CLEMSON

WRRI

Report No. 129

GROUNDWATER RESOURCES ASSESSMENT OF THE PIEDMONT REGION IN SOUTH CAROLINA

SOUTH CAROLINA
WATER RESOURCES RESEARCH INSTITUTE
Clemson, South Carolina
29634-2900

CLEMSON
UNIVERSITY

May 1988

TECHNICAL COMPLETION REPORT

GROUND WATER RESOURCES ASSESSMENT OF THE PIEDMONT REGION IN SOUTH CAROLINA

by

Richard K. White
Newman Professor of Natural Resource Engineering
Department of Agricultural Engineering

A. W. (Bud) Badr
Visiting Assistant Professor
Department of Agricultural Engineering

Ann D. Christy
Graduate Research Associate
Environmental Systems Engineering

Clemson University
Clemson, South Carolina 29631

Water Resource Research Institute
Clemson University
Clemson, South Carolina 29631

May, 1988

Technical Completion Report
G1448-02

GROUNDWATER RESOURCES ASSESSMENT OF THE PIEDMONT REGION IN SOUTH CAROLINA

Project Agreement No. 14-08-0001-G1448
Period of Investigation 5/1/87 - 4/30/88

Submitted to:
United States Department of Interior
U.S. Geological Survey
Reston, VA 22092

The research on which this report is based was financed in part by the United States Department of the Interior Geological Survey, through the South Carolina Water Resources Carolina Water Resources Research Institute

ABSTRACT

This report summarizes the available ground water databases found in the South Carolina District of the United States Geological Survey (USGS), the South Carolina Department of Health and Environmental Control (DHEC) and the South Carolina Water Resources Commission (WRC). All three agencies use paper files and various computer files for well data. The individual databases are described in the report.

Dependable ground water supplies in the Piedmont usually require drilling into the crystalline bedrock. The well yield depends on the number and size of fractures intercepted by the bore hole. Thus, fracture location becomes an important factor in the siting of wells. The existence of fractures can be predicted from fracture trace mapping and from the topography. Since 1985, all drillers are required to submit to the DHEC well completion reports which include yield estimates. Water quality data for public supply wells are reported to DHEC. Also, ground water quality data are available for identified contamination sites.

Only part of the data on ground water in the South Carolina Piedmont is computerized. Well data formats are not uniform between agencies and between divisions within agencies. The accuracy of the data is questionable, especially well head location and well log lithology.

The WRC has data for 3,166 wells stored by county on a dBASE III program. These well data were statistically analyzed to determine the relation between well yield, diameter and depth. The analysis showed that the single variable most closely correlated with well yield was diameter for all depth intervals. On average, well

yield showed a slight increase with depth down to about 350 feet and then decreased at greater depths.

The primary conclusion is the need for a common or compatible computerized ground water database. It is suggested that the USGS Ground Water Site Inventory could serve as a basis for the development of a state ground water data system. Any common database system should fit the various agency concerns and needs with respect to ground water information. Data should include identification of origin and protection against unauthorized alterations.

Because the accuracy of location and information is questionable for many well reports, verification and completion of existing data is a priority. The completion of a ground water database would help to determine regional water yield relationships. A hydrogeological unit map, which superimposes information of water-bearing properties and hydrogeochemistry of the region upon geological maps, would graphically portray the availability and quality of Piedmont ground water. Such analyses would greatly enhance the ability of ground water personnel to located higher yielding wells and to make more efficient use of the region's ground water resources.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDIX FIGURES

I. INTRODUCTION AND OBJECTIVES

The Piedmont province covers most of northwestern South Carolina. It is located between the Coastal Plain province to the East and the Blue Ridge province to the West. The regional geology of the Piedmont is composed of several belts of varying grades of metamorphism (Figure 1).

The Piedmont ground water system, as shown in Figure 2, can be divided into two zones: regolith and bedrock. The regolith zone is a mixture of unconsolidated material: saprolite, colluvium, alluvium, and soil. Its depth varies from zero to one hundred feet or more. The regolith contains both saturated and unsaturated zones. The depth to the water table ranges from a few feet to seventy feet or more, with an average depth of about 35 feet. The regolith serves as the water supply source to fracture spaces in the bedrock.

The bedrock zone is made up of metamorphic rocks such as mica schist, biotite gneiss, and granitic gneiss; and igneous rocks such as granite, quartz monzonite, diabase, and gabbro. Fractures of varying sizes and shapes are randomly scattered through the upper layers of the bedrock zone. These fractures are the source of water in the otherwise impermeable bedrock. However, some of these fractures may be dry or filled with clay.

Ground water in the regolith is stored and transmitted through the pores between soil particles, whereas ground water in the bedrock exists only in interconnected fractures or foliations in the rock. Generally, the number of fractures decreases with depth. The overlying regolith functions as a reservoir of water, and ground water seeps from the regolith into the bedrock fractures.

Weather in the Piedmont is moderate with an abundance of rainfall (40 to 70 inches annual precipitation). The storage capacity and transmissivity of the Piedmont ground water system varies from one site to another, depending on the hydrological characteristics of the watershed and the availability of fractures within the bedrock of a given site. It is not uncommon for Piedmont streams to run dry during droughts.

The droughts of 1981 and 1986 illustrated the need for dependable ground water supplies to support and supplement surface water supplies in times of scarcity. The urbanization and industrialization of South Carolina's Piedmont rely heavily on ground water availability and the potential for sustainable high well yields.

Aller et al. (1987) stated, "The Piedmont ... region has long been known as an area generally unfavorable for ground water development. This reputation seems to have resulted both from the small reported yields of the numerous domestic wells in use in the region, and from a failure to apply existing technology to the careful selection of well sites where moderate yields are needed. As water needs in the region increase and as reservoir sites on streams become increasingly more difficult to obtain, it will be necessary to make more intensive use of ground water."

The objectives of this research were to:

A. Summarize the available data bases for ground water quantity and quality in the Piedmont of South Carolina.

B. Evaluate the knowledge level for ground water in the Piedmont.

C. Identify areas or gaps in the knowledge base where research is needed.

The procedures were to contact all concerned state and federal agencies and identify the databases on ground water quantity and quality in the Piedmont. These data were then evaluated for completeness and statistically analyzed. Other states were contacted to learn about their ground water data management systems.

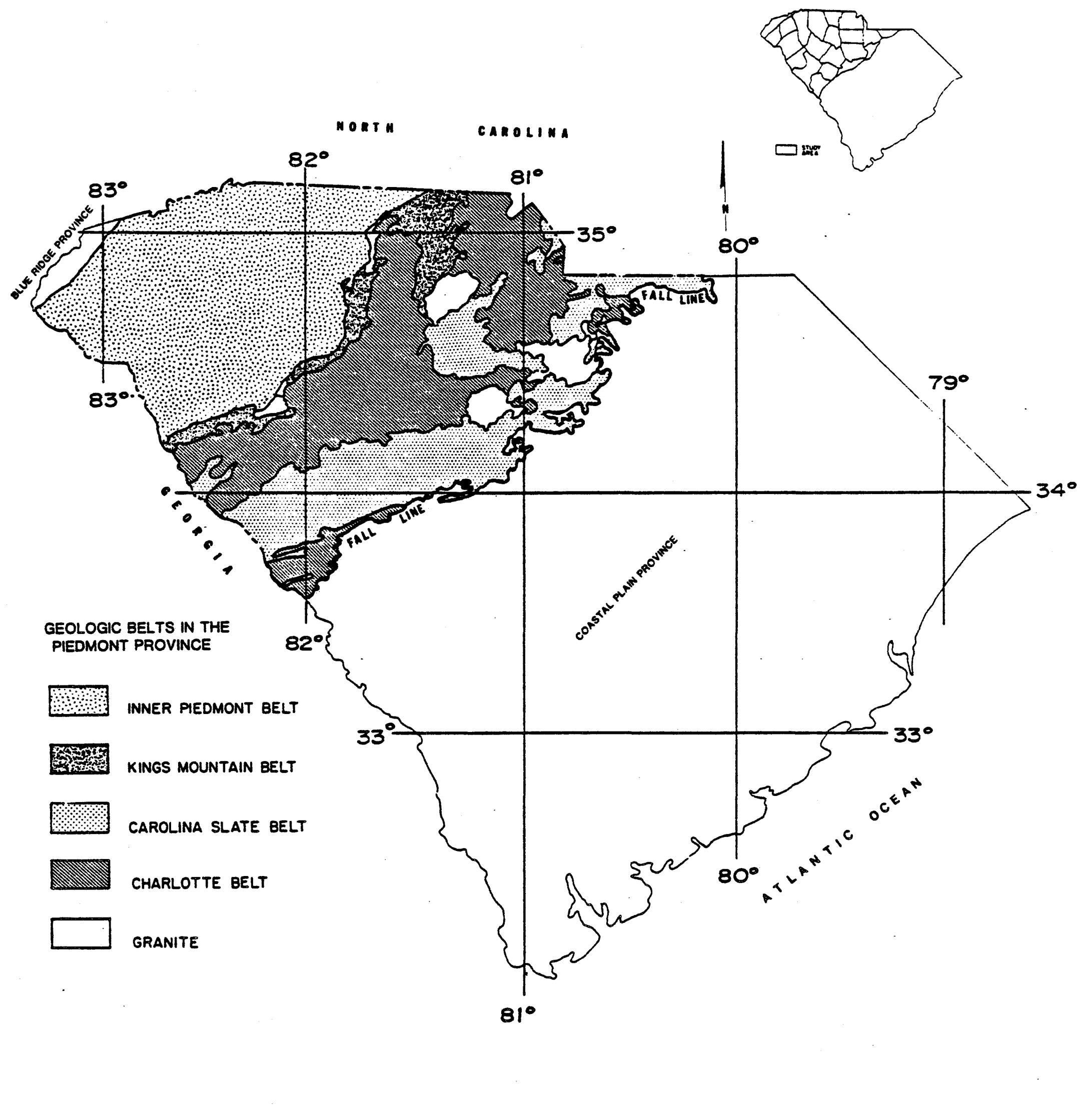


Figure 1. Geology of the South Carolina Piedmont (from Patterson and Padgett, 1984)

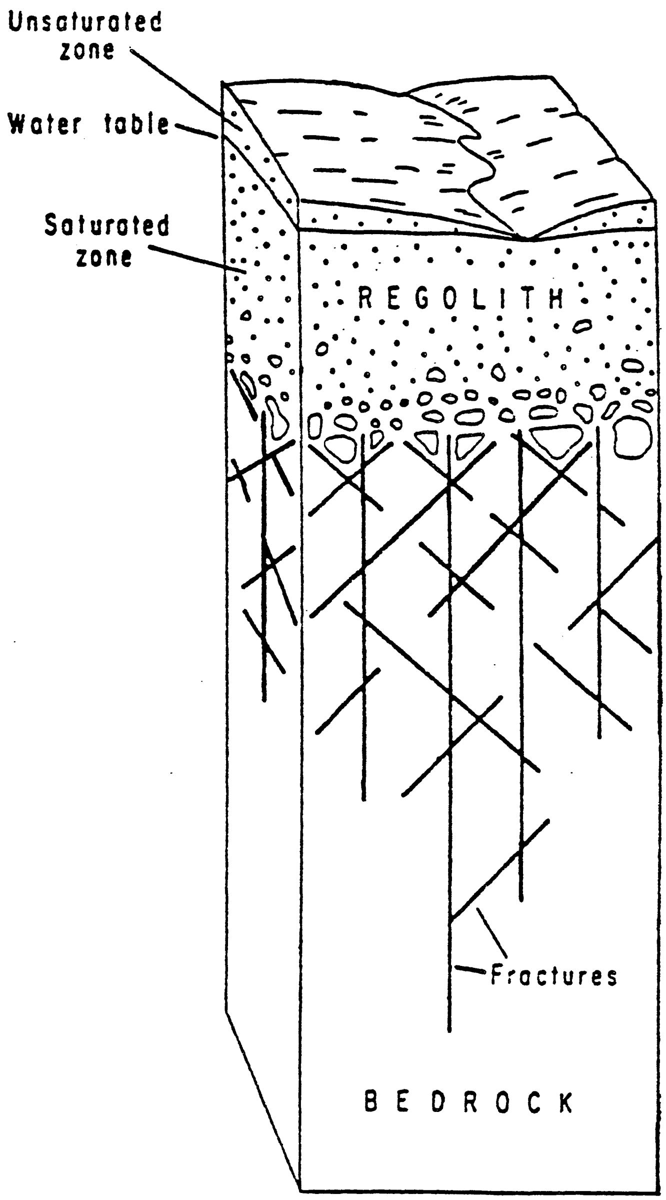


Figure 2. Principal components of the ground water system in the Piedmont and Blue Ridge provinces in North Carolina (Daniel and Sharpless, 1983)

Information was gathered on commercially available ground water database computer programs. Finally, recommendations were made based on the current status of ground water data management in the Piedmont of South Carolina.

II. LITERATURE REVIEW AND RELATED RESEARCH

A. South Carolina Piedmont

The South Carolina State Water Assessment prepared by the South Carolina Water Resources Commission has given an overall assessment of both surface and ground water (S.C. WRC Report 140, 1983). The document indicates that in the Piedmont Region of South Carolina only one county, Greenville, has ground water data and analysis whereby the major aquifers and hydrologic factors controlling ground water recharge, movement, availability and quality have been identified. There has been basic data acquisition (well data on construction, yield, water quality and geophysical logs) in four counties (Oconee, Pickens, Spartanburg and York). The remaining counties in the Piedmont have limited data available.

Each year the USGS in cooperation with the State of South Carolina prepares and publishes Water Resources Data for South Carolina. This publication has ground water level data from selected test wells across the State, including three wells in the Piedmont. There is an evaluation of surface water quality but no data on ground water quality.

Research by the S.C. DHEC (Stone et al., 1986) has found that the fractured-rock aquifers of the Piedmont in South Carolina are highly vulnerable to rapid contamination on a time scale of a few days in some place to three decades in other places. This vulnerability is indicated by contaminated well incidents, pumping test evidence for local recharging, and detection in well water of tritium from nuclear weapon fallout. They concluded that the Piedmont region overall should be considered a major ground water recharge area.

A Symposium on Ground Water and Environmental Hydrogeology in South Carolina was held in 1985 in Columbia (McGill and Stone, 1985). The symposium proceedings expressed the need for characterizing the status of ground water in the Piedmont region of South Carolina as well as the Coastal Plain. In these proceedings, Harry Legrand, a consulting hydrogeologist retired from the USGS, stated that "the most serious problem facing development of ground water supplies of the region (the Piedmont and Blue Ridge) in the future is the wide distribution of plumes of ground water contamination ... some wells are being contaminated now, and more will be contaminated in the future."

Ground water quality and quantity in fracture zones in the Piedmont of South Carolina were evaluated based on 237 well locations in Anderson and Oconee Counties (Snipes, 1981). Snipes concluded that well yields were significantly greater in fracture zones. Most of the ground water samples had good to excellent quality. Some ground water samples had pH values lower than recommended. Limits of Fe and Mn were exceeded by 31% and 19% respectively in some of the wells. In another study by Snipes et al. (1983) in Abbeville County, water quality problems were also found in some of the wells. The quality of ground water from bedrock aquifers in the S.C. Piedmont was reported by Patterson and Padgett (1984) based on data from 442 wells in the DHEC and USGS files. They identified that some constituents from natural sources could occur in high concentrations and be correlated with rock type.

The National Water Well Association, under the sponsorship of the U.S. Environmental Protection Agency, developed a methodology for evaluating the pollution potential of any hydrogeologic setting in the United States. This system, called DRASTIC (Aller et al., 1987) used the following factors to determine relative rankings: depth to water, net recharge, aquifer media, soil media, topography, impact of the vadose zone media, and hydraulic conductivity of the aquifer. This ranking was intended to help direct ground water contamination investigations and to prioritize protection and remediation. One of the ten demonstration maps prepared during the DRASTIC project was of Greenville County, S.C. During the course of their investigation of this county, Aller et al. (1987) noted that water level data were generally sparse and that net recharge rates and hydraulic conductivities were unavailable.

