USE OF A GEOGRAPHIC INFORMATION SYSTEM TO EVALUATE POTENTIAL SITES FOR PUBLIC-WATER-SUPPLY WELLS ON LONG ISLAND, NEW YORK

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	0.4047	hectare
square foot (ft^2)	0.09294	square meter
square mile (mi^2)	2.59	square kilometer
	Volume	
gallon (gal)	3.785	liter
	Flow	
foot per day (ft/d)	0.3048	meter per day
million gallons per day (Mgal/d)	0.04381	cubic meter per second

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called sea level datum of 1929.

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Abstract

Evaluation of physical factors that determine the suitability of a given site for a public-supply well typically involves the compilation and analysis of a large amount of data. Two factors that directly determine the suitability of a proposed site are the quantity and the chemical quality of the ground water; these in turn are influenced by many other factors, including aquifer characteristics and proximity to other wells and sources of contamination. Selected data from the U.S. Geological Survey and the New York State Department of Environmental Conservation were compiled into 26 data sets, each representing a single type of hydrogeologic, geologic, chemical, or other data. These data sets, or "coverages," were entered into a GIS (geographic information system) that can store, retrieve, analyze, and display the information. The 166.5-square-mile study area on eastern Long Island is largely undeveloped but contains a variety of land uses and is under the stresses of current development. Several computer programs were developed that enable users unfamiliar with the GIS software to extract data pertinent to the evaluation of any potential well site. The programs were not intended to make interpretations of the data, but to supply the information necessary for decisionmaking. Results indicate that the system can improve the efficiency and accuracy of such evaluations.

INTRODUCTION

The aquifer system that underlies Long Island is the sole source of drinking water for a population of 2.6 million people and has been designated as a "sole-source aquifer" by the U.S. Environmental Protection Agency under the provisions of the Federal Safe Drinking Water Act. Thus, the aquifer system is subject to stringent regulation and ground-water-management practices that combine the efforts of several Federal, State, and local agencies.

Applications for all public-water-supply wells and for private wells that withdraw 45 gal/min or more must be submitted to the New York State Department of Environmental Conservation (NYSDEC). Before issuing a permit to operate the well, the NYSDEC reviews permit applications by investigating features near or beneath the proposed site that may affect the quality and (or) quantity of withdrawn water, as well as any features that may be affected by the withdrawals.

The siting of a public-water-supply well raises several questions: (1) What is the chemical quality of the water to be withdrawn, (2) will the withdrawals affect the quality and (or) quantity of water at nearby wells, (3) will the withdrawals decrease streamflow, and (4) will the withdrawals cause saltwater intrusion? The answers to these questions can be obtained through reference to maps and tables of data that describe the surface features, contamination sources, stratigraphy, hydrologic properties, and water quality at and adjacent to the proposed site, but this process can be tedious and time consumimg.

A relatively new method of analysis incorporates the use of a computerized geographic information system (GIS) to retrieve the data needed to assess the suitability of potential sites for public-water-supply wells. GIS software can efficiently store a vast amount of information and link spatial data with hydrogeologic, chemical, and other data to generate maps and tables for review. Comparison of these maps and tables with established well-siting criteria enables the user to determine the suitability of the site for ground-water withdrawal. A GIS allows easy input, updating, and output of data, and the data base can be used in other hydrologic studies as well. A unique element of a GIS is its ability to link spatial data with topical data to associate a given feature or site with all information pertinent to that location. It also enables assessment of selected hydrologic conditions on a local or regional level through a variety of approaches. The use of a GIS in ground-water investigations and management is not wide-spread, and few reports on its applications have been published because such systems have become available only in the last decade.

In 1988, the U.S. Geological Survey, in cooperation with the NYSDEC, began a study to evaluate the use of a GIS as a tool in evaluating proposed sites for public-water-supply wells on Long Island. The objectives were to (1) create a prototype system for the compilation and retrieval of data that would expedite the well-site-evaluation process, (2) evaluate the system's efficiency in data retrieval and display, and (3) create a data base that could be used in future hydrogeologic studies. Political and socioeconomic factors that are typically involved in well-site evaluation were not considered. The data base represents a 166.5-mi^2 area on eastern Long Island that is largely undeveloped and provides recharge to the deep aquifer system (fig. 1).

The study entailed three major steps: (1) review and classification of the NYSDEC's well-site evaluation criteria, (2) selection, compilation, and storage of data pertinent to these criteria, and (3) creation of programs that access, retrieve, manipulate, and display the data. Well-site-evaluation criteria, supplied by the NYSDEC, were reviewed and categorized, and available maps and tables of data were examined for pertinence to these criteria. Each data group that seemed to address the criteria was evaluated, and 26 of the resulting "data layers" or "coverages" were entered into the system under quality-control measures.

The GIS software used in the study, ARC/INFO[1], was developed by Environmental Systems Research Institute. The utility of this software package is enhanced by AML (Arc Macro Language), a fourth-generation command-level programming language. AML programs enable the programmer to create user-friendly interfaces that can be menu driven and permit users unfamiliar with the software to use the system to its full potential.

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1 Use of trade or product names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Purpose and Scope

This report (1) describes the development of the data base and the computer programs that retrieve data pertinent to a well-site evaluation, (2) evaluates the utility of the GIS in this application, and (3) describes the major considerations in a well-site evaluation and summarizes previous research, including GIS applications in other parts of the United States. It also includes a brief discussion of the Long Island aquifer system, explains the design and application of the GIS used in this study, and includes a sample retrieval of a data table and map to illustrate the type of output that can be generated.

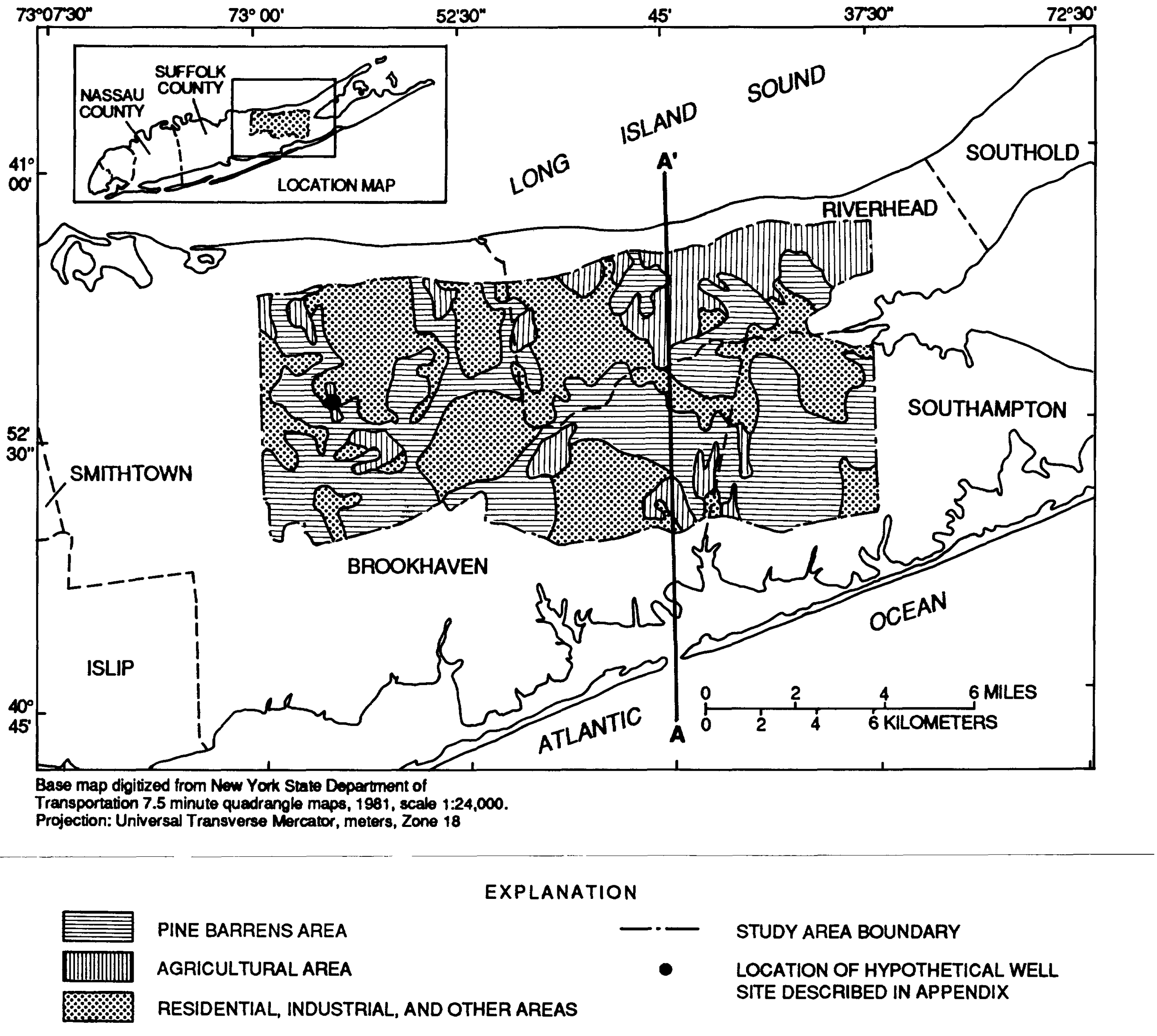

Figure 1.--Location and extent of pilot study area on eastern Long Island. (Section A-A' is depicted in fig. 2.)

