Contract Report 611

Delineation of Time-Related Recharge Areas for the City of Shelbyville Well Fields

by
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Prepared for the
City of Shelbyville, Illinois

April 1997

Illinois State Water Survey
Hydrology Division
Champaign, Illinois

A Division of the Illinois Department of Natural Resources

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FOR THE

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ISSN 0733-3927

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ABSTRACT

Time-related recharge areas, principally the 5-year recharge area, have been delineated for Shelbyville's north and south well fields for a variety of pumping scenarios. A network of wells was created using existing private domestic wells, and a mass measurement of water levels was conducted to create a ground-water contour map for the study area and to aid in the calibration of a computer-based ground-water flow model.

Recharge areas were determined using the United States Geological Survey (USGS) ground-water modeling code, MODFLOW, followed by the flow path analysis package, MODPATH, as contained in the graphical interface package, Visual MODFLOW©. A three-dimensional model domain was constructed with 57 columns, 72 rows, and three layers to simulate ground-water flow through the sand-and-gravel aquifer from which Shelbyville obtains its municipal water supply. The model was prepared based on previously conducted geological investigations, supplemented with more recently available well-log information, and on information collected during field investigations. Simulations of seven pumping schemes were used to derive 1-, 2-, 5-, and 10-year recharge areas for each of the two well fields which the city operates.

An important observation noted during the creation of the seven "sets" of recharge areas was that the 1, 2-, 5-, and 10-year recharge areas did not extend significantly further upgradient (northerly) as pumping rates were increased. The recharge areas did, however, expand in directions more transverse (i.e., to the east and west) as pumping rates were increased. Specifically, for all pumping rates, the 1-, 2-, 5-, and 10-year recharge areas calculated at Shelbyville's north well field extend upgradient (north-northeast) approximately 0.3 miles (mi), 0.5 mi, 0.9 mi, and 1.3 mi from the center of the well field, and "widen" (to the east and west) with increasing simulated pumping rates. At the south well field the recharge areas extend upgradient (northerly) and terminate near the Kaskaskia River, approximately 800 feet north of the center of the well field, indicating that significant ground-water recharge from the Kaskaskia River is occurring. Again, the recharge areas "widen" to the east and west with increasing simulated pumping rates.

INTRODUCTION

The city of Shelbyville operates two well fields southwest of the city (figure 1) that withdraw ground water from water-bearing sand-and-gravel deposits (aquifers) associated with an ancient bedrock valley, as well as from alluvial deposits associated with the Kaskaskia River and one of its tributaries, Robinson Creek. In recent years there has been increased interest in this aquifer system and its potential for continued use as a viable and safe source of water. This increased awareness has resulted in an expressed desire by city officials to learn more about the resource and to be better able to address resource development and management plans.

Also, as part of Shelbyville's ground-water management plan, the city is working with the Illinois Environmental Protection Agency (IEPA) to pursue a Safe Drinking Water Act (SDWA) monitoring waiver. As the wells that provide Shelbyville's ground water use an unconfined aquifer, which is vulnerable to surficial contaminants, some of the required steps to receive the monitoring waiver are:

1. Delineate the 5-year time-of-travel recharge area for the wells.

2. Identify potential ground-water contamination sources and potential routes within the 5-year recharge area.

3. Make provisions for contaminant source management within the 5-year recharge area, including the management of cropland agrichemical application.

4. Develop a contingency plan for dealing with potential ground-water contamination releases within the 5-year recharge area of the municipal wells.

As reflected above, delineation of the 5-year recharge area is the preliminary step for Shelbyville to begin its overall ground-water management plan. The city contracted with the Illinois State Water Survey (ISWS) in January 1996 for this task to be accomplished.

Lateral Areas of Influence and Ground-Water Capture Zones

The withdrawal of ground water by a well causes a lowering of the hydraulic head in the aquifer in the area around the well. The difference between water levels during nonpumping and pumping conditions is called *drawdown* (figure 2). From a three-dimensional perspective, the pattern of drawdown around a single pumping well resembles a cone with the greatest drawdown adjacent to the pumping well. The area affected by the pumping well, therefore, is called the *cone of depression* and is also referred to as the lateral area of influence (LAI). Within the LAI, the velocity of the ground water continuously increases as it flows toward the well due to the gradually increasing slope in the cone of depression. The slope of the surface which represents the hydraulic head is called the *hydraulic gradient.*

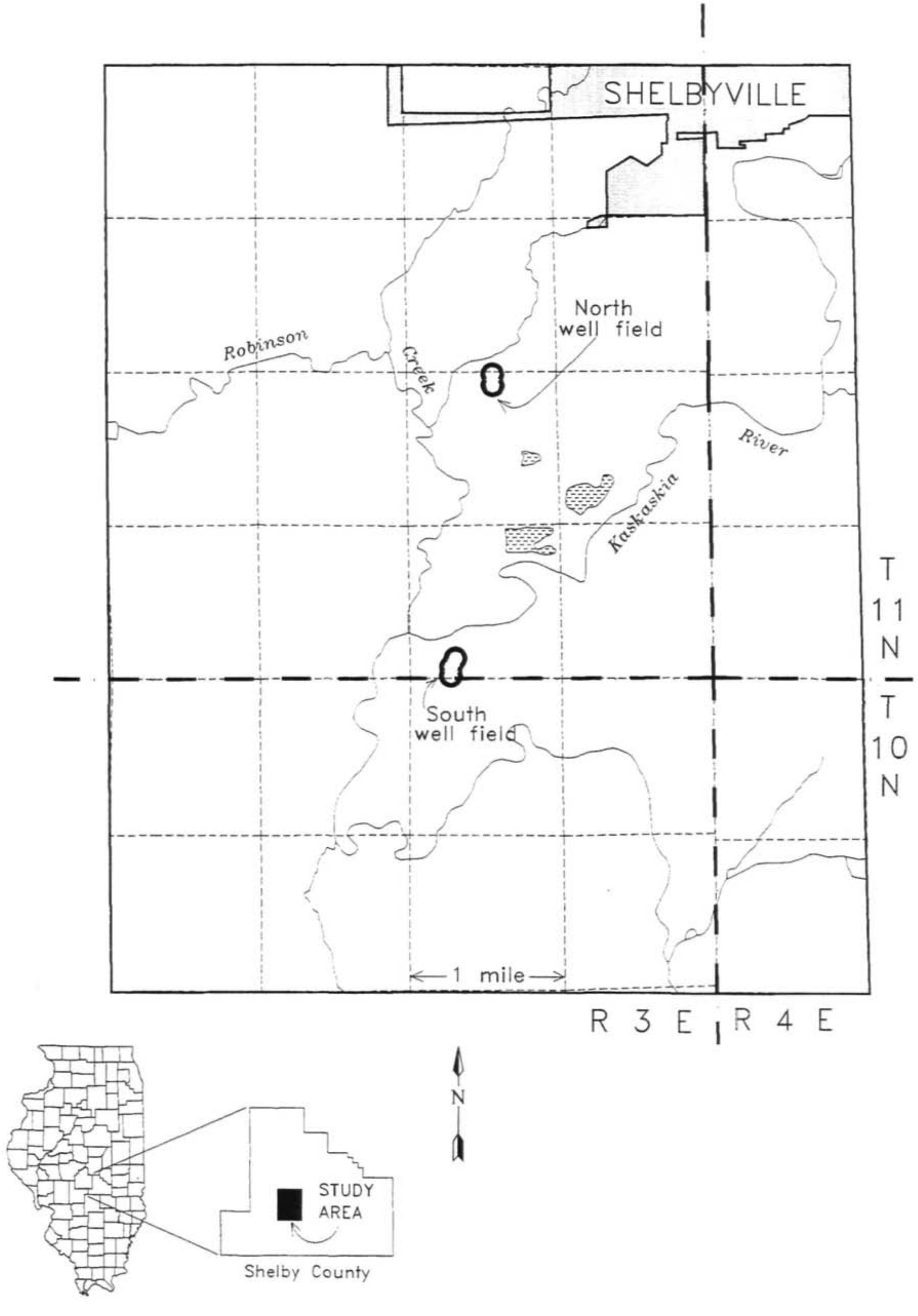
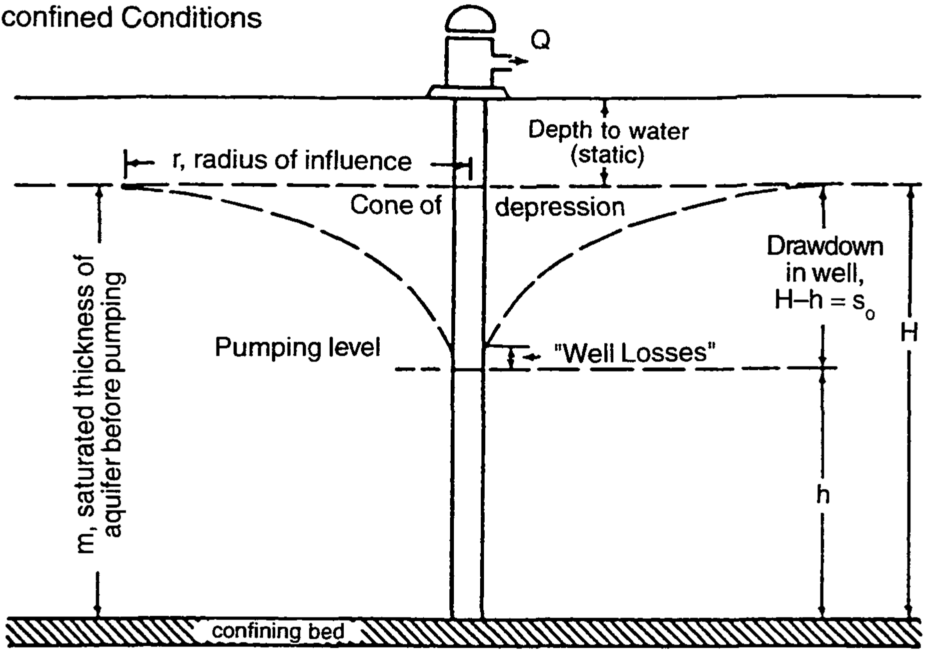


Figure 1. Location of the Shelbyville study area

a. Unconfined Conditions



b. Confined Conditions

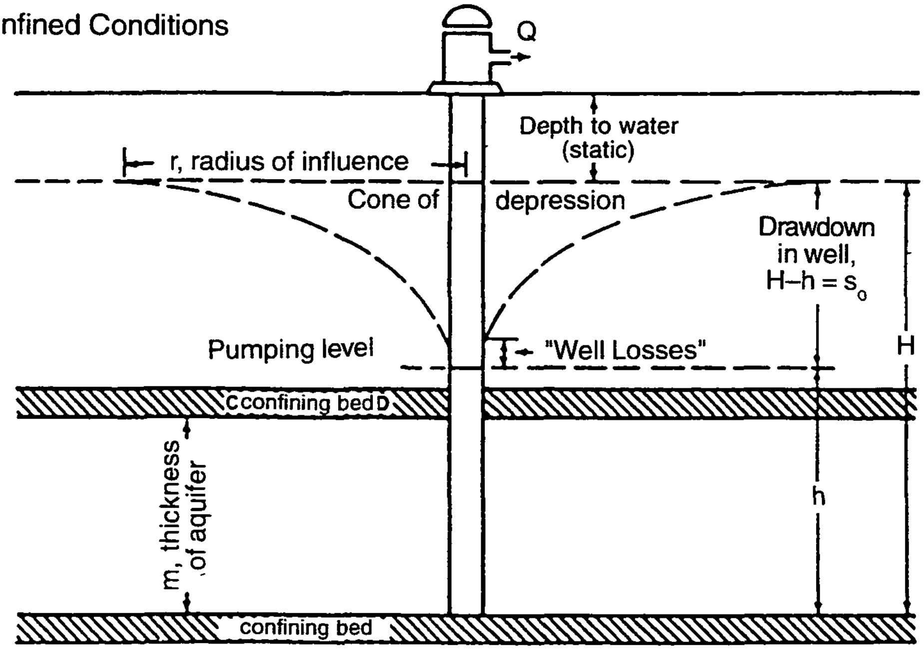


Figure 2. Drawdown, cone of depression, and radius of influence
under unconfined and confined conditions

If a computed drawdown cone is overlain on the nonpumping potentiometric surface, an area can be defined such that all water within that area will eventually be pulled into the well that is creating the cone of depression. The area of the water entering the LAI of the well is referred to as the *zone of capture* (ZOC). Figure 3 shows a diagram depicting the ZOC for a well within a regional flow field both in a vertical profile and in a plan view. Generally, the ZOC extends upgradient from the pumping well to the edge of the aquifer or to a ground-water divide (a line beyond which ground water is flowing in a different direction). The ZOC may receive recharge directly from the overlying land surface in the case of a water-table (unconfined) aquifer or may receive recharge from some distance away as is the case with some confined aquifers.

Often, the boundaries of a ZOC are calculated on the basis of time; that is, the boundary within which the captured ground water will reach the well in a certain period of time. Such a ZOC is referred to as a *time-related capture zone,* and the corresponding horizontal area (shown in plan view) is called the *time-related recharge area.* For example, a 5-year time-of-travel recharge area outlines the area within which the ground water at the edge of the area will reach the well within five years. Within this report, this area simply will be referred to as a *5-year recharge area.*

Illinois' Wellhead Protection Strategy

In accordance with the 1986 amendments to the Safe Drinking Water Act and with the passage of the Illinois Groundwater Protection Act in 1987, the Illinois Environmental Protection Agency (EPA) has implemented a Wellhead Protection (WHP) program for Illinois. This program initially established a WHP area (WHPA) of a fixed radius of 1000 feet around all community and noncommunity wells in Illinois. As more site-specific hydrogeologic information is gathered, this 1000-foot WHPA can be expanded to an area including the 5-year recharge area if the boundary of that area extends 1000 feet from the well. Expansion of the WHPA must include sufficient information to define the extent and direction of the 5-year recharge area.

The initial management zone within each 1000-foot WHPA, called a setback zone, occurs within 200 or 400 feet of all potable water-supply wells. These zones are designated for the regulation of activities which have a high potential for introducing contaminants into the ground-water system and thereby threatening the quality of the water supply. Regulation takes the form of outright prohibition of some activities (e.g., landfilling) and requires technology-based controls and ground-water monitoring for other activities (e.g., storing hazardous chemicals). A *minimum* setback zone with a 200-foot radius was established for all community supply wells. The minimum setback is increased to a 400-foot radius for community supply wells developed in sensitive geological settings (i.e., unconfined highly permeable bedrock or sand-and-gravel formations).

Communities also may adopt ordinances controlling the siting of new potential sources in a second management zone called the *maximum* setback zone. A maximum setback zone may have irregularly shaped boundaries, depending on the ground-water flow field established around the well, but the zone is limited to 1000 feet from the wellhead. No new potential primary

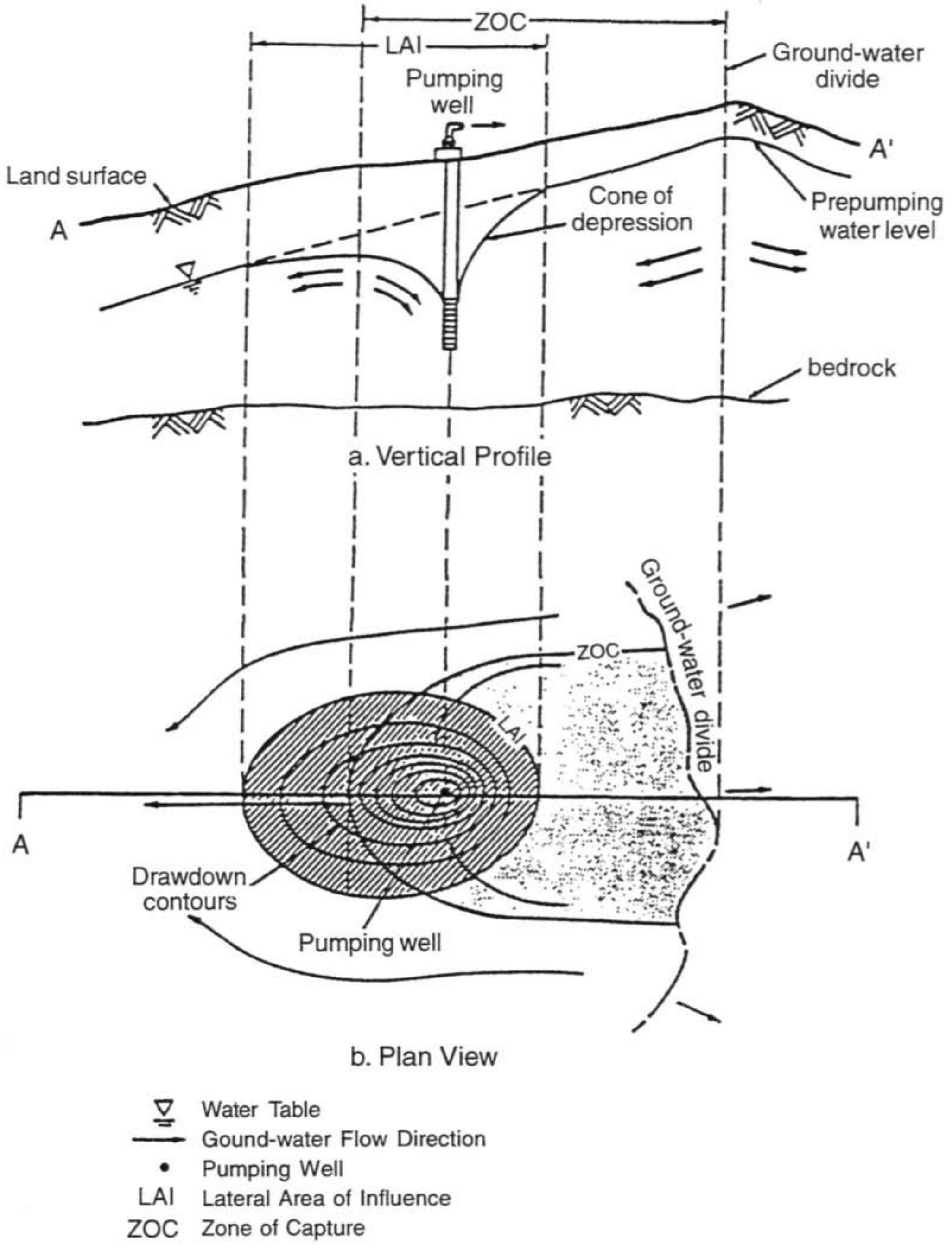


Figure 3. Relationship between the cone of depression, lateral area of influence, and the zone of capture within a regional ground-water flow field (from Todd, 1980)

sources may be sited within a maximum setback zone. Technology controls (e.g., enhanced monitoring, runoff containment, etc.) on existing primary sources within a maximum setback zone must also be implemented. As part of their commitment to the wellhead protection area concept, the EPA has completed well-site surveys and inventories of potential sources of ground-water contamination within 1000 feet of a well for all municipal wells in Illinois. With such information available to the communities, *it is the IEPA 's intention for the local communities to take up increased activity related to the protection of their own supplies.*

Communities can establish maximum setback zones around their wells by petitioning the IEPA. Petitions must demonstrate that under normal operating conditions the LAI of the well exceeds the minimum setback zone. Rules have been adopted that outline the procedures for determining the LAI of wells under normal operating conditions and for requesting the IEPA to review and confirm the technical adequacy of such a determination.