B. Other States

1. Michigan. In 1984, the Governor's Council on Environmental Protection published a set of initiatives to establish a comprehensive statewide plan to better manage Michigan's ground water resources. One of their recommendations was to develop and implement a computerized data management program. Williams et al. (1986) quoted the council's description that "At present, the state's information base on ground water is incomplete and haphazard. Some information already exists and has been computerized. Much has not been collected or is not readily usable because it is not computerized." A Statewide Ground water Data Base Strategy was written to provide a framework for decision makers. The three major classes of data to be addressed were water quantity, water quality, and subsurface geology. Other possible data included meteorology, topography, surface geology, surface hydrology, soil types, land use, demographics, and health statistics. The report pointed out the importance of education and support, saying, "It is not the EXISTENCE of a

ground water database, but effective USE of that database that will support improved ground water management decisions."

A related need was data evaluation and validation, especially for location of wells. A study by Beaulac et al. (1987) found that in one Michigan county only 41% of the well record locations were accurate. Another 24% were relocated in the field by the investigators, and the remaining 35% were not found. Accurate well locations are essential because other data such as water level, casing, well depth, and statigraphic layering are measured relative to the well head elevation. Relocating and verifying existing wells were very labor intensive, leading to recommendations that future data collection and verification be standardized and that local agencies supervise the data collection under a formal cooperative agreement.

2. Georgia. In 1984, the Georgia Environmental Protection Division began a state ground water management plan. Yearly summary reports, entitled "Ground Water quality and availability in Georgia," are published under this plan. The reports cover ground water use, drinking water monitoring data, hazardous facilities monitoring data, ground water withdrawal permits, and technical investigation findings. This uniform data reporting allows the early recognition of any adverse trends in quality or quantity. The data has not been collected in a computerized form.

3. North Carolina. No comprehensive computer data base currently exists in North Carolina. However, the Ground Water Section of the Department of Natural Resources and Community Development does have a limited (700 wells) database stored by a QuickBASIC program and accessible by the expert system, PC Plus, and by the database system, dBASE II. These wells are located statewide, including some in the Piedmont region.

C. Commercial Microcomputer Software for Ground Water Data Management

There are only a few commercially available software packages for microcomputer ground water data management. These include programs developed by Harms Products, Geomath, and Geotech. Appendix A contains some example output from these three systems.

1. Harms Products. Harms Products produces one package called Ground Water Data Management System (GWDMS). It is menu driven and allows the user to analyze, report, and plot chemical, water level, and lithologic data. The plotting package can create contour maps of chemical concentrations, water table levels, or transmissivities. GWDMS can also generate lithologic cross sections, time versus concentration graphs, and water level hydrographs.

2. Geomath. Geomath's GDM System was developed at the French Bureau of Geological and Mining Research. It is a large, powerful FORTRAN program which functions as a general purpose drill-hole data and graphics manager. Targeted toward the petroleum and minerals industries, GDM is also applicable to ground water applications. It produces an impressive range of graphical output: contour maps, plan views, well logs, cross sections, block diagrams, and 3-D displays.

3. Geotech. Geotech's offering, Well Data Master, is a menu driven microcomputer program which can accept data on location, well depths, stratigraphy, and user-defined analytical data (e.g. chemical concentrations). It is compatible with dBASE III and CPS/PC plotting software.

III. ASSESSMENT

A. Piedmont Databases

The three agencies, USGS, DHEC, and WRC, use and maintain the currently available ground water databases for the South Carolina Piedmont. Data can be found in paper files and in various computer systems. The database formats are not compatible and there is little interagency exchange of information. These individual databases are described below:

1. United States Geological Survey - South Carolina District Office. The USGS office in Columbia, S.C., maintains its ground water data in two forms: WATSTORE computer records and paper records filed by county. WATSTORE is the USGS's computer system for storing nationwide information on surface and subsurface water resources. A subprogram within WATSTORE, Ground Water Site Inventory (GWSI), contains limited ground water data for the Piedmont Region (20-40 wells), as shown in Figure 3. The sources of data include public supply wells and project sites. Due to the limited work in the Piedmont, there are large gaps in the data. The program itself is very comprehensive, including over 500 possible parameters under the categories shown in Table 1. The system runs on a PRIME computer and can be accessed after paying a user fee and receiving an authorization code. In addition, requests for specific information can be filled by USGS employees.

The USGS county well files are a collection of old and new well records, location maps, geophysical logs, pump test data, and chemical analysis data. Much

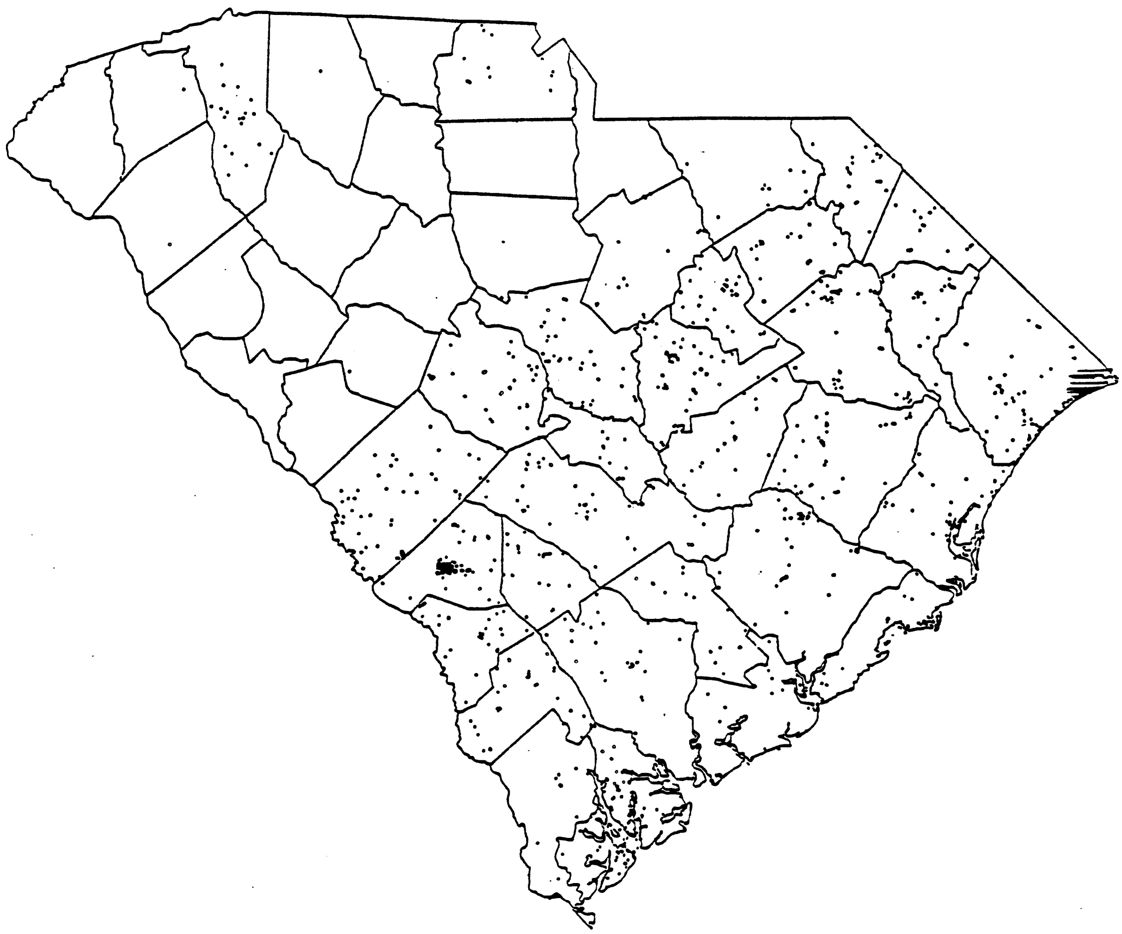


Figure 3. GWSI wells in South Carolina
(from WATSTORE User's Guide, 1982)

Table 1. Categories of data stored in GWSI (from WATSTORE User's Guide, 1982)

Schema Record	Description of Information
ENTRY	Site identifiers such as latitude and longitude, altitude, State, County, etc.
LIFT	Type, such as pump or bucket; includes horsepower, intake setting, etc.
MAJOR PUMP	Manufacturer, serial number, energy consumption, capacity, etc.
STANDBY	Alternative power types.
CONSTRUCTION	
CONSTRUCTION	Date of completion, contractor, seal type, finish, and seal bottom.
HOLES	Type of well dimensions, including diameter of top and bottom of hole.
OPENINGS	Depth intervals of perforated zones, size and shape, screen material.
CASINGS	Type and material, top in reference to land surface, depth to bottom and diameter of each string.
MINOR REPAIRS	Repair information.
GEOLOGY	
GEOHYDROLOGIC UNITS	Name of formation. Includes unit identifier and its depth.
AQUIFERS	Includes static water level in aquifer.
HYDRAULIC	Includes the unit identifier.
COEFFICIENTS	Includes conductivity, diffusivity, and leakance.
NETWORKS	
QUALITY NETWORK	Water-quality network. Includes name of agency that gathers samples at site.
LEVEL NETWORK	Water-level network. Includes name of agency that collects water level measurements at site.
PUMPAGE NETWORK	Pumpage network. Includes name of agency that monitors water withdrawal at site.
PRODUCTION	
FLOW DATA	Information about springs including flow period, and discharge.
PUMP PRODUCTION	Production of the well including production date, and method.
OWNERS	The site's owner, name, and ownership date.
SPRINGS	Spring data; for example, name and number of openings.
ADDITIONAL INFORMATION	
REMARKS	Additional remarks about the site.
MISCELLANEOUS DATA	Other references and sources of data.
SITE VISITS	Visits to the site, such as the inventory person and date of visit.
OTHER DATA	Location and formats of other data available about the site.
OTHER IDENTIFICATION	Other site identifiers.
WATER QUALITY	
FIELD WATER QUALITY	Field water quality data, such as the sample date, the constituent, its measurement and source (aquifer name).
LOG	
LOGS	Type of geophysical or other logs available for the well including type and source.
SPECIAL CASES	
WELL GROUP	Multiple wells that are manifolded to a single discharge pipe. Data includes the number of wells, and the deepest and shallowest wells in the group.
POND, TUNNEL, DRAIN	The length, width and depth of a pond, tunnel or drain.
COOPERATOR DATA	Data that cooperating local agencies need, such as cooperator's site identifier, registration number, etc.
LATERALS	Information about Ranney wells, including the depth, length and diameter of the laterals that drain to the central well.
MISCELLANEOUS VALUES	Data for which no other schema record has been established.
STATE WATER USE	
OBSERVATION WELLS	
HEADING	Textural information about the site.
YEAR	Specific year for data in the lower level schema record(s).
WATER LEVELS	Includes water-level measurements and respective dates.
MEASURING POINT	Data includes the measuring point height and the date when the measurement was made.

of the information is dated from the 1940's and 1950's with occasional copies of WRC reports from the 1980's.

2. South Carolina Department of Health and Environmental Control. Most ground water data is collected and used by two divisions in DHEC: Ground Water Protection and Water Supply. In addition, the Hydrogeology Division receives ground water quality data from hazardous waste (RCRA) and Superfund (CERCLA) sites. The Ground Water Protection Division maintains two files: Computerized STORET records and project paper files. The Water Supply Division has three paper files: well permits, chemical analyses, and private well problems. This division also works with a customized microcomputer dBASE III system.

STORET is the USEPA's mainframe system for storing nationwide information on sampling sites and their associated quality data, including both upgradient and contaminated wells. However, recent data are often not available for some time due to lags in data entry. The actual chemical parameters reported vary with site and are determined by the enforcement permit conditions. Depending on the site conditions and parameters being monitored, sampling may occur daily, quarterly, or yearly. Quarterly is the most common interval. STORET was originally developed for surface water data storage. Ground water data were added later. Quality data can include concentrations, not only for water, but also sediment and biological materials. Output can be in the form of files or digital maps. The system is frequently updated, and is diverse and complex. A high level of proficiency is needed to properly use the system. Direct modem linking requires a current agency code. DHEC presently has about two gigabytes of data on STORET.

Project files also contain correspondence and maps pertinent to the sites. Format is highly variable, depending on the consulting firm involved and the extent of contamination. This information is filed by county and site name, thus unindexed for future reference. Monitoring permits are usually issued for five year periods.

The Water Supply Division's well permit files are indexed by site and include well records, correspondence, permit records, and some maps. Usually, the well drillers' logs are not very descriptive; many can only be used to indicate approximate locations of fractures and approximate thickness of saprolite. Static water level information is considered good. Pumping test data often are useful for pump sizing only. Location information for public supply wells is more accurate than for private wells.

DHEC's water supply dBASE III program was developed to store water well inventory records, chemical/radiological/bacteriological analysis data, and compliance schedules. If maximum regulatory concentrations are exceeded, the record is flagged and a noncompliance notification is printed. Bacteria analyses are required every month for public supply wells. Chemical analyses are updated every three years, and radiological analysis every four years. Some of the information from this database is linked to STORET's national records. The hardcopy records of this database are found in the chemical analyses files. This information, and other data from DHEC, can be accessed by the public with a routine Freedom of Information (FOI) request.

Private well files are indexed by zip code and contain only analyses for the chemicals of concern. These files are biased toward water quality problems. Analysis data are kept for one year and then discarded.

3. South Carolina Water Resource Commission. The WRC maintains well construction data in two forms: a computerized file of well records and a paper file of the same.

The ground water section of the WRC has collected information on 3,166 wells in the Piedmont counties. The microcomputer software, dBASE III, was used to store and manipulate the data set. The variables in the database are shown in Table 2. The WRC designed their own well identification system to locate wells in South Carolina (Figure 4). The actual data were collected and stored on a county basis.

