IC 9401

BUREAU OF MINES
INFORMATION CIRCULAR/1994

PB94-214053

Computer Software for Monitoring the Hydrology of In Situ Leaching Operations

By Peter K. Mathison, Michael E. Salovich,
F. Brendan Murphy, and Eric Level

UNITED STATES DEPARTMENT OF THE INTERIOR

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Bruce Babbitt, Secretary

BUREAU OF MINES

Library of Congress Cataloging in Publication Data:

PB94-214053

Computer software for monitoring the hydrology of in situ leaching operations / by Peter K. Mathison . . . [et al.].

p. cm. — (Information circular; 9401)

Includes bibliographical references (p. 7).

Supt. of Docs. no.: I 28.27:9401.

1. In situ processing (Mining)—Computer simulation. 2. Hydrology—Measurement—Computer programs. 3. Leaching—Data processing. 4. Copper mines and mining—Arizona—Casa Grande Region. 5. Injection wells—Testing—Data processing. I. Mathison, Peter K. II. Series: Information circular (United States. Bureau of Mines); 9401.

TN295.U4 [TN278.3] 622'.22—dc20 93-48530 CIP

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

PB94-214053

2. REPORT DATE

3. REPORT TYPE AND DATES COVERED
Bureau IC (Information Circular)

4. TITLE AND SUBTITLE
Computer Software for Monitoring the Hydrology of In Situ Leaching Operations.

5. FUNDING NUMBERS

6. AUTHOR(S)
Peter K. Mathison, Michael E. Salovich, F. Brendan Murphy and Eric Level

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Bureau of Mines
Twin Cities Research Center
5629 Minnehaha Avenue South
Minneapolis, MN 55417

8. PERFORMING ORGANIZATION REPORT NUMBER
IC 9401

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Bureau of Mines
Research
810 7th Street NW
Washington, DC 20241

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
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14. SUBJECT TERMS

15. NUMBER OF PAGES
18

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT

18. SECURITY CLASSIFICATION OF THIS PAGE

19. SECURITY CLASSIFICATION OF ABSTRACT

20. LIMITATION OF ABSTRAC

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Block 7. Performing Organization Name(s) and Address(es). Self-explanatory.

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Block 9. Sponsoring/Monitoring Agency Name(s) and Address(es). Self-explanatory.

Block 10. Sponsoring/Monitoring Agency Report Number. *(If known)*

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Block 14. Subject Terms. Keywords or phrases identifying major subjects in the report.

Block 15. Number of Pages. Enter the total number of pages.

Block 16. Price Code. Enter appropriate price code *(NTIS only)*.

Blocks 17. - 19. Security Classifications. Self-explanatory. Enter U.S. Security Classification in accordance with U.S. Security Regulations (i.e., UNCLASSIFIED). If form contains classified information, stamp classification on the top and bottom of the page.

Block 20. Limitation of Abstract. This block must be completed to assign a limitation to the abstract. Enter either UL (unlimited) or SAR (same as report). An entry in this block is necessary if the abstract is to be limited. If blank, the abstract is assumed to be unlimited.

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot
in	inch
s	second

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CONTENTS

ILLUSTRATIONS

COMPUTER SOFTWARE FOR MONITORING THE HYDROLOGY OF IN SITU LEACHING OPERATIONS

By Peter K. Mathison,[1] Michael E. Salovich,[2] F. Brendan Murphy,[3] and Eric Level[4]

ABSTRACT

The U.S. Bureau of Mines has developed a hydrologic monitoring system for in situ leaching operations. This system records and displays flow and pressure information from sensors located in leachant injection and recovery wells. Continuous monitoring of hydrologic conditions is important during leaching operations because hydrologic factors such as aquifer permeability, solution injection rates, injection pressure, and solution recovery rates interact and change over time. This hydrologic monitoring system has been tested in an underground setting at the Cyprus Casa Grande copper mine. The system consists of hardware and computer software components and includes two Bureau-developed software applications. This publication describes the implementation of the hydrologic monitoring system and the software developed at the Bureau in support of in situ leaching research.

[1]Computer programmer.
[2]Computer systems programmer.
[3]Computer clerk.
[4]Mathematician.
Twin Cities Research Center, U.S. Bureau of Mines, Minneapolis, MN.

INTRODUCTION

This publication provides information about a hydrologic monitoring system for in situ leaching operations. It references the cooperative study that led to the development of the system, explains the design requirements, provides information regarding its operation, and discusses alternative monitoring systems. This publication assumes some knowledge of hydrology, in situ leach mining, the installation of sensors into wells, and the operation of multiplexors, data recorders, modems, and microcomputers.[5] A general overview of the design and structure of the system as implemented in the Cyprus Casa Grande Mine is followed by operation details of two software applications developed by the Bureau. The monitoring system as described herein can be used in other mines and/or as a prototype for alternative systems.

IN SITU LEACHING RESEARCH

As part of its mission to develop innovative mining technology, the U.S. Bureau of Mines has sponsored research into the safety and effectiveness of in situ leach mining, a technology that implements controlled circulation of fluids through ore deposits to extract minerals selectively with minimal disruption to the surrounding environment. This circulation is commonly achieved through the use of *injection* and *recovery wells*. Solution flows through the injection wells into the target ore zone, and recovery wells reclaim the leach solution pregnant with dissolved minerals. The minerals are then removed from the solution, and the solution is recycled back into the ore body through the injection wells. Working in concert with each other, injection and recovery wells can create a safe and effective circulation system to extract minerals that may not otherwise be minable. "In situ" is a Latin phrase that means "in place," and in this application connotes both economy and preservation because this technology offers a way to extract minerals without removing material from the deposit.

NEED FOR HYDROLOGIC MONITORING OF IN SITU LEACH OPERATIONS

In situ leach mining poses a special challenge in that much of the important hydrologic information is complex and can be difficult to obtain and organize. Important information about the circulation of leachant solution can be acquired only by carefully monitoring the performance of the pressure and flow rates in the injection and recovery wells. Analysis of the amount and rate of leachant solution injected and recovered, the respective well pressures, and changes in these factors over time yields information about the location, shape, and velocity of the leachant solution plume. Detailed monitoring and evaluation of the performance of wells, including the collection, organization, storage, and imaging of solution flow and well pressure information, is important.

Maintaining an optimum arrangement of injection and recovery wells to circulate leachant solution effectively within a mineral deposit is difficult, in part because in situ leaching is a dynamic process. As leach solution dissolves minerals in the ore body, hydrologic changes occur that require occasional redesign of the layout of injection and recovery wells. Consequently, wells need to be constructed so that they can easily be converted from recovery to injection modes (or vice versa). For example, high-pressure injection of leach solution can create fractures in the surrounding rock. A crack that connects an injection well with a recovery well may "short circuit" the circulation of leach solution so that the solution migrates through the fracture directly from the injection well to the recovery well. Mine personnel would need to respond immediately and perhaps convert the recovery well into an injection well, or vice versa, in an effort to maintain contact between the leach solution and the minerals in the ore. Another problem situation occurs when the leach solution reacts with surrounding minerals and creates zones of reduced permeability that can distort the circulation plume of the leach solution. Again, mine personnel would need to respond and modify the arrangement of injection and recovery wells. Designing and maintaining in situ leach operations can be like aiming at a moving target: the process is dynamic and requires continuous monitoring and adjustment.