Acknowledgments

The author thanks Philip Barbato, William Spitz, Dennis Jackson, and Brian Baker of the NYSDEC for providing the maps and tables of data used in this study and the criteria that the Department uses in evaluating well-permit applications. Special thanks are extended to Brian Baker, NYSDEC, who compiled, maintained, and verified the data base.

CONSIDERATIONS IN WELL-SITE EVALUATIONS

The ground-water system on Long Island has been extensively explored within the last 2 decades as public awareness of the need for ground-water protection has increased, and a large amount of data has been collected and published (for example, Long Island Regional Planning Board, 1986; New York State Department of Environmental Conservation, 1986; Franke and McClymonds, 1972).

Major Criteria

Two major factors that determine the suitability of a site for withdrawal of ground water for public supply are the available quantity of the water and its chemical quality. A public-supply well installed at a suitable site would be capable of withdrawing adequate amounts of potable water for several years without adversely affecting water levels in other supply wells and (or) flow in wetlands or streams.

The initial approach in most ground-water-protection efforts is to develop data-collection and management systems to quantify the hydrologic characteristics, flow patterns, and other factors such as contamination potential, contamination sources, and specific compounds involved. Although several rating systems have been devised for such purposes, the transferability of results is limited. For example, two distinct sites with vastly different characteristics may obtain similar "ratings." The ratings may serve to describe the severity or potential of a problem but fail to adequately describe specific conditions adjacent to the site. A synopsis of approaches that selected State and local governments have implemented to protect ground-water quality is given by David (1988).

Water-resource management in developed areas requires an approach that differs from that used in largely undeveloped areas. The quantity and complexity of data required for a developed area are greater than for an undeveloped area. Well sites in relatively undeveloped areas are best evaluated through use of small-scale maps (maps that cover large areas and are limited in resolution) that outline areas suitable for a supply well on the basis of aquifer properties, distance between the proposed well and the population to be served, overall ground-water quality, and other hydrogeologic factors. Well sites in more highly developed areas, and those areas that are currently under the threat of development, are best evaluated on the basis of detailed, site-specific investigations. The investigations would categorize hydrogeologic factors, land-use practices, sources of contamination, and other characteristics that are not clearly defined on small-scale maps to address the effects of the additional ground-water withdrawals.

Ground-Water Quantity

The quantity of ground water may be an important consideration where proposed wells are to be installed in aquifer systems with highly variable water-transmitting properties. The aquifer system that underlies Long Island, is relatively uniform, however--transmissivity values of all three major aquifers vary by only 1 or 2 orders of magnitude (McClymonds and Franke, 1972). The suitability of proposed sites for public-supply wells is therefore largely determined by water-quality considerations; thus, this study emphasized water quality rather than quantity. This approach was not intended to ignore water-quantity issues but to incorporate them into water-quality aspects.

Ground-Water Quality

Ground-water quality may be affected by natural and human factors (Johnston, 1988). Natural factors include precipitation, evapotranspiration, recharge, the nature of the geologic environment (composition and structure of soils and aquifers), regional and local ground-water flow patterns, and biological activity. Human factors include land-use practices within recharge areas, introduction of contaminants (accidental or otherwise), ground-water pumping or injection, and well-construction techniques. Ultimately, most human interactions with the environment can directly or indirectly affect the quality of ground water.

Two of the factors that have the greatest effect on ground-water quality are the land-use practices in the recharge area above the aquifer(s) and the ground-water-flow patterns within the aquifer(s). In this study, the area of primary concern is the area of recharge to the deeper aquifers, where flow is downward as well as horizontal and seaward. Thus, contaminants introduced at or near land surface in the recharge area may enter the deep aquifers and contaminate aquifer segments that previously contained water of pristine quality.

The effects of land use and associated contamination on ground-water quality in shallow aquifers have been extensively documented in Eckhardt and Oaksford (1988), Eckhardt and others (1988), Persky (1986), Helsel and Ragone (1984), and Fusillo and Hochreiter (1982). The effects of land use on water quality in deeper aquifers have not been researched in detail, however, because the contributing areas of water to deep wells are difficult to delineate. Delineation of contributing areas to deep wells requires extensive hydrogeologic data and ground-water flow modeling, which was beyond the scope of this study.

Previous Investigations

Most research on well-site evaluation has emphasized water quantity rather than water quality. For example, Daniel and Sharpless (1983) discuss relations between well yield and lithology to identify favorable locations for future well sites, and Daniel (1987) presents statistical analyses relating well yield to well-construction and siting practices to locate areas suitable for ground-water withdrawal in relatively undeveloped areas. Both studies were conducted in the Blue Ridge Province of North Carolina in terrains having relatively little development and diverse aquifer properties.

Methods of conducting well-site and hazardous-waste-site evaluations through a GIS have been documented by Gilliland and Baxter-Potter (1987), Merchant and others (1987), and Nystrom and others (1986). These reports address the production of small-scale maps that indicate suitable locations for a well site, or of maps that outline areas of high contamination potential, rather than detailed site-by-site evaluations of the type that are necessary on Long Island.

Two different approaches to well-site evaluations through use of a GIS are described by Nystrom and others (1986) and Broten and others (1987). Nystrom and others (1986) used a GIS for a relatively undeveloped area in Connecticut and delineated suitable areas on the basis of physical criteria rather than conducting individual site evaluations. The result of this work was a map that outlined all areas that met their well-site evaluation criteria. Broten and others (1987) used a GIS for management of hazardous wastes and ground-water contamination in a more highly developed area of California in conjunction with simulations of ground-water flow paths. That study used a GIS to examine in detail the area adjacent to a proposed well site. The two studies illustrate that GIS's can be used for widely differing approaches to well-site evaluation.

The use of a GIS has proved to be valuable in increasing the accuracy and efficiency in processing large data sets. Dickenson and Caulkins (1988) describe a study in which the implementation of a GIS led to significant decreases in processing time of a vast amount of geographic data for the Washington State Department of Natural Resources. The system, known as GEOMAPS, was designed to process and manipulate geographical data, such as land cover, wildlife, geology, and hydrography (Sugarbaker, 1986).

LONG ISLAND GROUND-WATER SYSTEM

The aquifer system that underlies the study area consists of three major unconsolidated aquifers and a single major confining unit that separates the lower two aquifers (fig. 2). The only natural source of recharge on the island is precipitation. Human activities have led to widespread contamination of the water-table aquifer, and drawdowns resulting from excessive pumping have induced contaminants in the water-table aquifer to migrate to the deep aquifers, the major source of public-water supplies for the western part of the island. Throughout the eastern part of Long Island, including the study area, the upper glacial aquifer is the primary source of potable water but is in danger of contamination through the stresses of development. A detailed description of the hydrology in the study area is given in Warren and others (1968).

Configuration and Boundaries

Long Island's aquifer system consists of a series of gently sloping Pleistocene glacial, glaciofluvial, and glaciolacustrine deposits and Cretaceous fluvial or deltaic deposits of unconsolidated sand, gravel, and clay (fig. 2). The upper surface of the ground-water system is the water table, which typically lies 0 to 150 ft beneath land surface; the lower limit is the Precambrian gneiss and schist bedrock that lies between 0 and 2,700 ft