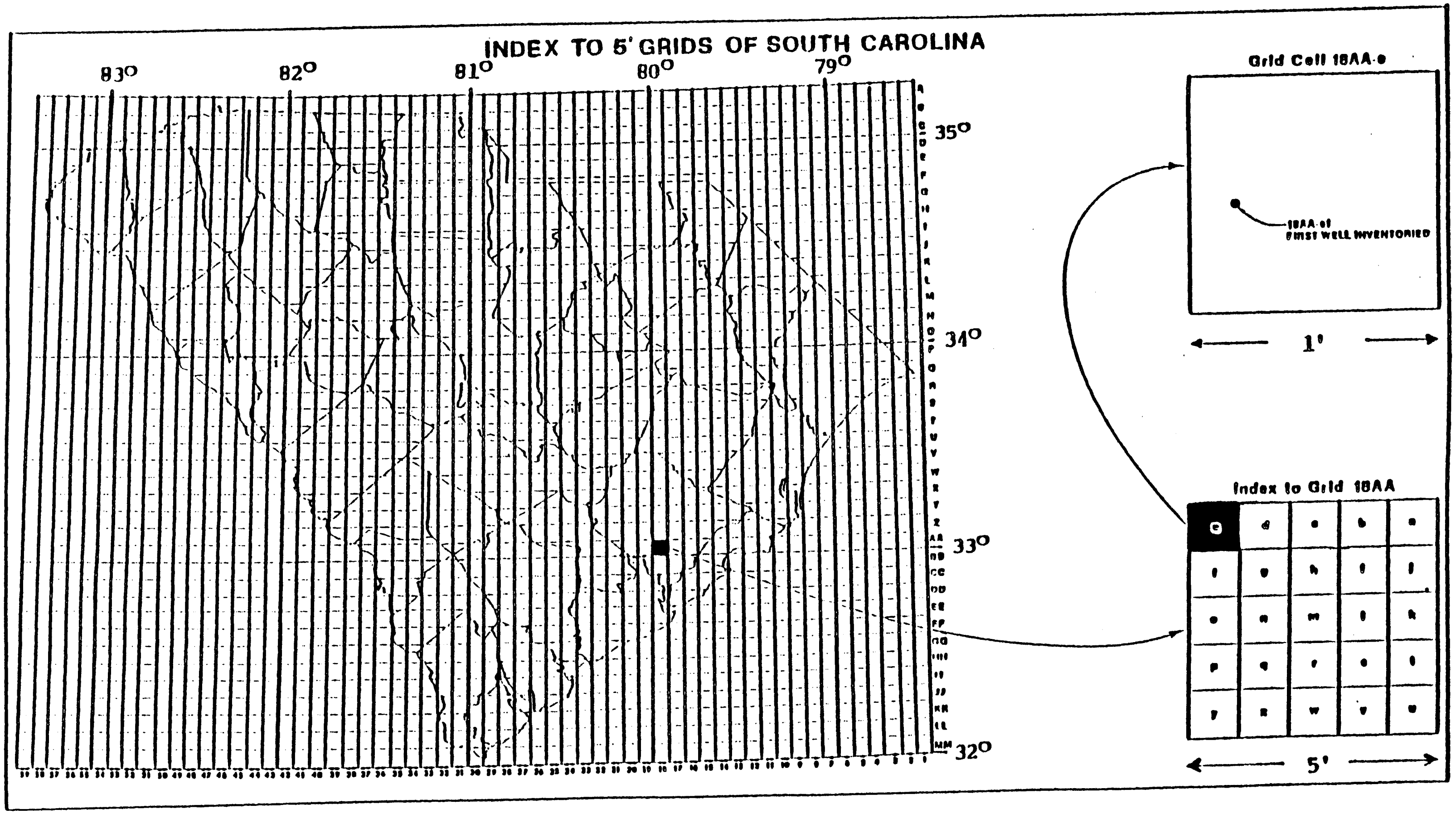
The WRC well files are the hardcopy sources of data entered into the dBASE III system. Since 1985, all drillers have been required to submit well completion reports. However, there are problems with noncompliance, or incomplete compliance.

B. Summary of Knowledge Level

1. Current issues of quantity and quality. Small supplies of water can be obtained from saprolite wells in the regolith. Larger water supplies usually require drilling into the bedrock. Bedrock wells have larger areas of influence and drawdowns. However, their actual yields will depend on the number and size of the fractures intercepted by the wells and their connection with the regolith. Thus, fracture location becomes an important factor in the siting of these wells. The existence of fractures can be predicted from fracture trace mapping and from the topography. Fracture trace maps drawn from aerial photographs identify surface lineaments associated with fractures in the bedrock below. Topography is also an important indication of the amount of fracturing in the bedrock. More intensely fractured areas tend to weather faster, creating valleys or draws. Mountains or ridges often indicate sparsely fractured bedrock and will produce low yielding wells. Areas with a thicker regolith layer will usually show larger well yields, presumably due to greater storage capacity.

Table 2. Categories of data stored in WRC dBASE III files (from WRC database documentation)

County #:	The number assigned sequentially to all recorded wells in each county.
Alternate #:	The well owner's number, if any.
SCWRC #:	The grid number assigned by the WRC according to a well's location and order of inventorying.
Latitude/Longitude:	Given in degrees, minutes, seconds.
Elevation:	Given in feet above mean sea level.
Method:	The well site elev.: T if estimated from topo map; R if reported; S if surveyed.
Owner:	Name of owner, company, municipality, etc.
Location:	Nearest city, lake or other feature. Topo: Well site topography: T = hilltop; V = valley; S = hillside; D = draw; F = flat.
Well Type:	S for screened wells; O for open holes (open holes in more detail: B = bored; D = drilled; H = hand dug).
Top of Intake:	Depth to top of screen for screened wells; depth to bottom of casing for open holes. Bottom of Intake: Depth to bottom of screen for screened wells; and bottom of well for open holes.
Water Use:	AB = abandoned: AR = recording observation well; AH = auger hole; CO = commercial; DH = dry hole; DO = domestic; GC = golf course irrigation: HP = heat pump; IN = industrial; IR = ag. irrigation; IS = institutional; LS = livestock; MI = mining; OB = observation (non-automated); PT = powerthermo; RE = recreation; RW = return well; ST = sewage treatment; TH = test hole; UN = unused; WS = public water supplier.
Total depth:	Completed depth of well.
Depth measurement:	R = reported; M = measured. Casing Diameter 1: Inside diam of casing (inches) if multiple casings, also listed under Casing Diam 2,3.
Casing Depth 1:	Depth in feet to bottom of casing; if multiple casings, also listed under Casing Depth 2 and Casing Depth 3.
Well Yield:	Yield in gallons per minute.
Pump Test:	Y = Yes, data may be available.
Static Water Level:	Depth to static water level in feet.
Static test date:	Date on which static water level checked.
Year well completed:	Self explanatory.
Chem Anal:	C = complete; P = Partial; S = single
Logs:	D = driller's log; R = single point resistance; LN = long normal; T= temp. FR = fluid resistivity; SP= spontaneous potential; LT = lateral; O = other; G = gamma; SN = short normal; C = caliper.



Note: The larger squares are 5 minute grids, while the 25 grid cells within each grid are 1 minute b6 1 minute in size. The wells within each grid cell are numbered sequentially.

Figure 4. Well location and numbering system of the South Carolina Water Resources Commission.

Quantity issues generally concern ground water in the bedrock, whereas quality issues are more often concerned with the saprolite layer. Quality data are available for individual contamination sites and for existing public supply wells. Patterson and Padgett (1984) produced a series of maps showing the geographic distributions of twelve water quality parameters for fractured rock wells in the Piedmont, but additional definition of chemical background levels is needed.

The demonstration DRASTIC project (Aller et al., 1987) produced ground water contamination vulnerability ratings for Greenville County, but little work has been done for other Piedmont counties. DRASTIC's standardized system for evaluating pollution potential yielded numerical ratings based on selected hydrogeologic factors. Nationally, DRASTIC indexes ranged from 65 to 223. Values computed for Greenville County varied from 87 to 152 as shown in Figure 5. High Drastic values indicate that an area is generally sensitive or vulnerable to contamination. Lower values indicate less hydrogeologic sensitivity. However, the numerical value does not by itself have intrinsic meaning. It is only useful in comparison with values from other areas. Also, it is the existence of contamination sources, in conjunction with the hydrogeologic factors, which will determine a site's actual pollution potential. DRASTIC addresses only hydrogeologic factors, but in so doing provides a good screening tool.

2. Current ground water data management. Only part of data on ground water in the South Carolina Piedmont are computerized. Thus, much information is lost to future users, and in addition, the money spent in obtaining those data is not employed to its fullest extent. This inaccessibility of data is the result of differing purposes, uses, and format of the data; filing without regard to ease of future reference for other purposes; and lack of awareness of the data's existence. Data formats are not uniform among agencies and even between departments within

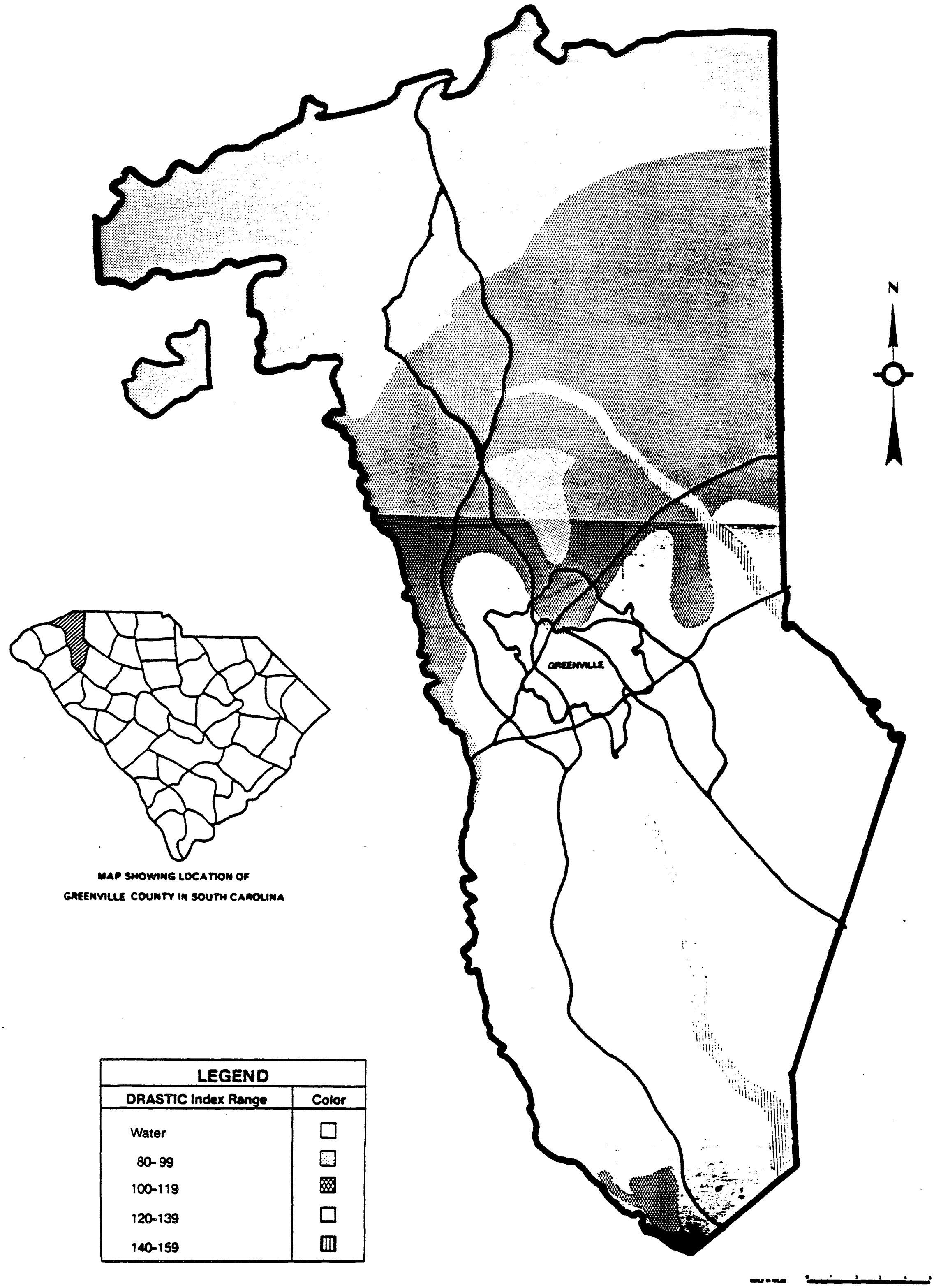


Figure 5. DRASTIC pollution potential map of Greenville County, South Carolina (from Aller et al., 1987)

agencies due to a highly fragmented approach to ground water management in South Carolina. The quality of the data is, in many cases, questionable. This is especially true about well head locations and well log lithology when such data are submitted to the various agencies.

C. Preliminary analysis of existing data

The ground water supply in the Piedmont region depends on the hydrogeological characteristics and relations of both the regolith and bedrock. The water yield in bedrock wells is controlled by the following:

i. Bedrock water bearing potential (related to degree of fracturing).

ii. The size or interconnections of those rock fractures that are intersected by well diameter.

iii. Regolith water storage potential (related to depth and characteristics of the regolith that overlays the bedrock).

Some earlier investigations were directed to quantify the ground water availability in the Piedmont region. However, the findings related to the correlations between well yield and well depth, rock type, topographic position, and regolith depth were very limited. The success in reaching significant conclusions to cover the entire Piedmont region were also limited due to the fact that the analysis was done on political, county boundaries instead of hydrogeological units.

1. USGS Data. The United States Geological Survey has established a network of ground water observation wells in South Carolina equipped with continuous water level recorders. Only three wells in the Piedmont region are currently included in this network. The USGS data and information priorities are increasing for the Piedmont region. One of the continuous observation wells is located in Greenville County, one in York County near Rock Hill, and one in Richland County north of Columbia (Figure 6).

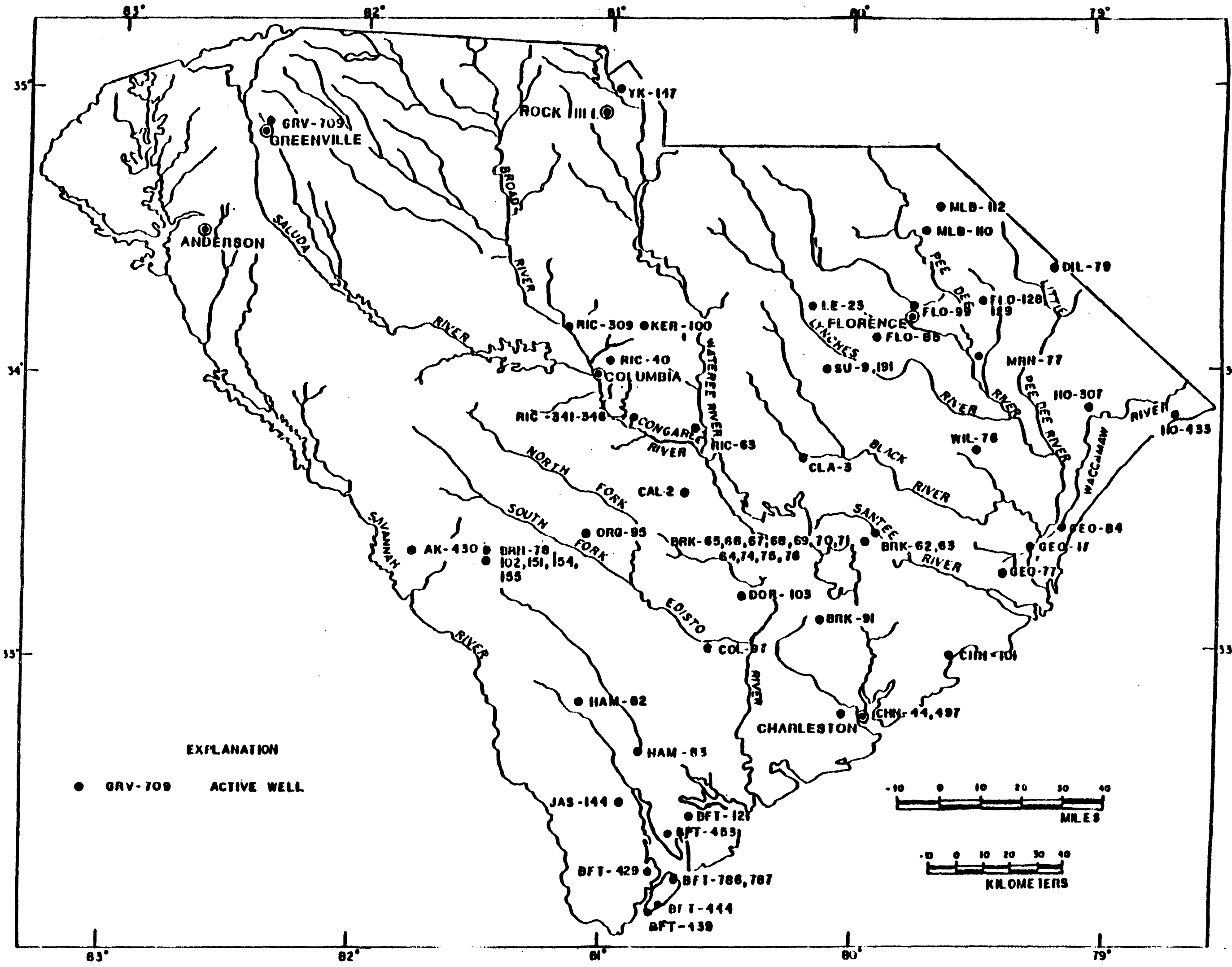


Figure 6. Location of ground water observation monitoring wells.