COOPERATIVE RESEARCH WITH CYPRUS MINERALS CASA GRANDE COPPER MINE

This system was developed in 1988-89 during a cooperative research project with the Cyprus Minerals Casa Grande copper mine. In 1988 the Cyprus Minerals Corp. provided Bureau researchers with an opportunity to study an in situ leach test facility in Casa Grande, AZ. In a cooperative arrangement, the Bureau and Cyprus Minerals jointly investigated the performance of a network of injection and recovery wells designed to circulate leachant solution through a deposit of copper oxide ore. The wells were drilled from within a mine tunnel located approximately 700 ft underground. The wells were 275 to 325 ft long and were arranged in groups of three to five, creating a pattern of parallel "fans" extending into the copper oxide ore zone (fig. 1). Each well borehole was 4 in. in diameter and held a 1-in stainless steel pipe that was perforated

[5]For more information, please contact the Bureau of Mines at 612/725-4647.

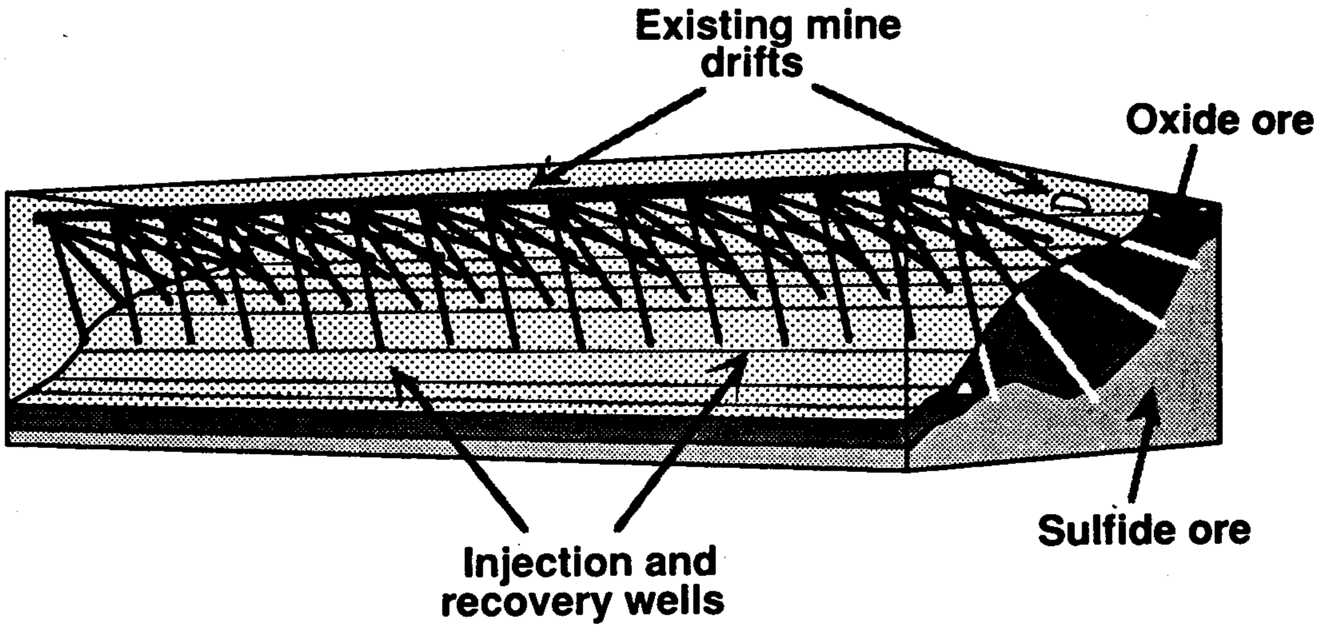

Figure 1.—Arrangement of wells in fans at the Cyprus Casa Grande Mine underground in-place leaching operation.

in sections where the well intersected the ore zone. This system was flexible in the sense that each well could easily be converted from an injection to a recovery well. The Bureau focused its study upon concerns relating to the permeability of the ore zone, the unsaturated conditions in the surrounding area, and strategies to distribute leach solution within the ore deposit (*6*).[6] Flow and pressure data from injection and recovery wells were critical to this investigation. The software described in this publication was developed in support of this research.

ACKNOWLEDGMENTS

The authors wish to express appreciation to Kermit Behnke and Donovan Morrow of Cyprus Casa Grande Corp. for their assistance in testing this system.

IMPLEMENTATION

DESIGN REQUIREMENTS

Researchers identified several specific components that needed to be included in the monitoring system. The most important of these was the need for detailed pressure and flow measurements from the wells. Measurements from injection and recovery wells can provide important information regarding changes in the hydrologic characteristics of an ore deposit during leaching. Permeability changes, for example, can affect the efficiency of wells and the distribution pattern of leach solution within the deposit. Changes in permeability have been identified as the most significant factor related to the hydrology and can occur in a matter of minutes or over the course of months. Researchers need a detailed record of pressure and flow values in the wells in order to understand and address these concerns.

Researchers also identified the usability of the software and the quality of the user interface as important considerations. Continuous monitoring of wells generates large databases. The ability to control the organization and accessibility of the data can have a tremendous effect on the time and energy researchers must invest in order to access and view their data.

Another feature researchers required was the visual display of well pressure and flow values. Two types of display were identified: a concurrent (or *real-time*) display of

[6]Italic numbers in parentheses refer to items in the list of references preceding the appendixes at the end of this report.

the readings and a display of stored data. Real-time display is especially important in identifying hydrologic events that occur quickly. Events such as sudden increases or decreases in pressure or flow often indicate conditions that require immediate responses from mine personnel. For instance, if a fracture opens near an injection well, the injection pressure may need to be reduced in order to minimize potential damage. Real-time display is valuable at the site of the injection and recovery wells and in the mine office. Retrieval and display of the stored data are important in identifying hydrologic trends and summarizing in situ activities.

Other factors influenced the development of the hydrologic monitoring system. First, when development began, no commercial systems were available that could meet all the design criteria; systems that were available included hardware and software as a package, were very expensive, and provided only subsets of the required features. Second, the harshness of the mine environment was considered to be a potential negative factor. The monitoring equipment was to be installed underground in a damp and dusty environment.