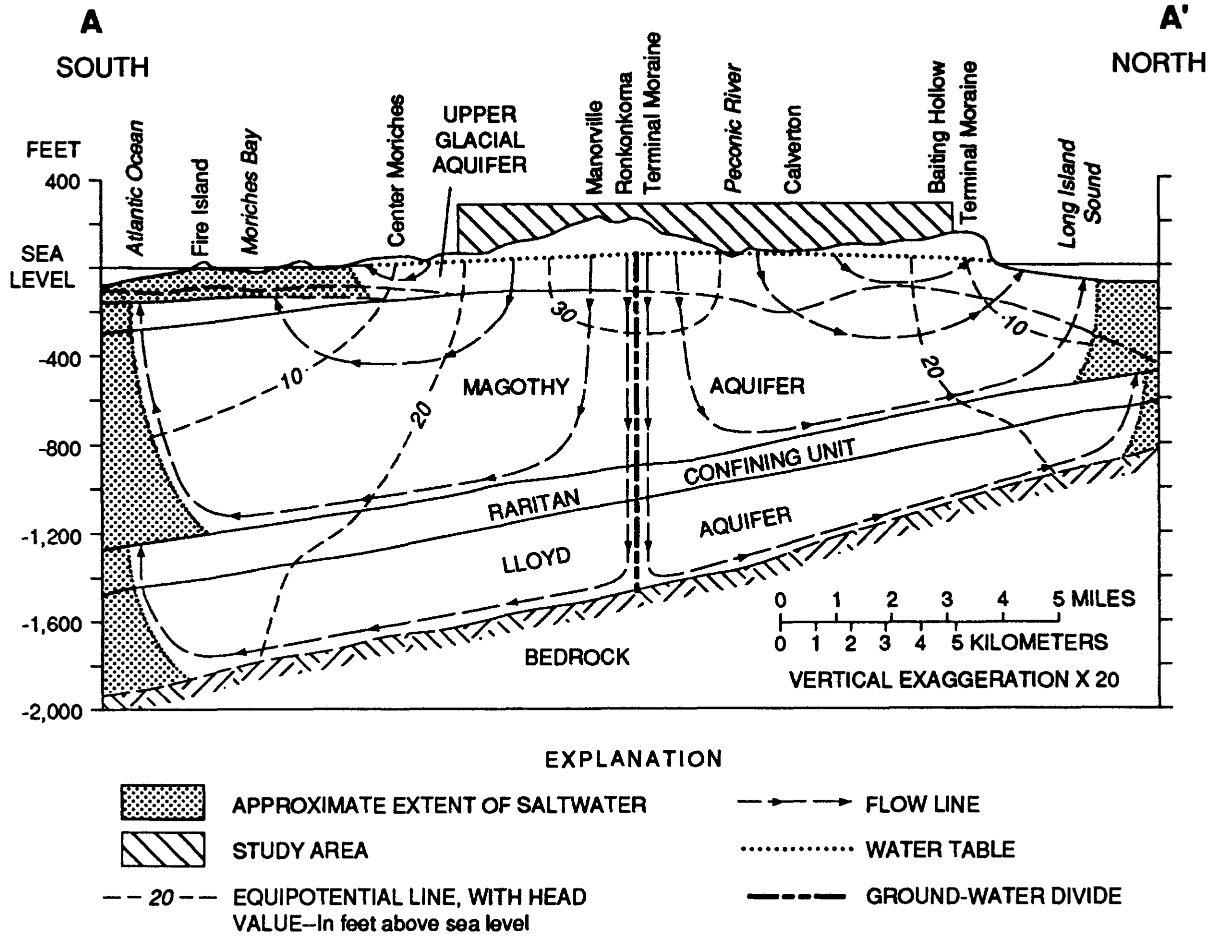

Figure 2.--Hydrologic section showing generalized flow patterns along section A-A'. (Location is shown in fig. 1. Modified from Jensen and Soren, 1974.)

below land surface. The ground-water system is bounded laterally by saltwater. The saltwater interface (the diffuse boundary between fresh and salty water) has generally migrated landward in response to ground-water withdrawal in near-shore areas and the rise in sea level since Pleistocene time.

The three major aquifers are the upper glacial aquifer, of Pleistocene age, which ranges from 0 to 600 ft thick; the Magothy aquifer, of Cretaceous age, which ranges from 0 to 1,100 ft thick; and the Lloyd aquifer of Cretaceous age, which ranges from 0 to 500 ft thick and is within the Lloyd Sand Member of the Raritan Formation (McClymonds and Franke, 1972). The Lloyd aquifer and the Magothy aquifer are separated by the Raritan confining unit (the unnamed upper clay member of the Raritan Formation), which may be up to 300 ft thick locally. The aquifers and confining units generally slope south-southeastward and increase in thickness to the south. Localized clay units within the upper glacial and Magothy aquifers have significant effects on local ground-water flow patterns.

Recharge

Recharge to ground water on Long Island is approximately 21 inches per year, about half of the total annual precipitation (Franke and McClymonds, 1972). The generalized flow pattern indicated in figure 2 shows that recharge to the deeper aquifers occurs near the center of the island, where the direction of ground-water flow is downward. Discharge of ground water occurs primarily along the northern and southern shores. Much of the precipitation that would have entered the ground-water system under predevelopment conditions falls on paved surfaces such as roads or parking lots and is channeled into storm drains that discharge the water elsewhere into the ground-water system, a surface-water body, or directly into the Atlantic Ocean, Long Island Sound, and (or) one of the surrounding bays.

Contamination

Most of the ground water pumped on eastern Long Island, including the study area, is from the upper glacial aquifer; only a relatively small amount has been pumped from the Magothy aquifer. Consequently, much of the water available for consumption is subject to potential contamination from a number of surface-based sources. Most of the sewage disposal in this area is through septic tanks and cesspools from which the effluent infiltrates to the upper glacial aquifer. This method of disposal has resulted in nitrate contamination of the upper glacial aquifer in several parts of Long Island (Katz and others, 1980). In contrast, south-central Long Island, which is more extensively developed, has sewers and treatment plants that discharge the effluent into the Atlantic Ocean to avoid contaminating the ground-water system. This method of disposal has resulted in a loss of water from the ground-water system, however. Additional contaminants of shallow ground-water on eastern Long Island include fertilizers and pesticides (Soren and Stelz, 1984; Leamond and others, in press); chloride, which has entered the aquifer system in some nearshore areas as a result of saltwater encroachment (Lusczynski and Swarzenski, 1966); and localized spills, landfills, and industrial activities (Eckhardt and Pearsall, 1985; Kimmel and Braids, 1980; Ku and others, 1978). Contamination of the shallow aquifer by these and other sources have forced water suppliers to obtain water from increasing depths within the Magothy aquifer (Reilly and others, 1983).

Water-Level Declines

Potentiometric levels within the upper glacial and Magothy aquifers have generally been declining during the last few decades, as indicated through comparison of potentiometric-surface maps by Doriski (1987) with those of Vaupel and others (1977), Donaldson and Koszalka (1983a,b), and Smolensky (1984). These declines, which result in saltwater encroachment and decreased streamflow as well as increased pumping costs, may be caused by several factors including excessive pumping of ground water, paving of critical recharge areas, diversion of wastewater, and channeling precipitation into storm drains that route water to the Atlantic Ocean, Long Island Sound, and the surrounding bays. The addition of new large-capacity wells in some areas could have adverse effects on water levels and in turn induce further streamflow declines and saltwater encroachment in nearshore areas.

Ground-Water-Protection Strategies

Several methods of prevention and remediation have been implemented to protect the quality and quantity of ground water on Long Island and to prevent further water-level declines. Recharge basins have been installed since the 1930's to increase ground-water recharge by directing precipitation into the ground-water system (Aronson and Seaburn, 1974). Other approaches that are being used to help ensure an adequate supply of potable ground water for the future include State-mandated water-conservation programs such as lawn-watering restrictions, and long-term ground-water-management strategies such as restrictions on pumping and designation of "Special Ground Water Protection Areas." A method of minimizing contaminant migration that can result from altered flow patterns due to excessive pumping is to place new large-capacity wells only in areas known to be suitable for large-scale pumping. GIS analysis of physical and chemical factors at and near proposed well sites is expected to provide an efficient means of evaluating such areas.

USE OF A GEOGRAPHIC INFORMATION SYSTEM TO EVALUATE POTENTIAL SITES FOR PUBLIC-SUPPLY WELLS

A GIS has many desirable features, perhaps the most useful of which is the ability to link spatial and topical data to a feature or site. The association between spatial and topical data is established through data items that are identical in the respective spatial and topical computer files. The combination of the spatial and topical computer files is collectively called a "data layer" or "coverage." The following section describes the steps involved in creating the GIS data base and the analyses used to extract the data.

Selection of Study Area

The area selected for this study was relatively small to allow evaluation of the GIS and to minimize data entry and verification. The 166.5-mi^2 area coincides with the Central Suffolk Special Ground Water Protection Area (SGPA) delineated in the New York State Ground Water Management Program for Long Island (New York State Department of Environmental Conservation, 1986) and in the Nonpoint Source Management Handbook (Long Island Regional Planning Board, 1984). The area overlies the regional ground-water divide and a deep-ground-water-recharge area (fig. 2). The reason an SGPA was chosen for this study was that these areas are defined as "significant, largely undeveloped or sparsely developed geographic areas of Long Island that provide recharge to portions of the deep-flow aquifer system" (Long Island Regional Planning Board, 1986). Within these areas, the principal threat to the water quality in deeper aquifers is thought to be contamination from surface sources (New York State Department of Environmental Conservation, 1986). The density of these sources within the study area is relatively low, however, which further minimizes data entry and verification.