The average annual water table depth was calculated for two wells for the period 1973 to 1985 in York County, and 1974 to 1985 in Greenville County. The annual rainfall data were obtained from the closest rainfall gauging station to the well sites. Both average water table depth and annual rainfall are plotted in Figures 7 & 8 for Greenville and York Counties. The data for both counties showed little variation in water table elevation on an annual basis even though rainfall varied greatly.

The average water table depth for the Greenville County well was 28.63 feet and 21.36 feet for the York County well. Deviation from the average values are given in Figures 9 & 10. The maximum deviation from the six year average at Greenville County was 1.3 feet in 1982 and 3.6 feet at York County in 1981. The ground water level dropped more in the York County well than the Greenville County well in spite of the higher average rainfall in York County in 1981.

No analysis was made during this study of the data in the USGS Ground Water Site Inventory database, or in the USGS hardcopy county well files.

2. <u>WRC Data</u>. A total of 3,166 well data points are stored in the WRC database. The number of entries for some variables of that database are given in Table 3. For this study, the data for each county were sorted on the basis of well diameter. The average well depth and yield were calculated for each diameter. The calculated averages and number of observations are tabulated in Table 4. The data in Table 4 showed increase in the well yield for larger well diameters and greater depths in almost all the counties. Similar results of well yields have been reported in the Piedmont region of South Carolina. Koch (1968) inventoried 519 drilled wells in Greenville County and reported an average yield of 17 gpm. The average yield of 86 wells drilled to obtain the maximum yield was 34 gpm. Bloxham et al. (1970) reported the average yield of wells inventoried in Spartanburg County

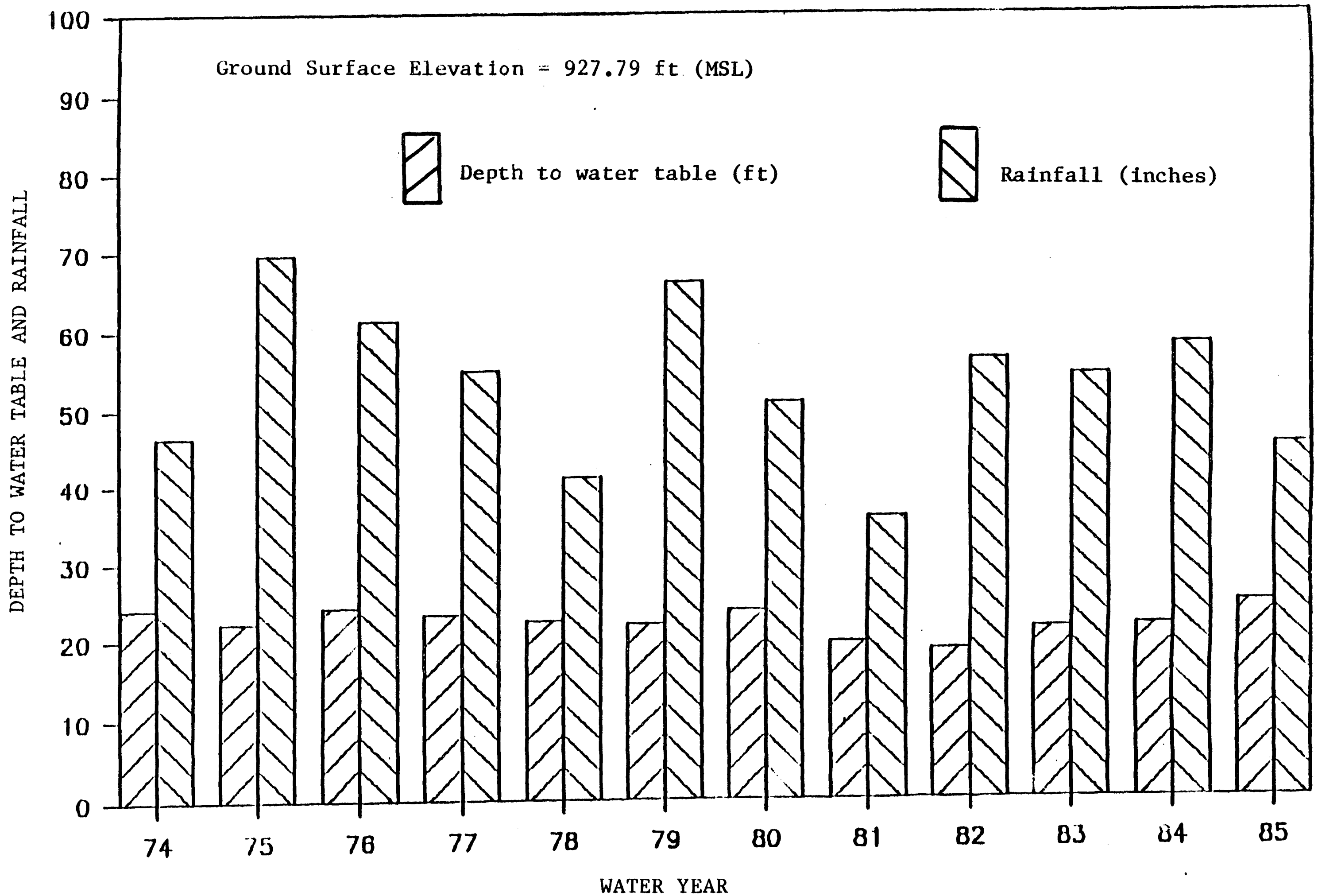


Figure 7. The average depth to the water table in Greenville County USGS ground water observation well and the annual rainfall in the well site.

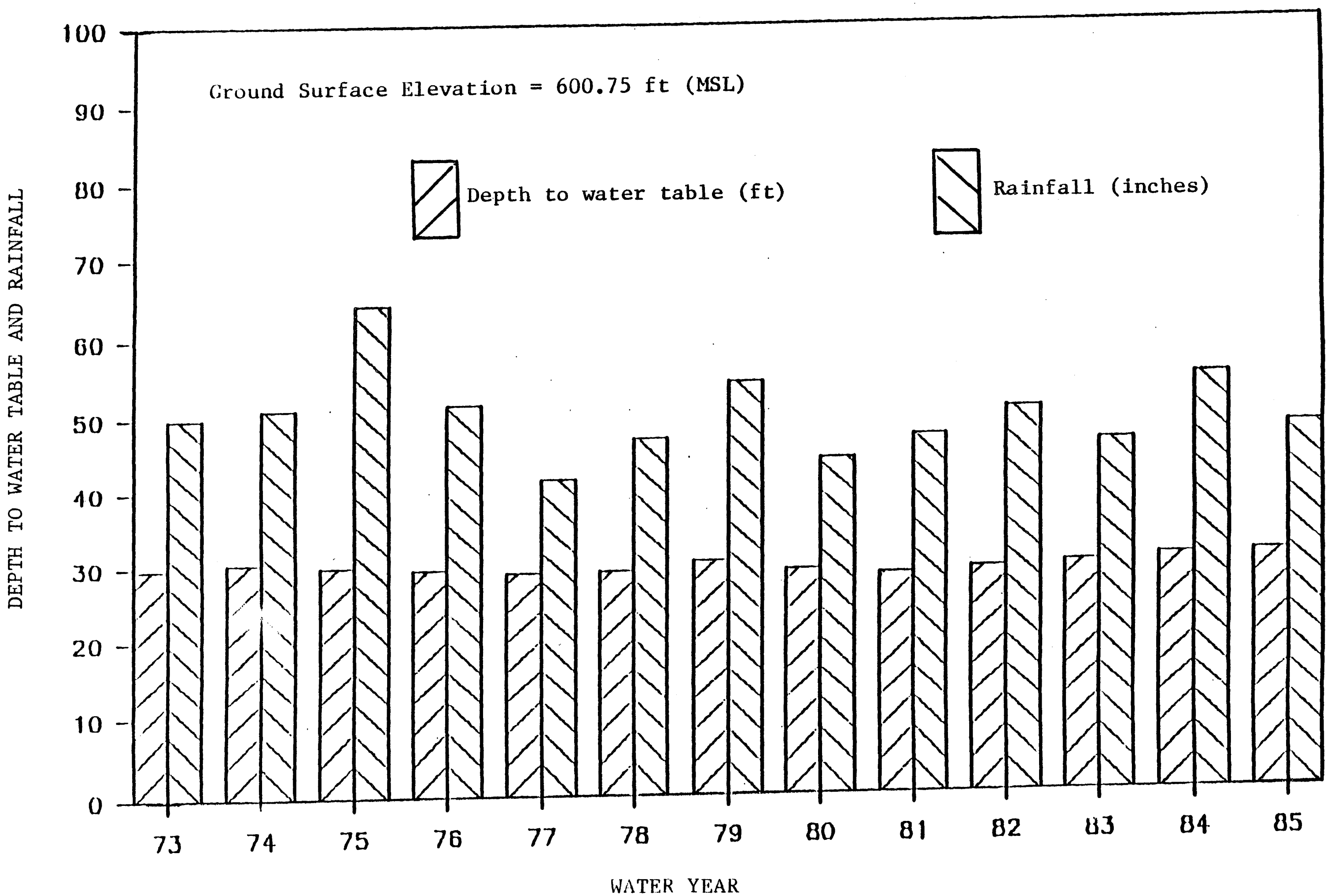


Figure 8. The average depth to the water table in york County USGS ground water observation well and the annual rainfall in the well site.

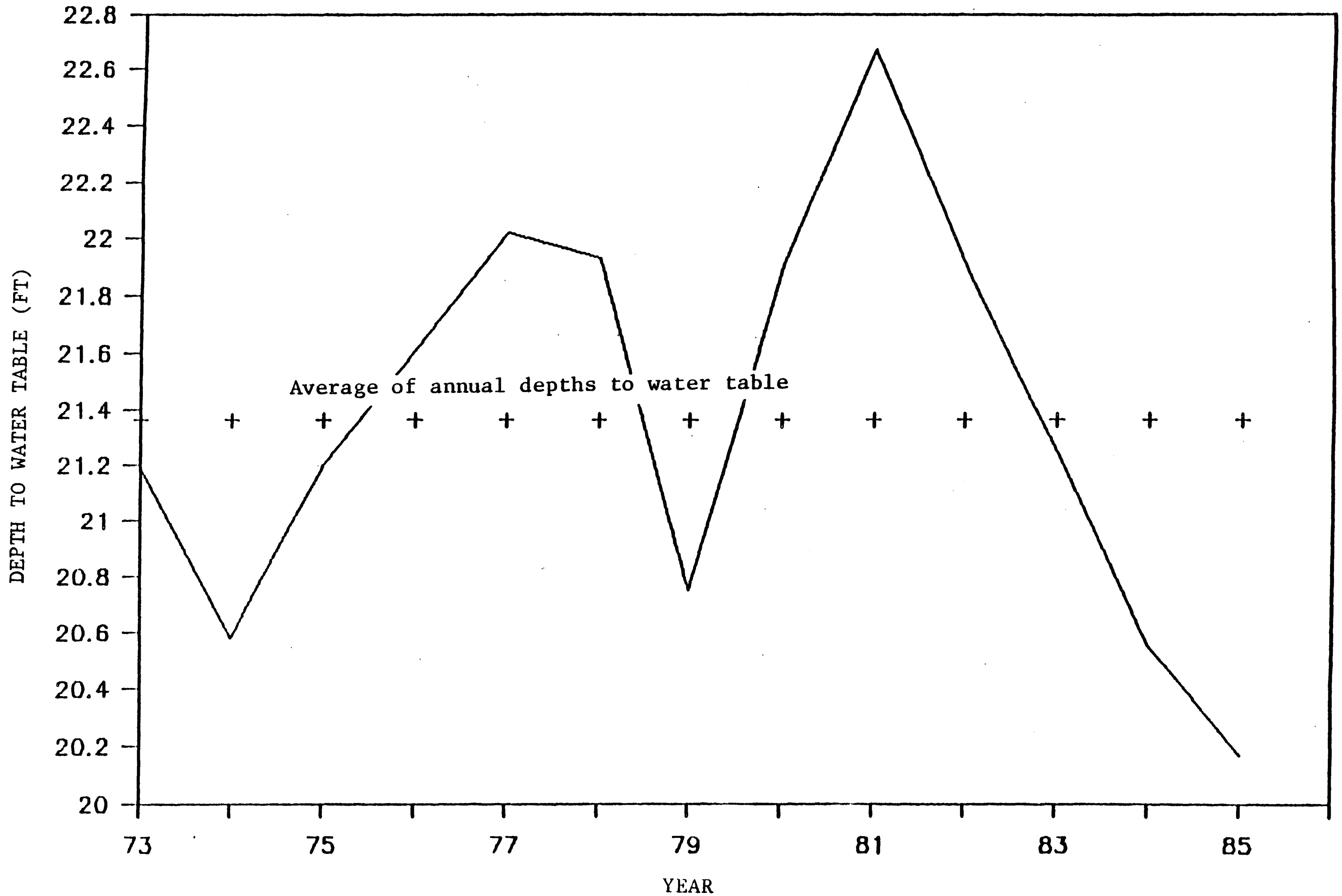


Figure 9. Annual average variation of depth from ground surface to water table for USGS ground water observation well in York County. Average of annual depths is 21.36 feet.

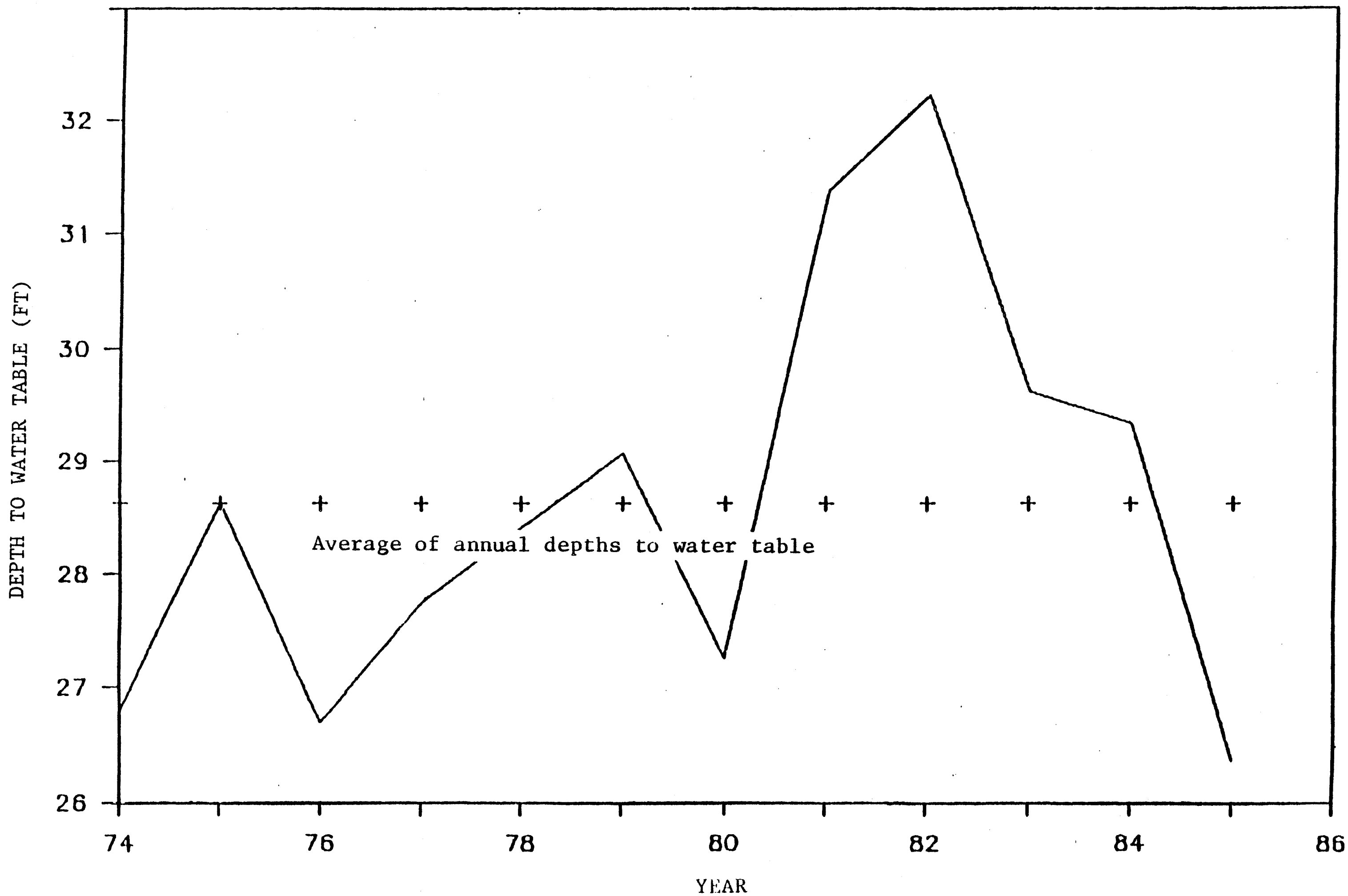


Figure 10. Annual average variation of depth from ground surface to water table for USGS ground water observation well in Greenville County. Average of annual depths is 28.63 feet.