FUNCTIONS OF THE SYSTEM

Given the criteria listed in the previous section, Bureau researchers designed and implemented a hydrologic monitoring system (fig. 2). Pressure and flow sensors are connected directly to injection wells. Since recovery wells operate under atmospheric pressure, which is known and constant, the wells require only flow sensors. The well manifold was designed so that it could accommodate either one or two sensors, since wells must be able to operate in either injection or recovery mode and can be switched from one to the other in the middle of testing. The manifold also accommodates external analog flow and pressure gauges, which are used to monitor and calibrate the system on location.

Pressure and flow sensors produce analog signals and are wired directly to a multiplexing unit within the mine. The multiplexor is connected to a data recorder, which provides a real-time display in the mine of the pressure or flow data from one sensor at a time as the data are received. It also samples all the incoming analog signals, converts them to digital signals, and prints a record of all designated sensor readings at specified intervals.

The data recorder is connected to a modem by a phone line. An Apple Macintosh computer[7] is connected to a modem on the other end of the line on the surface. The computer is dedicated to running Logger, the software responsible for data acquisition and storage. Logger was developed at the Bureau; details of its operation are discussed in the next section.

[7]Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

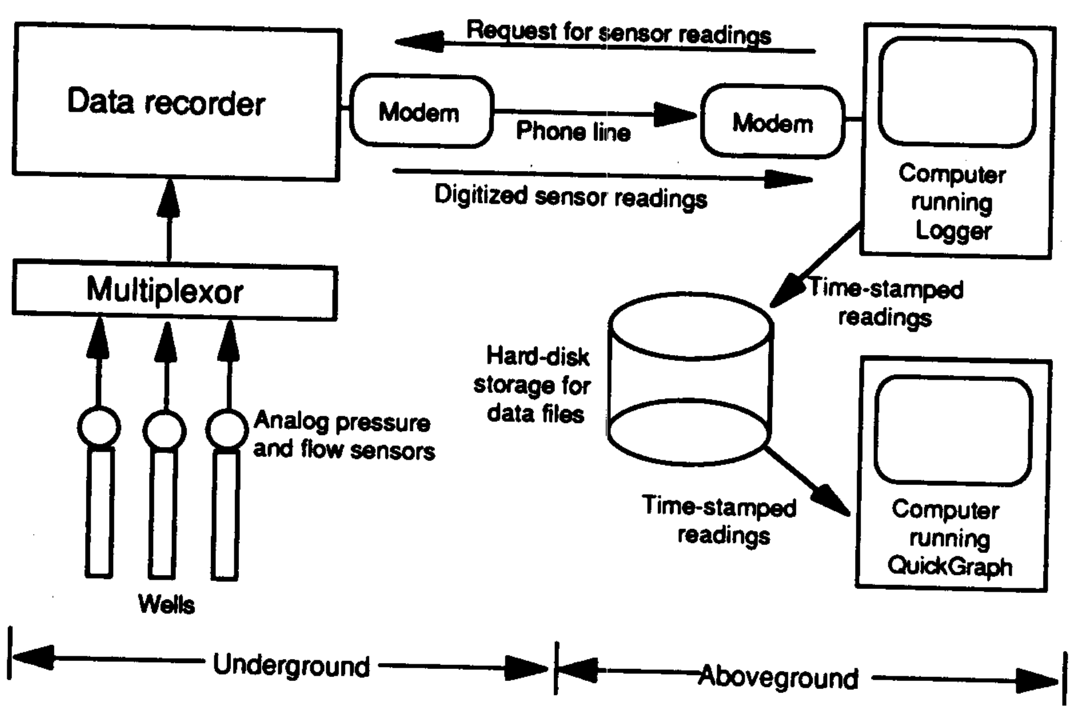

Figure 2.—Flow of information in the hydrologic monitoring system.

The other software package developed at the Bureau as part of this system is called QuickGraph. This application is named for its ability to access and organize large volumes of stored data and graph them in several different formats. Although QuickGraph is not part of the data acquisition process, it is considered an integral part of the monitoring system. Its functions are designed to meet several of the specific design criteria stated above. Its design and operation are also discussed in the next section.

Specific examples of the usefulness of this system and these software packages can be found in other publications related to in situ mining research at the Bureau (*1-7*).

SOFTWARE

LOGGER

Logger is a computer application that acquires, graphs, and stores pressure and flow readings from wells. This data acquisition application runs on an Apple Macintosh computer and features a graphical user interface that includes windows, pulldown menus, and point-and-click controls. Figure 3 shows the window that is used to control the data acquisition.

For each well in the configuration set, Logger creates a scheduling record containing all of the well parameters (identifier, type, plotting indicator, and sensor number), the next time at which to log, and the name of the data file to use. When logging begins, each of these records is placed into a scheduling queue, with each well scheduled to be first logged 30 s from the current time. This queue is a "first-in, first-out" data structure. Scheduling records are added to the queue in increasing chronological order of logging. If two or more records contain the same time for logging, they are added in the order in which they appear in the well configuration list.

Logger keeps track of which record is currently at the front of the scheduling queue and uses this information to fill the "Next log at:" area of the window. It does this by checking the current time and updating the time display periodically. When the current time exceeds the next scheduled log time found in this front record of the queue, data acquisition begins. Logger uses the information in this record to build a "read request" for the data recorder. This request consists of a string of characters specifying