This area is ideally suited for such a study because it contains a variety of land uses, and the density of available data is relatively low. Approximately 52.8 percent is open recreational land, vacant land, or water bodies;

19.1 percent is commercial, industrial, institutional, transportation, and utilities; 15.2 percent is agricultural; and 12.9 percent is residential (Long Island Regional Planning Board, 1982). The population increased during 1970-85 by about 18 percent to over 52,600 (U.S. Bureau of the Census, 1982, 1980 decennial census files, adjusted to the 1985 U.S. Bureau of the Census for county populations). The Village of Riverhead, in which most of the developed land lies, is on the eastern border of the study area. Much of the remaining area consists of pine barrens and farmland. A significant factor in the selection of this area was that development is encroaching upon recharge areas and therefore may jeopardize the quantity and quality of future supplies of drinking water.

Creation of Data Base

The data base was designed to meet the well-permitting criteria of the NYSDEC. Data sets provided by the U.S. Geological Survey and the NYSDEC were reviewed for conformance to these criteria and suitability for entry into the GIS. AML programs were created to access the data base and retrieve data of interest in the well-site-evaluation process.

Review of Well-Site-Evaluation Criteria

The well-site-evaluation criteria supplied by the NYSDEC were grouped into three categories--water quality, hydrogeologic features, and surface features that may affect the quality and (or) quantity of withdrawn water. The well-site-evaluation criteria, data requirements, sources of available data, and the resulting data layers are summarized in table 1. (Note that all items except aquifer thickness, extent, and location can be influenced by a combination of natural and human factors.) Review of these criteria revealed that the two most important measures of site suitability are (1) proximity to features that could affect the quality and (or) quantity of ground water, and (2) hydrogeologic and chemical characteristics of the aquifer and the water beneath the proposed site and surrounding area. The NYSDEC uses other information such as engineer's reports and site inspections to make their final evaluation; however, these data were not suitable for incorporation into the GIS data set.

Selection of Data Sets

A list of data layers and a brief description of their contents and characteristics are given in table 2. These data layers were selected through a review of the well-site-evaluation criteria, and each was considered to be useful and necessary in the characterization of a proposed well site. The data do not describe all aspects of ground-water quality or quantity, however. For example, a complete description of the hydrologic regime adjacent to a proposed well site would require information on both natural and stressed (pumping) conditions, which would in turn require the development of a local ground-water-flow model. The selection of data layers for use in this project was limited by the availability of data (only data that were in a form suitable for GIS data entry were used) and by the project-completion schedule.

Table 1.--Summary of well-site-evaluation criteria, data requirements, sources of available data, and data layers used in this study.

Well-site evaluation criteria	Data requirements	Sources of available data	Data layers used (see table 2 also)
		WATER QUALITY	
Proximity to known sources and areas of contaminated ground water	Location of contaminated aquifer segments	NYSDEC maps and tables; QWDATA	Private-well contamination areas SPDES Sites Oil-spill recovery sites QWDATA
Presence of saline water	Location of salt-water interface	QWDATA	QWDATA
Proximity to land-surface point sources of contamination	Location of land-surface point sources	NYSDEC maps and tables	Inactive hazardous-waste sites Road-salt storage sites SPDES Sites Oil-spill recovery sites
Conformance to drinking-water standards	Ground-water quality in relation to established drinking-water standards	Published drinking-water standards; NYSDEC guide-lines	Private-well contamination areas QWDATA
		HYDROGEOLOGY	
Effects of pumping on surface-water bodies	Location of lakes, ponds streams and wetlands; water-table configuration	USGS 7 1/2 minute quadrangle maps with surface-water features; NWI wetland maps; USGS water-table maps	Streams and surface-water bodies[1] Wetlands[1] 1984 Water-table map
Potentiometric-surface configuration	Head values within major aquifers	USGS potentiometric surface maps	1984 Water-table map 1984 Potentiometric-surface maps of: Magothy aquifer Lloyd aquifer
Water-bearing properties of aquifers	Conductivity and trans-missivity of major aquifers	USGS maps	Conductivity and transmissivity of: upper glacial aquifer Magothy aquifer Lloyd aquifer
Current withdrawal of ground water	Pumpage data	NYSDEC data recorded by well and water district	Public supply well data Water district data
Elevation and extent of hydrologic units	Structure contours of hydrologic units	USGS maps	Structure contour maps of: Magothy aquifer Raritan Formation, upper clay member Bedrock
Presence of confining units	Elevation, thickness, and extent of clay units	USGS maps	Surface elevation and extent of: Gardiners Clay Raritan Formation, upper clay member Smithtown clay "Twenty-foot" clay
		SURFACE FEATURES THAT MAY AFFECT THE QUALITY AND (OR) QUANTITY OF WITHDRAWN WATER	
Surface features that may affect the quality and (or) quantity of withdrawn water	Maps and data of surface features	Data from various federal, state and local sources	1981 Land use 1985 Population census Recharge basins Major roads Soils Water districts

1. Coverage still requires coding and is therefore incomplete.

Table 2.--Coverages used in well-site evaluation

[FANS, Flow Augmentation Needs Study; NYSDEC, New York State Department of Environmental Conservation; NYSDOT, New York State Department of Transportation; SPDES, State Pollutant Discharge Elimination System; USGS, U.S. Geological Survey]

Name	Description	Alternative topology (P=polygon, L=line)	Extent	Source Scale	Source Reference
Coverages created through this project					
			LINE COVERAGES		
BEDSURF	Bedrock structure contours	P	All Long Island	1: 250,000	Soren and Simmons, 1987
GARD.ALT	Gardiners Clay structure contours	P	FANS study area[1]	1: 125,000	Doriski and Wilde-Katz, 1983
GARD.EXT	Gardiners Clay extent	P	FANS study area	1: 125,000	Doriski and Wilde-Katz, 1983
GARD.THK	Gardiners Clay thickness	P	FANS study area	1: 125,000	Doriski and Wilde-Katz, 1983
LLYD.K	Lloyd conductivity	P	All Long Island	1: 250,000	McClymonds and Franke, 1972
LLYD.T	Lloyd transmissivity	P	All Long Island	1: 250,000	McClymonds and Franke, 1972
LLYDPMS84	Lloyd potentiometric surface 1984	P	All Long Island	1: 125,000	Doriski, 1987
MAG.K	Magothy conductivity	P	All Long Island	1: 250,000	McClymonds and Franke, 1972
SMITH.ALT	Smithtown clay structure contours	P	All Long Island	1: 281,600	Krulikas and Koszalka, 1983
SMITH.EXT	Smithtown clay extent	P	All Long Island	1: 281,600	Krulikas and Koszalka, 1983
SMITH.THK	Smithtown clay thickness	P	All Long Island	1: 281,600	Krulikas and Koszalka, 1983
MAG.T	Magothy transmissivity	P	All Long Island	1: 250,000	McClymonds and Franke, 1972
MAGPMS84	Magothy potentiometric surface 1984	P	All Long Island	1: 125,000	Doriski, 1987
TFOOT.ALT	Twenty-foot clay structure contours	P	FANS study area	1: 125,000	Doriski and Wilde-Katz, 1983
TFOOT.EXT	Twenty-foot clay extent	P	FANS study area	1: 125,000	Doriski and Wilde-Katz, 1983
TFOOT.THK	Twenty-foot clay thickness	P	FANS study area	1: 125,000	Doriski and Wilde-Katz, 1983
UPGL.K	Upper glacial conductivity	P	All Long Island	1: 250,000	McClymonds and Franke, 1972
UPGL.T	Upper glacial transmissivity	P	All Long Island	1: 250,000	McClymonds and Franke, 1972
WT84	Water-table elevation 1984	P	All Long Island	1: 125,000	Doriski, 1987
			POLYGON COVERAGES		
IHWS	Inactive hazardous-waste sites	-	Project study area	1: 24,000	NYSDEC files, 1988
LUNEW	Land use	-	Project study area	1: 24,000	Long Island Regional Planning Board, 1982
PRIWELL	Private-well contamination areas	-	Project study area	1: 24,000	NYSDEC files, 1988
SPDES	SPDES sites	-	Project study area	1: 24,000	NYSDEC files, 1988
WATDIS	Water districts	-	Project study area	1: 24,000	NYSDEC files, 1988
WETLAND	National Wetlands Inventory	-	Project study area	1: 24,000	U.S. Fish and Wildlife Service, 1980[2]
			POINT COVERAGES		
PUBSUP	Public-supply wells	-	Project study area	Generated[3]	NYSDEC files, 1988
QWDAT	Water-quality analyses	-	Project study area	Generated	USGS water-quality site files, 1980-88
SALTSTOR	Road-salt-storage sites	-	Project study area	1: 24,000	NYSDEC files, 1988
SPILLREC	Oil-spill-recovery sites	-	Project study area	1: 24,000	NYSDEC files, 1988