Table 3. Number of entries for selected categories in the WRC Well database. (see Table 2).

Category	Number of Date Entries*
County	3166
Water Use	2636
Topographic Setting	924
Total Depth	2885
Well Diameter	2566
Yield	2410
Casing Depth	1960
Static Water Level	992
Total Depth & Diameter & Yield	2202

*Based on data reports for 3166 wells

Table 4. Average Values of Well Depth and Yield for each County

County	Diameter of Well	Number of Wells	Average Well Depth (ft)	Average Well Yield (GPM)	Yield/ (ft)
Greenville	4"	2	-----	-----	-----
	5"	6	192.17	40.16	.2782
	6"	546	149.26	16.97	.1467
	8"	8	171.38	59.13	.3319
Spartanburg	2"	4	-----	-----	-----
	4"	2	-----	-----	-----
	5"	8	191.87	17.88	.113
	6"	186	244.10	33.05	.162
	8"	24	294.16	49.33	.186
Pickens	2"	7	20.00	8.86	.443
	4"	7	99.00	328.57	3.94
	5"	2	-----	-----	-----
	6"	173	166.18	20.16	.133
Oconee	1"	4	240.00	30.25	.229
	4"	1	-----	-----	-----
	6"	113	223.36	22.81	.136
	7"	1	-----	-----	-----
	8"	1	-----	-----	-----
Newberry	3"	1	-----	-----	-----
	4"	2	-----	-----	-----
	5"	1	-----	-----	-----
	6"	54	252.02	30.30	.144
	7"	2	-----	-----	-----
	8"	9	322.33	84.56	.353
Laurens	4"	1	-----	-----	-----
	6"	51	152.45	31.55	.26
	8"	11	418.45	66.81	.166
McCormick	4"	3	-----	-----	-----
	6"	15	208.07	39.66	.22
	8"	5	-----	-----	-----
Saluda	1"	1	-----	-----	-----
	6"	18	222.22	34.39	.213
	8"	2	-----	-----	-----
Union	2"	2	-----	-----	-----
	3"	2	-----	-----	-----
	4"	1	-----	-----	-----
	6"	10	289.5	22.1	.025
	8"	4	-----	-----	-----

Table 4. ...continued

County	Diameter of Well	Number of Wells	Average Well Depth (ft)	Average Well Yield (GPM)	Yield/ (ft)
York	2"	18	152.0	7.12	-----
	4"	1	-----	-----	-----
	5"	4	161.25	32.0	-----
	6"	128	247.51	37.125	.243
	8"	24	515.54	147.58	-----
Anderson	2"	15	54.13	48.67	1.51
	3"	1	-----	-----	-----
	4"	7	-----	-----	-----
	5"	4	-----	-----	-----
	6"	211	188.18	31.08	.26
	8"	8	-----	-----	-----
Fairfield	2"	4	-----	-----	-----
	3"	2	-----	-----	-----
	4"	2	-----	-----	-----
	6"	33	286.72	30.33	.119
	8"	1	-----	-----	-----
Abbeville	2"	1	-----	-----	-----
	4"	1	-----	-----	-----
	5"	1	-----	-----	-----
	6"	64	149.23	38.98	.397
	8"	1	-----	-----	-----

was about 20 gpm. Snipes (1981) inventoried 237 drilled wells in Anderson and Oconee Counties and reported an average yield of 33 gpm. Snipes et al. (1983) inventoried 280 wells in Abbeville County and reported an average yield of 28 gpm for 119 drilled wells.

The data in Table 4 indicates the importance of well diameter and depth to the well yield. It is expected that well yield also will vary according to well site topography. For a well yield analysis, the data should be sorted on topographic location basis, but topographic information was not included in the database for over two thirds of the wells.

The average well casing depth and average water table depth were calculated for each county. The casing depth was assumed equal to the total regolith depth. The saturated regolith depth was calculated by subtracting the water table depth from the casing depth. The calculated averages, yield per foot depth and total depth for 6 inch wells are given in Table 5. The information in Table 5 showed that when the saturated regolith which overlays the bedrock zone was thicker the well yield was higher in most cases. For example in Laurens County, the saturated regolith depth is 76 feet which was more than two times that in Pickens County (30 feet). The yield per foot in Laurens County is also two times that in Pickens County, and the average total depth is 152 feet compared to 222 feet in Pickens county.

Daniels (1987) concluded that his statistical analysis of rock wells in North Carolina "strongly suggested" a relation between well depth and yield and, also, well diameter and yield. About 2,200 wells in the WRC database had information about well diameter, depth and yield. Well data were statistically analyzed to determine the correlation between well yield and diameter and depth. The total number of wells was treated as one group due to the following reasons:

1. The lack of the hydrogeological and topographical information.
2. The well diameter variation within each county was limited.

There was no significant relation between well yield, diameter and depth.

Therefore, the well data were sub-grouped in one hundred foot intervals as follows: 0-100 ft., 101-200 ft., 201-300 ft., 301-400 ft., 401-500 ft., 501-600 ft., 601-700 ft. and 701-800 ft. A linear regression technique was employed to evaluate well yield in terms of well diameter and depth. The following quadratic equation or model was used to fit the data in each interval for all diameters.

$$Y = A + B\,(\text{dia}) + C\,(\text{depth}) + D\,(\text{depth})^2 + E\,(\text{dia})^2 + F\,(\text{dia})\,(\text{depth})$$

Table 5. Average values for variables in WRC database for S.C. Piedmont Counties.

County	Average* Casing Depth (ft)	Average Water Table (ft)	Saturated Regolith Depth (ft)	Yield/ft 6" Diameter (GPM)	Average Total Depth 6" Diameter Well (ft)
Abbeville	70	26.60	43.4	.397	149.23
Anderson	60	28.77	31.23	.26	188.18
Cherokee	68	44.06	23.94	.097	220.00
Chester	55	40.33	14.67	.186	240.00
Edgefield**	58	40.89	17.11		
Fairfield	64	52.55	11.45	.119	286.72
Greenville	53	36.71	16.29	.147	149.26
Greenwood	79	36.25	42.75	.137	149.12
Lancaster**	45	25.72	19.28		
Laurens	109	32.67	76.33	.26	152.45
McCormick	71	18.67	52.33	.22	208.07
Newberry	77	51.09	25.91	.144	252.02
Oconee	54	39.85	14.15	.136	223.36
Pickens	59	29.02	30.00	.133	166.18
Saluda	76	22.00	54.00	.213	222.22
Spartanburg	63	41.44	21.56	.162	244.10
Union	87	32.08	54.92	.025	289.50
York	73	32.02	40.98	.243	247.51

* Casing depth was assumed equal to the total regolith depth.
** 6,7 Well data reports, respectively.

Where A is the intercept and B through F are constants. Diameter is in inches and depth is in feet.

The forward selection, backward elimination and maximum R^2 procedure was used to determine the significance of the model variables for each depth interval. The most significant equation variables and R^2 values are given in Table 6. The analyses showed that the best one variable model for well yield was based on diameter for all depth intervals. The relationship between the well diameter and yield was not conclusive, probably due to an inadequate number of wells with diameters other than 6 inches.

The diameter variable was dropped from the model by applying the regression equations only to the 6-inch diameter wells. The new equation variables and R^2 values are given in Table 7. The analyses and the lower values of R^2 as a result of dropping the variable diameter from the model indicated the importance of the diameter among the variables that were used in this study. The new regression lines were plotted in Figures 11-16 over the scatter plots for the 6 inch well data. There were inconsistencies in the regression data, particularly at the beginning and end of the arbitrary intervals. This was in part due to data clustering before or after the interval boundaries. The best fit curves at the mid-range of the intervals indicate an increase in well yield with well depth up to about 350 feet. Above 350 feet yield tended to decrease with depth.

For more meaningful evaluation and conclusions, the well location data should be superimposed on a Piedmont Region hydrogeological unit map. Then within each hydrogeological unit the well data could be sorted on a topographic basis for statistical analyses.

The equations determined for each interval were applied to York County data. The analysis had the same trend of increasing the well yield with depth up to about 350 feet.

Table 6. The best fitting equation variables for each well depth interval and R^2 values for all the wells.

Depth Interval (ft)	The Equation Variables and Coefficients	Coefficient of Correlation (R^2)
0-100	Yield = 273.01 + 5.205(Depth) - 73.726(Diam) - .014(Depth)^2 + 3.488(Diam)^2 - .523(Depth)(Diam)	.42
101-200	Yield = -86.637 + .907(Depth) + 8.135(Diam) + .947(Diam)^2 - .11(Diam)(Depth)	.01
201-300	Yield = 132.61 + 6.83(Depth) - 271.32(Diam) - .01(Depth)^2 + 31.79(Diam)^2 - .66(Diam)(Depth)	.17
301-400	Yield = -2660.79 + 12.10(Depth) + 171.44(Diam) - .01(Diam)^2 - .43(Diam)(Depth)	.13
401-500	Yield = -116.81 + 41.98(Diam) - .04(Diam)(Depth)	.37
501-600	Yield = 3405.47 - 12.01(Depth) + .01(Depth)^2	.51
601-700	Yield = 10688.39 - 3460.01(Diam) - .02(Depth)^2 + 37.47(Diam)^2 + 4.49(Diam)(Depth)	.92

Table 7. The best fitting equation variables for each well depth interval and R^2 values for only 6" diameter wells.

Interval	The Equation Variables and Coefficients	R^2
1-100	Yield = 55.62 - .988(Depth) + .007(Depth)^2	.01
101-200	Yield = 4.692 + .097(Depth)	.008
201-300	Yield = -264.31 + 2.341(Depth) - .004(Depth)^2	.006
301-400	Yield = 1835.48 + 10.683(Depth) - .015(Depth)^2	.09
401-500	Yield = 304.92 - 1.008(Depth) + .001(Depth)^2	.11
501-600	Yield = 3392.861 + .011(Depth)^2 - 1.995(Diam)(Depth)	.48

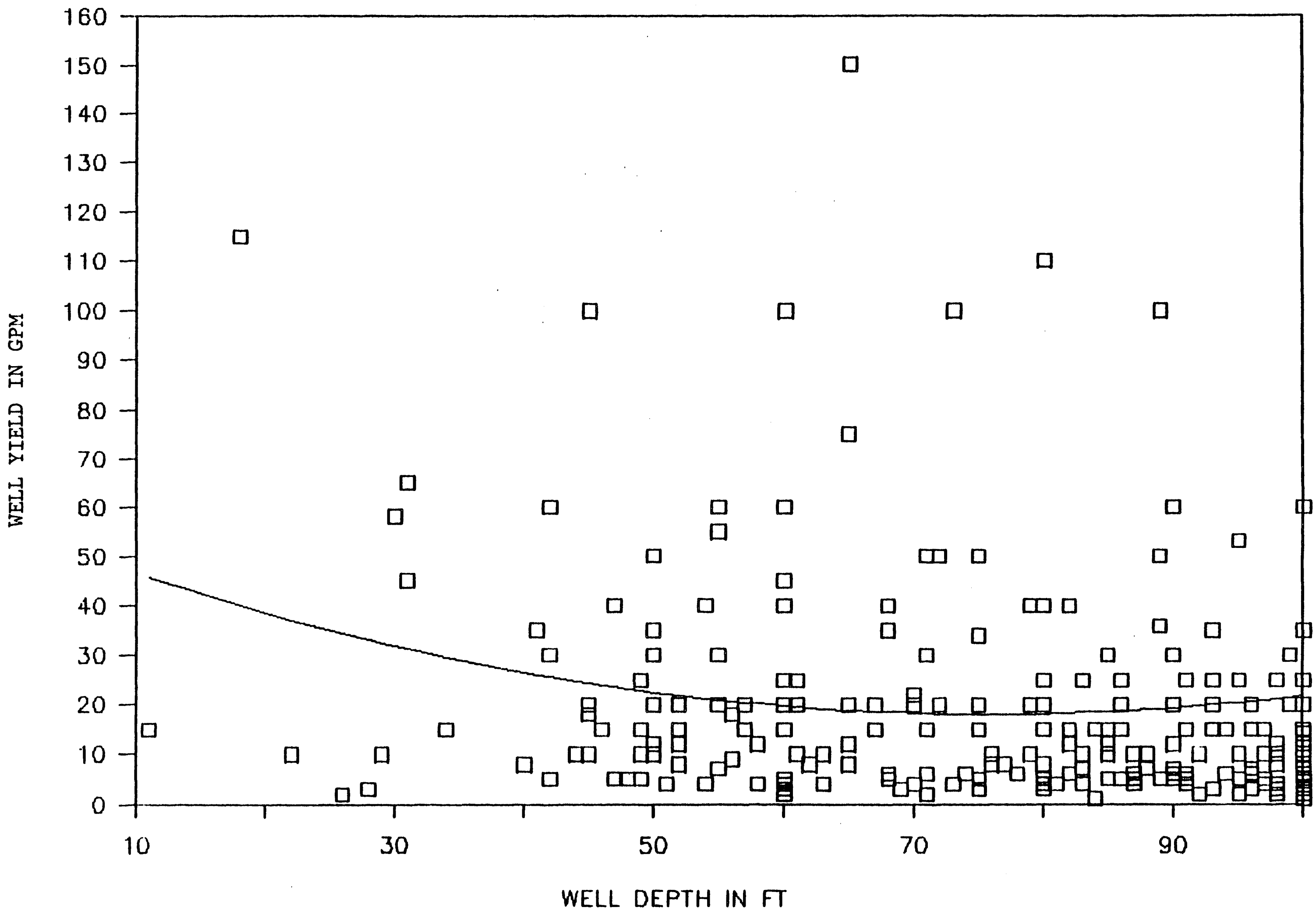


Figure 11. Scatter plot of depth versus yield data for 6 inch wells at depth interval, 0 to 100 feet.

