-

Table V-4. Partial Index of Help Files in the Stormwater Resources Expert System.

Help File Index

A.	General	General SWES information
B.	Data	Data entry, manipulaton, and contents
C.	Maps	Mapping techniques and uses
D.	Frequency	Frequency and time series analysis
E.	Sparam	Soil parameter calculations
F.	Runoff	Runoff models
G.	Flood	Flood routing models

tionships in the study area, as well as the design storm information. This information is determined from both previous studies and from the parameter estimation calculations in segment one. Pages in the design segment are connected directly to the knowledge base, so these calculated parameters are automatically input to the models and design criteria upon calculation (by entering +B25 in the appropriate cell to automatically enter the contents of cell B25 into that cell).

Models. The runoff and flow routing models, as well as the surface-groundwater model, are also included in the design and models section. Since the data and parameters are automatically fed into the models from the knowledge base, additional models may be added as alternatives to the supplied models.

In the case of SFWMD, the SCS method is required in stormwater design, but other methods could be added for comparison using the same input data. The expert system presented includes a space for calculating runoff by the unit hydrograph method, although it has not been added to the spreadsheet. A Lotus preprocessor for the Storm Water Management Model (SWMM), a comprehensive urban hydrologic model, is currently being developed (Miles and Heaney, 1986) that can be linked directly to the Stormwater Expert System's knowledge base. If it is desired to run the more comprehensive SWMM model, which uses a more complex method of runoff calculation and flood routing, the information can be fed to the preprocessor with little additional work. Lotus preprocessors for the other available hydrologic models are also possible.

Other types of analysis or design, such as for public water supplies may be added to the expert system, or may be adapted to separate systems. Although these analyses would be associated with completely different types of models and data bases, the concepts of development, organization, and implementation would be similar.

Program protection

Once a spreadsheet expert system has been developed for a particular problem, the user may want to prevent future users from inadvertently destroying any of the calculations. Spreadsheets may be globally protected through use of the /Worksheet Global Protection Enable command in Lotus 123, but such protection will not allow any of the cells to be altered, and input to the model will be impossible. However, several alternative methods are available.

The more awkward method is to include a statement in each macro that turns the protection off and on before and after each keyboard input. This will cause the macros to be very large, however, and may cause them to become quite confusing, but is often the best alternative for simple models.

A more convenient method is to use the /Range Input command in the macros, which only allows the cursor to be moved to unprotected cells. Individual cells in the globally protected spreadsheet may be unprotected by the /Range Unprotect command. The /Range Input command automatically causes the cursor to jump only to the unprotected cells, where input is allowed. This method is very useful in many situations, but has the drawback of not allowing the user to check the equations in the protected cells--one of the original advantages of using the spreadsheet instead of a traditional computer code.

The problem of supplying adequate spreadsheet protection while allowing user input and calculation checks can be solved through the use of a simple macro. The macro used in the SWES is divided into two parts: an input mode, and a calculation mode. The input mode uses the /Range Input command, by which data may be entered by the user into unprotected cells. The label Data Input Mode is typed at the top of the page in this mode to alert the user (Table V-5). When using a color monitor, the unprotected cells appear as a different color than the protected cells, so it is apparent where data will be entered to the model. By using the arrow keys, the cursor is moved only to the unprotected cells. When the cursor is on one of the unprotected input cells, the user may input a number, and move to another cell without striking the return key. The user strikes the return key only after entering the data to all cells; the entered data will appear in the cell after striking the arrow keys. Once all the data are entered and the return key is struck, the model enters the Calculation Check mode (Table V-6), where no data are allowed to be entered, but the cursor may be moved to any cell for inspection. In this manner, any cell may be reviewed in order to better understand the model being used or to check for errors.

Upon striking the return key once again, the main menu appears on the screen. If it is necessary to correct any protected cell, the global protection may be removed at any time. This process will be

Table V-5. Example of Data Input Mode in SWES.

DATA INPUT MODE

I. Valuation analysis

Land Use	Acreage		Units/ Acre	$1000/ DU	$1000/ Acre	Value 1000$
Golf Course		0	-		8	0
land	0					
water	0					
Residential						
single family		10				
golf view	0		3.1	80	248	0
water view	4		3.1	65	202	806
other	6		3.1	50	155	930
multi-family		14				
golf view	0		10	75	750	0
water view	4		10	60	600	2400
other	10		10	40	400	4000
Commmercial		0	-		250	0
Waterways		1	-		0	
Total		25				8136

Table V-6. Example of Calculation Check Mode of the SWES.

CALC CHECK MODE
DO NOT ATTEMPT TO ENTER DATA

I. Valuation analysis

Land Use	Acreage		Units/ Acre	$1000/ DU	$1000/ Acre	Value 1000$
Golf Course		0	-		8	0
land	0					
water	0					
Residential						
single family		10				
golf view	0		3.1	80	248	0
water view	4		3.1	65	202	806
other	6		3.1	50	155	930
multi-family		14				
golf view	0		10	75	750	0
water view	4		10	60	600	2400
other	10		10	40	400	4000
Commmercial		0	-		250	0
Waterways		1	-		0	
Total		25				8136

performed by a user knowledgeable about the system, however, and little risk of destroying the system is present.

Conclusions

The Stormwater Expert System contains data manipulation functions, data base analysis functions, mapping and graphing capabilities, and references for all calculations. Models such as runoff calculations, flood routing, areal distributions, and surface-groundwater interactions, as well as the capability to interface with the larger SWMM model, are all included in SWES, but many others are possible. As new models or analyses are needed, the system may be modified to handle a variety of water resources design problems.

The SWES can be used for a variety of water resources problems and analyses, but is not limited to the presented models and data sets presented above. This expert system's power is not necessarily in the included models, but in the spreadsheet analysis techniques and ideas that are used in the system. When these techniques are combined with the data handling capabilities and macro programs in Lotus 123 (or other spreadsheet software), a powerful method of organized and documented analysis can be created. As such programs are used by different experts, recommendations and other notes may be added to the help files, based on the experience of each individual that uses the models; thus creating a true expert system.

Although the electronic spreadsheet has been popularly used primarily for business purposes in the past, some other spreadsheet uses have been developed for data analysis and modeling; many of which may be used in conjunction with the previously discussed techniques. Some of these recent ideas, as well as other original spreadsheet modeling techiques, are discussed in the following chapter.

CHAPTER VI

OTHER SPREADSHEET MODELS AND ANALYSES

Electronic spreadsheets, such as Lotus 123, are able to import and export data to and from other formats, apply mathematical calculations and statistical analysis to data, and arrange data in a variety of ways; all by stroking a few keys. Instead of using spreadsheets to prepare and move data for use in other computer models and programs, many researchers have begun to move the models and programs to the spreadsheet. The following is a description of other inovative uses of the Lotus 123 spreadsheet.

Data Handling and Analysis

Aitken and Schiff (1985) describe a method of using Lotus 123 in the chemistry laboratory to analyze their results. By linking the spreadsheet with another data importation system and the BASIC language WRITE, results of performed experiments can be easily input to the spreadsheet, manipulated, graphed, and analyzed. Used in this manner, Lotus and the personal computer have become a low-cost and efficient method of data handling and analysis.

Mathematical Operations

Johansson (1985) describes a method for using Lotus 123 for solving simultaneous equations. The method described is an application to a macroeconomics problem, but it is easily adaptable to any type of problem. Simply by connecting all the equations involved, so as to create a circular situation (the Gauss-Seidel method), Lotus can iteratively calculate the equations for any or all variables. By continuously striking the calculation key, the solution will eventually converge. Alternatively, a simple macro in Lotus can be written to automatically perform the iteration (see Appendix D).

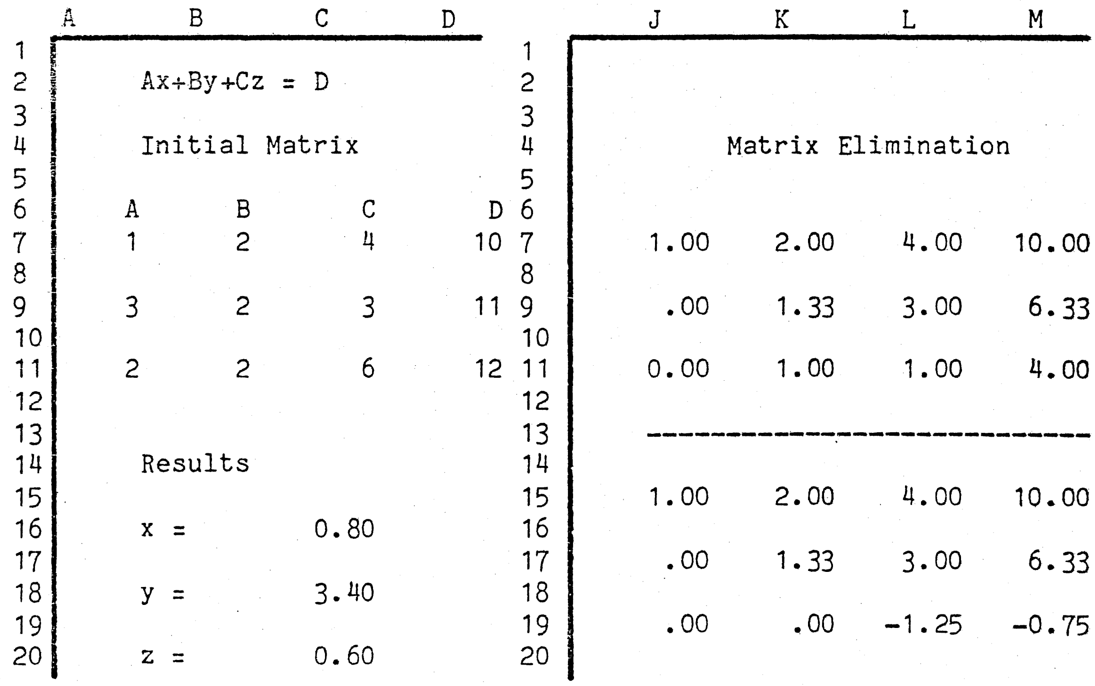
A simple model for solving simultaneous equations on an electronic spreadsheet is presented in Figure VI-1. The model is an automated version of the Gaussian elimination and backward substitution method. A window has been placed between the input-result section (on the left) and the actual calculations (on the right) in order to show two sections of the spreadsheet on one screen (the actual calculations for the model have been placed in a remote section of the spreadsheet).

The matrix of equations is input into the section labeled Initial Matrix. In order for the equations to be solved, there must be as many variables as there are equations: in this case, there are three equations with three variables. Each equation is in the form:

$$Ax + By + C = D \qquad \text{(VI-1)}$$

The parameters A, B, C, and D are placed in the appropriate cell in the model, and the iteration can begin.

The right side of the figure shows the elimination process used to solve the equations. By multiplying the second and third set of coefficients by a common multiplier of the first, the first term of the two sets can be reduced to zero (which has been done in matrix number one). If this process is repeated to reduce the second coefficient in the



	A	B	C	D
1				
2		Ax+By+Cz = D		
3				
4		Initial Matrix		
5				
6	A	B	C	D
7	1	2	4	10
8				
9	3	2	3	11
10				
11	2	2	6	12
12				
13				
14		Results		
15				
16		x =	0.80	
17				
18		y =	3.40	
19				
20		z =	0.60	

	J	K	L	M
1				
2				
3				
4		Matrix Elimination		
5				
6				
7	1.00	2.00	4.00	10.00
8				
9	.00	1.33	3.00	6.33
10				
11	0.00	1.00	1.00	4.00
12				
13	--------	--------	--------	--------
14				
15	1.00	2.00	4.00	10.00
16				
17	.00	1.33	3.00	6.33
18				
19	.00	.00	-1.25	-0.75
20				

Figure VI-1. Spreadsheet-Based Simultaneous Equation Problem Solver.

third set to zero (which is done in matrix number two), the third equation can be solved for c (which is done in the Results section). By substituting the c variable into the second equation, b can be solved, and so forth.

This system of simultaneous equation problem solving is very easily adapted to the spreadsheet, and can be automated through the use of simple macros to perform the iterations. Simply by increasing the size of the input and calculation matrices, any number of equations may be solved. The matrix inversion and multiplication commands on the Lotus 123 Release 2 spreadsheet provide a much easier way to solve such sytems of simultaneous linear equations.

Groundwater Modeling

As an adaptation to Johansson's idea, Olsthoorn (1985) presents a prototype for a three-dimensional finite difference groundwater model on an electronic spreadsheet. A simple confined aquifer groundwater model can be achieved by creating a grid of interlocking equations and using the relaxation method to solve the Laplace equation:

$$Ho = (H1 + H2 + H3 + H4 + Q/kD)/4 \tag{VI-2}$$

where Ho = head of node under consideration (L),

H1...H4 = heads of four surrounding nodes (L),

Q = flow into node (L^2/t),

k = permeability (L/t), and,

D = thickness of aquifer (L).

The components of the hydrologic cycle involved in such a groundwater model are presented in Figure VI-2. Since the model is concerned only with groundwater flow, surface runoff is not a factor (except when calculating recharge to the groundwater). The spreadsheet model divides the groundwater into two sections: the shallow aquifer, or unconfined layer; and the artesian aquifer, or confined layer. The shallow aquifer is the area above any impermeable layer, with its top boundary being the water table, or surface at which pore water pressure is equal to atmospheric pressure (Fetter, 1980). The artesian aquifer is located between two impermeable confining layers, and therefore has a pressure differing from that of atmospheric. Several artesian aquifers may exist, and may be included in the model.

Since the artesian aquifer is located between two impermeable layers, its thickness is considered constant. The water table, however, generally follows the topography of the land, and rises or falls depending on the amount of rain, evaporation, runoff and meteorologic conditions that occur.

The Artesian Aquifer

The thickness of the artesian aquifer does not change with time (although it may change spatially), so it is therefore an easier section to simulate in a Lotus steady-state model. The steady state groundwater model will solve for potentiometric heads, or the pressure induced head, as opposed to the actual elevation of the water in the aquifer.

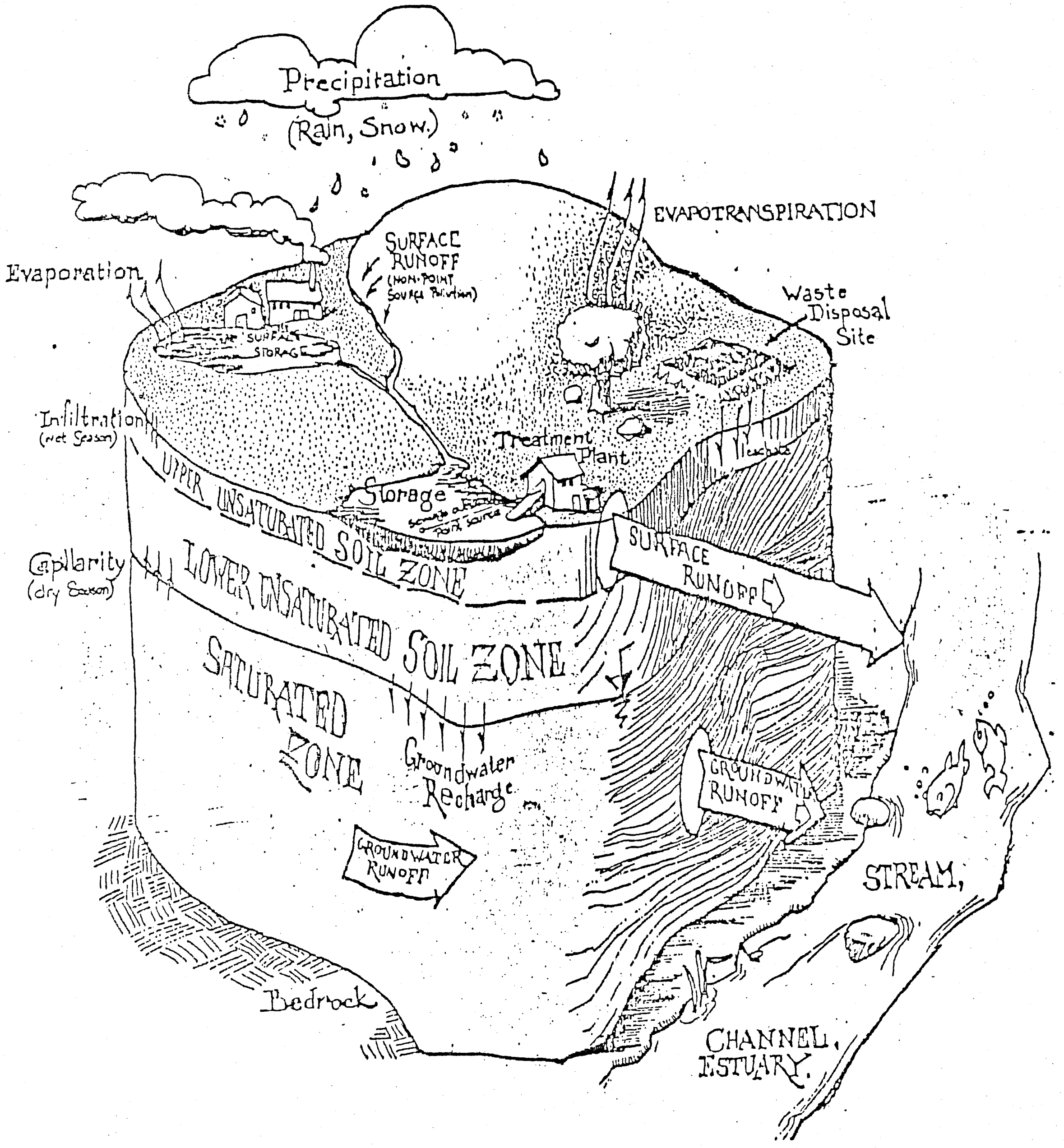


Figure VI-2. The Groundwater Hydrological Cycle.
(Bonazountas et al., 1981)

Creating an artesian matrix

The construction of finite difference matrices for different situations is discussed in several sources (Remson, 1971, Pinder, 1977, Huyahorn, 1979). A matrix of continuity equations (Equation VI-2) can be constructed on a Lotus spreadsheet, as is seen in Figure VI-3. If Equation VI-2 is entered into one cell, it may be copied into all others through use of the /Copy command. For example, the equation in cell D4 would be

$$(D3+E4+D5+C4+Q/kD)/4 \qquad \text{(VI-3)}$$

where the values for Q, K, and D are specified elsewhere on the spreadsheet.