Table 2.--Coverages used in well-site evaluation-- continued

Name	Description	Alternative topology (P=polygon, L=line)	Extent	Source Scale	Source Reference
Coverages created through other projects					
			LINE COVERAGES		
MAGSURF	Magothy structure contours	P	All Long Island	1: 125,000	Smolensky and others, 1989
RCSURF	Raritan Formation, upper clay member structure contours	P	All Long Island	1: 125,000	Smolensky and others, 1989
ROADS	Roads	-	All Long Island	1: 24,000	NYSDOT, 1981[4]
TOWNLINES	Town lines	-	All Long Island	1: 24,000	USGS, 1970[5]
			POLYGON COVERAGES		
COASTLINE	LI coastline (embayments edited)	-	Project study area	1: 24,000	NYSDOT, 1981
NASSOIL	Nassau County soils	-	Nassau County	1: 126,720	Wulforst, 1985
POPTRACTS	Population tracts	-	All Long Island	1: 24,000	US Bureau of the Census, 1985
QUADS	7.5 minute quadrangle boundaries	-	All Long Island	1: 24,000	NYSDOT, 1981
STREAMS	Streams and surface water (not coded)	L	All Long Island	1: 24,000	NYSDOT, 1981
SUFFSOIL	Suffolk County soils	-	Suffolk County	1: 253,440	Warner and others, 1972
			TIC COVERAGE - used for map registration		
TICCOVER	Registration tics	-	All Long Island	Generated	NYSDOT, 1981

1. Includes south shore of Long Island only.

2. National Wetlands Inventory Maps available from National Cartographic Information Center, U.S. Geological Survey, 507 National Center, Reston, VA 22092.

3. Coverage was created by inputting coordinates that were transformed into coverages through software.

4. New York State Department of Transportation 7.5-minute quadrangle maps available from Map Information, New York State Department of Transportation, State Campus, Albany, NY 12232.

5. U.S. Geological Survey 7.5-minute quadrangle maps available from National Cartographic Information Center U.S. Geological Survey, 507 National Center, Reston, VA 22092.

Automation

A digital representation of the map features of each selected data layer was entered into the GIS through a digitizing table. Topology was established internally by the ARC/INFO software. This mathematical relationship is constant among map features regardless of projection and scale and allows the software to recognize the position of features through two-dimensional space.

Map features can be characterized as point, line, or polygon features. Examples of point features include well sites and stream-sample sites, line features include roads and water-table contours, and polygon features include hazardous-waste sites and water districts. Each of these types of map features are stored and recognized by the software.

Each data layer was further developed by the addition of attributes that contain information associated with the map feature. An attribute can be described as any thematic data associated with a given map feature. For example, a data layer containing the locations of hazardous-waste sites would also contain attributes such as the address, type of wastes stored, degree of contamination (if known), method of remediation (if applicable), and other information pertinent to each site.

Finally, each data layer was documented on paper and with a computer program that creates a file of information containing the data source, accuracy, and resolution for each data layer. Documentation was stored with each data layer to ensure that it is copied each time the data layer is copied. Documentation was judged necessary because (1) future use by any user may require information on the source of the data, (2) it eliminates the need for the person responsible for data compilation to be present to explain the background of the data, and (3) it includes all information on when, how, where, and from what source(s) the data were obtained.

Structure of Data Layers

The data layers and their associated attribute files were designed and formatted to make the data easily accessible and to minimize computer storage space. This was done through use of a hierarchical, relational data base that includes both expansion files and look-up tables. The following example describes the data-layer structure in more detail.

Figure 3 depicts the structure of one of the data layers, called IHWS (inactive hazardous-waste site), that contains the location and attributes of inactive hazardous-waste sites. The uppermost data group, the PAT (polygon attribute table), contains information such as location and size of the polygon and, in this example, includes an item IDREL that also appears in the file below it (IHWS.EX1). IDREL has the same values in both files. To eliminate the need to store all the attribute data within the feature-attribute table (the PAT), attribute data were assigned to additional files, called expansion files and indicated by the suffix "EX1," "EX2," etc., indicated by the dashed outline. Storage of additional data within an expansion file is a convenient way to organize data. Thus, the separate computer files are internally related by common items with identical values in both files. A further relation is indicated by the SITECODE item in expansion file EX1 that links expansion file EX1 to expansion files EX2 and EX3.

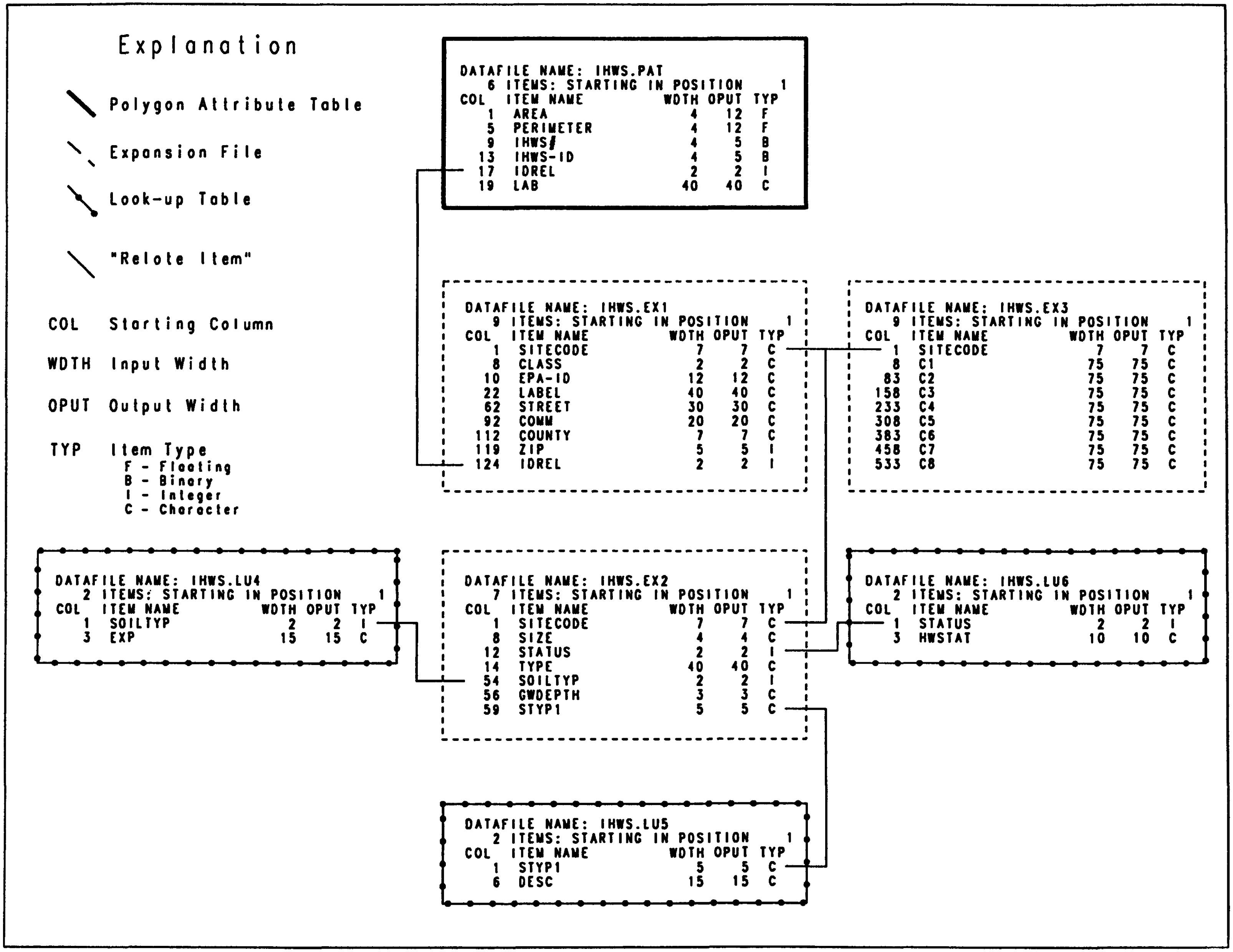

Figure 8.--Structure of sample coverage IHWS (Inactive Hazardous-Waste Sites).

Similar relations are indicated between file EX2 and files LU4, LU5, and LU6 (fig. 3), except that these files are look-up tables and not expansion files. A look-up table differs from an expansion file in that the look-up table contains codes and their explanations, whereas an expansion file generally contains additional feature-specific attributes not maintained as part of the feature-attribute table. The advantage of a look-up table is that many sites that have the same attributes (such as soil type or status, as in fig. 3) need to be labeled only with the coded value and are related by the common items, thus reducing computer storage space. In this example SOILTYP, STYPE1, and STATUS can be retrieved through a relation to EX2. These relations allow retrieval of all available information such as site status (STATUS), soil type (SOILTYP), and site type (STYPE1). Other data layers that were created as part of this project are structured similarly.

Quality Control

A major concern in GIS applications is whether the reproduced maps and associated data accurately represent the original maps from which they were derived. Care was taken to verify that the data layers matched the source maps in every detail. Because reproduced maps are only as accurate as the source maps at the original scale, enlargement of map features to scales larger than the original was avoided. All maps containing line or polygon features were digitized by following the center of the map line to minimize deviations from the actual locations.