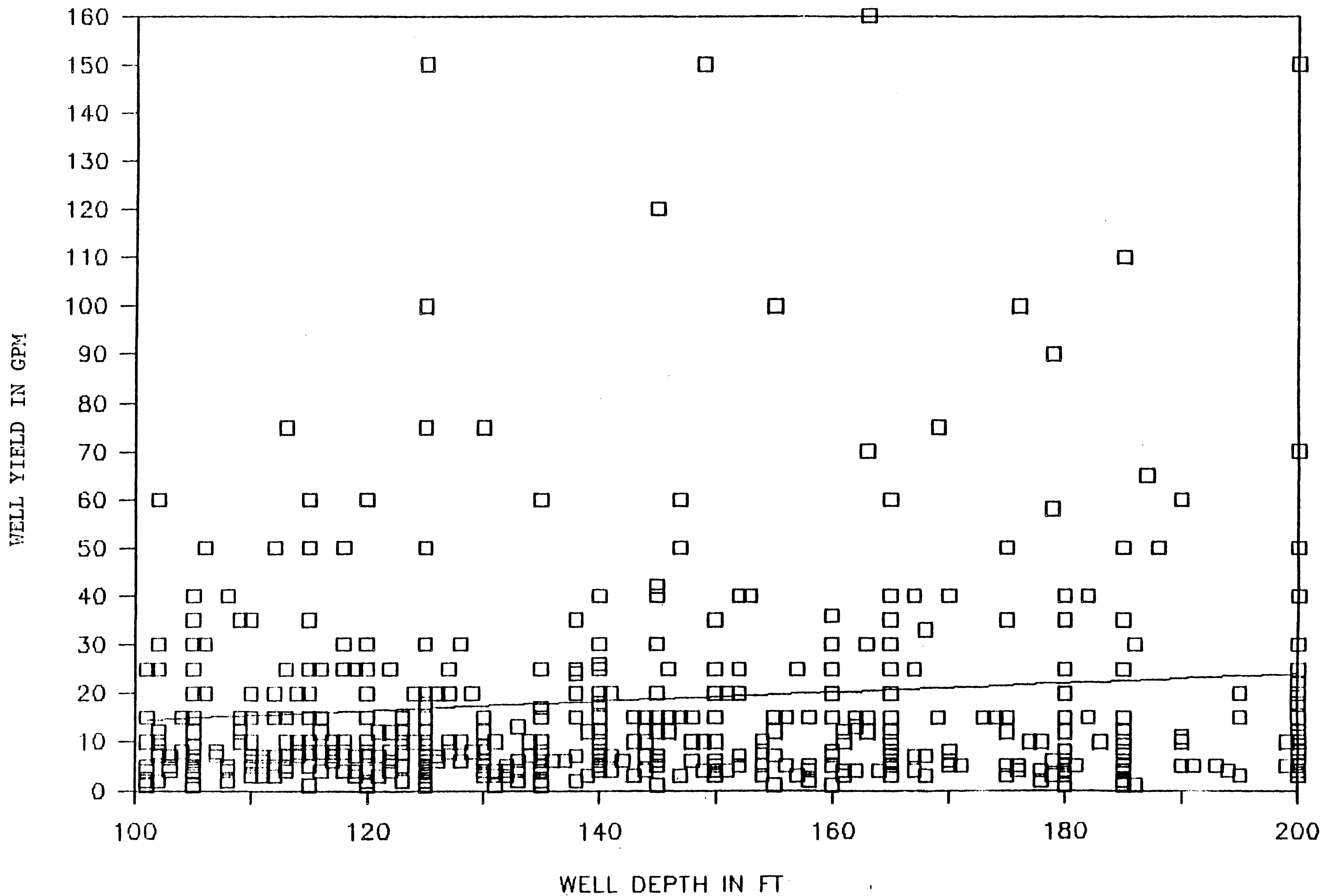


Figure 12. Scatter plot of depth versus yield data for 6 inch wells at depth interval, 101 to 200 feet.

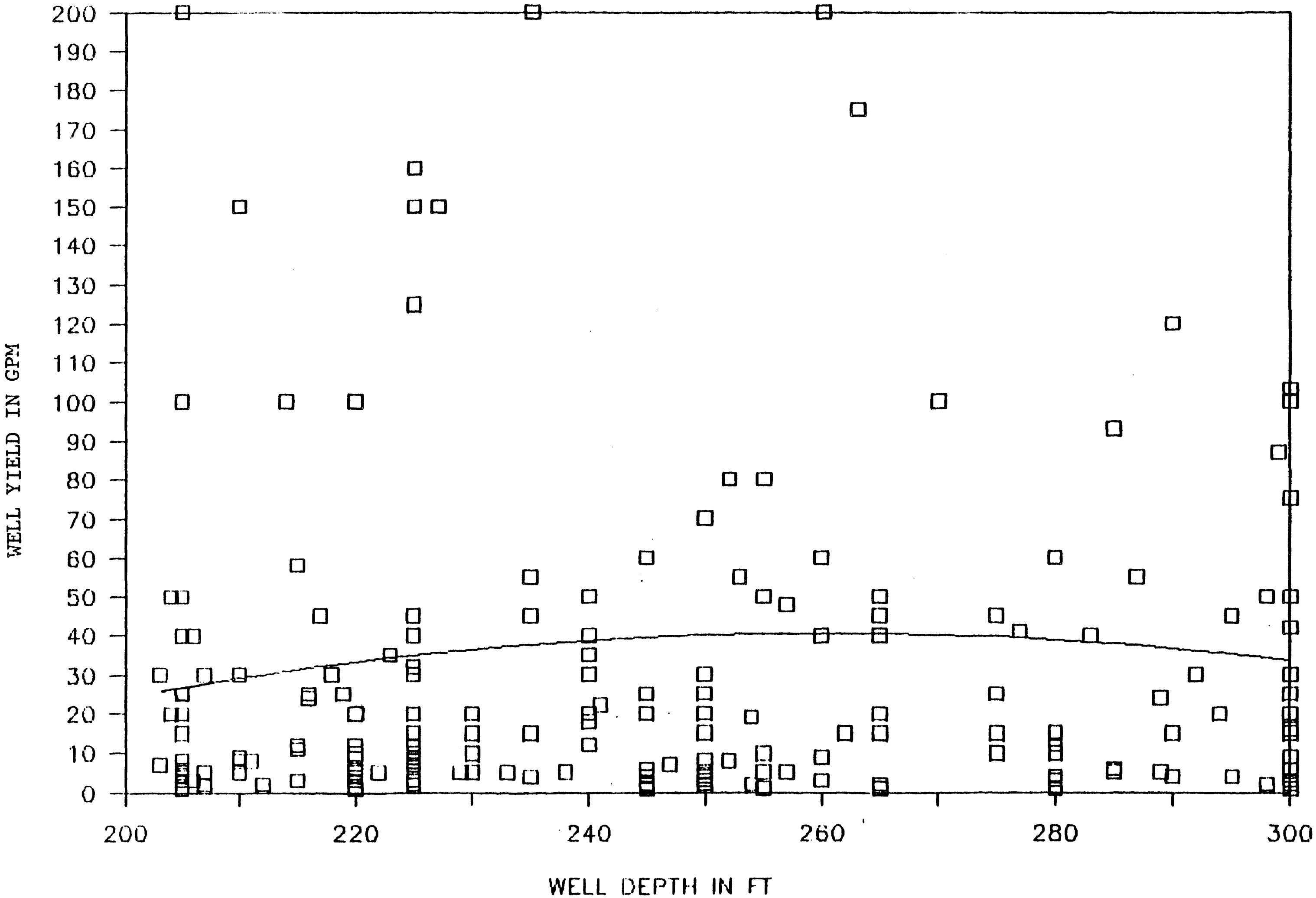


Figure 13. Scatter plot of depth versus yield data for 6 inch wells at depth interval, 201 to 300 feet.

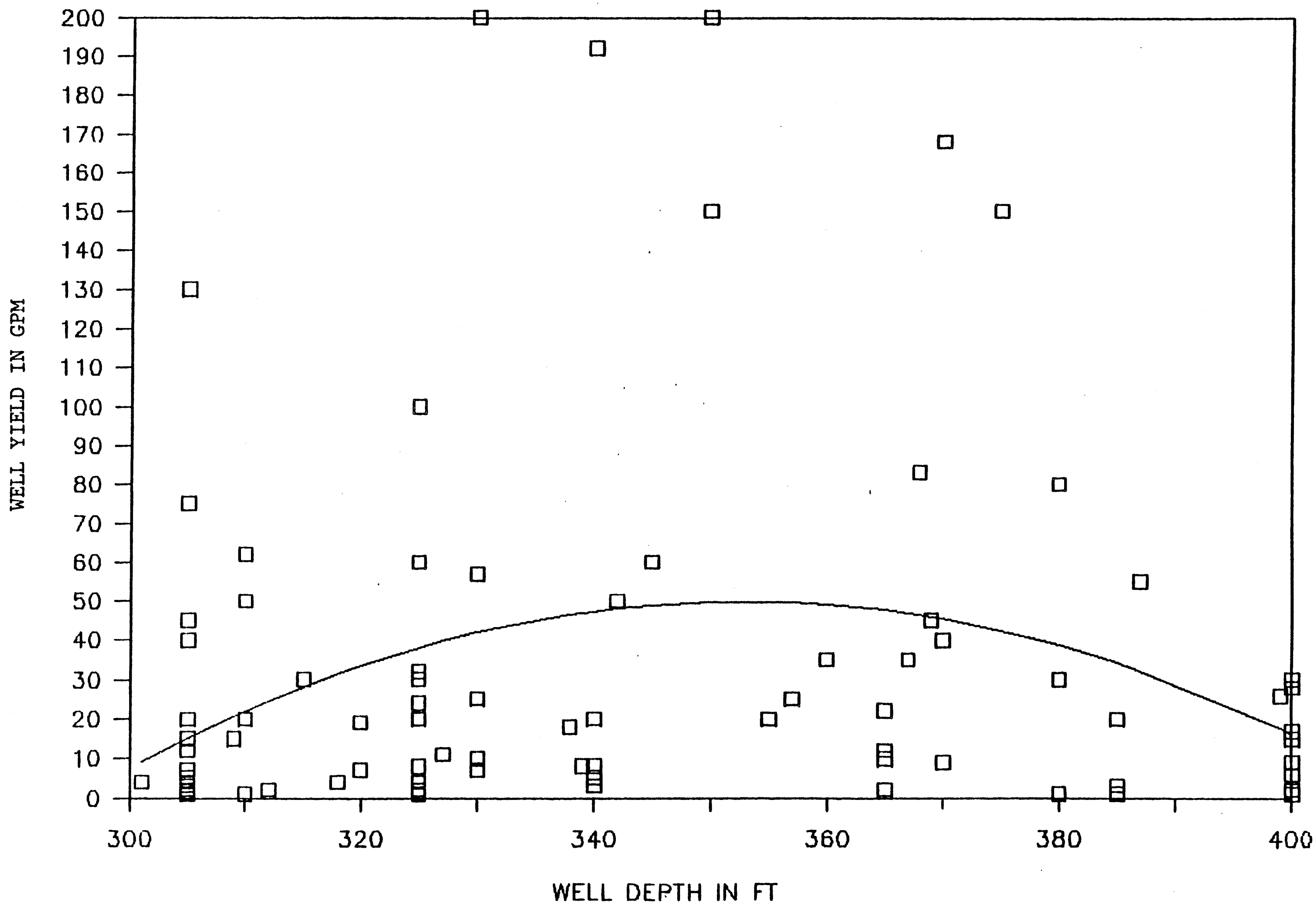


Figure 14. Scatter plot of depth versus yield data for 6 inch wells at depth interval, 301 to 400 feet.

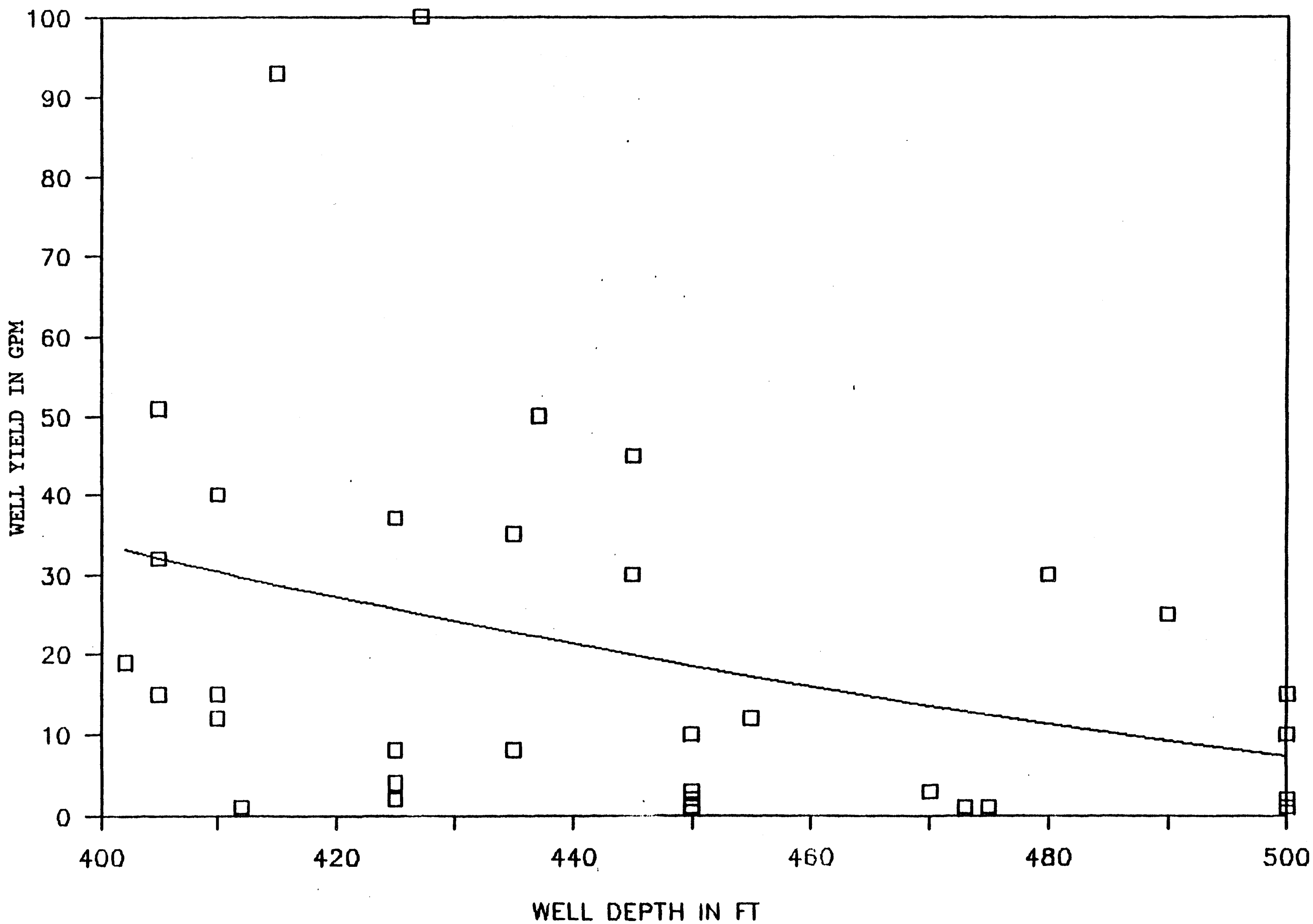


Figure 15. Scatter plot of depth versus yield data for 6 inch wells at depth interval, 401 to 500 feet.