If the delineation process determines that wellhead protection should be extended beyond 1000 feet (e.g., to a 5-year recharge area), a cooperative program between the state and local community water-supply officials is to be established. Community officials are voluntarily responsible for inventorying potential sources and routes of contamination outside of the 1000-foot zone (and within, for example, the 5-year recharge area). Within this area, technology controls can be required of potential sources or routes of contamination. In addition, the IEPA may propose to the Illinois Pollution Control Board a regulation establishing a *regulated recharge area* (RRA). An RRA is a compact geographic area, as determined by the Board, where the geology renders a potable resource ground water particularly susceptible to contamination. The IEPA can propose establishment of an RRA to the Board if a regional planning commission files a petition requesting and justifying such action. In proposing the RRA, the IEPA shall identify each community water-supply well for which protection up to 2500 feet will be provided by operation of regulations concerning new existing activities.

However, with the power of local zoning regulations, city officials can pass ground-water protection laws for whatever areas they see fit. Such land use restrictions can extend far beyond 2500 feet. For example, the city of Pekin has passed a ground-water protection area ordinance that "establishes regulations for land uses within the Groundwater Protection Areas for: inspection and monitoring standards for new regulated substance facilities; uniform standards for release reporting; emergency response; substance management planning; permit procedures; and enforcement" (IEPA, 1995). "Groundwater Protection Areas" were defined within the ordinance to include areas within the minimum setback zone, maximum setback zone, or 5-year capture zone (recharge area) of a well or well field.

Other Studies in Illinois

Investigations conducted by the Illinois State Water Survey in Rockford, Illinois (Wehrmann and Varljen, 1990) showed that for the aquifer conditions at Rockford, the 400-foot minimum setback zone provided little response time (approximately 60 days) in the event of a contamination incident. For some wells in Rockford, a 5-year recharge area extended beyond 2500 feet. A unique aspect of the Rockford study was the capability to model aquifer response to different pumping conditions and to simulate changes in capture zone configurations due to changes in well field operation. This was particularly significant in Rockford because of the loss of Well 7A due to contamination by trichloroethylene (TCE).

Similar capture zone delineations have been conducted for several other communities in Illinois. These include Cary (McHenry County), Pekin (Tazewell County), Loves Park (Winnebago County), and the Pleasant Valley Public Water District (Peoria County). Another ongoing modeling study at the ISWS includes Woodstock (McHenry County). In addition, Varljen and Shafer (1993) used a technique based on a numerical flow model of the Pekin area coupled with an unconstrained nonlinear optimization model to manage well field operations to control capture zones to minimize potential contaminant source capture and yet maintain water production at a minimum quantity.

Acknowledgments

This work was supported by a grant from the city of Shelbyville, Mr. J. Lowell Goleman, Mayor. The authors gratefully acknowledge the cooperation of the city of Shelbyville Water Department, and Brent Shull, Superintendent. In addition, this project would not have been possible without the willing cooperation and interest of the many residents within the study area who allowed their wells to be included in the mass measurement network and to be accessed for the water-level measurements and the collection of water samples. We extend our sincere appreciation to these individuals.

Field assistance was provided during the water-level mass measurement by Shelbyville High School students Megan McDonald and Jacob Hammond. Sean Sinclair, Geographical Information Systems (GIS) Technical Assistant (ISWS), provided assistance with computer mapping efforts. Adrian P. Visocky, Senior Hydrologist (ISWS), and Ellis W. Sanderson, Senior Engineer (ISWS), reviewed the report manuscript. Word processing to prepare the reproducible copy of this report was done by Pamela Lovett, Admininstrative Coordinator (ISWS). Linda Hascall finalized the graphics, and Eva Kingston edited the report.

RECHARGE AREA DELINEATION OVERVIEW

The primary objective of this project was to delineate a series of time-related capture zones for Shelbyville's north and south well fields. This includes the collection of necessary field data to make such determinations, as well as basic ground-water flow modeling and flow path analyses to estimate time-based ground-water recharge areas for the well fields.

Task Summary

The estimation of recharge areas beyond applicable setback zones should follow a logical progression from field investigation through ground-water flow modeling to the calculation of time-related capture zones. Table 1 summarizes a general plan containing the progressive steps used in collecting the field data, estimating aquifer parameters, and incorporating these data into

Table 1. General Project Task Descriptions

I. Estimate physical and hydraulic conditions of the aquifer
  A. Estimate geology (geometry and properties)
  B. Estimate natural ground-water flow direction and gradient
    i. *Find wells in which to measure ground-water levels*
    ii. *Measure depth-to-water in those wells and determine casing elevations*
    iii. *Prepare map of ground-water flow field*
  C. Estimate aquifer hydraulic properties
  D. Define aquifer boundary conditions

II. Create discrete head distribution over domain of interest
  A. Estimate initial and boundary conditions for flow model and verify model
  B. Numerically model ground-water flow under selected pumping conditions

III. Estimate time-related capture zones for selected pumping conditions
  A. Use flow model output with MODPATH to determine flow paths
  B. Determine time-related capture zones

a mathematical model. This plan was followed in the data collection and analysis phases of our work in the Shelbyville study area. The following discussions highlight how these tasks were accomplished and the results of those efforts. The work follows a sequence of tasks: 1) to estimate the physical and hydraulic conditions of the aquifer, 2) to simulate those conditions with a ground-water flow model, and 3) to use the modelled conditions to determine the time-related recharge areas under various pumping scenarios.

Estimation of the physical and hydraulic properties of the aquifer(s) is usually undertaken first by a review of available information. The goal of this task is to formulate a "conceptual" model of the aquifer and the nature of ground-water movement. This includes estimates of the aquifer's physical size and shape (thickness, lateral extent, and vertical position), direction of ground-water movement, interactions with other geologic and geographic features including surface-water bodies, confining beds (i.e., nonaquifer materials overlying or underlying the aquifer), contributions from or to other aquifers, and interactions between all these components. Available information can be in the form of previously published material (local, state, federal, and consultant's reports) or in raw form (well records and water-level data that include surface water stages and ground-water levels).

With sufficient water-level data obtained from new wells, previously existing wells, or a combination of the two, a map of the ground-water *potentiometric surface* can be prepared. The *potentiometric surface* is a theoretical surface which describes the level to which water will rise in wells completed in the formation of interest. This surface can be contoured just as the land surface is contoured on a topographic map. A contour of the mapped surface represents a line of equal hydraulic head (or potential). In many cases, the potentiometric surface of an aquifer looks similar to the overlying land surface topography, only much smoother and less pronounced. A map of this type is useful in determining the direction of ground-water movement and the hydraulic gradient (slope) of the potentiometric surface. The gradient will help to determine flow rate. Such a map is also useful for incorporation into a mathematical flow model to provide information to verify the model.

Site-specific information also should include results of aquifer tests and slug tests that can provide aquifer hydraulic properties. Principal properties include hydraulic conductivity, transmissivity, and storativity. Hydraulic conductivity and transmissivity are measures of a geologic material's ability to transmit water. These parameters are essential for ground-water flow modeling and accurate recharge area delineations.

Once the hydraulic properties of the aquifer system are satisfactorily estimated, the recharge area can be delineated. Simplified recharge areas (capture zones) may be determined using the equations presented by Todd (1980), as was done by Gibb et al. (1984). To delineate recharge areas more accurately, the most common technique is to use the hydraulic head field (the potentiometric surface calculated as ground-water flow model output) as input to another computer program that can calculate ground-water flow paths and velocities. With the flow paths and velocities determined, these computer "tools" can also portray the recharge areas for the selected travel time. Such techniques were used in the delineation of recharge areas for other Illinois cities: Rockford (Wehrmann and Varljen, 1990), Pekin (Adams et al., 1992), and Cary (Baxter and Woodman, Inc., 1992).

GEOLOGY AND GROUND-WATER HYDROLOGY IN THE VICINITY OF SHELBYVILLE'S MUNICIPAL WELL FIELDS

Bedrock Geology

Below the unconsolidated glacial deposits in Shelby County are layers of consolidated rocks representing several geological ages. The uppermost consolidated rocks consist of beds of shale, sandstone, and limestone arranged one upon the other; the top surface of these rocks is called the bedrock surface. Originally the bedrock formations were unconsolidated materials, deposited over many years as sediments in shallow seas or bordering marshes. They were then buried and hardened into solid rock during the several million years after the seas retreated from the area.

Erosion of the bedrock was not uniform throughout the county. In areas where soft shales and sandstone formations were exposed to weathering, valleys were formed by water and ice action, while hard sandstone and limestone formations in other areas resisted erosion and remained to form ridges and hills on the bedrock surface. Some of the old bedrock valleys coincide with present-day stream valleys, but some are partially or even completely buried by the glacial deposits so that there is little or no surface evidence of their presence. In parts of Shelby County, *the* bedrock surface is exposed in dry washes and gullies in the higher lands, and in some of the creek and river valley lowlands.

A detailed delineation of the bedrock surface in the study area is beyond the scope of this project. A generalized bedrock topography for the study area has been extracted from the statewide coverage (Herzog et al., 1994) and is shown in figure 4. This "extracted" coverage will not be used in any detailed definition of the ground-water model, but some general observations can be made, and correlations with the unconsolidated glacial deposits will be shown below.

First, a bedrock valley traverses the study area generally from the northeastern to the southwestern corners and is joined by two smaller "tributary" valleys from the west. For current purposes, these bedrock valleys can be thought of as being bounded by the 500 feet above mean sea level (ft-msl) contour lines of the bedrock surface. Also, the deepest portion (or thalweg) of this bedrock valley slopes generally downward (northeast to southwest), reaching a minimum elevation of approximately 450 ft-msl near the southeastern corner of the study area. This buried bedrock valley was identified by Horberg (1950) as the head of the preglacial Kaskaskia valley system. As will be discussed below, the areas with the thickest glacial deposits are confined to this bedrock valley.

Glacial Geology

Glacial Geology in Shelby County

The glacial geology of Shelby County is summarized in general terms in Illinois State Geological Survey (ISGS) Circular 225 (Selkregg et al., 1957). The following brief discusssion of geologic conditions in the county is taken largely from that publication. The files of the ISGS are available for greater definition of the geology in this portion of the state.

Information from wells and exposures of rocks indicates that the land surface of Shelby County has been shaped principally by ice and running water. The features produced by ice were developed long ago when glaciers, nourished by snow accumulation in Canada, advanced across Shelby County several times and melted away, leaving a vast quantity of rock debris. In front of the ice, sediment-laden meltwater escaped down valleys, partially filling them with outwash deposits of sorted sand, gravel, and finer material. Thick, extensive till sheets of unsorted clay, silt, sand, and pebbles also were laid down under the advancing ice or dumped in place during melting. Glacial deposits blanket practically all of Shelby County, resulting in a relatively level plain broken only by isolated knobs, stream valleys, and long ridges formed at the front of the glacier (end moraines). Running water continues to modify this surface today by cutting into the land, carrying away soil and rock particles, and depositing the debris in river bottoms. This modification is a small-scale version of the changes made on the bedrock surface by glacial meltwaters.

Glacial Geology in the Shelbyville Study Area

Cartwright and Kraatz (1967) conducted a geologic investigation in the vicinity of Shelbyville's two well fields. The following discussion of glacial geology for the present study area comes largely from that publication. Glacial deposits corresponding to the Wisconsinan (most recent) and the Ulinoian stages of glacial are present in the Shelbyville area. Shelbyville is

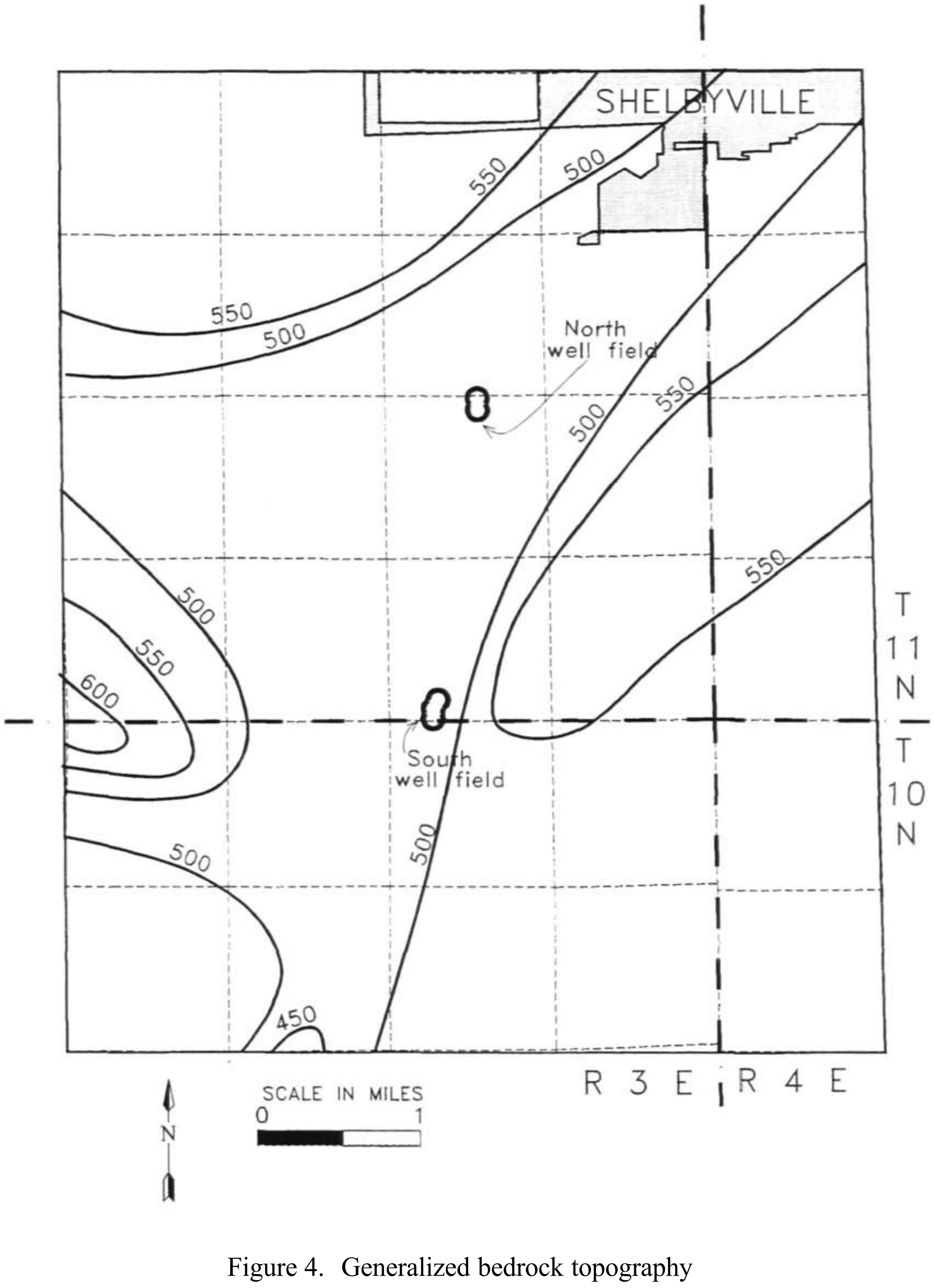


Figure 4. Generalized bedrock topography

situated where the Wisconsinan stage deposited till (clay, sand, gravel, and boulders) to form a large end moraine, the tip of which extends south from the city into Sec. 23, T. 11 N., R. 3 E. This protrusion of the front of the moraine extends to within approximately one quarter mile of the city's north well field (see figure 5). Illinoian till forms the rest of the upland surficial material in the remainder of the present study area.

Glacial deposits associated with the Wisconsinan and Illinoian stages of glaciation, as well as the possibly older deposits associated with the preglacial Kaskaskia valley system, were mapped in this previous study (Cartwright and Kraatz, 1967). Figure 6 reveals that the thickest glacial deposits are associated with this preglacial valley system.

Aquifers

Cartwright and Kraatz (1967) describe two aquifers in the vicinity of the municipal well fields. An upper aquifer is said to be found only in the valleys of the present Kaskaskia River and Robinson Creek. As Cartwright and Kraatz state, "This aquifer is generally slightly more than 10 feet thick, but attains a maximum thickness of 23 feet in some places, including the vicinity of the [north] Shelbyville well field in Sec. 26, T. 11 N., R. 3 E."

A lower aquifer is associated with the buried preglacial bedrock valley described above. During glacial periods, this bedrock valley was deposited with water-yielding sediments which constitute the aquifer. According to Cartwright and Kraatz, this aquifer attains a maximum thickness of 47 feet about half a mile north of the [north] Shelbyville well field, and thins to both the north and the south. Figure 7 shows a cross section displaying both of these aquifers, the overlying and underlying tills, and the general profile of the bedrock valley transverse to its longitudinal axis. Figure 6 shows the position of the cross section.

These two aquifers are reported to be in direct contact in some parts of the study area, where the lowlands of the modern-day Kaskaskia River and Robinson Creek overlie the preglacial Kaskaskia Bedrock valley. One such area is in the vicinity of the city's north well field in Sec. 26, T. 11 N., R. 3 E. Cartwright and Kraatz further state that other points of connection may occur in an area extending about three miles south of the north well field. Figure 8 shows the total thickness of the sands and gravels comprising these aquifers. As will be described later, this mapping of the aquifers was used as a basis for defining the aquifer boundaries for the computer-based ground-water model.

Hydraulic Data from Field Activities

A network of existing wells was established in the study area, so that ground-water-level information could be collected and used in calibrating the computer model, Existing private domestic wells were surveyed or "inventoried" to determine which wells might be suitable for inclusion in a network of wells for subsequent measurements. The water-level data collected were used to construct a map of the ground-water level (or potentiometric surface) associated with the aquifer to be modelled.