Boundary conditions and special points

Boundary conditions must be placed around the border of the matrix in order for the iteration to work. The boundary conditons are in terms of head (feet), as are the continuity equations, so the model will solve for head. The equation could be rearranged to solve for constant flow:

$$Q = kD(4Ho-(H1+H2+H3+H4)) \qquad \text{(VI-4)}$$

The boundary heads are constant at the top and bottom in the example (60-72 feet), with a constant gradient between the two , but a different boundary value could be placed in each of the boundary cells. By striking the calculation key (F9) several times (or writing a macro to do this automatically), the matrix will eventually converge.

		1	2	3	4	5		
	35	35	35	35	35	35	35	
1	34.09	34.09	34.09	34.09	34.09	34.09	34.09	
2	33.18	33.18	33.18	33.18	33.18	33.18	33.18	B
3	32.27	32.27	32.27	32.27	32.27	32.27	32.27	o
4	31.36	31.36	31.36	31.36	31.36	31.36	31.36	u
5	30.45	30.45	30.45	30.45	30.45	30.45	30.45	n
6	29.55	29.55	29.55	29.55	29.55	29.55	29.55	d
7	28.64	28.64	28.64	28.64	28.64	28.64	28.64	a
8	27.73	27.73	27.73	27.73	27.73	27.73	27.73	r
9	26.82	26.82	26.82	26.82	26.82	26.82	26.82	y
10	25.91	25.91	25.91	25.91	25.91	25.91	25.91	
	25	25	25	25	25	25	25	

Boundary

Figure VI-3. Matrix of Darcy-Continuity Equations for Artesian Groundwater Simulation.

Special points for impermeable walls or layers may be placed throughout the matrix, some of which are shown in Figure VI-4. Other variables may be added to the equation, such as pumping, rainfall, and other inputs and outputs to the system, in any or all of the cells. Also grids of varying transmissivity or flow may be entered elsewhere on the spreadsheet to be included in each of the model cells, as is seen in Figure VI-5.

Three Dimensions

Several groundwater problems may be solved by the one dimensional model alone. Each cell may be specified as any unit of area, and be calibrated to many conditions. If additonal matrices are created, and linked to each other, a three dimensional model can be formed. In this case, the cells would include equations that connect any aquifer matrices above and below:

$$Ho = (H1+H2+H3+H4+H5+H6+Q/kD)/6 \qquad \text{(VI-5)}$$

Layers at the top and bottom would of course contain only five grid node variables. A variable for the permeability of any confining layers between the separate aquifers must also be included

$$Ho = (H1+H2+H3+H4+r_1H5+r_2H6+Q/kD)/(4+r_1+r_2) \qquad \text{(VI-6)}$$

where $r_1 = L^2/(kDc_1)$,

$r_2 = L^2/(kDc_2)$, and,

c_1 and c_2 = resistances of top and bottom aquitards.

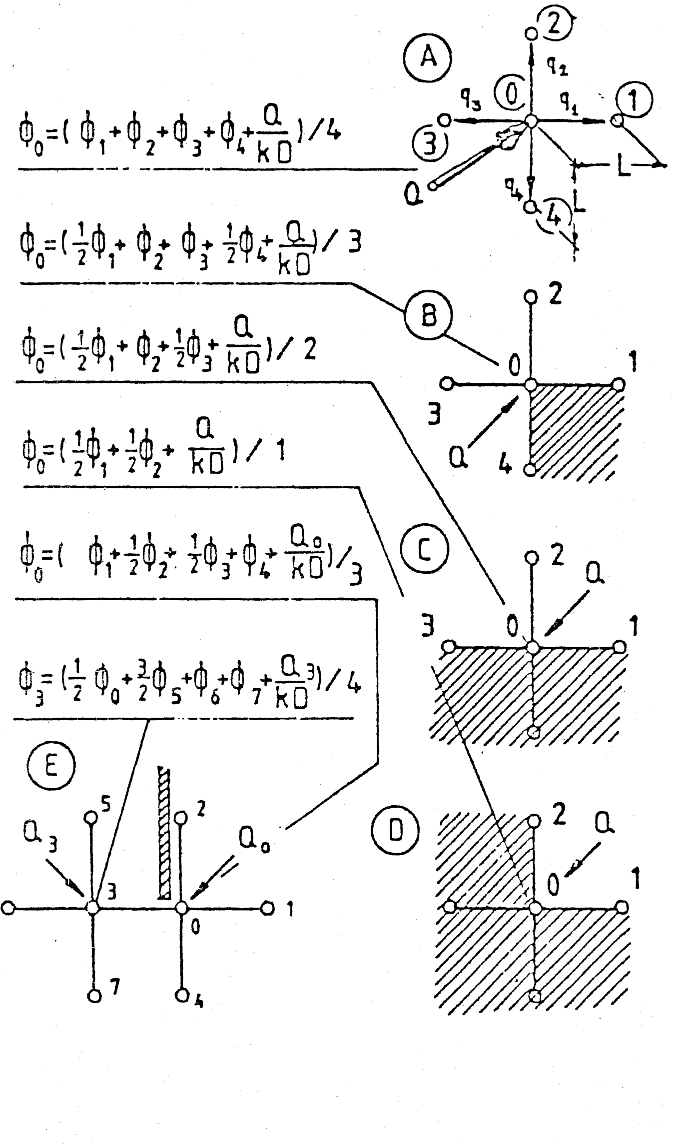


Figure VI-4. Calculation of the Head in a Meshpoint from the Values in the Surrounding Points for Various Situations: Single-Aquifer Model (Olsthoorn, 1984).

Boundary

40000	40000	40000	40000	40000	40000	40000	
40000	35000	40000	45000	50000	55000	40000	B
40000	35000	40000	45000	50000	55000	40000	o
40000	35000	40000	45000	50000	55000	40000	u
40000	35000	40000	45000	50000	55000	40000	n
40000	35000	40000	45000	50000	55000	40000	d
40000	35000	40000	45000	50000	50000	40000	a
40000	35000	40000	45000	50000	50000	40000	r
40000	35000	40000	45000	45000	45000	40000	y
40000	35000	40000	45000	45000	45000	40000	
40000	35000	40000	45000	45000	45000	40000	
40000	40000	40000	40000	40000	40000	40000	

Figure VI-5. Transmissivity Matrix for Use in 10 X 5 Unit Groundwater Model.

The Shallow Aquifer

The thickness of the shallow aquifer depends on the groundwater head, so a special nonlinearity problem arises. In order to solve this problem, the aquifer thickness must be connected to the head and floor height. Olsthoorn (1985) presents the derivations of the combination Darcy-continuity equation for phreatic water, to arrive at the result:

$$Ho = \frac{(1/2(H1^2+...+H4P^2) - z(H1+...+H4) + (L^2/kc)H6 + nL^2/k + Q/k)}{(2Ho - 4z + L^2/kc)} \qquad (VI\text{-}7)$$

where z = floor elevation

This equation also includes flow from another aquifer (upward leakance from the artesian), precipitation, and flow from an outside node: all or some of which may be excluded from the basic equation. With this equation entered into the nodes of a separate matrix, and combined with the artesian matrices, a useful finite difference steady state groundwater model can be developed.

Lotus 123 Groundwater Model

The Cypress Creek project was originally planned to include a groundwater modeling study using the main frame finite difference model developed by McDonald and Harbaugh for the United States Geological Survey (1984). Modeling of such a large area with little hydrogeologic data became very tedious and unproductive, so this analysis was eventually abandoned. In the process of deciding which analytical approach to pursue, a prototype Lotus 123 finite difference groundwater model was developed, based on Olsthoorn, McDonald, and Harbaugh's ideas, for use in the Cypress Creek study, although it was never used for actual analysis in the project. The model is a fully automated and menu driven spreadsheet model, that can used for simple problems or expanded for more advanced groundwater work.

Features

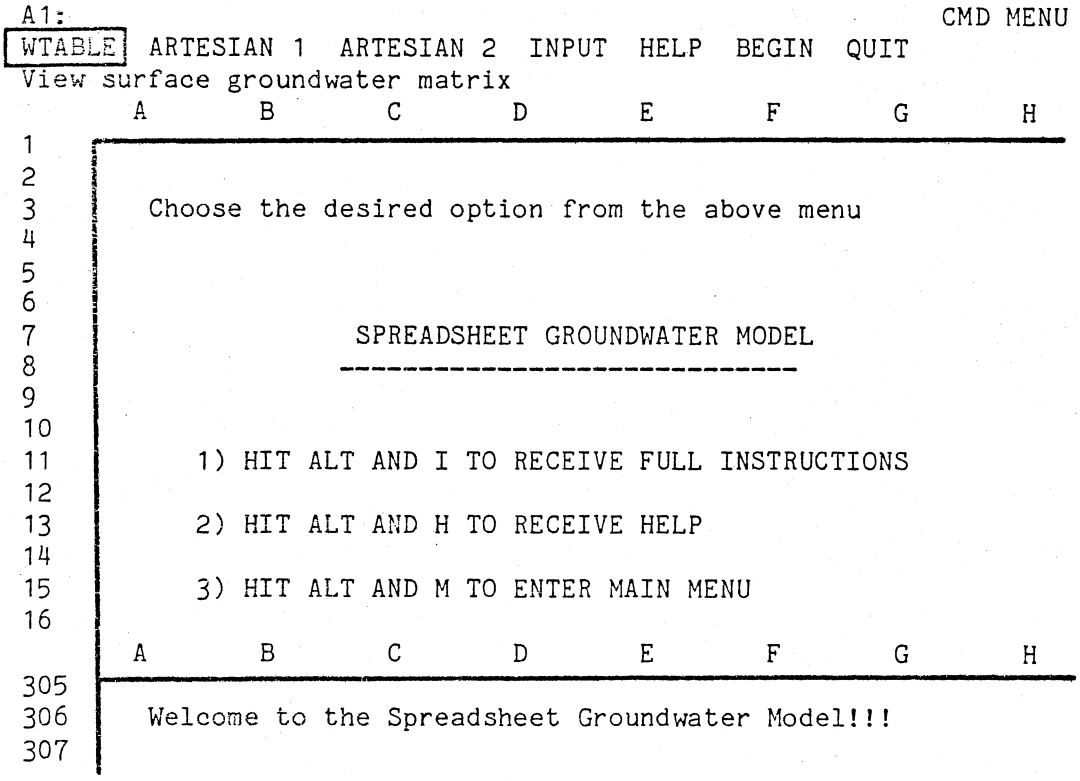
Upon entering the system, the user is prompted with a menu of options and a description of the model (Figure VI-6). The Input selection provides a spreadsheet page for the input of all constant parameters in the model, such as leakance, transmissivity, pumpage, and area units (Table VI-1). In the event that some of these parameters may vary from cell to cell, space is provided for input of parameter matrices.

By beginning the program, the user is prompted at each step of the matrix configuration. The user is asked for the dimensions of the matrices and the boundary conditions (a constant gradient boundary condition is automatically entered into the model, but a varying set of boundary conditions could be entered manually), and the program will automatically create the grids and perform the iterations.

The iterations are performed by the following macro:

`{calc}/XI@ABS(w18-w24)>0.01~{calc}/XG\S~` (VI-8)

This macro compares the sum of the current matrix values with the sum of the previous values (w18-w24), and stops when the difference is less



```
A1:                                                            CMD MENU
WTABLE  ARTESIAN 1  ARTESIAN 2  INPUT  HELP  BEGIN  QUIT
View surface groundwater matrix
        A       B       C       D       E       F       G       H
1
2
3       Choose the desired option from the above menu
4
5
6
7                     SPREADSHEET GROUNDWATER MODEL
8                     -----------------------------
9
10
11         1) HIT ALT AND I TO RECEIVE FULL INSTRUCTIONS
12
13         2) HIT ALT AND H TO RECEIVE HELP
14
15         3) HIT ALT AND M TO ENTER MAIN MENU
16
        A       B       C       D       E       F       G       H
305
306     Welcome to the Spreadsheet Groundwater Model!!!
307
```

Figure VI-6. Introductory Screen of the Spreadsheet Groundwater Model.

Table VI-1. Data Input Section of Lotus Groundwater Model.

DATA INPUT

DIMENSION OF GRID SIZE	1	SQ.METERS
ELEVATION OF SURFACE WATER AQUITARD	50	METERS
AQUITARD RESISTIVITY	2000	DAY
PERMEABILITY OF AQUITARD	10	M/DAY
RAINFALL	0.001	M/DAY
TRANSMISSIVITY	500	SQ.M/DAY
INFLOW	0	METERS
PUMPAGE	0	SQ.M/DAY
THICKNESS OF CONFINING LAYER	10	METERS

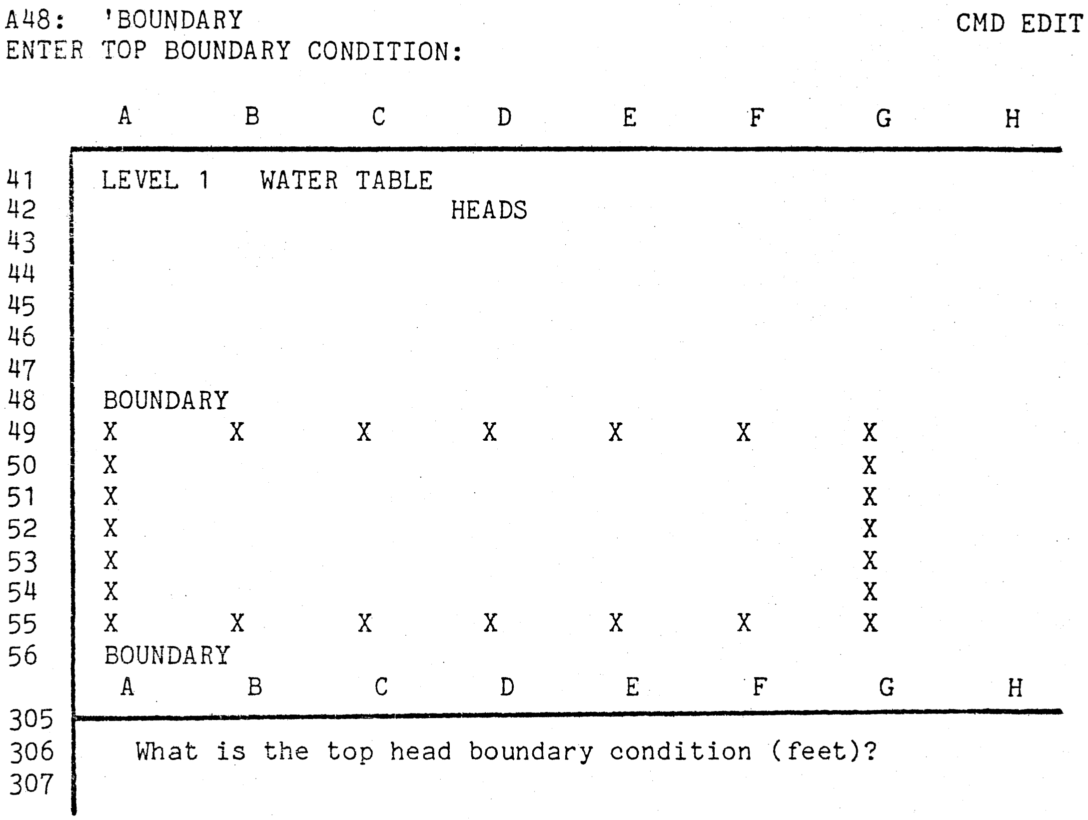
than the specified tolerance limit. Here a tolerance limit of 0.01 has been specified. If the limit has not been reached, the {calc} command performs another iteration, and so forth. The /XI is an IF statement in macro language, while the /XG\S command tells the program to GOTO the range name \S when the tolerance has been reached.

