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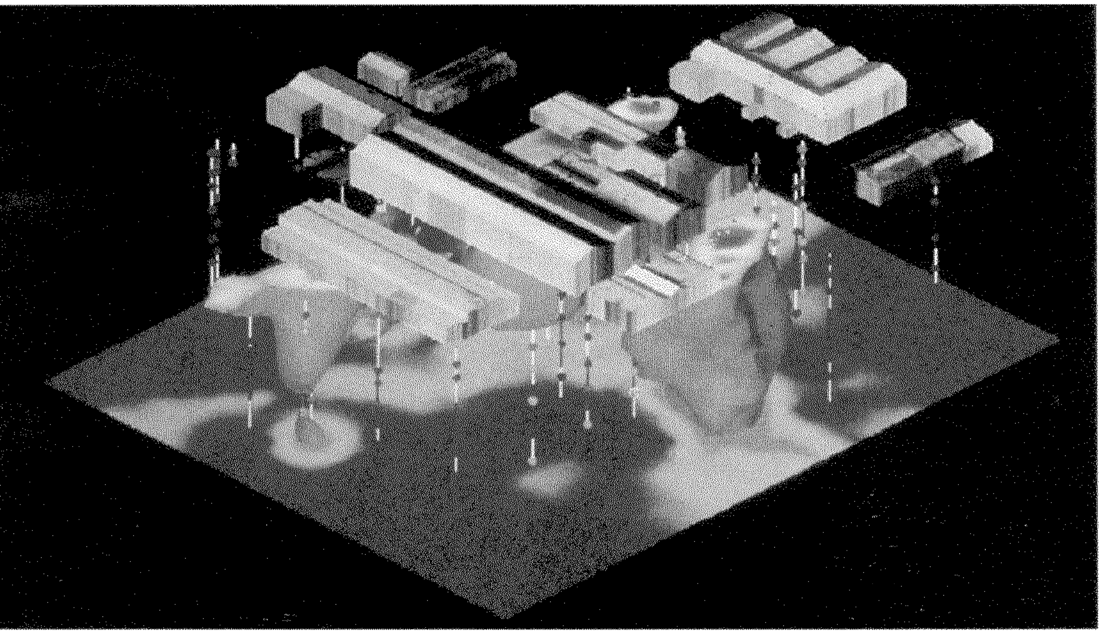
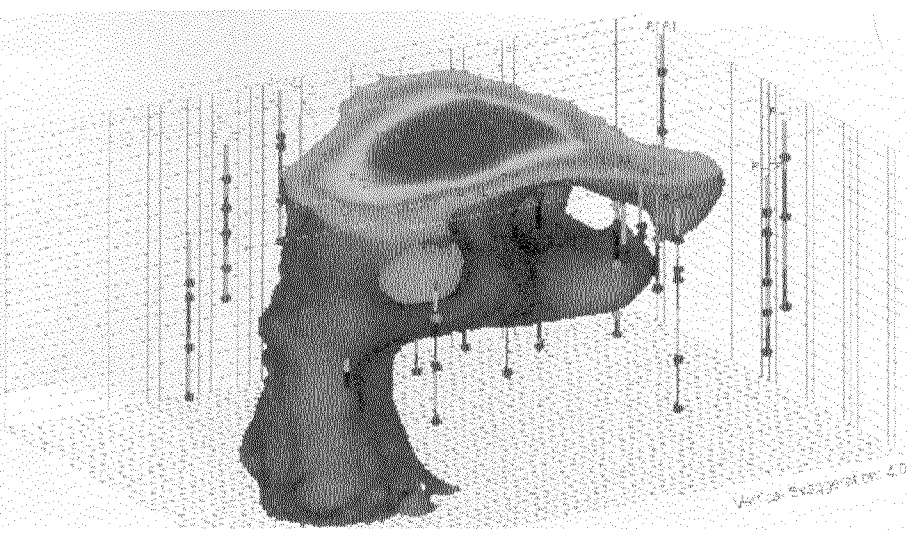
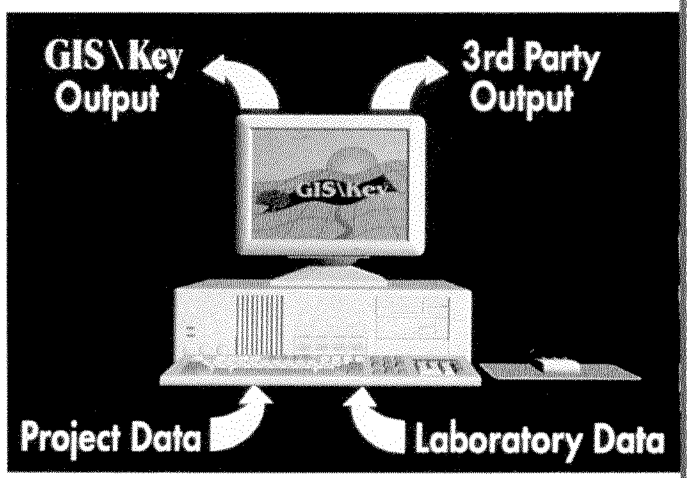
EPA

GIS/Key™ Environmental Data Management System

Innovative Technology Evaluation Report







SITE

SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION

EPA/540/R-94/505
March 1994

GIS\Key™ Environmental Data Management System
INNOVATIVE TECHNOLOGY EVALUATION REPORT

Risk Reduction Engineering Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

NOTICE

The information in this document has been prepared for the U.S. Environmental Protection Agency's (EPA) Superfund Innovative Technology Evaluation (SITE) Program under Contract No. 68-C0-0048. This document has been subjected to EPA's peer and administrative reviews and has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute an endorsement or recommendation for use.

FOREWORD

The Superfund Innovative Technology Evaluation (SITE) Program was authorized by the Superfund Amendments and Reauthorization Act (SARA) of 1986. The program is administered by the EPA Office of Research and Development (ORD). The purpose of the SITE Program is to accelerate the development and use of innovative cleanup technologies applicable to Superfund and other hazardous waste sites. This purpose is accomplished through technology demonstrations designed to provide performance and cost data on selected technologies.

This project consisted of an evaluation under the SITE Program of the GIS\Key™ Environmental Data Management System developed by GIS\Solutions, Inc. The software evaluation was conducted on data typical of a Superfund site. The evaluation provided information on the performance and cost of the software. This Innovative Technology Evaluation Report provides an interpretation of the data and discusses the potential applicability of the software.

A limited number of copies of this report will be available at no charge from EPA's Center for Environmental Research Information, 26 West Martin Luther King Drive, Cincinnati, Ohio, 45268. Requests should include the EPA document number found on the report's front cover. When the limited supply is exhausted, additional copies can be purchased from the National Technical Information Service (NTIS), Ravensworth Building, Springfield, Virginia, 22161, (703) 487-4600. Reference copies will be available at EPA libraries in the Hazardous Waste Collection. You can also call the SITE Clearinghouse hotline at (800) 424-9346 or (202) 382-3000 in Washington, D.C., to inquire about the availability of other reports.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

ADC	American Digital Cartography
ADS	AutoCAD Develop System
ARARs	Applicable Relevant and Appropriate Requirements
ATTIC	Alternative Treatment Technology Information Center
CAS	Chemical Abstracts Service
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CERI	Center for Environmental Research Information
CD ROM	Compact Disc Read Only Memory
DBF	dBASE Database File
DEM	Digital Elevation Model
DLG	Digital Line Graph
DOS	Disk Operating System
DWG	AutoCAD Drawing File
DXF	AutoCAD Drawing Exchange File
ESRI	Environmental System Research Institute, Inc.
FIPS	Federal Information Processing Standard
GIS	Geographic Information Systems
GMS	Geographic Names Information System
GRITS/STATS	Ground Water Information Tracking System/Statistics
ITER	Innovative Technology Evaluation Report
ITIR	Informal Technical Information Report
mg/l	Milligrams per liter
NBS	National Bureau of Standards (now NIST - National Institutes of Standards and Technology)
NPDES	National Pollutant Discharge Elimination System.
ORD	Office of Research and Development
OSC	Onsite Coordinator

OSWER	Office of Solid Waste and Emergency Response
PC	Personal Computer
QA/QC	Quality Assurance/Quality Control
RCL	Reporting Constituent List
RCRA	Resource Conservation and Recovery Act
RD/RA	Remedial Design/Remedial Action
RI/FS	Remedial Investigation/Feasibility Study
RMS	Root Mean Square
RPM	Remedial Project Manager
SITE	Superfund Innovative Technology Evaluation
SARA	Superfund Amendments and Reauthorization Act
SQL	Structured English Query Language
TCL	Template Constituent List
TCLP	Toxicity Characteristic Leaching Procedure
TIN	Triangulated Irregular Network
TPM	Technical Project Manager
TSCA	Toxic Substances Control Act
TSD	Treatment, Storage, and Disposal
	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
VGA	Variable Graphics Array
VISIT-I	Vendor Information System for Innovative Treatment Technologies

ACKNOWLEDGMENTS

This report was prepared under the direction and coordination of Mr. Richard Eilers, Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) Program Manager in the Risk Reduction Engineering Laboratory (RREL), Cincinnati, Ohio. EPA-RREL contributors and reviewers for this report were Dr. Ronald F. Lewis, Mr. Randy A. Parker, Mr. Gordon M. Evans, and Mr. Robert L. Stenburg. Other contributors and reviewers were Mr. Gary W. Reid and Mr. Charles Tupitza of GIS\Solutions, Inc

This report was prepared for EPA's SITE Program by the Technology Evaluation Division of Science Applications International Corporation (SAIC) in Cincinnati, Ohio under Contract No. 68-C0-0048. The evaluation of GIS\Key™ was performed by Dr. William B. Samuels and Mr. David Abercombie. Mr. Neal Panken served as the QA/QC Officer. Ms. Evelyn Meagher-Hartzell wrote the report with assistance from the individuals listed above. The Work Assignment Manager for the project was Mr. Clyde Dial.

EXECUTIVE SUMMARY

The GIS\Key™ Environmental Data Management System was selected for SITE Program testing to assess its ability to provide useful and effective information to aid in site investigations and remedial activities. GIS\Key™ is an integrated system for the management of chemical, geologic, and hydrologic data developed by GIS\Solutions, Inc. of Concord, California. During the evaluation, emphasis was placed on evaluating the system's performance with respect to ease of use, system requirements, personnel requirements, data entry and database creating procedures, data integrity procedures, and electronic data exchange capabilities.

This SITE project is a departure from the normal type of evaluation in that it involves a data management system, not a hardware system. Two Visitor's Days were held: in San Francisco and in Washington DC. During each Visitor's Day the software was demonstrated and third-party vendors explained and demonstrated how their software related to GIS\Key™.

This environmental data management system has been used at a number of sites including NASA's Moffett Field and King Samosa AFB, Alaska.

The evaluation found that GIS\Key™ is an effective way to prepare the wide variety of maps, graphs, tables, sections, and logs required at a typical hazardous waste site. These products were generated with relative ease. Because of the open architecture of GIS\Key™ and its use of commercial off-the-shelf products (i.e., AutoCAD graphics and FoxBASE database), numerous third-party database tools are available to perform queries and to create report formats not included with GIS\Key™. The system can be a cost-effective, time-saving method for managing large volumes of environmental data. A number of issues relating to the general usability of GIS\Key™ were addressed during the generation of the various GIS\Key™ products. The following functions and capabilities were assessed:

- New Project Setup: It was relatively easy to set up a new project, a project directory structure, and a project basemap during the evaluation. However, since all the project directories must be on the same drive as the GIS\Key™ directory, mass storage difficulties can arise as project files grow.

- Map Management: Standard AutoCAD drawing files are used for all GIS\Key™ basemaps. The utilities provided for the addition and editing of map symbols were tested and no problems were encountered. During the generation of the project basemap, the basemap and symbols were digitized using two methods. Satisfactory accuracy of the coordinates of map symbols was obtained.

- Data Entrv Screens: Data entry screens are available for geological, chemical, and hydrogeological data processed by GIS\Key™. These screens provide several time-saving features, including dynamic look-up lists and quick return to the most recent item accessed. Defaults are provided by GIS\Key™ for several fields, simplifying the entry of sequential data. Online help is not available during data entry.

- Data Import Routines: Electronic import routines allow the input of data in a wide range of formats. A utility routine called GIS\Build allows laboratory data to be downloaded into GIS\Key™. An instruction set to guide the labs in preparing the import file for GIS\Build is available from GIS\Solutions. The utility routine and instruction set were not evaluated.

- Data Integrity Checks: GIS\Key™ performs some data quality checks for consistency and reasonableness as part of the data entry screens and data import routines on all key fields and selected attribute fields. Third-party data management tools are needed to prepare data files for GIS\Key™ import routines and for data integrity checks beyond those included with GIS\Key™. The system tracks the significant figures of all chemical concentrations and reporting limits.

- Data Validation: GIS\Key™ can be used to compare QA/QC laboratory results to user-defined QC objectives. Reports are automatically generated outlining exceptions to project data quality objectives. Built-in routines are available to: identify chemical concentrations that fall outside historical ranges; identify concentrations in excess of action levels; check ionic balances, and compare QC results against QC objectives for method and field blanks, duplicates, splits, matrix spikes, control samples, surrogates, and holding times. Seven data validation fields are available to store data qualifiers reported by the lab or assigned by the user.

- Data Queries: The ability of GIS\Key™ to query data is one of the most powerful and often-used tools available to the user. Data queries are prompt-driven; therefore knowledge of a data query language is not required. The software conducts queries in such a manner that product quality and accuracy are maintained. GIS\Key™ is capable of performing both spatial and non-spatial queries, GIS\Key™ spatial data retrieval capabilities are provided by AutoCAD. GIS\Key™ supplements AutoCAD spatial data selection using "symbol lists," which are user-defined subsets of frequently used sample locations that can be grouped together and retrieved by name.

- Contouring: Contouring geology, hydrology, and chemistry data is carried out by QuickSurf, a third-party software package that is integrated with GIS\Key™ Version 2.91 of QuickSurf was evaluated as part of this demonstration. This version works well for surfaces that are continuous with respect to slope and curvature (first and second derivatives), but it cannot accurately represent surfaces which contain breaks or faults. A number of structure maps were successfully constructed to test the effect of editing posted values and adding contour control points.

- Calculations: During the entry of flow rate, fluid level, and QC data, GIS\KeyTM automatically performs specific calculations (average flow rate, cumulative flow, spike percent recoveries, and matrix spike duplicate relative percent differences). GIS\KeyTM calculates areas, perimeters, and lengths using standard AutoCAD commands. Volume calculations are supported through QuickSurf. Advanced statistical functions are also available by exporting data to the EPA Groundwater Information Tracking System/Statistics (GRITS/STAT) program. This capability of GIS\KeyTM was not evaluated as part of the demonstration.

- Products: GIS\KeyTM provides an effective way to produce contour maps, tabular chemistry reports, geology tables, hydrogeologic tables, geologic logs, and chemistry and hydrogeology graphs. Standard formats are available from the software; however, it can be custom tailored by GIS\Solutions staff or by the user through third-party software. The products produced by the system are of high quality.

- Hardware Configurations: GIS\KeyTM performs its functions on standard PC class systems in the DOS environment. When using the recommended hardware proposed by GIS\Solutions, the system works more effectively. Separate GIS\KeyTM modules for data entry only may be used to optimize the capital costs for large projects.

- Project Planning: One real challenge at any site is associated with determining how to manage the data being generated. Through proper project planning, GIS\KeyTM can be used to define codes and lists to categorize project data (sampling events, preparation fractions, program types) for storage and retrieval. GIS\KeyTM uses this information to organize or group related data and to simplify data entry. With a good data management perspective and the use of third-party software, these codes can be managed to avoid update and query anomalies.

- Training: Users can obtain basic and advanced training. Training covers AutoCAD and a detailed walk-through of GIS\Key™ capabilities. Users are guided through the creation of GIS\Key™ outputs. The training is well presented but needs additional emphasis on project planning and setup.

- Documentation and Support Services: The User Guide is well-prepared and covers the system's modules and activities. It does not represent in all cases the changes that occured as new versions of software were incorporated into GIS\Key™. The call-in support offered was readily available and of great help in understanding issues.

The benefits and limitations that were determined during the evaluation of the software are:

Benefits

GIS\Key™ does not require specialized computer skills to use its powerful and comprehensive data management capabilities. GIS\Key™ includes menu-driven routines that simplify complex tasks such as generating contours, adding title blocks to maps, and reviewing QC results. Advanced database and AutoCAD skills are not needed for routine use of GIS\Key™. Geologists and engineers can analyze data and produce reports directly; these individuals are typically more knowledgeable about site conditions than staff computer programmers. GIS\Key™ encourages interactive data analysis. Since contours and cross sections are easy to generate, users are able to refine their analyses. Assumptions, views, and queries can be modified, and alternative views of the data are produced in little time. GIS\Key™ enhances the ability to perform a thorough exploration of site information,

The open, nonproprietary nature of GIS\Key™ and use of industry standard DBF files greatly simplify and encourage the use of third-party tools to query data and produce custom-made reporting formats.

GIS\Key™ has a comprehensive scope: it includes chemistry, geology, and hydrology modules. The chemistry module includes review of QC parameters and checks against historical ranges. The geology module includes lithology, user-defined formations, and blow counts. The hydrology module includes derived aquifer parameters such as vertical and horizontal permeability. GIS\Key™ is a turnkey environmental data management system.

GIS\Key™ stores information in a unified database that provides several validity and consistency checks. To use the system, users must manage and improve project data quality. For example, sample results must be associated with a sample location before they can be entered into GIS\Key™. Also, each sample location must have a single location in X-Y-Z space. GIS\Key™ enforces many data integrity rules, so its use can improve overall project data quality.

GIS\Key™ relates data across data categories, improving report and map consistency. For example, monitoring well measuring point elevation is entered once for each well during well construction data entry. This single value will be used for all groundwater contour maps, well logs, cross sections, and tables,

GIS\Key™ reviews chemical laboratory QC data and generates exception reports. Also, sample locations that provided samples which fail to meet QC objectives are indicated visually to the user (i.e., they flash red). This feature helps the user to avoid using suspect data in maps and reports.

GIS\Key™ provides a predefined database design that can be used in other contexts. This could be very beneficial to users that currently do not have a comprehensive environmental database design.

GIS\Key™ provides several reference lists, including a list of regulatory thresholds (with references) and a list of chemical names, aliases, CAS registry numbers, and test methods. These tables are used internally by GIS\Key™, but they can be used independently. For example, the registry numbers supplied by the chemical laboratory can be compared to the GIS\Key™ list to verify their accuracy.

GIS\Key™ produces presentation quality graphics. The tables generated by GIS\Key™ are designed to be included directly into reports. The maps, sections and well logs require little editing before submittal. GIS\Key™ provides a wide variety of output formats, and menu selections automate output production.

GIS\Solutions, the developers of GIS\Key™, provide excellent technical support, and they operate a bulletin board to facilitate exchange of files. Callers are typically put through to the system programmers, so detailed and responsive help is available to solve any problem.

GIS\Key™ uses industry standard file formats for data storage (DXF, DWG and DBF). Knowledgeable users can readily exchange GIS\Key™ data with other applications. Third party graphics tools can be used to modify or enhance GIS\Key™ graphic output.

GIS\Key™ uses AutoCAD for its graphic capabilities. AutoCAD provides very powerful and complete graphic editing capabilities. AutoCAD graphics are well suited to the scientific and engineering environment in which GIS\Key™ is typically used. Many potential users of GIS\Key™ are already familiar with AutoCAD, thus reducing training costs.

Overall, GIS\Key™ is very efficient. Many predefined routines and queries are included. For example, a well log can be produced from the GIS\Key™ database with selection of a few menu options:

GIS\Key^{TM} automatically performs the tedious data retrieval and standard log preparation steps. GIS\Key^{TM} eliminates much duplication of effort. For example, borehole lithology must be entered only once; these data will be reused for subsequent borehole logs, cross sections, and structure maps. An attribute of the system is the speed at which queries and postings can be made.

GIS\Key^{TM} runs on standard DOS PCs and on local area networks. More expensive workstations and operating system software is not required. Many potential users of GIS\Key^{TM} already own the necessary hardware.

Data management costs can be reduced using the GIS\Key^{TM} software, especially by using it on multiple projects.

GIS\Key^{TM} has a modular design. Stand-alone data entry modules can be purchased separately.

Limitations

Some specialized AutoCAD and database management system skills, beyond those required to use GIS\Key^{TM} itself, are needed to make full use of GIS\Key^{TM}. Additional expertise is needed to manage electronic data transfer or to correct major system crashes.

GIS\Key^{TM} enforcement of database integrity could be improved. It is relatively easy to enter invalid or inconsistent data. For example, GIS\Key^{TM} allows the user to enter a sample depth greater than the total borehole depth. It is also possible to enter or edit data that will cause query anomalies. It is possible to enter sampling results for a date outside existing “sampling events;” such results cannot be posted on the site map using the predefined query.

GIS\Key^{TM} enforcement of basemap integrity is limited. Improper use of certain AutoCAD commands can cause a major problem. For example, the “handles off” command will destroy the links between the map and the database. Also, sample locations can be deleted using the AutoCAD “erase” command, creating inconsistencies between the map and the database.

Third party tools are needed for ad hoc queries. For example, after sample locations have been selected, a predefined GIS\Key^{TM} query is available to display the concentrations of a specific chemical measured within a specific time interval. However, it is not possible to query for the maximum concentration of a specific chemical ever measured at the site.

The GIS\Key^{TM} database structure is incompletely documented. The developer will supply a listing of the physical schema, but relationships, key rules, domain rules, and triggering operations are not documented. This lack of documentation limits usefulness of electronic data transfer.

Flexibility of printed report format and appearance is limited under GIS\Key^{TM}. The user can select the subset of chemicals that will be printed, but cannot choose the location of the date on the printed page. No general report-writing capabilities are provided. However, ASCII option outputs are offered for all tables, allowing the user to custom design tables using a familiar spreadsheet program such as Lotus, Excel, or Quattro.

GIS\Key^{TM} has three spatial entity selection techniques. AutoCAD individual entity selection, AutoCAD rectangular selection windows, and manually created GIS\Key^{TM} "symbol lists." Circles, irregular shapes, and spatial operators cannot be used for sample location selection. For example, GIS\Key^{TM} cannot automatically select all wells within 1,000 feet of a stream, nor automatically select all soil borings within a 500-foot radius of a given well. Sample locations meeting these criteria would need to be selected manually. GIS\Key^{TM} does not support general GIS spatial analysis operators. Although polygons can be created using the AutoCAD graphics capabilities, polygon operations are not available. For example, GIS\Key^{TM} cannot determine which wells are located within the intersection of two arbitrary polygons,

The GIS\Key^{TM} database has certain inherent limits. Only a limited amount of location information (i.e., SITE-ID, symbol lists only) can be stored. Work-arounds may be needed if a site is divided into several areas and subareas. GIS\Key^{TM} imposes certain limits on well construction and log information that can be stored (e.g., maximum of five screen intervals). Certain QA/QC data cannot be stored in the GIS\Key^{TM} database; these include 2nd column confirmations and QC data pertaining to other QC data (e.g., surrogate results of blanks).

GIS\Key™ is limited to post-project data analysis only; no planning capabilities are provided. No tools or forms are provided that would allow data gathering in a manner that would optimize input into GIS\Key™ at a later date.

GIS\Key™ does not include audit or transaction logging capabilities. If an error occurs, it is not possible to roll back the database to a previous known and verified state. Also, it is not possible to store rationales nor dates of changes to the database or map. GIS\Key™ does provide a very limited “audit trail” command for contouring data. However, this information is stored in plain ASCII text files, so use of this feature requires the user to develop additional auditing techniques outside of GIS\Key™ to maintain and track these files.

The ease of use of the data entry screens is limited. Users accustomed to modern graphical, "Windows"-like dialog boxes may feel uncomfortable with the GIS\Key™ text-based screens.

GIS\Key™ has certain limitations related to DOS. For example, the user can individually examine the map (in AutoCAD) or the database (in FoxBASE), but cannot view both simultaneously. Also, DOS filename limitations may require use of valid DOS filenames for sample locations that have textual lithology data.

GIS\Key™ stores only limited meta-data. For example, it is not possible to store sample location data source information.

Site data related to ecological assessments and air emissions is not managed by this software.

SECTION 1
INTRODUCTION

This section provides background information regarding the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) Program, discusses the purpose of this Innovative Technology Evaluation Report, and describes the GIS\Key™ Environmental Data Management System developed by GIS\Solutions, Inc. (GIS\Solutions). Additional information about the SITE Program, this software, and the evaluation process can be obtained from the contacts listed at the end of this section.

1.1 Background

The GIS\Key™ Environmental Data Management System was selected for SITE testing to assess its ability to provide useful and effective information to aid in site investigations, remediation activities, and reporting on those activities. This system, which is compatible with 386 and 486 personal computers (PCs) using Disk Operating System (DOS), facilitates the collection, reporting, and analysis of site management data. The GIS\Key™ Software System can produce geologic cross sections, boring logs, potentiomehic maps, isopleth maps, structure maps, summary tables, hydrographs, chemical time series graphs, tables, and other maps and line graphs meeting Resource Conservation and Recovery Act (RCRA) and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) reporting requirements. According to the developer, built in checks are provided to ensure the quality of the data. Checks include comprehensive quality assurance/quality control (QA/QC) protocols.

Any AutoCAD compatible digital basemaps can be imported into GIS\Key™. There are a number of vendors who can provide general basemap data, usually based on the U.S. Geologic Survey (USGS) 7.5-minute quadrangle maps. Additionally, users usually import specific project map data (i.e., RCRA facility and CERCLA sites), which provide greater detail and resolution necessary for comprehensive studies. With GIS\Key™, users add graphic points representing wells, borings, and sampling locations on to this basemap. GIS\Key™ provides the ability for one-time entry and verification of the chemical, geologic, or hydrologic information. GIS\Key™ “ties” this information to specific wells placed on the basemap.

1.2 Brief Description of Program and Reports

In 1986, EPA's Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) established the SITE Program to promote the development and use of innovative technologies to clean up Superfund sites across the country. Now in its eighth year, the SITE Program is helping to provide the treatment technologies necessary to implement new Federal and state cleanup standards aimed at permanent remedies rather than quick fixes. The SITE Program is composed of four major elements : the Demonstration Program, the Emerging Technologies Program, the Measurement and Monitoring Technologies Program, and the Technology Transfer Program. These programs are briefly discussed below.

The major focus has been on the Demonstration Program, which is designed to provide engineering and cost data for selected treatment technologies. To date, the Demonstration Program projects have not involved funding for technology developers. EPA and developers participating in the program share the cost of the demonstration. During treatment technology demonstrations, developers are responsible for demonstrating their innovative systems at chosen sites, usually Superfund sites. EPA is responsible for sampling, analyzing, and evaluating all test results. The final product of each demonstration is an assessment of the treatment technology's performance, reliability, and cost. This information is used in conjunction with other data to select the most appropriate treatment technologies for the cleanup of Superfund sites

Recently, however, the Demonstration Program expanded its scope to include the evaluation of innovative technologies or systems used to support remedial activities. These "support" systems may be used to help Remedial Project Managers (RPMs) evaluate treatment alternatives during the Remedial Investigation/Feasibility Study (RI/FS) and Remedial Design/Remedial Actio n (RD/RA) phases. The GIS\Key TM software falls within this program category. Like remedial technology demonstrations, the final product of a support system evaluation is an assessment of the system's performance, reliability, and cost.

Developers of both treatment technologies and support systems apply to the Demonstration Program by responding to EPA's annual solicitation. EPA also accepts proposals for treatment technology demonstrations any time a developer has a Superfund waste treatment project scheduled. To qualify for the program, a new technology must be available as a pilot- or full-scale system and offer some advantage over existing technologies. Mobile treatment technologies are of particular interest to EPA.

Once EPA has accepted a proposal, EPA and the developer work with the EPA regional offices and state agencies to identify a site containing waste suitable for testing the capabilities of the technology. However, since GIS\Key™ is used to manage and analyze site data, EPA and developer efforts were instead directed toward generating a data set that could be used to test the unit's effectiveness.

During the demonstration of a treatment technology, EPA prepares a detailed sampling and analysis plan designed to evaluate the technology thoroughly and to ensure that the resulting data are reliable. The duration of a demonstration varies from a few days to several years, depending on the type of technology and the quantity of waste needed to assess the technology. A similar process and time-frame applies to the evaluation of a support system. However, durin the GIS\Key™ evaluation, instead of developing a detailed sampling and analysis plan, emphasis was placed on developing evaluation criteria that would thoroughly test the software's performance.

Results of the SITE Demonstration evaluations are published in two documents: the ITER and the SITE Technology Capsule. The ITER provides a comprehensive description of the evaluation and its results. The SITE Technology Capsule is a concise summary of the ITER. Both the SITE Technology Capsule and the ITER are intended for us by RPMs and others who are making a detailed evaluation of the technology for a specific site and waste. The GIS\Key™ ITER includes information on cost, performance, implementation problems/limitations, and an evaluation of the software in relation to RCRA and CERCLA reporting requirements during the RI/FS and RD/RA processes. The ITER also describes the evaluation, the developer's experience prior to the evaluation and the flexibility of the software. The purpose of this ITER is described in greater detail in the following subsection.

The second component of the SITE Program is the Emerging Technologies Program, which fosters the investigation and development of treatment technologies that are still at the laboratory scale. Successful validation of these technologies can lead to the development of a system ready for field demonstration and participation in the Demonstration Program. The Measurement and Monitoring Technologies Program, the third component of the SITE Program, provides assistance in the development and demonstration of innovative techniques that better characterize Superfund sites. The fourth component of the

SITE Program is the Technology Transfer Program, which reports and distributes the results of both Demonstration Program and Emerging Technology studies through ITERs and SITE Technology Capsule reports. Abbreviated bulletins are issued to inform the public of SITE project completion.

1.3 Purpose of the ITER

This ITER provides information on the GIS\Key™ Environmental Data Management System, including a comprehensive description of the evaluation and its results. The ITER is intended for use by EPA RPMs, on-scene coordinators (OSCs), contractors, and others involved in the remediation decision-making process and in the implementation of specific remedial actions. The ITER is designed to aid decision makers in determining whether this specific software warrants further consideration as an aid in data management during investigation and cleanup operations. To encourage the general use of evaluated software, EPA provides information regarding applicability of the software to a generalized set of site data and the type of reporting products and data management techniques provided by the software. The ITER includes information on cost and application of the software. It also discusses advantages, disadvantages, and limitations of the software. This report is a critical step in the development and commercialization of the GIS\Key™ Environmental Data Management System.

This software evaluation examines the performance of the software in managing data typical of a Superfund site. The data reporting requirements of other sites may differ from the generalized requirements evaluated in this project. Successful evaluation of the software for one set of data does not necessarily ensure applicability at other sites. Only general conclusions relating to data reporting can be drawn from this GIS\Key™ Environmental Data Management System evaluation. Site- and project-specific conditions restrict the conclusions drawn from the SITE evaluation of a support system such as GIS\Key™.

1.4 Technology Description

GIS\Key™ is a comprehensive environmental database management system designed to meet the needs of industry and to satisfy RCRA and CERCLA reporting requirements. GIS\Key™ is a custom developed software system that uses several commercial off-the-shelf products (e.g., AutoCAD, FoxBASE, and QuickSurf) to produce a variety of site-specific tables, graphs, and maps, thereby facilitating the collection, reporting, and analysis of site management data. GIS\Key™ and its associated third-party software components can be installed and used on 386 and 486 personal computers (DOS).

Environmental data for a project — chemical, geological, and hydrological — is stored in the GIS\Key^{TM} Database, which is a relational data management application implemented in FoxBASE. The database is tied to the graphical component, GIS\Key^{TM} Graphics, which is built into AutoCAD. The GIS\Key^{TM} graphical interface depicts wells and boreholes on a map of the site. The user chooses a report from a menu, picks a location from the map, and then follows the prompts to create a variety of output. GIS\Key^{TM} can prepare geologic cross sections, boring logs, potentiometric maps, isopleth maps, structure maps, summary tables, hyrodrographs, chemical time series graphs, and numerous other maps and line graphs. QuickSurf (Version 2.91), a third-party contouring program developed by Schrieber Instruments, is used to contour geology, hydrology, and chemistry data stored in GIS\Key^{TM} Database. The GIS\Key^{TM} Database Menu Structure is shown in Figure 1. The GIS\Key^{TM} Graphic Menu Structure is shown in Figure 2. These figures provide an overview of the types of procedures used and products available through GIS\Key^{TM} Software.

Digitized regional basemaps, typically USGS 7.5-minute quadrangle maps, provide the background basemap for the GIS\Key^{TM} data management system. Project maps (i.e., RCRA facilities and CERCLA sites) are stored inside the regional basemaps and act as the visual starting points from which users can obtain specific chemical, geologic, and hydrologic data for each well location. During the generation of a project map, GIS\Key^{TM} symbols representing wells, borings, and other sampling locations are placed on the basemap. The data for each map point is related by location, media, sample number, date, and depth. The geographic organization of information allows data to be displayed as discrete points on the map.

Data can be entered into the GIS\Key^{TM} Database either manually or electronically. Existing databases can be converted into GIS\Key^{TM} format, and laboratory reports on magnetic media can be directly imported. Pull-down menus, data entry forms, and look-up lists for frequently used values aid manual data entry. The lists store such information as EPA test methods, practical quantification limits, Chemical Abstract Service (CAS) numbers, chemical aliases, and regulatory threshold values for over 3,500 chemicals.

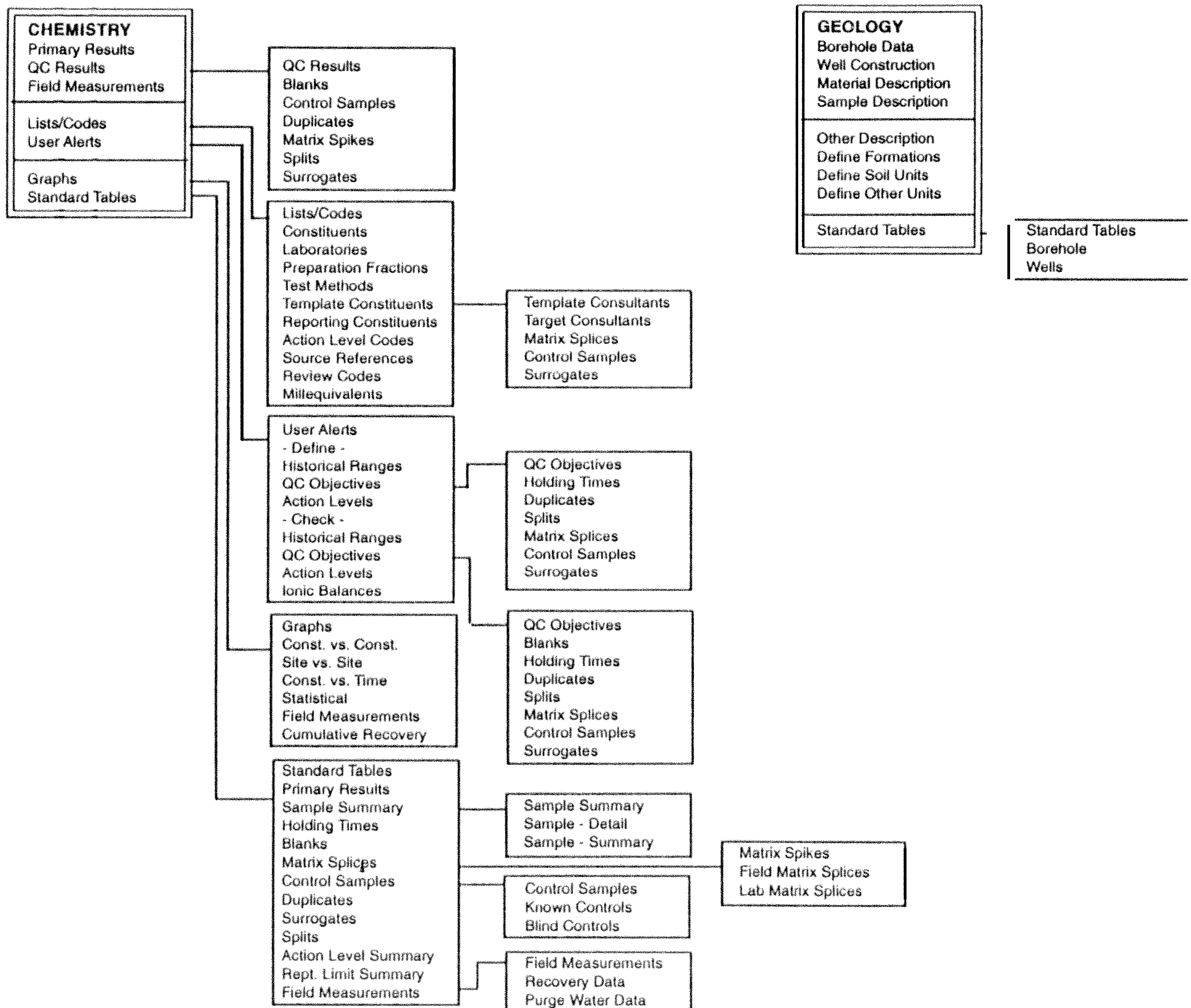


Figure 1. GIS\Key™ database menu structure.

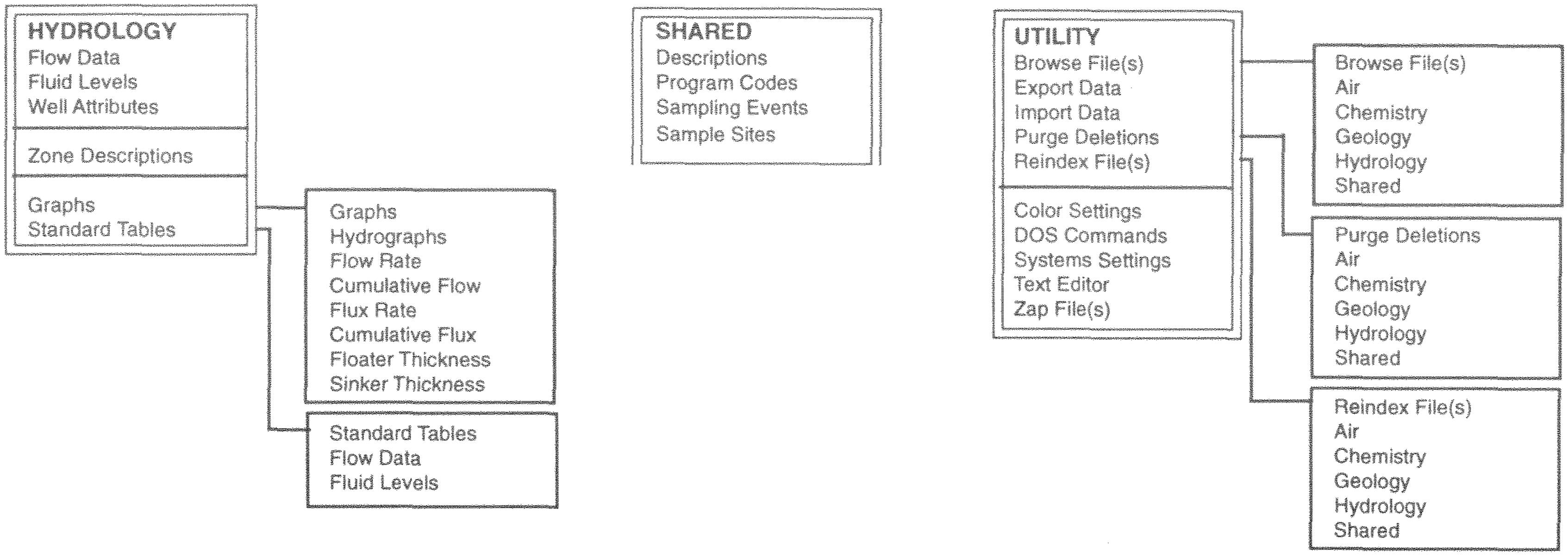


Figure 1. GIS\Key™ database menu structure (continued).