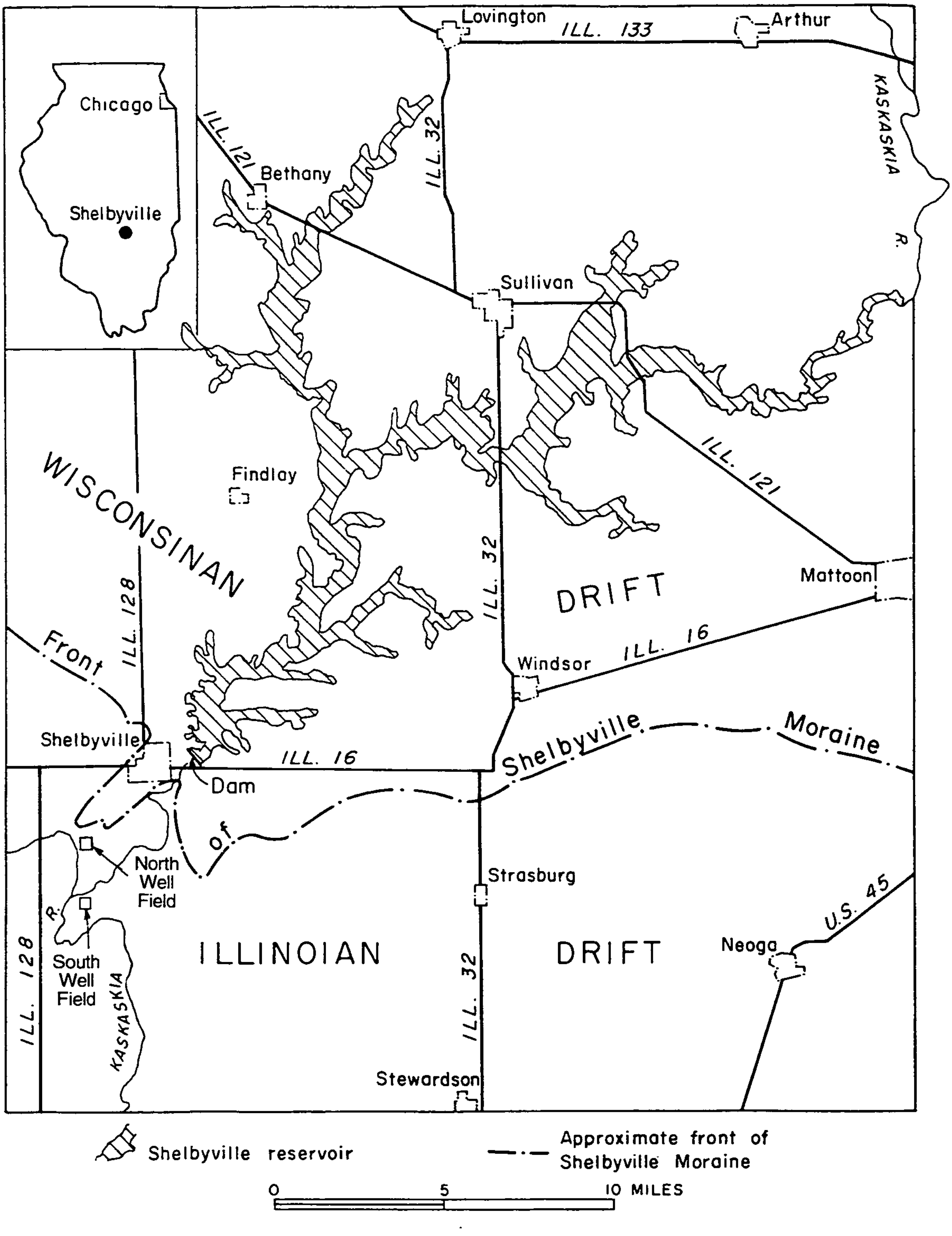


Figure 5. Surficial glacial materials in the vicinity of the study area

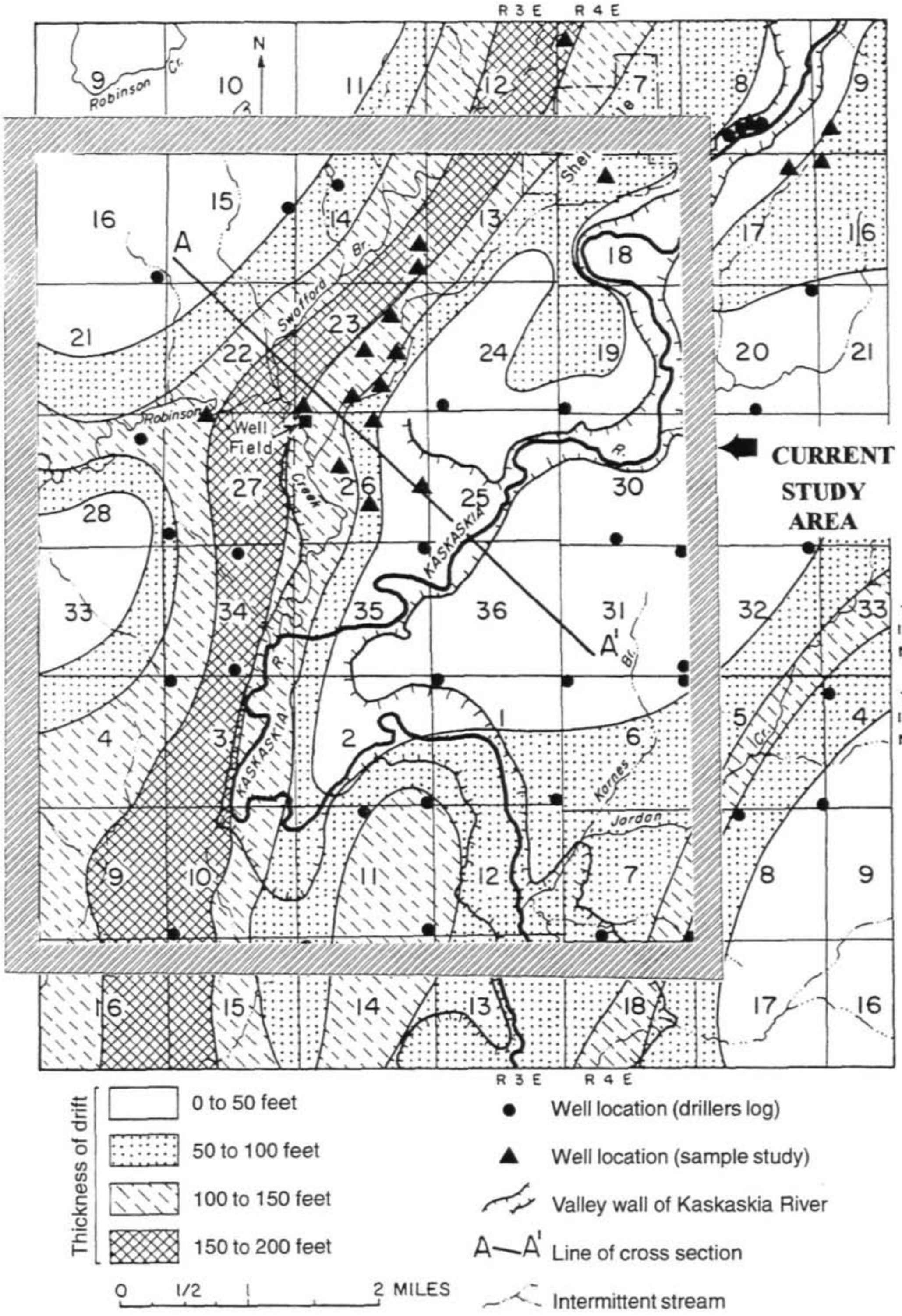


Figure 6. Thickness of glacial drift in the study area (from Cartwright and Kraatz, 1967)

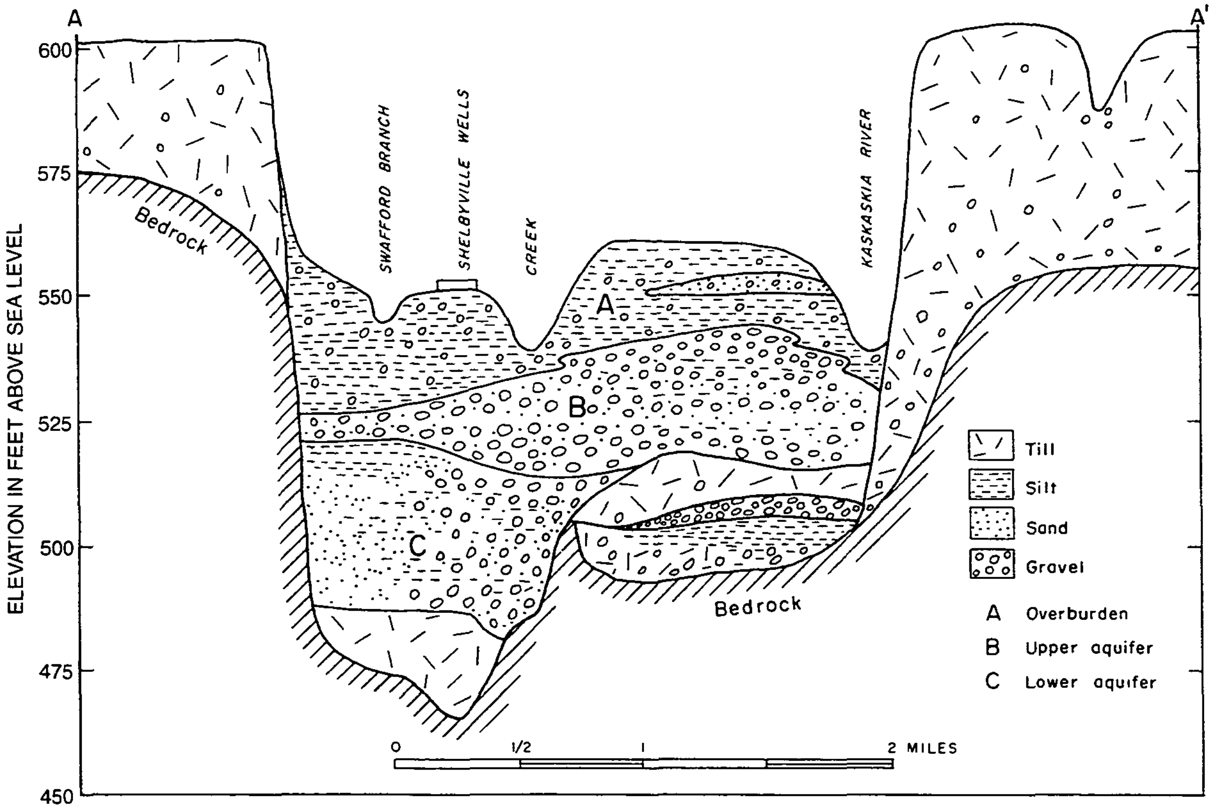


Figure 7. Generalized cross section of the aquifer at Shelbyville (from Cartwright and Kraatz, 1967)

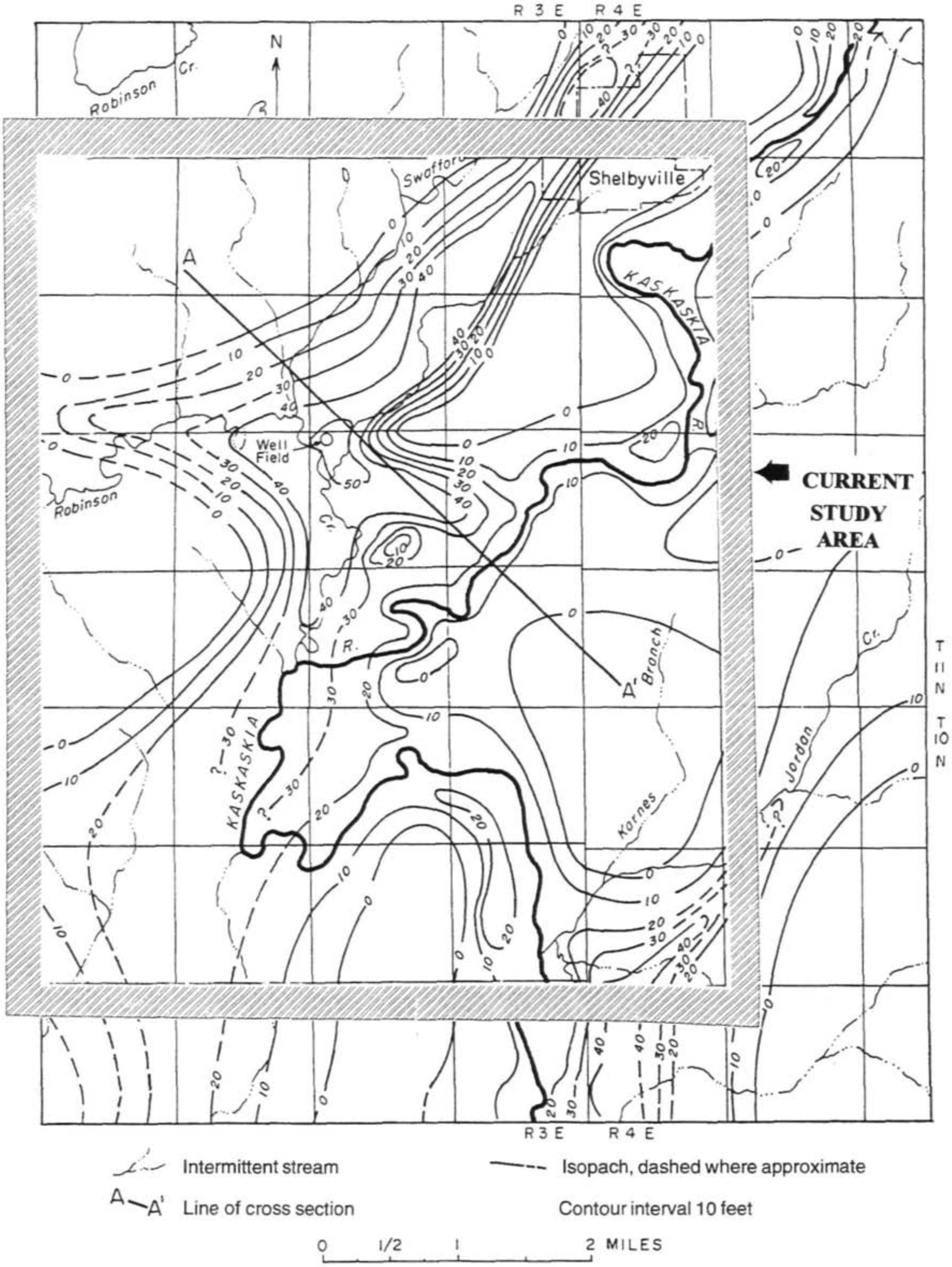


Figure 8. Total thickness of sand and gravel (from Cartwright and Kraatz, 1967)

For the wells that were determined to be physically accessible for measurement and for which the well owner had granted permission for access, information was collected regarding well location, measuring point, construction features, owner name and address, etc. This documentation will facilitate future location and measurements by others, as necessary.

Field Inventory of Existing Wells

The process of inventorying the wells to be included in the network involved both office and field work. The office work conducted prior to the actual field inventory included obtaining topographic maps, county road maps, plat books, ground-water-level record sheets, and related information for documenting available information for those wells to be inventoried. Available data for wells in the study area were also retrieved from the well-information databases maintained at the Water Survey. As it was desirable to have well-construction reports for those wells included in the network, existing well-construction reports for the study area were copied for reference during field inventory efforts. To establish a consistent routine for the collection of well and water-level information, a *Ground-Water-Level Record Sheet* (appendix A) was used to record appropriate well and water-level information during both the well inventorying and future measurements of ground-water levels.

Before the field work began, a one-page informational flyer outlining the project's goals was produced and presented to the Shelbyville City Council for their approval (appendix B). During the field inventorying work, this flyer was left at residences, if an initial visit found no one at home. This flyer was also left with cooperating well owners, in case future questions arose regarding the purpose and protocol of the study.

The field inventory was conducted on a part-time basis from approximately April 15 to May 17, 1996. Inventory work began near the center of the study area and progressed roughly concentrically outward to the study area boundaries. When permission was obtained to include a well into the well network and the well was determined to be accessible for water-level measurements, the *Ground-Water-Level Record Sheet* was completed. Additional information collected during the inventory process included the name and mailing address of the well owner or property resident, legal description and sketch of the well location, the estimated land surface at the well, and the reference or "measuring point" from which the depth-to-water measurement was taken. At the conclusion of the well inventory work, there were 65 wells in the mass measurement network. Figure 9 shows the spatial distribution of the inventoried wells, and appendix C includes a listing of all the wells in the network.

Mass Measurement of Water Levels

During June 10-14, 1996, depth-to-water measurements were taken at each well while the well was not pumping. The depth-to-water readings were then subtracted from the elevation of the measuring point for each well site, as estimated from U.S. Geological Survey (USGS) topographic maps in order to determine water-level elevations in feet above mean sea level (ft-msl).

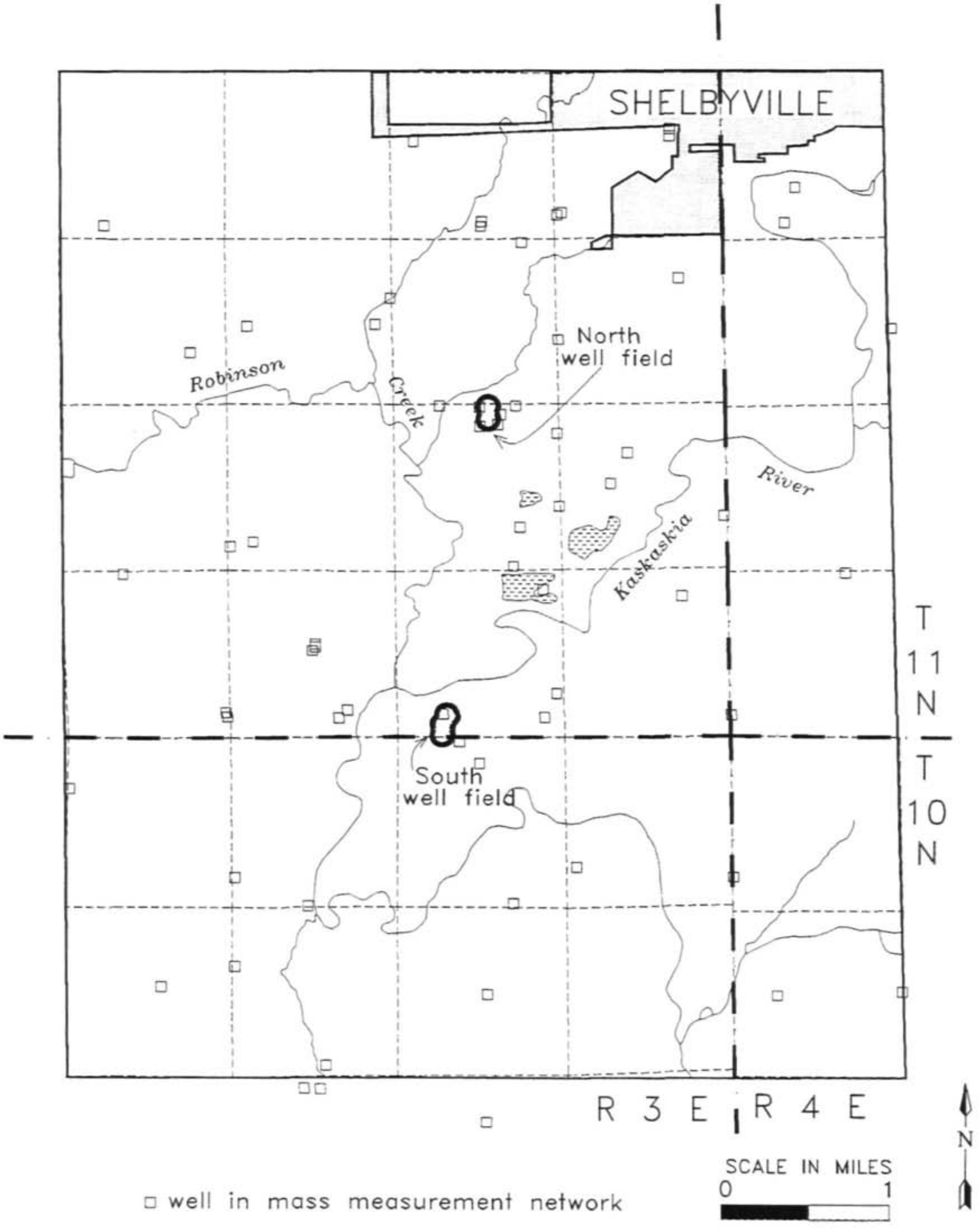


Figure 9. Location of wells used for mass measurement

When it was possible to collect a water sample and permission to do so was granted by the resident, a sample was taken. The city's engineering consultant had made prior arrangements with the Water Survey's Chemistry Division for these water samples to be analyzed for nitrate concentrations. These data are being used for a concurrent study being conducted by Shelbyville's engineering consultant.