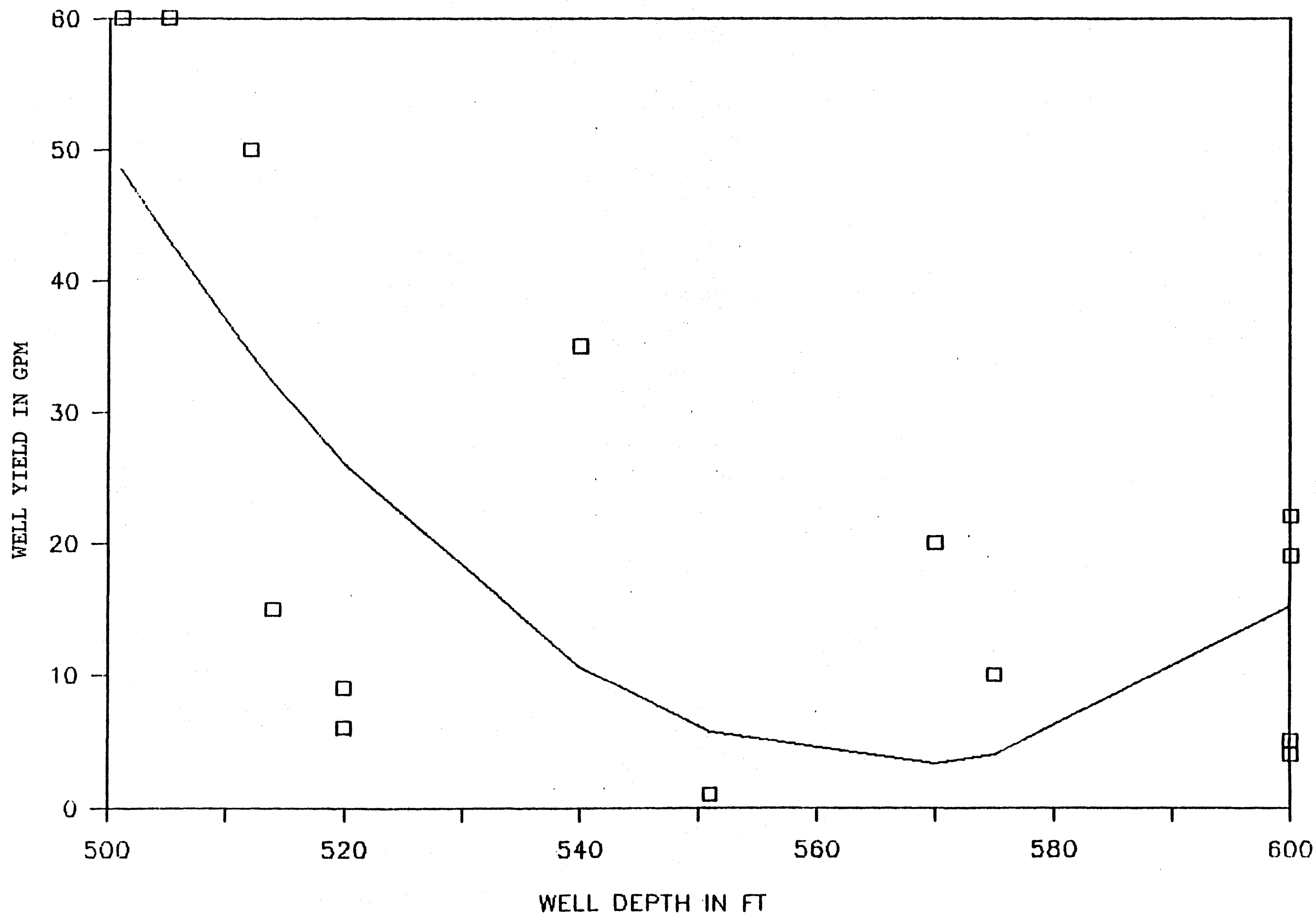


Figure 16. Scatter plot of depth versus yield data for 6 inch wells at depth interval, 501 to 600 feet.

IV. CONCLUSIONS

Economic development in the Piedmont Region will become more dependent on securing a reliable ground water well yield. The key question is where and how deep a well should be drilled for adequate water yield. A better understanding of the Piedmont ground water system is needed.

Ground water and well data for the Piedmont Region in South Carolina have been collected by three agencies: The U.S. Geological Survey, The South Carolina Water Resources Commission and the South Carolina Department of Health and Environmental Control. USGS and WRC data are related primarily to well yield and water supply. DHEC data relate primarily to water quality.

Each agency has its own data filing system with different formats. Each agency is computerizing recent data files. A major problem is incomplete and, in some cases, inaccurate information for wells. The format of data files is unique to each agency and therefore data cannot be easily transferred from one agency to another.

The following four recommendations are priority needs in order to have a data base from which a comprehensive study of ground water resources for the entire Piedmont Region in South Carolina can be made.

A. Common computerized database and interagency cooperation.

It is recommended that all ground water data for South Carolina, including Piedmont data, be placed in a common, computerized form. It should be accessible to all participating organizations, and compatible with established federal databases, e.g. WATSTORE (GWSI) and STORET. Because of its comprehensive nature, GWSI could serve as the basis for the development of a state ground water data system. Appendix B lists the data fields currently in use, indexed to the appropriate agency. These data fields or their equivalents would need to be incorporated into the final system. GWSI includes most of the items listed under "site identification" and "well construction information". More extensive chemical analysis data fields could be added to GWSI. Location information could be given in several forms. Latitude and longitude identification is essential if interfacing with a Geographic Information System (GIS) program is desired. Identification of the county, hydrologic unit, and hydrogeologic unit would be useful. Individual agencies may also want an internal identifier for each well site.

Careful study should be made of the various agencies needs with respect to ground water information. This would include detailed descriptions of required data, menu formats, output reports, technical documentation, and training. Any common database system should take these needs and concerns into account. Provisions should be made to update and maintain the data, and to protect its validity. Data should include identification of the agency of origin and protection against unauthorized alterations. The list of potential users of the database is lengthy. It would include state agencies (e.g. DHEC, WRC, Departments of Agriculture, Commerce, Transportation, Police, etc.), federal agencies (USGS, USEPA, USDA-SCS, USDA-Forest Service), local agencies and organizations, private businesses, and universities (Clemson University, University of South Carolina, etc.). As an example, Appendix C shows the summary of organizations participating in Michigan's ground water database program.

Careful consideration must be made of computer hardware requirements and compatibility. It is often most economical to set up a network of microcomputers which are then linked to a central mainframe or powerful minicomputer.

Participating agencies would each have their own microcomputer which could be used for data entry and analysis (and other non-ground water applications). The central computer could serve as a repository for all data and any common ground water or statistical programs. It would also be helpful to provide centralized training and support personnel. An alternative system configuration is to allow each agency to store and maintain their own files, but in a common form that is accessible to other agencies via modem phone lines. This eliminates the need for a central storage computer, but may create problems in networking many diverse, potentially incompatible computers. In this case, knowledgeable support personnel would be a necessity.

B. Verification and completion of existing data

All data entries must be verified to insure their quality. Locating the wells in the field and determining the hydrogeological unit will enhance significantly the data base quality and allow evaluation and statistical analysis. Older well locations should be field verified and all new wells should be correctly located at time of drilling. The wells can be located by satellite based global positioning or other applied methods. The USGS and WRC are currently working on a verification project for wells in a small watershed in Newberry County, S.C.

There are also gaps in the existing database. Many well records are only partially filled out. Perhaps the agencies which receive these records could provide training for and periodic checks of driller compliance and accuracy. To complete the database, a mobile team could obtain missing data for selected wells. Measurements should include both quantity and quality data.

Lithologic information, as found in well records, is often poor. A more accurate characterization of the geology could be determined if a trained geologist could be on site with the driller while new wells are being constructed. This could be done for a selected number of sites located throughout the Piedmont. An alternative to having someone on site is to supply a kit for the drillers themselves to take geologic samples which would later be analyzed by agency geologists.

C. Analysis of completed data.

The completed database should be used to determine regional water yield relationships. Such analyses would greatly enhance the ability of ground water personnel to locate higher yielding wells, leading to more efficient use of the region's ground water resources. More accurate prediction models of water quantity and quality could be developed based on a comprehensive, verified database. The models would reduce the need for extensive and costly field experiments. Other uses for such a database include assessing conditions near existing and proposed industrial facilities, waste disposal sites and accidental spill sites.

D. Hydrogeological unit map.

Hydrogeological unit map of the South Carolina Piedmont should be developed. This would involve updating geological maps of the region and superimposing information of the water-bearing properties and hydrogeochemistry associated with the area. It would provide a comprehensive summary of the general availability and quality of Piedmont ground water.

V. REFERENCES

Aller, L., T. Bennett, J.H. Lehr, R.J. Petty, and G. Hackett. 1987. DRASTIC: A standardized system for evaluating ground water pollution potential using hydrogeological settings. EPA 600/2-87-035.

Barber, N.L., K.R. Davis, J.C. Donahue, M.D. Grandison, W.R. Mason, D.L. Meehan, and R.W. Weathersby. 1986. "Ground water quality and availability in Georgia for 1984." Georgia Department of Natural Resources, Environmental Protection Division, and Georgia Geologic Survey. Circular 12A.

Beaulac, M.N., C.P. Grobbel, R. Borst, G. Burgess, and R. Elias. 1987. "Well record location verification and automation -- a pilot project for Isabella County." Michigan Department of Natural Resources, Ground Water Quality Division.

Bloxham, W.M., George E. Siple, and T. Ray Cummings. 1970. Water Resources of Spartanburg County, South Carolina. SC WRC Report No. 3.

Daniel, C. 1987. Statistical analysis relating well yield to construction practices and siting of wells in the Piedmont and Blue Ridge provinces in North Carolina. U.S. Geological Survey, Water Resources Investigations Report 86-4132.

Daniel, C.C. and N.B. Sharpless. 1983. Ground Water Supply Potential and Procedures for Well-Site Selection, Cape Fear River Basin Study. North Carolina Department of Natural Resources and Community Development and U.S. Water Resources Council. October 1983.

Davis, K.R. and M.C. Turlington. 1986. "Ground water quality and availability in Georgia for 1985." Georgia Department of Natural Resources, Environmental Protection Division, and Georgia Geologic Survey. Circular 12B.

Johnson, F.A., George E. Siple, and T.R. Cummings. 1968. A reconnaissance of water resources of Pickens County, South Carolina. SC WRC Report No. 1. Columbia, S.C.

Koch, C. 1968. Ground water resources of Greenville County, South Carolina. State Development Board, Bulletin No. 32.

McGill, H.J. and P.A. Stone, ed. 1985. Proceedings: Symposium on Ground Water and Environmental Hydrogeology in South Carolina.

Patterson, G.G. and G.G. Padgett. 1984. Quality of water from bedrock aquifers in the South Carolina Piedmont. U. S. Geological Survey, Water Resources Investigations Report 84-4028.

Snipes, D.S., G.G. Padgett, W.B. Hughes, and G.E. Springston. 1983. Ground Water quantity and quality in fracture zones in Abbeville County, South Carolina. Clemson University Water Resources Research Institute. Technical Report No. 102.

South Carolina Water Resources Commission. 1983. South Carolina Water Assessment. SC WRC Report 140.

Stafford, D.B., J.T. Ligon, and D.S.Snipes. 1983. Fracture trace mapping and water well yield in the Piedmont region of South Carolina. Clemson University Water Resources Research Institute. Technical Report No. 112.

Stone, P.A., S.L. Clark, and T.D. Mathews. 1986. "Recharging relationships and contamination susceptibility of fractured crystalline rock aquifers in the Piedmont and Blue Ridge Provinces of South Carolina."In Proceedings of the Southern Regional Ground Water Conference, San Antonio, TX. Published by the NWWA, Worthington, Ohio.

United States Geological Survey. Yearly. Water Resources Data for South Carolina. USGS Water Resources Division. Columbia, S.C.

United States Geological Survey. 1982. WATSTORE User's Guide: Ground Water Site-Inventory File.

Williams, G.W., E.L. Ganson, and I.E. Lecker. 1986. "A statewide ground water database strategy." Office of Management and Information Systems, Department of Management and Budget, State of Michigan.

IV. APPENDIXES

A. Commercially available software packages

B. Summary of data fields currently used by agencies

C. Summary of Participating Users of the Michigan database

APPENDIX A

The Ground Water Data Management System (GWDMS) was developed by Harms Products of Larkspur, California. It is a microcomputer based, menu driven, data management system for chemical, water level, and lithologic data from large or small monitoring programs. The program provides data reports of various formats or of customized specifications. The GWDMS is complemented with an optional plotting package that provides the ability to plot chemical, water level, and transmissivity contour maps; lithologic cross sections; time-concentration graphs; and water level hydrographs (as shown in Figure A.1). GWDMS has the ability to handle air, biological, and radiation samples in addition to water and soil samples. utility programs are available to input chemical data from ASCII files of any format, allowing laboratory analyses to be entered directly into GWDMS. System requirements include an IBM (286 or 386) or compatible running at 8 MHz or greater with 512K RAM, DOS 2.1 or later, 20+ meg hard disk for programs and user data, 200+ cps wide carriage printer, and an 8087 or 80287 math co-processor. Plotters that are supported by GWDMS include HP 744-A, 7470A, 7475A, 7550A, 7580A, 7585A, 7586A, 2686A, 2686A Laserjet Plus; HI DMP-51, DMP-52, DMP-56.

The GDM system is distributed by Geomath Inc. of Wheat Ridge, Colorado. It is the latest version of more than a decade of experience and development in data handling and display related to geostatistical modeling at the French Bureau of Geological and Mining Research. The program is made up of over 120,000 lines of FORTRAN code. A database system forms the core of GDM and includes all

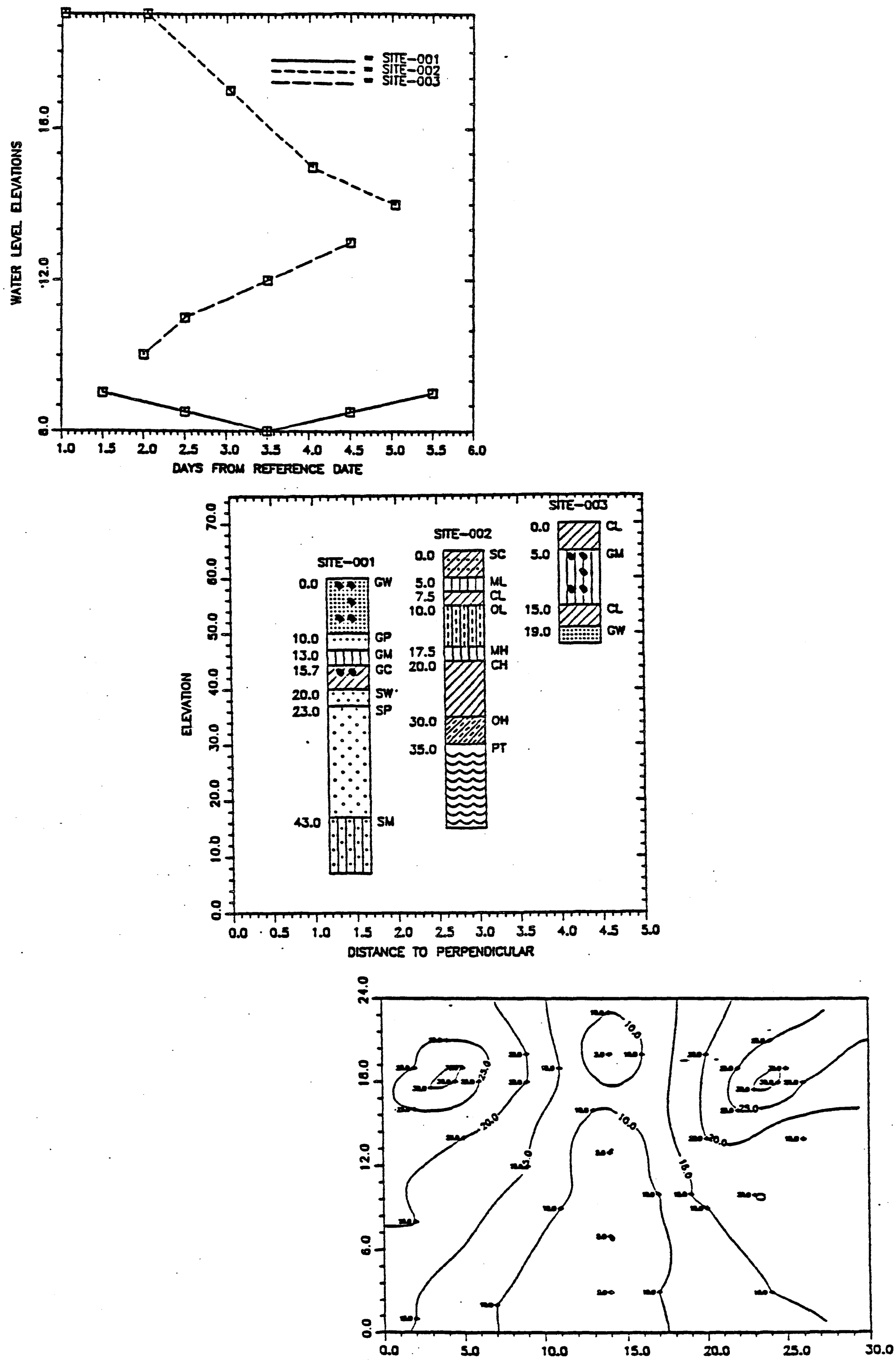


Figure A.1 Sample output from Harms Products' Ground Water Data Management System.

the subroutines handling data files and command files. Numerous programs and packages are available to extend the basic system. Although originally developed for mining application, this powerful system is readily applicable to ground water also. Figure A.2 shows some samples of GDM's graphical output. Several versions are available for different computers from micros to mainframes.