GIS\FILE	GIS\CHEM	GIS\GEO	GIS\HYDRO	QuickSurf	UTILITIES
AutoCAD Menu	Graphs	Logs...	Graphs...	Extract Plines	Site Map Symbols...
GIS\Key Database Menu	Maps-Water Isopleths...	Maps-Structure...	Maps-Fluid Level...	Set Options	Ground Control...
Shell to DOS	Maps-Soil Isopleths...	Maps-Isopleths...	Maps-Horizontal Conductivity...	Run QuickSurf	Archive Grid(s)
Text Editor One	Sections-Soil Isopleths...	Sections...	Maps-Specific Storage...	Label Contours	Rotate Camera
Text Editor Two	Tables-User Alerts...	GIS\Help		Smooth	Views...
Save to Path	GIS\Help			Hatchure	Title Block and Border...
Save				Volume	Symbol Lists...
End				3-D View	Modify Layers
Quit					GIS\Help
Plot					
Printer Plot					
GIS\Help					

Figure 2. GIS\Key™ graphics menu structure.

GIS\Key™ includes features that help the user identify erroneous or questionable data. Data validation routines include graphical display of summary statistics and user alerts when QA/QC results fall outside data quality objectives, sample results fall outside historical ranges, sample results exceed applicable regulatory standards, and ionic balances fall outside data quality objectives.

The following is a brief description of the types of products that are available through the GIS\Key™ software. A list of GIS\Key™ chemical, geologic, and hydrologic products that GIS\Key™ provides is shown in Table 1.

1.4.1 Boring Logs

GIS\Key™ generates well logs and boring logs that use graphical patterns to depict soil types and details of well construction. The log reproduces the field geologist's written description of soils encountered during drilling. Graphic log formats can be designed to customer specifications.

1.4.2 Structure Maps

GIS\Key™ can create contour maps for structural interfaces based on soil unit, geologic formation, blow counts, or user-defined flags. Structural elevation is stored in the GIS\Key™ Database. These elevations are used to generate contour lines, and the result is stored as a three-dimensional grid. A feature of GIS\Key™ is that any type of contoured structural information, such as top and bottom water-bearing units or equilibrium water levels, can be stored as a three-dimensional grid. GIS\Key™ integrates this grid information into geologic cross section routines, allowing the user to visualize the structural interfaces along any cross section line.

1.4.3 Geologic Cross Sections

Cross sections show selected wells and borings along with the soil units encountered in each. Sections can include structural information such as the ground surface layer, water-bearing zones, or any other surface that has been contoured and saved as a three-dimensional grid.

1.4.4 Isopleth Maps

Isopleth maps depict areas of equal chemical concentrations in soil or water samples. GIS\Key™ can generate isopleths in plan view and section view. Isopleths are represented as contours drawn on either a linear or a logarithmic scale. An isopleth map is based on the media, sample locations, chemical(s), and time period.

Table 1. GIS\Key^{TM} Products

Chemistry	Geology	Hydrology
Isopleth maps of soil or water quality-plan section view	Boring logs with company logos	Density-corrected water level contour maps
Chemical concentration time series graphs	Geologic cross section maps	Floating product contour maps
Chemical versus chemical graphs, inter- and intra-well	Isopach maps	Hydraulic conductivity contour maps
Trilinear Piper diagrams	Structure maps	Water elevation versus time graphs
Chemical concentration versus distance graphs	Presentation-quality data tables	Floating product thickness versus time graphs
Presentation-quality data tables		Extraction well graphs .flow versus time *concentration versus time • chemical flux versus time
		Presentation-quality data tables

1.4.5 Chemistry and Hydrology Graphs

GIS\Key^{TM} makes available a number of different types of graphs for displaying chemical constituents and hydrologic properties. The GIS\Chem Menu displays the concentrations of one or more constituents over time, correlating the concentrations of two chemicals at the same sampling station, comparing concentrations at two different sites, showing variation in concentration at different distances from a sampling site, generating trilinear Piper diagrams, and displaying a variety of statistical parameters.

Under the GIS\Hydro Menu, hydrographs or flux graphs can be plotted. To create a graph, the type of graph is chosen, and then GIS\Key^{TM} guides the user through a series of well selections and prompts. For example, to prepare a chemical time series graph, the user selects the time period, chemicals of interest, and default values for concentrations less than the detection limit (zero, one-half, or full detection limit). Either individual or total chemical concentrations are displayed on the graph.

1.4.6 Tabular Reports

Over 100 tabular reporting formats for chemical test results are available within GIS\Key^{TM}. Format options include landscape or portrait views, display of chemicals across the top or side, presentation of data validation qualifiers, and listing of only those chemicals with detectable levels in one or more sample sites. Tabular data displays are of presentation quality.

1.5 Key Contacts

For more information on the demonstration of the GIS\Key^{TM} Environmental Data Management System technology, please contact:

1. EPA Project Manager for the SITE software evaluation:

   Mr. Richard Eilers
   U.S. Environmental Protection Agency
   Risk Reduction Engineering Laboratory
   26 West Martin Luther King Drive
   Cincinnati, Ohio 45268
   (513) 569-7809

2. Software Vendor:

   Mr. Garry Reid
   GIS\Solutions, Inc.
   1800 Sutter Street, Suite 830
   Concord, CA 94520
   (510) 827-5400, Ext. 208

Information on the SITE Program is also available through the following online information clearinghouses:

- The Alternative Treatment Technology Information Center (ATTIC) is a comprehensive, automated information retrieval system that integrates data on hazardous waste treatment technologies into a centralized, searchable source. This database provides summarized information on innovative treatment technologies. The system operator can be reached at 301-670-6294.

- The Vendor Information System for Innovative Treatment Technologies (Hotline: 800-245-4505) database contains information on 154 technologies offered by 97 developers.

- The OSWER CLU-IN electronic bulletin board contains information on the status of SITE technology demonstrations. The system operator can be reached at 301-585-8368.

Technical reports can be obtained by contacting the Center for Environmental Research Information (CERI), 26 West Martin Luther King Drive, Cincinnati, Ohio 45268 at 513-569-7562.

SECTION 2

SOFTWARE APPLICATION ANALYSIS AND EFFECTIVENESS

2.1 Background

GIS\Key™ is an environmental data management system that consists of custom developed software that integrates several commercial-off-the-shelf products: AutoCAD, FoxBASE, and QuickSurf. This system, which is compatible with 386 and 486 personal computers (DOS), facilitates the collection, reporting, and analysis of site management data. Digital map data is imported into GIS\Key™. This data can be made up of USGS 7.5-minute quadrangle digital data and site-specific (i.e., RCRA facilities and CERCLA site) digital data. With GIS\Key™, users add graphic points representing wells, borings, and sampling locations on to the basemap along with the pertinent chemical, geologic or hydrologic information. Geologic cross sections, boring logs, potentiometric maps, isopleth maps, structure maps, summary tables, hydrographs, chemical time series graphs, tables, and other maps and line graphs meeting RCRA and CERCLA reporting requirements can be produced using GIS\Key™.

The GIS\Key™ Environmental Data Management System was selected for SITE testing to assess its ability to provide useful and effective information to aid in site investigations and remediation activities. The specific objectives of the evaluation were to:

- Determine if the software performs the functions that are claimed by GIS\Solutions.
- Assess the accuracy of the GIS\Key™ output, including figures and tables, and review GIS\Key™ procedures used to ensure the data integrity.
- Review the general usability of GIS\Key™, including ease of use, system requirements, personnel requirements, data entry or database creation procedures, and electronic data exchange capabilities.
- Compare GIS\Key™ features to user requirements. Requirements were based on both user interviews and a review of general software evaluation guidelines developed by the USGS and other government agencies.

The steps used to evaluate GIS\Key™ mirrored, in some respects, the guidance developed by the USGS for evaluating geographic information systems (GIS) products. Many of the evaluation criteria were compiled from relevant Federal Information Processing Standard (FIPS) and National Institutes of Standards and Technology (NIST) publications; some were obtained from standard software testing and evaluation guidance (USGS, 1988 and Mosley, 1993). Emphasis was placed on analyzing several procedures and capabilities common to GIS\Key™ chemistry, geology, and hydrology modules. Ultimately, the evaluation sought to determine how well the various procedures and capabilities associated with GIS\Key™ performed during collection, reporting, and analysis of a set of site management data. Table 2 is a listing of items evaluated. The specific elements examined during evaluation were agreed upon by the EPA Technical Project Manager (TPM) and GIS\Solutions prior to the evaluation.

Because GIS\Key™ Software is an environmental database management system, it can be used at any Superfund site. The system handles both soil and groundwater contaminants but does not provide a means for managing ecological assessments or air pollutant data.

The GIS\Key™ Environmental Data Management System is presently being used commercially at a number of hazardous waste and Superfund sites. The software can be obtained through direct purchase from GIS\Solutions. The computer hardware required to operate the system efficiently is standard "off-the-shelf" equipment.

The vendor's claims are provided in Appendix 1.

2.1.1 Key Features of the GIS\Key™ Environmental Data Management System

GIS\Key™ Environmental Data Management System fulfills a set of needs that are often performed by multiple independently run pieces of software. GIS\Key™ has taken these proven pieces of software and has put them under one shell. The results of this integration allow for enhanced database management activities that would otherwise be more difficult or costly to perform.

GIS\Key™ forces a level of integrity and data consistency upon entry of the information to the database. Since environmental data of various classes and categories are collected and maintained by GIS\Key™ in one database management system, analysis of the interaction and relationships of the data is more apparent.

Reporting of information is streamlined and cuts across the data categories. Evaluations can be

Table 2. Items Evaluated for GIS\Key™

New Project Setup
    System/Database Management
    User Interface
    Database Creation
    Database Development

Data Entry
Electronic Data Transfer (Input/Output)
Updates and Edits
Definition and Modification of Lists and Codes
Work Flow

Query Capabilities and Procedures
    Manipulation and Analysis of Spatial Data
        Retrieval,
        Restructuring,
        Transformation, and
        Statistics
    Menu-Prompted Database Queries
        Sampling Period,
        Program Type,
        Chemical Constituent(s), and
        Preparation Fraction
    Display and Product Generation
    Map and Map Feature Annotation

Contouring General Procedures
Cross Section General Procedures
Ancillary Graphics Procedures
Documentation and Support
Hardware Considerations
System Training

performed in different reporting formats. Repetitive reporting requirements often become simpler exercises

In general, GIS\Key™ reduces most of the mechanical drudgery associated with database import/export, management, maintenance and report generation, and facilitates engineering and scientific interpretation, thereby allowing the user to focus on analysis and site management,

2.2 Methodology

Two analysts experienced in GIS and environmental database management performed the evaluation. One analyst had previous experience with GIS\Key™; the other did not. This allowed for two differing perspectives: a new user versus an experienced user. A third analyst, with an environmental database background and previous GIS experience served as the QA/QC officer, reviewing both the evaluation protocol and the results. The evaluators were provided with a condensed version of the GIS\Key™ basic training course. The full course (3-1/2 days) was completed in 2-1/2 days and covered the following topics: AutoCAD essentials; new project setup; geology, hydrology, and chemistry modules; and GIS\Key™ utilities. A detailed discussion of the GIS\Key™ training course is addressed in Subsection 2.3.9. The evaluation included obtaining information on performance from a limited number of current users through telephone interviews.

The GIS\Key™ software runs on DOS-based personal computers. For this evaluation, which occurred between April and December 1993, GIS\Key™ was installed on three separate computer platforms (both 386 and 486 MHz) located at SAIC's McLean, Virginia; Cincinnati, Ohio; and San Francisco, California offices. GIS\Key™ Release 1.1.2, AutoCAD Release 12, and QuickSurf Release 2.91 were installed and used during the evaluation. A description of the hardware configurations used by the three SAIC offices during the evaluation can be found in Subsection 2.3.8.

The GIS\Key™ software is evolving and being changed periodically as is typical of such systems. As a consequence, some of the findings from this evaluation would be modified by an evalution of a later release or version,

2.2.1 Test Data Set

The test data set used in this evaluation was derived from three sources:

1. Sample data supplied by GIS\Solutions that consisted of:

   - a basemap in AutoCAD drawing format provided by American Digital Cartography (ADC), which was derived from USGS 1:24,000 scale Digital Line Graph (DLG) data and the Geographic Names Information System (GNIS)

   - site map symbols and attribute data (i.e., DBF files) for 12 onsite monitor ing wells, 4 offsite monitoring wells, 5 onsite soil borings and 6 offsite control borings This data set consisted of 339 files organized into 8 directories and totaled over 5 Mb.

2. An ADC supplied AutoCAD drawing for the Valdosta, GA 7.5-minute quadrangle. This data was derived from USGS DLG and GNIS. This file was 1.5 Mb.

3. Six QuickSurf test files supplied by Schrieber Instruments:

   - strshale.qs = the structure of the Opeche shale in NE Wyoming
   - isodolo.qs = the thickness of a dolomite layer overlying buried sand dunes
   - isosand.qs = the thickness of a set of buried sand dunes
   - topo.qs = the topography overlying the above described geology
   - hpv.qs = pore volume of a fluid
   - hpvbig.qs = same as hpv.qs but with more control points

2.3 Evaluation Results

The criteria listed in Table 2 were organized under the following major categories to conduct the evaluation:

- New Project Setup
- Data Entry
- Data Checks, Updates, and Edits
- Data Processing
- Graphical Procedures
- Products
- Software Products Versus Reporting Requirements
- Hardware Considerations
- System Training and Support

2.3.1 New Project Setup

Setting up a new project involves a database creation step that includes generation of (1) the project directory tree structure on the hard drive and (2) the project basemap, i.e., an AutoCAD DWG file. These two steps are discussed below.

Creating Project Directories

GIS\Key™ facilitates the creation of the project directory tree structure by providing a NEW PROJECT DISKETTE with an INSTALL program. This program prompts the user for a project name and then creates the appropriate subdirectories, data structures, and data files under that project name. The end result of the install program is a directory structure similar to the one shown in Figure 3. According to the User Guide "all project directories must be on the same drive as the GISKEY directory"; this may pose limitations as project files grow and if the hard drive is formatted into relatively small partitions.

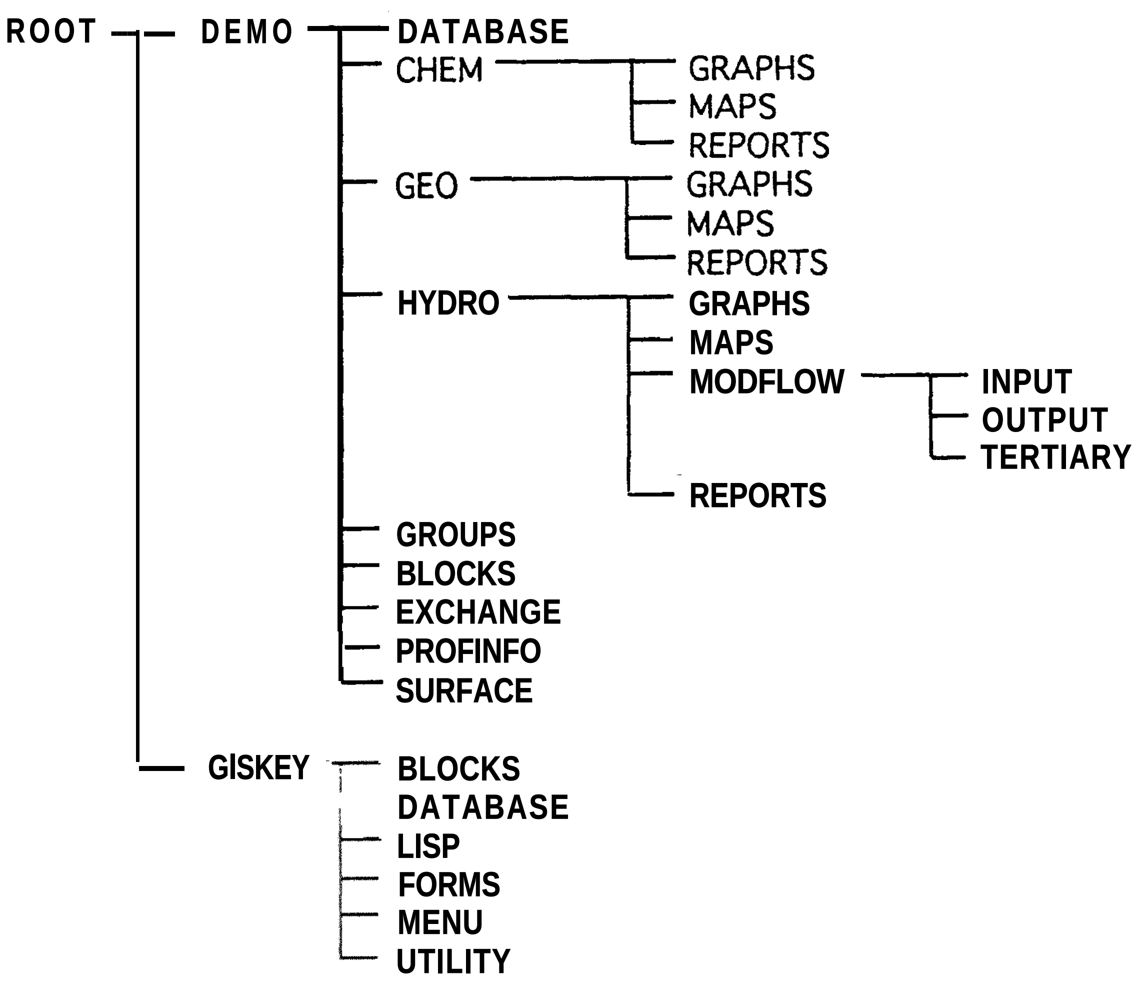


Figure 3. GIS\Key™ directory structure.

Creating a Basemap

After successful installation of the new project data files and directories, the project map is created. Any map in DWG format is an acceptable basemap; many users insert their site map into a digitized USGS quadrangle map. These maps, in DWG format, can be obtained from American Digital Cartography, a vendor that can supply USGS DLG, GNIS, Digital Elevation Model (DEM) and other spatial data products in DWG format.

To test the incorporation of a basemap into GIS\Key™, a DWG file was obtained from ADC for the USGS 7.5minute quadrangle for Valdosta, Georgia. This file was 1.5 Mb, consisting of 47 layers of DLG and GNIS data and 20 geodetic control points in the Georgia West state plane coordinate system (see Figure 4). This dataset was successfully loaded with no problems.

Adding Well Locations

Well locations and other features (buildings, tanks, etc.) can be added to the basemap. Adding a well location to the map is a two-step process: (1) the map symbol is added using the GIS\Key™ utilities menu, and (2) the environmental information is filled in using the GIS\Key™ database menu. This subsection of the report discusses methods for accomplishing the first step. The procedures required for the second step are discussed in detail in the data entry subsection (Subsection 2.3.2).

Two alternate methods of digitizing (inserting well locations on the map) were evaluated. In Method 1, it was assumed that the x,y,z coordinates of the well were known and in the same coordinate system as the basemap. In Method 2, it was assumed that wells were marked on a map and their coordinates needed to be determined.

Method 1

This method follows the UTILITIES - SITE MAP SYMBOL menu selection. The user selects one of the predefined well symbols. To add the well to the map, the user can physically place it with the mouse or enter the x,y coordinates at the keyboard. Several sample wells were inserted using this method; no problems were encountered.

Method 2

A user faced with determining coordinates for well locations or other features for inclusion in a GIS\Key™ map must rely strictly on AutoCAD and software external to GIS\Key™ to digitize their

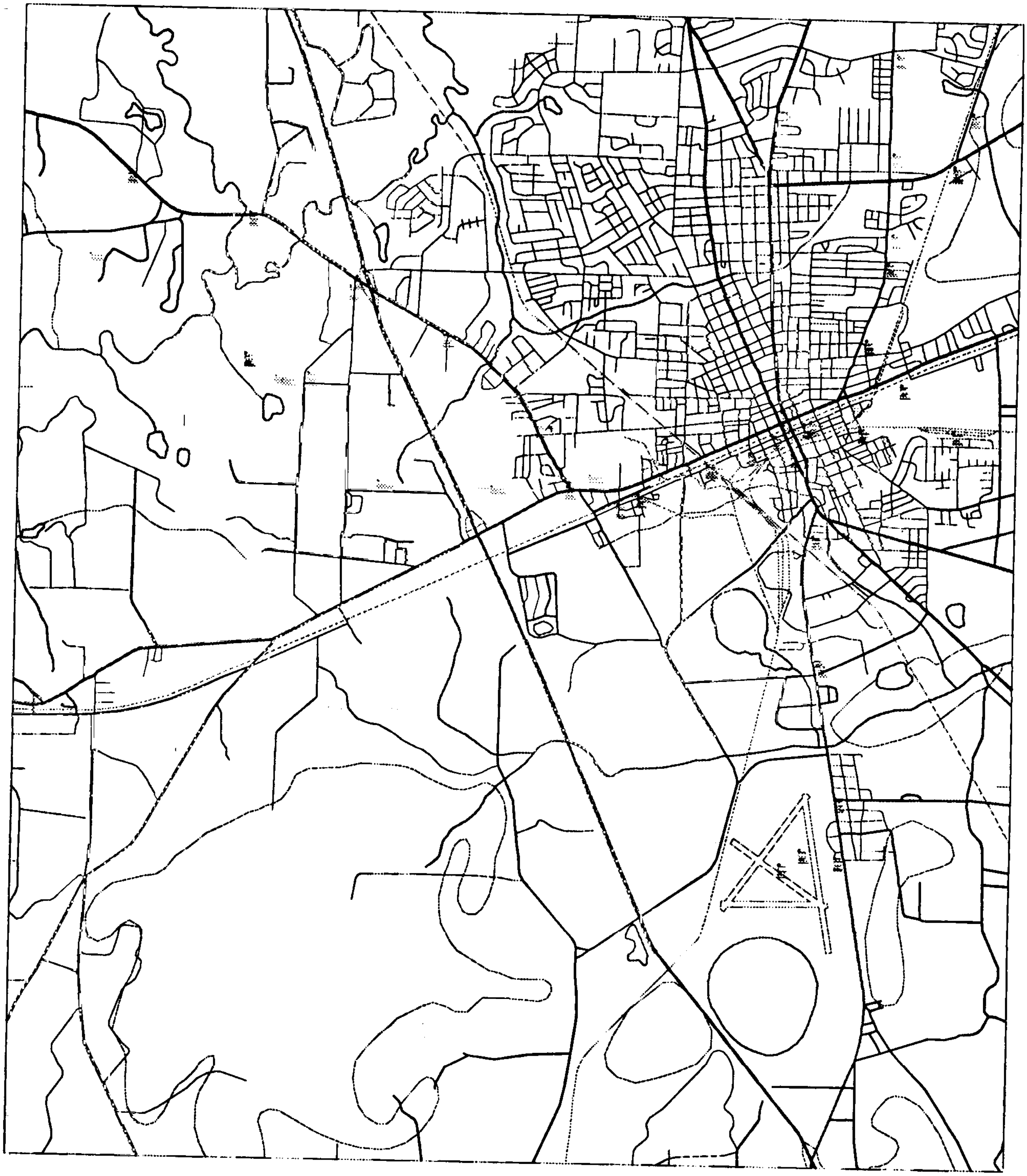


Figure 4. Example map (Valdosta, GA Quadrangle) provided by ADC in AutoCAD drawing format.

locations. For this exercise, it was assumed that point locations (i.e., wells, geodetic control points) needed to be digitized and inserted on the Valdosta, Georgia basemap previously described. A view was created in GIS\Key™ corresponding to a region in the vicinity of the Valdosta airport (see Figure 5). Steps were performed to evaluate this process and to address such issues as coordinate transformation, accuracy and resolution (see Appendix II). From this exercise it was found that additional software resources (map transformation software) were needed to transform geographic coordinates to Georgia West state plane coordinates. Sufficient accuracy ($\pm$ 3 feet) was obtained when using the AutoCAD digitizing and ARC/INFO map transformation software to add ground control points. Given the limitations of the hardware, software, and map scale of the hard copy basemap, it is also important to know the level of accuracy associated with the digitizing process; specific accuracy objectives may be explicitly required for the project results to be considered useful and valid.

Lists and Codes

GIS\Key™ uses many user-defined codes and lists to categorize project data for storage and retrieval. Several codes or lists that can be modified are provided with GIS\Key™; others must be defined by the user. Some codes are shared among all projects managed by a single installation of GIS\Key™; others are specific to individual projects. In general, correct definition and maintenance of these codes are essential to proper functioning of GIS\Key™. Each list or code is discussed separately below. The various lists and codes may be specific to each project.

Chemical Names and Aliases

GIS\Key™ stores chemical information according to Chemical Abstracts Service (CAS) Registry Numbers. CAS numbers are used in many menu-prompted database queries, and a look-up list is available to obtain the needed CAS numbers by typing the beginning of the chemical name. GIS\Key™ allows the user to add new chemicals and alternative chemical names at any time. Chemicals or materials that do not have CAS numbers can also be added to the list, provided that an artificial CAS number is used. GIS\Key™ documentation provides useful guidance on the use and generation of artificial CAS numbers. Several users report that a common use for these numbers is to store the “tentatively identified compounds” sometimes reported by laboratories. Chemical name identifications and CAS numbers are shared by all projects managed by a single installation of GIS\Key™.

Action Level Codes, Source References, and User Alerts

GIS\Key™ supplies many lists of regulatory thresholds, primarily based on Federal and California

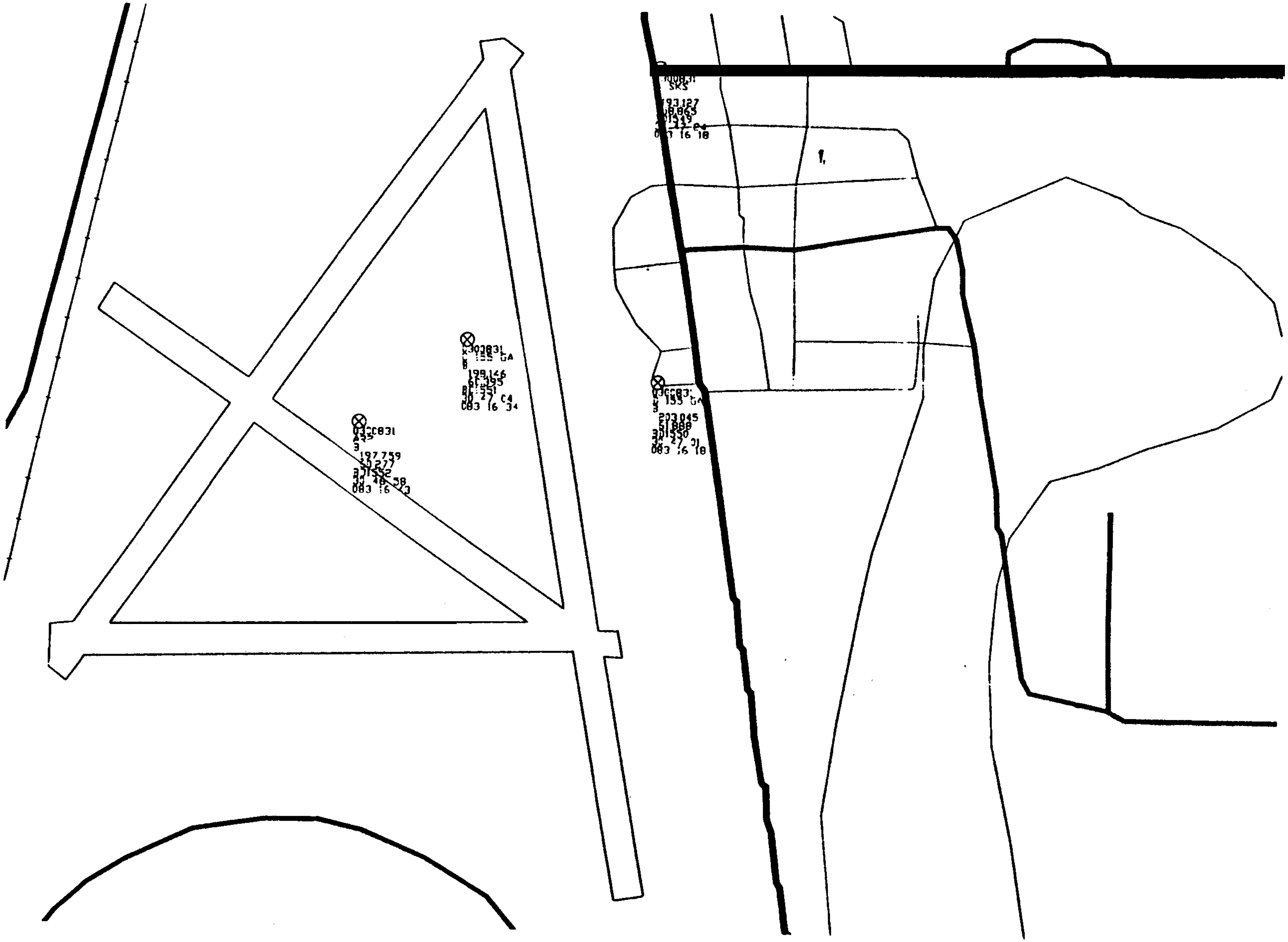


Figure 5. GIS\Key™ view showing the Valdosta Airport and geodetic control points.

standards. GIS\Key™ includes a disclaimer in the documentation warning the user to verify the appropriateness of these action levels prior to use. GIS\Key™ allows users to modify existing action levels and add new ones to make them specific to their project. New action levels are added using three database menu options. To do this, the user must understand several GIS\Key™ concepts including "action level codes," "source reference codes," "source reference levels," "user alerts," and "action levels." The GIS\Key™ documentation for this process could be improved. For example, the GIS\Key™ User Guide discusses how to enter "action level codes" before it describes how to enter new "source reference codes." A brief note in the margin of the documentation indicates that this order is incorrect, that is, the "source reference codes" must actually be entered before entering "action level codes." Testing showed that if the user attempts to use a nonexistent "source reference code" while entering a new "action level code," then GIS\Key™ will warn the user that the "source reference code" is invalid, but it will accept it if the user insists.

Geologic Formation and Soil Classifications

GIS\Key™ supplies USGS soil classification codes that can be used (via a look-up list) for data entry of borehole soil material descriptions. The user can also add additional soil material descriptions to the look-up list. The user may define a list of formations and formation codes. For example, the user could define the top of the "A" aquitard to be associated with the code "AQTA". These codes are easy to define and edit.

Laboratories

Laboratory identifications and associated code letters are required for chemical data entry. Laboratory codes are easy to define and edit, and can be specific to each project. Laboratory codes cannot be used in the menu-prompted database queries.

Preparation Fractions and Program Codes

These project-specific codes refer to the sample preparation procedure used by the laboratory prior to analysis. For example, soil samples are often analyzed for total metal content as well as metal concentrations in the water-extract of the sample. One use of the "preparation fraction" code is to distinguish these two types of results. User-defined program codes allow the user to distinguish data obtained for different purposes. For example, they can be used to distinguish routine water level measurements from aquifer pump test water level measurements. The user may define up to 26 "preparation fraction" and "program" codes. Both codes are very easy to add or modify; they are available for editing in a single menu option. Proper use of these codes is essential for obtaining accurate results from the menu-prompted database queries. These codes are almost too easy to modify; it is possible for the user to redefine these codes so that query results are incorrect or misleading (see Subsection 2.3.3). GIS\Key™ includes default codes for all projects for the following preparation fractions: total, dissolved, TCLP, California wet extraction procedure (STLC), acid rain extract, EPTox, and water extract. GIS\Key™ users indicate that these categories are suitable and rarely need to be modified

Sampling Events

GIS\Key™ uses the term "sampling event" to refer to date intervals that encompass field sampling activities. For example, the user can define a sampling event called "93-FALL" to refer the date interval between September 1, 1993 through September 14, 1993. The user may define an unlimited number of "sampling events" using a single menu option. Overlaps or gaps between "sampling events" can exist, and sampling events can be easily redefined at any time. This flexibility may benefit certain project situations, but if not handled carefully can cause incorrect results when using menu-prompted database queries

Test Methods

GIS\Key™ uses "test methods" to indicate which chemicals and units of measure are associated with which laboratory methods. GIS\Key™ supplies a lengthy list of test methods, and the user can easily add to this list at any time

Template Constituent Lists

GIS\Key™ uses a concept called "template constituent list" (TCL) to simplify laboratory data entry and reporting of quality control data. A TCL actually consists of several associated lists: a target constituent list and lists of matrix spikes, control samples, and surrogates. TCLs are unique for each combination of matrix, lab, and test method. A TCL is first selected by the user to initiate data entry; the data entry screens then have the proper lists of chemicals with their detection limits displayed. The user needs to enter less data, since most defaults are set by the TCL. The process of setting up TCLs involves naming the TCL, identifying the lab and test method, and then selecting individual chemicals and detection limits associated with the TCL. The User Guide provides clear step-by-step instructions on this essential task. The documentation warns against modifying TCL lists since they provide a record of useful laboratory information such as detection limits, Reporting Compounds

Reporting constituent lists (RCLs) are used by GIS\Key^{TM} for hard copy report production. They provide the user with the flexibility to prepare a report showing results from more than one TCL, and specific chemicals can be included in or suppressed from any RCL. The process of creating RCLs is well described in the documentation, and is very similar to the process used for creating template constituent lists.

Review Codes

GIS\Key^{TM} allows the user to store laboratory QA/QC data validation qualifiers with the chemical results. Two categories of these codes can be used: standard EPA Contract Laboratory Program codes and user defined “expert codes." The “expert codes” can be easily modified.

Milliequivalents

GIS\Key^{TM} supplies a table of ionic milliequivalents that are used for checking ionic balances. The user may edit and add to this list at any time. This list is shared by all projects managed by a single GIS\Key^{TM} installation. No users contacted indicated that they used GIS\Key^{TM} to check ionic balances

2.3.2 Data Entry

GIS\Key^{TM} provides data entry screens to assist input of user data. These screens are available under the GIS\Key^{TM} Database Menu option in the AutoCAD graphical environment, or by entering the database directly from DOS

Separate modules for data entry only are available. The user therefore has the flexibility to have several data entry modules in use, which could all provide data files to a full, graphical GIS\Key^{TM} installation. For larger projects these modules can be used to optimize capital costs. No direct support is provided for double-key entry. The data entry modules require fewer computer resources for operation, and they will run on machines that cannot support the full GIS\Key^{TM} product.

User Interface - Menus, Graphic Displays

Overall, the user interface is well organized and easy to operate. It is necessary to frequently switch between GIS\Key^{TM} and AutoCAD menus. A mouse-driven menu “toggle” switch made this relatively easy. Within the GIS\Key^{TM} graphics environment (as well as AutoCAD), functions were executed by selecting menu items with the mouse. In the GIS\Key^{TM} database environment, the mouse is not active, and as a result users must navigate the menus with letter keys, arrow keys, tabs, and carriage returns. Specific user interface elements included in the evaluation are briefly described below.

The majority of the GIS\Key^{TM} spatial and database module functions are invoked by selecting items from pull-down or pop-up menus; the user then responds to prompts that usually display default answers. In AutoCAD most commands can either be invoked through the command line or through menu selection. The following user interface elements are not provided by GIS\Key^{TM} but are available in AutoCAD.

- Interactive command language interface
- Ability to use command abbreviations
- Online help screens
- Online user manual and tutorial

GIS\Key^{TM} does not provide the capability for building macros, shell scripts, or batch files to execute complex functions automatically from an aggregate of simpler individual functions, but does allow the user to add custom AutoLISP applications to the existing GIS\Key^{TM} functions. AutoCAD provides the ability to change menus, program dialog boxes, and use scripts through AutoLISP, Structured English Query Language (SQL), and the AutoCAD development system (ADS) programming languages. GIS\Key^{TM} uses the AutoCAD undo command to retract previous entries. In GIS\Key^{TM}, pressing the Enter key or space bar at the AutoCAD command prompt restores the previous command

Error messages are not always clear. For example, when attempting to process a QuickSurf file for gridding and contouring, a filename with the .qs extension was entered in response to a GIS\Key^{TM} prompt. The QuickSurf software processed the data but failed to display the grid and contour layers. An error message was displayed with no indication on how to solve the problem. Through trial and error it was determined that the filename had to be specified without the ".qs" extension.

In the example error message described above, a soft error recovery was possible. The program did not fatally terminate but allowed the user to respecify the filename. In several instances during the evaluation process, GIS\Key^{TM} terminated prematurely and fatally in the middle of a database query or in the generation of a contour map; the error messages usually indicated a memory or page fault problem had occurred (probably related to the fact that a 386 PC with only 4 Mb of RAM was being used).

GIS\Key™ had to be restarted; however the drawing file could not be opened until it was “unlocked” using an AutoCAD utility function. To alleviate memory problems, GIS\Solutions recommends a minimum of 8 Mb of RAM.

User Interface - Data Entry

GIS\Key™ data entry screens are text-based (rather than graphical), and no mouse support is available. User input must usually be provided in a specific order. This is in contrast to the graphical “dialog boxes” found in AutoCAD. Online help is not available during data entry.

Look-up lists are available for many user responses. The look-up lists are often dynamic, so that when the user enters new data into a field, GIS\Key™ will prompt the user to confirm that the new data is actually desired and is not a typing error. The new data entered will be added to the look-up list and will be available for subsequent data entry. For example, while entering data about a new well, the user is prompted to enter the “well type.” The user may press a key to be shown a list of all “well types” previously entered, and may select one of the previously entered types or choose to type in a new type of well. If a new well type is entered, GIS\Key™ will ask for confirmation that a new well type was intended (i.e., that it was not an entry error). If the user confirms that a new well type was intended, then it is entered for that particular well and is also added to the look-up list for subsequent use.

GIS\Key™ provides a time-saving function related to look-up lists. The user can very easily return to the last item that was edited or entered by pressing the <F4> key. This feature is especially useful when entering borehole or well construction data. The user can enter borehole information, bypass the initial site location look-up list, and go directly to the well construction data entry screens.

GIS\Key™ usually requires the user to input data in a certain order. Once the essential data fields are completed, the remaining optional fields can be skipped with a single keystroke (i.e., the <F3> key). The distinction between essential fields and optional fields is not always consistent. For example, the first well construction data entry screen has a field for the well “tailpipe” material of construction. This field can be skipped over and left blank by using the <F3> key to skip to the second data entry screen. However, if the cursor arrow keys are used instead to move past the “tailpipe” material of construction field, then GIS\Key™ will display a look-up list and will require completion of this field before data entry can proceed. In this example, “tailpipe” material of construction is required, even though no tailpipe was used. Selection of the choice [unknown/NA] is the equivalent of a null entry. The documentation does not clearly indicate which fields are optional and which are required.

If the user notices that a mistake has been made, the cursor keys can usually be used to return to the entry and correct the error before it has been committed to the database. It is not always possible to correct a minor error by returning to a field using the cursor keys. For example, assume that the user notices a minor error on the first well construction data entry screen. If the user presses the back-arrow cursor key too many times (i.e., accidentally attempting to move before the first entry), then GIS\KeyTM will display the second well construction screen. The user can no longer see nor edit the first data entry screen.