Potentiometric Surface of the Aquifer

If an aquifer is extensively tapped by wells for domestic water supply, the water-level elevations in those wells can be used to create a map depicting the water-level surface. This surface is called the *potentiometric surface* and represents the spatially dependent elevation (or potential) to which water will rise in a properly constructed well in the aquifer. This three-dimensional potentiometric surface is displayed on paper in two dimensions by drawing contour lines signifying locations of equal "potential" or hydraulic head.

When a potentiometric surface map is created from water-level information collected in a short period of time, the result is a near instantaneous or "snapshot" view of regional water levels (potentiometric surface) free of significant temporal effects. This potentiometric surface provides an indication of the directions of ground-water movement in an aquifer and can be used as a benchmark to monitor the effects of future changes in regional ground-water withdrawals.

Not all of the wells in the mass measurement network were determined to be screened (finished) in the aquifer from which Shelbyville obtains its ground water. An examination of water-level data, available well-construction information, and well locations relative to the mapped boundaries of the aquifer resulted in 16 of the inventoried wells being categorized as finished in the subject aquifer (see figure 10). Figure 11 shows the potentiometric surface for the aquifer from which Shelbyville obtains its source of city water. (Note: this figure shows the boundaries for the aquifer as modelled, as will be discussed below.) Since only three wells in the southern half of the study area were categorized as being finished in the subject aquifer, and water-level contours had to be based largely on surface water elevations and land surface elevations from topographic maps, the potentiometric surface contour lines in these areas should be viewed as approximate (dashed). This was done similarly for the alluvial deposits associated with the Kaskaskia River in the northeastern portion of the study area, where few wells screened in the subject aquifer were found, inventoried, and measured.

Aquifer Hydraulic Properties

Extensive studies conducted in the 1960s (Cartwright and Kraatz, 1967; Walker, 1964) summarized evaluations made by the Illinois State Water Survey and the Illinois State Geological Survey regarding the aquifer hydraulic characteristics at Shelbyville's north well field. During the course of those earlier investigations, all available pumping test data were analyzed to determine the hydraulic properties (transmissivity, T; hydraulic conductivity, K; and storage coefficient, S) of the aquifer. These analyses indicated the following: T= 130,000 gallons per day per foot (gpd/ft); K=3,000 gpd per square foot (gpd/ft^2)=400 feet per day (ft/day); and S=0.10.

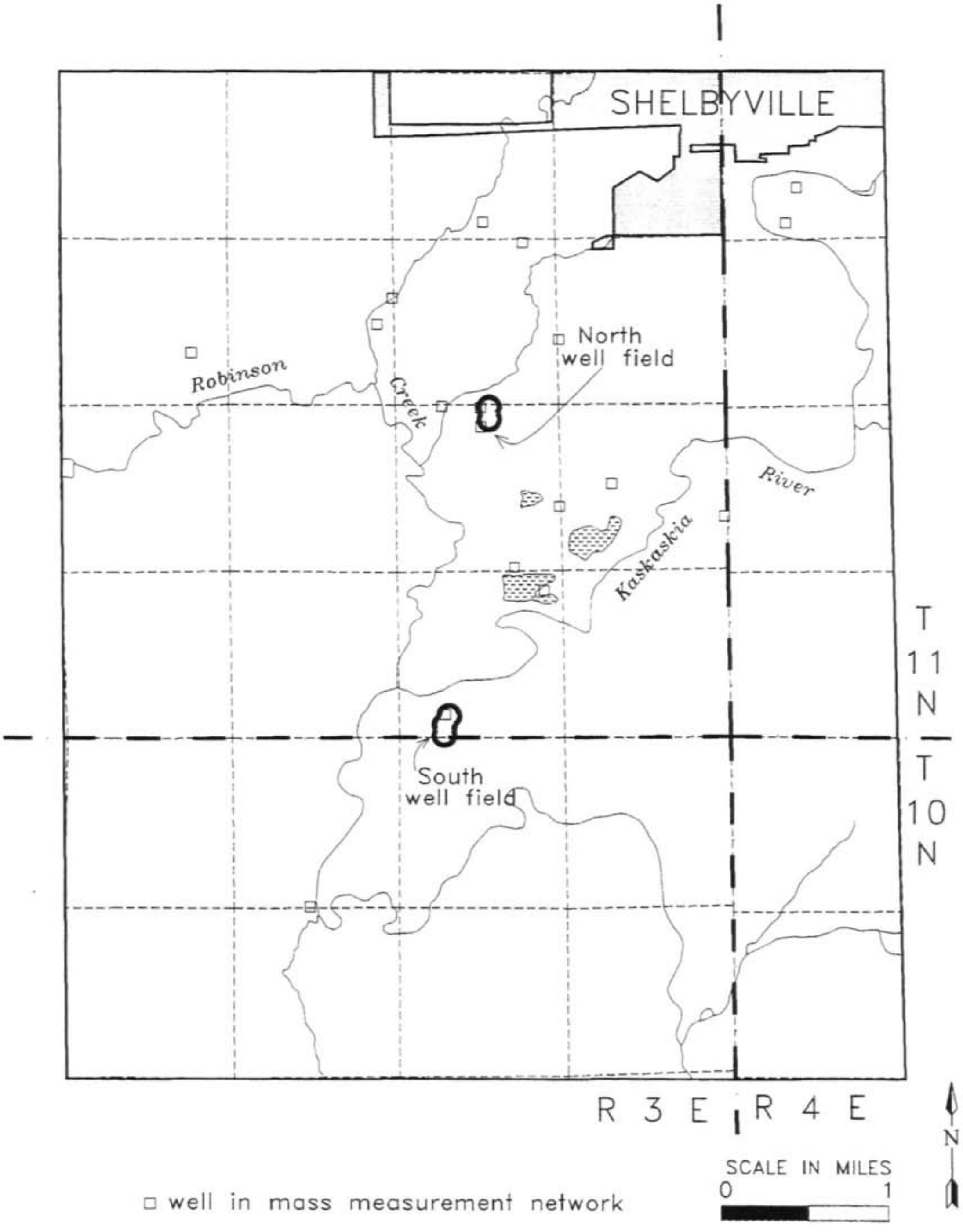


Figure 10. Wells in mass measurement network in the aquifer at Shelbyville

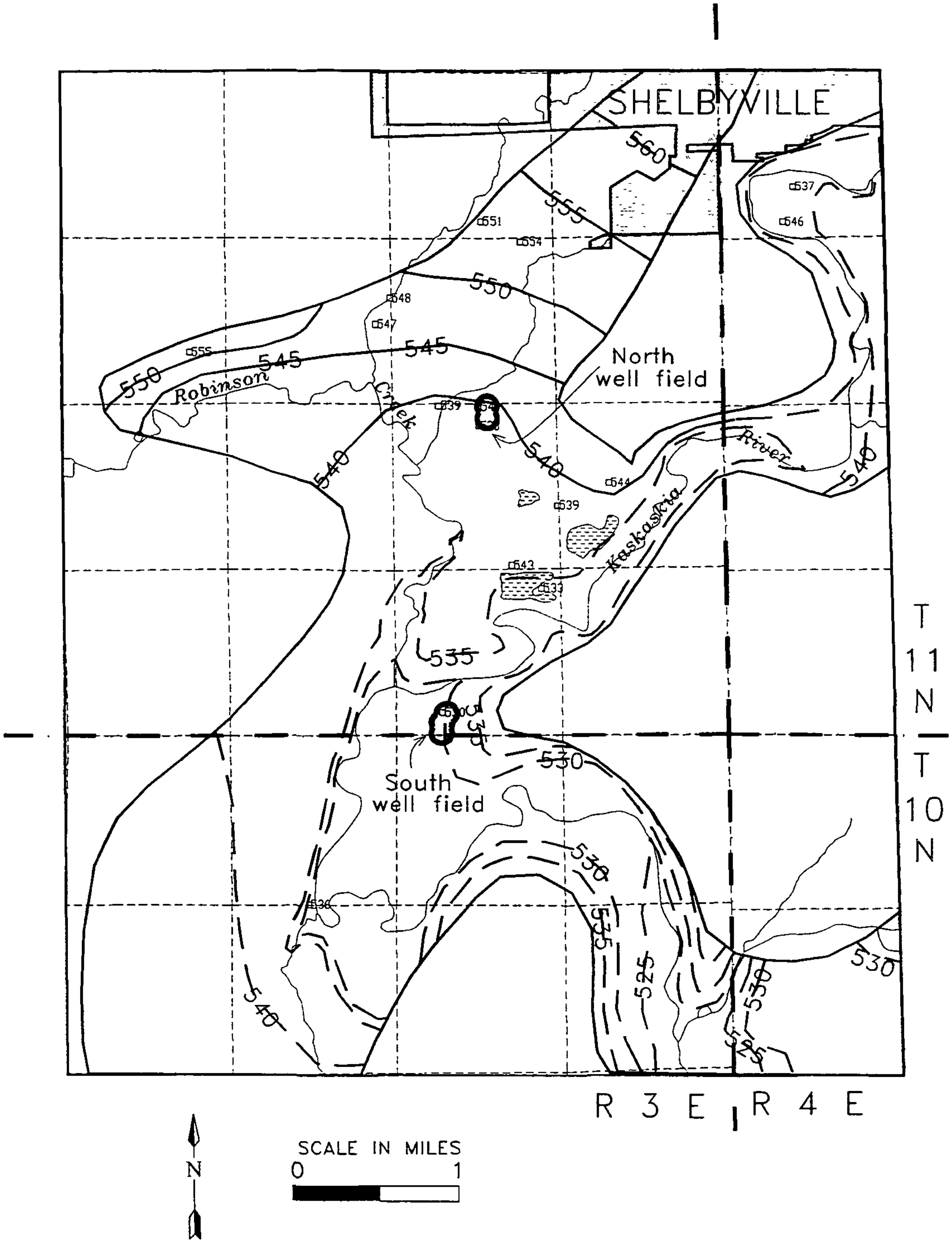


Figure 11. Potentiometric surface for the aquifer at Shelbyville

Preliminary results listed for well production tests conducted at the south well field during the period 1969-1970 (Kohlhase, 1989, unpublished) list three values for hydraulic conductivity at the south well field as follows: 1,030 gpd/ft^2, 2,750 gpd/ft^2, and 4,000 gpd/ft^2. These values compare favorably with the published values at the north well field (see previous paragraph).

GROUND-WATER FLOW MODELING AND FLOW PATH ANALYSIS

Model Design

A model of the ground-water flow was constructed for the Shelbyville study area using the software package Visual MODFLOW© (Guiguer and Franz, 1996), which is a graphical interface for the programs MODFLOW (McDonald and Harbaugh, 1988) and MODPATH (Pollock, 1994). Visual MODFLOW© enables the creation of a three-dimensional model that divides a three-dimensional study "area" into a grid of discrete cells. These cells are assigned variable values for the hydraulic parameters across the study area. Wells, rivers, and other boundary conditions are simulated by adding specified head or discharge conditions to appropriate cells. MODFLOW then calculates a hydraulic head value at each cell, using a finite-difference algorithm, with partial-differential equations that combine Darcy's Law with a mass-balance expression. The resulting hydraulic heads and flow budgets for each cell are then used as input for the program, MODPATH, which then determines the water particle flow lines for a chosen period of time. Time-related capture zones, or time-of-travel recharge areas, can then be determined for the subject water production wells.

The model grid (see figure 12) extends over the same area as the potentiometric surface map (figure 11). The grid covers an area five miles east to west and six miles south to north and is divided into 57 columns, 72 rows, and three layers. The cells vary in area from approximately 530 feet square to 265 feet square, with the smallest cells near both well fields, where hydraulic gradients are greatest and where the greatest accuracy is desired. The Kaskaskia River and Robinson Creek (and their associated tributaries) are areas where ground-water discharge occurs. These areas of ground-water discharge were simulated with river nodes in the digitized model. Water is not discharged (pumped off site) at the gravel pits between Shelbyville's north well field and the Kaskaskia River. Therefore, no depression in the potentiometric surface (water table) was expected or observed in the vicinity of these pits. For this reason little or no effect on the local ground-water flow regime is expected, and no modifications to the model cells were made at these locations.

The ground-water flow model was constructed with three layers and is based largely on information contained in the geological study by Cartwright and Kraatz (1967). This three-layer model consists of a top (till) layer, a middle (aquifer) layer, and a lower (bedrock) layer. Although Cartwright and Kraatz describe both an upper and a lower aquifer in the study area, a geological study to delineate these "separate" aquifers or any intervening till has not been conducted. As shown previously (see figure 8), what has been mapped is the *total* thickness of sand and gravel associated with both aquifers. Also, these two aquifers are reported to be in

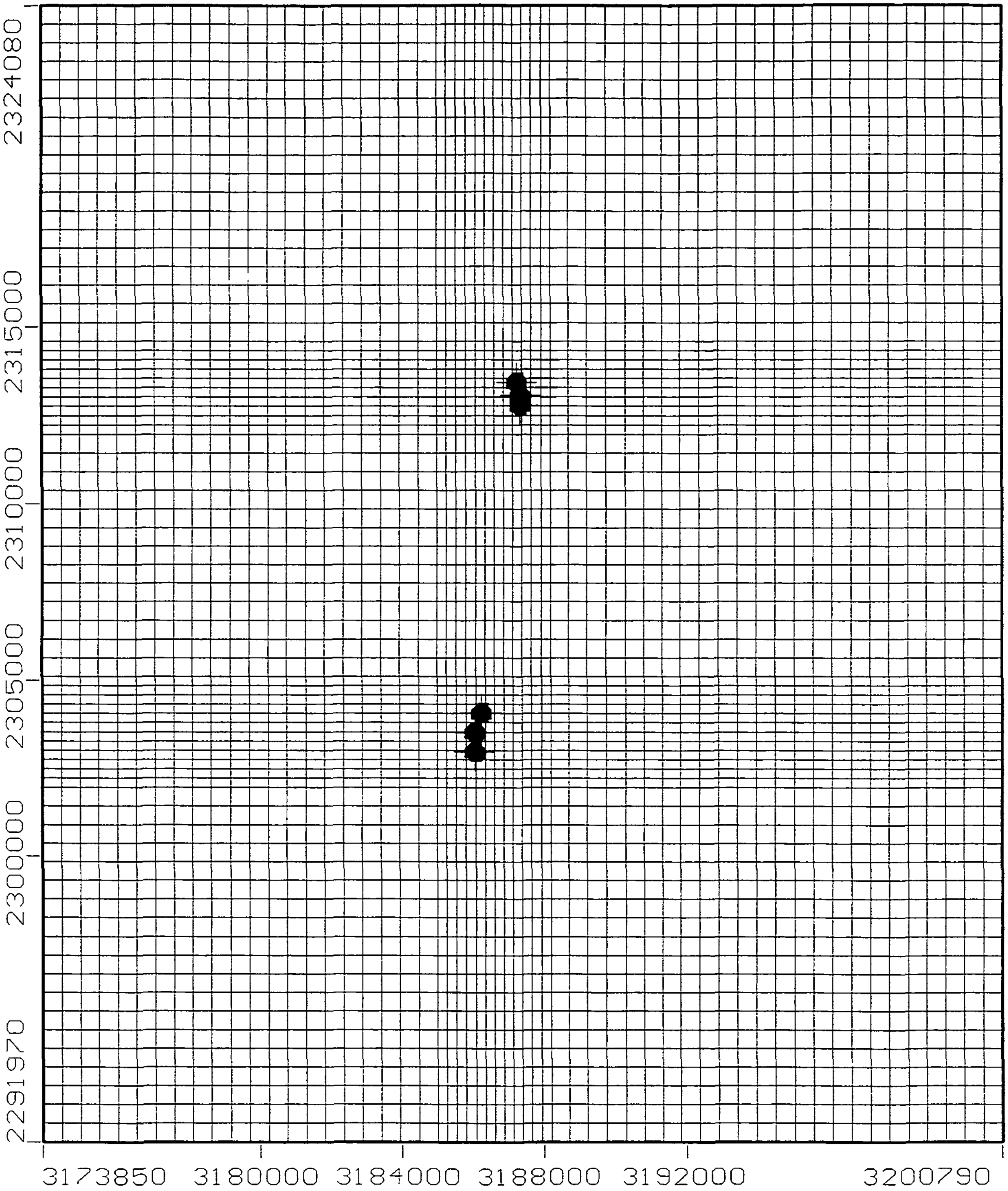


Figure 12. Model grid used for MODFLOW model (axis labels in Lambert feet)

direct contact in some parts of the study area; one such area is in the vicinity of the city's north well field. Another location is in an area extending from the city's north well field about three miles south of the north well field. This would include area surrounding the city's present-day south well field. (Note: the above referenced geological report was published in 1967, before construction of the south well field in 1968-1970.) Given the lack of a definitive physical delineation of these upper and lower aquifers, coupled with the understanding that they are hydraulically connected at numerous locations, it was concluded that these aquifers could be reasonably represented as a single layer for the purposes of the current modeling.

As was mentioned above, figure 8 was used as a basis to begin defining the horizontal extent of the aquifer for modeling. A few modifications were incorporated into the present model. First, the 10-foot (aquifer) thickness contour mapped by Cartwright (figure 8) was used as a basis in defining the aquifer boundary in the present model after field observations revealed that the 10-foot contour line closely follows the bluff line along the Kaskaskia River, which is likely the border for the shallow alluvial sands mapped at locations distant from the buried bedrock valleys. No evidence was found to indicate that the subject aquifer extends beyond this boundary. Additional changes incorporated into the present computer model included shifting the boundaries of the aquifer (as shown in figure 8) to the east in the vicinity of the north well field. This is to account for the well field being incorrectly positioned at the northwest corner of Section 26 (T. 11 N., R. 3 E.) in the geological mapping (Cartwright and Kraatz, 1967) as opposed to its actual location at the north central part of Section 26. Also, based on observations conducted in the field, an area of low hydraulic conductivity was incorporated into the model approximately one half mile northeast of the south well field to simulate an outcropping of bedrock observed in that location. Accepting these changes to the aquifer boundaries defined by Cartwright and Kraatz (1967) results in the aquifer depicted by the darker shaded area in figure 13. This figure is actually showing the two different zones of hydraulic conductivity as defined in layer 2 of the computer model. This will be discussed in more detail below.

Layer Definition

To define the three-layer model in Visual MODFLOW$^{\copyright}$ (Guiguer and Franz, 1996), three surfaces representing the top of each layer were created for input into the modeling software. Visual MODFLOW$^{\copyright}$ is able to accept these surfaces as represented by "grid" files (*.GRD) created with the contouring software package, SURFER® (Golden Software, 1994). SURFER®, as well as other contouring software packages, use as input irregularly spaced, spatially variable data and assign interpolated values to each node of a regularly spaced, user-defined grid. This "grid" file can then be used as input for a contouring algorithm to display a three-dimensional surface in two dimensions; or as in the present situation, the grid file can define a surface corresponding to the top of each layer in a multi-layered ground-water flow model.