The interactive process can be achieved through the use of the /XL and /XN macro commands that respectively prompt the user for label and number entries. Labels are also added to a window area below the working area to fully explain each process to the user at each step. An example of one step involving both prompt type is presented in Figure VI-7.

Difficulties

A microcomputer with sufficient memory can handle large matrices, so it does not appear that the size of the grid is a problem. The prototype allows for a maximum of a 25 unit square grid, although it could be altered to include larger grids. The iterative process for such large grid may take as long as an hour for complex situations, but over-relaxation forms of the equations can speed the process. Memory and time contraints may prove to be a problem when large matrices and data sets are used, so the spreadsheet modeling may be best reserved for smaller simulations or as a calibration tool for larger main frame models.

Although not fully developed, the spreadsheet groundwater modeling process may be a very plausible alternative to the complicated and costly main frame models now available. As with the other models and techniques previously described, all other models may be used in



```
A48:  'BOUNDARY                                                    CMD EDIT
ENTER TOP BOUNDARY CONDITION:

          A        B        C        D        E        F        G        H
      ___________________________________________________________________
41  | LEVEL 1   WATER TABLE
42  |                           HEADS
43  |
44  |
45  |
46  |
47  |
48  | BOUNDARY
49  | X        X        X        X        X        X        X
50  | X                                                     X
51  | X                                                     X
52  | X                                                     X
53  | X                                                     X
54  | X                                                     X
55  | X        X        X        X        X        X        X
56  | BOUNDARY
    |   A        B        C        D        E        F        G        H
305 |__________________________________________________________________
306 |   What is the top head boundary condition (feet)?
307 |
```

Figure VI-7. Example Screen Showing Two Types of Prompts in the Spreadsheet Groundwater Model.

conjunction with the groundwater model, such as spatial and time series analyses. Since the results are obtained relatively quickly, and the processes can be viewed by the user, the spreadsheet groundwater model may have many uses.

Conclusions

The electronic spreadsheet may be used for a variety of analytical processes, and can be used to create a variety of hydrologic models. Data handling, mathematical processes, and groundwater models are just some of the uses that are currently being developed for spreadsheets, although many more are possible.

As spreadsheets become more widely used by professionals in the engineering sciences, such modeling processes may become a better alternative to main frame models. Although main frame computers offer a greater amount of memory as compared to the personal computers, the increased efficiency of current spreadsheets programs and the expandability of current microcomputers allow the engineer to solve many hydrologic design problems in little time, and at a smaller cost. Most of the spreadsheet techniques allows the engineer to accomplish alone what once required a computer specialist, and allow him/her to customize the work to the local conditions, understand the processes more fully, and explain the work to others.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Objectives

As the science of hydrology advances, more accurate ways of planning and designing water systems are being used by engineers throughout the world. Many of these advanced techniques are incorporated into large comprehensive digital computer models, that are able to quickly simulate many of the hydrologic and hydraulic processes that would take the engineer many hours to accomplish. These models have become too comprehensive in many cases, however, and require so much data and time that most permitting agencies and design engineers are reluctant to use them, and revert to the simpler and better understood procedures. A method of localized data analysis, documentation, and modeling on an electronic spreadsheet, proposed to help alter the current trend away from comprehensive computer modeling in permitting agencies, is the subject of this thesis.

Specific objectives of the discussion are as follows:

1) Methods of data handling and documentation performed entirely on an electronic spreadsheet on the microcomputer.
2) Mapping and graphing techniques that can be included in spreadsheet data bases as further documentation.
3) Data preparation for use in larger computer models or spreadsheet-based analysis of local data.

4) Customized hydrologic models constructed and applied entirely on the electronic spreadsheet that are fully referenced and explained to permitting agencies and other reviewers.
5) Methods of including manuals and help files within hydrologic models that can be located with a few keystrokes.
6) Spreadsheet expert systems linking models, parameter estimates, and references, as well as providing advice on estimating model parameters.
7) A discussion of two case studies in which these spreadsheet analysis techniques were applied.
8) A review of other spreadsheet and microcomputer-based hydrologic design techniques that can be used in conjunction with the previously described procedures.

The Electronic Spreadsheet

The electronic spreadsheet is the most popular piece of software since the personal computer was first made available to the general public in 1977. Although the spreadsheet has been available since 1978, many uses have been found for the simple-to-use software, by professionals in a variety of fields.

Appearing as a large matrix, the spreadsheet can be considered to be a giant sheet of electronic paper, capable of data manipulation, mathematical and statistical calculations, and graphics. With a wide variety of commands, automated functions, and programming options, the electronic spreadsheet allows the user to quickly perform tasks on a single file that would otherwise require hours of hand calculations and reams of paper. The Lotus 123 spreadsheet, the most popular microcomputer spreadsheet software, has been used to solve a variety of water resources problems.

Data Handling

Data may be easily imported, exported, and stored on spreadsheets, and can be manipulated in a variety of ways through the use of the many functions and commands. Of particular use are the /Copy and /Move commands that allow quick data entry, maneuverability, and analysis. Other commands that allow a variety of analytical techniques are the /Data and /Graph commands.

By using the variety of spreadsheet options, well organized and fully documented knowledge bases may be constructed for hydrologic studies. Each type of data may be reserved as a separate file, with all references, explanations, and local data maps. Elementary statistics may also be included in the knowledge bases, and the data may be exported for use in other computer programs. This spreadsheet data handling technique was used in a large hydrologic study in Florida with much success.

Data Analysis

The spreadsheet may be used in conjunction with larger computer models in order to provide a method of preprocessing data, but can also aid in the acceptance of large models by permitting agencies by providing explanations and documentation for all parameter estimates. Many analytical methods of parameter estimation, including spatial distribution, soil characterization, rainfall frequency analysis, and time series analysis are discussed, all of which were used in previous hydrological studies. Many other analyses may be performed on the spreadsheet, which can aid in this ability to efficiently analyze local data.

Spreadsheet Modeling

Since many comprehensive main frame computer models are designed for used in all geographical regions, adapting the models to local hydrological conditions is often difficult. Spreadsheets may be used as an alternative in order to create hydrologic models that are not only easy to understand, but can be customized to the local conditions.

Several of the analytical techniques discussed may be expanded to simulate hydrologic processes, linked to references and manuals directly on the spreadsheet, and all accessed by a few keystrokes. Several spreadsheet models constructed on the Lotus 123 spreadsheet are discussed, including a runoff simulation, flood routing simulation, and a continuous surface-groundwater model. All of these models may be automated by using the macros programming options included in Lotus, and may be adapted to many situations by simple manipulations. The surface-groundwater model was used in a large hydrologic study, also with much success.

Water Resources Expert Systems

The field of artificial intelligence has developed a method of computer problem-solving using the past experience of human experts, known as the expert system. A prototype of such a system on an electronic spreadsheet is presented, developed originally for stormwater system design in South Florida.

The prototype spreadsheet expert system is completely menu-driven by an main table of contents and self-designed menus. The system includes all data knowledge bases, parameter estimations, design requirements and agency accepted criteria. Each parameter may be fully documented, and any notes or expert analyses may be added at any time. The data in the knowledge base may be automatically linked to any number of simulation models on the spreadsheet, or fed to more comprehensive models such as the EPA Storm Water Management Model.

This system provides a method of creating organized problem solving systems that may be customized to any local conditions or problem type. Design calculations may be submitted to permitting agencies using either accepted standard methods, or parameter estimates for more comprehensive models may be submitted, both fully documented and organized for more efficient agency review.

Additional Spreadsheet Uses

Spreadsheets may be used for data handling and analysis with other computer software, and have been used in several other fields besides hydrology and environmental engineering. The calculation options contained in most spreadsheet programs allow for mathematical models. A simultaneous equation problem solving model was constructed that can be adapted to any number of equations.

Groundwater modeling techniques, inspired by the ideas of several other researchers, have been adapted to the Lotus 123 spreadsheet to create a finite difference three dimensional groundwater model that is also adaptable to many situations. Steady-state aquifers may be simulated by a series of interconnected continuity equations that may be solved iteratively on the spreadsheet through the use of repetitive Calculation keystrokes, or through the use of Lotus macros. A prototype for a menu and prompt-driven style model was created as an alternative to main-frame groundwater models.

Conclusions

The electronic spreadsheet may be used alone or with other personal computer software to solve a variety of water resources problems. The data entry and manipulation commands provide a convenient method of data handling, and the calculation capabilities and graphics allow for many types of data analysis. Although memory limitations may be present for small microcomputers and large data sets, careful use of files and spreadsheet space will allow most data sets to be analyzed entirely on the spreadsheet.

Since both text and calculations can be presented on the same screen, all parameter estimations and design calculations may be fully documented and explained to permitting agencies. The actual calculations for all designs may be easily inspected on a personal computer, and changes in design are easy, making the spreadsheets an efficient way to present designs to permitters.

Linkage to other models and the creation of customized models entirely on the spreadsheet may make the use of comprehensive models more acceptable to most agencies since all work may be easily understood and inspected. The organization, data storage, and modeling techniques, coupled with low cost, make the spreadsheet expert systems and analytical techniques attractive to the professional in water resources. The spreadsheet may be a means to create better understanding and communication links between water resource engineers and permitting agencies, resulting in better design and environmental management.

Suggestions for Additional Investigations

This thesis discusses some of analyses, models, and systems that are possible by using an electronic spreadsheet, although there are many additional methods that may be created. The use of spreadsheet models in other types of hydrologic studies and water resource system designs would further advance the ideas presented in this thesis, and would create other ideas or more efficient ways of performing water resources designs.

The spreadsheet is an excellent means for creating data systems for individual projects, and supplies many valuable functions and commands for easy data manipulation. A more intensive study of how the spreadsheet may be used with other software and main frame networks to create easy-to-use and large scale data systems in water resources projects would be very useful to researchers and engineers alike.

The connection of spreadsheets to comprehensive models and other software may also be of great use. As previously discussed, work has been performed on designing a Lotus 123 preprocessor for the EPA Storm Water Management Model, so other links between spreadsheets and other existing programs would also be beneficial in creating better data and design systems.

The groundwater model presented in Chapter VI appears to be a useful alternative to large main frame models, but there has been no hydrologic study applying such a model to a real hydrologic system. The spreadsheet surface-groundwater proved beneficial in a hydrological study discussed previously, and other spreadsheet models may prove to be more useful than existing models in other studies. A comparative study between spreadsheet and conventional main frame models would better clarify the advantages and disadvantages of both types of modeling analysis.

Finally, the application of a spreadsheet-based expert system to other permitting agency systems would determine which aspects of the spreadsheet would be more beneficial to both agencies and engineers. As such a system is used, more efficient methods of data handling, analysis, modeling, and documentations could be added, and communications between engineers and permitting agencies would improve in order to achieve better water resources problem solving and design.

APPENDIX A

SPATIAL ANALYSIS COMPARISONS AND LOTUS 123

Introduction

Most techniques of data analysis and modeling are highly dependent on the accuracy of spatial distribution of certain point estimates throughout a watershed. Several techniques for the distribution of such data points are available, with each method possessing various levels of difficulty and accuracy. Depending upon whether the data under analysis are raingage data, hydraulic conductivities of soil, or evapotranspiration estimates, different types of data distribution may be more or less appropriate, and often several types of distribution techniques may need to be examined before the appropriate method can be chosen.

The following is a review of several techniques that were applicable to the analysis of several types of point data in the Cypress Creek watershed, most of which was accomplished entirely on a Lotus 123 spreadsheet.

Distribution Techniques

The locations of the three raingages, Cypress Creek, Rose, and Saint Leo, are shown on the 16 square mile grid (Figure A-4). The outline of the Cypress Creek watershed is represented by the stars. Since there are only three data points in the analysis, the number of

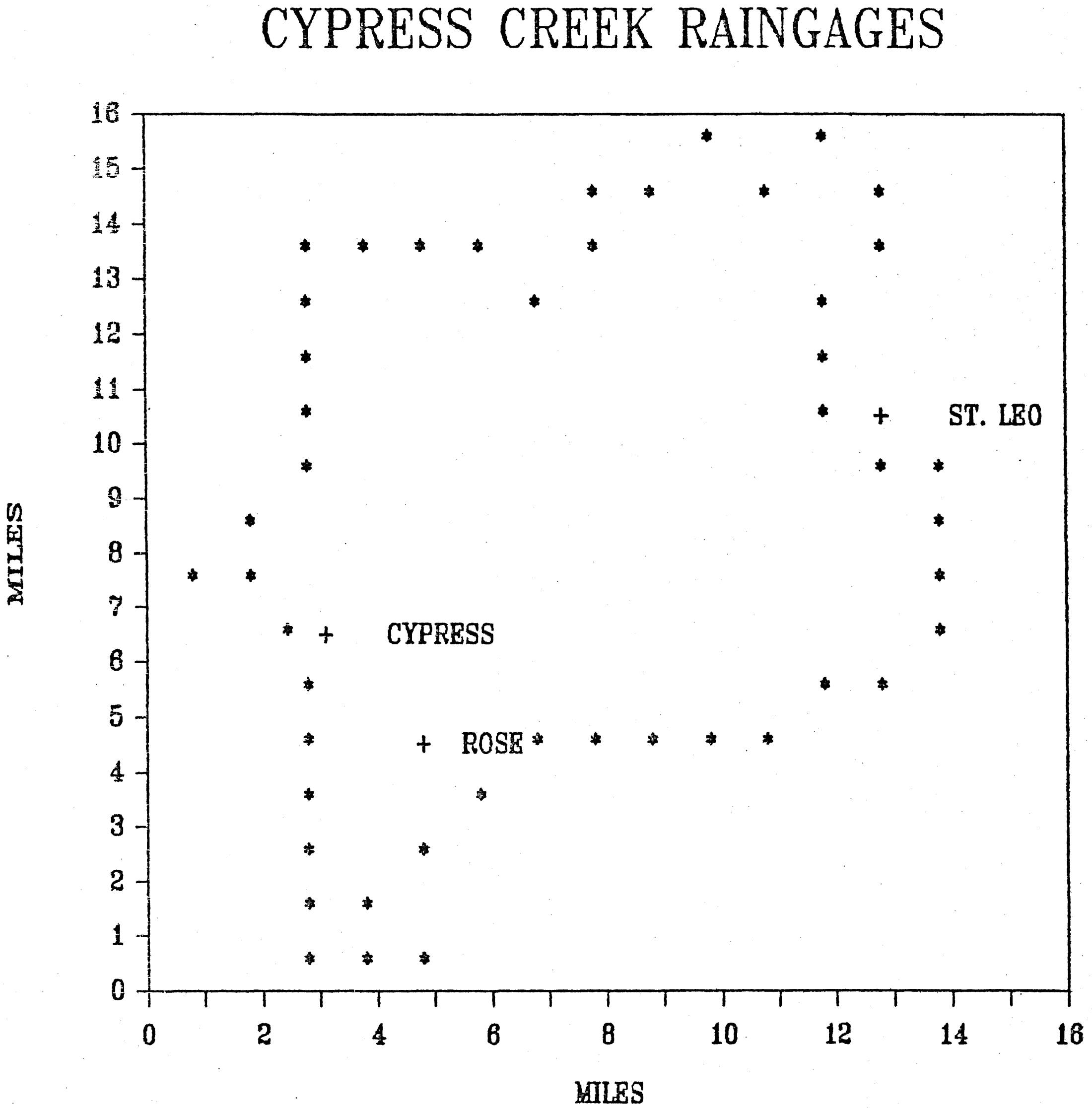


Figure A-1. Location of Raingages in the Cypress Creek Region.

suitable techniques for the distribution of rainfall throughout the watershed is quite limited. Many more point estimates are desirable in almost all methods of data analysis, but in this case of limited data, several distribution techniques can provide reasonable accuracy.