Data that had been previously entered is displayed as appropriate on subsequent screens. It is displayed in a contrasting color and cannot be edited. For example, borehole and well names, x-y locations, and elevations are shown in this fashion on the database data entry screens (this information is entered in the graphical AutoCAD environment when adding or modifying well locations),

GIS\KeyTM function key use is fairly consistent. For example, the <F2> key provides a look-up list, and the <F3> key skips over any optional data entry fields. Pressing undefined function keys sometimes results in an error beep, sometimes is ignored, and sometimes simulates pressing the <Enter> key.

GIS\KeyTM uses the <Escape> key inconsistently. For example, after entering “program code” definitions, the <Escape> key will cancel any changes; after entering primary chemical data, the <Escape> key is used to save changes and exit.

Default menu options are presented in the database differently than the way they are presented in the graphical environment. In the graphical environment, a default choice on the AutoCAD command line is displayed surrounded by brackets; pressing the <Enter> key will select the bracketed default. However, in the database, the first letter of every option is surrounded by brackets; pressing the <Enter> key generally selects the first item in the list.

In summary, GIS\KeyTM data entry screens are functional and provide several time-saving features. These include look-up lists and quick return to the most recent item accessed. Data entry screen functionality and user interface is fairly consistent throughout the database, but is quite different from the graphical AutoCAD GIS\Key^{TM} environment. These screens are fairly typical for text-based screens, but have some idiosyncrasies that need to be learned. Users accustomed to graphical user interface methods of data entry (e.g., dialog boxes, pop-up menus, radio buttons, check boxes, etc.) may need additional time to feel comfortable with GIS\Key^{TM} data entry screens.

Geologic Data Entry

Geologic data tracked by GIS\Key^{TM} includes information about boreholes, well construction, material description (i.e., lithology), sample retrieval and formation. Geological information needs to be entered before chemical or hydrogeological information, since samples and water level measurements can only be taken from existing boreholes or wells.

Borehole Data

The primary data that is entered using this screen is borehole type, total depth, and completion depth. Optional fields include free-form textual descriptions of borehole location, names of companies and individuals responsible for the borehole, drilling start dates, and drilling method. GIS\Key^{TM} will check to make sure that entered drilling dates are valid and that the completion depth is less than the total depth. Error messages are generated if these constraints are not met. GIS\Key^{TM} stores sample descriptions and blow counts obtained during soil borings.

Well Construction Data

Well construction information is entered into the database using two data entry screens. The first screen is used to enter general information such as depths, dates, and names; the second screen is used for detailed screened interval information.

The first data entry screen has fields to describe blank casing, tail pipe, conductor casing, and seal material. Look-up lists are available for well cover type, casing material, and seal material. GIS\Key^{TM} will prompt the user for information for all of these fields. During data entry, GIS\Key^{TM} does not check for conflicts or inconsistencies with the lengths, depths, and diameters of blank casing, tail pipe, or conductor casing. It is possible to enter invalid data using these screens. For example, it is possible to enter a conductor casing depth that is greater than the depth of the borehole. The “completion depth,” which the GIS\Key^{TM} manual defines as “total depth of well, as applicable,” does not appear on the well completion data entry screens, and it does not appear to be used for consistency checks.

The second data entry screen is used to enter detailed information on screened intervals and seals. GIS\Key^{TM} has a limit of five screens and four seals. If more intervals are needed, special "program code" definitions can be used to work around this limitation. GIS\Key^{TM} does not check for overlap of the screen and seal intervals. GIS\Key^{TM} provides fields for both bentonite seal and grout seals, regardless of the type of seal material selected. Non-zero thicknesses must be entered for the thicknesses of each seal or else the well log production routine will not function properly. However, GIS\Key^{TM} does not check this condition during data entry.

Lithological Material Description

GIS\Key^{TM} stores lithological material descriptions in two ways. For each borehole, the depth to the top of USGS soil unit classifications and the depth to the top of user-definable formation codes may be entered into a database using data entry screens. For each borehole, a free-form textual description of the lithology may be entered. This free-form textual information is stored in an ASCII text file, which may be edited or produced using third-party tools. The use of data entry screens for the USGS soil unit classifications and user-definable formation codes is very similar to other GIS\Key^{TM} screens.

There are some important limitations to the method GIS\Key^{TM} uses for entry and storage of free-form textual description of the lithology. By default, GIS\Key^{TM} uses the minimal text editor that is a part of FoxBASE for entry of this information. The GIS\Key^{TM} manual recommends that a familiar word processor be used instead, since unlike the FoxBASE editor, they support line numbering and spell checking. Line numbering is especially important, since the line number determines the depth interval at which the free-form text appears on the well logs. For example, a soil description entered on the third line will be displayed on the well log three foot depth interval. It is not possible to enter the USGS soil unit classifications and the free-form textual descriptions at the same time.

The free-form textual descriptions are kept in a DOS file that has the same name as the sample location ID with a file extension of "MAT". For example, the text for well MW-06B will be stored in a DOS file named "MW-06B.MAT" A major implication of this design is that wells and boreholes should have names where the first eight characters are unique and conform to DOS naming limitations. Well names are entered in the graphical AutoCAD environment, but no warning is issued if invalid DOS names are used for well names. GIS\Key^{TM} will use only the first eight characters of a well name to create a text file. For example, if two wells are named “LF-MW-06A” and **“LF-MW-06B”** (nine-character names), then GIS\Key™ will create only a single DOS name “LF-MW-06.MAT” to store the textual material descriptions for both wells. Separate text files cannot be created for these example wells. Acceptable well-naming conditions are discussed in the User Guide.

Chemical Data Entry

GIS\Key™ provides data entry screens for several categories of chemical information. These categories include the following:

> Primarv Results: Laboratory results from the analysis of field samples. Primary results are used to characterize site conditions.
>
> QC Results: Laboratory results from the analysis of blanks, control standards, duplicates, spikes, and surrogates. QC results are used to assess the performance of the laboratory and field procedures.
>
> Field Measurements: Results from the field measurements of parameters such as temperature, pH, turbidity, and purge volume. Field measurements provide supplemental characterization of site conditions.

Several codes, which were discussed previously in Subsection 2.3.1, must be defined by the user before chemical data can be entered. GIS\Key™ uses these codes to organize or group related data and to simplify data entry.

GIS\Key™ enforces database integrity for the entry of certain data elements by accepting only valid or predefined values. However, GIS\Key™ does not check the validity of all data input. Details regarding input data validity checks are provided below for each category of chemical information.

Primary Results

Two preliminary data entry screens must be completed before the user is able to enter actual chemical data. These preliminary screens require entry of sample description information, including sampling locations and dates. Data entry and input validation findings for these initial screens are described below.

- GIS\Key™ enforces the requirement that primary results can be entered for only existing sample locations. However, it does not require that sample type correspond to sample location type. For example, GIS\Key™ will not allow the user to enter primary water sample results for a well that does not exist, but has the ability to allow entry of primary water sample results for a borehole should this be appropriate.

- GIS\Key^{TM} requires a sampling date for all primary results, but does not require that the date fall within one of the predefined "sampling event" intervals. For example, GIS\Key^{TM} will not allow the user to enter an impossible date of February 31, 1993, but it will allow entry of sampling data from outside the predefined sampling event ranges.

- Valid "program type" code letters are required for GIS\Key^{TM} data entry. GIS\Key^{TM} allows the user to set a default code which saves time if most of the data belongs to the same "program type." GIS\Key^{TM} also provides a look-up list for this field, which appears if the user attempts to enter an invalid code.

- GIS\Key^{TM} allows entry of sample "case" and "sample delivery group" information. This information is optional, since it is required only of QC data validation. Look-up lists are available for these fields. GIS\Key^{TM} does not check to determine whether valid "case" and "sample delivery group" information has been entered by the user but does check for duplication between sampling events.

GIS\Key^{TM} uses "template constituent lists" (TCLs) to simplify entry of laboratory data. ATCL is essentially a set of user-defined defaults for a laboratory method (or group of methods). As described in Subsection 2.3. a user defines a list of related chemicals, methods, and detection limits during project setup. These lists can be defined specific to each project and provide limited ability to customize data entry. For example, a user working on a fuel tank project may ask the laboratory to report concentrations of benzene, toluene, xylenes, diesel, and total petroleum. These fuel components are typically measured using different lab methods. The user could request that the laboratory report results for all methods on the same printed report page, and also set up a GIS\Key^{TM} TCL including these constituents with their laboratory-specific detection limits. These lists are only a data entry aid; menu-prompted database queries cannot use "template constituent lists" as selection criteria. Findings related to data entry using "template constituent lists" are shown below.

- GIS\Key^{TM} requires a valid TCL prior to chemical data entry. A look-up list is available.

- The default list of chemicals and detection limits is displayed on the data entry screen after the user selects a "template constituent list." Often, the hard copy laboratory results show a majority of "non-detects," and only a few compounds are detected. The user needs only to enter these few detection compounds using the data entry screen. Detection limits for non-detects will be automatically determined by GIS\Key^{TM} through reference to the TCL defaults. Reported detection limits can be changed by the user if necessary.

- The user may enter data for chemicals not included on the “template constituent list.” A look-up list is available for this purpose. This ability is useful, for example, in entering tentatively identified compounds.

QC Results

Entry of QC data is optional. GIS\Key™ requires separate entry of QC laboratory data; this data cannot be entered along with the primary data. For analysis of the QC data, GIS\Key™ requires that the user initially specify control limits as described in Subsection 2.3.1, Codes and Lists.

GIS\KeyTM allows entry of the following types of QC results:

- Method, Rinsate, Travel, and Field Blanks
- Duplicates
- Splits
- Matrix Spikes (Lab and Field)
- Control Samples (Known and Blind)
- Surrogates
- Holding Times

Second column confirmation results cannot be stored and analyzed. Also, certain QC data cannot be stored and analyzed. For example, an individual result can be either a surrogate or a duplicate, but not both.

Different screens are used to enter each type of QC result. These screens require different data fields, depending on the type of QC information. For example, since laboratory control samples are not associated with any particular sample location, the data entry screen does not have a field for sample location. However, laboratory control samples have other attributes that are used to associate them with the primary samples. GIS\Key™ requires that the user provide sufficient information to link QC results to the primary samples.

GIS\Key™ performs certain QC calculations at data entry. For example, spike percent recoveries are calculated automatically from spike concentrations. Matrix spike duplicate relative percent differences are also calculated upon entry of concentration information.

Field Measurements

A standard GIS\Key™ data entry screen is used for input of field measurements. For soil and water, possible entries are pH, temperature, organic vapor, and specific conductance. In addition, dissolved oxygen, turbidity, well purging information, and water removal and disposal methods (with look-up lists) can be added for water.

Hydrogeologic Data Entry

GIS\Key^{TM} provides data entry screens for several categories of hydrogeologic information: flow rate information, fluid level information, and well attributes,

GIS\Key^{TM} calculates flow rate values upon data entry. For example, the average flow rate and cumulative flow is calculated from input time internal and meter reading information. Defaults are provided by GIS\Key^{TM} for several fields, simplifying the entry of sequential data. GIS\Key^{TM} also performs validity and consistency checks for the time interval data. However, GIS\Key^{TM} does not prevent the user from entering flow measurements or fluid level information for a borehole.

GIS\Key^{TM} provides data entry screens containing several defaults to simplify entry of fluid level information. GIS\Key^{TM} stores the current measuring point elevation with each depth of water measurement and calculates water level elevation relative to the current measuring point elevation entered in the well construction data entry screens. If the elevation measuring point changes (due to settling or heave), then future measurements reflect this change, while past measurements remain unchanged. Accordingly, if historical water elevation contour maps need to be produced, no change in the measuring point elevation is required

GIS\Key^{TM} does not perform data validity or consistency checks on depth or thickness input. For example, the user may mistakenly enter a water depth greater than the well depth. Errors of this type would normally be obvious on contour maps.

GIS\Key^{TM} provides a screen for entry of aquifer attributes including hydraulic conductivity, vertical conductivity, specific storage, and yield. GIS\Key^{TM} has a limit of five water-bearing zones.

Upon first entry to the well attribute screen, the depth to the top and bottom of the water-bearing zone(s) is derived from the minimum and maximum depths of the well screened intervals. These values can be changed by the user, but GIS\Key^{TM} does not verify whether user input values are consistent with well construction information (e.g., water-bearing zone depths greater than total well depth may be entered).

Data entry fields for aquifer characteristics are displayed for the five user-defined water-bearing zones. However, the documentation does not explain how to enter top to bottom-depth information for more than one water-bearing zone.

Electronic Data Transfer

The GIS\Key™ database menu provides commands for electronic import and export. These menu commands are straightforward and well-documented in the User Guide.

Database files can be imported directly into GIS\Key™. Data can also be exported for use in another program. Import and export file format options include the following formats:

Blank Delimited:	ASCII text files with values separated by single blanks and quotes around character strings
Comma Delimited:	ASCII text files with values separated by commas and quotes around character strings
DBF:	Industry standard dBASE database files
SDF:	"System data format," i.e., fixed length fields without delimiters

Any of the database files used by GIS\Key™ can be used with the general import and export commands available in the database menu. However, the GIS\Key™ User Guide warns that several issues must be considered before data transfer is attempted. For example, care must be taken that field types are converted correctly. Also, the data import command only adds new records; it does not update existing records with new data. Finally, the user is responsible for ensuring that imported data exactly simulates data content and structure that would be created by using the GIS\Key™ data entry screens. Direct data import and export requires an operator with database management expertise.

Testing verified the User Guide warnings that the input file must match exactly the file content and structure that would be generated through the use of the data entry screens.

Data export routines are limited to creation of relational "projections" of data. This means that the user is limited to one table at a time, can select either all fields or a subset of fields, and cannot provide any row selection criteria. For example, it is not possible to select for export only names and measuring point elevations for monitoring wells that are located within certain X and Y coordinates. This type of export is not possible directly from GIS\Key^{TM} for two reasons: no geographic selection criteria (i.e., location coordinates) are available, and these data are stored in two separate files (as required by sound database design). For these reasons, all users who reported that they exported data indicated that they used third-party database programs that can readily handle such data manipulation operations.

Spreadsheet files cannot be directly imported or exported. However, most modem spreadsheet software has the capability to import or export DBF files; this limitation has little practical importance. In general, because of the need to manage the import or export process carefully, the DBF file format is selected by most users. Most database management programs can use these files and provide the degree of control over the data that is needed to reliably manipulate complex datasets.

Data subsets can be exported in a format compatible with the EPA GRITS/STAT program. GRITS/STAT is a program developed to manage RCRA groundwater monitoring data, and it includes powerful statistical routines that conform to RCRA guidance. This export capability provides the opportunity to perform statistics more complicated than supported directly by GIS\Key^{TM}.

Because GIS\Key^{TM} is an integration of AutoCAD and FoxPRO, the data exchange formats supported by these products (i.e., DBF and DXF files) are supported by GIS. With respect to GIS, the ability to exchange data between GIS\Key^{TM} and ARC/INFO was investigated.

GIS\Key^{TM} and ARC/INFO manage both spatial and attribute data. The components of each system that handle these data types are as follows:

SYSTEM	SPATIAL DATA	ATTRIBUTE DATA
GIS\Key^{TM}	AutoCAD	FoxPRO
ARC/INFO	ARC	INFO

The exchange of spatial data between the two systems was accomplished using standard AutoCAD and ARC/INFO functions to import and export DXF files. A DXF file constructed within GIS\Key^{TM} containing only well data was imported by ARC/INFO without error. The file was exported out of ARC/INFO as a DXF file and read in by AutoCAD without error.

To take advantage of the full capabilities of **GIS\Key^{TM}** and ARC/INFO, the attributes (i.e., geology, chemistry, hydrology data) associated with the well locations must also be exchanged. This is not a straightforward procedure within the current version of GIS\Key^{TM} The user would have to export the non-spatial data in the GIS\Key^{TM} DBF files into a flat text file, load the text files into an INFO table, and then join the INFO table to the spatial entities. The attribute item DXF-TEXT is imported into ARC/INFO from the AutoCAD DXF file and can be used to join the INFO table (non-spatial data) to the spatial data.

GIS\Key^{TM} provides an optional program called LABDATA.EXE that is designed to prepare electronic laboratory data for import into GIS\Key^{TM}. A simplified flat-file structure is available to laboratories to supply data. The GIS\Key^{TM} user would take the file from the laboratory, add additional information not provided to the laboratory (such as sample location), and then use this GIS\Key^{TM} program. This program checks the single file for internal consistency and accuracy before it prepares the individual files needed by GIS\Key^{TM}. In practice, it requires special effort to work with the laboratory to ensure that its files are usable by this program. Checking the laboratory file format (names and types of fields) only is not sufficient; the data within the format must be consistent, accurate, and complete for this method of data import to be usable.

Data Consistency

A primary benefit of GIS\Key^{TM} is that nearly all project data is stored in a single, unified, and structured database. Data redundancy is reduced or eliminated, providing a greater ability to manage data quality. For example, USGS soil types for a borehole are stored one time in one location. Several types of GIS\Key^{TM} output may use this data. These output types include structure maps, isopach maps, geographic cross sections and well logs. Users report that prior to using GIS\Key^{TM}, they often used one program to prepare well logs, another program for contouring, another for map preparation, and yet another system for cross sections. In this approach there is a greater opportunity for error as data is manually moved from one application to the next.

Since GIS\Key^{TM} stores data in a consistent and unified manner, it requires that data input be consistent and unambiguous. Prior to input into GIS\Key^{TM}, the data must be critically examined and made consistent. Users report that the process of gathering data and ensuring its consistency and quality is often the most time-consuming part of a GIS\Key^{TM} project, but forces them to address and correct data quality problems.

2.3.3 Data Checks, QA/QC Analysis, Updates, and Edits

GIS\Key^{TM} provides routines that allow the user to verify the quality of data imported and provides alerts when data falls outside predetermined levels or ranges. These QC procedures as well as the ability to edit and to update the database and basemap were assessed and are discussed in this section,

Using the Tables - User Alerts option on the GIS\Chem menu, the user can run built-in routines that identify the location, date, time and depth of samples with the highest reported concentration of each chemical, chemical concentrations that fall outside historical ranges, look for concentrations in excess of action levels, check ionic balances, and compare QC results against QC objectives. If a problem is detected, GIS\Key^{TM} flags it by generating a report. The affected sites are highlighted by changing the color of their map symbols to red. For example, if a field blank alert report is run, all samples collected on the same day or in the same batch as a failed field blank for a specified test are highlighted on the map. In addition, a report is prepared that provides a list of the associated samples, which can in turn be used to assign data review qualifiers.

The user alerts function was tested for all the monitoring wells in the sample database, and it ran without error. Identified wells flashed in a red color and a report was written to the GIS\Key^{TM} exchange directory (i.e., for historical ranges, the report filename was hrcheck.rpt). Tables 3 through 5 show examples of reports for the historical range check, holding time check, and action level check. When the ionic balance check is invoked, the user is prompted to choose the percentage difference threshold to report on. If no alerts are found, the system displays the message, “nothing to report”, and on the AutoCAD command line, the message, “no user alerts found” is displayed. This occurred when the ionic balance check was run with a threshold of 10 percent

The historical range check report (see Table 3) is confusing. Hyphens in front of the high historical range value may be misinterpreted as minus signs. It is not clear if zeros indicate no data or an actual measurement of zero. In the holding time check report (see Table 4), each monitoring well is listed twice,

Table 3. Historical Ranges Check

GIS\Key Demo 3/30/92

Historical Ranges Check

Constituent	Name	PF	Historical Range (Low-High)			Tested Conc.	
** MW-05A							
* 01/01/90							
71-43-2	Benzene	T	0	-0	mg/l	0.1	mg/l
108-88-3	Toluene	T	0	-0	mg/l	0.08	mg/l
100-41-4	Ethylbenzene	T	0	-0	mg/l	0.06	mg/l
1330-20-7	Xylene (total)	T	0	-0	mg/l	0.1	mg/l
86290-81-5	TPH (as gasoline)	T	0	-0	mg/l	0.61	mg/l
** MW-OSB							
* 01/01/90							
71-43-2	Benzene	T	0	-0	mg/l	0.022	mg/l
108-88-3	Toluene	T	0	-0	mg/l	0.03	mg/l
100-41-4	Ethylbenzene	T	0	-0	mg/l	0.009	mg/l
1330-20-7	Xylene (total	T	0	-0	mg/l	0.004	mg/l
86290-81-S	TPH (as gasoline)	T	0	-0	mg/l	0.19	mg/l
** MW-06A							
* 01/01/90							
71-43-2	Benzene	T	14	-28.1	mg/l	6	mg/l
108-88-3	Toluene	T	4.1	-12.7	mg/l	3.7	mg/l
100-41-4	Ethylbenrene	T	0.36	-1.4	mg/l	0.32	mg/l
86290-81-S	TPH (as gasoline)	T	70	-140	mg/l	35	mg/l
** Mw-06B							
* 01/01/90							
71-43-2	Benzene	T	0.0016	-0.022	mg/l	0.03	mg/l
108-88-3	Toluene	T	0	-0.009	mg/l	0.01	mg/l
100-41-4	Ethylbenzene	T	0	-0.001	mg/l	0.0018	mg/l
1330-20-7	Xylene (total)	T	0	-0.002	mg/l	0.003	mg/l
** MW-07A							
* 01/02/90							
108-88-3	Toluene	T	0.6	-2.2	mg/l	3.3	mg/l
** MW-09A							
* 01/02/90							
71-43-Z	Benzene	T	0.005	-0.39	mg/l	0.82	mg/l
108-88-3	Toluene	T	0	-0.28	mg/l	0.42	mg/l
100-41-4	Ethylbenzene	T	0	-0.01	mg/l	0.04	mg/l
1330-20-7	Xylene (total)	T	0	-0.02	mg/l	0.09	mg/l

Table 4. Holding Time Check

GIS\Key Demo 3/30/92

Holding Time Check

Site	Prog.	Sampled Date	Sampled Time	Sampled Depth	Time Held (days) C->E	E->A	C->A	R->E	R->A
** Water									
* BTEX-TPHG		Allowed Holding Times:			0	0	14	0	0
MW-01A	A	10/01/90	01:01		-1	1	8	-1	7
MW-01A	A	10/01/90	01:01		-1	1	8	-1	7
MW-01A	A	10/01/90	01:01		-1	1	8	-1	7
MW-04A	A	10/01/90	01:01		-1	1	8	-1	7
MW-04B	A	10/01/90	01:01		-1	1	8	-1	7
MW-04B	A	10/01/90	01:01		-1	1	8	-1	7
MW-05A	A	10/01/90	01:01		-1	1	8	-1	7
MW-05A	A	10/01/90	01:01		-1	1	8	-1	7
MW-05B	A	10/01/90	01:01		-1	1	8	-1	7
MW-05B	A	10/01/90	01:01		-1	1	8	-1	7
MW-06A	A	10/01/90	01:01		-1	1	8	-1	7
MW-06A	A	10/01/90	01:01		-1	1	8	-1	7
MW-06B	A	10/01/90	01:01		-1	1	8	-1	7
MW-06B	A	10/01/90	01:01		-1	1	8	-1	7
MW-07A	A	10/02/90	01:01		-1	-1	11	-1	11
MW-07A	A	10/02/90	01:01		-1	-1	11	-1	11
MW-07B	A	10/02/90	01:01		-1	1	22	-1	21
MW-07B	A	10/02/90	01:01		-1	1	22	-1	21
MW-08A	A	10/02/90	01:01		-1	1	22	-1	18
MW-08A	A	10/02/90	01:01		-1	1	22	-1	18
MW-09A	A	10/02/90	01:01		-1	1	22	-1	17
MW-09A	A	10/02/90	01:01		-1	1	22	-1	17
MW-10A	A	10/02/90	01:01		-1	1	22	-1	17
MW-10A	A	10/02/90	01:01		-1	1	22	-1	17
MW-11A	A	10/02/90	01:01		-1	1	22	-1	17
MW-11A	A	10/02/90	01:01		-1	1	22	-1	17
MW-12A	A	10/02/90	01:01		-1	1	22	-1	21
MW-12A	A	10/02/90	01:01		-1	1	22	-1	21

and negative values and zeros need to be explained. A legend needs to be provided to explain the time held (days) columns (i.e., C->E = time from sample collection to extraction). The action level check report (see Table 5) is straightforward, except that the units are not consistent between action levels and tested concentrations.

GIS\KeyTM has the capability to compare QA/QC laboratory results to user-defined QC objectives. GIS\KeyTM can prepare exception reports and signal to the user those sample locations associated with samples that failed to meet QC objectives. The types of QC objectives that GIS\Key™ can review include the following:

- Method, Rinsate, Travel, and Field Blanks
- Duplicates
- Splits
- Matrix Spikes (Lab and Field)
- Control Samples (Known and Blind)
- Surrogates
- Holding Times

QC objectives are user-defined and can be specific to each project. GIS\Key™ cannot store or review second column confirmation samples. It also cannot handle sample results that may fall into more than one category (e.g., surrogate results in a sample that also was a matrix spike duplicate). Perhaps the most important limitation is that GIS\Key™ can review only one QC objective at a time. If it is necessary to review certain QC results within the context of other QC results, this must be done manually. GIS\Solutions indicates that these limitations have now been addressed.

GIS\Key™ uses the data entry screens for database updates and edits. With a few exceptions, the database menu options provide the ability to delete data. For example, options exist for deleting the results from one chemical in a test, all chemicals in a test, or all chemicals in all tests associated with a particular sample.

"Sampling event" information (i.e., date intervals encompassing field sample retrieval activities) can be quickly and easily redefined. GIS\Key™ does not check for the existence of samples affected by sampling event modification. This allows for the unintentional loss of the relationship between particular data and a redefined sampling event.

Table 5. Action Level Check

GIS\Key Demo 3/30/92

Action Level Check

Constituent	Name	Action Level Code	Action Level		Tested Conc.	
** MW-02A						
* 10/01/90						
71-43-2	Benzene	ADV-EPA-C	1	ug/l	3.3	mg/l
71-43-2	Benzene	ADV-EPA-NC	200	ug/l	3.3	mg/l
71-43-2	Benzene	EBE-CA-HH	21	ug/l	3.3	mg/l
71-43-2	Benzene	ISW-CA-DW	0.34	ug/l	3.3	mg/l
71-43-2	Benzene	ISW-CA-NDW	21	ug/l	3.3	mg/l
71-43-2	Benzene	MCLG-EPA	0	ug/l	3.3	mg/l
71-43-2	Benzene	NAWQC-CHH	0.66	ug/l	3.3	mg/l
71-43-2	Benzene	NAWQC-SAL7	700	ug/l	3.3	mg/l
71-43-2	Benzene	OP-CA-HH	5.9	ug/l	3.3	mg/l
71-43-2	Benzene	PMCL-CA	1	ug/l	3.3	mg/l
71-43-2	Benzene	PMCL-EPA	5	ug/l	3.3	mg/l
71-43-2	Benzene	PROP65-CA	3.5	ug/l	3.3	mg/l
108-88-3	Toluene	ADV-EPA-NC	1	mg/l	3.1	mg/l
108-88-3	Toluene	AL(TOX) -CA	100	ug/l	3.1	mg/l
108-88-3	Toluene	MCLG-EPA	1	mg/l	3.1	mg/l
108-88-3	Toluene	PMCL-EPA	1	mg/l	3.1	mg/l
108-88-3	Toluene	SMCL-EPA	40	ug/l	3.1	mg/l
108-88-3	Toluene	SNARLS-NC	340	ug/l	3.1	mg/l
100-41-4	Ethyl benzene	SMCL-EPA	30	ug/l	0.41	mg/l
1330-20-7	Xylene (total)	SMCL-EPA	20	ug/l	0.33	mg/l
** MW-06A						
* 10/01/90						
71-43-2	Benzene	ADV-EPA-C	1	ug/l	2.3	mg/l
71-43-2	Benzene	ADV-EPA-NC	200	ug/l	2.3	mg/l
71-43-2	Benzene	EBE-CA-HH	21	ug/l	2.3	mg/l
71-43-2	Benzene	ISW-CA-DW	0.34	ug/l	2.3	mg/l
71-43-2	Benzene	ISW-CA-NDW	21	ug/l	2.3	mg/l
71-43-2	Benzene	MCLG-EPA	0	ug/l	2.3	mg/l
71-43-2	Benzene	NAWQC-CHH	0.66	ug/l	2.3	mg/l
71-43-2	Benzene	NAWQC-SAL7	700	ug/l	2.3	mg/l
71-43-2	Benzene	OP-CA-HH	5.9	ug/l	2.3	mg/l
71-43-2	Benzene	PMCL-CA	1	ug/l	2.3	mg/l
71-43-2	Benzene	PMCL-EPA	5	ug/l	2.3	mg/l
71-43-2	Benzene	PROP65-CA	3.5	ug/l	2.3	mg/l
108-88-3	Toluene	ADV-EPA-NC	1	mg/l	1.1	mg/l
108-88-3	Toluene	AL(TOX)	100	ug/l	1.1	mg/l
108-88-3	Toluene	MCLG-EPA	1	mg/l	1.1	mg/l
108-88-3	Toluene	PMCL-EPA	1	mg/l	1.1	mg/l
108-88-3	Toluene	SMCL-EPA	40	ug/l	1.1	mg/l
108-88-3	Toluene	SNARLS-NC	340	ug/l	1.1	mg/l
100-41-4	Ethylbenzene	SMCL-EPA	30	ug/l	0.1	mg/l
1330-20-7	Xylene (total)	SMCL-EPA	20	ug/l	0.5	mg/l

In a similar manner, "program type" codes can be added or redefined by the user at any time, but definition updates are not propagated throughout the database. If the "program type" code letters are later redefined, the test result databases will continue to store the old code letter. For example, the code letter "A" may initially refer to routine monitoring. The user would thus provide the code "A" while entering routine monitoring data. If "program type" codes are later redefined so that "A" refers to "audit program" and routine monitoring becomes associated with the code letter "R," the laboratory result databases are not updated. Routine monitoring data originally stored with the code letter "A" will be considered to be from the "audit program" after the example code redefinition.

GIS\KeyTM also allows the user to delete the "program type" and "preparation fraction" definitions from the list of code letter definitions after data has been entered using the code. Later, when performing a menu-prompted query, it will appear to the user that no data had been entered using the now undefined code. GIS\KeyTM does not issue a warning message if the user redefines or deletes a "program type" associated with sample results in the database.

In summary, database update capabilities and procedures are essentially identical to regular data entry. However, extra care needs to be taken when modifying certain database tables. GIS\KeyTM does not check all database updates for consistency and reasonableness. There is a danger that project codes can be redefined in a way that decreases the accuracy and usefulness of subsequent menu-prompted database queries. For certain codes such as "preparation fraction" and "program type", which are not stored in dBASE-compatible DBF files) the user can create a DBF file (and recreate it after any code redefinitions) in order to use third-party database software (Paradox, FoxPRO, DB2/2) to check and verify the project database.

Basemap modifications such as new sample locations or wells must be added to a project through the use of the GIS\KeyTM menus. After providing a sample location or well name, the user is prompted to provide location coordinates, creating a situation where the location could be placed beyond the area displayed on the screen. If it is not visible on the screen, the user might decide to re-enter it creating a basemap that contains two well symbols of the same name. The "second" well will be stored with a specially encoded name in the GIS\KeyTM database to enable identification of this error. However, the encoded name is not displayed on the map in such a way as to alert the user to a possible error. It may take substantial effort to correct this type of error.

2.3.4 Data Processing

The ability to query the data that has been input to GIS\Key™ is one of the most powerful and often used tools available to the user. The integrity of the query is critical because the data that is selected is usually passed on to another procedure, for example, contouring, or is incorporated into a table, map, or graph. If the query does not work correctly, the results of the procedures that operate on the selected data are invalid. No integrity problems were encountered with the queries tested. GIS\Key™ offers the user both spatial and non-spatial query capabilities. GIS\Key™ has the ability to perform spatial queries through the building of AutoCAD selection sets and the creation of symbol lists. The database queries are conducted through a series of menu prompts

Spatial Queries

GIS\Key™ spatial data retrieval capabilities are provided by AutoCAD. Spatial queries operate by allowing the user to select objects displayed on the map graphically. AutoCAD handle IDs of the selected objects are passed to the GIS\Key™ database module, thus allowing extraction of data. GIS\Key™ provides for all of the AutoCAD spatial query capabilities (the creation of selection sets) as well as a specific function (the creation of a symbol list), which increases the efficiency of well selection. When the user selects one or more entities for processing, the collection of entities is called a selection set. The selection set window operation was used quite often within GIS\Key™ for selecting all or a subset of wells. AutoCAD and the GIS\Key™ System are limited to rectangular selection windows. Arbitrary polygon or circle selection is not supported

AutoCAD highlights the selected entities as a cueing aid. AutoCAD is flexible; the user can select objects first, and then enter a command to process them or enter the processing command first, and then select the objects. Entities can be interactively added or removed from the selection set

GIS\Key™ supplements AutoCAD spatial data selection by providing “symbol lists.” These are user-defined subsets of frequently used sample locations that can be grouped together and retrieved by name.

AutoCAD categorizes spatial data by layer. Entities of similar types are generally placed on a single layer distinct from other layers. There is no limit to the number of layers in a drawing (AutoCAD

Release 12). Layers can be activated or deactivated. Entities within a layer can either be easily selected by making the layer active (and then selecting entities with the mouse), or selection can be prevented by deactivating the layer. Proper layer management with standardized layer naming schemes can make working with GIS\Key™ maps much more efficient.

All GIS\Key™ map symbols must be on one of two layers: wb_zone_on, or wb_zone_off. GIS\Key™ surfacing and modeling routines look for map symbols only on these two layers. According to the vendor, the only correct way to remove a map symbol from the display is by moving it to the invisible layer: wb_zone_off. Removing map symbols using other AutoCAD techniques will destroy the linkage of the symbol (well location) to the database.

The creation of symbol lists was evaluated by using the GIS\Key™ test data set to make two well selection lists: (1) intermediate water-bearing zone wells and (2) ghost wells (wells that define the boundary conditions of a computational grid that is input to a hydrological model). The procedural steps for creating a symbol list were straightforward and were easy to follow and create correctly. Use of the symbol list to select data efficiently for further processing was examined by reading in the two well lists created to select data for a structure map. The results of reading in symbol list "inhvells" are shown in Figure 6; only the four wells in the list: MW-04B, MW-05B, MW-06B, MW-07B are shown. The wells from symbol list, "wells" were also read in without error. A structure map showing the elevation of the top of water-bearing zone 2 was created from the wells in these two symbol lists. The elevations posted at the selected wells corresponded exactly to information in the database for this structure (Table 6).

Symbol lists can be modified by changing wells included and saving it with a new name. Alternatively, the symbol list ASCII file can be edited outside of GIS\Key™.

Menu-Prompted Database Queries

GIS\Key™ provides a set of menus to retrieve subsets of data from the project database for use in display or analysis. For example, to prepare a chemical concentration contour map, the user starts by selecting the sampling locations by using spatial query techniques. The user then selects the chemicals, sampling programs, and time periods that are needed for contouring and display. GIS\Key™ uses menu-prompted database queries to solicit this information from the user.

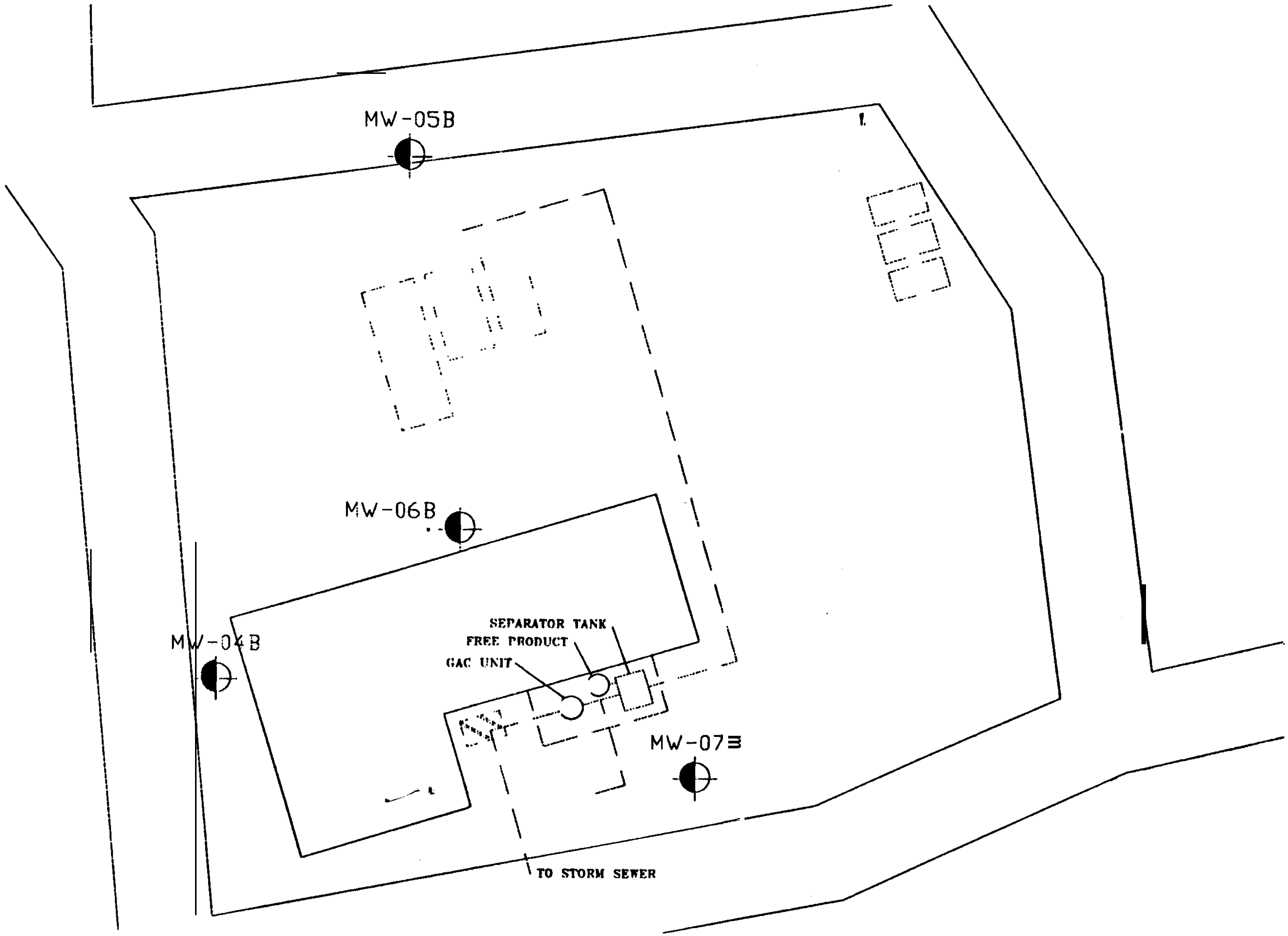


Figure 6. Map showing the four intermediate-zone wells in the Intwells symbol list.

Table 6. Comparison of Well Elevation vs. Posted Values

Well ID	Elevation (Feet)	Top of Unit (Feet)	Posted Value (Feet)
CB-NE	164	45	119
CB-NW	135	40	95
CB-SE	135	45	90
CB-SE-A	118	40	78
CB-SE-B	127	40	87
CB-SW	111	35	76
MW-04B	160.5	45	115.5
MW-05B	162.5	45	117.5
MW-06B	160.8	45	115.8
MW-07B	159.0	47	112.0

After the wells are selected, GIS\Key™ leaves the AutoCAD environment and displays a text-based menu to guide the user through data selection. These text-based menus are quite similar, regardless of the type of map selected. GIS\Key™ obtains a data subset based on the user menu selections and then returns to the graphical AutoCAD environment with the selected data values posted next to the sampling locations.