The top of layer 1 (i.e., the land surface) was created by first manually digitizing land surface elevations from United States Geological Survey (USGS) topographic maps. In so doing, land surface contours from the topographic maps were manually smoothed to create a surface for modeling more congruous with the level of discretization (i.e., cell size 530 feet x 530 feet) used

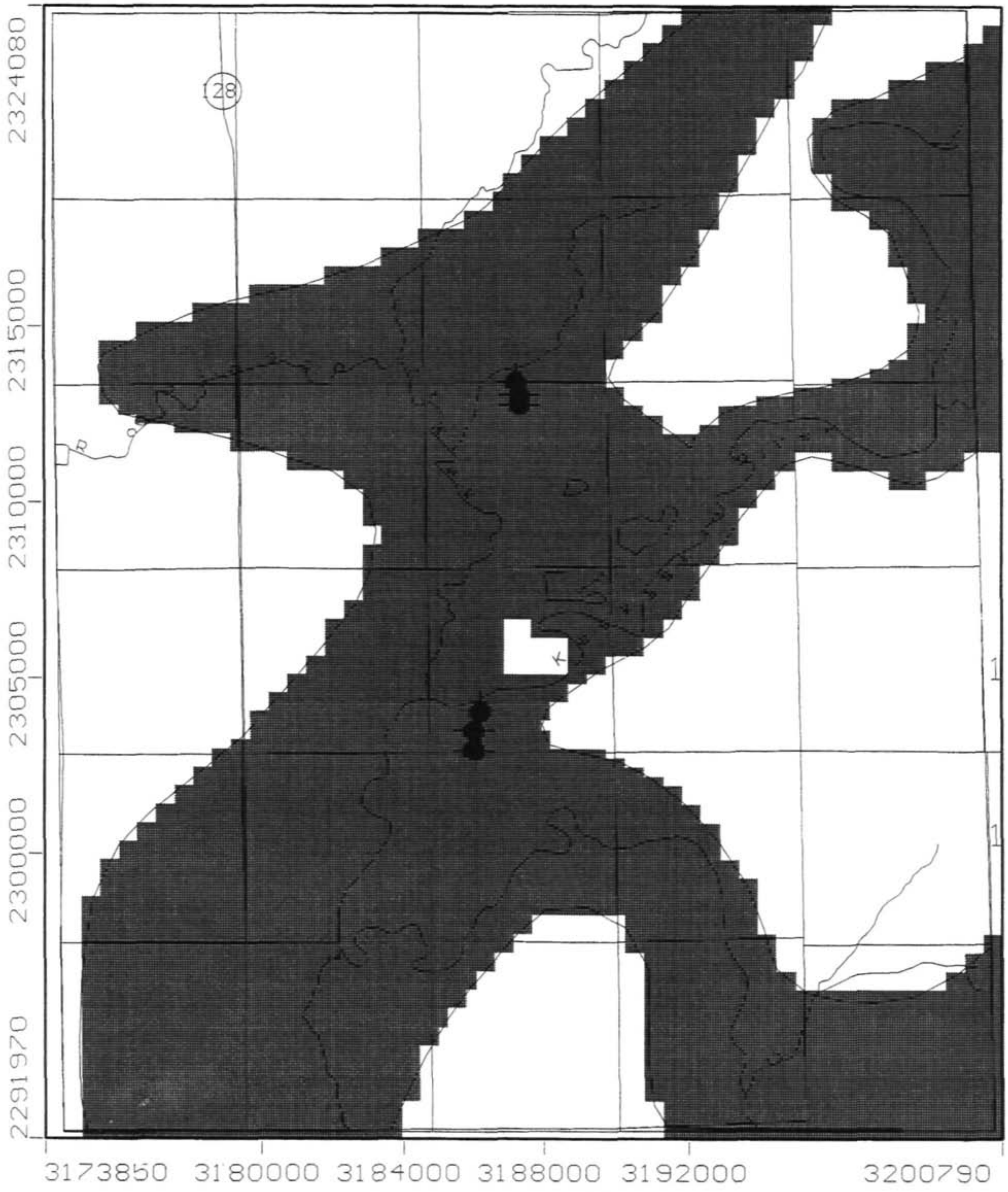


Figure 13. Horizontal extents of the aquifer used for the MODFLOW model
(dark areas represent the aquifer)

to define the model in the majority of the model domain. Figure 14 shows the surface representing the top of layer 1.

In order for the aquifer to be correctly placed at the appropriate elevation in the model domain, surfaces representing both the top and bottom of layer 2 (aquifer) were created. The surface representing the top of the aquifer was produced giving consideration to land surface topography, well log information at the city's two well fields, and the geological investigation conducted by Cartwright and Kraatz (1967). Minor changes were incorporated to reflect information available as a result of construction of the south well field and additional information gleaned during the study:

1. The thicknesses of the overlying till, as indicated on available well logs for each well field, were incorporated into the surface representing the top of layer 2. Till thicknesses at the north well field averaged approximately 10 feet, while those at the south well field were approximately 5 feet.

2. Data available as a result of construction of the south well field indicate that the aquifer materials are thicker at that location than previously mapped by Cartwright and Kraatz (1967). More specifically, the well logs at the south well field indicate a thickness of sand and gravel of approximately 55 feet, as opposed to a thickness of 20 to 30 feet as mapped previously (figure 8).

3. A well inventoried as part of this study (i.e., Well 13 in appendix C) and deemed to be finished in the Shelbyville aquifer indicates that the aquifer materials may be thicker in an area west of the north well field and along Robinson Creek. Incorporating this into the model was accomplished by extending the 530 ft-msl contour for the top surface of the aquifer to the approximate location of this well.

Figures 15 and 16 show the surfaces defined to represent the top and bottom of the aquifer, and they incorporate the considerations mentioned above. Except for the minor differences noted above, the surfaces used to define the top and bottom of model layer 2 (i.e., the aquifer) result in aquifer thicknesses corresponding closely to the interpretation mapped by Cartwright and Kraatz (figure 8). To maintain mathematical continuity in the model, the areas beyond the horizontal extents of the aquifer (light areas in figure 13) were assigned a thickness of 10 feet.

Conceptually, the top of the aquifer was modelled to correspond to the "upper aquifer" described by Cartwright and Kraatz (1967). As stated in their report, "the upper aquifer is found only in the valleys of the present Kaskaskia River and Robinson Creek...." The above description corresponds with the surface shown in figure 15, except for the 530 ft-msl contour extending northward from the north well field (i.e., toward Shelbyville). The top of the aquifer in this area conceptually corresponds to the top of the lower aquifer, as it is assumed to slope upward to the northeast in similar fashion to the surface of the bedrock valley (see figure 4).

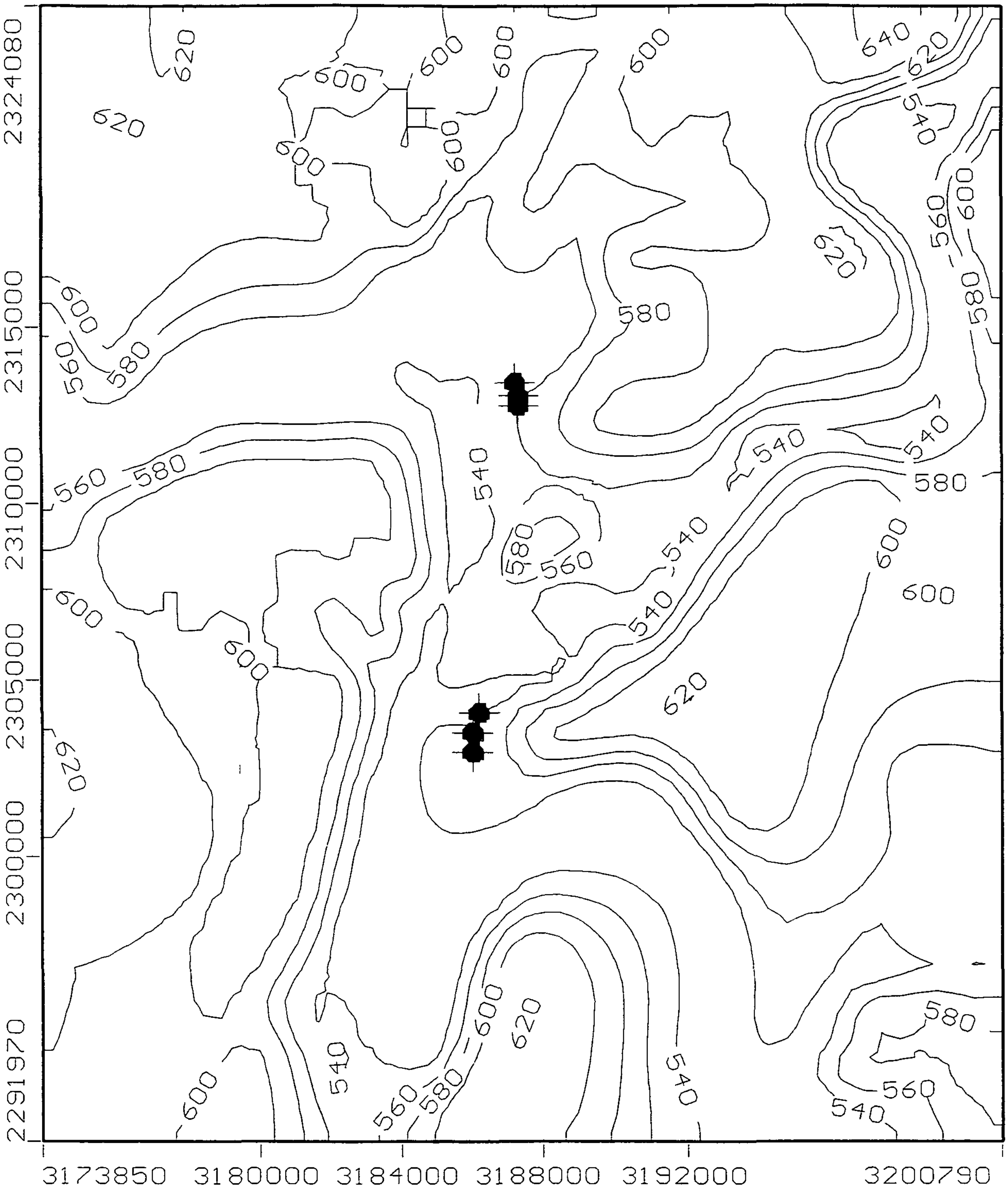


Figure 14. Top surface of layer 1 (land surface)

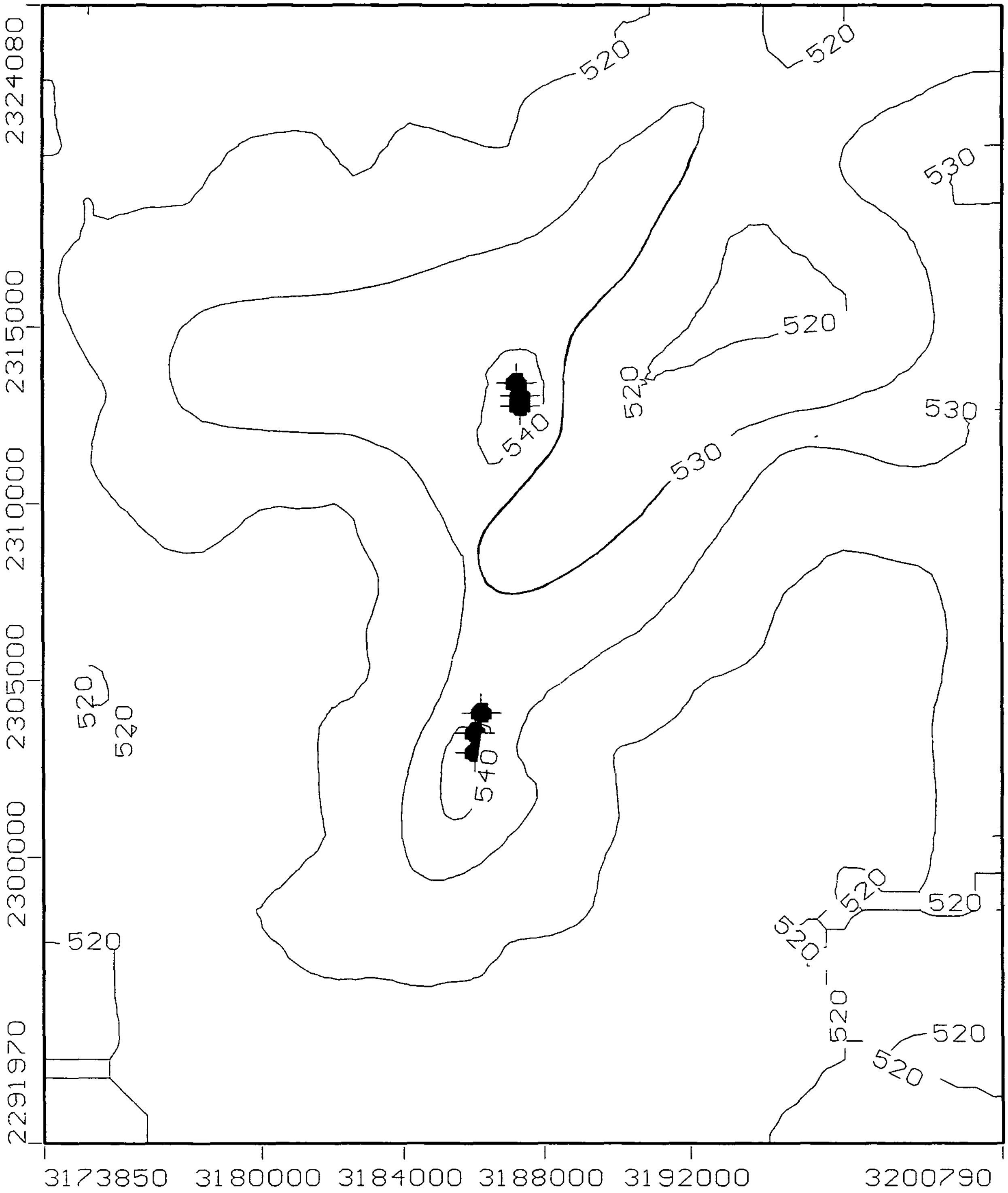


Figure 15. Top surface of layer 2 (aquifer)

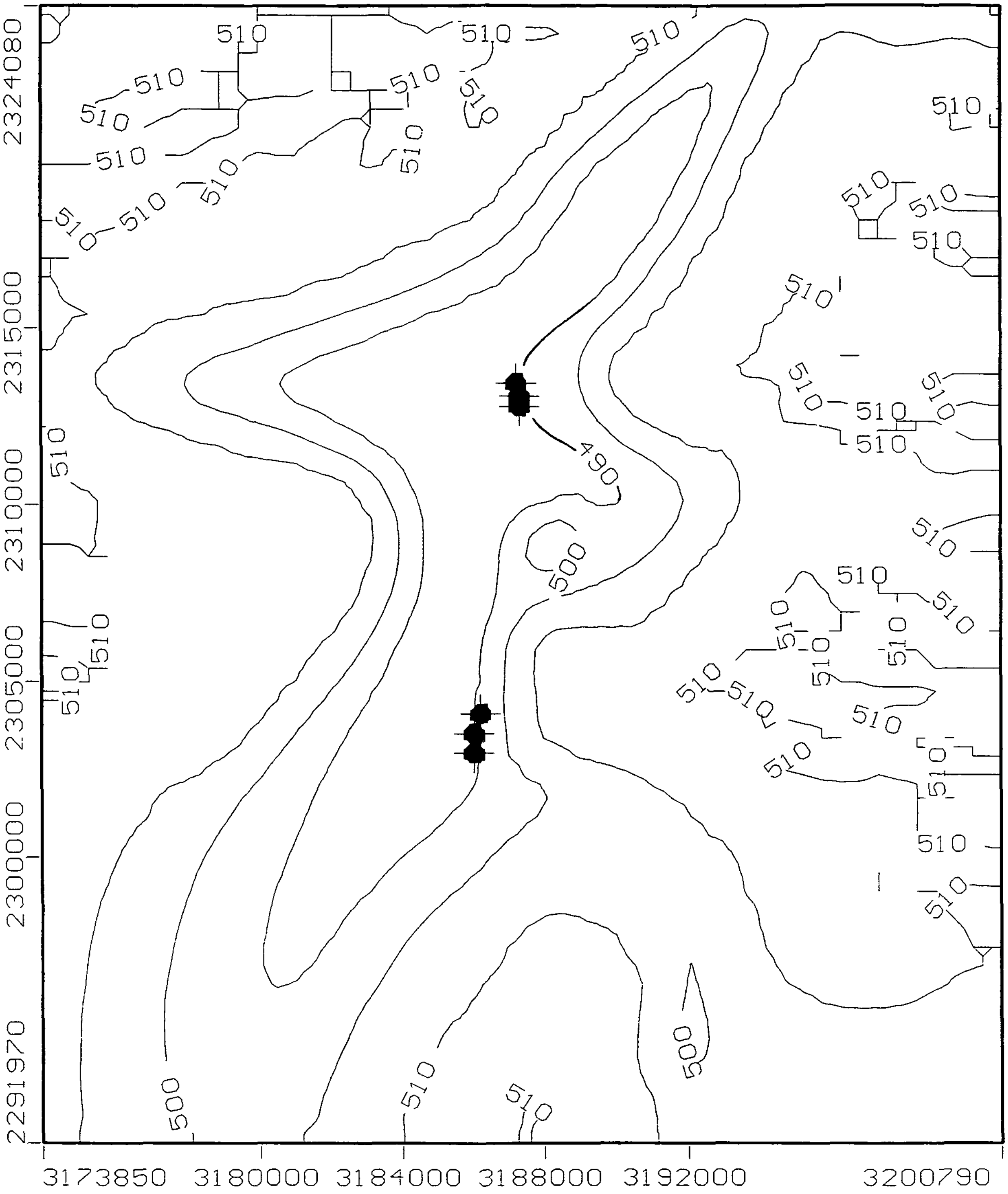


Figure 16. Bottom surface of layer 2 (aquifer)

The lower model layer (layer 3) is designed to simulate the relatively impermeable bedrock and till layers below the aquifer materials modelled in layer 2. The top of this layer corresponds to the bottom of layer 2 (aquifer) and the bottom of this layer was arbitrarily assigned an elevation of 450 ft-msl, and corresponds to the bottom of the model domain.

Hydraulic Conductivity by Layer

Two values for hydraulic conductivity were assigned in layer 1. The major portion of the layer was assigned a conductivity of 1 ft/day to correspond to a silty sand, following the description of this upper till as given by Cartwright and Kraatz (1967). Those portions of layer 1 underlying the Kaskaskia River and the lower reaches of Robinson Creek were assigned a higher conductivity, equal to that prescribed in layer 2 (i.e., 400 ft/day). The decision to do this was based on field reconnaissance work conducted on August 16, 1996, during which riverbed materials were surveyed along the reaches of both the Kaskaskia River and Robinson Creek within the study area. Figure 17 shows the portions of layer 1 in which the conductivity was changed based upon where sands and gravels were observed in the river and creek beds overlying the aquifer.

As was mentioned earlier, figure 8 was used as a basis in defining the extent of the subject aquifer in layer 2, and minor changes were incorporated into the current aquifer definition based on more recently available information. The boundary between the aquifer and the adjacent low permeability materials in layer 2 was shown in figure 13, with the darker area corresponding to the higher hydraulic conductivity (K=400 ft/day). In the areas outside the mapped boundaries of the aquifer, the hydraulic conductivity was assigned a much lower value (K=0.05 ft/day) to model the relatively impermeable bedrock and till materials beyond the boundaries of the aquifer.

Layer 3 also was assigned a hydraulic value of 0.05 ft/day to (again) simulate the relatively impermeable bedrock and till materials underlying the aquifer as modelled in layer 2.

Figure 18 is a vertical slice through the model along the grid row (east-west orientation) that contains Shelbyville Well #2 (i.e., middle well at north well field) and loosely corresponds to the geological cross section in figure 7, which had a northwest-southeast orientation, as can be seen in figure 6.