Arithmetic Mean

The easiest method of distribution of the data throughout the entire watershed is to simply average the data points and use the average as a constant for a given time period. In the case of Cypress Creek, two raingages, Cypress Creek and Rose, are too close to allow for a well distributed result characteristic of the entire watershed, so the Saint Leo raingage may be given slightly more "weight" by averaging Rose and Cypress Creek first, and then averaging the result with Saint Leo:

$$\text{Rainfall} = ((\text{Cypress} + \text{Rose})/2 + \text{St Leo})/2 \qquad \text{(A-1)}$$

Although this method is easy to use, the actual data points, variability, and possible drifts are lost, and is useful only in the very crudest of data analysis. This technique is very easily performed on the Lotus 123 spreadsheet.

Nearest Neighbor Approach

Possibly the safest technique is a nearest neighbor approach, in which data are distributed to all other points on a basis of their proximity to the actual data points. The value used for each block is that of the closest gage. Although this method is somewhat less accurate than many other techniques, actual data points are preserved, and in the case of limited data points such as ours, the method may be the most reasonable. The data surface has been fit to a step function, however, and problems may arise when considering nodes near or at the raingage data interfaces.

A similar technique, known as the Theissen polygon method, was used in determining which raingages should be used in the Cypress Creek analysis. In this technique, lines are drawn between each of the raingages under consideration for use in the analysis, and perpendicular bisectors are drawn for each of the connecting lines. The area within each of the polygons forms by the result is considered to be the area controlled by each raingage, and its value is assigned to that area. By using this method, it was determined that the Cypress Creek, Rose, and Saint Leo raingages would be the controlling data estimates for the Cypress Creek watershed.

Distance Weighting

Another possible approach is to use a distance weighted approach. Several equations may be used in weighing data inversely with distance, D, including $1/D$, $1/D^2$, and $1/D^6$, as well as more complicated versions such as $(1-D/1.1xD_{max})^2/(D/1.1xD_{max})^2$, often used in commercial contouring (dropping off at a rate similar to $1/D^2$) (Sampson, 1978). A series of weights for each point are thus developed, covering the entire surface of the watershed. These weights can then be applied to each period of rainfall, in this case yearly, in order to get a rainfall value for each node on the grid.

Since the weighting method would give weight to raingages outside of the reasonable range (the area surrounded by the actual data points), a condition may be added to give total weight to the closest raingage when grid points outside the range of actual data are considered. In other words, when a point beyond the area surrounded by raingages is considered, the value of the closest raingage is used as the point estimate.

The technique of distance weighting retains the actual data points and provides a very reasonable data set, but does have the problem of not discriminating against redundant data, such as the closely located Cypress Creek and Rose raingages. Since the two stations are very close in relation to their location of Saint Leo, it is reasonable to assume that their information may be redundant, which may give undeserved extra weight to that section of the watershed through use of a weighted interpolator (Gambolati and Volpi, 1979). In the case of the Cypress Creek watershed, the yearly means for these two stations seem different enough to allow the use of this distribution technique.

Chapter III discusses methods of applying distance-weighted analyses to spatial data on Lotus 123. The Golden Software microcomputer package (1985) can also be used for inverse distance weighting distributions.

Least Squares and Regression Techniques

This technique is best used when larger point data sets are available. A simple least squares fit may be applied by requiring that the sum of the squared deviations of the plane from the observed points be minimized. This will provide a plane covering the watershed which will show the average trend (or drift) of the true variables. This method will lose the actual data points, and actually only provide the basic trend of the data points.

Other methods of multiple linear regression may be applied to include further variables, but again the actual data points will be lost in the the regression. A polynomial regression is not possible in this case of Cypress Creek rainfall because the number of data points must always be greater than the number of variables in the model. Since there are only three data points, only three variables are possible.

These polynomial regression techniques may create an oversimplified surface. In areas not controlled by actual data points, the function may increase or decrease sporadically and uncontrollably, producing highly unreasonable or negative data point estimates. Of course there is no real method to assuredly estimate data points in uncontrolled areas of a study area, but polynomials may create more problems than they solve.

In addition to the above mentioned problems, polynomial fitting through regression can become very complicated, and when performed on a computer can become very costly and subject to large variations due to rounding errors.

An alternative to the above mentioned global polynomial fitting procedure is one based on local polynomial fitting, where a trend surface is fit about each individual data point through use of a specified number of nearest neighbor points (Sampson, 1978). After the trend is calculated, the constants of the regressed equation are adjusted so that the plane passes through the specific data point. Once this is completed, the data value for each grid node is estimated by using a distance-weighted average of the regression equations of another specified number of nearest neighbor data points. This method allows for the creation of contours, and provides a much more accurate means of estimating the actual surface of the data. However, sporadic fluctuations may still occur in uncontrolled areas, larger data sets are needed, and computer costs may be high.

The latest version of Lotus 123, Release 2, provides regression and matrix operations that may be used for these types of data distributions analyses.

Polynomial Fitting and Simultaneous Equations

In order to create a polynomial to fit the data without losing the actual data points, a polynomial can be fit by directly solving the set of simultaneous equations. Through the use of a Gauss-Siedel, Gauss-Jordan backward substitution, or any other method of solving sets of linear equations, the original data points are not lost in the process. This method may be desirable when a simple average trend is not satisfactory. In the case of the rainfall example, where there are only three data points, the planar fit this way is the same as the planar fit through use of least squares. A polynomial may be fit using this method.

Chapter VI describes a method of solving simultaneous equations on a Lotus 123 spreadsheet. The Release 2 version of 123 provides addition options to aid in this procedure.

Other methods are available for surface fitting, such as Spline fitting and "optimal" interpolation (Creutin, 1982), that can create better or "smoother" fits to data point surfaces, but can become very complicated. For instances where data are limited, these methods may be inappropriate.

Universal Kriging

Kriging is a method originally developed for geostatistical purposes in the mining industry to locate areas of high quality ore concentrations (Matheron, 1973), but has become increasingly useful in hydrologic analysis. This method provides the optimal estimate of the surface at each grid node through use of a predetermined spatial autocorrelation. A semivariogram is constructed by the user in order to estimate the autocorrelation function. The semivariogram consists of a plot of semivariances, or one half of the variance of the difference in data values between data points separated by a distance d, versus the increasing distances between data points. The resulting function can then be used to weight the data points according to the location of grid nodes, and create not only the optimal estimate for each node, but a grid of expected errors for the fitted surface.

Although universal kriging can produce a very accurate grid of point estimates, it is the most complicated of the surface fitting techniques, and is only applicable if fairly large sets of data points are available. In many cases, the large amount of extra work required to compute the semivariogram and the excess amount of computer time required make kriging not worth the effort. Study areas containing less than twenty or so data points can be fitted as accurately as needed by most of the other techniques discussed above (Hughes et al., 1981).

Universal kriging may be performed on the 123 spreadsheet, but it is a long and complicated procedure. Since the development of a semivariogram is necessary before the process can begin, the spreadsheet does not offer an easy method of kriging. The Golden Software package includes a kriging option, which determines the semivariogram as well as performing the actual kriging. The Golden Software package does not provide the error estimate grid, however, so other main frame programs may be appropriate for detailed kriging studies.

APPENDIX B

LOTUS SURFACE-GROUNDWATER MODEL SIMULATION OF 1979: CYPRESS CREEK ABOVE SAN ANTONIO

			RAIN IN INCHES					CALCULATED		CALC. WELL STAGE FEET	MEAS. FLOW @SA CFS	MEAS STAGE WELL 4 FT
NO	MO	DAY	CYP CRK	ST LEO	WGT AVG	EVAP INCH	E-T INCH	FLOW @ CFS	SA IN.			
	12	31								65.65	0.00	65.65
1	1	1			0.00	0.05	0.03	0.0	0.00	65.60	0.00	65.71
2	1	2	1.57	0.97	1.27	0.05	0.03	0.0	0.00	66.79	0.00	65.75
3	1	3			0.00	0.05	0.03	0.0	0.00	66.73	0.00	65.90
4	1	4			0.00	0.05	0.03	0.0	0.00	66.67	0.00	66.03
5	1	5			0.00	0.05	0.03	0.0	0.00	66.62	0.00	66.13
6	1	6			0.00	0.20	0.14	0.0	0.00	66.46	0.00	66.17
7	1	7			0.00	0.14	0.10	0.0	0.00	66.34	0.00	66.20
8	1	8	0.7	0.35	0.53	0.11	0.07	0.0	0.00	66.76	0.00	66.2
9	1	9			0.00	0.16	0.11	0.0	0.00	66.63	0.00	66.23
10	1	10			0.00	0.18	0.12	0.0	0.00	66.48	0.01	66.29
11	1	11			0.00	0.08	0.05	0.0	0.00	66.41	0.01	66.29
12	1	12	1.93	1.89	1.91	0.06	0.04	0.0	0.00	68.22	0.12	66.83
13	1	13	0.54	0.82	0.68	0.07	0.05	4.9	.00	68.81	0.18	67.16
14	1	14			0.00	0.08	0.06	10.8	0.01	68.72	0.24	67.25
15	1	15			0.00	0.09	0.07	9.7	0.01	68.62	2.1	67.35
16	1	16			0.00	0.11	0.08	8.6	0.01	68.51	3	67.43
17	1	17			0.00	0.16	0.12	7.5	0.01	68.36	2.3	67.45
18	1	18			0.00	0.17	0.13	6.1	.00	68.20	1.8	67.45
19	1	19			0.00	0.11	0.08	4.8	.00	68.10	1.8	67.43
20	1	20	0.1	0.06	0.08	0.10	0.07	4.0	.00	68.08	1.9	67.5
21	1	21	0.5	0.48	0.49	0.10	0.07	3.8	.00	68.46	2.1	67.51
22	1	22			0.00	0.10	0.08	7.0	0.01	68.35	1.6	67.4
23	1	23			0.00	0.09	0.07	6.1	.00	68.26	1.4	67.86
24	1	24	0.72	1.01	0.87	0.07	0.05	5.2	.00	69.03	2.4	67.76
25	1	25			0.00	0.07	0.05	13.6	0.01	68.94	2	67.66
26	1	26			0.00	0.07	0.05	12.5	0.01	68.86	3.4	67.7
27	1	27	0.04	0.03	0.04	0.13	0.10	11.4	0.01	68.76	3.9	67.77
28	1	28			0.00	0.18	0.14	10.2	0.01	68.59	3.6	67.69
29	1	29			0.00	0.12	0.09	8.4	0.01	68.48	3.2	67.57
30	1	30			0.00	0.09	0.07	7.2	0.01	68.38	2.7	67.56
31	1	31	0.15	0.21	0.18	0.11	0.08	6.3	.00	68.45	2.6	67.58
32	2	1			0.00	0.05	0.04	6.9	0.01	68.38	2	67.47
33	2	2			0.00	0.13	0.10	6.3	.00	68.26	1.8	67.42
34	2	3			0.00	0.12	0.09	5.2	.00	68.14	1.6	67.39
35	2	4			0.00	0.05	0.04	4.3	.00	68.08	1.6	67.36
36	2	5	0.07	0.05	0.06	0.17	0.13	3.8	.00	67.99	1.5	67.31
37	2	6	0.1	0.05	0.08	0.10	0.07	3.2	.00	67.96	1.3	67.32
38	2	7	0.55	0.45	0.50	0.00	0.00	3.1	.00	68.43	1.5	67.28
39	2	8			0.00	0.35	0.27	6.7	0.01	68.14	1.3	67.28
40	2	9			0.00	0.03	0.02	4.3	.00	68.09	1	67.28
41	2	10			0.00	0.11	0.08	3.9	.00	67.99	1	67.2
42	2	11			0.00	0.09	0.07	3.2	.00	67.90	1	67.17
43	2	12			0.00	0.15	0.11	2.6	.00	67.76	0.91	67.38
44	2	13			0.00	0.16	0.12	1.9	.00	67.62	0.96	67.21

45	2	14			0.00	0.00	0.00	1.3	.00	67.60	0.96	67.69
46	2	15			0.00	0.24	0.18	1.2	.00	67.40	0.87	67.97
47	2	16			0.00	0.19	0.14	0.5	.00	67.25	0.83	67.98
48	2	17			0.00	0.55	0.39	0.2	.00	66.84	0.67	67.43
49	2	18			0.00	0.10	0.07	0.0	0.00	66.75	0.57	67.12
50	2	19			0.00	0.07	0.05	0.0	0.00	66.68	0.4	67.03
51	2	20			0.00	0.00	0.00	0.0	0.00	66.65	0.33	66.9
52	2	21			0.00	0.08	0.06	0.0	0.00	66.58	0.27	67.5
53	2	22		0.04	0.02	0.01	0.01	0.0	0.00	66.57	0.22	67.89
54	2	23		0.01	0.01	0.12	0.08	0.0	0.00	66.47	0.35	68.25
55	2	24	1.1	0.13	0.62	0.25	0.17	0.0	0.00	66.88	1.1	68.3
56	2	25	1.7	1.6	1.65	0.14	0.10	0.0	0.00	68.38	8.4	67.53
57	2	26			0.00	0.19	0.14	6.3	.00	68.21	13	67.69
58	2	27			0.00	0.00	0.00	4.9	.00	68.19	16	67.75
59	2	28			0.00	0.18	0.14	4.6	.00	68.03	14	67.76
60	3	1			0.00	0.10	0.07	3.5	.00	67.93	12	67.75
61	3	2			0.00	0.12	0.09	2.8	.00	67.82	9.1	67.73
62	3	3			0.00	0.21	0.15	2.2	.00	67.64	7.5	67.7
63	3	4	0.2	0.22	0.21	0.04	0.03	1.4	.00	67.79	5.9	67.7
64	3	5	0.01	0.25	0.13	0.28	0.21	2.1	.00	67.70	4.8	67.62
65	3	6	1.6	2.11	1.86	0.22	0.16	1.6	.00	69.33	11	68.37
66	3	7	0.36	0.35	0.36	0.22	0.18	18.0	0.01	69.47	19	68.72
67	3	8	0.07	0.1	0.09	0.19	0.15	20.2	0.02	69.37	23	68.77
68	3	9			0.00	0.04	0.03	18.5	0.01	69.30	23	68.73
69	3	10			0.00	0.28	0.22	17.5	0.01	69.05	24	68.77
70	3	11		0.08	0.04	0.04	0.03	13.8	0.01	69.02	24	68.78
71	3	12			0.00	0.12	0.09	13.5	0.01	68.90	23	68.65
72	3	13			0.00	0.25	0.20	11.9	0.01	68.67	21	68.63
73	3	14			0.00	0.12	0.09	9.2	0.01	68.55	19	68.63
74	3	15			0.00	0.11	0.08	8.0	0.01	68.44	18	68.57
75	3	16			0.00	0.20	0.15	6.9	0.01	68.26	16	68.39
76	3	17			0.00	0.24	0.18	5.3	.00	68.06	13	67.35
77	3	18			0.00	0.21	0.16	3.7	.00	67.88	11	68.32
78	3	19			0.00	0.19	0.14	2.6	.00	67.72	8.6	68.26
79	3	20			0.00	0.08	0.06	1.7	.00	67.64	6.9	68.19
80	3	21			0.00	0.33	0.24	1.3	.00	67.38	5.5	68.15
81	3	22			0.00	0.09	0.06	0.5	.00	67.29	4.3	68.03
82	3	23	0.66	0.52	0.59	0.22	0.16	0.3	.00	67.69	4.5	68
83	3	24			0.00	0.20	0.15	1.6	.00	67.52	4.7	68
84	3	25			0.00	0.13	0.09	0.9	.00	67.41	4.4	67.95
85	3	26			0.00	0.17	0.12	0.6	.00	67.27	3.7	67.9
86	3	27			0.00	0.01	0.01	0.2	.00	67.24	3	67.8
87	3	28			0.00	0.28	0.20	0.2	.00	67.02	2.4	67.7
88	3	29			0.00	0.30	0.21	.0	.00	66.79	1.9	67.6
89	3	30			0.00	0.18	0.13	0.0	0.00	66.64	1.6	67.5
90	3	31			0.00	0.15	0.10	0.0	0.00	66.52	1.3	67.45
91	4	1			0.00	0.19	0.13	0.0	0.00	66.37	1.2	67.4
92	4	2			0.00	0.39	0.27	0.0	0.00	66.08	1.2	67.37
93	4	3			0.00	0.13	0.09	0.0	0.00	65.98	1.1	67.34