GIS\Key™ does not provide any method to perform ad hoc or user-defined database queries. The advantage of this design is that the user does not need to know a database language, such as SQL. Since no special database training is required to select data from the database, individuals with little computer expertise can select data subsets. If an ad hoc database query is desired, the open, nonproprietary nature of GIS\Key™ makes it easy for database savvy users to implement their own queries outside of GIS\Key™.

Testing of the GIS\Key™ demonstration database provided the following findings. GIS\Key™ allows more than one laboratory result for a given well and chemical combination to be within the same sampling event. For example, benzene could have been measured in well MW-06B on four different dates in 1990. Also, a sampling event could have been defined to include all of 1990. In this example, four laboratory results for this well and chemical concentration would be included within the sampling event. Under these circumstances, GIS\Key™ will select the maximum concentration observed in the sampling event for display and analysis. GIS\Key™ does not provide any indication to the user that multiple results were found within the sampling event. It is not possible to instruct GIS\Key™ to select an average or minimum concentration instead of the maximum. GIS\Key™ does not provide any means to determine which data is outside of any sampling event.

GIS\Key™ provides flexibility to quickly and easily redefine sampling events. Since sampling event information is not stored with the chemical result information, the user can unintentionally lose the relationship between particular data and the redefined sampling event for samples originally included but redefined outside the sampling event. GIS\Key™ does not provide the means to check for samples "orphaned" this way.

In summary, the sampling event selection criteria provide a useful way to group related samples together based on sampling date. However, GIS\Key™ does not provide the direct means to check for sampling event definition ambiguities or conflicts.

"Program types" are typically defined as a part of new project setup. After selection of the sampling event the user is presented with a listing of all existing program types to aid selection. GIS\Key™ allows selection of multiple program types for a single query. For example, benzene could have been measured in well MW-02A under both routine monitoring and the extraction test. If the user selects both "program types", then GIS\Key™ selects the maximum concentration observed in the two "program types" for display and analysis. GIS\Key™ does not indicate that multiple results were found. It is not possible to instruct GIS\Key™ to select an average or minimum concentration instead of the maximum.

Following the "program type" selection the user selects the chemical to be included. A look-up list is available allowing the user to select chemicals easily by typing the initial letters of the chemical name. This list includes all the chemicals known to GIS\Key™. No preselection of chemicals is possible.

More than one chemical may be selected for a single query. Graphs will display up to five individual chemicals; maps will display the sum of up to ten chemical concentrations.

"Preparation fraction" types are typically defined as a part of new project setup. After selection of the chemical as part of a menu-prompted query, the user is presented with a listing of all existing "preparation fractions" to aid selection. GIS\Key™ allows selection of multiple "preparation fractions" for a single query. For example, dissolved toluene could have been measured in a well and also analyzed for EP toxicity. If the user selects both "preparation fraction" codes, GIS\Key™ selects the maximum concentration observed for display and analysis. GIS\Key™ does not indicate that multiple results were found or which "preparation fraction" provided the result for display. It is not possible to instruct GIS\Key™ to select an average or minimum concentration. "Preparation fraction" codes can be redefined or deleted, but are not propagated throughout the database.

Summary of Menu-Prompted Database Queries

GIS\Key™ menu-prompted database queries allow users with little computer expertise to retrieve and use information from the project database. The menus guide the user through criteria selection with structured and ordered steps. Look-up lists are available as appropriate to simplify user choices. GIS\Key™ does not support ad hoc queries, and no on-line help is available. Proper project setup and data entry are essential to ensure accurate queries. It is possible to set up projects incorrectly so that certain data are not retrieved. The user must understand GIS\Key™ concepts such as "program type," "preparation fraction," and "sampling event." The user must also be aware of how GIS\Key™ presents data when the selection criteria include multiple results for the same well.

Manipulation and Analysis of Spatial and Attribute Data

GIS\Key™ supports calculation of areas, perimeters, and lengths, through standard AutoCAD commands. Volume calculations are supported by QuickSurf for any grids created in GIS\Key™.

Descriptive statistics such as means, medians, and ranges are available for chemical data only and presented in graphical form. These statistics are displayed on time-domain graph of concentration at a single well. The advanced statistical functions are available by exporting to the EPA GRITS/STAT program. These include t-tests, analysis of variance, tests for normality, confidence intervals, tolerance intervals, and prediction intervals. Parametric and non-parametric versions are available.

Using QuickSurf, GIS\Key™ can generate contours from either randomly spaced data or regularly spaced (gridded) data, or data extracted from contours. QuickSurf uses a single algorithm to generate the grid and subsequent contour lines from randomly spaced data using a triangulated irregular network (TIN). The TIN is generated by QuickSurf using the randomly spaced input data.

The AutoCAD component of GIS\Key™ provides direct capabilities for mathematical adjustment of vector data or control points using rotation/translation/scale in x and y (four parameter), local area rubber sheeting, polynomials, and other types of least squares adjustment. As discussed in the digitizing section of the report, the AutoCAD tablet calibration command provides the capability to transform coordinates from a digitizer to the drawing coordinate system using one of three transformation types:

- Orthogonal: a transformation consisting of arbitrary translation, uniform scaling, and rotation
- Affine: a transformation consisting of translation, independent x-scaling and y-scaling, rotation, and skewing, i.e., an arbitrary linear transformation in two dimensions
- Projective: a transformation equivalent to a perspective projection of one plane in space onto another plane. This transformation provides a limited form of rubber sheeting, in that different portions of the digitizer surface get stretched by different amounts. The transformation only works from the digitizing tablet to AutoCAD drawing. Transformation of the coordinates of an existing digitized map would have to be accomplished outside of GIS\Key™.

Data Processing Speed

A query was performed by an independent user on a 486/66 Hz PC with 16 Mb of RAM and a 1 Gb hard drive. The size of the basemap for this query was 1.7 Mb. The database included 2224 wells/ sample locations and over 10 years of chemistry data. Included in the database were approximately 443,000 primary result records for soil and water quality chemistry. The elapsed time for completing the decision criteria to posting TCE concentration under each map symbol was 25 seconds.

2.3.5 Graphical Procedures

Contouring General Procedures

Contouring geology, hydrology, and chemistry data in GIS\Key™ is carried out by QuickSurf, a third-party software package developed by Schrieber Instruments (Denver, Colorado). QuickSurf provides only one algorithm for gridding and contouring the input data, the DeLaunay triangulation. This is a widely known and universally accepted algorithm for computing a TIN, a set of adjacent, non-overlapping triangles computed from irregularly spaced points with x, y coordinates and z values.

QuickSurf constructs triangular frameworks using observed data as the vertices or nodes of the framework. The contouring process interpolates between nodes in the mesh, so interpolation is implicitly bounded by the data. Triangular mesh systems are good at interpolating point data, but generally only project beyond the data when the analyst has provided boundary conditions at dummy locations. GIS\Key™ allows for this through two means: (1) adding contour control points and (2) creation of artificial boundary locations with values stored in the database.

The procedures for contouring chemistry and hydrology data are similar to the geology example that follows. The QuickSurf algorithm works well for surfaces that have continuous slopes and curvature, but does not accurately represent surfaces that contain breaks or faults. This requires the analyst to recognize such situations when interpreting the resultant contour map.

A geologic structure map is a contour map in which each line represents the top of a geologic formation or facies. The test data set used to evaluate the procedure contained sample elevation data for a hypothetical geologic structure, the Reid formation. In the first step all wells were moved to the layer wb_zone_on, so that they would be included as data points. Following the menu prompts, all the displayed wells were highlighted to indicate that they were selected and would be included as data points for retrieving structure data.

Menu-Prompted Database Query

After the wells have been graphically selected, GIS\Key™ shells out to its database module (FoxBASE). Within the database module, the menu prompts will vary depending on the type of data (geology, hydrology, chemistry) to be contoured. In the example described above (contouring structure data), one of four parameters can be selected: formation, blow counts, soil units, and other units. The formation parameter was chosen and the Rd (Reid) formation was selected from the look-up list on the screen. No problems were encountered during this procedure. Within the database module, arrow keys instead of the mouse are used to navigate around the menus.

After the formation parameter was chosen in the database module, GIS\KeyTM switches back to AutoCAD and displays the wells with the values for the selected parameter posted to the map (see Figure 7). A message at the bottom of the display screen indicates the units of the posted values.

Figure 7 shows that all the wells selected except E-l had values for the elevation of this geologic formation. No value was posted under E-l since the null value was chosen to represent a data point without a value. The default GIS\Key™ value to represent no data is 9999. This no data value was posted when the default was chosen.

Figure 8 shows the grid and contour lines for a geologic structure map produced from the posted elevation values. Editing a posted value changes the data in the contourtmp file; this is an ASCII file which contains the data points to be contoured. In order for this changed data to be reflected in the contour map, the update contour file procedure (which is part of the maps-structure menu) must be invoked. This procedure transfers the data in contourtmp to contour.qs, which is read by the contouring software. It is important to note that editing posted values does not change the original database, only the contourtmp file is modified. GIS\Key™ provides a command called “Add Audit Trail” that allows users to add comments and rationale to the text file containing contour data. Users will need to rename and manage these files should they wish to maintain a permanent record of edited values; the “audit trail” is not stored in the GIS\Key™ database.

The save data file command on the maps-structure menu allows the user to save the contents of the contourtmp file under a different file name. The contour.tmp file used to build the structure map for this example was saved in a file called struct.dat. GIS\Key™ prompts the user to specify whether the data is for a map or graph and in which subdirectory (Chem, Geo, Hydro) the file should be stored in. Since this was geologic map data, the file was stored in the /demo/geo/maps subdirectory. The file can be read back in by using the update contour file procedure.

Run QuickSurf

Once the data has been retrieved from the database and any editing and updating performed, the grid and contour lines are generated by the Run QuickSurf procedure. The user is prompted for several parameters that control the x and y dimensions of the grid, contour interval, and names of the grid and contour layers. QuickSurf then executes and the layers are generated.

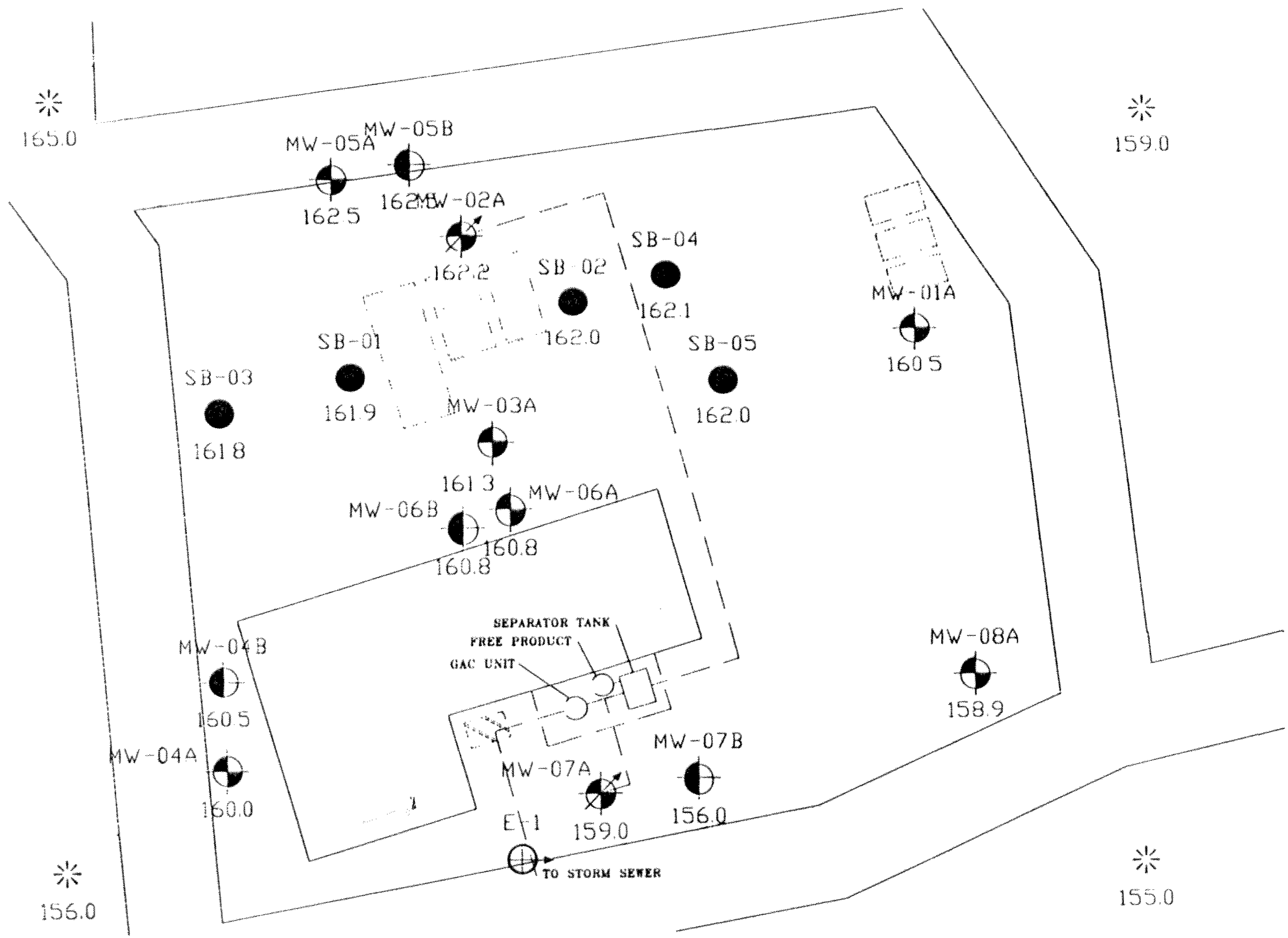


Figure 7. Posted elevation (ft) values for the wells selected to build the formation structure map.

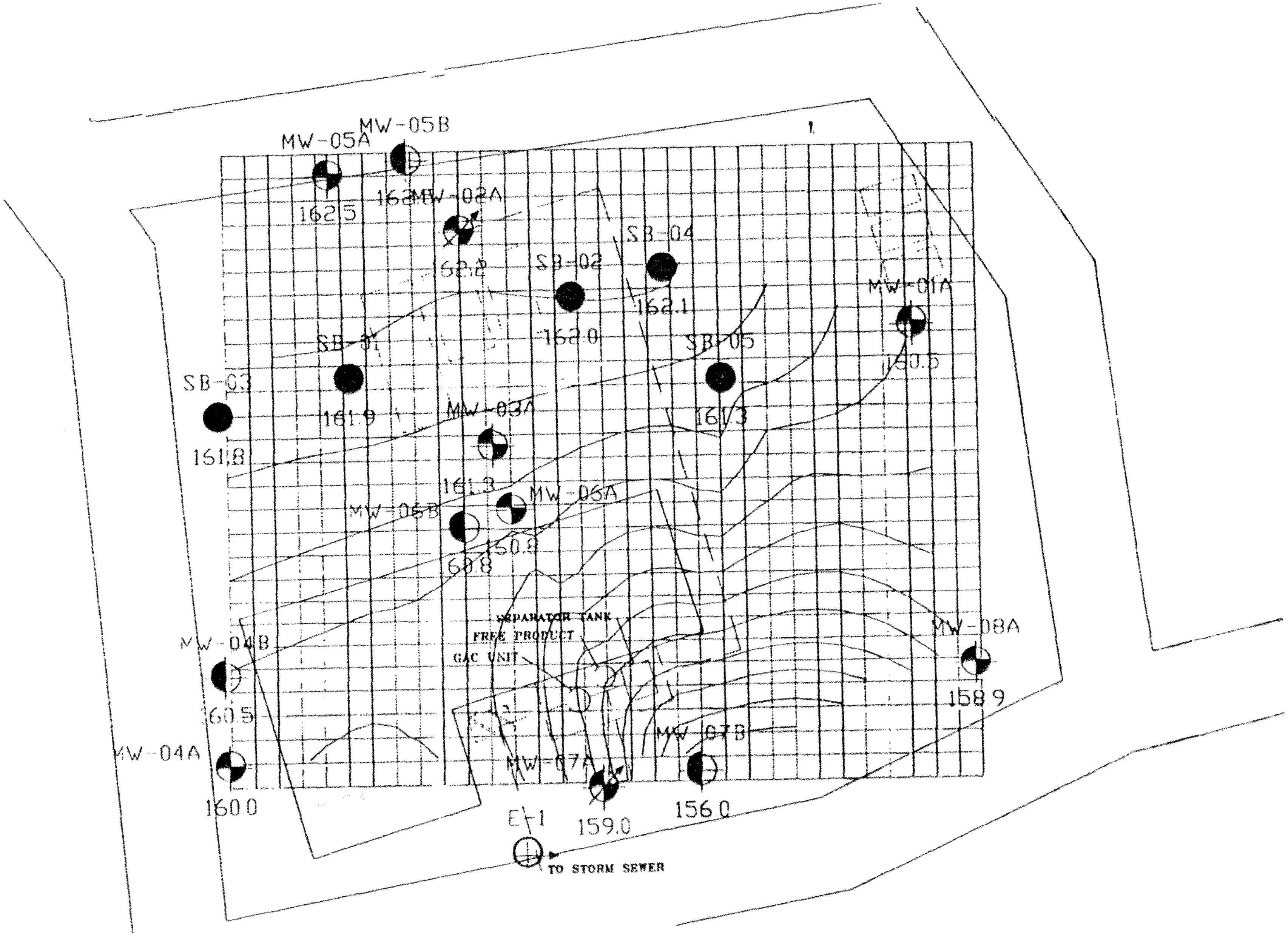


Figure 8. Geologic structure map showing grid and contour lines.

When Run QuickSurf is invoked, GIS\Key^{TM} shells out of AutoCAD. QuickSurf takes over and displays status messages regarding which processing step is running and its associated CPU time. A file is produced and is automatically imported to AutoCAD. Two layers are generated within the current drawing; one for the grid and one for the contours. If no ghost wells or contour control points are included in the data, then the grid extents are formed by the minimum and maximum coordinates of the wells (see Figure 8).

A number of structure maps were constructed to test the effect of editing posted values and adding contour control points. With respect to editing posted values, Figures 9 and 10 show the structure maps generated from the original data (i.e., SB-05 = 161.3 ft.) and the edited data (SB-05 = 162.0 ft.) respectively. For both maps, the posted values lie within the correct contour interval, and contour lines pass through data points (wells) that match the contour value.

When four contour control points were added (see Figure 7), the grid constructed by QuickSurf extended out to these points (see Figure 11). The new contours produced (see Figure 12) extend out to reflect the values at these control points. It was noted that after the grid and contours are produced, the control points disappeared from the screen, eliminating the reminder to the user where they were placed and what their values were.

Chemistry data can often range over several orders of magnitude within a site. To accommodate this situation, GIS\Key^{TM} provides the user with the option of contouring the logarithm of the data. To test this procedure, a water isopleth map was constructed for benzene values in the test data set. During the test of this procedure, a contouring dataset was created and then edited to contain concentrations ranging over several orders of magnitude. These edited values are not physically reasonable, but were used to evaluate log contouring capabilities. The posted values were edited and are shown in Figure 13.

Figure 13 shows the water isopleth map produced by running log contouring on the posted benzene concentration data (note that soil borings SB-01 through SB-05 as well as MW-03A had no values and were not included as data points for contouring). Compare this set of contours with those in Figure 14, which were produced from the same data without running log contouring. Because the data range is so wide, the map in Figure 14 is difficult to read.

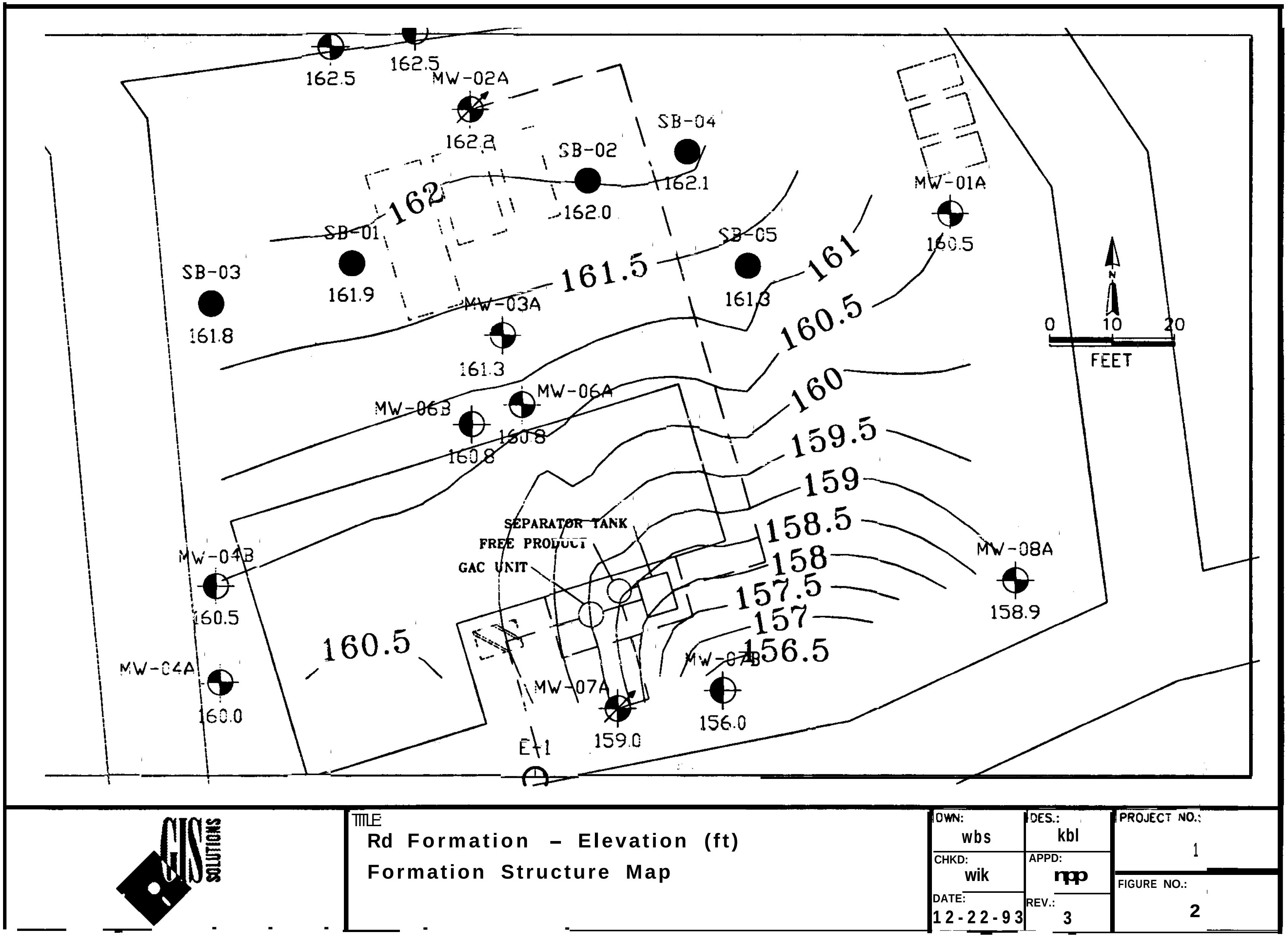


Figure 9. Example geologic formation structure map.

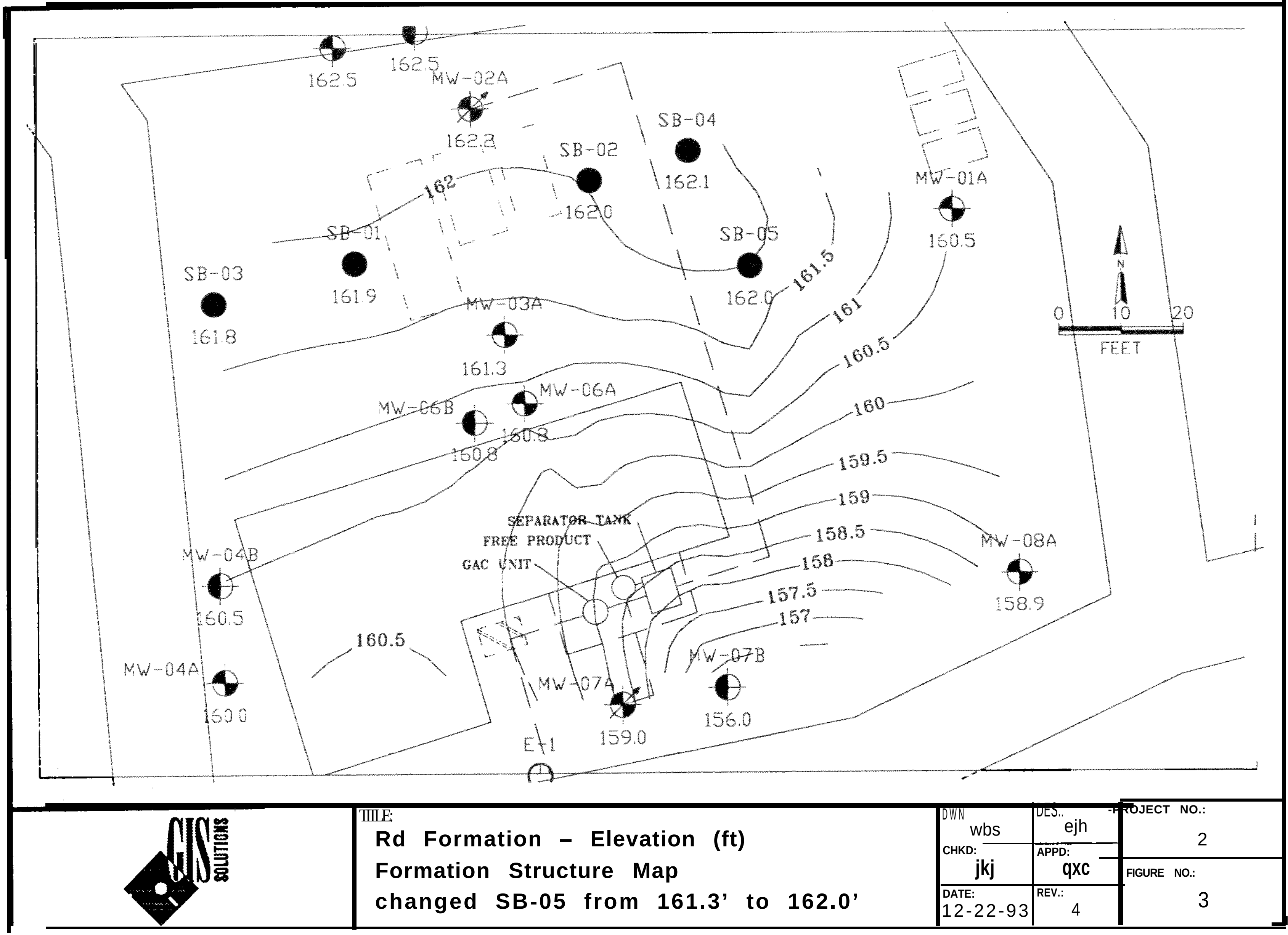


Figure 10. Example geologic formation structure map showing the results of editing a posted value.

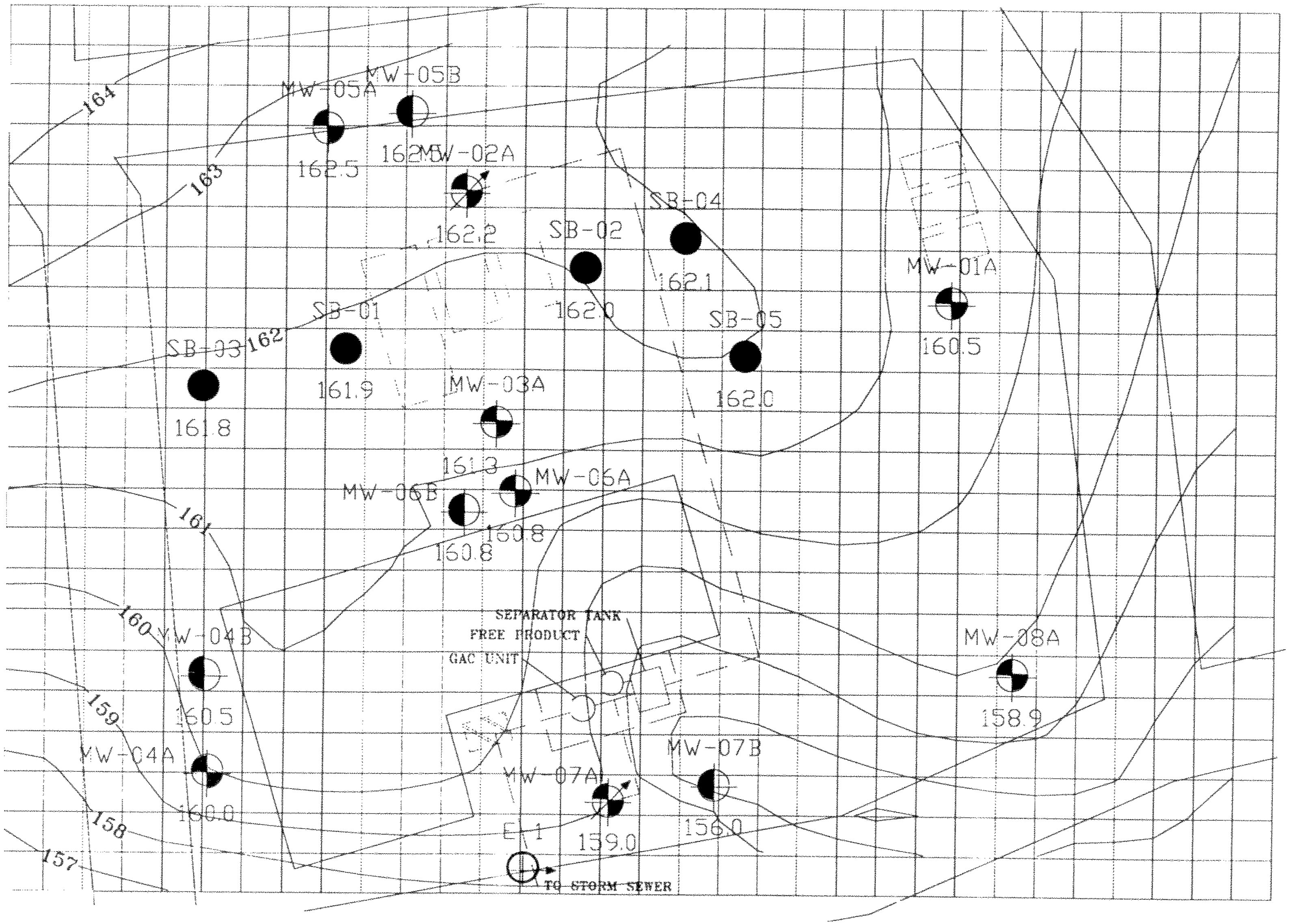


Figure 11. Generation of a new grid and contour lines based on the addition of four contour control points.

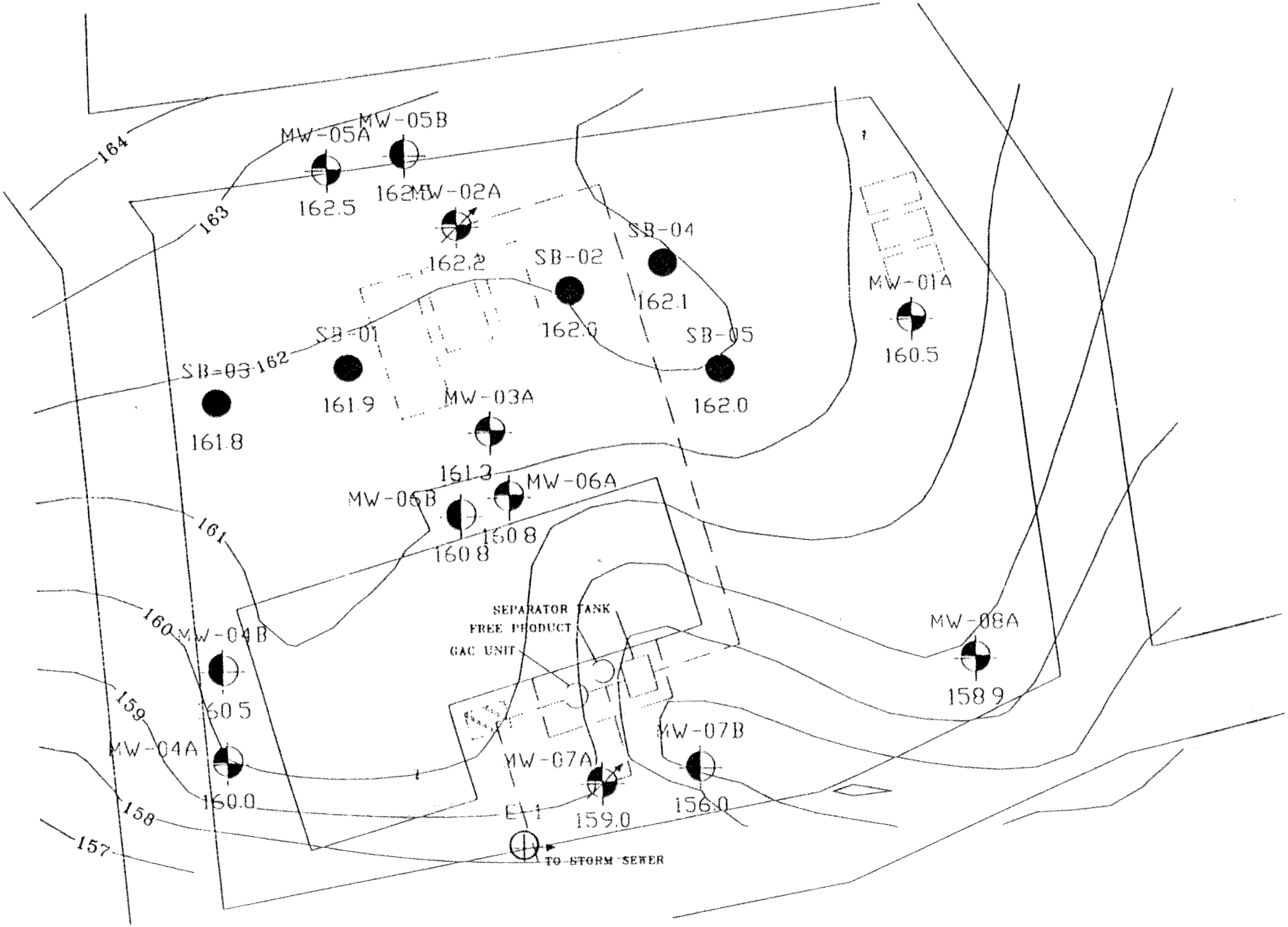


Figure 12. Structure map reflecting new contour lines generated from original data points plus four contour control points.

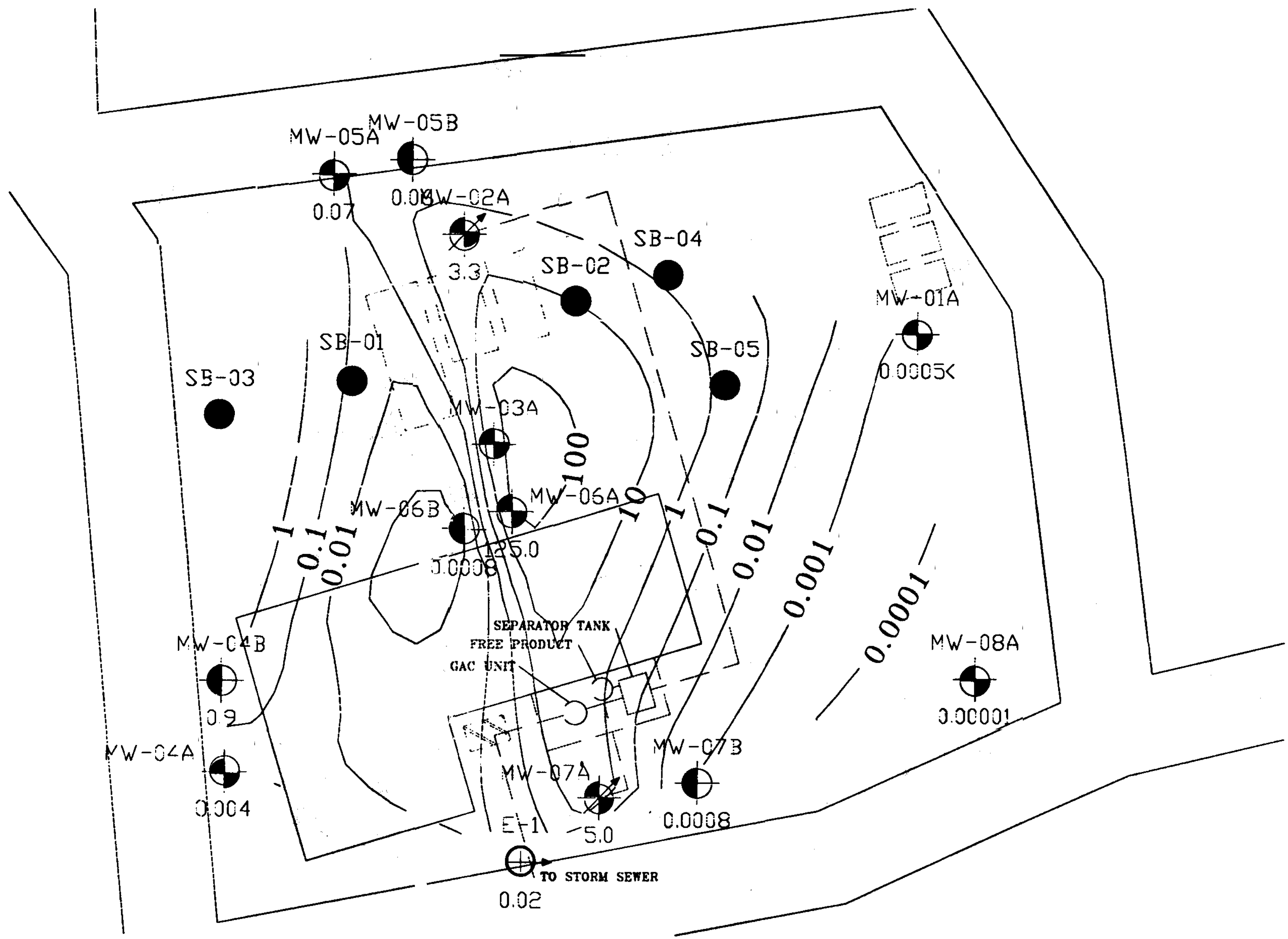


Figure 13. Contour map of benzene concentration (mg/l) using log QuickSurf.