Model Calibration

The hydraulic parameters not adjusted in the calibration process were the hydraulic conductivity, K, for the aquifer layer; porosity for all three layers, and recharge value for the portion of the study area overlying the aquifer. The selected value for aquifer hydraulic conductivity, K, is based upon conclusions stated in prior hydrologic and hydrogeologic investigations (Walker, 1964; Cartwright and Kraatz, 1967), which indicated an appropriate value for K to be 3000 gpd/sq ft (400 ft/day). Values for porosity for each layer were based on conservative values, for the purposes of recharge area delineation, for silt (layer 1), sand (layer 2), and limestone (layer 3) materials (Freeze and Cherry, 1979, p. 37). The recharge for the area

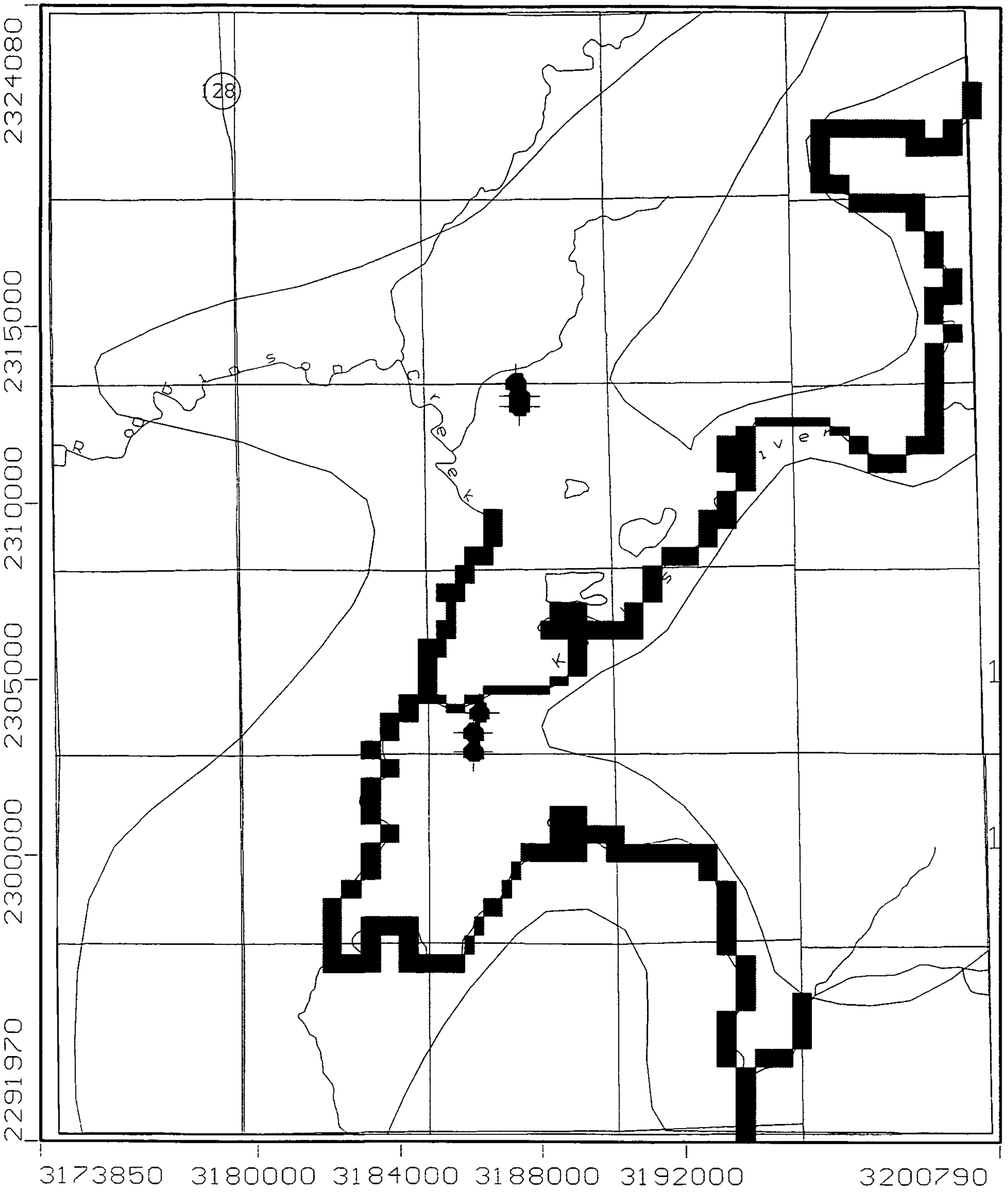


Figure 17. Conductivity zones for layer 1
(darker areas correspond to higher hydraulic conductivity)

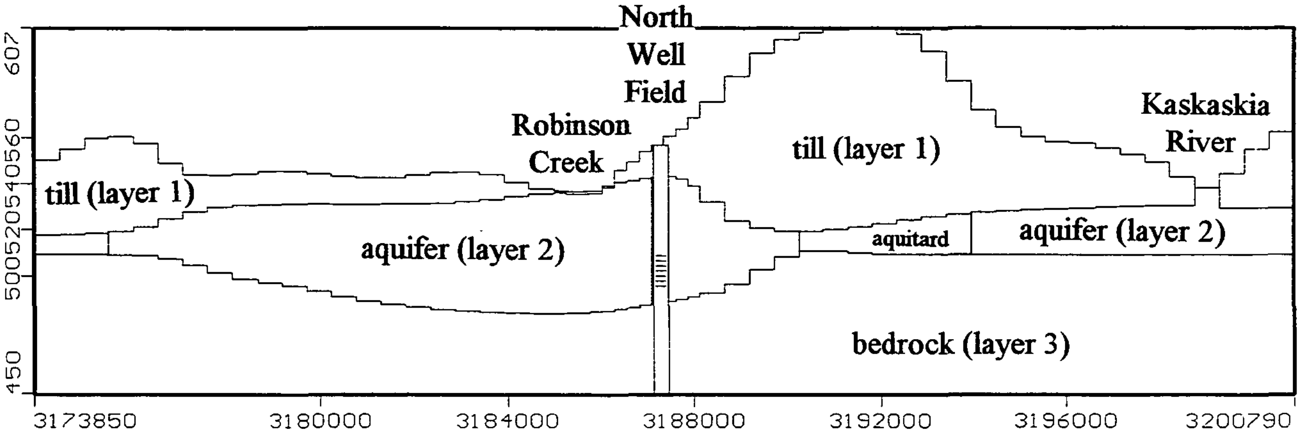


Figure 18. East-west cross section through Shelbyville well #2

of land overlying the aquifer was based upon published values for similar type aquifers in Illinois (Walton, 1965), and follows prior estimates for recharge (350,000 gpd/sq mi, or 7.35 in./yr) for the aquifer supplying Shelbyville's ground water (Visocky, 1969).

The model was calibrated to the water levels measured during June 10-14, 1996. Only those wells completed in the aquifer from which Shelbyville obtains its water were used in this calibration. Additional considerations included finding reasonable values of hydraulic conductivity for layers 1 and 3 and a recharge rate for that portion of layer 1 that overlies the aquitard materials such that the resulting hydraulic heads in layer 1 were reasonable (i.e., they did not exceed approximate land surface elevations). Table 2 lists the hydraulic and physical properties of the model layers following calibration of the model, and figure 19 shows the resulting potentiometric surface map for the aquifer supplying Shelbyville's ground water corresponding to a pumping condition with each of the three wells at the north well field operating at 174 gpm. This condition was chosen to simulate operation of the well fields during the time period of the mass measurement of water levels.

Table 2. Hydraulic Parameters Used in the Shelbyville Ground-Water Flow Model

Hydrogeologic unit	*Model layer*	*Hydraulic conductivity (ft/day)*	*Porosity (%)*	*Top elevation (ft-msl)*	*Bottom elevation (ft-msl)*	*Recharge (in./yr)*
surficial till	1 (upper)	1	25	535 to 620	520 to 540	7.35 (over aquifer) 0.5 (over aquitard)
aquifer/ aquitard	2 (middle)	400 (aquifer) 0.05 (aquitard)	25(aquifer) 5 (aquitard)	520 to 540	490 to 510	N/A
bedrock	3 (lower)	0.05	5	490 to 510	450	N/A

Figure 20 displays the correlation between the water levels (heads) obtained via the computer model and the water levels measured in the field at those wells deemed to be finished in the subject aquifer. The mean error for the 16 wells is -4.29 feet, while the mean absolute error is 4.93 feet and the root mean squared error is 5.94 feet. A more rigorous calibration of this model would require significant additional expenditures by Shelbyville for a more detailed geological investigation to better delineate the boundaries of the aquifer and aquitard materials and to better define the physical properties of these materials. Additional pumping tests to obtain better estimates of aquitard and aquifer hydraulic and physical properties would also be necessary, as would the construction of additional observation wells in the subject aquifer.

Particle Tracking Analysis

To approximate the recharge area of the Shelbyville well fields, the results of the ground-water flow model were used as input for the post-processing program MODPATH. This

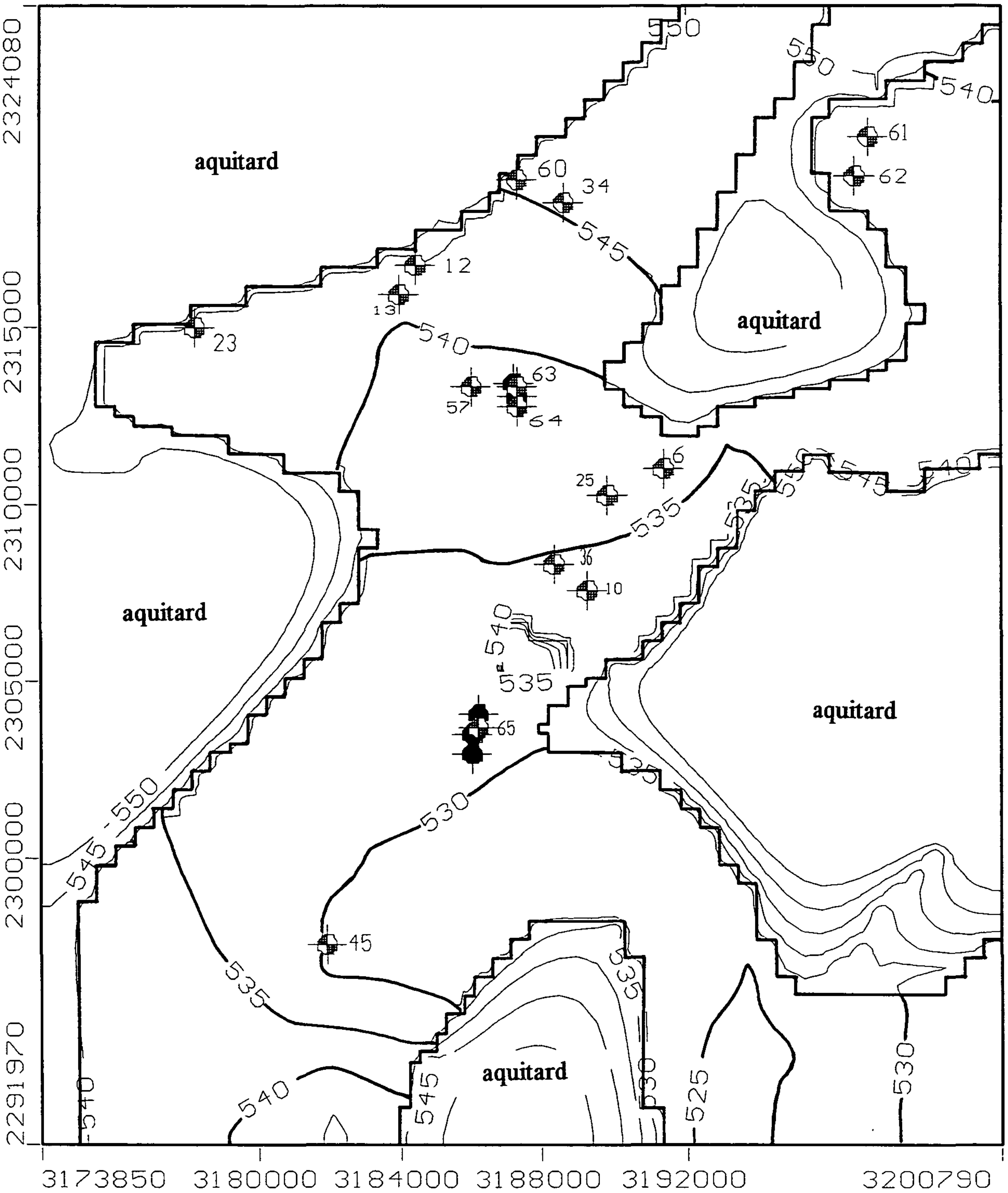


Figure 19. Potentiometric surface of the aquifer at Shelbyville after model calibration

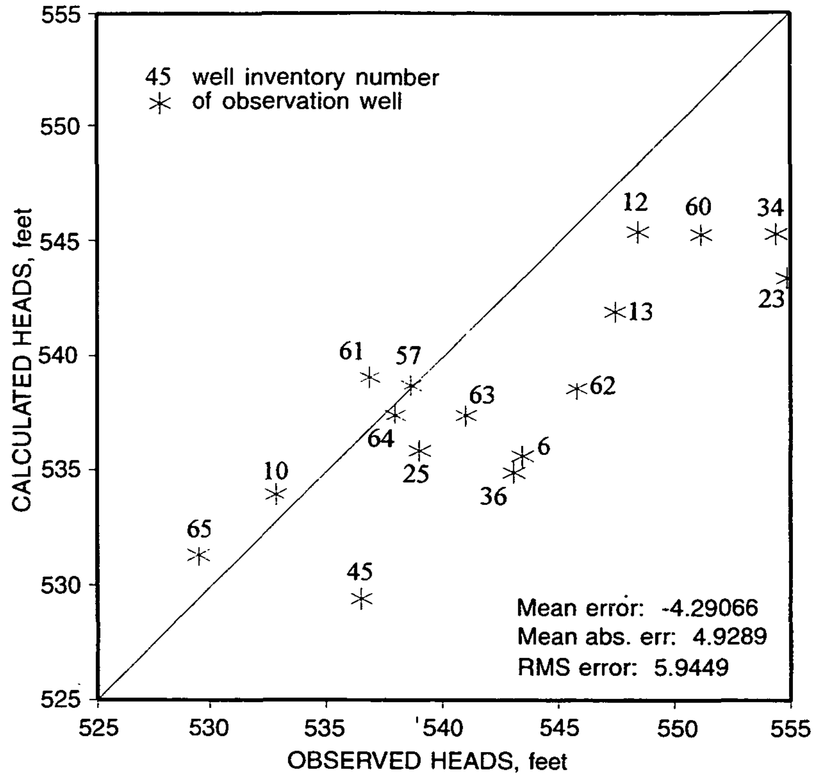


Figure 20. Scatter plot showing the differences between measured and calculated head at each "observation" well finished in the aquifer

program tracks particles of water through the steady-state ground-water flow field in the downgradient forward direction. Conversely, by reversing this tracking protocol, MODPATH can trace the water particles upgradient to their source for a given time period. By placing several particles in the cells very near the production wells, a capture zone for the given time period can be determined by connecting the endpoints of the "reverse-tracked" particle paths. Such a result is known as a time-related recharge area.

Recharge Area Determinations

Time-related recharge areas were determined for the two Shelbyville well fields for varying pumping conditions. For the pumping rates used in the following simulations, it was observed that the calculated time-based recharge areas for the north well field were independent of the operation of the south well field, and vice versa. Stated more succinctly, the effects due to pumping at one well field are not observed at the other.

Pumping rates utilized in the model were chosen based on past average daily pumpages for Shelbyville and assume that the total pumpage is approximately evenly split between both well fields. Table 3 shows the past 10-year pumpage history for the city and reflects that combined pumpages have ranged between 710,000 and 757,000 for the three most recent years of record.

Table 3. Historic Total Pumpage at Shelbyville

Year	*Average daily ground-water withdrawals (gpd)*
1985	639,000
1986	530,000
1987	691,000
1988	756,000
1989	553,000
1990	540,000
1991	756,000
1992	675,000
1993	710,000
1994	720,000
1995	757,000

The first recharge areas to be delineated were calculated based on a total average daily pumpage of 750,000 gallons (375,000 gpd per well field). This pumping rate was chosen in an attempt to best approximate the current level of ground-water withdrawals by Shelbyville. Figure 21a shows the recharge areas for this pumping rate and for 1-, 2-, 5-, and 10-year time periods in the context of the entire study area. Figures 21b and 21c show the recharge areas on an enlarged scale for the north and south well fields individually at this same pumping rate. On these three figures and the additional figures to follow, the time marks (arrows) nearest the wells

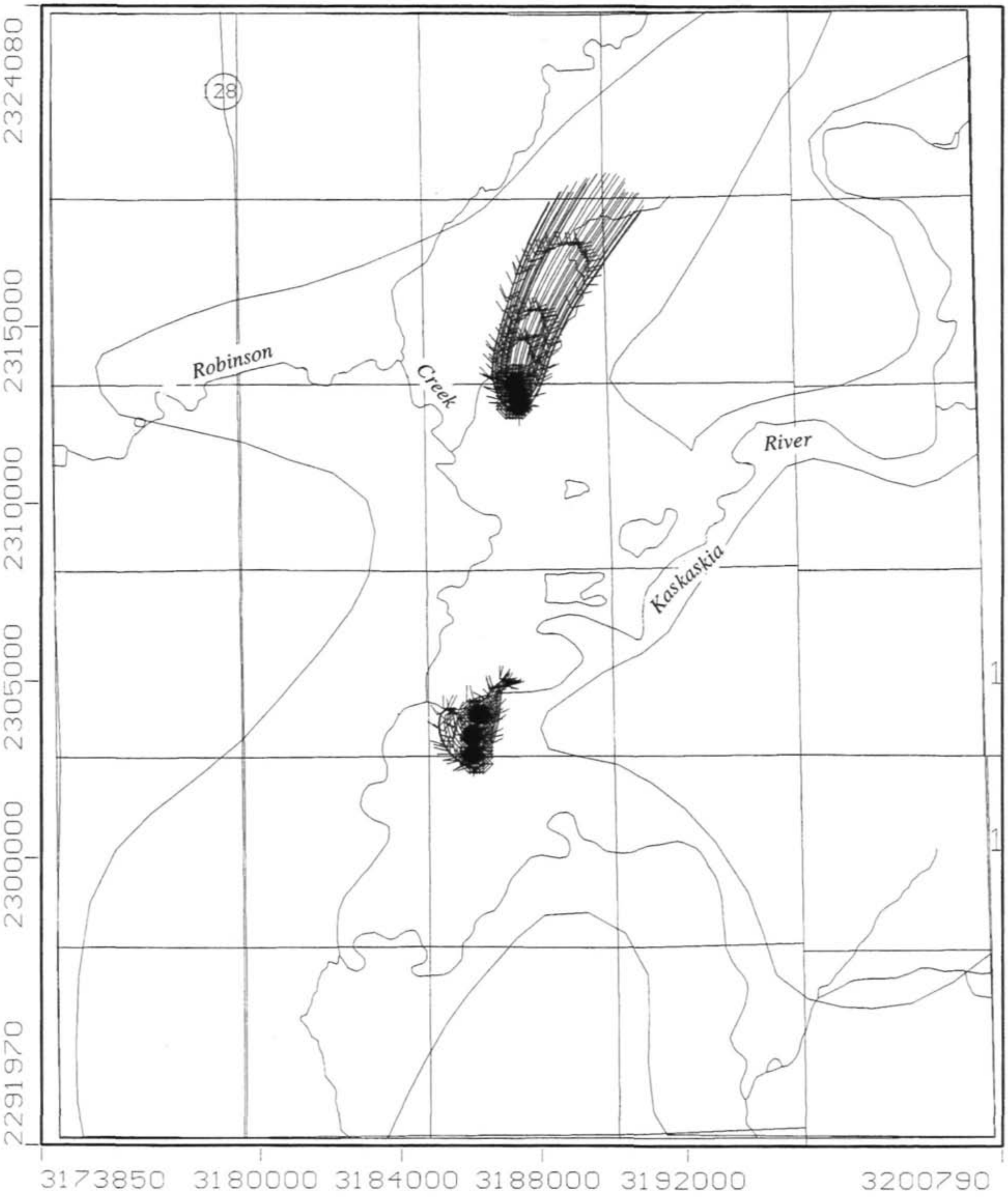


Figure 21a. 1 -, 2-, 5-, and 10-year recharge areas for total ground-water withdrawal of 750,000 gpd