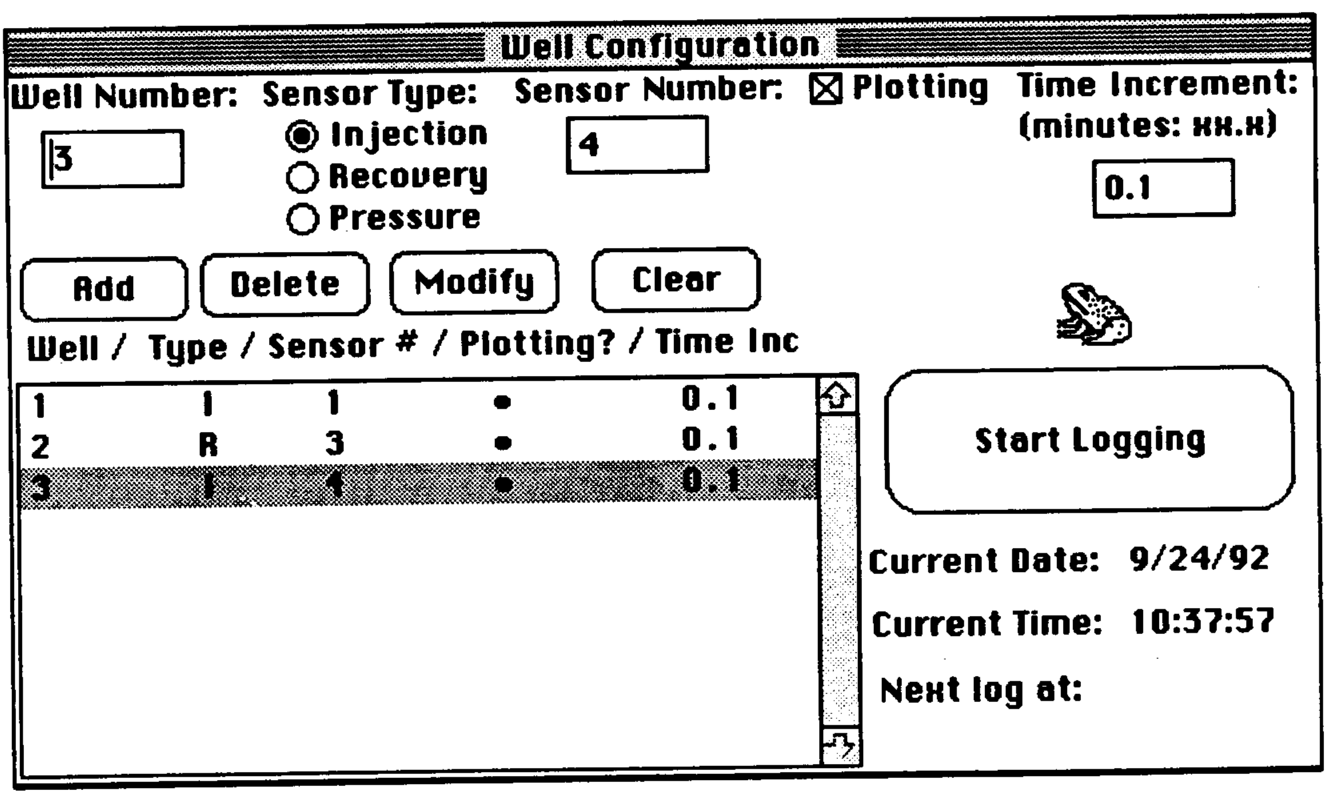

Figure 3.—Logger well configuration window.

that a reading is desired from a particular channel of the data recorder.

Logger sends this string of characters out through the computer's serial port, which is connected by modems and phone line to the data recorder. The data recorder captures the analog reading from the desired flow or pressure sensor, digitizes it into a string of characters representing the numeric value, stores this string internally, and returns the digitized reading to Logger. Logger notes the time and date at which the reading was made (the timestamp) and writes both the reading's numeric value and the timestamp to an appropriate data file. The scheduling record is removed from the front of the queue, updated with the time of its next scheduled reading (current time plus time increment), and reinserted in the queue to preserve the chronological ordering of the queue's records.

There is one data file per day for each entry in the well configuration list. Each of these files is given a unique name, which is a combination of the date, the well number, the well status (injection or recovery), and a number distinguishing multiple sessions on a single day. This approach allows the mine operator to determine quickly what sort of information the file contains and when the information was acquired. If a logging session covers more than one calendar date (i.e., if midnight occurs during the logging session), Logger will close and save the old file and create a new file with the new date.

While Logger is acquiring data, it also provides an optional real-time display of the data being logged (fig. B-4, appendix B). To see the real-time display, the operator sets the viewing range by using the display-parameters window, (fig. B-5) and selecting the "Show Plot Window" option in Logger's graph menu (fig. B-3). The display shows a graph of the data for the specified wells taken during the same logging session and on the same day. The graphical display is updated each time a reading is logged, providing a means to monitor well activity in a remote location.

QUICKGRAPH

QuickGraph organizes and graphs the data collected by Logger. QuickGraph, like Logger, runs on a Macintosh computer and features a graphical user interface. The application allows the user to manipulate graphing parameters, graph data in several different ways, save and reopen graphing configurations, export data as text or as PICT format graphics, and print graphs and text. Graph types include pressure versus time, flow versus time, and pressure versus flow. These graphs can also be combined and annotated.

Graphing configurations are stored in templates which contain information about the well data, time ranges, graph types, and graphing options related to the display of the data points. Templates may be modified by using the template window shown figure C-8, appendix C. New templates can be created and existing ones modified by using the controls in this window.

A format window (fig. C-10), is used to change the parameters of an existing graph. Once the user has created a graph using the template window, individual elements of the graph can be modified by using the controls in the format window and replotting the graph.

Logger was written in Pascal using procedural programming techniques and the MPW programming environment. QuickGraph was written using THINK Pascal, the THINK class libraries, and object-oriented programming techniques. Object-oriented programming differs from procedural programming in that data and procedures are combined into objects. This technique provides greater source code modularity and will make it easier to reuse portions of the code in future versions of QuickGraph and in other applications.

DISCUSSION

The following are some observations about the system and the software.

- The system has met the design criteria. It provides continuous monitoring of wells with real-time display and printed records of the readings. Logger organizes and stores the data efficiently; QuickGraph provides the means to access the data, organize the database, and view the data in several different ways.
- The system has generated a large and extensive database. This database is a record of the progress of in situ leaching tests at the Cyprus Casa Grande Mine. Examination of this database has led Bureau researchers to some important insights regarding the hydrology of in situ leaching (*6*).
- The system is used on a regular basis. When in situ leach testing is not in progress, mine personnel use the real-time components of the system to monitor other hydrologic activity at the mine. The organizational and graphing components are also used, but mostly by researchers. The ability to organize and sort through an extremely large hydrologic data base has been very important to researchers in discovering hydrologic relationships in mining areas and in designing tests and pumping patterns for in situ leaching.

• Hardware and software options have changed since development began. Some considerations that affected the design of the system are different now from what they were a few years ago. Computers are far less expensive than they were in 1988. There are more hardware and software options for data acquisition with computers. These options include data acquisition boards for computers and software to access and analyze data from those boards. Computer systems tend to be more flexible and provide better ways for software packages to communicate with each other. Computer networks are simpler and more versatile.

To summarize, this in situ hydrologic monitoring system has been a useful tool for researchers and mine personnel. Observations of the monitoring systems, as detailed in the previous section, have resulted in new ideas for an enhanced design of the hardware for this monitoring system. An enhanced monitoring system could provide greater functionality at a lower cost and could include the ability to integrate alarm and process control systems.

One possible design for an enhanced system would involve a computer installed in a mine. When the system was first designed, computers were considered to be too expensive for such an installation. In the last few years, however, computer costs have dropped significantly. A new computer with data acquisition capabilities would cost less than the equipment it would replace and would have other uses in the mine as well. The computer could be used to keep notes, to communicate with other computers on the network, to execute automatic backup of data, and to implement alarm and process control features.

A local area network (LAN) could use existing phone lines to connect the computer in the mine to other computers and peripheral devices on the surface or in remote locations. In this way, data being logged could be displayed or printed in the mine office or in any other location on the network.

Pressure and flow sensors could be connected to data acquisition boards installed in the computer. The data acquisition boards would convert analog signals to digital format and make the digital information available to other software packages.