Well DataMaster, developed by Geotech Computer Systems of Englewood, Colorado, is another microcomputer based well data management tool. It is menu driven, containing an on-line help screen. Well data can either be loaded from computer files or entered manually, and then edited or viewed through several full-screen forms. Screens are provided to work with general well information, formation types, well tests and completion data, and general purpose fields determined by the user. Customized reports sorted by location of ID number may be created or one of the built-in report forms may be used. In addition, Well DataMaster can write files that may be used directly with Radian's CPS/PC mapping software. Examples are shown in Figure A.3. System requirements include an IBM PC, XT, or AT (or compatible) with 10+ meg hard disk, 256K RAM, and DOS 2.1 or later.

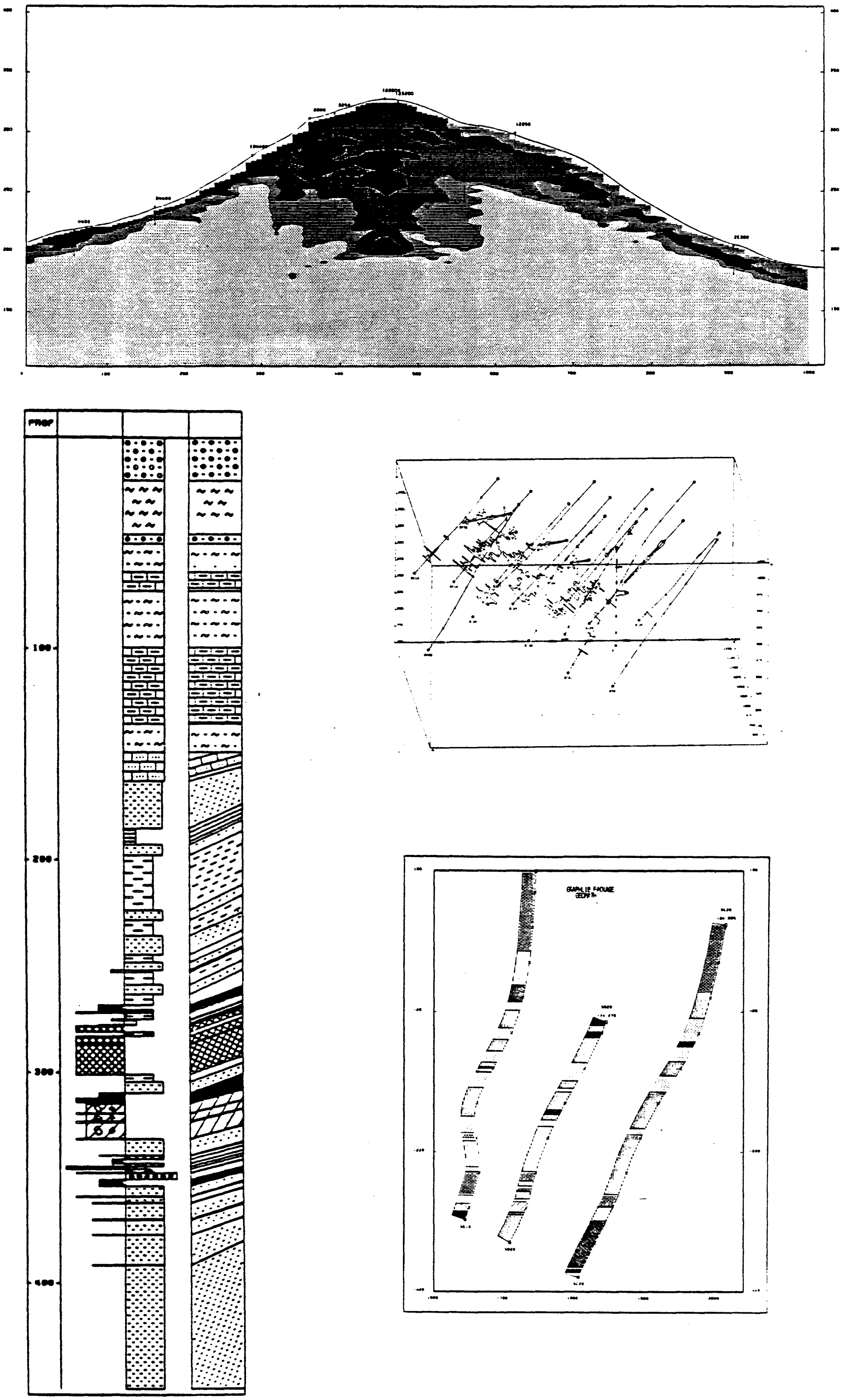


Figure A.2 Sample output from Geomath's GDM System.

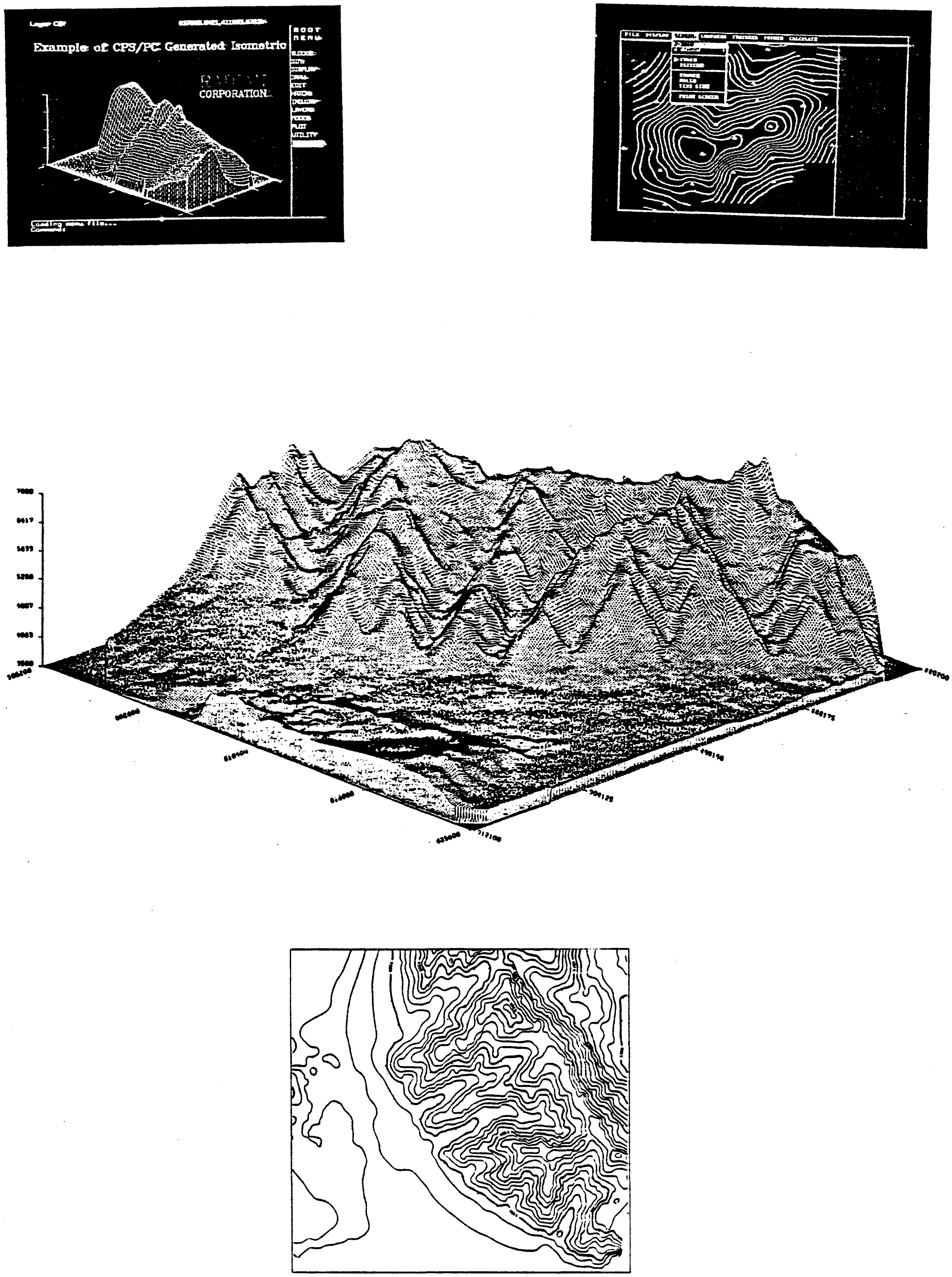


Figure A.3 Sample output from Geotech's Well DataMaster System with CPS/PC

APPENDIX B

SUMMARY OF DATA FIELDS CURRENTLY USED BY AGENCIES

AGENCY IDENTIFIER:
(1) S.C. DHEC, Ground Water Protection Division
(2) S.C. DHEC, Public Water Supply Division
(3) USGS
(4) S.C. WRC

SITE IDENTIFICATION:
- county (1)
- drainage basin (4)
- facility name (1)
- latitude (2,4)
- longitude (2,4)
- location map (4)
- nearest source of possible contamination (2)
- sampling date (1)
- sampling time (1)
- station location or identification number (1,3)
- topography (4)

SAMPLE ANALYSES:
- Physical and biological analyses:
  - coliform bacteria (1)
  - color Pt-Co (1,2,3)
  - conductivity (1,3)
  - corrosivity (1)
  - hardness (2)
  - MBAS (1,2)
  - odor (1,2)
  - pH (1,2,3)
  - solids, residue at 180°C, dissolved (3)
  - solids, sum of constituents, dissolved (3)
  - total alkalinity (1,2,3)
  - temperature (1,3)
  - total dissolved solids (1,2)
- Inorganic Chemical analyses:
  - arsenic (1,2)
  - barium (1,2)
  - beryllium (1)
  - cadmium (1,2)

chloride (1,2)
cyanide (1)
fluoride (1,2)
hydrogen sulfide (1)
iron (1,2,3)
lead (2)
magnesium (2,3)
manganese (1,2,3)
mercury (1,2)
nickel (1)
nitrate (1,2)
potassium (2,3)
selenium (1,2)
silver (1,2)
sodium (2,3)
sulfate (1,2)
zinc (1,2)

Organic Chemical Analyses:
COD (1)
TOC (1,2)
DOC (1)
TOX (1)
GC/MS scan for organics (1)
endrin (1,2)
lindane (1,2)
toxaphene (1,2)
2,4 - D (1,2)
2,4,6 - TP (1,2)
chloroform (2)
bromodichloromethane (2)
dibromochloromethane (3)
bromoform (2)
total trihalomethanes (2)
trichloroethylene (2)
carbon tetrachloride (2)
vinyl chloride (2)
1,2 - dichloroethane (2)
benzene (2)
1,1 - dichloroethane (2)
benzene (2)
1,1 - dichloroethylene (2)
p - dichlorobenzene (2)
others (1)

Radiological analysis:
gross alpha (1,2)
gross alpha error (1)
gross beta (1,2)
gross beta error (1)
radium (1)
radium 226 (2)
radium 228 (2)

tritium (2)
strontium - 90 (2)
strontium - 89 (2)
iodine 131 (2)
cesium 134 (2)
uranium (2)

WELL CONSTRUCTION INFORMATION:

owner: name, address, phone (2,4)
engineer: name, address, phone (2,4)
contractor: name, address, phone (2,4)
date started (2,4)
date completed (2,4)
Const. diag. Y/N (4)
well construction method (2,4)
hole size: diam., type bit (4)
well depth: rept., test hole, completed, measured (2,4)
method developed (4)
drill mud type/brand (4)
grout: type, method, vol., thickness, depth (2,4)
casing: diam., depth, thickness, type, installation method (2,4)
screen: open hole/screen: diam, depth, type, material, slot width (2,4)
gravel pack filter: type, method, volume, thickness, depth (2,4)
pump: type, make, HP, diam., intake depth, installer, date GPM (2,4)
water use (2,3,4)
flow meter: type, date installed (4)
well used daily/weekly/monthly/other (4)
geophysical logs Y/N (2,4)
pumping test: hr, gpm, date (2,4)
aquifer test: hr, gpm, date (4)
sieve analysis Y/N (4)
driller log Y/N (2,4)
geologist log Y/N (4)
geologic samples: Y/N method (2,4)
water level monitored Y/N (4)
water quality monitored Y/N (4)
elevation, method, elev. meas. pt. (4)
static water level (1,2,4)
pumping water level: after __ hrs pumping at __ gpm (2,4)

APPENDIX C

SUMMARY OF PARTICIPATING USERS OF THE MICHIGAN DATABASE
(Williams et al., 1986)

PRIMARY OWNERS/USERS

- Department of Natural Resources
  - Ground Water Quality Division - Remedial Action Section
  - Geological Survey Division
  - Land Resource Programs Division
  - Surface Water Quality Division
  - Engineering - Water Management Division
  - Environmental Services Division - Laboratory
  - Environmental Services Division - Toxic Chemical Evaluation
  - Community Assistance Division - Solid Waste Planning Unit
  - Hazardous Waste Division
  - Environmental Enforcement Division
  - Management Information Division
  - Grand Rapids Field Office
  - Rose Lake Field Station

- Department of Public Health
  - Water Supply Division
  - Ground Water Quality Control Section
  - Office of Management and Information Systems
  - Bureau of Laboratories/Microbiology Division
  - Center for Environmental Health Science
  - Division of Environmental Health
  - Office of Local Health Coordination

OTHER STATE ORGANIZATIONS

- Office of the Governor
- Governor's Cabinet Council on Environmental Protection

- Department of Agriculture
  - Environmental Division, Water Resources Section
  - Plant Industry Division
  - Toxic Substances and Emergency Services
  - Soil Conservation Districts
  - Food Processing
  - Methods Management Division

- Department of Commerce
  - Business Information Division
  - Business Development Division

Department of Transportation
- Ecological Services Division
- Testing and Research Division
- MDOT Data Center

STATE ORGANIZATIONS

Department of State Police
- Fire Marshal
- Toxic Substance Control Commission
- Michigan Environmental Review Board
- Michigan Water Connections Project
- Michigan Water Planning Commission
- MDMR/MDPH Ground Water Database Committee

FEDERAL ORGANIZATIONS

U.S. Environmental Protection Agency - Region V
U.S. Environmental Protection Agency - STORET System
U.S. Department of Agriculture - Soil Conservation
U.S. Department of Agriculture - Forest Service
U.S. Geological Survey - Water Resources Division

LOCAL ORGANIZATIONS

46 Local Health Departments
Michigan Rural LPHD Information management Board
South East Michigan Council of Governments (SEMC)
South West Michigan Ground Water Survey and Monitoring Program
Tri-County Regional Planning Commission/GW Mgmt.

PRIVATE BUSINESS

Detroit Edison
Dow Chemical
General Foods Company
General Motors
Kelloggs
Upjohn
Kellogg Foundation
Aquatic Systems, Inc. - Ludington
Prien and Newhof - Grand Rapids
Analytic and Biological Labs, Inc.
National Water Well Association

UNIVERSITIES

Uofm Computer Services - MERIT System
MSU Computer Lab - Computer Services
MSU Department of Geology
MSU Center for Remote Sensing

MSU Institute for Water Research
WMU Department of Geology Research Center
WMU Science for Citizens Center of SW Michigan
WMU Science for Citizens Computer Consultant