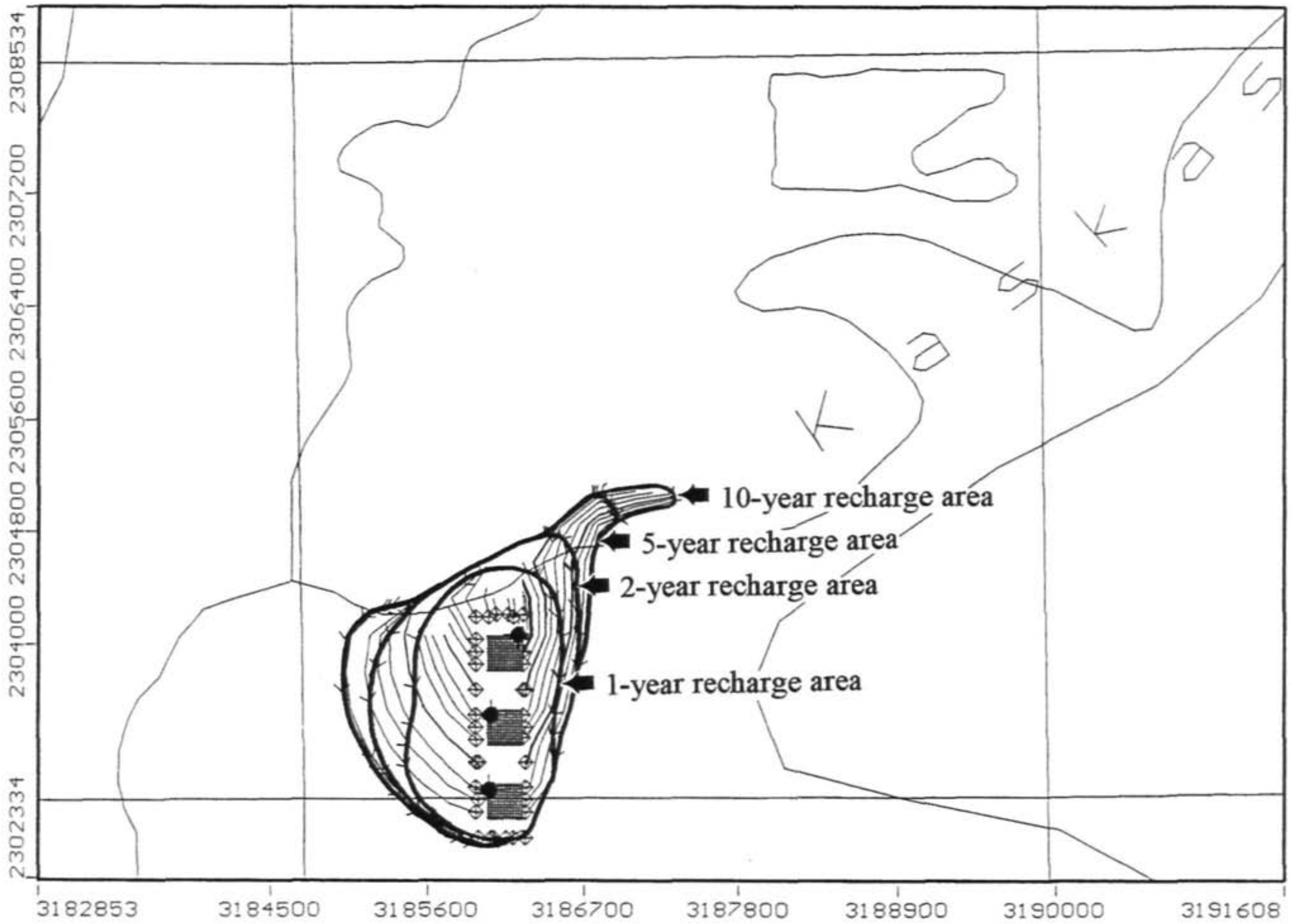


Figure 21b. 1-, 2-, 5-, and 10-year recharge areas for ground-water withdrawal of 375,000 gpd at north well field

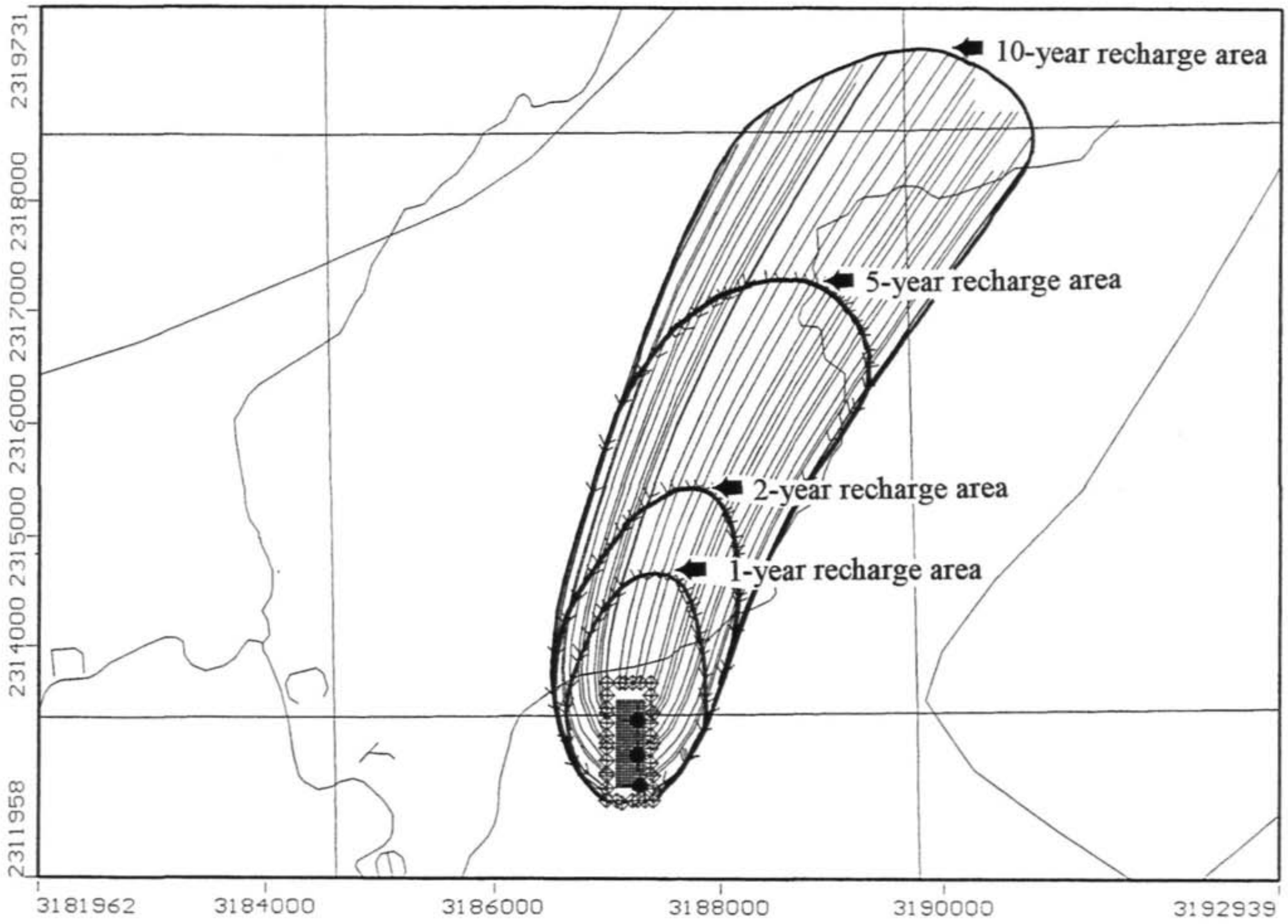


Figure 21c. 1-, 2-, 5-, and 10-year recharge areas for ground-water withdrawal of 375,000 gpd at south well field

correspond to a 1-year time-of-travel recharge area. Proceeding further out from the wells, the next two sets of time marks correspond to 2- and 5-year recharge areas, respectively, and the pathlines extend outwardly to a 10-year time-of-travel recharge area.

For the approximate current level of municipal pumpage of 750,000 gpd (375,000 gpd per well field on average) the 1-, 2-, 5-, and 10-year recharge areas at the *north well field* extend upgradient (north-northeast) approximately 0.32,0.45, 0.87, and 1.3 mi, respectively, from the center of the well field. The width of the recharge area at the north well field is approximately 0.22 mi (east to west) at the well field and expands to approximately 0.32 mi where the 10-year time-of-travel pathlines terminate. Notably, as simulated pumpages increase to 1.5 mgd (i.e., 750,000 gpd at each well field), the pathlines do not extend significantly further upgradient, but the recharge areas do expand transverse to the flow pathlines (i.e., to the east and west), effectively creating a "wider" recharge area.

For the approximate current level of municipal pumpage (375,000 gpd per well field on average) the recharge areas at the *south well field* are roughly oval in shape and centered around the well field. Due to the apparent recharge effects of the Kaskaskia River, the 1- and 2-year recharge areas appear to effectively terminate at the river (figure 21c). For the 5- and 10-year recharge areas, there are indications that the recharge areas may extend beyond the river, but only in a very localized area in the northeast corner of the recharge areas. Even for the 10-year period, the calculated recharge areas do not extend beyond approximately 0.4 mi from the center of the well field.

So that the effects of differing pumping rates can be observed, the model was run for total average daily pumping rates of 600,000 gpd, 700,000 gpd, 800,000 gpd, 900,000 gpd, 1 mgd, and 1.5 mgd, split evenly between the two well fields. Figures 22-27 show the results of these respective modeling runs.

SUMMARY

During the course of this study, a network of wells was established from existing private domestic wells and observation wells associated with Shelbyville's municipal well fields. Water-level information was obtained from this network of wells during June 10-14, 1996, and a potentiometric surface map was created from these data for the aquifer that Shelbyville uses as its source of municipal water supply.

A ground-water flow model was developed for the aquifer system in the vicinity of the two municipal well fields. The development of this model was based on available geological information gleaned from existing geologic and hydrologic reports and supplemented with more recently available basic data (well logs) from the construction of the newer (south) municipal well field. This model was then calibrated using *modeled* pumping conditions congruous with the *actual* pumping conditions that Shelbyville was using at the time of the mass measurement of water levels.

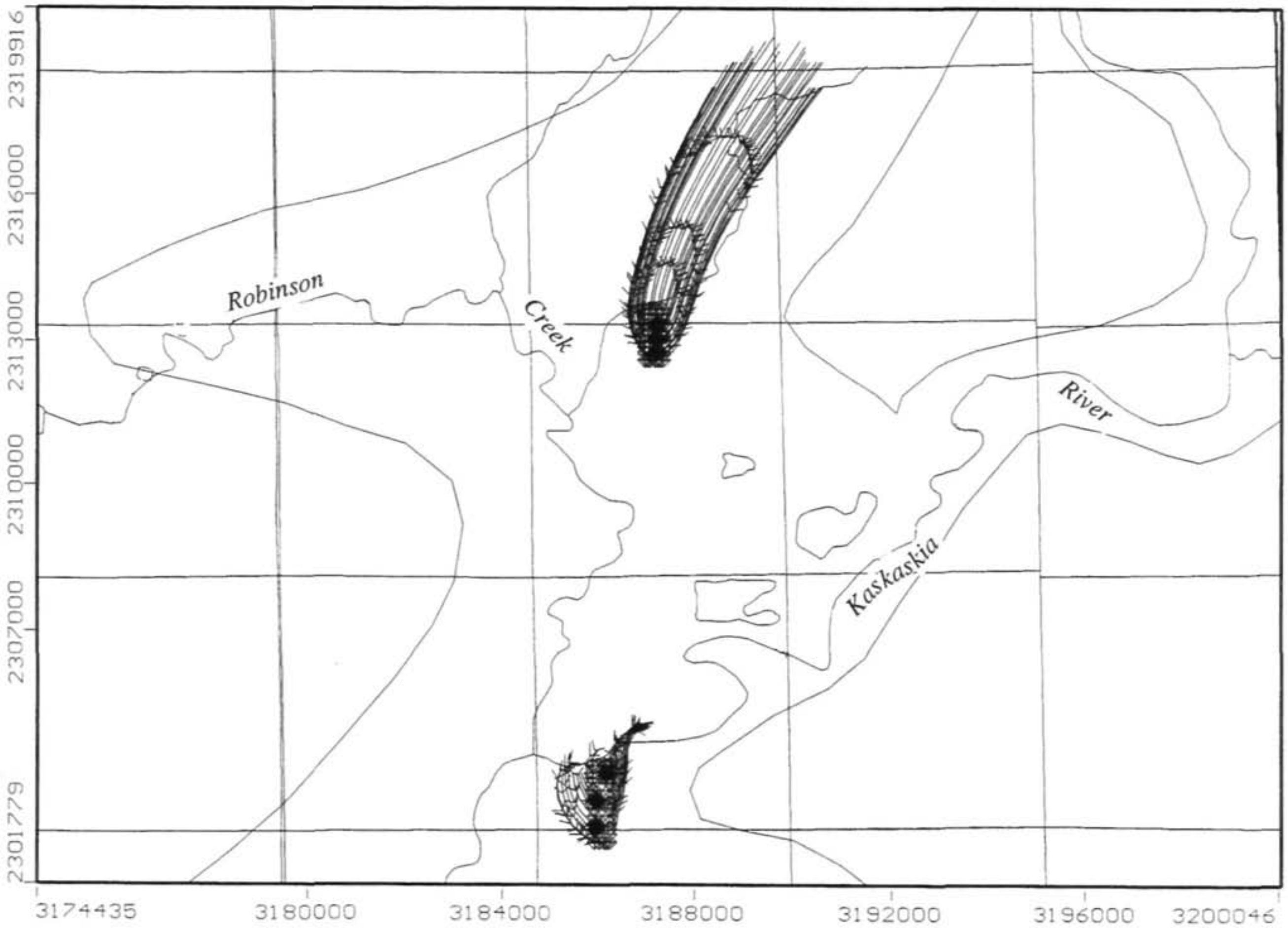


Figure 22a. 1-, 2-, 5-, and 10-year recharge areas for total ground-water withdrawal of 600,000 gpd

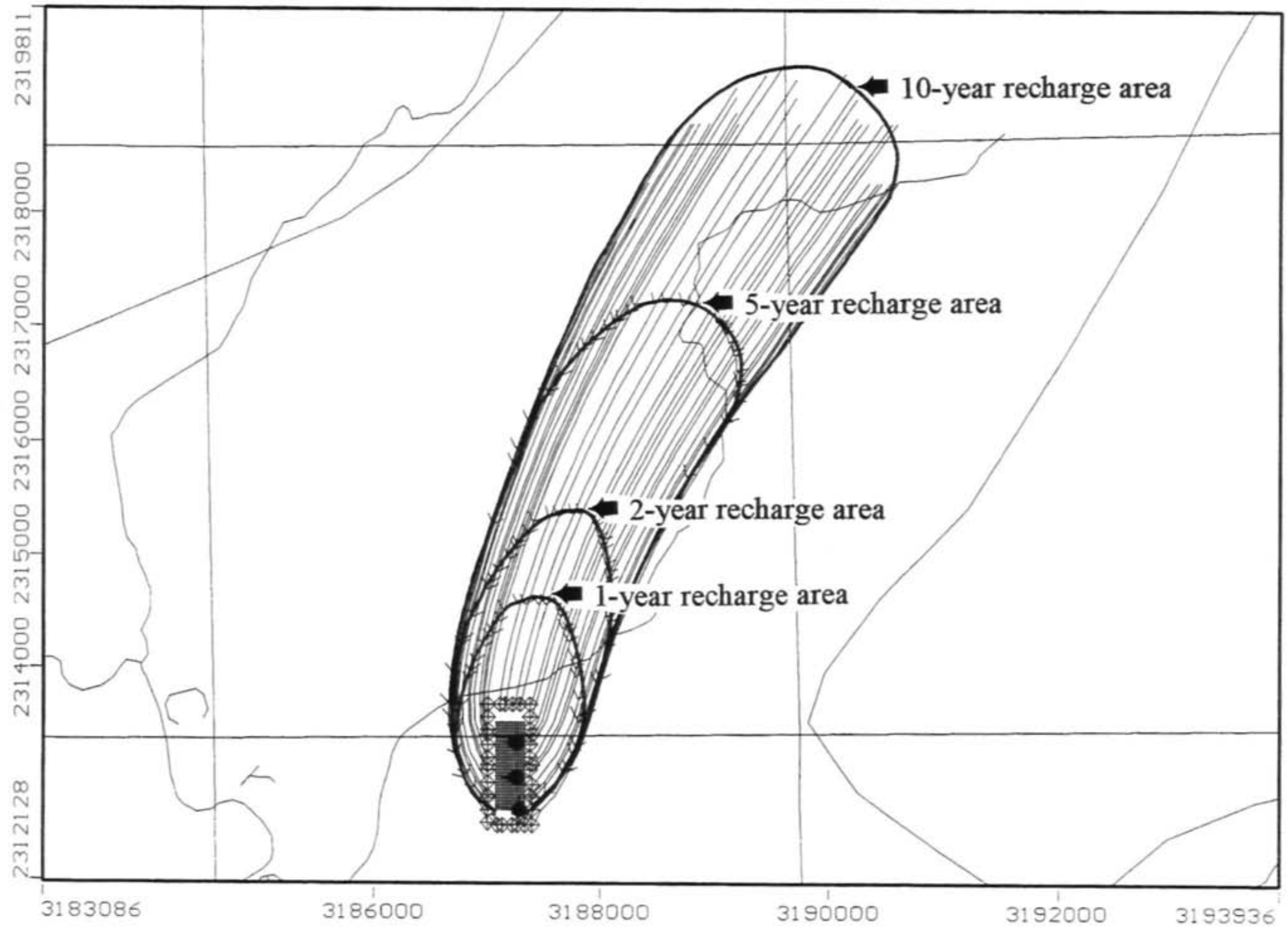


Figure 22b. 1-, 2-, 5-, and 10-year recharge areas for ground-water withdrawal of 300,000 gpd at north well field