94	4	4			0.00	0.15	0.10	0.0	0.00	65.86	0.83	67.28
95	4	5			0.00	0.27	0.18	0.0	0.00	65.66	0.54	67.22
96	4	6		0.1	0.05	0.27	0.18	0.0	0.00	65.51	0.39	67.13
97	4	7			0.00	0.18	0.12	0.0	0.00	65.37	0.21	67.03
98	4	8			0.00	0.38	0.24	0.0	0.00	65.11	0.13	67.00
99	4	9			0.00	0.20	0.13	0.0	0.00	64.97	0.08	66.99
100	4	10			0.00	0.21	0.13	0.0	0.00	64.82	0.05	66.90
101	4	11			0.00	0.23	0.14	0.0	0.00	64.65	0.03	66.91
102	4	12			0.00	0.45	0.28	0.0	0.00	64.36	0.02	66.78
103	4	13			0.00	0.13	0.08	0.0	0.00	64.26	0.01	66.71
104	4	14			0.00	0.11	0.07	0.0	0.00	64.17	0.01	66.61
105	4	15			0.00	0.14	0.08	0.0	0.00	64.07	0.00	66.55
106	4	16			0.00	0.09	0.05	0.0	0.00	63.99	0.00	66.47
107	4	17			0.00	0.35	0.21	0.0	0.00	63.77	0.00	66.40
108	4	18			0.00	0.21	0.12	0.0	0.00	63.63	0.00	66.34
109	4	19			0.00	0.25	0.14	0.0	0.00	63.47	0.00	66.28
110	4	20			0.00	0.29	0.16	0.0	0.00	63.28	0.00	66.32
111	4	21			0.00	0.27	0.15	0.0	0.00	63.11	0.00	66.20
112	4	22			0.00	0.19	0.11	0.0	0.00	62.99	0.00	66.23
113	4	23	0.04		0.02	0.03	0.02	0.0	0.00	62.97	0.00	66.22
114	4	24	0.04	0.12	0.08	0.23	0.13	0.0	0.00	62.90	0.00	66.43
115	4	25	0.25	0.99	0.62	0.00	0.00	0.0	0.00	63.48	0.00	66.67
116	4	26		0.02	0.01	0.20	0.11	0.0	0.00	63.36	0.00	66.67
117	4	27			0.00	0.20	0.11	0.0	0.00	63.23	0.00	66.65
118	4	28			0.00	0.32	0.18	0.0	0.00	63.03	0.00	66.60
119	4	29			0.00	0.20	0.11	0.0	0.00	62.90	0.00	66.51
120	4	30			0.00	0.27	0.15	0.0	0.00	62.73	0.00	66.45
121	5	1	0.09	0.04	0.07	0.10	0.05	0.0	0.00	62.72	0.00	66.44
122	5	2			0.00	0.33	0.18	0.0	0.00	62.52	0.00	66.32
123	5	3			0.00	0.14	0.07	0.0	0.00	62.43	0.00	66.30
124	5	4			0.00	0.30	0.16	0.0	0.00	62.25	0.00	66.19
125	5	5			0.00	0.13	0.07	0.0	0.00	62.16	0.00	66.11
126	5	6			0.00	0.26	0.13	0.0	0.00	62.01	0.00	66.06
127	5	7	0.8	3.45	2.13	0.00	0.00	0.0	0.00	64.07	0.00	66.00
128	5	8	10.5	11.0	*****	0.15	0.09	0.0	0.00	74.54	16.00	68.98
129	5	9	0.46	0.55	0.51	0.15	0.15	187.6	0.15	74.72	97.00	70.53
130	5	10			0.00	0.23	0.23	196.7	0.15	74.32	160.00	70.90
131	5	11			0.00	0.20	0.20	176.8	0.14	73.97	180.00	71.00
132	5	12		0.05	0.03	0.33	0.32	160.1	0.13	73.53	156.00	71.01
133	5	13			0.00	0.21	0.20	140.6	0.11	73.20	125.00	70.94
134	5	14			0.00	0.18	0.17	126.8	0.10	72.91	99.00	70.90
135	5	15	0.07	0.39	0.23	0.23	0.22	115.3	0.09	72.81	81.00	70.56
136	5	16			0.00	0.20	0.19	111.6	0.09	72.52	68.00	70.26
137	5	17			0.00	0.31	0.29	100.7	0.08	72.14	58.00	70.07
138	5	18			0.00	0.32	0.29	87.3	0.07	71.77	50.00	69.96
139	5	19			0.00	0.38	0.34	75.0	0.06	71.36	44.00	69.82
140	5	20			0.00	0.18	0.16	62.6	0.05	71.13	38.00	69.69
141	5	21			0.00	0.32	0.28	56.3	0.04	70.79	33.00	69.59
142	5	22			0.00	0.13	0.11	47.5	0.04	70.62	28.00	69.48

143	5	23			0.00	0.34	0.29	43.4	0.03	70.29	23.00	69.31
144	5	24	2.25	1.14	1.70	0.33	0.28	35.6	0.03	71.63	23.00	69.61
145	5	25			0.00	0.20	0.18	70.7	0.06	71.38	22.00	69.72
146	5	26	0.01		0.01	0.33	0.29	63.2	0.05	71.03	18.00	69.62
147	5	27			0.00	0.16	0.14	53.5	0.04	70.83	16.00	69.47
148	5	28			0.00	0.27	0.23	48.4	0.04	70.54	14.00	69.30
149	5	29			0.00	0.26	0.22	41.4	0.03	70.27	12.00	69.18
150	5	30	0.36	0.03	0.20	0.38	0.32	35.3	0.03	70.10	11.00	69.06
151	5	31	0.01	0.08	0.05	0.21	0.17	31.8	0.02	69.93	10.00	69.12
152	6	1			0.00	0.29	0.24	28.3	0.02	69.65	7.70	69.05
153	6	2	0.07		0.04	0.26	0.21	23.2	0.02	69.44	6.20	68.92
154	6	3			0.00	0.31	0.25	19.6	0.02	69.16	5.10	68.84
155	6	4			0.00	0.13	0.10	15.4	0.01	69.02	3.60	68.80
156	6	5			0.00	0.00	0.00	13.5	0.01	68.99	2.70	68.66
157	6	6			0.00	0.10	0.08	13.1	0.01	68.88	2.00	68.53
158	6	7			0.00	0.10	0.08	11.7	0.01	68.77	1.50	68.43
159	6	8			0.00	0.16	0.12	10.4	0.01	68.62	1.10	68.30
160	6	9			0.00	0.35	0.27	8.7	0.01	68.33	0.79	68.20
161	6	10			0.00	0.23	0.17	5.8	.00	68.13	0.52	68.14
162	6	11			0.00	0.31	0.23	4.2	.00	67.88	0.33	68.11
163	6	12			0.00	0.46	0.34	2.5	.00	67.52	0.23	67.97
164	6	13		0.01	0.01	0.59	0.43	0.9	.00	67.08	0.16	67.84
165	6	14	0.03		0.02	0.20	0.14	.0	.00	66.93	0.10	67.77
166	6	15			0.00	0.20	0.14	0.0	0.00	66.77	0.08	67.68
167	6	16			0.00	0.07	0.05	0.0	0.00	66.70	0.06	67.62
168	6	17			0.00	0.23	0.16	0.0	0.00	66.52	0.05	67.53
169	6	18			0.00	0.29	0.20	0.0	0.00	66.31	0.04	67.39
170	6	19			0.00	0.30	0.20	0.0	0.00	66.08	0.03	67.28
171	6	20	0.03	0.26	0.15	0.30	0.20	0.0	0.00	66.01	0.02	67.18
172	6	21			0.00	0.14	0.09	0.0	0.00	65.89	0.01	67.10
173	6	22	0.28		0.14	0.26	0.17	0.0	0.00	65.84	0.00	67.07
174	6	23		0.15	0.08	0.13	0.09	0.0	0.00	65.80	0.00	67.03
175	6	24			0.00	0.26	0.17	0.0	0.00	65.61	0.00	66.97
176	6	25			0.00	0.15	0.10	0.0	0.00	65.50	0.00	66.95
177	6	26	0.02	0.05	0.04	0.06	0.04	0.0	0.00	65.47	0.00	66.85
178	6	27	2.3		1.15	0.23	0.15	0.0	0.00	66.43	0.01	66.84
179	6	28	0.24	1.66	0.95	0.07	0.05	0.0	0.00	67.29	0.48	67.24
180	6	29	0.03		0.02	0.26	0.19	0.3	.00	67.10	6.00	67.21
181	6	30		0.01	0.01	0.32	0.23	.0	.00	66.86	6.20	67.24
182	7	1			0.00	0.29	0.20	0.0	0.00	66.64	3.60	67.25
183	7	2			0.00	0.18	0.12	0.0	0.00	66.49	1.70	67.19
184	7	3			0.00	0.32	0.22	0.0	0.00	66.26	0.85	67.08
185	7	4	0.03		0.02	0.47	0.32	0.0	0.00	65.94	0.42	66.99
186	7	5		0.19	0.10	0.40	0.27	0.0	0.00	65.75	0.30	66.94
187	7	6			0.00	0.37	0.24	0.0	0.00	65.49	0.17	66.87
188	7	7	0.58		0.29	0.33	0.21	0.0	0.00	65.54	0.09	66.80
189	7	8	0.06	0.69	0.38	0.18	0.12	0.0	0.00	65.77	0.09	66.79
190	7	9	0.01		0.01	0.30	0.20	0.0	0.00	65.56	0.08	66.81
191	7	10			0.00	0.45	0.29	0.0	0.00	65.25	0.07	66.75

192	7	11			0.00	0.16	0.10	0.0	0.00	65.13	0.06	66.63
193	7	12	0.46		0.23	0.21	0.13	0.0	0.00	65.20	0.06	66.55
194	7	13	0.06	0.5	0.28	0.24	0.15	0.0	0.00	65.30	0.16	66.59
195	7	14	0.11		0.06	0.23	0.15	0.0	0.00	65.19	0.36	66.55
196	7	15	0.02		0.01	0.09	0.06	0.0	0.00	65.12	0.21	66.53
197	7	16	0.14	0.17	0.16	0.39	0.25	0.0	0.00	65.01	0.17	66.49
198	7	17	0.01		0.01	0.09	0.06	0.0	0.00	64.94	0.24	66.48
199	7	18	0.12		0.06	0.25	0.16	0.0	0.00	64.82	0.20	66.51
200	7	19	0.67	0.05	0.36	0.13	0.08	0.0	0.00	65.07	0.22	66.45
201	7	20	0.03		0.02	0.31	0.20	0.0	0.00	64.87	0.14	66.33
202	7	21			0.00	0.23	0.14	0.0	0.00	64.71	0.06	66.29
203	7	22		0.22	0.11	0.01	0.01	0.0	0.00	64.79	0.04	66.24
204	7	23	0.61	0.17	0.39	0.57	0.35	0.0	0.00	64.80	0.04	66.19
205	7	24	0.1	0.03	0.07	0.00	0.00	0.0	0.00	64.84	0.03	66.12
206	7	25	0.01	0.07	0.04	0.16	0.10	0.0	0.00	64.76	0.02	66.11
207	7	26	0.01		0.01	0.12	0.07	0.0	0.00	64.67	0.01	66.07
208	7	27			0.00	0.21	0.13	0.0	0.00	64.52	0.00	66.01
209	7	28			0.00	0.28	0.17	0.0	0.00	64.33	0.00	65.96
210	7	29			0.00	0.33	0.20	0.0	0.00	64.12	0.00	65.91
211	7	30			0.00	0.26	0.15	0.0	0.00	63.94	0.00	65.87
212	7	31			0.00	0.15	0.09	0.0	0.00	63.83	0.00	65.81
213	8	1			0.00	0.31	0.18	0.0	0.00	63.64	0.00	65.75
214	8	2	1.05		0.53	0.52	0.30	0.0	0.00	63.83	0.00	66.09
215	8	3	0.03	0.64	0.34	0.27	0.16	0.0	0.00	63.99	0.00	65.85
216	8	4	0.02	0.29	0.16	0.32	0.19	0.0	0.00	63.93	0.00	65.71
217	8	5	0.1		0.05	0.24	0.14	0.0	0.00	63.82	0.00	65.65
218	8	6	1.55		0.78	0.19	0.11	0.0	0.00	64.45	0.00	65.64
219	8	7	0.15	1.97	1.06	0.26	0.16	0.0	0.00	65.31	0.00	65.72
220	8	8	1.3	1.3	1.30	0.15	0.10	0.0	0.00	66.47	0.00	65.79
221	8	9	0.01	1.36	0.69	0.14	0.10	0.0	0.00	67.03	0.11	65.99
222	8	10	0	2.25	1.13	0.21	0.15	.0	.00	67.96	7.50	66.26
223	8	11	1.55	1.99	1.77	0.20	0.15	3.0	.00	69.52	17.00	66.69
224	8	12	1.5	0.09	0.80	0.11	0.09	21.0	0.02	70.18	28.00	67.90
225	8	13	0.3	0.93	0.62	0.04	0.03	33.3	0.03	70.70	50.00	68.73
226	8	14			0.00	0.11	0.09	45.2	0.04	70.55	83.00	69.13
227	8	15		0.02	0.01	0.13	0.11	41.6	0.03	70.40	92.00	69.50
228	8	16	0.42	0.87	0.65	0.25	0.21	38.1	0.03	70.77	82.00	69.50
229	8	17	0.78	0.04	0.41	0.17	0.15	47.0	0.04	70.98	73.00	69.39
230	8	18	0.02		0.01	0.18	0.16	52.2	0.04	70.77	61.00	69.33
231	8	19	1.05		0.53	0.22	0.19	46.9	0.04	71.04	57.00	69.70
232	8	20	0.54	1.15	0.85	0.24	0.21	53.9	0.04	71.60	68.00	70.09
233	8	21	0.01	0.78	0.40	0.20	0.18	69.9	0.05	71.74	91.00	70.37
234	8	22	0.01	0.1	0.06	0.24	0.21	74.2	0.06	71.51	101.00	70.22
235	8	23	0.24	0.05	0.15	0.18	0.16	67.0	0.05	71.42	98.00	70.50
236	8	24	1.45	1.51	1.48	0.17	0.15	64.4	0.05	72.65	103.00	70.72
237	8	25	0.01	0.45	0.23	0.21	0.19	105.4	0.08	72.58	127.00	70.84
238	8	26	0.15	0.13	0.14	0.20	0.18	102.8	0.08	72.44	132.00	70.74
239	8	27	0.14	0.17	0.16	0.21	0.19	97.5	0.08	72.30	120.00	70.96
240	8	28	0.01		0.01	0.21	0.19	92.7	0.07	72.02	103.00	70.83