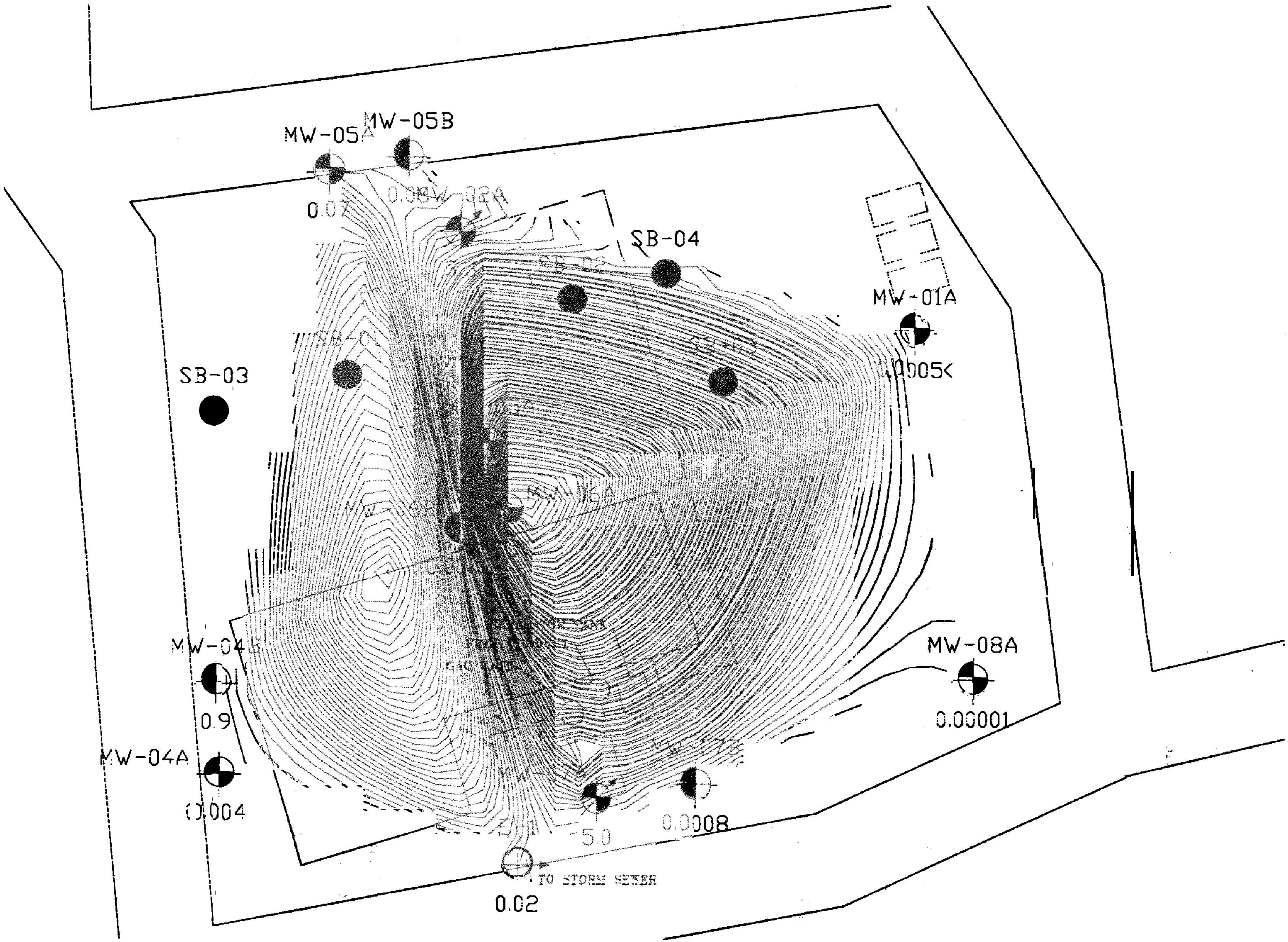


Fig ure 14. Contour map of benzene concentration (mg/l) created without running log QuickSurf.

The GIS\Key™ User Guide warns against having zero concentration values in the data passed to log contouring. To test the behavior of log contouring when a zero value occurs, the original value at MW-06A (125 mg/l) was changed to 0, and log contouring was run. There were no warnings issued during the processing, and a grid and contour map was produced (see Figure 15). It was not obvious how this zero value was treated. Clarification should be provided to explain how zero concentrations are treated

The contouring configuration file, qs.cfg, is an ASCII file that can be edited to allow the user to have some control over the contouring algorithm. Three variables: weight, derive, and honor provide control over, respectively, the degree to which the contour is influenced by outlying control points; whether first, second, or no derivatives are calculated for each point; and whether local maxima and minima of the generated surface occur at the places as the input data. The user should be aware of the variable values when creating contours.

In addition to the specific contouring elements discussed above, GIS\Key™ provides the following capabilities:

> Archiving a GRID - allows grids to be removed from the basemap and stored on disk in a compressed form. By archiving a grid, disk space is saved and the grid can be accessed faster if its values are to be extracted when building a cross section. Archiving also reduces the size of the basemap.
>
> Labeling Contours - elevation labels can be interactively placed on the contour lines. The user has control of placement and text size.

Cross Section

Geologic and soil isopleth cross sections can be created in GIS\Key™. For geologic sections, the lithology of individual wells and soil borings can be portrayed on the section. In addition, profiles of previously created surfaces, such as the top of a water-bearing zone, can be displayed on the section. For soil isopleth sections, chemical concentrations at individual soil borings and wells can be displayed along with contour lines. The evaluation of this GIS\Key™ function focuses on the following elements: creation of section lines, selection of stick data versus hatch patterns, grid selection, apparent borehole width, and scale control.

To create a section line, the following menu items are selected: GIS\Geo, Sections, Get Stick Data

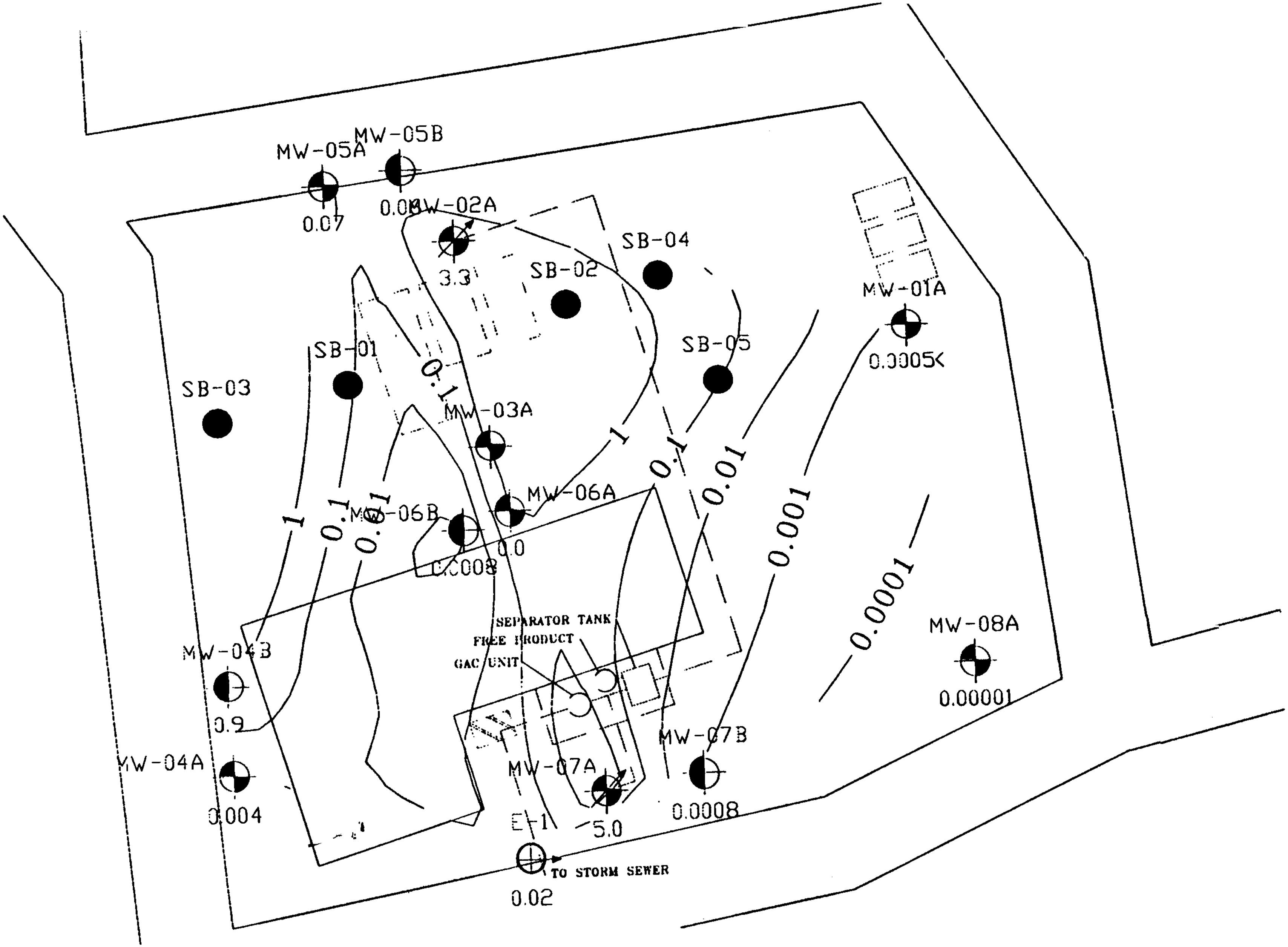


Figure 15. Contour map produced with log QuickSurf when a well (MW-06A) has a concentration value of 0.

At this point, either a new section line can be created or an existing section line can be selected using the mouse. Figure 16 shows an example section line (BB') created by the process described above. The user then selects the wells to be projected onto the section line.

No problems were encountered during this process. The following observations were noted: (1) sections do not have to be straight lines, (2) the user controls how many segments to divide up the section line, (3) the user controls whether to display the ground surface profile as well as profiles of any other previously created layers (i.e., water-bearing zones, etc.), (4) wells are projected at right angles to the section line, and (5) if the well can be projected orthogonally at two locations on the section line, the user has the option to pick either location. An additional capability to allow for the projection along the strike of a geologic formation should be included; this would allow for a more realistic portrayal of the geologic profile.

The data associated with the wells or boreholes projected onto the section line can be displayed as either stick or hatch. If stick is chosen, then the two-letter USGS abbreviation for the soil type is written along the vertical profile. If hatch is chosen, then predefined hatch patterns are displayed along the vertical profile.

Figures 17 and 18 show respectively the stick and hatch profiles for section BB'. No problems were encountered in creating these sections. GIS\Key™ provides standard soil hatch patterns (see Figure 19). The user can also define custom soil hatch patterns using AutoCAD.

In addition to vertical profiles of wells, profiles of user-selected grid layers can also be displayed on the section. The user is prompted for the individual layer names to be displayed. During the creation of the section line, the user specifies the number of intervals to divide the section line into. At each interval point, GIS\Key™ averages the values of the four closest grid nodes and then connects the interval points to draw the cross section,

For this test, four grid layers (the top and bottom of water-bearing zones 1 and 2) and the ground surface elevation layer were chosen. The cross sections of these layers are shown in Figures 17 and 18.

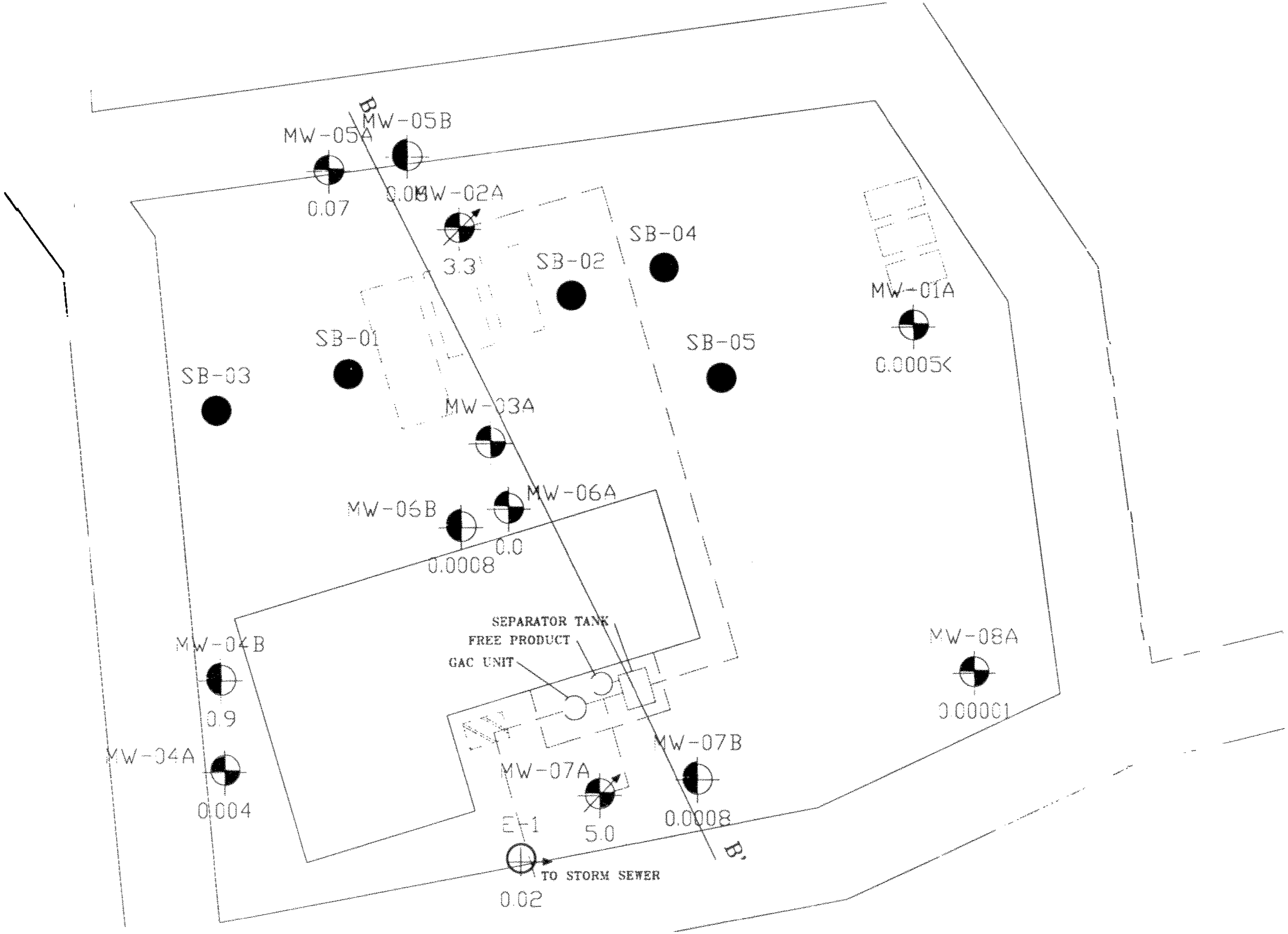


Figure 16. Creating a section line line B and B' across the site.

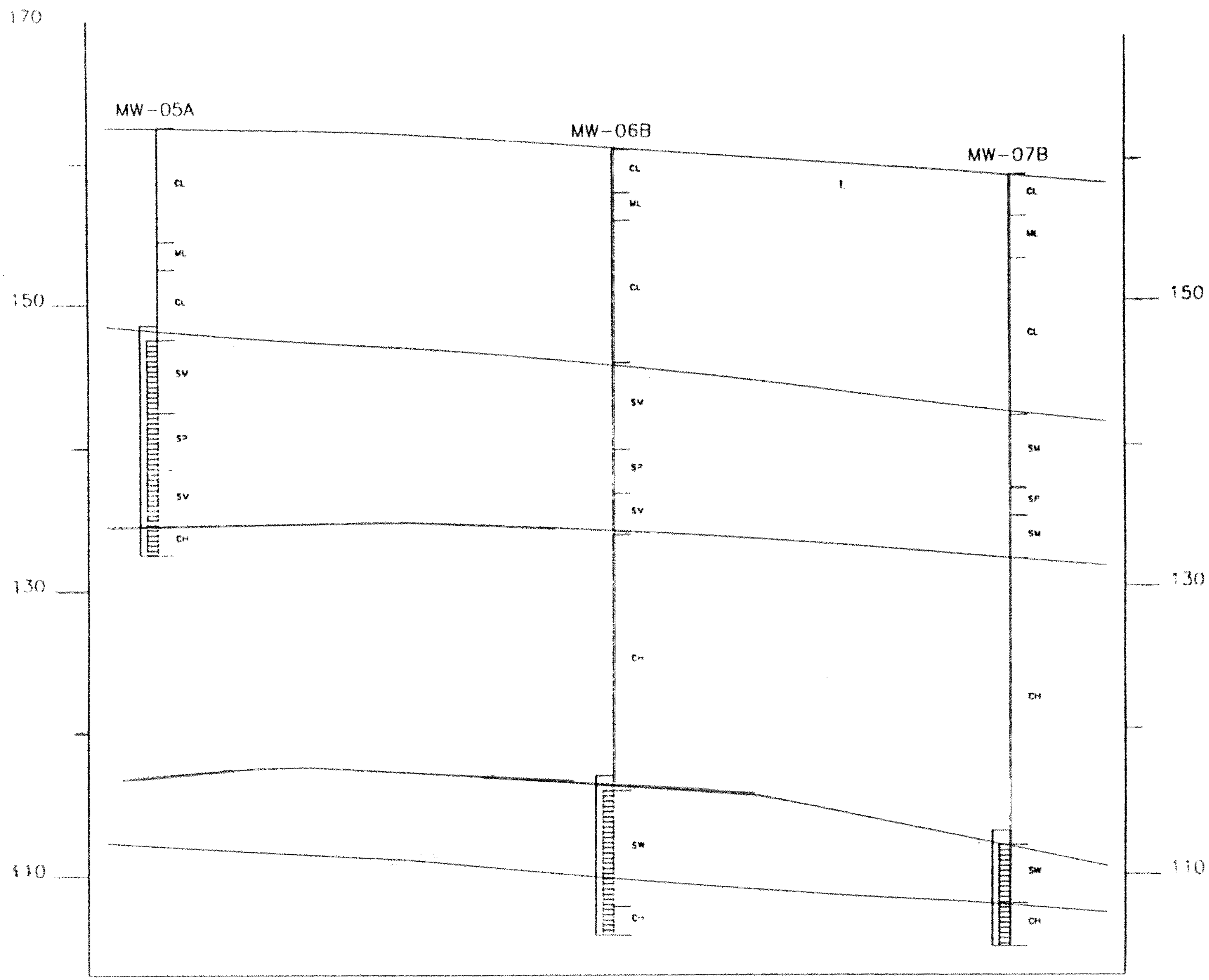


Figure 17. Geologic section (B-B') displaying stick data.

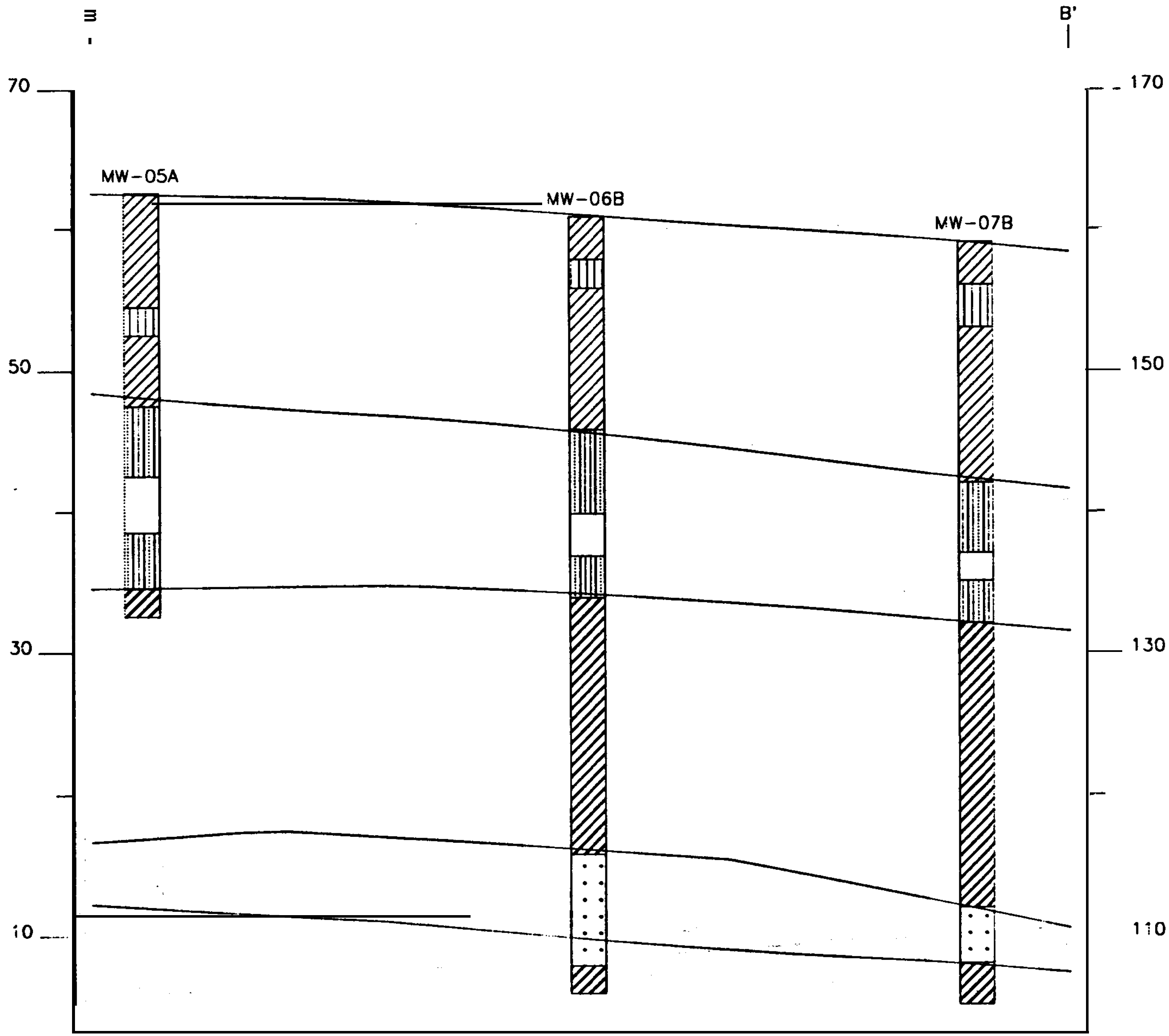


Figure 18. Geologic section (B-B') displaying hatch data.

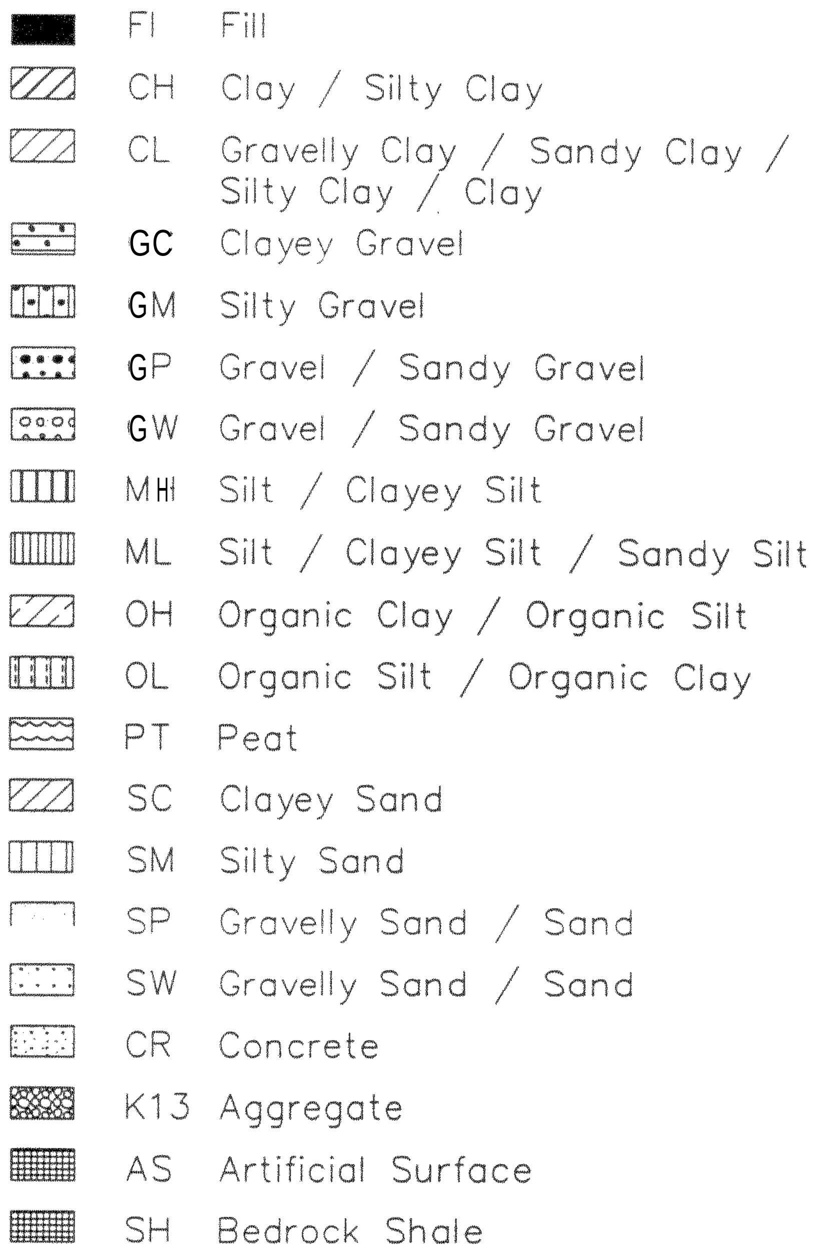


Figure 19. GIS\Key™-provided soil hatch patterns.

One drawback to the cross section display is that the section lines are not labeled or symbolized to indicate what they represent. It would be helpful to the user if each section line could be plotted with a different line type or color and a legend provided to relate the symbolization to the layer it represents.

Since the diameter of a borehole is very small in comparison to the length of a profile line, few details would be visible if the width of the borehole were drawn to scale on the section. GIS\KeyTM allows the user to draw boreholes and wells as if they had a much larger diameter, thereby making the lithology and construction details easier to see.

Figure 17 shows three monitoring wells drawn with an apparent borehole width of 5 feet. The well sand pack (dot pattern) on one side of the hole is visible. There is no indication on the plot of the apparent borehole width used or the true width.

Scale control is provided by GIS\Key^{TM} in three areas: (1) vertical exaggeration, (2) scaling the hatch pattern, and (3) changing the default scale of the section when a title block is added to prepare the cross section for plotting. Figures 17 and 18 were prepared with a vertical exaggeration factor of 2. This is not indicated on the plot; nor is the horizontal distance presented with a scale symbol but is added when a block and border are placed on with plot. This information should be added to the cross section display. Figures 18 and 20 show the results of changing the hatch scale factor; note that a legend is not provided that relates the hatch patterns to the soil types.

GIS\Key^{TM} makes it possible to display chemical concentrations in soil samples on geologic cross sections as well as on plan views. For each well and borehole selected, the concentration of a constituent is shown at every depth where a soil sample was taken. Using QuickSurf, contour lines can be added to depict the diffusion of a chemical through the soil.

Figure 21 shows a soil isopleth cross section for benzene concentration (mg/l). Since the data spread was over several orders of magnitude, log QuickSurf was used to construct the contour lines. This procedure worked well and appeared to be a useful visualization of the diffusion of a chemical through the soil.

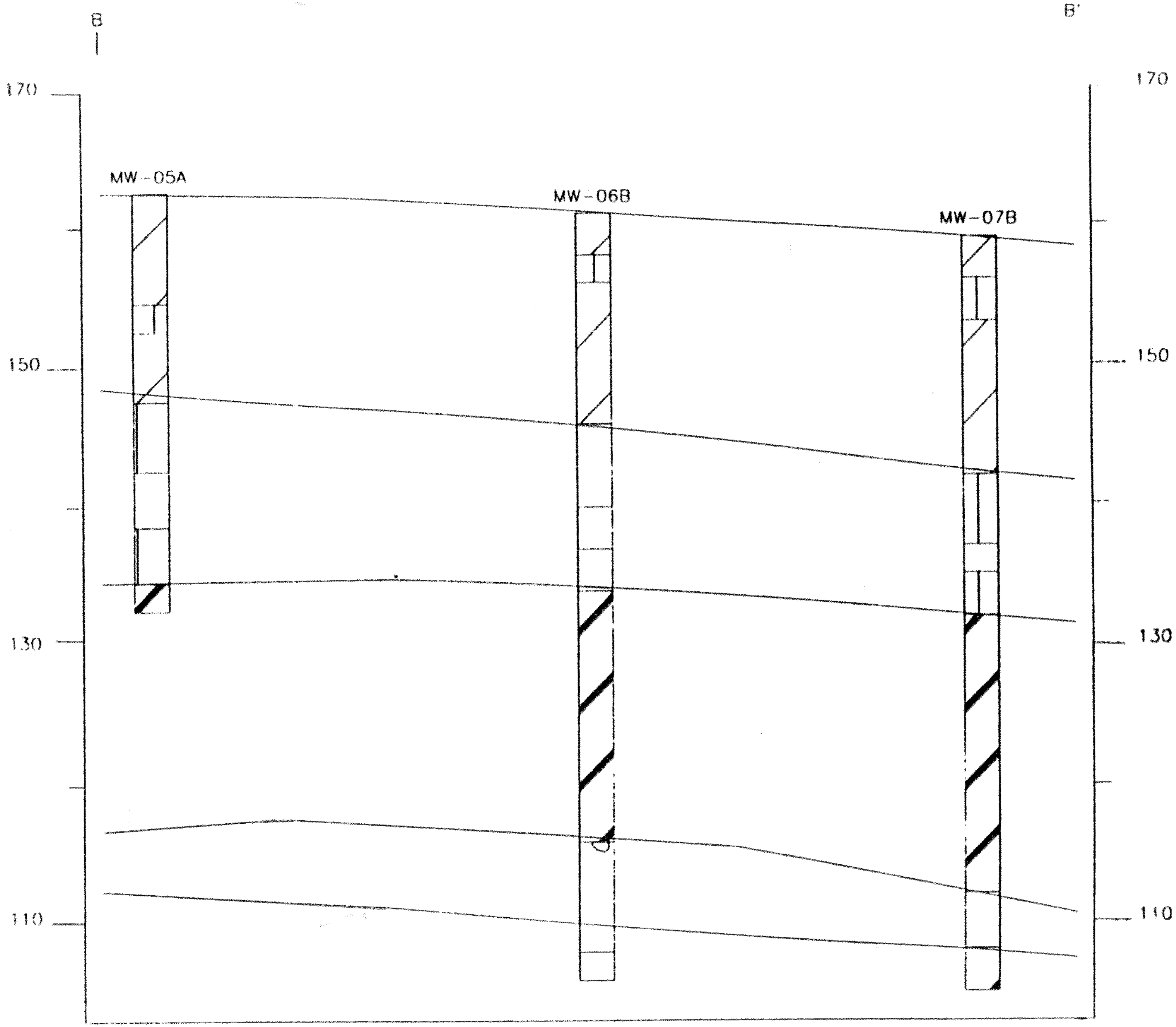


Figure 20. Geologic section (B-B′) showing the results of changing the hatch scale factor.

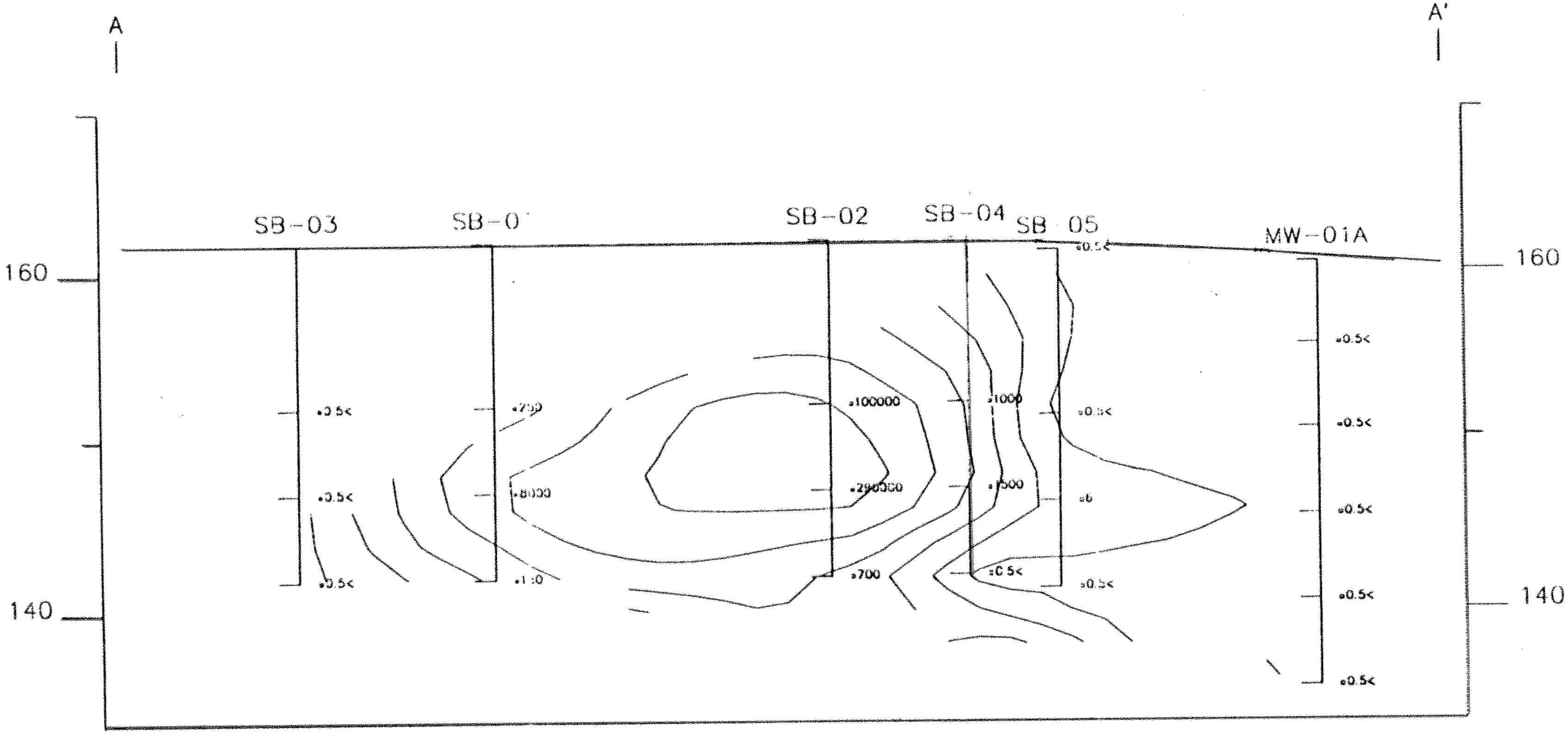


Figure 21. Soil isopleth cross-section with benzene concentration contours (mg/L).

Miscellaneous Graphics Procedures

GIS\Key™ provides several utility graphics procedures for the preparation of report-ready graphics, control of sampling site location, layer display, and rapid display of a particular portion of the basemap (a view). These elements are investigated in this subsection.

Title Block and Borders

Any of the maps, cross sections, well logs, or plots can be made report-ready by adding a title block and border. This is one of the GIS\Key™ utility functions. Figure 9 illustrates the results of adding a title block and border to a geologic structure map. The procedure was easy to use and was flexible in that: (1) the map border area could be specified interactively, (2) A-E size drawings are supported, (3) the determination and placement of the scale and north arrow is under user control, (4) the user is prompted for each item in the title block, and (5) a company logo can be placed in the title block.

Sampling Site Location Control

Within the GIS\Key™ Utilities menu, the site map symbols submenu provides the capability to change symbol location. To change the location of a well, the well symbol is selected and the user can either type in new x,y coordinates or pick a new location with the mouse. Prior to completing the change, the user is warned that the database will also be altered, and the user is required to confirm that this location change should take place.

Layer Control

GIS\Key™ stores the spatial themes associated with a project on different layers. The modify layer menu item allows the user to examine and change the characteristics of each layer. The modify layer command is easy to use and allows control over: (1) which layers to display, freeze, and thaw, (2) color and line type, and (3) which layer is active. It does not allow the user to delete or purge a layer. To delete a layer, the user must first load the AutoCAD application "DELLAYER" and use it to specify which layers to delete. Deleting only removes the data contained in the layer; the layer name remains. To completely remove a layer from the AutoCAD drawing, the purge command must be executed.

Views

Views are pre-defined rectangles that specify the minimum and maximum x,y extents of a portion of the basemap. When a view is selected, only that portion of the basemap within the view extents is displayed. This is a useful function that allows for rapid display of a section of the basemap where the site under investigation is located. Frequently, when a lot of zooming in or out is taking place, it is desirable to return to the portion of the basemap that contains the site, by having a saved view, the user can easily accomplish this. Multiple views can be defined that pertain to different portions of the basemap.

Map and Map Feature Annotation

In general, GIS\Key™ map annotation capabilities are very good since all of the AutoCAD features are available. Final production and editing of maps can be performed by a user trained only in AutoCAD; GIS\Key™ is not needed for map annotation. To make full use of the AutoCAD capabilities, skills beyond those taught in basic GIS\Key™ training are needed. No limitations or flaws in GIS\Key™ map annotation capabilities were noted during testing.

The user has almost complete control over titles, legends, and scales. Custom title blocks and borders can be easily created by modifying those supplied by GIS\Key™. These titles will be automatically used if the files containing these titles are named according to GIS\Key™ conventions. After creation, the title and legend information can be easily edited by a skilled AutoCAD user.

A very wide range of character font functions are supported by AutoCAD. Third-party AutoCAD fonts are available, but are seldom needed by GIS\Key™ users. Text size and position can be modified in numerous ways using standard AutoCAD commands. It provides the capability to store often-used entities in "blocks" that can be easily imported and modified. Assignment of style characteris tics and batch patterns is very flexible and straightforward.

Display and Product Generation

Through AutoCAD, GIS\Key™ can generate displays on graphic terminals, digital plotters, inkjet printers, color ribbon printers, matrix printers, laser printers, electrostatic printers, character printers, and film recorders. Output from GIS\KeyTM can be directed to any of the AutoCAD-supported video displays and plotters. Table 7 provides a list of these devices.

The capability to generate maps via copy of the display screen is supported by GIS\Key™ using the MSLIDE command within AutoCAD. Through the AutoCAD plot function, standard A-E size plots can be generated. In addition, custom sizes larger than the maximum size supported by the output display device can also be specified.