Although there are no plans to convert the current monitoring system in use at Cyprus Casa Grande, a new system such as this would have some benefits over the current monitoring system. The number of specialized and dedicated devices would be reduced. The multiplexor and data recorder would be unnecessary since their functions would be performed more flexibly by the computer and data acquisition board. The modems in the mine and on the surface would be replaced by the network connection between the computers. Since researchers have found that the features provided by Logger and QuickGraph are important tools for in situ leaching, a new system would retain most of the software elements described above, even though some hardware-specific portions of Logger would need to be replaced.

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APPENDIX A.—HARDWARE AND SOFTWARE REQUIREMENTS

Logger and QuickGraph will run on a Macintosh Plus, an SE, an SE30, and all Mac II's. Logger requires the use of modems and the DDR10 digital data recorder from Tracor Westronics. Macintosh system software 6.0 or greater is required. A hard disk is highly recommended.

There are two versions of QuickGraph. QuickGraph 2.0 SE will run on all machines but does not take advantage of the 68881/68882 math coprocessor hardware. QuickGraph 2.0 Mac II will only run on an SE30 and on Mac II's equipped with math coprocessors; it will take full advantage of the math coprocessor, thereby significantly speeding up graphing operations.

To set up the Logger and QuickGraph software, drag (copy) the Logging folder from the floppy disk onto the target hard drive. This folder may reside anywhere on the hard disk. QuickGraph will search all folders within the Logging folder for data. Logger will create data files only in the directory it resides in. QuickGraph may be moved to another folder, but do not place QuickGraph on the top level or over any directory structure you do not want searched. Logger and QuickGraph may be run simultaneous under Multifinder or System 7. Logger will continue to collect data while it is in the background.

APPENDIX B.—LOGGER

LOGGER MENUS

Listed below are descriptions of the menu selections available in Logger.

Figure B-1.

About Logger...

Displays a dialog with information on authorship, disclaimer clause, and version number. Click anywhere inside the window to dismiss the dialogue window.

Figure B-2.

Open Config...

Configuration files can be opened through this command. The configuration will be loaded into the "Well Configuration" window (fig. 3, main text). A standard file selection dialogue will appear in which the configuration file may be selected. Any configuration that existed in the well configuration window will be cleared before the new configuration is loaded.

Save Config...

Saves the current configuration in the well configuration window. A standard file save dialogue will appear in which you may name the file and save it.

Quit

Exits the application.

Figure B-3.

Update Plot

The real-time plot window will be updated immediately with the settings from the Parameters window.

Plot Ranges...

Bring up a "Parameters" window where changes to the plot ranges in the real-time plot window can be made. The following attributes may be changed; pressure axis, flow axis, dates, and tick marks. You may also choose how often data points should be labeled.

Show Plot Window or Hide Plot Window

Causes the real-time plot window to appear or disappear.

LOGGER WINDOWS

Figure B-4:

- This graph displays in real-time pressure and flow readings from sensors located in wells. The display shows two types of graphs: flow versus time and pressure versus time.

- Logger displays only data from the current logging session and the current day.

Figure B-5:

- Used to set up and stop a logging session.
- Each sensor to be logged is specified by well number, well type (injection or recovery), sensor number, time between readings, and whether the reading should be added to the real-time plot.
- Shows the current time and time of the next scheduled reading, and provides feedback when a reading is being taken.
- Logger Plot Range Parameters: Controls the parameters of the real-time display.

Figure B-1.—Logger Apple menu.

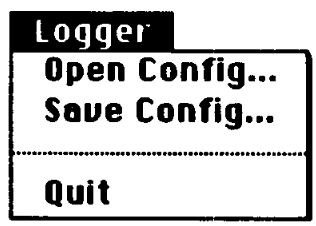

Figure B-2.—Logger menu.

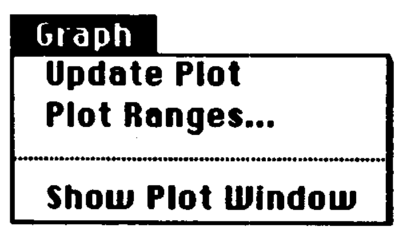

Figure B-3.—Logger graph menu.

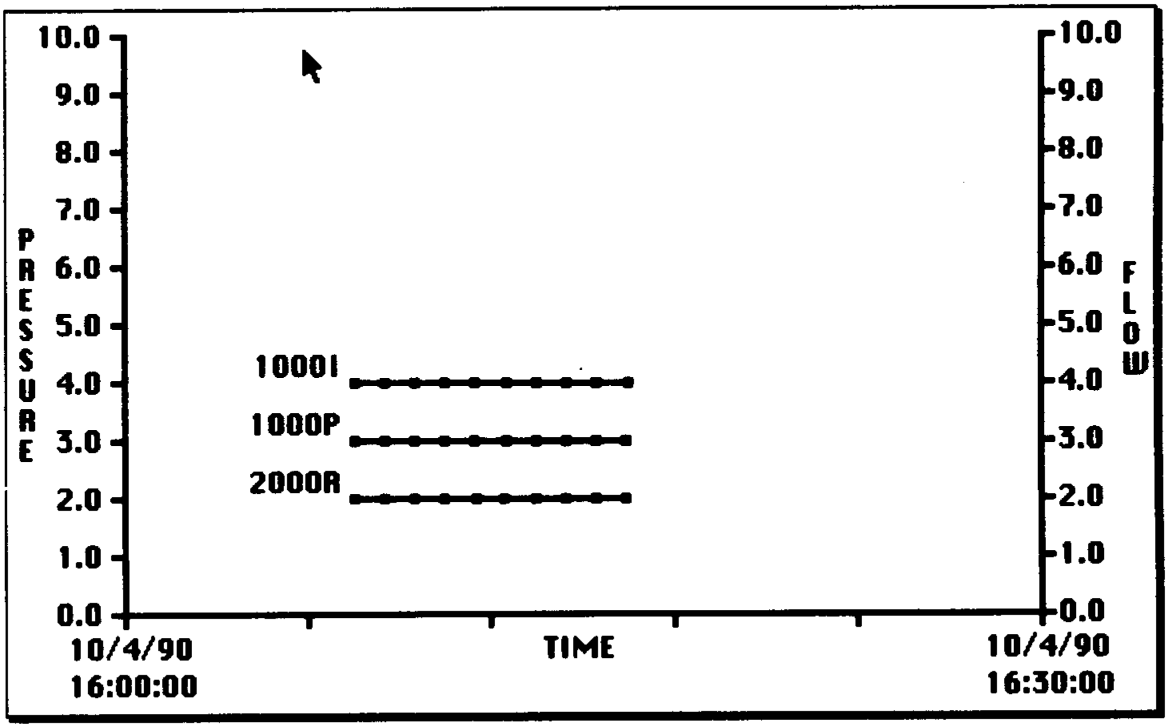

Figure B-4.—Logger real-time display window.