Data layers were checked for accuracy by plotting them at the original scale, then overlaying them on the source maps. Each feature was labeled with an item from the attribute files (such as site name or well number) to ensure positive identification between the plotted computer version and the source map. Attribute files were compared with paper files of the original source data, and the GIS software was used to detect any values that lay outside the range of actual values. Where errors were encountered, the data layer and attributes were edited, topology reestablished, and the data layer rechecked against the source map.

Spatial Analyses

The spatial analyses incorporated in these evaluations were made through a series of computer programs written in AML. The programs were designed to establish a user interface that allows a person unfamiliar with the software to access, manipulate, and analyze the data layers and retrieve the desired information. A simplified flow chart depicting the program logic is presented in figure 4. At the beginning of an analysis or session, the user is presented with the "main menu," which offers various options that lead to the desired output. Three routines deemed most crucial to the retrieval and display of the pertinent data were (1) a proximity analysis, (2) an overlay analysis, and (3) a graphical presentation (plotting) program, as described below.

<u>Proximity analysis</u> computes the distance between the proposed well site and surface features of a selected data layer within a given search radius. The user is asked to specify a latitude and longitude for a proposed well

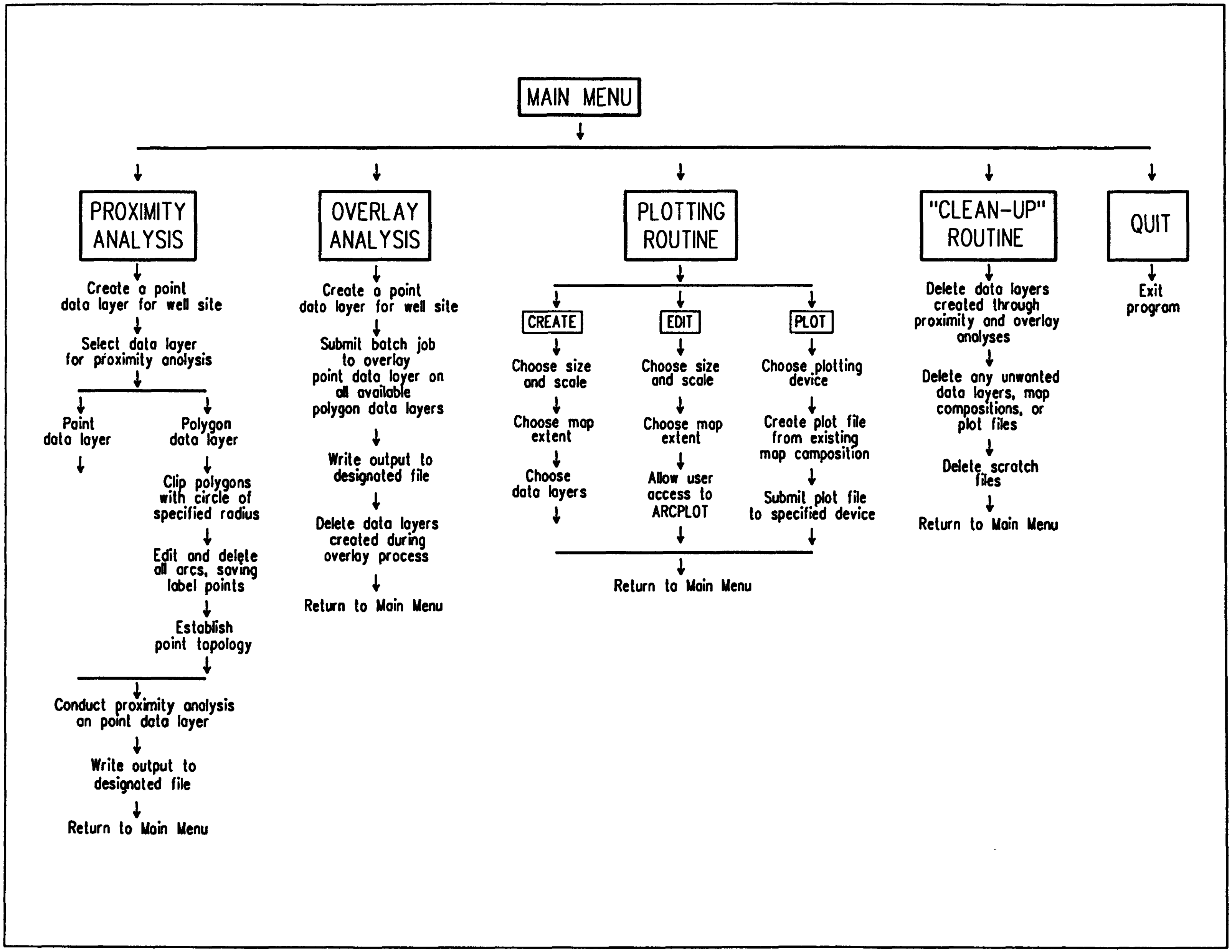

Figure 4.--Generalized flow chart of AML (ARC Macro Language) program.

site. This location is compared to the location of features associated with a specified data layer. The output from this routine is a data table that identifies the feature, all attribute information associated with that feature, and the distance between the feature and the proposed well site.

Overlay analysis allows the user to identify characteristics at or beneath the well site (such as soil type, aquifer thickness, and presence of confining units) and produces a table containing that information. The user is asked to specify a latitude and longitude of the proposed site, which is overlaid on available polygon data layers. This routine also overlays the location of a proposed well site on a three-dimensional version of the water table to determine the approximate gradient and direction of shallow ground-water flow.

Graphical presentation enables the user to create, edit, and (or) plot a map that displays selected data layers and their spatial distribution. The user can specify the size, scale, and extent of the map to customize the output to his or her needs.

An abbreviated version of the output from a sample run of the three routines is presented in the appendix. The proximity analysis was performed on only the IHWS data layer but can be executed on other data layers as well.

Many routines in the computer programs create temporary files while processing data that require additional computer storage space. These files originate from procedures that analyze the data layers and use intermediate versions of files that are not required upon completion of the analysis. A routine was therefore incorporated in the program to allow the user to delete files and data layers not essential to the final output.

This set of computer programs allows the user to access all information stored as part of a data layer without knowing any commands except how to initiate the program. The output from these analyses are intended to be interpreted and evaluated by experienced personnel. Consequently, no attempt has been made to interpret the information or define a ground-water-contributing area to a potential well site. To define a zone of contribution, the ground-water flow paths near the well would be defined according to pumping quantities and hydrologic characteristics, as discussed by Morrissey (1987).

Geographic Information System Utility in Well-Site Evaluation

The GIS used in this study has demonstrated its potential for complex procedures such as well-site evaluation. Large data sets can be quickly and efficiently accessed, manipulated, and displayed. The results of the computer analyses are as accurate as the source maps at the given scale and allow output display of all available information. Updating, adding, and editing attributes of a particular data layer are also relatively simple tasks as long as the user is familiar with the software and the design of the data base. The average time required to produce tables and maps of the proposed site is approximately 1 hour. In contrast, manual compilation of the same information may require 3 hours or more (Brian Baker, New York State Department of Environmental Conservation, oral commun., 1989).

Entry and verification of the data into the GIS may be time consuming, however, especially when data layers are extremely complex or contain features that are extremely close together at the given scale. Data accuracy can be impaired through fatigue associated with digitizing. Quality assurance may take more time to complete than the initial entry into the GIS. Once the data layers have been compiled and verified, however, any of the associated data can be retrieved, manipulated, and displayed with relative ease.

The value of the software package used in this study, ARC/INFO, without the use of AML computer programs must be weighed against the number of hours necessary to learn how to use the system and become proficient with its commands. The initial training and subsequent learning process involved in the development and implementation of a GIS involves a considerable expense, as do the purchase of the computer hardware and software themselves; thus, the utility and value of a GIS can initially be negligible, as recognized by De Man (1988). Once a data base is established and the system incorporated into routine use, tasks that were once extremely time consuming can be completed relatively quickly. The benefits of a GIS may become evident only several months, or even years, after the system is implemented. A benefit of the GIS is that it serves as an extremely efficient data-storage system for the vast amount of hydrogeologic and water-quality data available for Long Island. Another benefit directly related to this study was that users with no previous knowledge of GIS applications were able to learn about the advantages of the system and find uses for it in other applications.

The data layers that were created as a result of this study can be accessed without the computer programs, although this requires that the user be knowledgeable about the use of the software and the structure of the data base and its relational files. All data layers are independent and can be manipulated to suit a user's needs. The data layers also can be used for other hydrologic appraisals and have substantially added to the content of the GIS data base. The NYSDEC, which is responsible for issuing well permits on Long Island, has tested the program and found the software and AML programs to greatly increase the speed and efficiency of their site investigations. Nevertheless, the data and software have limitations and are simply a tool to aid in the interpretation and decisionmaking process.