Table 7. AutoCAD-Supported Peripherals

Device	Model
Video Displays	Protected-mode ADI version 4.2 and previous
	Real-mode ADI version 4.1 and 4.0 or earlier
	COMPAQ Portable III Plasma Display (obsolete)†
	Hercules Graphics Card™ (obsolete)†
	XGA Display Adapter
	8514/A
	IBM Enhanced Graphics Adapter (obsolete)†
	TARGA+
	Video Graphics Array (VGA) and Super VGA (SVGA)
	VESA-compliant display
	Null display†
Plotters	Null plotter (none)†
	Protected-mode ADI version 4.2 and previous
	Real-mode ADI version 4.0 and 4.1 or earlier
	AutoCAD file formats
Plotters	CalComp Colormaster Plotters
	CalComp DrawingMaster Plotters
	CalComp Electrostatic Plotters
	CalComp Pen Plotters
	Canon Laser Beam Printer
	Epson Printers
	Hewlett-Packard HP-GL and HP-GL/2 Plotters
	Hewlett-Packard Laserjet (PCL)
	Hewlett-Packard Paintjet (PCL)
	Houston Instrument DMP Series
	IBM 7300 Series
	IBM Graphics Printer (obsolete)
	IBM ProPrinter
	JDL-750 Printer (obsolete)
	NEC Pinwriter P5, P5XL, and P9XL (obsolete)
	PostScript Laser Printer
	Raster file formats

Table 7. AutoCAD-Supported Peripherals (continued)

Device	Model
Digitizers	Null digitizer (none)+
	Protected-mode AD1 version 4.2 and previous
	Real-mode ADI version 4.0 and 4.1 or earlier
	CalComp 2500 Series Tablet
	CalComp 9100 Series Tablets
	GTCO Digi-Pad 5 Tablets (obsolete)
	Hitachi HICOMSCAN HDG Series Tablet
	Kurta Tablet, IS/ONE (Series I is obsolete)
	Kurta Tablet, SLC (Series III is obsolete)
	Kurta Tablet, Series II (obsolete)
	Kurta Tablet, IS/THREE
	Logitech Logimouse
	Microsoft Mouse (Mouse Systems Mouse and IBM PS/2 Mouse supported with this driver)
	Numonics 2200 Series Tablet (obsolete)
	Summagraphics SummaSketch MM Series Tablet
	Summagraphics MicroGrid Tablet (series II or later)

GIS\Key™ uses the AutoCAD point command (command line input or item selection from the contour menu) to produce a 3-D orthographic view of a gridded surface created by QuickSurf (see Figure 22). GIS\Key™ provides no direct capability to produce a two-point perspective view. The AutoCAD DVIEW command provides the capability to specify a camera and target position to view objects in 3-D perspective.

GIS\Key™ allows users to add interactively a map border and title block to any of the generated maps, cross sections, logs, or plots. In addition, the user has control over which layers to display; symbolization and placement of points, lines, and areas; text font and size; map scale; and north arrow. AutoCAD provides many interactive commands to control the display and layout of the spatial data.

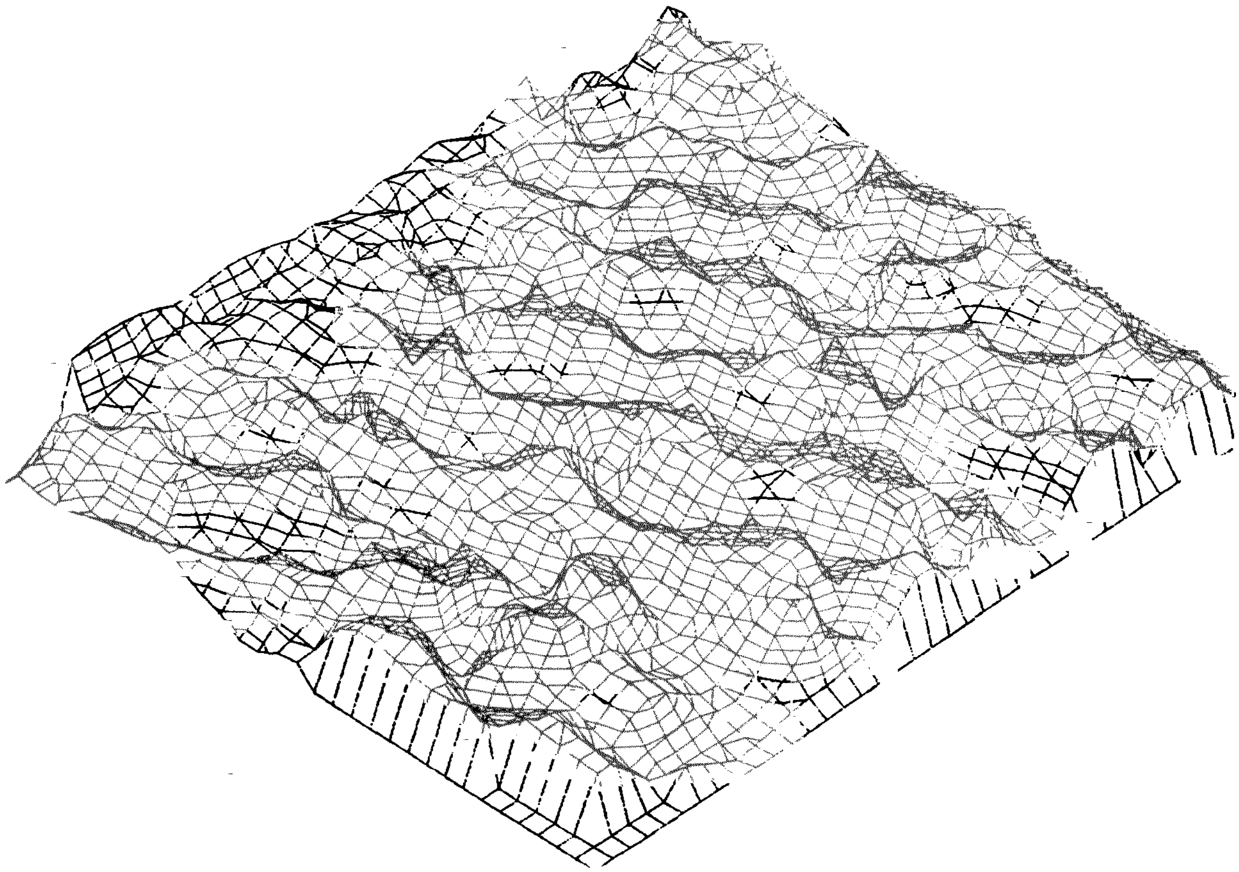


Figure 22. 3-dimensional orthographic display of the grid and contour lines generated by QuickSurf.

GIS\Key™ provides no capabilities to specify the location, size, scale, and orientation of multiple view ports on a single display. The AutoCAD view ports command allows for the designation of non-overlapping multiple view ports on the display screen. GIS\Key™ displays point (i.e., wells), line (i.e., streams, roads, contours), and polygon (i.e., lake, building outline) data.

GIS\KeyTM can display many map elements (neat-lines, grid lines, tick marks, in a latitude/ longitude, state plane or Universal Transverse Mercator (UTM) coordinate reference with annotation at specified scale) if they are digitized and included as separate layers in the AutoCAD drawing file. The coordinate system is predetermined by the user; conversions between different coordinate systems have to be done outside of GIS\Key™. The AutoCAD GRID command can display a reference grid of dots (no automatic annotation of the grid) with any desired spacing.

GIS\Key™ provides a set of 47 predefined map symbols, which the user can choose from for symbolizing wells and other point data (see Figure 23). In addition, a set of 20 different soil hatch patterns is provided (see Figure 23). AutoCAD also provides a variety of point symbol types, line types (selectable color and width), fill patterns, and text fonts, all selectable from existing tables.

2.3.6 Products

The ability of GIS\Key™ products to assist analysts in achieving the goals of the site characterization were assessed. Definition of the hydrogeological regime, identification of the uppermost aquifer, and evaluation of potential pathways for chemical migrations are the foundation for groundwater monitoring programs and are crucial to the placement of monitoring wells. This subsection discusses the following products: contour maps, tabular chemistry reports, geology tables, hydrogeologic tables, geologic logs, and types of graphs.

Contour Maps

The mapping of movement of contaminated groundwater is an important aspect in the design of any landfill, holding or disposal pond, or reclamation project. Four types of contour maps can be produced by GIS\Key™ to assist in groundwater mapping: hydrogeologic maps, chemical concentration isopleths, geologic structure elevation maps, and geologic structure thickness isopach maps. The components of each of these contour maps and their uses are provided in Table 8.

Tabular Chemistry Reports

Several standard chemical reports are available through GIS\Key™ standard menus. The report generation process provides the user with several standard options. For example, on the primary results table, the user can choose whether or not to display the printing date on a tabular report, to filter the results for selected test methods, portrait or landscape orientations, to show Contract Laboratory Program (CLP) and expert (i.e., user defined) review qualifiers, or to screen out chemicals that are non-detects for all wells and sampling points detected.

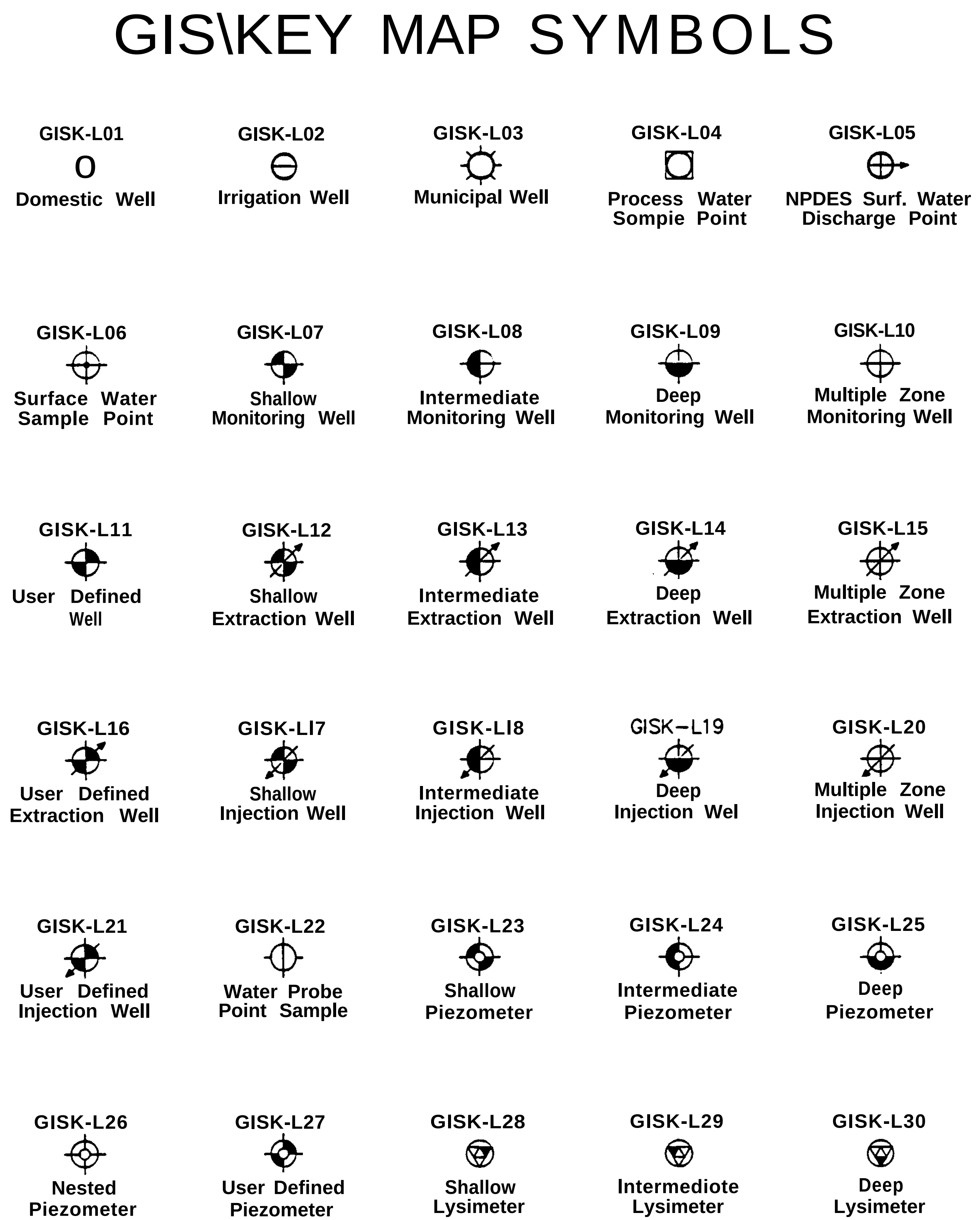


Figure 23. GIS\KeyTM map symbols

GIS\KEY MAP SYMBOLS

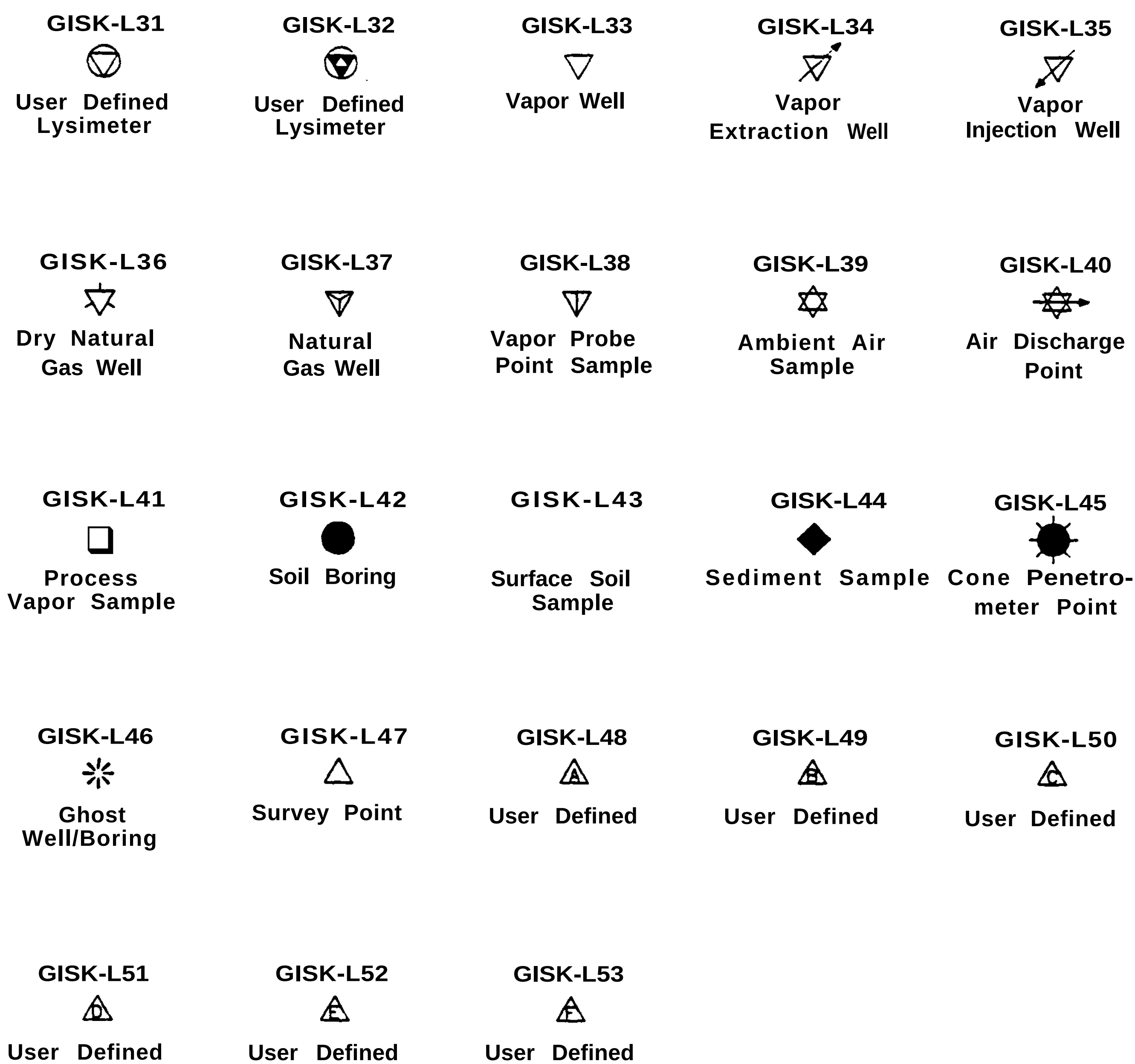


Figure 23. GIS\KeyTM map symbols (continued)

Table 8. Types of Contour Maps

Contour Type	Uses	
Hydrogeologic Maps	Determine which way and how fast the groundwater is moving	
Fluid level elevation - water table contour maps	Show elevation data (hydraulic head) from unconfined water beanng units where the fluid surface is in equilibrium with atmospheric pressure	Help to evaluate the direction of ground water flow and the energy gradient under which it is flowing
Fluid level elevation - potentiometric surface maps	Show elevation data from confined water bearing units where the fluid surface is under pressure because of the presence of a confining geologic unit	
Equivalent freshwater head	Fluid level elevation map which takes into account the specific gravity of both the floating product and water in a well plus the base elevation of the water bearing zone that the well intersects	Essentially a density-corrected water elevation map
Hydraulic conductivity	Show the rate of water flow through soil under a unit gradient per unit area Portray the variations in the water-bearing properties of materials which comprise each water bearing zone	GIS\Key™ stores vertical and horizontal conductivity data for up to five water bearing zones Necessary parameter for computing ground water flow rates, which is important since groundwater velocity exerts a major control on plume shape
Specific storage	Show the volume of water released from storage by a unit volume of saturated aquifer under a unit decline in hydraulic head	Graphically shows the variations in potential water release for each defined water bearing zone
Specific yield	Show the volume of water released from storage by an unconfined aquifer, of unit area of aquifer, under a unit decline in the water table level	Commonly referred to as the amount of water that can be drained from a soil by gravity
Chemical Concentration Zsopleths	Portray areas of equal concentration for one or more chemicals	If the chemical concentration ranges over several orders of magnitude, log transformed isopleths can be generated Isopleth maps can be generated in both plan and section view
Plan view isopleths	Show chemical concentration in either soil or water samples	Figure 14 is an example plan view, log transformed, isoplet map for benzene concentration in water
Section view isopleths	For visualizing the diffusion of a chemical through soil	Created only for soil samples

Table 8. Types of Contour Maps (continued)

Contour Type	uses	
Geologic Structure Elevation Maps	Contour maps in which each line represents the elevation of the top of a geologic material or facies	GIS\Key™ can produce these maps based on the selection of one of four structure parameters
Geologic formations	Contours the top of a user defined geologic formation	
Blow counts	Contours the top of a structure identified by the first, second, or third occurrence of a specified range of blow counts	A blow count is defined as the number of standard blows required to advance a sampling device into six inches of soil
Soil units	Contours the top of a structure identified by the first, second, or third occurrence of one or more soil types	
Other units	Contours a structure surface identified via user defined characteristics (i.e., top and/or bottom of a water bearing zone)	
Geologic Structure Thickness Zsopach Maps	Contour maps that show the thickness of a specified feature	They can be created for the same structure parameters described above To compute thickness, the top and bottom of the desired layer must be identified

The choices to specify the data to be reported are presented in a way similar to those required to perform a menu-prompted database query. Differences between table selection criteria and database queries are outlined below. These differences correspond to the need to tabulate a variety of data required for tables, rather than select a specific subset of data required for contour map generation.

- A range of dates or "sampling events" can be specified for tables, rather than the single "sampling event" available during menu-prompted database query.
- Template Constituent Lists and Reporting Constituent Lists are used to determine which chemical results should be tabulated. This allows user-defined groups of chemicals to be easily selected.
- Units of measurement can be specified. GIS\Key™ automatically performs any necessary unit conversions.

Although the variety of tabular formats is fairly large, many users expressed the need for additional selection criteria and greater flexibility in table presentation. Many users reported that they needed to use third-party database tools to perform such complex queries and to design their own report format.

The chemistry data tables supported by GIS\Key™ include the following:

- Sample Summary
- Sample Detail
- Holding Times
- Blanks
- Matrix Spikes
- Control Samples
- Duplicates
- Surrogates
- Splits
- Action Level Summary
- Reporting Limit Summary
- Field Measurements (purge water, recovery)

Geology Tables

Well construction and borehole summary tables can be prepared using GIS\Key™ menu commands. Format flexibility is similar to the chemistry tables. Many users reported that they used third-party database tools to design their own report format.

Hydrogeologic Tables

A "flow data" and a "fluid level" table design is available as output from GIS\Key™. Options available include the following:

- Inclusion of floater thickness and equivalent freshwater head
- Sort by date or by site
- Date interval
- Units of measurement (cubic feet or gallons)
- Program type

Geologic Logs

GIS\Key™ can prepare well and borehole logs based on the information in the project database. Standard borehole logs include a comprehensive amount of information:

- Location, drilling methods, and dates
- A depth scale

- Soil sample information
- Blow counts
- Graphic soil hatch patterns
- Textual lithology descriptions

Well construction logs additionally include:

- Casing diameters and lengths
- Pack and seal information
- Perforation descriptions
- Measuring point information

The user cannot prespecify any well or borehole log options. However, logs generated from the graphical GIS\Key™ environment can be edited with AutoCAD. GIS\Key™ does not check all well construction parameters for consistency during data entry. Incorrectly entered well data may cause well log production routine failure. In addition, several user fields have been added that can be incorporated into the custom templates.

Types of Graphs

A variety of chemistry and hydrology graphs can be produced by GIS\Key™. A description of the various graphs and their components that can be generated is listed in Table 9.

2.3.7 Software Products versus Reporting Requirements

The subsection discusses the general reporting requirement associated with a hazardous waste site and how the GIS\Key™ software can assist in making these reports. Reporting varies for each site. The reporting requirements for a site are not as dependent upon the specific legislation, but are generally established by the needs of the state and local regulatory authorities.

For a Superfund site, specific stages in the remedial activity have been outlined under CERCLA For preliminary assessments, site characterization data including topography, geology, hydrology, and location of the release are generally required. Once the preliminary site characteristics have been deter-

Table 9. Types of Graphs

Graph Types	Uses
Chemistry Graphs	
Concentration vs. time	Shows the variation in the concentration of one or more chemicals over time (see Figure 24)
Chemical vs. chemical	Shows the correlation between the concentrations of two chemicals at the same sampling site (see Figure 25)
Site vs. site	Shows the correlation between the concentrations of the same chemical at two different locations (see Figure 26)
Distance concentration	Shows how chemical concentration varies with distance along a user-defined profile (see Figure 27)
Statistics	Creates a statistical summary of chemical concentration over time, showing mean, standard deviation, and confidence interval (see Figure 28)
Depth vs. constituent	Shows the variation in concentration as a function of depth for one or more chemicals (see Figure 29)
Trilinear Pipers	Creates a triangular diagram that shows the concentration of cations and anions as percentages, allowing major groupings and trends to be identified visually (see Figure 30)
Hydrology Graphs	
Hydrograph	Shows the variation in fluid levels over time (see Figure 31)
	Included in this graph is water surface elevation, floater surface elevation, and equivalent freshwater head
Flow rate	Shows average flow rate between measurements during a specified interval of time (see Figure 32)
Cumulative flow	Shows total flow to date for a specified period of time (see Figure 33)
Flux rate	Shows the average flux rate (the product of the flow rate and chemical concentration) for a single chemical between measurements (see Figure 34)
Cumulative flux	Shows the total flux to date for a single chemical for a specified period of time
Floater thickness	Shows the thickness over time of floating product in a selected well
Sinker thickness	Shows the thickness over time of sinking product in a selected well

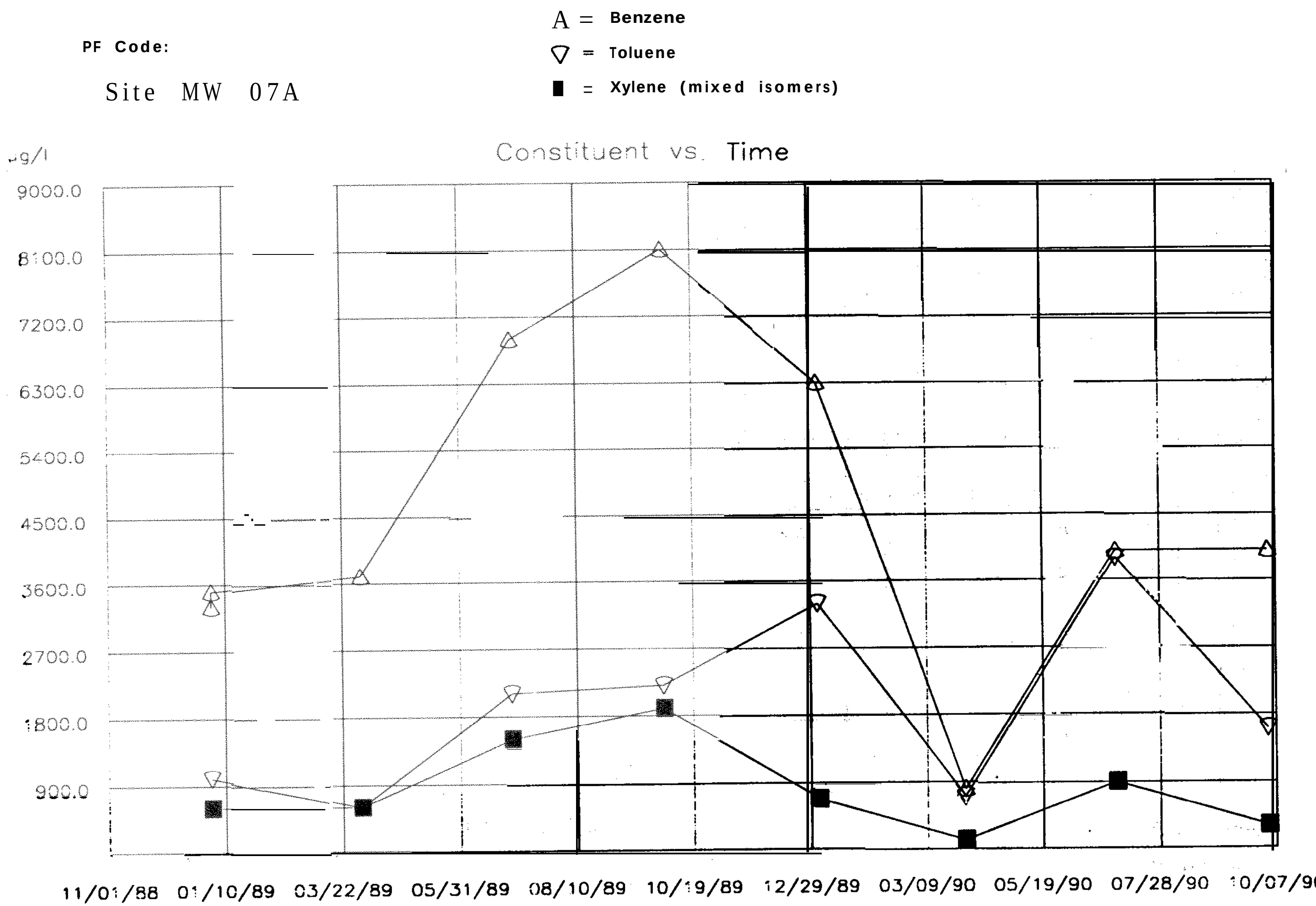


Figure 24. Plot of concentration vs. time for benzene, toluene, and xylene (Well MW-07A).

Site: MW-06A

PF Code: T

X = Benzene

Y = Toluene

Event: 88-S-01 thru 90-Q-04

Period: 11/01/88 - 10/07/90

Correlation Coefficient 0.9080

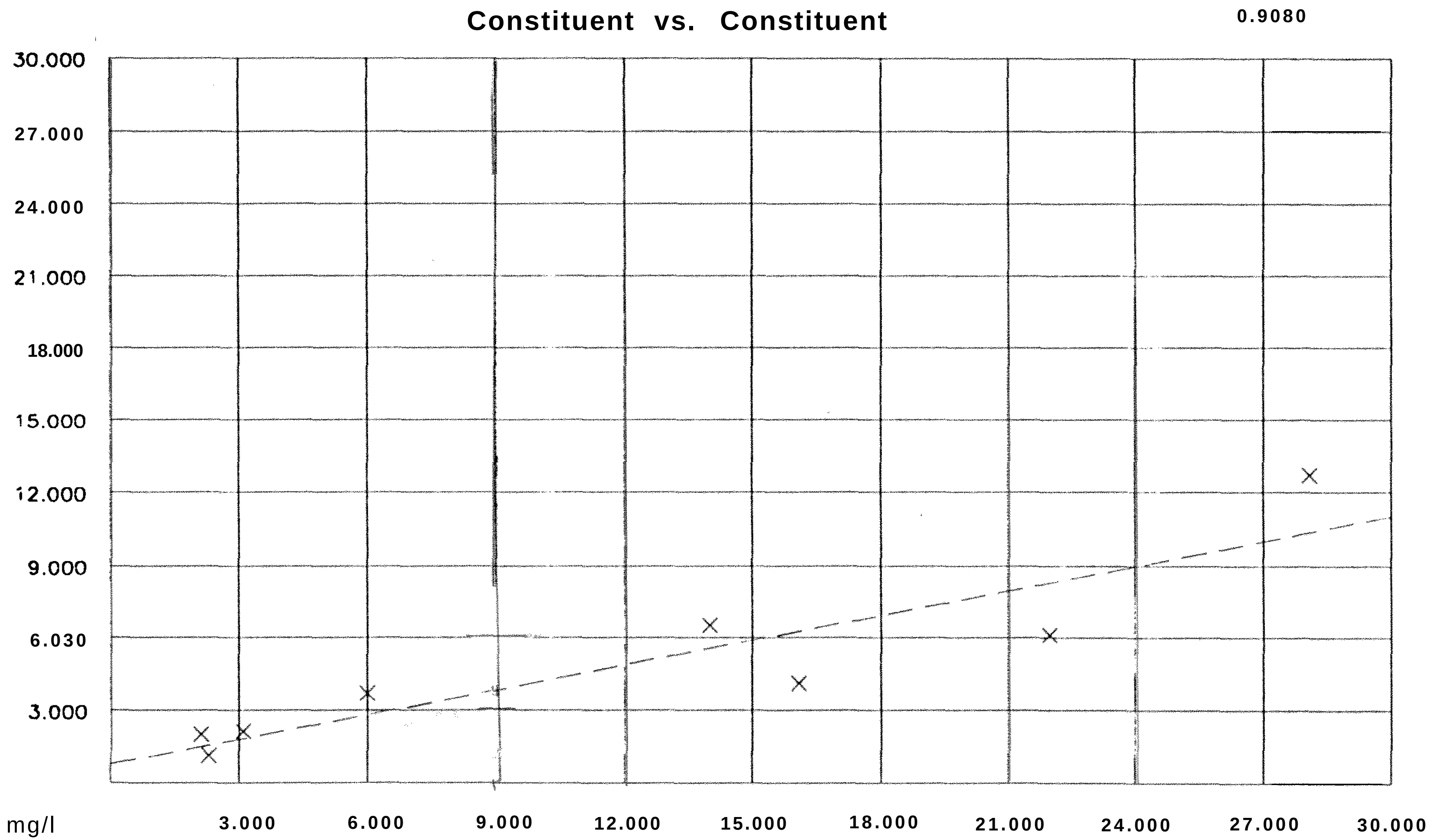


Figure 25. Plot of benzene vs. toluene for monitoring well

Constitutents Toluene

Code:1

X –MW- 06A

Y– MW-07A

Event: 66-S-01 thru 90-0-04

Period: 11/01/88 – 10/07/90

Correlation Coefficient -0.0479

Site vs. Site

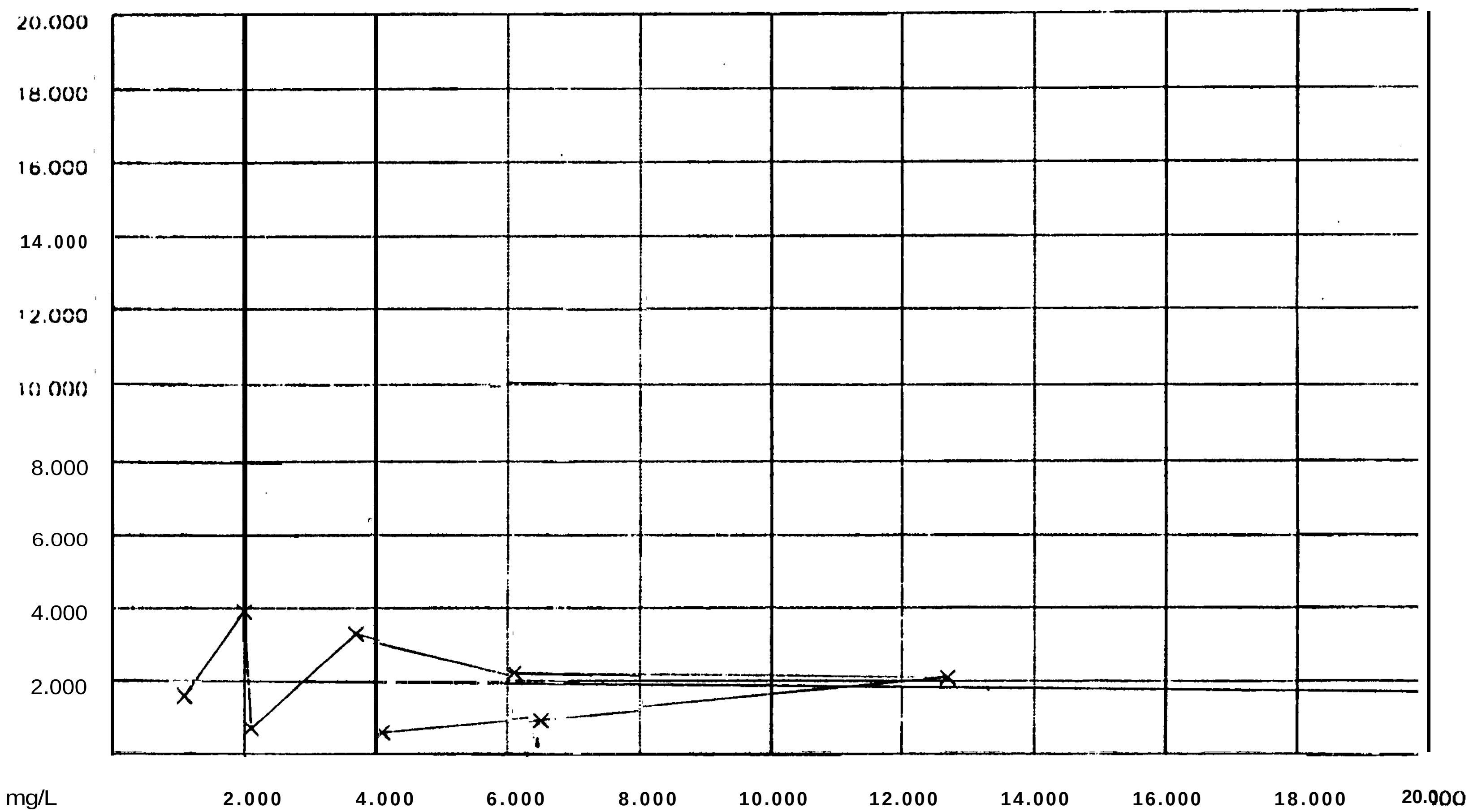


Figure 26. Plot of toluene concentration at wells MW-06A and MW-07A.

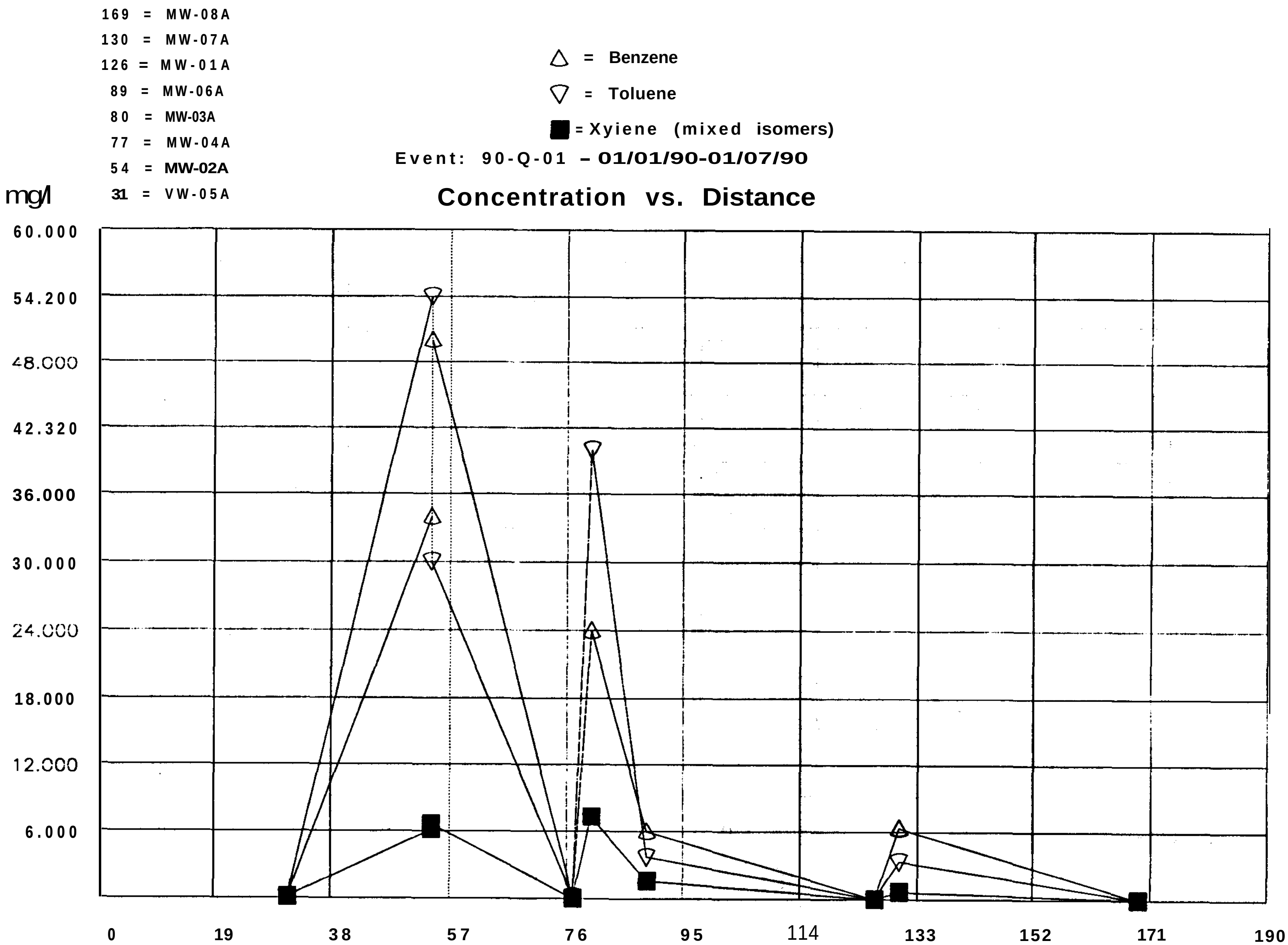


Figure 27. Plot of benzene, toluene, and xylene concentration along a user-defined profile.