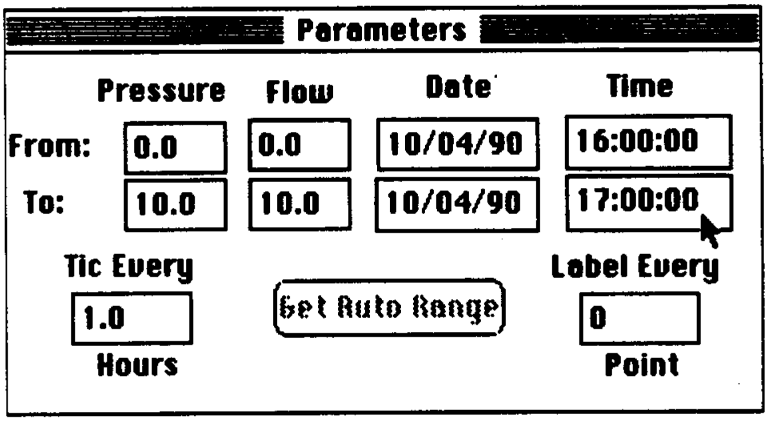

Figure B-5.—Logger display-parameters window.

APPENDIX C.—QUICKGRAPH

QUICKGRAPH MENUS

Listed below are descriptions of the menu selections available in QuickGraph.

Figure C-1.

About QuickGraph 2.0...

Displays a dialogue with information on authorship, disclaimer clause, and version number. Click anywhere inside the window to dismiss the dialogue window.

Figure C-2.

Open Template Window

Opens the template window (fig. C-8) for creating, changing, and saving templates. Another function of this window is to select graphs from a template.

Open Graphs From Template...

Opens an existing template created in the template window (fig. C-8) and plots all the graphs within that template. A standard get-file dialogue will appear. Select the template file within the selection box and click on the open button. QuickGraph will then plot all graphs found in that template.

Close or Close Graph

Closes the top graph window or the clipboard.

Close All Graphs

Closes all graph windows.

Save

Saves the current active graph window in the specified format. The format is selected from the hierarchical menu that will appear when the save selection is highlighted. There are three choices—PICT, Zero Based Text, and Date Based Text.

PICT - saves the graph in the standard Macintosh PICT format for exportation into drawing or page layout applications. Another way to export the graph as a PICT is to copy it to the clipboard. Graphs can be copied to the clipboard by choosing "copy" under the edit menu.

Zero Based Text - saves the graph data in a text format with the time axis being represented by real numbers greater than or equal to zero. Each integral value (1, 2, 3,...) represents 1 day. The left end of the time axis of the graph is equated to zero, and the rest of the axis is scaled as stated above. Use this format to export data to another application that requires the X (time), Y (value) format, where X and Y will be separated by a tab. An example is **1.023189393 756.00.**

Date Based Text - saves the graph data in a text format that is easy to read. The format of the data will be the same as that for Zero Based Text except that the X (time) will be replaced by the English equivalent. An example is **5/2/90 1:24:32 PM 756.00.**

Page Setup

Displays the standard Macintosh page setup dialogue.

Print...

Displays the standard Macintosh print dialogue. If the print button is clicked on, then a dialogue asking for comments to be printed with the graph will be displayed. After the continue button is clicked, a "Printing the graph..." dialogue will appear. This dialogue will be displayed as long as the graph is being sent to the printer or printing queue. To cancel the printing operation while the "Printing the graph..." dialogue is up, press command-period.

Quit

Exits the application.

Figure C-3.

Copy

Creates a PICT of the graph and stores it on the clipboard. Use this selection to transfer a PICT of the graph to drawing applications and page layout applications via the clipboard.

Show Clipboard or Hide Clipboard

Makes the clipboard window visible or invisible.

Figure C-4.

Stack Windows

Moves and resizes all graph windows so that they are all neatly stacked upon one another and offset down and to the right of the preceding window.

Tile Windows

Moves and resizes all graph windows so that they are all neatly tiled on the screen without overlapping. If there are more windows than can be tiled on the screen, QuickGraph will beep.

No Open Windows or Window Names

Selecting "No Open Windows" has no effect. If open graphs are present or the clipboard is visible, the "No Open Windows" selection will be replaced by a list of the titles of the graph windows. If a window title is selected from this menu, that window will be immediately brought forward and made the active graph window. Use this selection to find a window among a plurality of windows.

Figure C-5.

Plot

Plot is a hierarchical menu that automatically replots the top graph window with the characteristics displayed in the submenu. The choices for replotting are as follows: Lines, Points, Lines-Points, Lines-Smoothing, Points-Smoothing, and Lines-Points-Smoothing.

Show Format Window

Opens the format window for changing and replotting graphs (fig. C-10).

Show Mouse Window

Opens the mouse window for tracking mouse movement on the graph. The left axis, right axis (if there is one), and time axis will be tracked according to the position of the cursor in the active graph window (fig. C-6).

Figure C-7.

Setup Database

Creates folders and organizes the data files within the folders. When the "Setup" button is clicked, Quickgraph moves Logger data files into appropriate folders. If there is no folder for the data to go into, one is created. Template files created by QuickGraph are also put into a separate folder.

QUICKGRAPH WINDOWS

Figure C-8:

- First window to appear after the splash screen.
- Scans the database for well data files; wells are displayed in the scrolling view in the upper left corner.
- Creates graph descriptions (in the central scrolling view).
- Used to set the original graphing parameters for a set of graphs. Choose from Line, Bar, or PvF graphs; Set bar width; Choose or combine point and line display; Set day and time range.
- Opens windows for selected graphs.

Figure C-9:

- Shows sample output from the application: one well with one pressure and one flow sensor. The plot depicts two lines - flow versus time and pressure versus time.
- Includes the mouse window which shows the current location of the mouse in terms of the graph's local coordinate system.

Figure C-10:

- Used to control an existing graph's parameters.
- Displays the parameters for the graph in the front window.
- Parameters may be changed and the graph may be replotted from this window.

Figure C-11:

- Prepares a database structure by creating appropriate folders for the data files and the graph templates.

Figure C-1.—QuickGraph Apple menu.