SUMMARY

A total of 26 data layers were automated in response to an evaluation of the types of data needed to describe the conditions surrounding any given proposed public-supply well site. The design and efficiency of the data layers may also benefit other hydrogeologic evaluations. The AML computer programs developed in this study can retrieve, compile, and display stored data that may be of interest during the well-site-evaluation procedure. The computer program increases the efficiency and accuracy of data retrieval and supports comparisons among proposed well sites.

The GIS used in this study is a fully integrated data-entry display and analytical software package. The results of this application to public-water-supply well-site evaluation have shown that a GIS can be used as a tool to support hydrogeologic investigations.

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GLOSSARY

AAT (Arc Attribute Table) - a special computer file in a relational data base that contains thematic, topological, geometric, and identification information about the arcs in a coverage.

AML (Arc Macro Language) - a fourth-generation command level programming language designed for use with ARC/INFO software.

Attribute - topical or thematic information associated with a given map feature. Attributes are typically stored within feature-attribute tables or expansion files that can be related to these attribute tables through a common item.

Coverage - a set of computer files that contain the location, extent, and other characteristics of a given set of map features. In this report, the term coverage is used interchangeably with data layer. Types of features that make up a coverage include point, polygon, and line.

Expansion file - a computer file that stores additional thematic information about a coverage feature and can be related to a coverage PAT or AAT through a common item.

GIS (Geographic Information System) - an integrated hardware and software system designed to collect, manage, retrieve, analyze, and display spatially referenced data.

Look-up table - a computer file that contains coded symbols and their values. The coded symbols are stored within a coverage PAT, AAT, or expansion file and related to the look-up table through a common item with an identical coded value. The use of look-up tables can vastly reduce computer storage space because coded symbol values need only be stored once.

PAT (Polygon or Point Attribute Table) - a special computer file in a relational data base that contains thematic, topological, geometric, and identification information about the polygons or points in a coverage.

Topology - a mathematical relation that describes the relative positions of connecting or adjacent map features. This relation is constant regardless of scale or projection.

APPENDIX

Sample retrieval showing data tables for inactive hazardous-waste-sites coverage.

This retrieval depicts data found during a search within a 2-mile radius around a hypothetical well site. Included are a proximity analysis (below), an overlay analysis (p. 31-32), and a map (fig. A1, p. 33), all of which were generated by the AML programs. All features that were identified by the proximity analyses are also plotted on the map.]

```
***************************************************************************
SITEPROX.AML

TESTCOVER at latitude/longitude 4053300725730
***************************************************************************

Inactive Hazardous Waste Sites
Proximity Report

1 feature(s) found as a result of search
```

Site Code	Distance to well (feet)	Distance to well (miles)
152101	6,749.604	1.278

Site Code	Class	Site Name	Town
152101	2	BROOKHAVEN AGGREGATES LTD	CORAM

Site Code	Size (acres)	Status	Primary Site Type	Secondary Site Type
152101	19.7	CONFIRMED	LANDFILL	NONE GIVEN

Site Code	EPA ID	Site Contaminant	Depth to GW	Soil Type
152101	--	SOLVENTS	45	SANDY GRAVEL

Comments on selected sites

Sitecode:152101
Total site is 217 acres, sand mining operation comprises 104.7 acres; of that, a 19.7 acre site is used for a C & D disposal area.
Site was investigated and groundwater samples were taken in 1984 and 1986. The analytical results of a groundwater sample taken in 1986 indicate contravention of standards. PHASE II INVESTIGATION

****

Private Well Contamination Areas
Proximity Report

2 feature(s) found as a result of search

Site Name	Distance to well (feet)	Distance to well (miles)
SWEZEYTOWN RD (N)	3,812.620	0.722
SWEZEYTOWN RD	5,362.190	1.016

Site Name	Community	Contaminants (See Table 1)	Source
SWEZEYTOWN RD (N)	MIDDLE ISLAND	1 2 3 4 5	UNKNOWN
SWEZEYTOWN RD	MIDDLE ISLAND	1 3 4 5 7	UNKNOWN

Site Name	Streets Affected
SWEZEYTOWN RD (N)	SWEZEYTOWN;EVERGREEN;CEDAR BRANCH;POINSETTA
SWEZEYTOWN RD	SWEZEY LA;WEST ST;DENNIS LA;FRANK AV;COLONIAL DR

Site Name	Number of Wells Affected	Treatment (See Table 2)
SWEZEYTOWN RD (N)	23	1 3 0
SWEZEYTOWN RD	34	1 2 0

APPENDIX (continued)

Table 1.
Contamination Code Explanation

Code	Contaminant
0	NONE
1	TETRACHLOROETHYLENE (PCE)
2	TRICHLOROETHYLENE (TCE)
3	TRICHLOROETHANE (TCEA)
4	DICHLOROETHYLENE (DCE)
5	DICHLOROETHANE (DCEA)
6	DICHLOROPROPANE
7	CHLOROFORM
8	BENZENE
9	TOLUENE
10	XYLENE
11	VOLATILE ORGANICS (UNSPEC.)

Table 2.
Treatment Code Explanation

Code	Treatment
0	NONE
1	BOTTLED WATER SUPPLIED
2	PWS MAINS INSTALLED
3	PWS MAINS PLANNED
4	CONNECTED TO EXISTING PWS
5	WELLS BEING MONITORED
6	CARBON FILTRATION
7	DEEPENED EXISTING WELL(S)

****

Public Supply Wells
Proximity Report

3 feature(s) found as a result of search

Well Number	Distance to well (feet)	Distance to well (miles)	Owner	Permit Number	Authorized Capacity (GPM)	Actual Capacity (GPM)
S 36711	4,549.237	0.862	SCWA	5837	500	500
S 49606	4,443.707	0.842	SCWA	6177	1200	1200
S 40161	4,450.099	0.843	SCWA	5837	1200	1200

Well Number	Pumpage 1985 (x1000 gallons)	Pumpage 1986 (x1000 gallons)	Pumpage 1987 (x1000 gallons)	Depth (feet)	Aquifer
S 36711	63374	58200	42800	143	GLACIAL
S 49606	72144	110100	132600	703	MAGOTHY
S 40161	85783	100300	130100	138	GLACIAL

****

Carbamate Analyses from Monitoring Wells
Proximity Report

[All values in micrograms per liter; n.d., no data]

50 ug/L - overstressed; 40 ug/L - cautionary

Well Number	Distance to well (feet)	Aldicarb Sulfoxide		Aldicarb Sulfone	
		Date	Conc.	Date	Conc.
S 47225	9,480.010	07-13-82	< 1.00	07-13-82	< 1.00

****

Benzene and Toluene Analyses from Monitoring Wells
Proximity Report

[All values in micrograms per liter; n.d., no data]

50 ug/L - overstressed; 40 ug/L - cautionary

Well Number	Distance to well (feet)	Benzene		Toluene	
		Date	Conc.	Date	Conc.
S 45838	8,123.447	10-30-85	< 3.00	10-30-85	< 3.00
S 47225	9,480.010	10-06-86	< 3.00	10-06-86	< 3.00
S 47745	4,761.994	10-07-86	< 3.00	10-07-86	< 3.00
S 51979	9,233.283	08-25-86	< 3.00	08-25-86	< 3.00
S 66506	4,583.995	10-08-86	< 3.00	10-08-86	< 3.00
S 66507	7,904.113	04-20-87	< 3.00	04-20-87	< 3.00
S 36711	4,553.097	12-03-85	< 1.00	12-03-85	< 1.00
S 40161	4,453.536	12-17-85	< 1.00	12-17-85	< 1.00
S 49606	4,451.184	04-25-84	< 1.00	04-25-84	< 1.00

APPENDIX (continued)

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Inorganic Compound Analyses from Monitoring Wells
Proximity Report

[All values in milligrams per liter; n.d., no data]

50 mg/L - overstressed; 40 mg/L - cautionary

Well Number	Distance to well (feet)	Nitrogen		Chloride		Sulfate	
		Date	Conc.	Date	Conc.	Date	Conc.
S 45838	8,123.447	07-31-86	0.09	07-31-86	36.0	07-31-86	4.3
S 47218	4,636.029		n.d.	05-31-73	4.9	05-31-73	7.8
S 47225	9,480.010	04-15-87	6.40	04-15-87	15.0	04-15-87	27.0
S 47725	9,480.010	05-10-76	5.00	05-17-79	7.0	05-17-79	44.0
S 47745	4,761.994	04-16-87	1.90	04-16-87	41.0	04-16-87	20.0
S 51979	9,233.283	08-25-86	4.60	08-25-86	22.0	08-25-86	20.0
S 66506	4,583.995	04-16-87	1.60	04-16-87	28.0	04-16-87	20.0
S 66507	7,904.113	04-20-87	3.70	04-20-87	5.5	04-20-87	13.0
S 36711	4,553.097	12-03-85	0.70	01-16-87	7.2	01-16-87	8.3
S 40161	4,453.536	12-17-85	0.57	12-17-85	5.0	12-17-85	12.3
S 49606	4,451.184	12-17-85	1.50	09-18-87	6.1	09-18-87	6.3