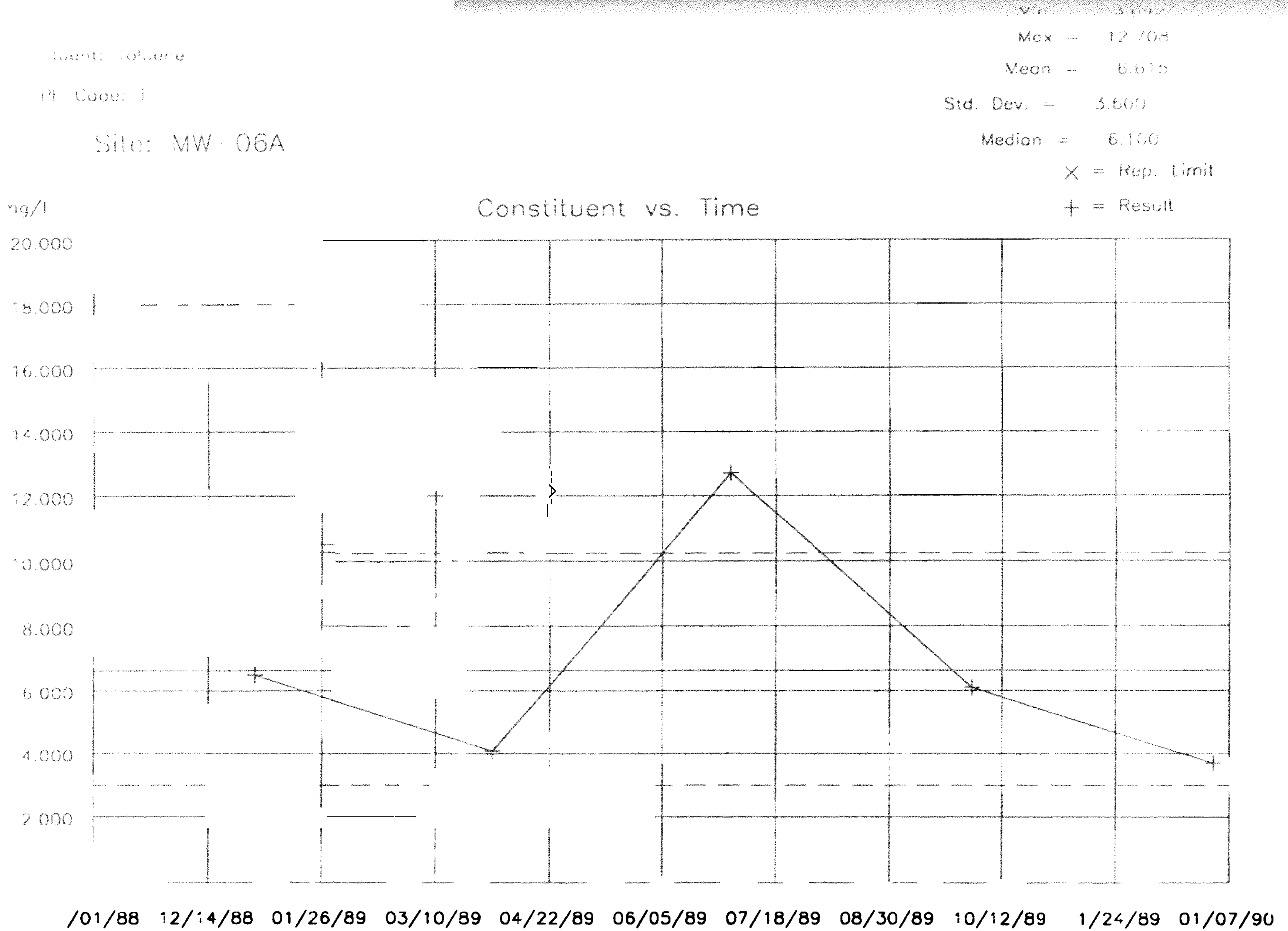


Figure 28. Plot showing toluene concentration vs. time and statistical summary results.

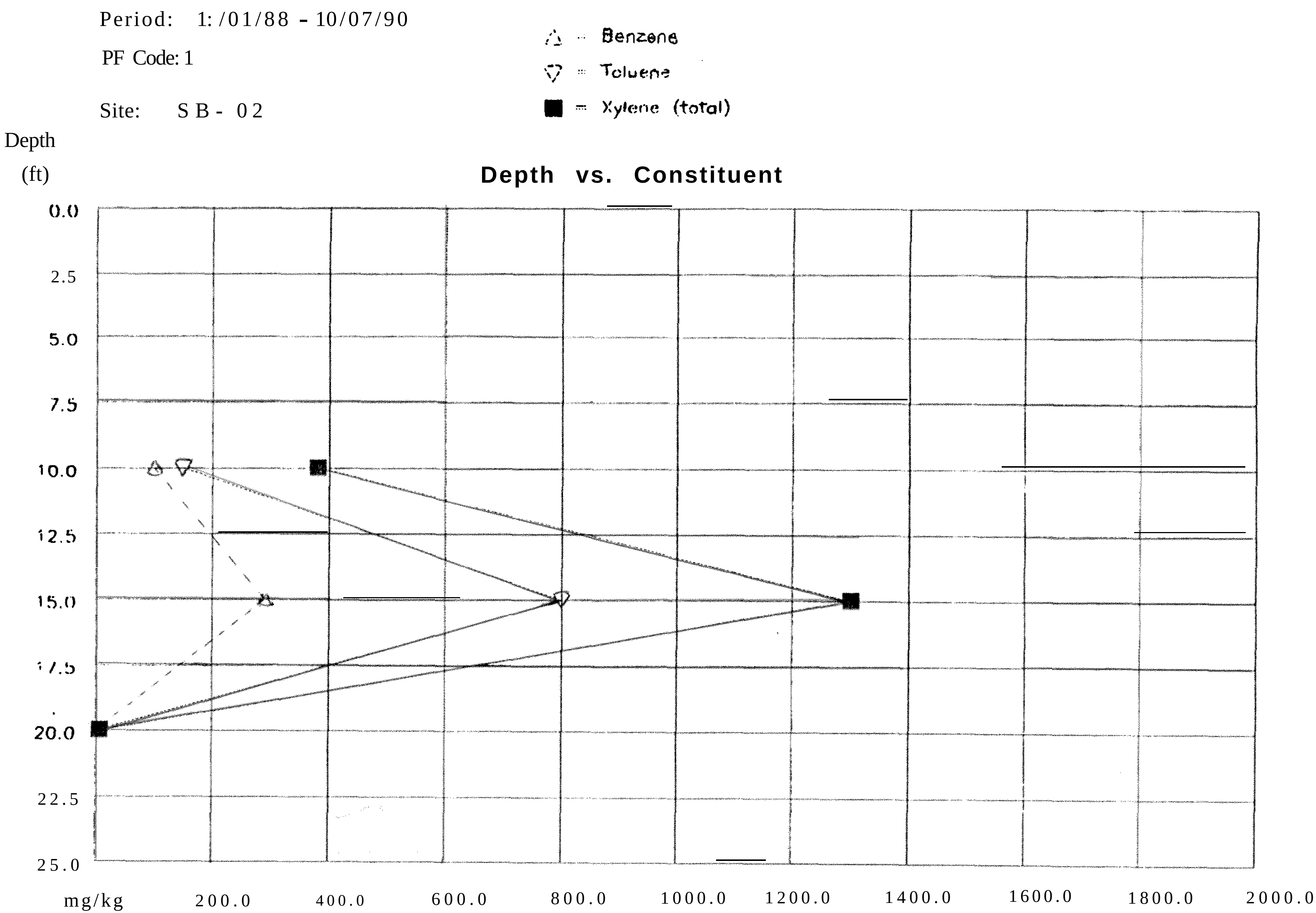


Figure 29. Plot of concentration vs. depth for benzene, toluene and xylene.

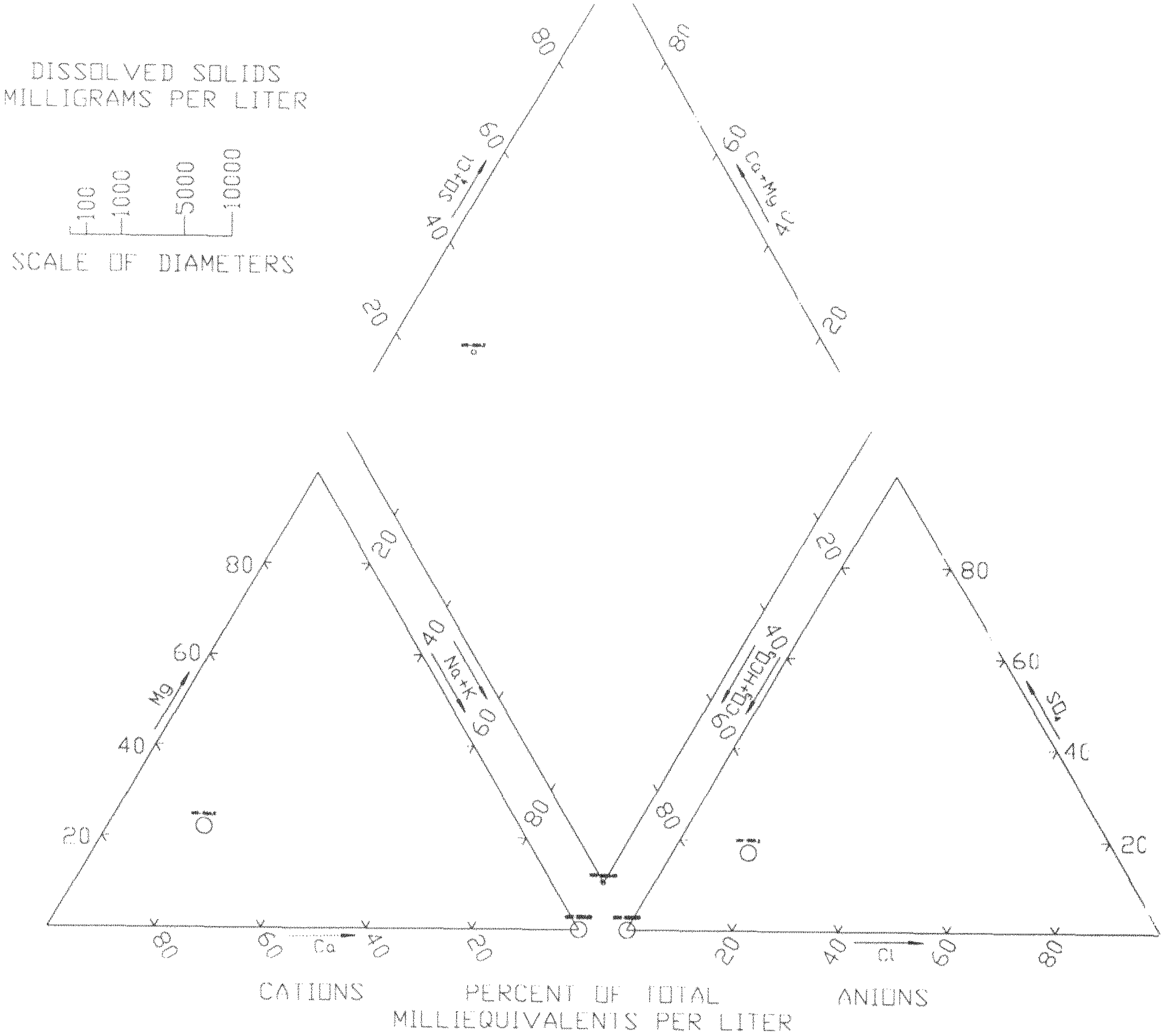


Figure 30. Trilinear Piper diagram for Well MW-06A.

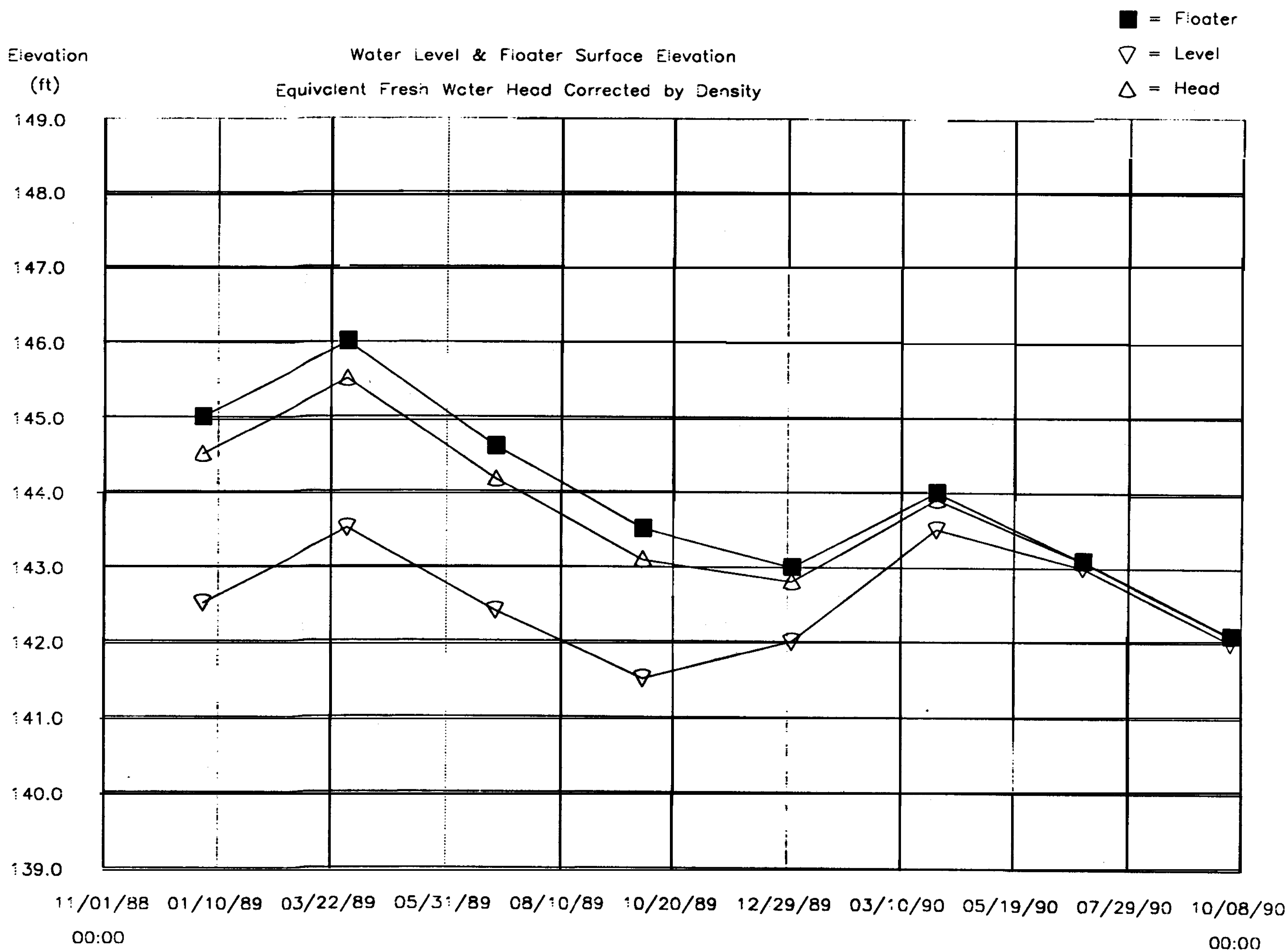


Figure 31. Hydrograph for site MW-03A.

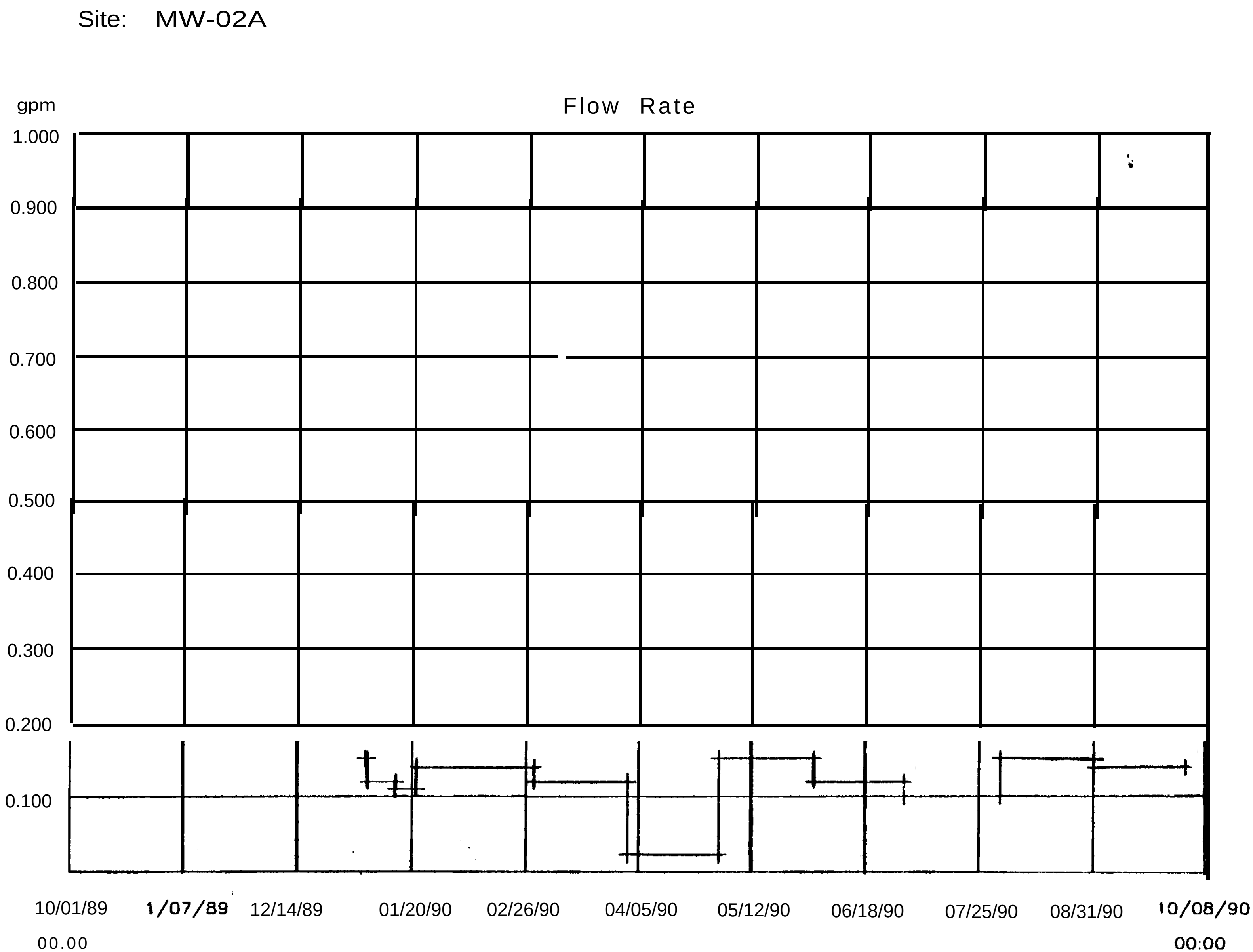


Figure 32. Flow rate for site MW-02A.

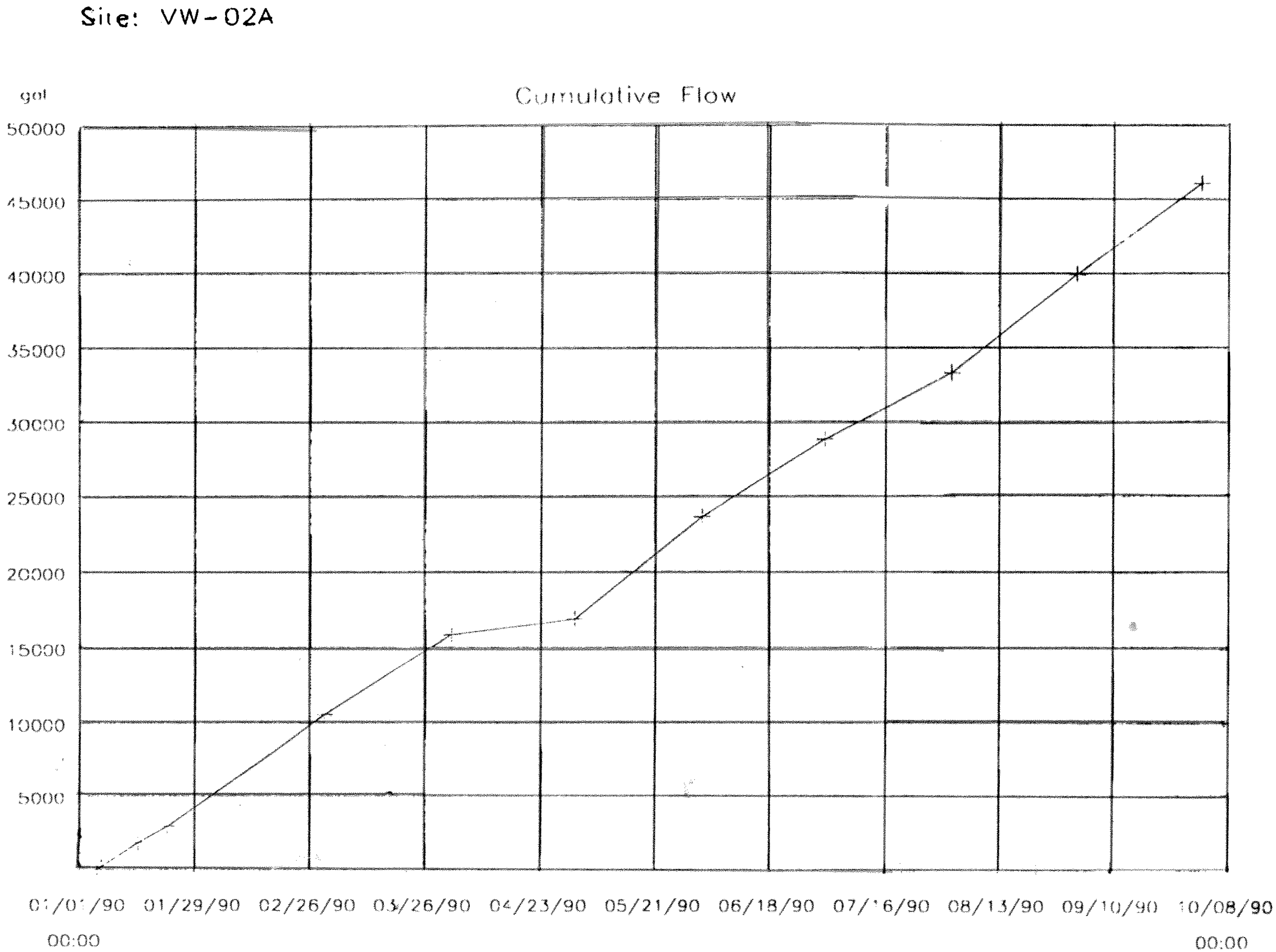


Figure 33. Cumulative flow for site MW-02A.

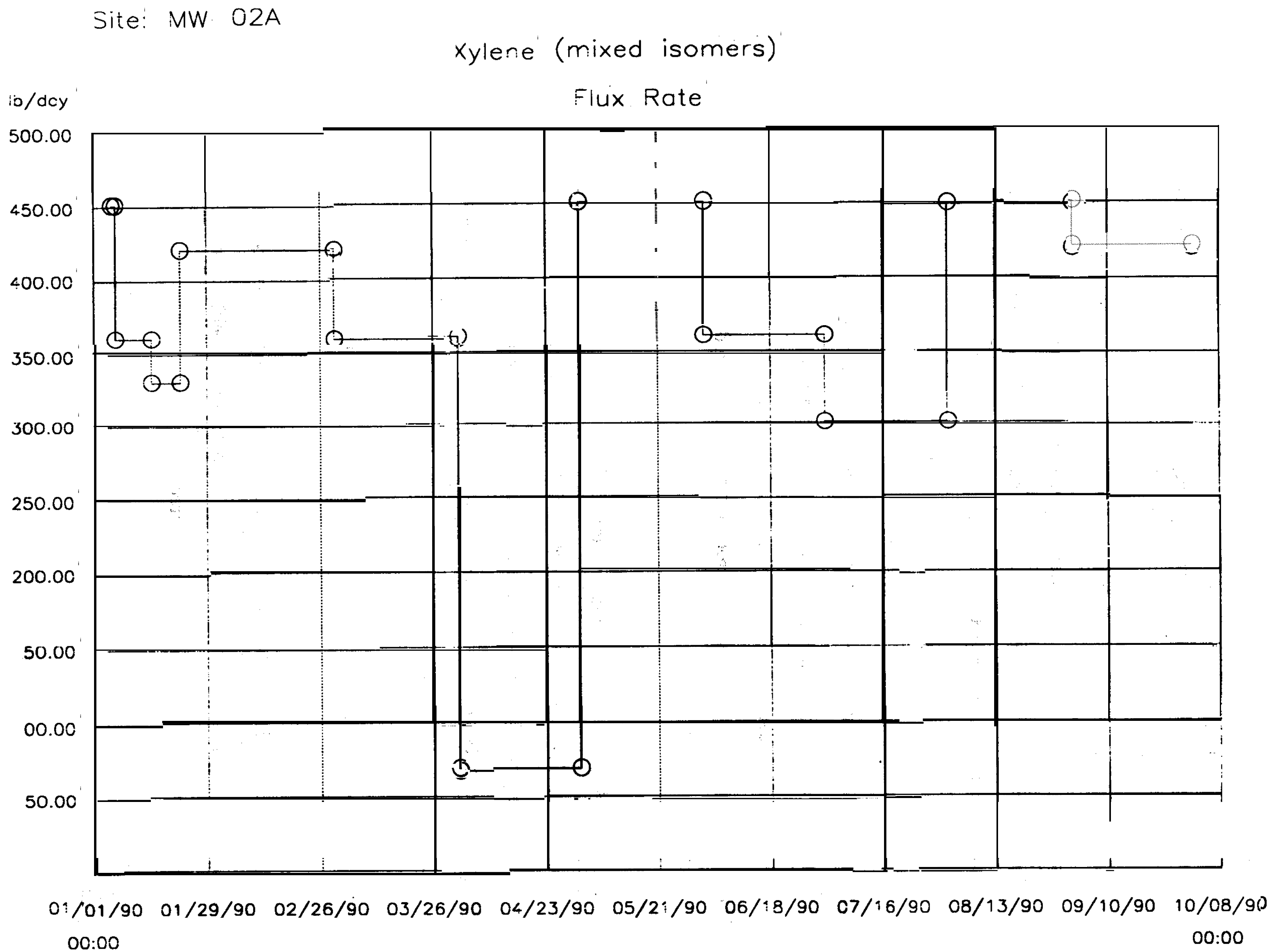


Figure 34. Flux for xylene at site MW-02A.

mined, an RI/FS is undertaken, where the site conditions are assessed and remediation alternatives are evaluated. Field investigations are conducted to assess the characteristics of the site including important surface features, soils, geology, hydrogeology, meteorology, ecology, and exposure pathways.

OSWER has defined certain critical data elements that should be included during the submittal of site characterization data. These elements should help site managers thoroughly and accurately characterize the geology, hydrology, and plume development found at a site with groundwater contamination. Table 10 lists these reporting elements and the GIS\Key™ module that would be used to generate the report.

When a hazardous waste management unit is being closed, it must meet the closure and post-closure requirements found in 40 CFR 264 or 265. These requirements include monitoring groundwater if residues remain, and if a release was detected from a surface impoundment, semi-annual reporting of the progress of the corrective action program and groundwater monitoring data. All surface impoundments, waste piles, land treatment units, and landfills receiving waste after July 26,1982, must be able to detect, characterize, and respond to releases of hazardous constituents to the uppermost aquifer. Sections 40 CFR 264.91 through 264.100 include requirements for conducting a compliance groundwater monitoring program whenever hazardous constituents are detected. General groundwater monitoring requirements (40 CFR 264.97) include provisions for a sufficient number of wells installed at appropriate locations and depths, determination of background concentrations, and sampling of the wells at least four times per year.

It is in the interest of the responsible party to collect and compile all of the site data in such a way as to make it understandable to the public and EPA. The GIS\Key™ Environmental Data Management System can greatly assist in this undertaking. Topographical and geological features can be depicted, hydrogeological characteristics can be shown, locations of contaminants within the soil and groundwater can be described, and contaminant pathways can be predicted.

2.3.8 Hardware Considerations

The three hardware configurations used during the evaluation of GIS\Key™ at the SAIC offices in McLean, Virginia, San Francisco, California, and Cincinnati, Ohio are listed in Table 11. The details of

Table 10. Reporting Elements and Associated GIS\Key™ Module

Critical Element	GIS\Key™ Module
Depict significant geologic or structural trends and geologic and structural features relative to groundwater flows	GIS\Geo- Sections GIS\Geo- Maps-Structure
Surface topographic features like contours, man-made features, water bodies, wells, site boundaries, RCRA units, and waste management areas	Contouring ADC basemaps imported to GIS\Key™ as .dwg files User-digitized map layers Utilities - Site map symbols
Groundwater direction and variation, hydraulic conductivities of hydrogeologic units	GIS\Hydro- Maps: fluid level, horizontal conductivity, specific storage, specific yield GIS\Hydro- Graphs: hydrograph, flow rate, cumulative flow, flux rate, cumulative flux
Identification of the uppermost aquifer and the confining layer	GIS\Geo- Maps-structure GIS\Geo- Maps-isopachs

the minimum and recommended hardware configurations for running GIS\Key™, as well as peripheral device support, can be found in Table 12.

GIS\Key™ supports data capture indirectly through the AutoCAD supplied drivers for digitizers (see Table 7). The one configuration tested included a Summagraphics Summasketch MM Series tablet which could function as a digitizer or a mouse. No problems were encountered with this digitizer or its driver. The tablet operated in interrupt mode through a serial connection (COM2,9600 baud, odd parity, 8 data bits, 1 stop bit, binary data stream). These specifications are compatible with the AutoCAD driver.

GIS\Key™ direct data conversion utilities are provided by AutoCAD. Using the AutoCAD tablet configuration command, a conversion from digitizer x,y to map coordinates were established without a problem.

Table 11. Configurations and Peripherals

	McLean, Virginia	San Francisco, California	Cincinnati, Ohio
Configuration	**386-33** MHz PC with math co-processor (DOS 5.0)	486-33 MHz PC with math co-processor (DOS 5.0)	48633 MHz PC with math co-processor (DOS 6.0)
	4MbRAM	8MbRAM	16MbRAM
	300 Mb hard drive	230 Mb hard drive	240 Mb hard drive
	3.5" and 5.25" floppy drives	3.5" and 5.25" floppy drives	3.5" and 5.25" floppy drives
	VGA card and 14" color monitor	SVGA card and 17" color monitor	SVGA card and 14" monitor (0.28 DP)
	Logitech mouse	Microsoft mouse	Dexxa MF21 mouse
	2 serial ports	2 serial ports	2 serial ports
	1 parallel port	1 parallel port	1 parallel port
Peripherals	Hewlett-Packard Paintjet color plotter (180 dpi) connected to the parallel port Summagraphics Summasketch MM II digitizing tablet (500 dpi, 12" x 12" surface) connected to the second serial port (COM2)	None	Hewlett-Packard Laserjet II printer (300 dpi, 4 Mb memory) connected to the parallel port

Processing large (> 1 Mb) AutoCAD drawing files was slow due to the limited memory available. Table 13 presents timing results for several processes on three different platform configurations. Although GIS\Key™ performed all its functions on a 386 class PC (4 Mb RAM), the timing results shown in Table 13 indicate that the optimum hardware configuration should be used to achieve work efficiency.

Table 1 lists the video displays supported by AutoCAD. The configuration using a VGA card

Table 12. Recommended and Minimum Hardware Configurations for GIS\Key™ Release 1.1.2

Recommended Hardware Configuration	Minimum Hardware Configuration
486-66 Motherboard with 256K Cache	386-20 Motherboard with 387-20 Coprocessor
16MbRAM	4 Mb RAM (8 Mb for AutoCAD release 12)
20” Monitor	14” VGA Monitor
1.2 Gb SCSI Hard Drive	100 Mb IDE Hard Drive
3.5” and 5.25” Floppy Drives	3.5” Floppy Drive
101 Keyboard and Mouse/Digitizer	101 Keyboard & Mouse
SCSI Controller	
250 Mb Tape Backup	

Table 13. Selected Processing Times

Process	Time		
	386-33/4Mb RAM	486-33/8Mb RAM	486-33/16Mb RAM
Load GIS\Key™	40 seconds	23 seconds	13 seconds
Open a 1.9 Mb drawing	3 minutes 45 seconds	1 minute, 50 seconds	1 minute, 21 seconds
Open a 322 Kb drawing	40 seconds	18 seconds	14 seconds
Swap out to database	35 seconds	22 seconds	2 seconds
Plot 1.9 Mb drawing	14 minutes	NA	1 minute, 28 seconds
Plot 322 Kb drawing	5 minutes	NA	1 minute, 22 seconds

NA - Not available

which was satisfactory but lacked sufficient resolution to display readable text when zoomed out. The 17", 1024 x 768,256 color monitor provided a much better display. A standard 101 keyboard and Logitech mouse were also considered satisfactory. Initially, the mouse was used as the pointing device in GIS\Key™. Later, the Summagraphics tablet and cursor were substituted for the mouse. This change was easily accomplished by substituting the proper digitizer driver in AutoCAD.

A 300 Mb internal Seagate hard drive proved satisfactory for the evaluation but may be inadequate for projects with large data requirements. Tape backup is recommended to avoid data loss due to hard disk failure. A CD-ROM reader would be useful since many digital data sets are now being released on this medium,

Hard copy can be output by GIS\Key™ to a variety of devices which are supported by AutoCAD (see Table 7). A Hewlett-Packard Paintjet plotter proved to be quite satisfactory for making 8.5 x 11 inch plots. In addition to the plotters listed in Table 7, Postscript files can also be created by AutoCAD through the psout command. This function was tested and worked well; output was sent to an Apple Laserwriter II printer.

2.3.9 System Training and Support

Two levels of training are available with GIS\Key™ basic and advanced. Basic training takes 3-1/2 days of hands-on practice; while advanced training involves 2 more additional days. Basic training is designed for users of all levels of computer expertise; advanced training is designed for users who need to know more about GIS\Key™ internal design and functions. At appropriate points throughout the text, the potential need for users to have different skill levels is defined. The following discussion of the basic training provided by GIS\Solutions is based on attendance at two training courses and on user interviews.

Basic training typically starts at a very fundamental level. Essential elements of DOS (e.g., directories, starting programs, etc.) are covered first. The majority of the first day is spent on AutoCAD; this reflects the absolute necessity of knowing basic AutoCAD in order to use the graphic component of GIS\Key™. AutoCAD topics covered include simple drawing and editing commands, views and zooms, layer control, and basic system commands (“open file,” “list,” “status,” etc.). The material covered is sufficient to enable users to perform basic GIS\Key™ functions, but more advanced AutoCAD skills will be needed to maintain site basemap and prepare final production maps and figures. Proper use of AutoCAD commands to maintain links between the basemaps and database are reviewed.

The remainder of the training is essentially a detailed walk-through of GIS\Key™ capabilities. The GIS\Key™ demonstration map and database are used often since they contain data of sufficient quantity and complexity to demonstrate realistic situations. Users are guided through the creation of the types of outputs GIS\Key™ can produce. A portion of the training is devoted to data entry where the user is guided through the steps required to enter various types of data that GIS\Key™ stores.

One significant area that may need additional emphasis is project planning and setup. Users get an opportunity to start a new project the second day of training. This project setup training takes place before the user is introduced to GIS\Key™ concepts of "program codes," "preparation fraction,"' "sampling events," and "template constituent lists." These important details regarding new project setup are not discussed before the new setup instruction.

Users generally found the GIS\Solutions trainers to be patient, flexible, and helpful. Training most often occurs at the user's location. Users reported universally that on-the-job use of the software system was the only way to become proficient in its execution. The call-in support offered by GIS\Solutions was readily available and of great help in understanding issues that arose while working with the software.

User Requirements

GIS\Key™ menus, both graphical and text-based, guide the user through complex data manipulation and display steps. While performing these actions the user does not need to have detailed knowledge of the inner workings of the software. For example, the user can easily prepare a map of the portion of the site, complete with a title block and border, without knowing many AutoCAD details. To prepare such a map manually, the user would need to be familiar with AutoCAD concepts such as model space versus paper space, block import and export, tilemode, view ports, attribute editing, and zooming relative to paper space. The GIS\Key™ menu-driven procedure is much simpler and more accessible to the casual user.

Another example of accessibility is provided by the retrieval of specific chemical concentration data and these posting values on a map. To perform such a query manually, the user would need to know a computer data manipulation language such as SQL or FoxBASE. The user would then need to import the data values onto the basemap using AutoCAD commands.

Although GIS\Key^{TM} information retrieval often requires little computer expertise, preparation of a GIS\Key^{TM} system for use can require special computer skills. For example, basemap preparation can require specialized AutoCAD skills. Field and laboratory data import may require that users have Data Management System skills. Most GIS\Key^{TM} project data is stored in industry-standard database (DBF) files, so these data are generally accessible (outside of GIS\Key^{TM} to users with more advanced database skills and appropriate software.

The following are typical tasks and situations that require the ability to use more advanced AutoCAD or third-party database management skills. They are briefly described below. For the more advanced user, GIS/Key^{TM} provides a platform from which the user may integrate third-party software to achieve desired reporting results.

- Preparation and Review of Laboratory Data Prior to Batch Loading
- Basemap Preparation and Maintenance
- System Installation
- Advanced Data Visualization Skills
- Contour Control Point Management
- Error Recovery and TroubleShooting
- Hard Copy Report Generation Beyond the Limits of GIS\Key^{TM} Prepared Report Formats
- Electronic Data Entry
- Ad hoc Queries
- Multiple Posting
- Location Designation
- Data Maintenance
- Management of Graphic Images
- Project Planning

Before electronic data can be imported into GIS\Key^{TM} field information needs to be combined with the electronic data from the laboratory. For example, the laboratory does not generally know the name of the well from which a sample was retrieved. The GIS\Key^{TM} batch loading routine expects this information prior to import. A person with general relational database skills is required to join the field information to the laboratory database. Also, relational database skills are required to manage and review the submission of electronic data from the laboratory. Any errors need to be identified and corrected early in the project.

Basemap preparation and maintenance often require AutoCAD skills beyond those required to operate GIS\Key™. For example, AutoCAD block imports and exports, as well as external references are often required to maintain a reasonably small basemap drawing file. Basemaps may be provided by the client or other third-party sources; these often need substantial revision before use.

System installation may require skills more advanced that those required for the routine use of GIS\Key™. For example, DOS memory configuration may require modification, and AutoCAD video and printer drivers may require extra effort to optimize.

Advanced data visualization skills, beyond those provided by GIS\Key™, may be required. For example, contouring of several formations or aquifers in the same region, independently, may provide misleading results that can only be resolved using more advanced AutoCAD techniques. If a groundwater potentiometric surface contour and a contour map of the top of the aquitard (i.e., the bottom of the aquifer) are both generated, it is possible that the contoured surfaces will intersect, since GIS\Key™ generates these two maps independently. Either map alone may appear reasonable, but if they are combined (e.g., in a cross section), then anomalies may become evident. The contoured bottom of the aquifer may appear to rise above the groundwater level. More advanced three-dimensional AutoCAD techniques can be used to resolve these situations. In this example, these techniques may show that the aquitard really does rise above the interpolated groundwater elevation, or it may be that insufficient data were available to interpolate these surfaces adequately within the anomalous region. GIS\Solutions reports that export functions to such higher end graphic packages such as Dynamic Graphics EarthVision are now available.

GIS\Key™ provides the ability to add control points to capture professional judgment that can improve computer-generated contour maps. Control points may be entered directly onto the basemap in the AutoCAD environment, but they are not entered into the GIS\Key™ database. If the user needs to track and manage these control points (e.g., in a database), then additional AutoCAD and database skills are required

Error recovery and troubleshooting will eventually be needed. AutoCAD may abort in the middle of an operation, possibly due to a lack of swap space. After such a crash, lock files may need to be deleted. This is not part of routine GIS\Key™ operation and is not discussed in the training manual. However, system errors of this type can occur with any software, and expertise is generally required to solve or prevent them. If duplicate well names have been entered into a project, then the basemap drawing will contain two well symbols of the same name, but the second one will be stored in the database under a name prefixed with the "!" character (e.g., the second “MW-06” in the database will be stored as “!MW-06”). Relational database and AutoCAD skills, as well as good familiarity with GIS\Key™ are needed to identify and correct such errors in the project.

The user may need tabular reports that are different from those supplied by GIS\Key™. Two options are available: custom reports may be purchased from the GIS\Key™ developers, or the user may choose to use third-party Data Management System software to run queries and generate custom reports. ASCII output formats for all tables are provided to assist in the latter approach.