241	8	29	0.01		0.01	0.28	0.25	83.3	0.07	71.69	87.00	70.72
242	8	30	0.76	0.16	0.46	0.27	0.24	72.7	0.06	71.83	74.00	70.75
243	8	31	0.17	0.74	0.46	0.13	0.12	77.0	0.06	72.08	69.00	70.85
244	9	1	0.03	0.91	0.47	0.20	0.18	85.2	0.07	72.28	69.00	71.07
245	9	2	0.07	0.06	0.07	0.10	0.09	91.9	0.07	72.16	59.00	71.04
246	9	3	0.13	0.07	0.10	0.25	0.23	87.8	0.07	71.94	60.00	70.96
247	9	4	0.11	0.44	0.28	0.07	0.06	80.6	0.06	72.07	61.00	70.95
248	9	5	0.02	0.01	0.02	0.17	0.15	84.7	0.07	71.84	58.00	70.81
249	9	6			0.00	0.17	0.15	77.4	0.06	71.61	55.00	70.67
250	9	7			0.00	0.20	0.18	70.2	0.06	71.36	60.00	70.66
251	9	8			0.00	0.18	0.16	62.8	0.05	71.14	64.00	70.65
252	9	9			0.00	0.23	0.20	56.5	0.04	70.87	61.00	70.53
253	9	10	0.44	0.17	0.31	0.20	0.17	49.5	0.04	70.94	56.00	70.48
254	9	11	0.15	0.58	0.37	0.22	0.19	51.3	0.04	71.05	53.00	70.41
255	9	12	0.74	0.71	0.73	0.08	0.07	54.3	0.04	71.63	51.00	70.66
256	9	13	0.22	0.46	0.34	0.16	0.14	70.9	0.06	71.75	50.00	70.81
257	9	14	0.65	0.83	0.74	0.10	0.09	74.5	0.06	72.31	58.00	71.66
258	9	15	1.1	0.45	0.78	0.17	0.16	93.0	0.07	72.82	155.00	71.84
259	9	16	0.01	0.2	0.11	0.19	0.18	111.9	0.09	72.64	268.00	71.89
260	9	17	0.09		0.05	0.16	0.15	105.1	0.08	72.44	239.00	71.82
261	9	18	0.01	0.05	0.03	0.21	0.19	97.6	0.08	72.18	184.00	71.58
262	9	19			0.00	0.27	0.25	88.6	0.07	71.85	143.00	71.50
263	9	20	0.1		0.05	0.13	0.12	77.6	0.06	71.70	115.00	71.28
264	9	21	0.64	0.68	0.66	0.23	0.20	73.0	0.06	72.07	97.00	71.35
265	9	22	0.26	1.52	0.89	0.09	0.08	84.8	0.07	72.78	88.00	71.43
266	9	23	2	0.25	1.13	0.09	0.08	110.1	0.09	73.69	83.00	71.73
267	9	24	1	0.47	0.74	0.12	0.12	147.6	0.12	74.16	118.00	72.32
268	9	25	0.45		0.23	0.15	0.15	169.1	0.13	74.08	145.00	72.44
269	9	26	0.64	0.62	0.63	0.25	0.25	165.5	0.13	74.31	170.00	72.52
270	9	27	0.34	0.93	0.64	0.06	0.06	176.3	0.14	74.72	188.00	72.55
271	9	28	0.3	0.52	0.41	0.15	0.15	196.4	0.15	74.80	212.00	72.65
272	9	29	0.64	0.33	0.49	0.20	0.20	200.5	0.16	74.90	398.00	72.70
273	9	30	0.02	0.01	0.02	0.16	0.16	205.7	0.16	74.57	500.00	72.71
274	10	1			0.00	0.13	0.13	189.1	0.15	74.27	382.00	72.55
275	10	2	0.5		0.25	0.18	0.18	174.6	0.14	74.19	287.00	72.32
276	10	3			0.00	0.12	0.12	170.5	0.13	73.92	219.00	72.13
277	10	4			0.00	0.19	0.19	157.9	0.12	73.59	170.00	72.06
278	10	5	0.07		0.04	0.19	0.18	143.4	0.11	73.31	134.00	71.93
279	10	6		0.18	0.09	0.19	0.18	131.6	0.10	73.10	108.00	71.77
280	10	7	0.02		0.01	0.14	0.13	122.8	0.10	72.86	90.00	71.58
281	10	8			0.00	0.19	0.18	113.5	0.09	72.58	77.00	71.44
282	10	9			0.00	0.16	0.15	102.8	0.08	72.33	66.00	71.34
283	10	10			0.00	0.11	0.10	93.9	0.07	72.14	59.00	71.25
284	10	11	0.03	0.09	0.06	0.17	0.15	87.2	0.07	71.96	53.00	71.20
285	10	12			0.00	0.15	0.14	81.1	0.06	71.74	49.00	71.11
286	10	13	0.04		0.02	0.13	0.12	74.2	0.06	71.57	45.00	71.03
287	10	14		0.33	0.17	0.06	0.05	68.8	0.05	71.60	41.00	71.01
288	10	15			0.00	0.16	0.14	69.9	0.05	71.39	37.00	70.92
289	10	16	0.02	0.3	0.16	0.15	0.13	63.5	0.05	71.34	34.00	70.85

290	10	17	0.03	0.04	0.04	0.11	0.10	62.2	0.05	71.21	31.00	70.78
291	10	18			0.00	0.11	0.10	58.6	0.05	71.05	29.00	70.68
292	10	19			0.00	0.18	0.16	54.2	0.04	70.83	27.00	70.60
293	10	20	0.06		0.03	0.12	0.10	48.5	0.04	70.70	25.00	70.55
294	10	21			0.00	0.16	0.14	45.3	0.04	70.51	22.00	70.49
295	10	22			0.00	0.16	0.13	40.7	0.03	70.33	21.00	70.41
296	10	23			0.00	0.19	0.16	36.5	0.03	70.12	19.00	70.35
297	10	24			0.00	0.01	0.01	32.1	0.03	70.06	17.00	70.27
298	10	25			0.00	0.23	0.19	31.0	0.02	69.83	16.00	70.18
299	10	26			0.00	0.14	0.11	26.5	0.02	69.68	14.00	70.10
300	10	27			0.00	0.16	0.13	23.6	0.02	69.51	13.00	70.02
301	10	28			0.00	0.11	0.09	20.8	0.02	69.38	12.00	69.98
302	10	29			0.00	0.12	0.10	18.8	0.01	69.25	11.00	69.93
303	10	30			0.00	0.15	0.12	16.8	0.01	69.10	10.00	69.84
304	10	31		0.02	0.01	0.11	0.09	14.6	0.01	68.99	10.00	69.78
305	11	1		0.01	0.01	0.14	0.11	13.1	0.01	68.86	9.30	69.73
306	11	2	0.82	0.2	0.51	0.11	0.09	11.4	0.01	69.24	9.10	69.74
307	11	3	0.03	0.61	0.32	0.10	0.08	16.6	0.01	69.44	9.90	69.85
308	11	4			0.00	0.13	0.10	19.7	0.02	69.30	10.00	69.78
309	11	5			0.00	0.10	0.08	17.5	0.01	69.19	10.00	69.69
310	11	6			0.00	0.09	0.07	15.8	0.01	69.08	11.00	69.64
311	11	7			0.00	0.09	0.07	14.3	0.01	68.98	11.00	69.54
312	11	8			0.00	0.10	0.08	13.0	0.01	68.87	10.00	69.44
313	11	9			0.00	0.07	0.05	11.6	0.01	68.79	9.90	69.39
314	11	10			0.00	0.08	0.06	10.5	0.01	68.70	9.10	69.34
315	11	11	0.28		0.14	0.05	0.04	9.5	0.01	68.77	8.70	69.29
316	11	12	0.05	0.05	0.05	0.07	0.05	10.3	0.01	68.73	8.60	69.32
317	11	13	0.46	1.3	0.88	0.10	0.08	9.9	0.01	69.49	9.40	70.24
318	11	14			0.00	0.06	0.05	20.4	0.02	69.40	9.70	70.70
319	11	15			0.00	0.09	0.07	19.0	0.01	69.29	9.90	71.11
320	11	16			0.00	0.03	0.02	17.4	0.01	69.24	11.00	70.09
321	11	17			0.00	0.07	0.06	16.5	0.01	69.15	13.00	69.65
322	11	18			0.00	0.05	0.04	15.2	0.01	69.07	12.00	69.48
323	11	19			0.00	0.04	0.03	14.2	0.01	69.01	12.00	69.23
324	11	20			0.00	0.05	0.03	13.3	0.01	68.94	11.00	69.33
325	11	21			0.00	0.07	0.04	12.5	0.01	68.87	10.00	69.35
326	11	22			0.00	0.05	0.05	11.6	0.01	68.79	9.60	69.64
327	11	23			0.00	0.10	0.04	10.6	0.01	68.72	8.90	69.10
328	11	24			0.00	0.07	0.08	9.8	0.01	68.62	8.30	69.02
329	11	25	0.26	0.1	0.18	0.07	0.05	8.6	0.01	68.71	7.80	68.99
330	11	26	0.04	0.06	0.05	0.04	0.05	9.6	0.01	68.68	7.50	69.03
331	11	27			0.00	0.11	0.03	9.3	0.01	68.62	6.90	69.10
332	11	28	0.12	1.19	0.66	0.04	0.08	8.6	0.01	69.15	6.70	68.72
333	11	29	0.05	0.02	0.04	0.04	0.03	15.2	0.01	69.12	6.80	69.52
334	11	30			0.00	0.14	0.03	14.8	0.01	69.05	6.70	69.65
335	12	1			0.00	0.04	0.11	13.9	0.01	68.91	6.60	68.94
336	12	2			0.00	0.04	0.03	12.0	0.01	68.85	6.50	68.88
337	12	3			0.00	0.07	0.05	11.3	0.01	68.76	6.50	68.79
338	12	4			0.00	0.03	0.02	10.3	0.01	68.71	6.50	68.82

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339 12   5           0.00 0.03 0.02    9.6  0.01  68.66    6.40 68.78
340 12   6 0.13 0.01 0.07 0.04 0.03    9.1  0.01  68.67    6.40 69.31
341 12   7 0.14 0.37 0.26 0.02 0.02    9.2  0.01  68.87    6.40 68.85
342 12   8      0.04 0.02 0.03 0.02   11.6  0.01  68.84    6.60 68.62
343 12   9           0.00 0.10 0.08   11.1  0.01  68.73    6.30 68.55
344 12  10           0.00 0.03 0.02    9.9  0.01  68.68    6.20 68.97
345 12  11           0.00 0.05 0.04    9.3  0.01  68.61    6.10 68.63
346 12  12           0.00 0.00 0.00    8.5  0.01  68.58    6.10 68.56
347 12  13           0.00 0.07 0.05    8.2  0.01  68.50    6.10 69.01
348 12  14           0.00 0.04 0.03    7.4  0.01  68.44    6.00 68.64
349 12  15           0.00 0.04 0.03    6.8  0.01  68.38    6.00 68.57
350 12  16 0.62 0.53 0.58 0.05 0.04    6.3   .00  68.88    6.50 68.64
351 12  17           0.00 0.03 0.02   11.7  0.01  68.83    7.00 68.71
352 12  18           0.00 0.10 0.08   11.0  0.01  68.72    6.90 68.67
353 12  19           0.00 0.01 0.01    9.8  0.01  68.68    6.90 68.63
354 12  20           0.00 0.04 0.03    9.3  0.01  68.62    6.60 68.65
355 12  21           0.00 0.04 0.03    8.7  0.01  68.56    6.60 68.62
356 12  22           0.00 0.02 0.02    8.1  0.01  68.52    6.50 68.65
357 12  23           0.00 0.04 0.03    7.6  0.01  68.46    6.30 68.62
358 12  24 0.16      0.08 0.01 0.01    7.0  0.01  68.50    6.10 68.57
359 12  25      0.09 0.05 0.08 0.06    7.5  0.01  68.46    6.00 68.21
360 12  26           0.00 0.08 0.06    7.0  0.01  68.37    5.60 68.14
361 12  27           0.00 0.04 0.03    6.2   .00  68.32    5.40 68.18
362 12  28           0.00 0.03 0.02    5.7   .00  68.27    5.10 68.11
363 12  29           0.00 0.02 0.02    5.3   .00  68.23    4.90 68.12
364 12  30 0.06 0.04 0.05 0.05 0.04    5.0   .00  68.21    4.70 68.14
365 12  31           0.00 0.04 0.03    4.8   .00  68.16    4.60 68.03
NO  MO DAY             P    E   ET      Q   Q,IN  CAL H MEAS Q MEAS H
    TOTAL  61.0 66.8 63.9 60.0 45.1 10051. 7.886          10140.
    MEAN                      0.12 27.538        68.394 27.783 68.48
    MAX                       0.42 205.72        74.895    500 72.71
    MIN                          0      0        62.009      0 65.64
    S DEV                     0.07 44.508         2.842 58.465 1.768
    KEY ASSUMPTIONS:
    1.E-T=(ETMAX-ETRATE*(GRDEL-WTEL))*E            GRDEL      74
                                                   ETMAX       1
                                                   ETRATE   0.04
    2.DRAINAGE AREA,SQ. MI.=                                47.4
    3.STORAGE COEF.=                                       0.085
    4.DISCHARGE-HEAD RELATIONSHIP=K*H^B               K=     3.3
                                                      B=       2
    5.ELEV. FOR WHICH BASE FLOW=0,FT                          67
    6.LEAKANCE,IN/YR                                         8.2
    7.WEIGHTS ON RAIN GAGES         CYPRESS CRK              0.5
                                    ST LEO                   0.5

    CONTINUITY CHECK: dS/dT=(P-ET-Q-L)

                          P=                          63.975 IN.
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                       ET=                      45.169 IN.
                       Q=                        7.886 IN.
                       L=                        8.200 IN.


                       dS/dT=      CALC         2.7191 IN.
                                   MEAS         2.6107 IN.

PERCENT CONTRIBUTIONS        INFLOWS

                             P=      100%

                             OUTFLOWS

                             ET=    73.74%
                             Q=     12.87%
                             L=     13.39%
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APPENDIX C

LOTUS SURFACE-GROUNDWATER MODEL SIMULATION OF 1979: SAN ANTONIO TO DREXEL

			RAIN IN INCHES						CALC.	MEAS
			WGT	CYP	ST	EVAP	E-T	CALC	WELL	STAGE
								LEAK.	STAGE	WELL 4
NO	MO	DAY	AVG	CRK	LEO	INCH	INCH	INCH	FEET	FT
	12	31							57.65	65.65
1	1	1	0.00			0.05	0.03	0.06	57.60	65.71
2	1	2	1.27	1.57	0.97	0.05	0.03	0.06	58.25	65.75
3	1	3	0.00			0.05	0.04	0.06	58.20	65.90
4	1	4	0.00			0.05	0.04	0.06	58.15	66.03
5	1	5	0.00			0.05	0.04	0.06	58.09	66.13
6	1	6	0.00			0.20	0.14	0.06	57.98	66.17
7	1	7	0.00			0.14	0.10	0.06	57.89	66.20
8	1	8	0.53	0.7	0.35	0.11	0.08	0.06	58.11	66.2
9	1	9	0.00			0.16	0.11	0.06	58.01	66.23
10	1	10	0.00			0.18	0.13	0.06	57.91	66.29
11	1	11	0.00			0.08	0.06	0.06	57.84	66.29
12	1	12	1.91	1.93	1.89	0.06	0.04	0.06	58.85	66.83
13	1	13	0.68	0.54	0.82	0.07	0.05	0.07	59.16	67.16
14	1	14	0.00			0.08	0.06	0.07	59.09	67.25
15	1	15	0.00			0.09	0.07	0.07	59.01	67.35
16	1	16	0.00			0.11	0.08	0.07	58.93	67.43
17	1	17	0.00			0.16	0.12	0.07	58.82	67.45
18	1	18	0.00			0.17	0.12	0.07	58.72	67.45
19	1	19	0.00			0.11	0.08	0.07	58.63	67.43
20	1	20	0.08	0.1	0.06	0.10	0.07	0.07	58.60	67.5
21	1	21	0.49	0.5	0.48	0.10	0.07	0.07	58.80	67.51
22	1	22	0.00			0.10	0.07	0.07	58.72	67.4
23	1	23	0.00			0.09	0.06	0.07	58.64	67.86
24	1	24	0.87	0.72	1.01	0.07	0.05	0.07	59.06	67.76
25	1	25	0.00			0.07	0.05	0.07	58.99	67.66
26	1	26	0.00			0.07	0.05	0.07	58.92	67.7
27	1	27	0.04	0.04	0.03	0.13	0.09	0.07	58.85	67.77
28	1	28	0.00			0.18	0.13	0.07	58.74	67.69
29	1	29	0.00			0.12	0.09	0.07	58.65	67.57
30	1	30	0.00			0.09	0.06	0.07	58.58	67.56
31	1	31	0.18	0.15	0.21	0.11	0.08	0.07	58.60	67.58
32	2	1	0.00			0.05	0.04	0.07	58.54	67.47
33	2	2	0.00			0.13	0.09	0.07	58.45	67.42
34	2	3	0.00			0.12	0.09	0.07	58.37	67.39
35	2	4	0.00			0.05	0.04	0.06	58.31	67.36
36	2	5	0.06	0.07	0.05	0.17	0.12	0.06	58.24	67.31
37	2	6	0.08	0.1	0.05	0.10	0.07	0.06	58.21	67.32
38	2	7	0.50	0.55	0.45	0.00	0.00	0.06	58.45	67.28
39	2	8	0.00			0.35	0.25	0.07	58.28	67.28
40	2	9	0.00			0.03	0.02	0.06	58.23	67.28
41	2	10	0.00			0.11	0.08	0.06	58.15	67.2
42	2	11	0.00			0.09	0.06	0.06	58.09	67.17
43	2	12	0.00			0.15	0.11	0.06	57.99	67.38
44	2	13	0.00			0.16	0.11	0.06	57.90	67.21