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Volatile Organic Compound Analyses from Monitoring Wells
Proximity Report

[All values in micrograms per liter; n.d., no data]

50 ug/L - overstressed; 40 ug/L - cautionary

Well Number	Distance to well (feet)	1,1,1 TCA Date	1,1,1 TCA Conc.	1,1,2 TCA Date	1,1,2 TCA Conc.
S 45838	8,123.447	10-30-85	< 2.00	10-30-85	< 5.00
S 47225	9,480.010	10-06-86	< 2.00	10-06-86	< 5.00
S 47745	4,761.994	10-07-86	< 2.00	10-07-86	< 5.00
S 51979	9,223.283	08-25-86	< 2.00	08-25-86	< 5.00
S 66506	4,583.995	10-08-86	< 2.00	10-08-86	< 5.00
S 66507	7,904.113	04-20-87	< 2.00	04-20-87	< 5.00
S 36711	4,553.097	12-03-85	< 1.00	12-03-85	< 3.00
S 40161	4,453.536	12-17-85	< 1.00	12-17-85	< 3.00
S 49606	4,451.184	12-17-85	< 1.00	12-17-85	< 3.00

Well Number	Distance to well (feet)	TCE Date	TCE Conc.	Tetrachloroethane Date	Tetrachloroethane Conc.
S 45838	8,123.447	10-30-85	< 5.00	10-30-85	< 2.00
S 47225	9,480.010	10-06-86	< 4.00	10-06-86	< 2.00
S 47745	4,761.994	10-07-86	< 5.00	10-07-86	< 2.00
S 51979	9,223.283	08-25-86	< 5.00	08-25-86	< 2.00
S 66506	4,583.995	10-08-86	< 5.00	10-08-86	< 2.00
S 66507	7,904.113	04-20-87	< 5.00	04-20-87	< 2.00
S 36711	4,553.097	12-03-85	< 1.00	12-03-85	< 1.00
S 40161	4,453.536	12-17-85	< 1.00	12-17-85	< 1.00
S 49606	4,451.184	12-17-85	< 1.00	12-17-85	< 1.00

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SITEPROX.AML

Overlay analysis from point coverage - data is from directly beneath site.

TESTCOVER at latitude/longitude 4053300725730


 General Information
 ===================

   7 1/2 Minute Quadrangle    : MIDDLE ISLAND

   Soil Name                  : Haven-Riverhead
   Geomorphologic Description : OUTWASH PLAINS

   Water District Data (if any)
   -------------------
       District: SCWA PORT JEFF DIST.

                WD Pumpage
       Year   (X 1000 gallons)     WD Population
       -------------------------------------------
       1984      6431534                124038
       1985      6794600                127428
       1986      7690000                131379

   Statistics within 2 mile radius
   -------------------------------
       Population (data from 1985 Census Tracts)
         8863 people (average of 1.1 people per acre)

       Land Use (by area)
          0.00%  NONE GIVEN
          0.02%  COMMERCIAL RECREATION
          0.02%  RESIDENTIAL (5-10 DU/ACRE)
          0.54%  WATER BODIES
          1.08%  INSTITUTIONAL
          1.40%  TRANSPORTATION AND UTILITIES
          2.47%  COMMERCIAL
          2.76%  RESIDENTIAL (> 11 DU/ACRE)
          5.09%  INDUSTRIAL
          6.61%  AGRICULTURAL
          8.09%  RESIDENTIAL (< 1 DU/ACRE)
         12.02%  RESIDENTIAL (2-4 DU/ACRE)
         28.20%  OPEN SPACE AND RECREATIONAL
         31.70%  VACANT
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APPENDIX (continued)

Hydrogeologic Information

(all elevations are given in feet above or below sea level)

Ground Water Flow Direction: N 66 E
Approximate gradient : .000664 feet per foot

Upper glacial aquifer

Water Table Elevation	: between	50	and	60	feet
Conductivity	: between	1500	and	2000	gallons per day per foot
Transmissivity	: between	200000	and	300000	gallons per day per foot

Magothy aquifer

Surface Elevation	: between	-400	and	-300	feet
Potentiometric Surface	: between	50	and	60	feet
Conductivity	: between	300	and	400	gallons per day per foot
Transmissivity	: between	200000	and	300000	gallons per day per foot

Raritan Formation, upper clay member

Surface Elevation	: between	-900	and	-800	feet

Lloyd aquifer

Potentiometric Surface	: between	35	and	40	feet
Conductivity	: between	300	and	400	gallons per day per foot
Transmissivity	: between	60000	and	80000	gallons per day per foot

Bedrock

Surface Elevation	: between	-1200	and	-1100	feet

Smithtown clay

Surface Elevation	: between	50	and	75	feet
Thickness	: between	100	and	150	feet

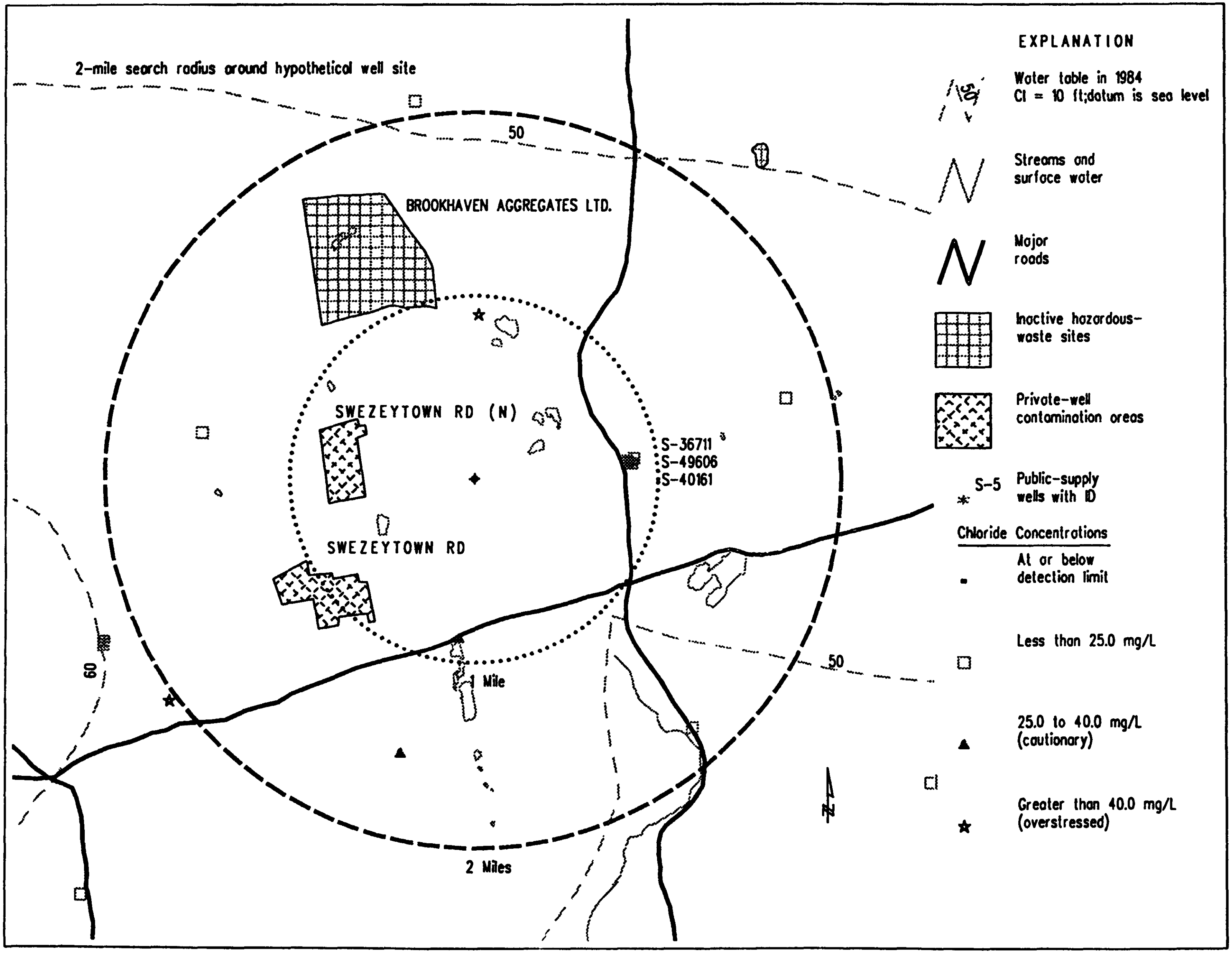

Figure A-1. Sample map output showing pertinent features within 2-mile radius of well site.