Separate GIS\Key™ data entry modules may be purchased from GIS/Solutions, Inc. However, no native support for double-key data entry is provided by GIS\Key™. Specialized database skills and third-party database software may be needed to use these techniques.

Ad hoc queries require specialized database management skills, third-party database software, and a good familiarity with the GIS\Key™ database structure. For example, as discussed in Subsection 4.3.5, ad hoc queries such as “what is the second highest soil concentration of benzene ever found onsite?” cannot be directly answered using GIS\Key™. It is possible to browse the database tables using GIS\Key™, but manual browsing can be inefficient and error-prone. Third-party database software can provide the ability to perform arbitrarily complex ad hoc queries.

GIS\Key™ data retrieval methods post only a single value beneath the sample location symbol. If multiple chemicals are selected during the menu-prompted query, then the sum of the individual concentrations is posted as a single value. If, for example, the user would like to post the individual concentrations of benzene, toluene, and xylene, more advanced techniques and computer skills are needed.

Use of site or sample location designations beyond those incorporated into GIS\Key™ may require additional database skills. Large sites may be divided into regions and subregions, often because of site history or client needs. GIS\Key™ provides limited region and subregion categorization. Sample locations are distinguished in the database by "Site-ID." A free-form text field "Location" is also available, however this field cannot be used as selection criteria for analysis or reporting. The graphical AutoCAD environment provides the ability to create "symbol lists" to manage regions and location subsets. These "symbol lists" are integrated with "site groups" in the GIS\Key™ database, but must be manually created and maintained. However, if a project requires a greater degree of subset location management (i.e., another finer level of subregion), then an independent database using third-party database software may be required.

Maintenance of data source information is sometimes required. For example, several consultants may have worked on a site, and sample locations may have been surveyed independently. The user may wish to keep track of the source of each data element to provide accountability and an audit trail. More advanced database skills will be required to design, implement, and maintain such a database.

Management of graphic images may be required on larger projects. For example, a series of maps may be generated for a single area using different data selection criteria or contouring assumptions. GIS\Key™ does not include the capability to manage such "meta-data" about the generated maps.

Project planning should be done to obtain data elements in the format required by GIS\Key™. For example, sample IDs and well names must be carefully planned and managed for efficient use of electronic data. GIS\Key™ does not include any project planning tools, so special data management system skills and good familiarity with the GIS/Key™ internal database structure will assist in project planning.

Documentation and Support

Overall the GIS\Key™ User Guide was easy to follow and adequately explained the operation of each of the modules. It provides the user with a chapter entitled, "AutoCAD essentials," which gives a basic introduction to the primary AutoCAD commands with which a new user should be familiar. In addition, for users not familiar with DOS, Appendix C of the User Guide provides instruction on DOS basics. The “Guided Tour” chapter was very helpful in getting started with GIS\Key™ and provides a well-organized tutorial-guiding the user through many of the commands necessary for generating maps, well logs, sections; viewing the database; working with map symbols and views; plotting graphics; and printing tables.

It was observed that certain portions of the documentation did not coincide with the displays generated by the software. For example, a figure illustrating the “modify layers” command (page 3-13 of the User Guide) did not resemble the screen display when this command was invoked. There were other similar discrepancies. The User Guide (printed for Version 1.1) needs to be updated to reflect accurately the latest version of the software (Version 1.1.2). Release notes for Version 1.1.2 were provided and did document several updates to the software, but did not cover all the discrepancies that were observed.

The appendices were useful by providing graphics showing the GIS\Key™ standard map symbols, soil hatch patterns, and well cover symbols. The section on troubleshooting gave some suggestions on how to resolve certain problems that might arise during a GIS\Key™ session. The glossary served as a useful reference to the terminology found throughout the User Guide. During installation and execution of the software, several errors (i.e., incorrect paths to font file locations) occurred that could not be resolved by reading the User Guide. The GIS\Key™ staff were responsive in addressing these errors through telephone support. In addition, GIS\Solutions operates an electronic bulletin board, which was used to download several software modules (i.e., the lab data module which is used to assist in loading laboratory data in electronic format).

2.4 References

Guptill, Stephen C., 1988, A Process for Evaluating Geographic Information Systems. U.S. Geological Survey Open-File Report, pages 88 through 105.

Mosley, Daniel J., 1993, The Handbook of MIS Application Software Testing: Methods, Techniques, and Tools for Assuring Quality Through Testing.Prentice Hall, XXVIII.

SECTION 3
ECONOMIC ANALYSIS

The primary purpose of this economic analysis is to evaluate the costs associated with using GIS\Key^{TM} to manage environmental data. This section discusses conclusions of the economic analysis, basis of the analysis, issues and assumptions and results of the analysis. The economic analysis is based on the results of a SITE evaluation of the GIS\Key^{TM} system and on comments provided by individuals who work with the GIS\Key^{TM} system on a regular basis. All costs used in this analysis were as of July 1993. The assumptions made to arrive at various cost components are detailed within this section, thereby allowing variations to be made to develop costs to conform with a specific situation.

3.1 Conclusions of Economic Analysis

This analysis presents the estimated cost of using the GIS\Key^{TM} system to manage environmental data. The estimated cost of using the GIS\Key^{TM} system is compared to the estimated cost of completing the same project using an alternative system consisting of three independent pieces of software: a spreadsheet, a database, and a computer drafting package.

Table 14 presents per project costs for use of GIS\Key^{TM} and alternative systems for one to nine projects per year. As shown in Table 14, the cost-effectiveness of the GIS\Key^{TM} system is strongly influenced by the number of projects for which it is used. The relationship between the number of projects completed in 1 year and the cost per project is presented as a graph in Figure 35. When a time period of 1 year is evaluated, the GIS\Key^{TM} system is more cost-effective than the alternative system, when two or more projects of this magnitude are conducted. If the GIS\Key^{TM} system was evaluated for smaller projects, more projects would be required to make the system cost-effective.

For this cost analysis, all projects are assumed to be of the same magnitude as the project evaluated in this analysis. The project evaluated in this analysis uses geology, hydrology, and contaminant concentration data for 40 wells and 4 sampling events. The project includes data entry and preparation of well logs, contour maps, cross sections, time-series plots, concentration versus distance plots, concentra-

Table 14. Project Data Management Costs, 1-Year Basis

Number of Projects	Cost per Project Using GIS\Key™ System($)	Cost per Project Using Alternative System ($)
1	44,457	33,224
2	28,679	31,340
3	23,419	30,711
4	20,789	30,397
5	19,211	30,814
6	18,160	30,587
7	17,408	30,426
8	16,845	30,304
9	16,406	30,210

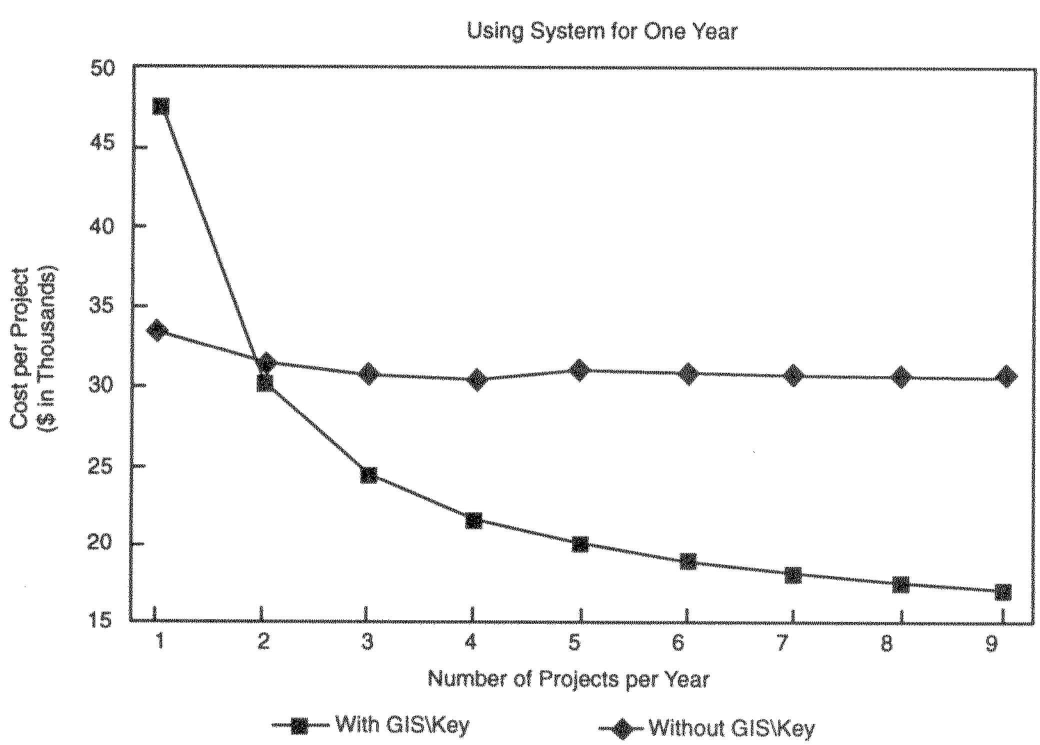


Figure 35. Project cost with and without GIS\Key™.

tion versus depth plots, contaminant concentration tables, and QA/QC tables. The basis of this cost analysis and the assumptions used are further discussed in Subsections 3.2,3.3, and 3.4.

3.2 Basis of Economic Analysis

In this economic analysis the user has one copy of the GIS\Key™ system. In this scenario, a technician is the primary operator of the system and an engineer or scientist evaluates the output. It is assumed that the GIS\Key™ system is in use 8 hours per day every day except weekends, holidays, and days when the technician is sick or on vacation. It is estimated that the project evaluated in this analysis requires the use of the GIS\Key™ system for 196 hours. As a result, this analysis indicates that nine projects of this magnitude can be completed in 1 year using one copy of the GIS\Key™ system.

The economic analysis compares the use of GIS\Key™ in this scenario to performance of the same project using an alternative system consisting of three independent software packages: a spreadsheet, a database, and a computer drafting program. In the alternative scenario, data is manually entered into the database, which is used to sort the data and prepare tables. The data can be exported to the spreadsheet, which is used to manipulate the data and create graphs. Maps and figures describing site geology and hydrology are prepared manually using the drafting package. It is estimated that the project evaluated in this analysis requires the use of the drafting package, the spreadsheet, and the database for 416 hours, 34 hours, and 130 hours, respectively. As a result, using the assumptions employed in the GIS\Key™ scenario, this analysis indicates that four projects of this magnitude can be completed in 1 year using one copy each of the three software packages. Five to nine projects can be completed in 1 year if a second copy of the drafting package is purchased.

The overall costs for both scenarios are broken down into four categories: 1) system and accessories, 2) hardware and support software, 3) labor, and 4) training and maintenance. The four cost categories, examined as they apply to the GIS\Key™ system and the alternative system, are discussed individually in Subsections 3.4.1 through 3.4.4.

3.3 Issues and Assumptions

Certain differences between the GIS\Key™ system and the alternative system cannot be effectively compared on a cost basis. For example, the GIS\Key™ data entry routines check the validity of data as it is entered. GIS\Key™ may detect errors that would only be detected with considerable effort if the project were conducted using the alternative system. Errors or data quality issues may also be detected much earlier in the project when the GIS\Key™ system is used. Early detection requires additional time at the beginning of the project but is likely to save time overall, since errors detected at the end of the project are likely to require changes to plots, graphs, tables, etc. that have already been prepared.

The quality of the output may also differ between the two systems. Although no side-by-side comparison has been made, the products generated using the computer drafting package included in the alternative system should be comparable to the products generated using the AutoCAD portion of GIS\Key™. Products that fall into this category include the well logs, contour maps, and cross sections. However, the graphs and tables generated by the alternative system may be significantly different from those generated by GIS\Key™.

Another difference between the two systems is the flexibility of their output. Because GIS\Key™ uses preset formats to reduce labor, the output from GIS\Key™ is not as easily modified as the output from the alternative system, in which all formats are developed by the user.Examples of the flexibility limitations of GIS\Key™ are discussed further in Subsections 2.2.1 and 4.3.1.

There are other factors that affect the cost comparison between GIS\Key™ and the alternative system. For example, the repetitiveness of the projects impacts the cost comparison. The impact of this factor has not been quantified, but the GIS\Key™ system is expected to be more cost-effective for highly repetitive work. Similarly, GIS\Key™ should be more cost-effective in reviewing different scenarios such as contour interval, number of wells to include, and/or to include or not include grids, etc.

3.4 Results of Economic Analysis

3.4.1 System and Accessories

This cost analysis treats the purchase prices of both the GIS\Key™ system and the alternative system as one-time costs. The total cost of the GIS\Key™ system evaluated in this analysis is $12,500. This price includes one copy each of the GIS\Key™ Basic Version, User Guide, and Training Guide; itemized costs are presented in Table 15. As discussed in Subsection 3.2, up to nine projects similar to the project evaluated in this analysis can be completed in 1 year using one copy of GIS\Key™. If necessary,

Table 15. GIS\Key™ System and Accessory Costs[1]

Item	Cost ($)
GIS\Key™ (Basic Version)	12,500 [2]
GIS\Key™ Database	5,500[2]
GIS\Key™ User Guide	250[3]
GIS\Key™ Training Guide	50[3]

1 Prices effective through December 31, 1993 and subject to annual update thereafter.
2 Price for the first copy purchased by a given company. The next five copies purchased by the company have a cost of 15 percent less, and copies after the sixth, a cost of 30 percent less. Discounts of up to 50 percent may be negotiated for large purchases.
3 Included with the purchase of the basic version of GIS\Key™.

GIS\Key™ capabilities can be expanded by the purchase of a second copy of either the GIS\Key™ database or the GIS\Key™ system. If the user has one copy of the GIS\Key™ system (which includes the GIS\Key™ database) and one copy of the GIS\Key™ database, the database copy can be used for data entry and table creation while the complete GIS\Key™ system is being used to create contour maps, well logs, and other products that cannot be created with the database alone. As a result, the additional copy of the GIS\Key™ database doubles the project capacity for less than half the cost of the entire GIS\Key™ system. This makes the system more cost-effective when more than nine projects per year are performed.

In the alternative scenario, a spreadsheet, database, and drafting program were purchased. If only one copy of each program is required, the total system cost is estimated to be $3,769. As discussed in Subsection 3.2, additional copies of certain programs are required if the work completed in 1 year includes more than four projects of the magnitude of the project evaluated. The system cost for performance of five to nine projects per year is $6,794.

3.4.2 Hardware and Support Software

GIS\Solutions claims that the GIS\Key™ system runs on 386 and 486 PCs (DOS) or SUN workstations (UNIX). During this SITE demonstration, the performance of the system was evaluated using three computer configurations. The results of the performance comparison are tabulated in Subsection

4.3.7. Purchase prices for the computer systems described in Subsection 4.3.7 can be obtained from any computer supplier. The actual hardware cost to a user that adopts the GIS\Key™ system depends on the computer facilities available in that office. If GIS\Key™ is used for numerous projects, it may be necessary to place the system on a dedicated machine. In some cases, it may be necessary or preferable to purchase a new system. In other cases, it may be possible to use or upgrade an existing computer.

The hardware requirements for the alternative system are similar to the hardware requirements for the GIS\Key™ system. Although the hardware requirements for the alternative system depend on the exact software purchased, they are assumed to be slightly lower than the hardware requirements for the GIS\Key™ system. However, because the alternative scenario requires more computer time, it may necessitate the use of more than one computer. As in the GIS\Key™ scenario, the user may choose to purchase new equipment, upgrade existing equipment, or use existing equipment without modification, This cost estimate assumes that existing hardware is sufficient for both scenarios.

Several third-party software packages can be purchased from GIS\Solutions or a local dealer for use with the GIS\Key™ system. These applications are described in Subsection 1.4 and their purchase prices are presented in Table 16. This cost estimate assumes that AutoCAD Version 12, QuickSurf Version 4.5, Cadvert, PKZIP, JetForm, and FoxPRO are purchased as support software for the GIS\Key™ system. The total cost of support software for the GIS\Key™ scenario is $5,395. For the alternative scenario, this cost estimate assumes that no support software is required.

3.4.3 Labor

For both scenarios, it is assumed that the work is performed by technicians and engineers or scientists. This analysis assumes loaded labor rates of $30 per hour and $65 per hour for technicians and engineers/scientists, respectively. Tables 17 and 18 summarize estimated labor requirements to complete the listed tasks under both scenarios. Data entry labor in the GIS\Key™ scenario may be significantly reduced if an efficient system is established to allow the user to import electronic laboratory data directly into the system.

3.4.4 Training and Maintenance

Support services including employee training, telephone support, custom programming, data

Table 16. GIS\Key^{TM} Support Software

Item	Cast ($)
AutoCAD, Version 12	3,025 [3]
QuickSurf, Version 2.91	499 [1]
QuickSurf, Version 3.2	999 [1]
QuickSurf, Version 4.5	1,500 [1]
Cadvert*	299 [1]
PKZIP	47 [1]
JetForm	199 [1]
FoxPRO	325 [2]

*No longer needed with current release

Table 17. Labor Requirements Using GIS\Key^{TM}

Task/Product	Technician Labor (hours)	Engineer/Scientist Labor (hours)	Loaded Labor Cost ($)
Data Entry	60	11	2,515
Well Logs	10	3	495
Contour Maps	60	80	7,000
Cross sections	2	2	190
Time-Series Plots	20	4	860
Concentration versus Distance Plots	4	1	185
Concentration versus Depth Plots	10	2	430
Contaminant Concentration Tables	6	1	245
QA/QC Tables	24	4	980
Totals	**196**	**108**	**12,900**

Table 18. Labor Requirements Using the Alternative System

Task/Product	Technician Labor (hours)	Engineer/Scientist Labor (hours)	Loaded Labor Cost ($)
Data Entry	100	20	4300
Well Logs	160	3	4,995
Contour Maps	200	120	13,800
Cross Sections	56	8	2,200
Time-Series Plots	0	20	1,300
Concentration versus Distance Plots	0	4	260
Concentration versus Depth Plots	0	10	650
Contaminant Concentration Tables	0	6	390
QA/QC Tables	0	24	1,560
Totals	516	215	29,455

management, and system maintenance are available from GIS\Solutions. Costs for these services are summarized in Table 19. Services not listed in Table 19 are priced at cost plus 15 percent. The economic analysis assumes that the user purchases the GIS\Key™ annual maintenance contract, which includes 10 hours of free telephone support and a periodic "freshening" of the program code. Other than training, this maintenance contract is assumed to be the only technical support cost associated with the GIS\Key™ system.

For the GIS\Key™ scenario, it is assumed that the engineer/scientist is sent to GIS\Solutions for 3-1/2 days of basic training and 2 days of advanced training. The technician receives on-the-job training from the engineer/scientist in the use of the GIS\Key™ system. The total cost of training the engineer/scientist is $10,862, which includes round-trip airfare, 7 nights in a hotel, 7 days of per diem, 56 hours at the engineer/scientist's loaded labor rate, and the training fees paid to GIS\Solutions. As an alternative, GIS\Solutions will provide training at the customer's facility on a time-and-materials basis. If several employees are to be trained simultaneously, onsite training is typically more cost-effective.

Table 19. GIS\Key™ Support Services

Item	Cost
GIS\Key™ basic training	$3,500 for up to 5 people (or on a time-and-materials basis if given at the customer's facility)
GIS\Key™ annual maintenance contract	$2,500
Database annual maintenance contract	$1,500
Use of microcomputer and text processing equipment by modem	$15 per connect hour (rounded to the nearest 30 minutes)
Custom reports or forms	$750 per report or form
Mileage	$0.40 per mile
In-house copying	$0.15 per page
Telephone support [1]	Labor is charged at the rates given below. Users who have not completed GIS™ basic training are also charged an additional $50 per call.
Labor rates	
GIS\Solutions Principal	$125 per hour
Senior Level	$100 per hour
Project Level	$80 per hour
Staff Level,	$65 per hour
Clerical	$35 per hour

[1]GIS\Solutions claims that telephone support is available 24 hours per day.

In both scenarios, it is assumed that the technician's education included training in the use of computer drafting packages. In the alternative scenario, it is assumed that the engineer/scientist is familiar with the spreadsheet and database packages. As a result of these assumptions, no training is required in the alternative scenario. On-the-job training costs associated with both scenarios are not included in this cost estimate.

3.5 References

GIS\Solutions, Inc Software License and Support Services Fee Schedule. 1993.

Misco® Computer Products Catalog, Fall 1993.

Price quote provided by A/E Microsystems, November 1993.

SECTION 4
OTHER TECHNOLOGY REQUIREMENTS

4.1 Personnel Issues

As mentioned in Section 2, GIS\Key^{TM} users fall within two categories: general users and system administrators. General users responsible for the day-today operation of the GIS\Key^{TM} system (i.e., information retrieval) do not need specialized computer skills to operate the software. As a result, their training requirements should be met by the basic training course offered by GIS\Solutions, Inc. Project administrators, on the other hand, will need to understand the inner data structure of GIS\Key^{TM} in order to perform some of the more advanced project setup and maintenance tasks. As a result, in addition to the basic training provided by GIS\Solutions, project administrators will probably need to take the advanced training course on the inner data structure of the software.

All GIS\Key^{TM} operators must be familiar with AutoCAD. General users usually require only a basic knowledge of AutoCAD, which can be obtained from the basic training course. Project administrators, however, require an more advanced understanding of AutoCAD, which in general cannot be obtained in either the basic or advanced courses. These advanced AutoCAD skills will help project administrators during basemap preparation and maintenance, as well as final map and figure production.

In addition to computer skills, project administrators should have some experience in evaluating subsurface conditions. Project administrators must be able to tell if the maps obtained using GIS\Key^{TM} are reasonable or useful. They must be able to determine if the correct assumptions and methods were used and whether there is an adequate amount of data of sufficient quality to generate reliable maps and other outputs.

SECTION 5

SOFTWARE STATUS

GIS\Solutions, Inc., a California corporation, was organized in July 1990 to provide an integrated, comprehensive, map-based relational database and engineering analysis software product to manage, interpret and report environmental data. This product, named GIS\Key™, enhances the cost effectiveness of performing hazardous waste site feasibility studies, remedial investigations and design, and long-term monitoring. In fulfilling this need, GIS\Solutions objectives related to development and continued support of the software are as follows:

- Establish GIS\Solutions as an innovative technical leader in environmental data management and analysis software
- Develop user-friendly software products which offer significant reductions in environmental compliance costs while improving accuracy and quality of environmental data
- Provide highly qualified professional scientists, geologists and engineers for technical training and client support to enhance the efficiency of the software further
- Build market strengths and sustain growth, so that GIS\Solutions will be viable in the long term

GIS\Solutions products are sold to industry, environmental consultants, government owners/operators, and regulatory agencies, directly and through distributors. All modules are designed to address different aspects of compliance reporting and data evaluation. The core product is a fully integrated GIS and data management system which consists of chemical, geologic and hydrologic modules.

Time and materials technical services, such as software customization, client site data management and other requested technical support are also provided at the client's request. Technical support packages, such as annual software maintenance and GIS\Key™ training, are combined with each software sale.

APPENDIX I
DEVELOPER'S CLAIMS FOR GIS\KEY^{TM} SOFTWARE

I.1 Developer's Claims

This appendix summarizes claims made by GIS\Solutions Inc. in regards to the GIS\Key^{TM} Environmental Data Management System. The information presented herein represents the developer's point of view; its inclusion in this appendix does not constitute U. S. Environmental Protection Agency (EPA) approval or endorsement.

I.1.1 Introduction

GIS\Solutions is very appreciative of the honor of being the first software developer to be accepted into the EPA SITE Program. We believe that GIS\Key^{TM} software represents a state-of-the-art advance in the integrated management of environmental data. As concluded in this SITE Program report, GIS\Key^{TM} dramatically reduces the cost of managing and reporting environmental data at sites ranging in size from comer gas station investigations to large Superfund sites. At the same time, the data integration, validation, and reporting features of GIS\Key^{TM} significantly improve data quality and any resulting decisions pertaining to this data.

This SITE Program report provides a comprehensive overview of the many features of GIS\Key^{TM} software and where appropriate, its limitations. Accordingly, these features and limitations will not be repeated in this appendix. Rather, the focus of this section is on the new features that have been added to GIS\Key^{TM} in the year since the release of the version used as a basis for this evaluation. These features were added primarily in response to feedback received from our existing clients, which we, a client service-driven company in this rapidly evolving field, constantly encourage. You will note that many of the limitations noted in this report have been addressed by our current version of GIS.

I.2 New Features of GIS\Key^{TM} Software

Recently added features to GIS\Key^{TM} and integrated third-party software are described in the following paragraphs. Added features have been grouped into the following categories:

- Custom Boring Logs and Geology Database Modifications
- Hydrology Database Modifications
- Chemistry Database Changes and ITIR Reporting
- GIS\Key™ Utilities, Menus and Dialog Boxes
- Stand-Alone Database Modifications
- AutoCAD Improvements (i.e., ADE)
- Contouring Package Improvements
- Third-Party Software Integration

I.2.1 Custom Boring Logs and Geology Database Modifications

Users are now able to create their own custom templates for well and borehole logs easily. To create a new template, the user picks the Create New Template option from the geology pull-down menu, names the template, selects the data fields to be shown in the header and body from a list, and then snaps the fields into the desired locations. The user is given options to control all aspects of the final appearance of the log, including text style, height and width of all field and column displays, text lines per foot, feet per page, number of remark lines, and so on. Users can design these templates to match the formats currently used exactly or use GIS\Key™ to improve current designs or create custom templates for specific applications. For example, it may be desirable to include a column for Organic Vapor Concentrations on a log template to be used for petroleum hydrocarbon investigations. Alternatively, at a site involving a release of acid, a template with a column summarizing field pH measurements may be appropriate. With the GIS\Key™ custom log routine, log templates with company logos can be created in less than an hour to create presentation-quality well and borehole logs.

Several important changes to the geology database were made to support the custom log template feature. Users are now allowed to enter the type, diameter, and depth interval of an infinite number of well screen, sand pack, and seal intervals. Packers and centralizer information can be added to the database and graphically depicted in the finished logs, as can equilibrium and first-encountered water levels and organic vapor concentrations. Three user definable fields have been added to the database that can be optionally depicted on the finished logs. These borehole-specific fields can be used to present field chemical analysis results (such as the pH example) or geotechnical test results. Drilling remarks can be separated from material description calls and presented in separate columns.

The custom borehole routine is available as a stand-alone package. It is included with the purchase of each complete copy of GIS\Key™

I.2.2 Hydrology Database Modifications

A few minor changes to the hydrology database and tabular reporting routines were made in response to client feedback. Feedback basically involved the inability to note unsuccessful attempts to make water level measurements. More specifically, consulting clients wanted to be able to document an attempt to collect data, even when field conditions prevented a measurement from being taken.

Users are now allowed to record in the database that a water level measurement was attempted but that the well was obstructed or in some way blocked. In addition, a field was added to record the presence of a hydrocarbon sheen too small to measure. These hydrology module modifications are a response to client suggestions.

I.2.3 Chemistry Database Changes and ITIR Reporting

ITIRs use four tabular reporting formats for chemical data required by the Air Force. The tables combine chemical analysis results of primary results and associated QC data for ease of review.

GIS\Solutions has developed an ITIR reporting package that has been Beta-tested at NASA's Cape Canaveral site in Florida. The ITIR reporting package includes a preprocessor for importing field and laboratory data files in the IRPIMS (Installation Restoration Program Information Management System) formats into GIS\Key™. Following the import of data into the GIS\Key™ Database, numerous data validation and reporting options are available in addition to the ITIR reporting formats.

Data import and verification are performed in three phases.

- In the first phase, field sample information and IRPIMS laboratory downloads are combined and compared; exception reports are generated when laboratory results are incomplete or inconsistent with work order specifications. Field information can be hand entered or electronically downloaded from files generated using the Contractors Data Loading Tool (CDLT).

- In phase two, the combined field and laboratory data is converted into GIS\Key™ format, with the resulting file checked for completeness and internal consistency using the GIS Build utility.

- The third phase occurs as the data files are imported into the project database. Primary and secondary relationships of the GIS\Key™ database are checked during this phase.

Once the data has been imported into the project database, any of the ITIRs can be generated by selecting the desired format from a pull-down menu and responding to a series of prompts.

To accommodate the preparation of ITIRs, several significant features were added to the GIS\Key^{TM} Database. First, GIS\Key^{TM} is now structured to receive multiple results from the same test for the same sample. Whether these multiple results are from different columns, different dilutions, or some combination of both, GIS\Key^{TM} can now store and report all of this data. Second, GIS\Key^{TM} can now store and report the practical quantitation limits for each chemical analysis result in addition to the detection limit. Third, GIS\Key^{TM} can now receive QC data (e.g., surrogate results of a matrix spike sample). Fourth, additional fields were added to allow the separate association of field, travel and rinseate blanks with primary result samples.

1.2.4 GIS Utilities, Menus, and Dialog Boxes

The current release of GIS\Key^{TM} includes full utilization of the dialog boxes and menu design that AutoCAD 12 has to offer. For example, the addition and editing of map symbols is now performed through dialog boxes instead of separate prompt-driven routines for editing the location, name, elevation, etc., of each borehole. The custom borehole routine discussed previously is another excellent example of the use of dialog boxes.

In response to client feedback, the menu structure for contouring has been consolidated and simplified. The user now has better control of the addition and visibility of control symbols and posted values. Additional improvements have become available with the incorporation of Release 5.0 of QuickSurf (see Subsection A.2.7).

GIS\Key^{TM} now supports up to 26 aliases or names for each sample location, any of which can be selected for reporting purposes. For example, private domestic wells are often sampled and given names like DW-01. An alias category called “owner” can be created and tabular and graphical work products can use the site owner’s name rather than DW-01. The site alias feature is particularly useful in tracking the nomenclature changes to wells at large sites. In many cases wells have been repeatedly renamed to avoid duplication or suggest current hydrogeologic interpretations.

I.2.5 Stand-Alone Database Modifications

The GIS\Key^{TM} database is now offered as a stand-alone package. Site sample locations and chemical, geologic, and chemical data relative to these locations can be added to the database without the use of th eGIS\Key Graphic component or other third-party tools.

I.2.6 AutoCAD Improvements

I.2.6.1 AutoCAD Data Extension

AutoCAD has recently released a new product called AutoCAD Data Extension. This product removes the previous barriers to managing large AutoCAD basemaps. ADE allows the user to load only the portions of a large map needed for a particular task. Using ADE, a current GIS\Ktey ^{TM} customer is managing environmental data on a 92 Mb site map. Another customer recently ordered over 20 USGS quadrangle maps for an area-wide environmental investigation being managed with GIS\Key ^{TM}.

I.2.6.2 AutoCAD 12 for Windows

With the release of AutoCAD 2 for Windows, GIS\Key ^{TM} now runs in the Windows environment. The current Windows release supports many of the features associated the windowing environment such as DDE document linking. For example, users now have the ability to cut a report-ready graph, boring log, cross-section or contour map into a word processing document. Alternatively, by clicking on a well from a basemap they are now able to show a picture of the well, video taken during its construction, or a document summarizing permit conditions or other applicable information in text or spreadsheet format.

I . 2 . 7 Contouring Package Improvements

The SITE Program evaluation was performed based on Version 2.91 of QuickSurf. QuickSurf Version 5.0 is now available and includes many additional features including break lines, kriging, and continuous coloring of contoured data.

I.2.8 Third-Party Software Integration

GIS\Solutions works closely with other third-party software vendors to integrate GIS\Key ^{TM}

software with other specialized applications that depend on the input of reliable, validated data from a site. A good example of current integration efforts is reflected by the export function of chemical data to GRITS/STAT, the statistics module developed under contract to EPA for the evaluation of data under RCRA and CERCLA . GIS\Solutions is working to develop export functions to other statistical packages, such as GSAS from Intelligent Decisions Technology and The Monitor System from Entech Inc.

As mentioned in this report, GIS\Solutions is working closely with ESRI to integrate GIS\Key TM and ArcINFO using ArcCAD. Current integration efforts allow users to create work products that combine GIS\KeyTM data and ArcINFO data. For example, it is possible to prepare a map showing areas with sandy soil types where chemical concentrations in soil or groundwater exceed a specified level and the distance to the nearest domestic well is less than 1000 feet.

For advanced visualization of hydrogeologic and chemical data, GIS\Key TM currently supports various export functions to Dynamic Graphics EarthVision software. For advanced visualization on a PC platform, export routines to Entec Inc. SURPAC software are currently being developed.

In the area of groundwater modeling, GIS\Key TM has developed pre- and post-processors to the USGS flow model MODFLOW These processors allow the user to define variable length grid arrays on the basemap , graphically define MODFLOW input parameters, and when the modeling run is completed, graphically present the modeling ouput on the basemap. GIS\Solutions is currently investigating the integration of other flow and transport models into GIS\Key TM.

I.2.9 Data Security

The GIS\KeyTM software includes password protection to prevent unauthorized edits.

I.3 GIS\KeyTM Features Currently Under Development

In addition to the improvements listed above that have been added since the release of the GIS\KeyTM version used for this evaluation, GIS\Solutions is actively working on other modules. Brief descriptions follow.

I.3.1 Field Module

The GIS\Key^{TM} field module will allow project managers to create field sampling instructions from the GIS\Key^{TM} database and transfer these instructions in electronic form to a pen-based computer ruggedized for field use. The pen-based computer will record all field activities and prepare sample bottle labels and chain-of-custody forms. In addition, it will create field activity summary files in a format suitable for direct import into GIS\Key^{TM} or for use with the GIS\Build utility for the electronic download of laboratory data.

The use of a pen-based computer to record field sampling activities has long been recognized as a field need. As hardware prices continue to decline, such systems will become economically viable.

I.3.2 Support of Multiple Databases

GIS\Solutions, as part of the Cordant Inc. team, was awarded a 12-year contract by the Naval Information Technology Aquisition Center for the Naval Facilities Engineering Command Computer-Aided Design Second Acquisition Program (NAVFAC CAD 2). The total delegation authority under this contract is 550 million dollars. GIS\Key^{TM} is the only PC-based environmental data managaement software selected under this contract. As a condition of the award, GIS\Solutions is committed to the development of a client-server product. Accordingly, GIS\Solutions plans to introduce support for Oracle, Sybase, and Informix during the latter part of 1994.

I.3.3 Air Module

The GIS\Key^{TM} Air Module will allow the entry of air chemistry data and compressible flow data into GIS\Key^{TM}. It will also include interfaces to selected flow models. The Air module is slated for completion during the fourth quarter of 1994.

I.3.4 Risk Module

The GIS\Key^{TM} Risk Module will allow the user to define exposure pathways and assumptions for chemical intake and associated risks. It is slated for completion during the second quarter of 1995.

I.4 Summary

GIS\Key^{TM} is an innovative and cost-effective tool for managing the wealth of data generated from environmental investigations ranging from small property site assessments to major Superfund sites. GIS\Key^{TM} leads to higher quality and lower costs for the following reasons.

- GIS\Key^{TM} improves efficiency and reduces costs by providing a work product oriented tool. Report-ready graphics can be created by simply selecting a desired graphic from a pull-down window and responding to a series of prompts. GIS\Solutions customers report a 25% to 75% reduction in data management costs using GIS\Key^{TM}.

- The intuitive design of GIS\Key^{TM} requires no previous computer background to prepare report-ready graphics and tables. The desired product is selected from a pull-down window and the user then responds to prompts. A query language does not have to be mastered to get results.

- The user-friendly design means all data management training costs can be standardized and controlled. Its comprehensive user guide is an excellent aid for training new employees.

- GIS\Key^{TM} combines proven third-party software packages such as AutoCAD, FoxPlus, QuickSurf, and JetForm under one seamless graphic interface.

- GIS\Key^{TM} runs on 286,386, and 486 PCs. Additional investments in computer hardware are not required for the implementation of the GIS\Key^{TM}.

- Contour maps, geologic cross sections, graphs, boring logs, and tables can be created without data having to be reentered or reformatted. GIS\Key^{TM} integrated design allows data to be entered only once.

- Numerous data validation and error checking routines are incorporated into GIS\Key^{TM}. These routines protect the integrity of databases, whether site or laboratory data is being manually entered or electronically imported.

- Every time data must be copied, there is the opportunity for a transcription error. GIS\Key^{TM} data entry/validation features and automated data transfers for graphics preparation effectively minimize transcription errors and associated liabilities.

- The fully integrated design of GIS\Key^{TM} means that geologic, hydrologic and chemical data can be viewed and evaluated collectively, leading to improved data interpretation. For example, automated routines allow display of soils data, well construction data, water level data and chemical data in cross section view.

- GIS\Key^{TM} encourages project managers to take ownership of a project. Providing a tool that makes it easier to produce reports on time and on budget improves employee morale and pride in their work.

- By implementing GIS\Key^{TM} on a company-wide basis, the format of report graphics could be quickly standardized between offices. The high-quality graphics produced by GIS\Key^{TM} help to establish a reputation for consistent, superior work.

- GIS\Key^{TM} provides a cost-effective mechanism for peer review and/or project reassignment. GIS\Key^{TM} encourages timely peer review and inter-office cooperation by supplying a convenient platform for modem transfer of project data between offices. In an industry where the average length of employment at any one office is less than 3 years, GIS\Key^{TM} provides a data management bridge between one project manager and the next.

APPENDIX II

A METHOD FOR DETERMINING DIGITIZING ACCURACY WITHIN GIS\KEY™

1. A hard copy basemap of the Valdosta, Georgia quadrangle (1:24,000 scale) was obtained from the USGS.

2. A view was created in GIS™ corresponding to a region in the vicinity of the Valdosta airport (see Figure 5).

3. Four control points of known latitude/longitude were marked on the hard copy map. Their latitude/longitude coordinates were converted to Georgia West state plane coordinates (feet) using map coordinate transformation procedures in an external software system (ARC/INFO GIS).

4. The portion of the hard copy map corresponding to the Valdosta airport view was placed on the digitizer and the AutoCAD tablet command was invoked in its calibration mode. The four control points were digitized and their x,y coordinates keyed in.

5. The tablet calibration mode supports three transformation types: orthogonal, affine, and projective. The affine transformation was chosen since it provides an arbitrary linear transformation in two dimensions independent of x and y scaling, rotation, and skewing. The RMS error associated with this transformation as computed by AutoCAD was 2.6 feet. Given the digitizer resolution (500 dpi), the x and y paper space dimensions of the view (6.5 x 7.5 inches), and the x and y model space dimensions of the view (13,208 x 13,259 feet), the x and y ground resolution of the digitizer was computed as follows:

   Xres = 13208 ft/(6.5 in x 500 dots/in) = 4.06 ft/dot

   Yres = 13259 ft/(7.5 in x 500 dots/in) = 3.54 ft/dot

   Thus, an RMS error of 2.6 feet is consistent with the ground resolution for this digitizer setup and probably could not be improved upon significantly without increasing the resolution of the digitizing tablet.

6. Once the map transformation was established, the accuracy of a given point being digitized could be determined. This was done by digitizing a geodetic control point (point 0300831) which appeared both on the hard copy map and the AutoCAD DWG file. The latitude/longitude of this point (30°47'04" N, 83°16'34" W) was converted to Georgia West state plane coordinates (x = 779648.1 feet, y = 286382.2 feet). The cursor was placed on the hard copy map at this point and its x,y coordinates were read off the AutoCAD display. These coordinates were x = 779649.5 feet, y = 286384.8 feet, resulting in a delta of 1.4 feet in x and 2.6 feet in y.

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