45	2	14	0.00			0.00	0.00	0.06	57.86	67.69
46	2	15	0.00			0.24	0.17	0.06	57.74	67.97
47	2	16	0.00			0.19	0.13	0.06	57.63	67.98
48	2	17	0.00			0.55	0.38	0.06	57.39	67.43
49	2	18	0.00			0.10	0.07	0.05	57.32	67.12
50	2	19	0.00			0.07	0.05	0.05	57.27	67.03
51	2	20	0.00			0.00	0.00	0.05	57.24	66.9
52	2	21	0.00			0.08	0.05	0.05	57.18	67.5
53	2	22	0.02		0.04	0.01	0.01	0.05	57.16	67.89
54	2	23	0.01		0.01	0.12	0.08	0.05	57.09	68.25
55	2	24	0.62	1.1	0.13	0.25	0.17	0.05	57.31	68.3
56	2	25	1.65	1.7	1.6	0.14	0.10	0.05	58.14	67.53
57	2	26	0.00			0.19	0.13	0.06	58.03	67.69
58	2	27	0.00			0.00	0.00	0.06	58.00	67.75
59	2	28	0.00			0.18	0.13	0.06	57.90	67.76
60	3	1	0.00			0.10	0.07	0.06	57.83	67.75
61	3	2	0.00			0.12	0.08	0.06	57.75	67.73
62	3	3	0.00			0.21	0.15	0.06	57.63	67.7
63	3	4	0.21	0.2	0.22	0.04	0.03	0.06	57.70	67.7
64	3	5	0.13	0.01	0.25	0.28	0.19	0.06	57.64	67.62
65	3	6	1.86	1.6	2.11	0.22	0.15	0.06	58.55	68.37
66	3	7	0.36	0.36	0.35	0.22	0.16	0.07	58.63	68.72
67	3	8	0.09	0.07	0.1	0.19	0.14	0.07	58.56	68.77
68	3	9	0.00			0.04	0.03	0.07	58.51	68.73
69	3	10	0.00			0.28	0.20	0.07	58.36	68.77
70	3	11	0.04		0.08	0.04	0.03	0.06	58.33	68.78
71	3	12	0.00			0.12	0.09	0.06	58.25	68.65
72	3	13	0.00			0.25	0.18	0.06	58.11	68.63
73	3	14	0.00			0.12	0.08	0.06	58.03	68.63
74	3	15	0.00			0.11	0.08	0.06	57.96	68.57
75	3	16	0.00			0.20	0.14	0.06	57.85	68.39
76	3	17	0.00			0.24	0.17	0.06	57.72	67.35
77	3	18	0.00			0.21	0.15	0.06	57.61	68.32
78	3	19	0.00			0.19	0.13	0.06	57.50	68.26
79	3	20	0.00			0.08	0.05	0.05	57.44	68.19
80	3	21	0.00			0.33	0.23	0.05	57.29	68.15
81	3	22	0.00			0.09	0.06	0.05	57.22	68.03
82	3	23	0.59	0.66	0.52	0.22	0.15	0.05	57.44	68
83	3	24	0.00			0.20	0.14	0.05	57.33	68
84	3	25	0.00			0.13	0.09	0.05	57.26	67.95
85	3	26	0.00			0.17	0.12	0.05	57.16	67.9
86	3	27	0.00			0.01	0.01	0.05	57.13	67.8
87	3	28	0.00			0.28	0.19	0.05	57.00	67.7
88	3	29	0.00			0.30	0.20	0.05	56.86	67.6
89	3	30	0.00			0.18	0.12	0.05	56.77	67.5
90	3	31	0.00			0.15	0.10	0.05	56.68	67.45
91	4	1	0.00			0.19	0.13	0.05	56.59	67.4
92	4	2	0.00			0.39	0.26	0.04	56.42	67.37
93	4	3	0.00			0.13	0.08	0.04	56.35	67.34

94	4	4	0.00			0.15	0.10	0.04	56.27	67.28
95	4	5	0.00			0.27	0.18	0.04	56.15	67.22
96	4	6	0.05		0.1	0.27	0.17	0.04	56.06	67.13
97	4	7	0.00			0.18	0.12	0.04	55.98	67.03
98	4	8	0.00			0.38	0.24	0.04	55.82	67.00
99	4	9	0.00			0.20	0.13	0.04	55.73	66.99
100	4	10	0.00			0.21	0.13	0.04	55.64	66.90
101	4	11	0.00			0.23	0.14	0.03	55.54	66.91
102	4	12	0.00			0.45	0.28	0.03	55.36	66.78
103	4	13	0.00			0.13	0.08	0.03	55.30	66.71
104	4	14	0.00			0.11	0.07	0.03	55.24	66.61
105	4	15	0.00			0.14	0.09	0.03	55.18	66.55
106	4	16	0.00			0.09	0.06	0.03	55.13	66.47
107	4	17	0.00			0.35	0.21	0.03	55.00	66.40
108	4	18	0.00			0.21	0.13	0.03	54.91	66.34
109	4	19	0.00			0.25	0.15	0.03	54.81	66.28
110	4	20	0.00			0.29	0.18	0.03	54.70	66.32
111	4	21	0.00			0.27	0.16	0.02	54.60	66.20
112	4	22	0.00			0.19	0.11	0.02	54.52	66.23
113	4	23	0.02	0.04		0.03	0.02	0.02	54.51	66.22
114	4	24	0.08	0.04	0.12	0.23	0.14	0.02	54.47	66.43
115	4	25	0.62	0.25	0.99	0.00	0.00	0.02	54.80	66.67
116	4	26	0.01		0.02	0.20	0.12	0.03	54.72	66.67
117	4	27	0.00			0.20	0.12	0.02	54.64	66.65
118	4	28	0.00			0.32	0.19	0.02	54.52	66.60
119	4	29	0.00			0.20	0.12	0.02	54.44	66.51
120	4	30	0.00			0.27	0.16	0.02	54.34	66.45
121	5	1	0.07	0.09	0.04	0.10	0.06	0.02	54.34	66.44
122	5	2	0.00			0.33	0.19	0.02	54.22	66.32
123	5	3	0.00			0.14	0.08	0.02	54.16	66.30
124	5	4	0.00			0.30	0.18	0.02	54.05	66.19
125	5	5	0.00			0.13	0.08	0.02	54.00	66.11
126	5	6	0.00			0.26	0.15	0.02	53.91	66.06
127	5	7	2.13	0.8	3.45	0.00	0.00	0.02	55.08	66.00
128	5	8	*****	10.5	11.0	0.15	0.09	0.03	61.01	68.98
129	5	9	0.51	0.46	0.55	0.15	0.12	0.09	61.17	70.53
130	5	10	0.00			0.23	0.18	0.10	61.02	70.90
131	5	11	0.00			0.20	0.16	0.09	60.88	71.00
132	5	12	0.03		0.05	0.33	0.26	0.09	60.70	71.01
133	5	13	0.00			0.21	0.16	0.09	60.55	70.94
134	5	14	0.00			0.18	0.14	0.09	60.43	70.90
135	5	15	0.23	0.07	0.39	0.23	0.18	0.09	60.41	70.56
136	5	16	0.00			0.20	0.15	0.09	60.27	70.26
137	5	17	0.00			0.31	0.24	0.09	60.09	70.07
138	5	18	0.00			0.32	0.24	0.08	59.91	69.96
139	5	19	0.00			0.38	0.29	0.08	59.71	69.82
140	5	20	0.00			0.18	0.14	0.08	59.59	69.69
141	5	21	0.00			0.32	0.24	0.08	59.41	69.59
142	5	22	0.00			0.13	0.10	0.08	59.32	69.48

143	5	23	0.00			0.34	0.25	0.07	59.14	69.31
144	5	24	1.70	2.25	1.14	0.33	0.24	0.07	59.90	69.61
145	5	25	0.00			0.20	0.15	0.08	59.77	69.72
146	5	26	0.01	0.01		0.33	0.25	0.08	59.59	69.62
147	5	27	0.00			0.16	0.12	0.08	59.48	69.47
148	5	28	0.00			0.27	0.20	0.08	59.33	69.30
149	5	29	0.00			0.26	0.19	0.07	59.18	69.18
150	5	30	0.20	0.36	0.03	0.38	0.28	0.07	59.09	69.06
151	5	31	0.05	0.01	0.08	0.21	0.15	0.07	58.99	69.12
152	6	1	0.00			0.29	0.21	0.07	58.84	69.05
153	6	2	0.04	0.07		0.26	0.19	0.07	58.71	68.92
154	6	3	0.00			0.31	0.22	0.07	58.55	68.84
155	6	4	0.00			0.13	0.09	0.07	58.46	68.80
156	6	5	0.00			0.00	0.00	0.07	58.43	68.66
157	6	6	0.00			0.10	0.07	0.06	58.35	68.53
158	6	7	0.00			0.10	0.07	0.06	58.27	68.43
159	6	8	0.00			0.16	0.11	0.06	58.18	68.30
160	6	9	0.00			0.35	0.25	0.06	58.00	68.20
161	6	10	0.00			0.23	0.16	0.06	57.88	68.14
162	6	11	0.00			0.31	0.22	0.06	57.73	68.11
163	6	12	0.00			0.46	0.32	0.06	57.52	67.97
164	6	13	0.01		0.01	0.59	0.40	0.06	57.27	67.84
165	6	14	0.02	0.03		0.20	0.14	0.05	57.17	67.77
166	6	15	0.00			0.20	0.14	0.05	57.07	67.68
167	6	16	0.00			0.07	0.05	0.05	57.01	67.62
168	6	17	0.00			0.23	0.15	0.05	56.90	67.53
169	6	18	0.00			0.29	0.19	0.05	56.77	67.39
170	6	19	0.00			0.30	0.20	0.05	56.63	67.28
171	6	20	0.15	0.03	0.26	0.30	0.20	0.05	56.58	67.18
172	6	21	0.00			0.14	0.09	0.04	56.50	67.10
173	6	22	0.14	0.28		0.26	0.17	0.04	56.46	67.07
174	6	23	0.08		0.15	0.13	0.08	0.04	56.43	67.03
175	6	24	0.00			0.26	0.17	0.04	56.31	66.97
176	6	25	0.00			0.15	0.10	0.04	56.23	66.95
177	6	26	0.04	0.02	0.05	0.06	0.04	0.04	56.21	66.85
178	6	27	1.15	2.3		0.23	0.15	0.04	56.74	66.84
179	6	28	0.95	0.24	1.66	0.07	0.05	0.05	57.22	67.24
180	6	29	0.02	0.03		0.26	0.18	0.05	57.10	67.21
181	6	30	0.01		0.01	0.32	0.22	0.05	56.96	67.24
182	7	1	0.00			0.29	0.19	0.05	56.82	67.25
183	7	2	0.00			0.18	0.12	0.05	56.73	67.19
184	7	3	0.00			0.32	0.21	0.05	56.58	67.08
185	7	4	0.02	0.03		0.47	0.31	0.04	56.40	66.99
186	7	5	0.10		0.19	0.40	0.26	0.04	56.28	66.94
187	7	6	0.00			0.37	0.24	0.04	56.12	66.87
188	7	7	0.29	0.58		0.33	0.21	0.04	56.15	66.80
189	7	8	0.38	0.06	0.69	0.18	0.12	0.04	56.27	66.79
190	7	9	0.01	0.01		0.30	0.19	0.04	56.14	66.81
191	7	10	0.00			0.45	0.29	0.04	55.96	66.75

192	7	11	0.00			0.16	0.10	0.04	55.88	66.63
193	7	12	0.23	0.46		0.21	0.13	0.04	55.91	66.55
194	7	13	0.28	0.06	0.5	0.24	0.15	0.04	55.96	66.59
195	7	14	0.06	0.11		0.23	0.15	0.04	55.89	66.55
196	7	15	0.01	0.02		0.09	0.06	0.04	55.84	66.53
197	7	16	0.16	0.14	0.17	0.39	0.25	0.04	55.77	66.49
198	7	17	0.01	0.01		0.09	0.06	0.04	55.72	66.48
199	7	18	0.06	0.12		0.25	0.16	0.04	55.65	66.51
200	7	19	0.36	0.67	0.05	0.13	0.08	0.03	55.78	66.45
201	7	20	0.02	0.03		0.31	0.20	0.04	55.66	66.33
202	7	21	0.00			0.23	0.14	0.03	55.56	66.29
203	7	22	0.11		0.22	0.01	0.01	0.03	55.60	66.24
204	7	23	0.39	0.61	0.17	0.57	0.36	0.03	55.60	66.19
205	7	24	0.07	0.1	0.03	0.00	0.00	0.03	55.62	66.12
206	7	25	0.04	0.01	0.07	0.16	0.10	0.03	55.56	66.11
207	7	26	0.01	0.01		0.12	0.08	0.03	55.51	66.07
208	7	27	0.00			0.21	0.13	0.03	55.42	66.01
209	7	28	0.00			0.28	0.17	0.03	55.30	65.96
210	7	29	0.00			0.33	0.20	0.03	55.17	65.91
211	7	30	0.00			0.26	0.16	0.03	55.07	65.87
212	7	31	0.00			0.15	0.09	0.03	55.00	65.81
213	8	1	0.00			0.31	0.19	0.03	54.88	65.75
214	8	2	0.53	1.05		0.52	0.32	0.03	54.98	66.09
215	8	3	0.34	0.03	0.64	0.27	0.16	0.03	55.06	65.85
216	8	4	0.16	0.02	0.29	0.32	0.20	0.03	55.02	65.71
217	8	5	0.05	0.1		0.24	0.15	0.03	54.95	65.65
218	8	6	0.78	1.55		0.19	0.12	0.03	55.30	65.64
219	8	7	1.06	0.15	1.97	0.26	0.16	0.03	55.79	65.72
220	8	8	1.30	1.3	1.3	0.15	0.10	0.04	56.44	65.79
221	8	9	0.69	0.01	1.36	0.14	0.09	0.04	56.74	65.99
222	8	10	1.13	0	2.25	0.21	0.14	0.05	57.26	66.26
223	8	11	1.77	1.55	1.99	0.20	0.14	0.05	58.14	66.69
224	8	12	0.80	1.5	0.09	0.11	0.08	0.06	58.51	67.90
225	8	13	0.62	0.3	0.93	0.04	0.03	0.07	58.80	68.73
226	8	14	0.00			0.11	0.08	0.07	58.71	69.13
227	8	15	0.01		0.02	0.13	0.09	0.07	58.63	69.50
228	8	16	0.65	0.42	0.87	0.25	0.18	0.07	58.85	69.50
229	8	17	0.41	0.78	0.04	0.17	0.12	0.07	58.97	69.39
230	8	18	0.01	0.02		0.18	0.13	0.07	58.86	69.33
231	8	19	0.53	1.05		0.22	0.16	0.07	59.03	69.70
232	8	20	0.85	0.54	1.15	0.24	0.18	0.07	59.36	70.09
233	8	21	0.40	0.01	0.78	0.20	0.15	0.08	59.46	70.37
234	8	22	0.06	0.01	0.1	0.24	0.18	0.08	59.35	70.22
235	8	23	0.15	0.24	0.05	0.18	0.13	0.08	59.31	70.50
236	8	24	1.48	1.45	1.51	0.17	0.13	0.07	60.02	70.72
237	8	25	0.23	0.01	0.45	0.21	0.16	0.08	60.01	70.84
238	8	26	0.14	0.15	0.13	0.20	0.15	0.08	59.96	70.74
239	8	27	0.16	0.14	0.17	0.21	0.16	0.08	59.91	70.96
240	8	28	0.01	0.01		0.21	0.16	0.08	59.78	70.83