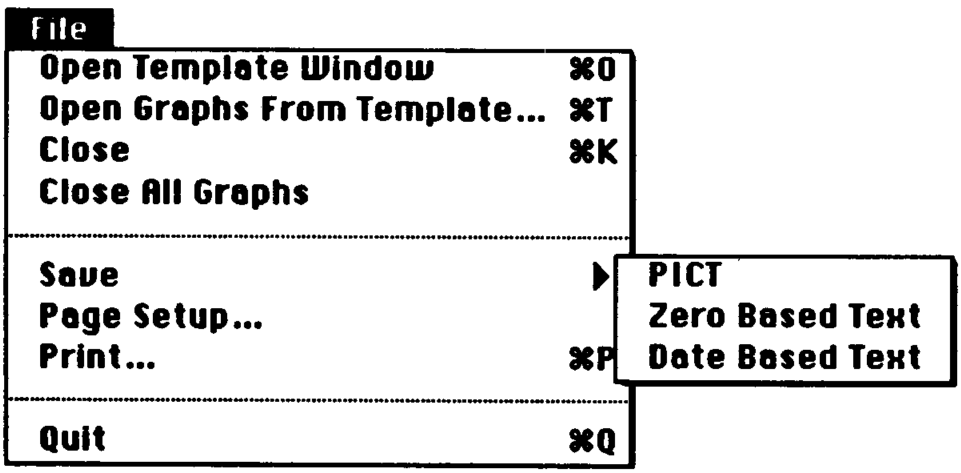

Figure C-2.—QuickGraph file menu.

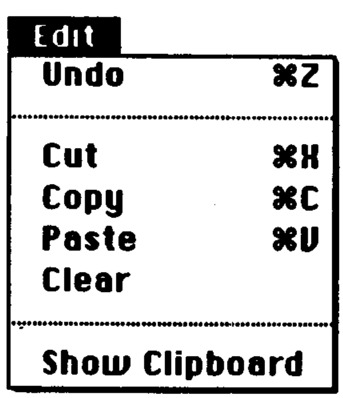

Figure C-3.—QuickGraph edit menu.

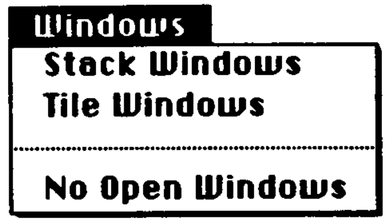

Figure C-4.—QuickGraph windows menu.

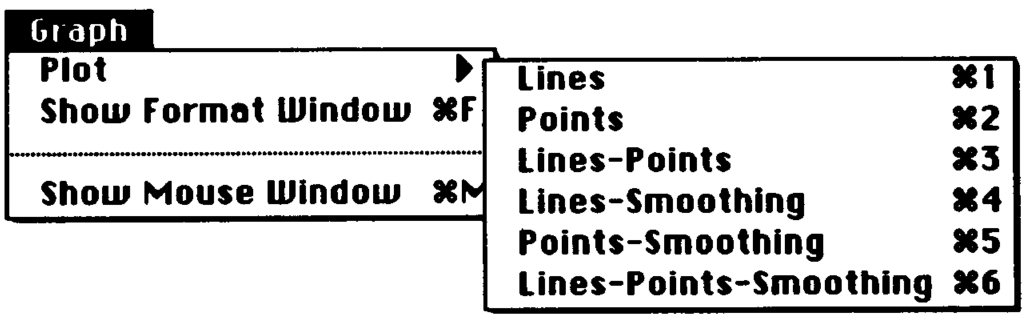

Figure C-5.—QuickGraph graph menu.

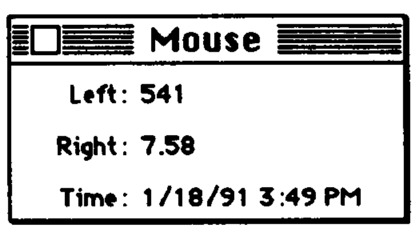

Figure C-6.—QuickGraph mouse window.

Figure C-7.—QuickGraph utilities menu.

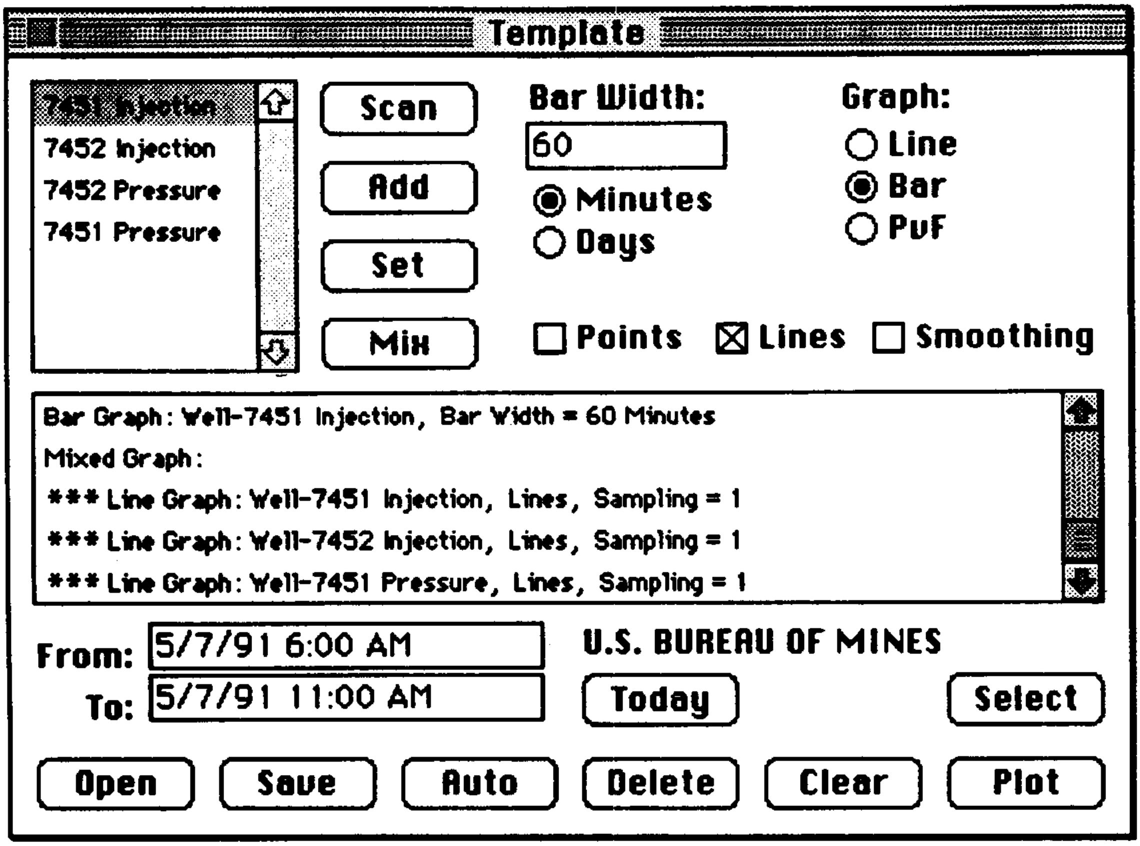

Figure C-8.—QuickGraph template window.