241	8	29	0.01	0.01		0.28	0.21	0.08	59.62	70.72
242	8	30	0.46	0.76	0.16	0.27	0.20	0.08	59.72	70.75
243	8	31	0.46	0.17	0.74	0.13	0.10	0.08	59.88	70.85
244	9	1	0.47	0.03	0.91	0.20	0.15	0.08	60.01	71.07
245	9	2	0.07	0.07	0.06	0.10	0.08	0.08	59.96	71.04
246	9	3	0.10	0.13	0.07	0.25	0.19	0.08	59.86	70.96
247	9	4	0.28	0.11	0.44	0.07	0.05	0.08	59.94	70.95
248	9	5	0.02	0.02	0.01	0.17	0.13	0.08	59.83	70.81
249	9	6	0.00			0.17	0.13	0.08	59.72	70.67
250	9	7	0.00			0.20	0.15	0.08	59.59	70.66
251	9	8	0.00			0.18	0.13	0.08	59.47	70.65
252	9	9	0.00			0.23	0.17	0.08	59.33	70.53
253	9	10	0.31	0.44	0.17	0.20	0.15	0.07	59.38	70.48
254	9	11	0.37	0.15	0.58	0.22	0.16	0.08	59.45	70.41
255	9	12	0.73	0.74	0.71	0.08	0.06	0.08	59.78	70.66
256	9	13	0.34	0.22	0.46	0.16	0.12	0.08	59.86	70.81
257	9	14	0.74	0.65	0.83	0.10	0.08	0.08	60.18	71.66
258	9	15	0.78	1.1	0.45	0.17	0.13	0.08	60.49	71.84
259	9	16	0.11	0.01	0.2	0.19	0.15	0.09	60.42	71.89
260	9	17	0.05	0.09		0.16	0.12	0.09	60.33	71.82
261	9	18	0.03	0.01	0.05	0.21	0.16	0.09	60.21	71.58
262	9	19	0.00			0.27	0.21	0.08	60.05	71.50
263	9	20	0.05	0.1		0.13	0.10	0.08	59.97	71.28
264	9	21	0.66	0.64	0.68	0.23	0.17	0.08	60.20	71.35
265	9	22	0.89	0.26	1.52	0.09	0.07	0.08	60.61	71.43
266	9	23	1.13	2	0.25	0.09	0.07	0.09	61.14	71.73
267	9	24	0.74	1	0.47	0.12	0.10	0.09	61.44	72.32
268	9	25	0.23	0.45		0.15	0.12	0.10	61.45	72.44
269	9	26	0.63	0.64	0.62	0.25	0.20	0.10	61.63	72.52
270	9	27	0.64	0.34	0.93	0.06	0.05	0.10	61.90	72.55
271	9	28	0.41	0.3	0.52	0.15	0.12	0.10	62.01	72.65
272	9	29	0.49	0.64	0.33	0.20	0.16	0.10	62.13	72.70
273	9	30	0.02	0.02	0.01	0.16	0.13	0.11	62.00	72.71
274	10	1	0.00			0.13	0.11	0.10	61.88	72.55
275	10	2	0.25	0.5		0.18	0.15	0.10	61.89	72.32
276	10	3	0.00			0.12	0.10	0.10	61.77	72.13
277	10	4	0.00			0.19	0.15	0.10	61.63	72.06
278	10	5	0.04	0.07		0.19	0.15	0.10	61.51	71.93
279	10	6	0.09		0.18	0.19	0.15	0.10	61.42	71.77
280	10	7	0.01	0.02		0.14	0.11	0.10	61.31	71.58
281	10	8	0.00			0.19	0.15	0.10	61.17	71.44
282	10	9	0.00			0.16	0.13	0.10	61.05	71.34
283	10	10	0.00			0.11	0.09	0.09	60.95	71.25
284	10	11	0.06	0.03	0.09	0.17	0.13	0.09	60.85	71.20
285	10	12	0.00			0.15	0.12	0.09	60.74	71.11
286	10	13	0.02	0.04		0.13	0.10	0.09	60.64	71.03
287	10	14	0.17		0.33	0.06	0.05	0.09	60.66	71.01
288	10	15	0.00			0.16	0.12	0.09	60.54	70.92
289	10	16	0.16	0.02	0.3	0.15	0.12	0.09	60.51	70.85

290	10	17	0.04	0.03	0.04	0.11	0.09	0.09	60.44	70.78
291	10	18	0.00			0.11	0.09	0.09	60.34	70.68
292	10	19	0.00			0.18	0.14	0.09	60.22	70.60
293	10	20	0.03	0.06		0.12	0.09	0.08	60.14	70.55
294	10	21	0.00			0.16	0.12	0.08	60.02	70.49
295	10	22	0.00			0.16	0.12	0.08	59.91	70.41
296	10	23	0.00			0.19	0.14	0.08	59.78	70.35
297	10	24	0.00			0.01	0.01	0.08	59.73	70.27
298	10	25	0.00			0.23	0.17	0.08	59.59	70.18
299	10	26	0.00			0.14	0.10	0.08	59.49	70.10
300	10	27	0.00			0.16	0.12	0.08	59.38	70.02
301	10	28	0.00			0.11	0.08	0.08	59.30	69.98
302	10	29	0.00			0.12	0.09	0.07	59.21	69.93
303	10	30	0.00			0.15	0.11	0.07	59.10	69.84
304	10	31	0.01		0.02	0.11	0.08	0.07	59.03	69.78
305	11	1	0.01		0.01	0.14	0.10	0.07	58.93	69.73
306	11	2	0.51	0.82	0.2	0.11	0.08	0.07	59.13	69.74
307	11	3	0.32	0.03	0.61	0.10	0.07	0.07	59.23	69.85
308	11	4	0.00			0.13	0.10	0.07	59.13	69.78
309	11	5	0.00			0.10	0.07	0.07	59.05	69.69
310	11	6	0.00			0.09	0.07	0.07	58.98	69.64
311	11	7	0.00			0.09	0.07	0.07	58.90	69.54
312	11	8	0.00			0.10	0.07	0.07	58.82	69.44
313	11	9	0.00			0.07	0.05	0.07	58.75	69.39
314	11	10	0.00			0.08	0.06	0.07	58.68	69.34
315	11	11	0.14	0.28		0.05	0.04	0.07	58.70	69.29
316	11	12	0.05	0.05	0.05	0.07	0.05	0.07	58.67	69.32
317	11	13	0.88	0.46	1.3	0.10	0.07	0.07	59.08	70.24
318	11	14	0.00			0.06	0.04	0.07	59.01	70.70
319	11	15	0.00			0.09	0.07	0.07	58.94	71.11
320	11	16	0.00			0.03	0.02	0.07	58.89	70.09
321	11	17	0.00			0.07	0.05	0.07	58.82	69.65
322	11	18	0.00			0.05	0.04	0.07	58.76	69.48
323	11	19	0.00			0.04	0.03	0.07	58.71	69.23
324	11	20	0.00			0.05	0.04	0.07	58.65	69.33
325	11	21	0.00			0.07	0.05	0.07	58.58	69.35
326	11	22	0.00			0.05	0.04	0.07	58.53	69.64
327	11	23	0.00			0.10	0.07	0.07	58.45	69.10
328	11	24	0.00			0.07	0.05	0.07	58.38	69.02
329	11	25	0.18	0.26	0.1	0.07	0.05	0.06	58.42	68.99
330	11	26	0.05	0.04	0.06	0.04	0.03	0.06	58.40	69.03
331	11	27	0.00			0.11	0.08	0.06	58.32	69.10
332	11	28	0.66	0.12	1.19	0.04	0.03	0.06	58.63	68.72
333	11	29	0.04	0.05	0.02	0.04	0.03	0.07	58.60	69.52
334	11	30	0.00			0.14	0.10	0.07	58.50	69.65
335	12	1	0.00			0.04	0.03	0.07	58.45	68.94
336	12	2	0.00			0.04	0.03	0.07	58.40	68.88
337	12	3	0.00			0.07	0.05	0.06	58.34	68.79
338	12	4	0.00			0.03	0.02	0.06	58.29	68.82

```
339 12   5 0.00           0.03 0.02  0.06  58.24 68.78
340 12   6 0.07 0.13 0.01 0.04 0.03  0.06  58.23 69.31
341 12   7 0.26 0.14 0.37 0.02 0.01  0.06  58.33 68.85
342 12   8 0.02      0.04 0.03 0.02  0.06  58.29 68.62
343 12   9 0.00           0.10 0.07  0.06  58.22 68.55
344 12  10 0.00           0.03 0.02  0.06  58.17 68.97
345 12  11 0.00           0.05 0.04  0.06  58.12 68.63
346 12  12 0.00           0.00 0.00  0.06  58.08 68.56
347 12  13 0.00           0.07 0.05  0.06  58.02 69.01
348 12  14 0.00           0.04 0.03  0.06  57.97 68.64
349 12  15 0.00           0.04 0.03  0.06  57.92 68.57
350 12  16 0.58 0.62 0.53 0.05 0.03  0.06  58.19 68.64
351 12  17 0.00           0.03 0.02  0.06  58.14 68.71
352 12  18 0.00           0.10 0.07  0.06  58.07 68.67
353 12  19 0.00           0.01 0.01  0.06  58.03 68.63
354 12  20 0.00           0.04 0.03  0.06  57.98 68.65
355 12  21 0.00           0.04 0.03  0.06  57.93 68.62
356 12  22 0.00           0.02 0.01  0.06  57.89 68.65
357 12  23 0.00           0.04 0.03  0.06  57.85 68.62
358 12  24 0.08 0.16      0.01 0.01  0.06  57.85 68.57
359 12  25 0.05      0.09 0.08 0.06  0.06  57.81 68.21
360 12  26 0.00           0.08 0.06  0.06  57.75 68.14
361 12  27 0.00           0.04 0.03  0.06  57.70 68.18
362 12  28 0.00           0.03 0.02  0.06  57.66 68.11
363 12  29 0.00           0.02 0.01  0.06  57.62 68.12
364 12  30 0.05 0.06 0.04 0.05 0.03  0.06  57.60 68.14
365 12  31 0.00           0.04 0.03  0.06  57.55 68.03
NO  MO DAY   P  CY C ST L   E   ET     L   CAL H MH  4
    TOTAL  64.0 61.1 66.9 60.1 41.8 22.33
    MEAN                                    58.1  68.5
    MAX                                    62.13 72.71
    MIN                                    53.91 65.64
    STD DEV                                 1.80  1.77

    KEY ASSUMPTIONS:
    1.ET=(ETMAX-ETRATE*(GRDEL-WTEL))GRDEL     68
                                    ETMAX      1
                                    ETRATE  0.03
    3.STORAGE COEF.=                        0.15
    4.MAXIMUM LEAKANCE                        70
    6.INDICATOR RAIN GAGE WEIGHTS   CY C     0.5
                                    ST L     0.5


    CONTINUITY CHECK: dS/dT=(P-ET-Q-L)

                               P=                      63.975 IN.
                               ET=                     41.819 IN.
                               L=                      22.331 IN.
```

```
                    dS/dT=     CALC          -0.175 IN.
                               MEAS          -0.084

PERCENT CONTRIBUTIONS        INFLOWS

                             P=       100%

                             OUTFLOWS

                             ET=    65.19%
                             L=     34.81%
```

APPENDIX D

CONSTRUCTION OF LOTUS 123 MENUS

Lotus 123 menus that are similar to those included in the 123 program may be easily created through the use of programming macros. Each menu may contain up to 8 choices, but can be linked to as many other menus as is desired. The following is a description of the construction of the menu system used in the Stormwater Expert System presented in Chapter V. It is strongly recommended that The user should review the basics of creating macros in the Lotus 123 manual (Release 1A, 1983) before reading further. Other excellent macro programming references include Anderson and Cobb (1984) and Riddington and Williams (1985).

The table of contents was called (Figure D-1) by implementing the M macro (Alt-M), which began with a simple {goto} OUTLINE command. The table of contents was given the range name OUTLINE. Each choice in the table has a letter directly to the left, and a macro was provided for each choice to create menus for each category. By assigning each menu macro the range name corresponding to each letter, the user is able to move the cursor to the letter of choice, strike return, and have the menu of subcategories appear at the top of the screen. This process is accomplished in the following manner:

Step 1. Create the macro \M ---------- {GOTO}OUTLINE~

Step 2. Directly below, place the following macro line:

Table D-1. Table of Contents for the Stormwater Expert System.

MOVE CURSOR TO PART LETTER, HIT RETURN TO CHOOSE CATEGORY, AND THEN CHOOSE FROM MENU.

Part	Table of Contents	Knowledge Base			
1.	Description of the Study Area				
A	Data Set	Study Area	Soils	Land Use	Topo
B	Rainfall	Rainfall General Stats	Design Storm Conditions	Storm Frequency Analysis	
C	Runoff	Design Conditions	Soil Infiltration	Imperviousness	Initial Abstraction
D	Ground Water	Design Conditions	Well Data	Well Data Graph	Leakance
II.	Design of Stormwater Management System				
E	Stage-Area-Volume	Stage-Area	Stage-Volume		
F	Design Storm(s)	Default Value	120 hr Rain	24 hr Rain	Frequency Analysis
G	Runoff Estimation	SCS Method	Unit Hydrograph	SWMM	DABRO
H	Stage Discharge Relation		Storage Routing		
I	Benefit Cost Analysis	Flood Damages	Control Costs	Optimal Design	

```
{?}/c{esc}~AA5~{goto}AA5~{edit}{home}{del}~{goto}OUTLINE~        (D-1)
/xg

~
```

This macro will pause for the user to move the cursor to the letter of choice, strike return, and copy the chosen letter into cell AA5 (which is the blank cell below the /xg and above the ~). The second line, /xg, is a goto which now tells the program to move to the range name of the letter which is now in the cell below. If the letter A was chosen, an A will be placed in the blank space, and the macro will move to the menu range named \A.

Step 3. A menu, as described in Table IV-8, is placed in the cells given the range names with each letter in the table of contents, as follows:

```
/xmAA12~                                                        (D-2)
/xgAA2~
AREA     LANDMAP  LANDDATA
Map of thShows lanAllows inspection of data
{GOTO} GAG{GOTO}USE{GOTO}DATA
```

The cell containing /xmAA12 is given the range name \A and is the macro for producing the menu for choice A. This command simply begins execution of the menu beginning in cell AA12. The menu is as described in Table IV-8. Each cell is given a menu choice, which is why only part of each command is visible on the spreadsheet. By moving the cursor to each cell, the contents may be read, and the entire menu may be read at the top of the screen when executed (exactly like the command macros in 123).

> Finally, the /xgAA2 command instructs the macro to return to the outline macro in cell AA2 (the macro previously described in Step 2) when the user is finished with menu A. The user may now make another choice of letters, and the process is repeated.

Step 3 is repeated for each letter in the table of contents. This method will create a system in which the user remains within the macro program throughout the use of the expert system. By creating looping macros within each of the individual menu commands, a very intricate and complete system can be constructed.

Lotus 123 macros are usually very easy to construct and interpret, but there are two problems that will be present in all macro programming: 1) long macros may become very confusing to both the initial programmer and to others, so documentation is recommended nearby in order to explain each step in plain English; and 2) since the macros are constructed as labels, not equations, the programs will not change cell references when moved. It is therefore recommended that a section of the spreadsheet, far away from other calculations and text, be reserved for macros only. Any movement of macros will often cause confusing programming problems, so once a program is written, it should not be moved without careful consideration of the consequences.

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BIOGRAPHICAL SKETCH

Michael Curtis Hancock was born on March 26, 1962, in Gardner, Massachusetts, to Mr. and Mrs. Richard C. Hancock. He has an older brother and sister, and one younger sister. He was raised in Gardner, attending public schools and graduating from Gardner High School in 1980. He matriculated at Clark University in Worcester, Massachusetts, and received a Bachelor of Arts in both chemistry and science, technology, and society. In 1984, he entered the graduate program in the Department of Environmental Engineering Sciences at the University of Florida, with a concentration in water resources analysis. He received his Master of Science degree in August, 1986. While a graduate student, he coauthored several reports for funded research projects, including a study of hazardous waste problems in U.S. Air Force bases, and an analysis of the effects of wellfield pumping on the surrounding hydrologic system in west-central Florida.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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