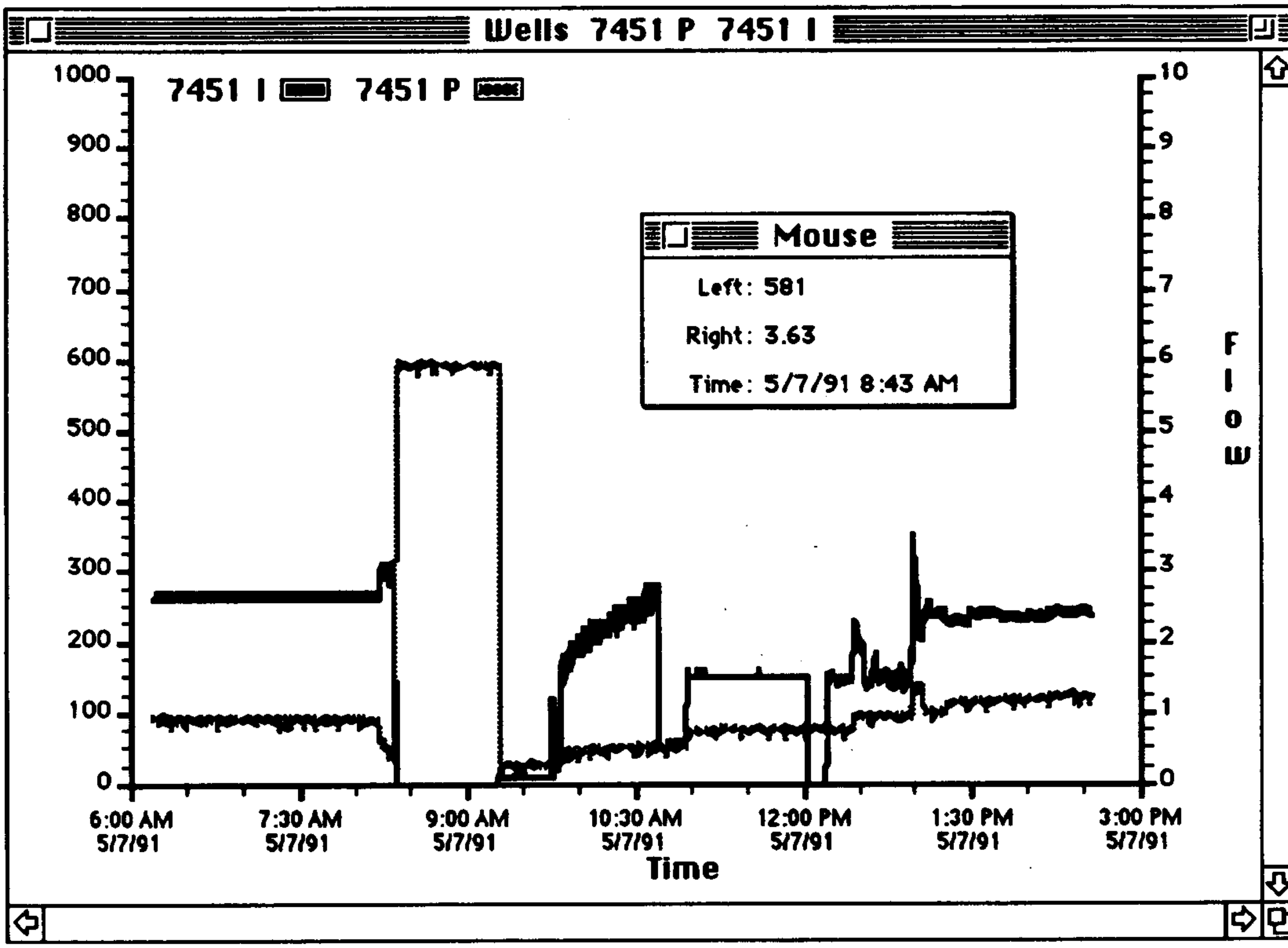

Figure C-9.—QuickGraph plot window.

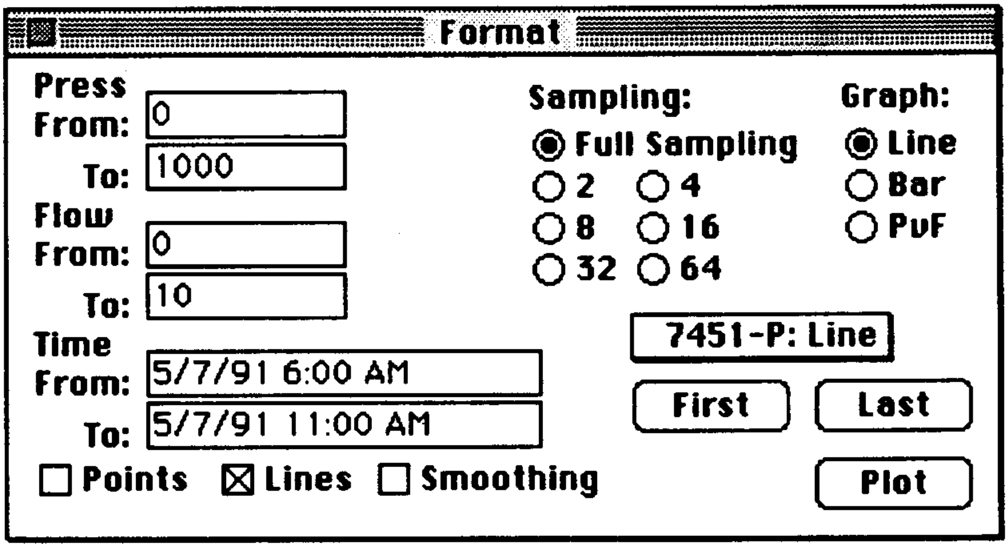

Figure C-10.—QuickGraph format window.

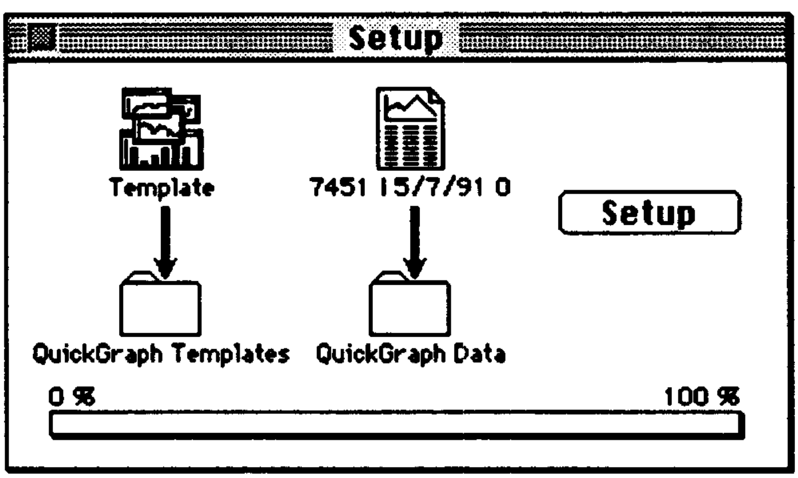

Figure C-11.—QuickGraph set up database window.