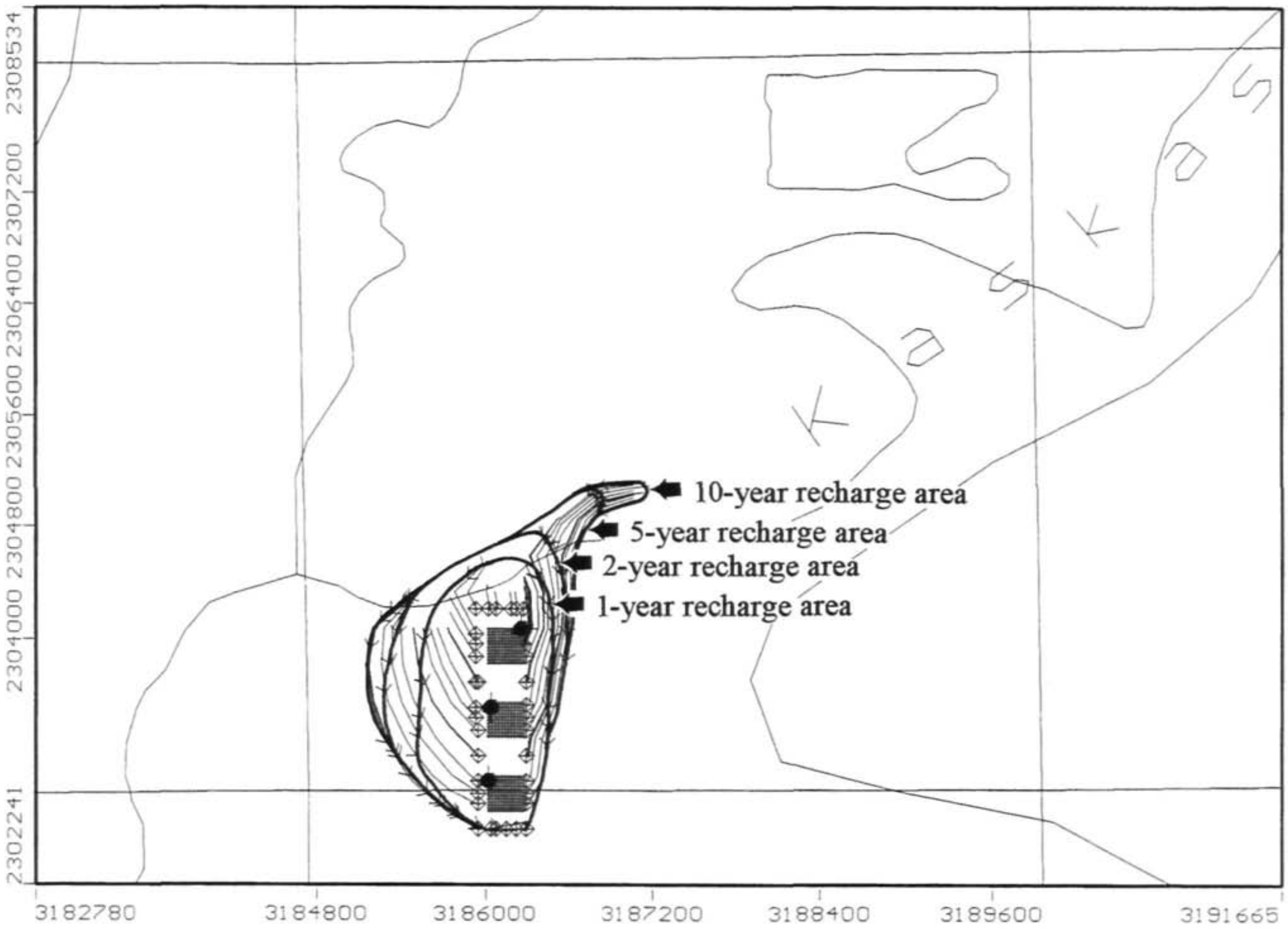


Figure 22c. 1-, 2-, 5-, and 10-year recharge areas for ground-water withdrawal of 300,000 gpd at south well field

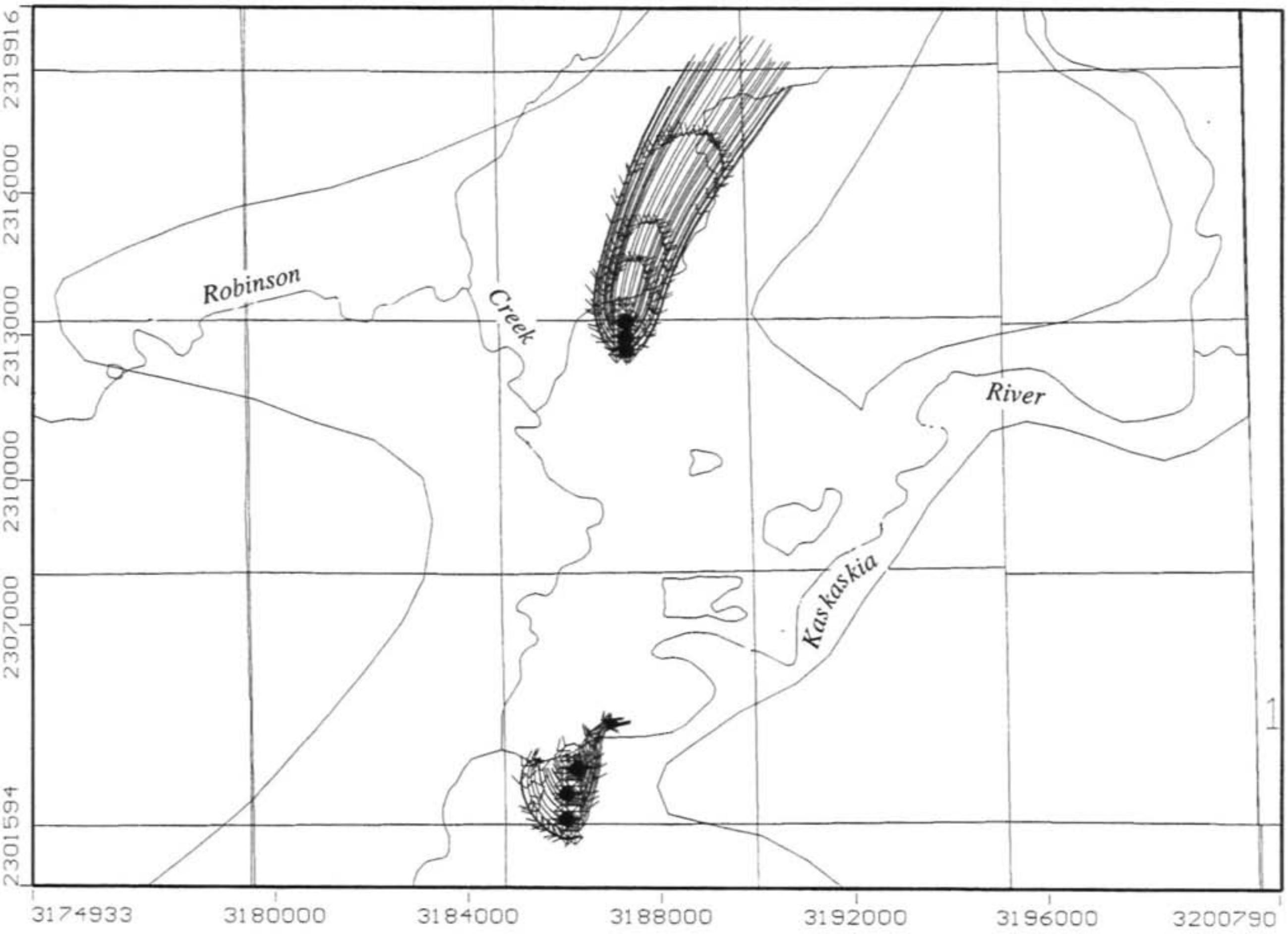


Figure 23a. 1-, 2-, 5-, and 10-year recharge areas for total ground-water withdrawal of 700,000 gpd

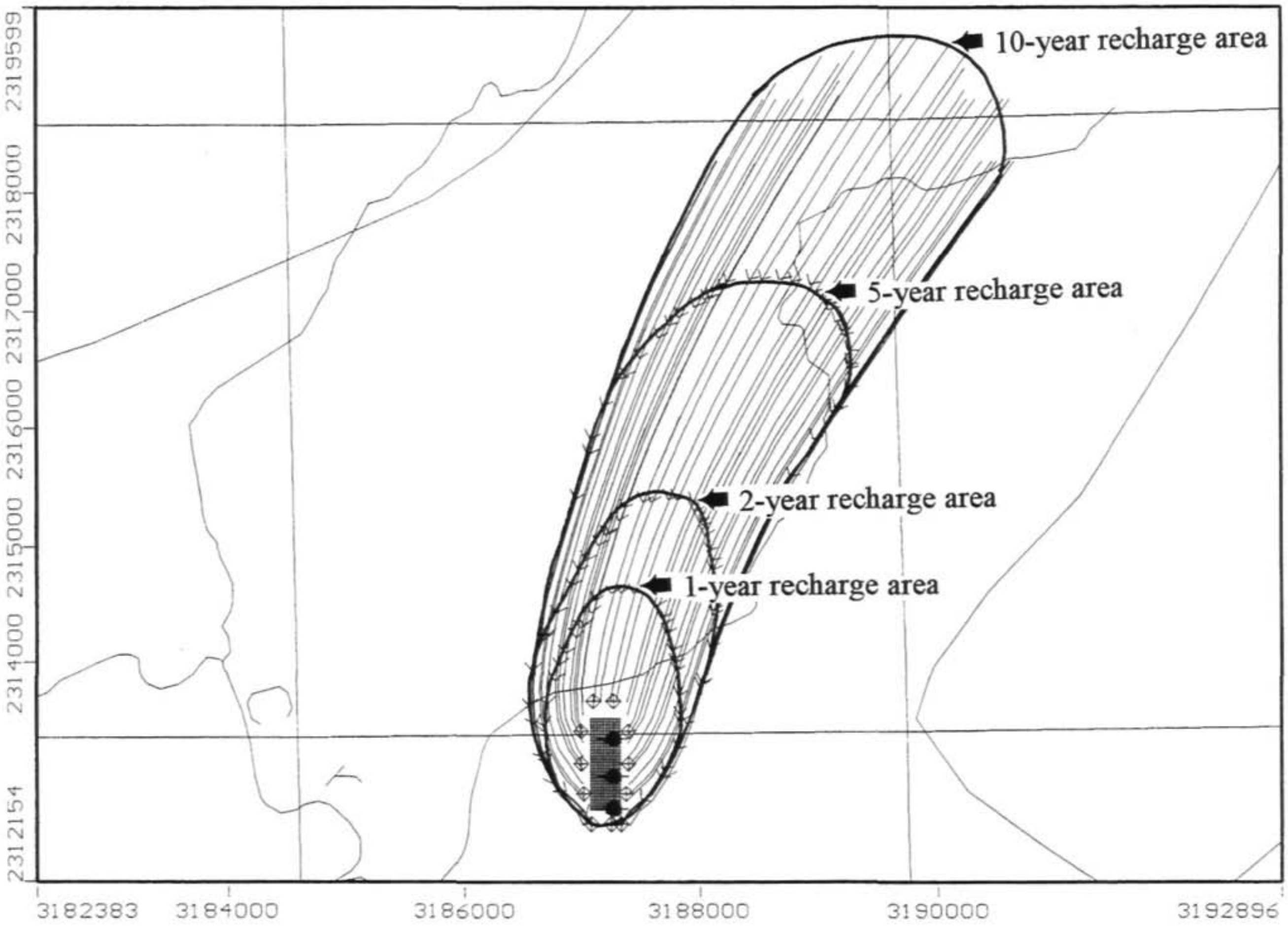


Figure 23b. 1-, 2-, 5-, and 10-year recharge areas for ground-water withdrawal of 350,000 gpd at north well field

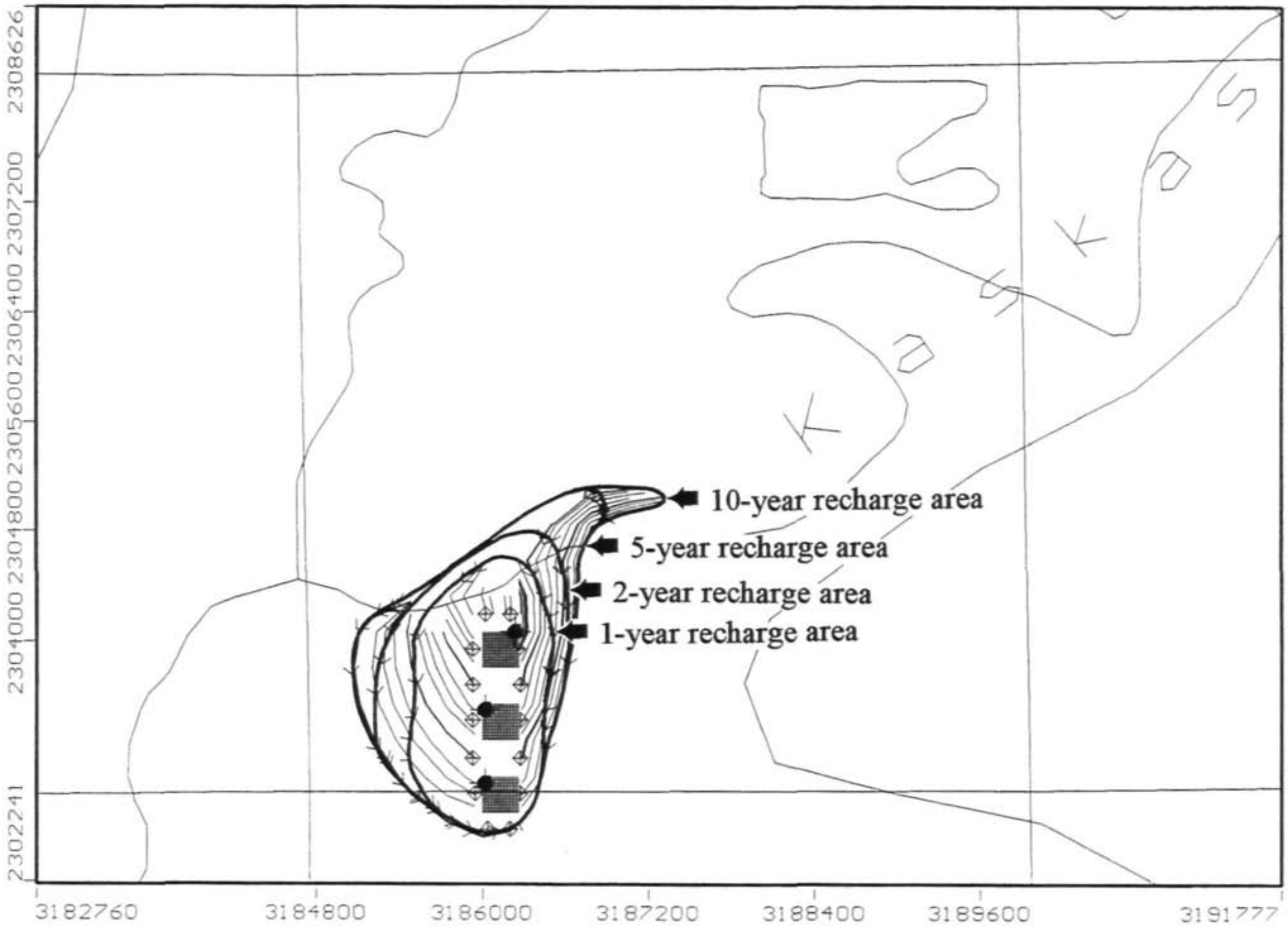


Figure 23c. 1-, 2-, 5-, and 10-year recharge areas for ground-water withdrawal of 350,000 gpd at south well field

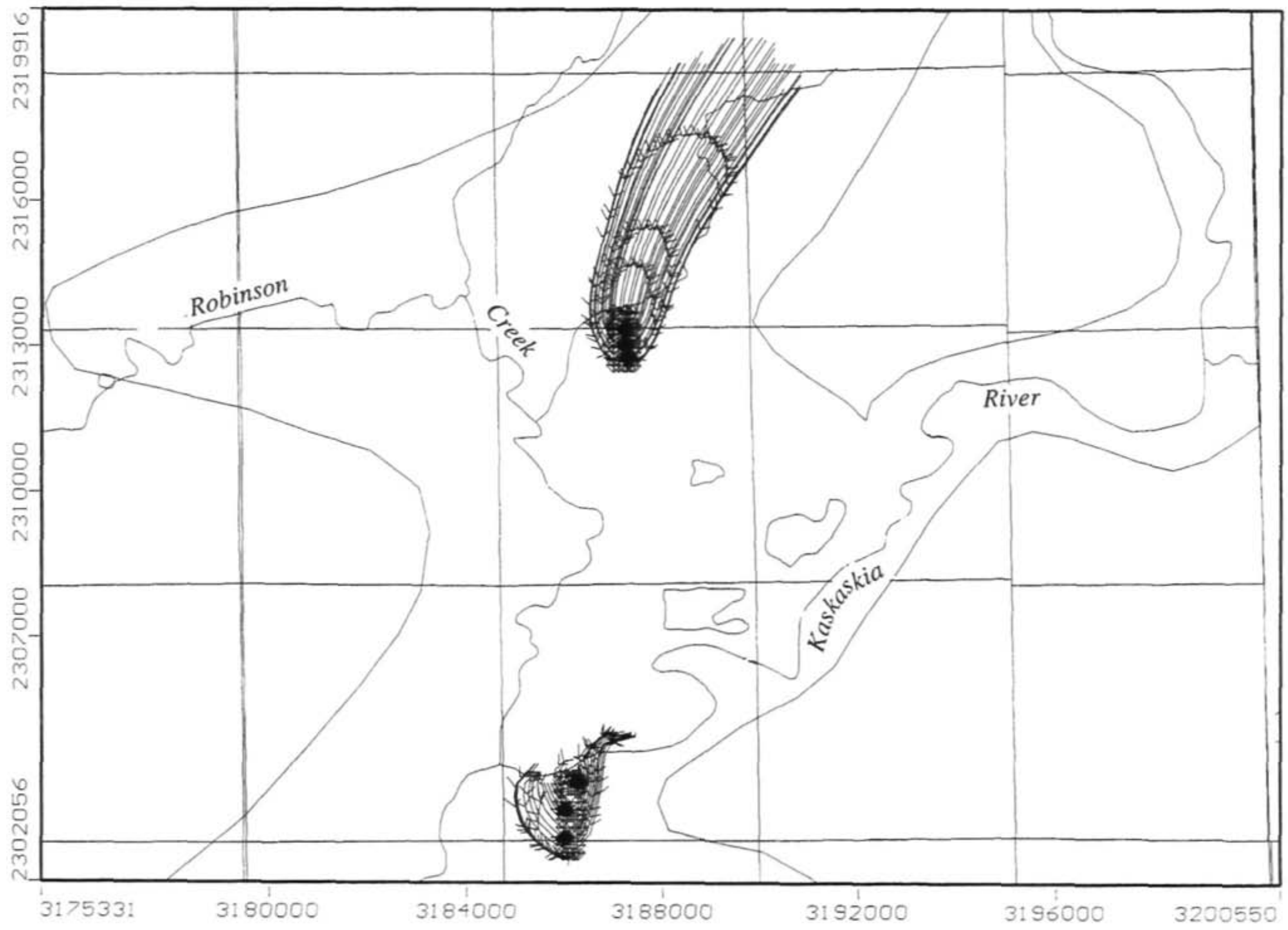


Figure 24a. 1-, 2-, 5-, and 10-year recharge areas for total ground-water withdrawal of 800,000 gpd

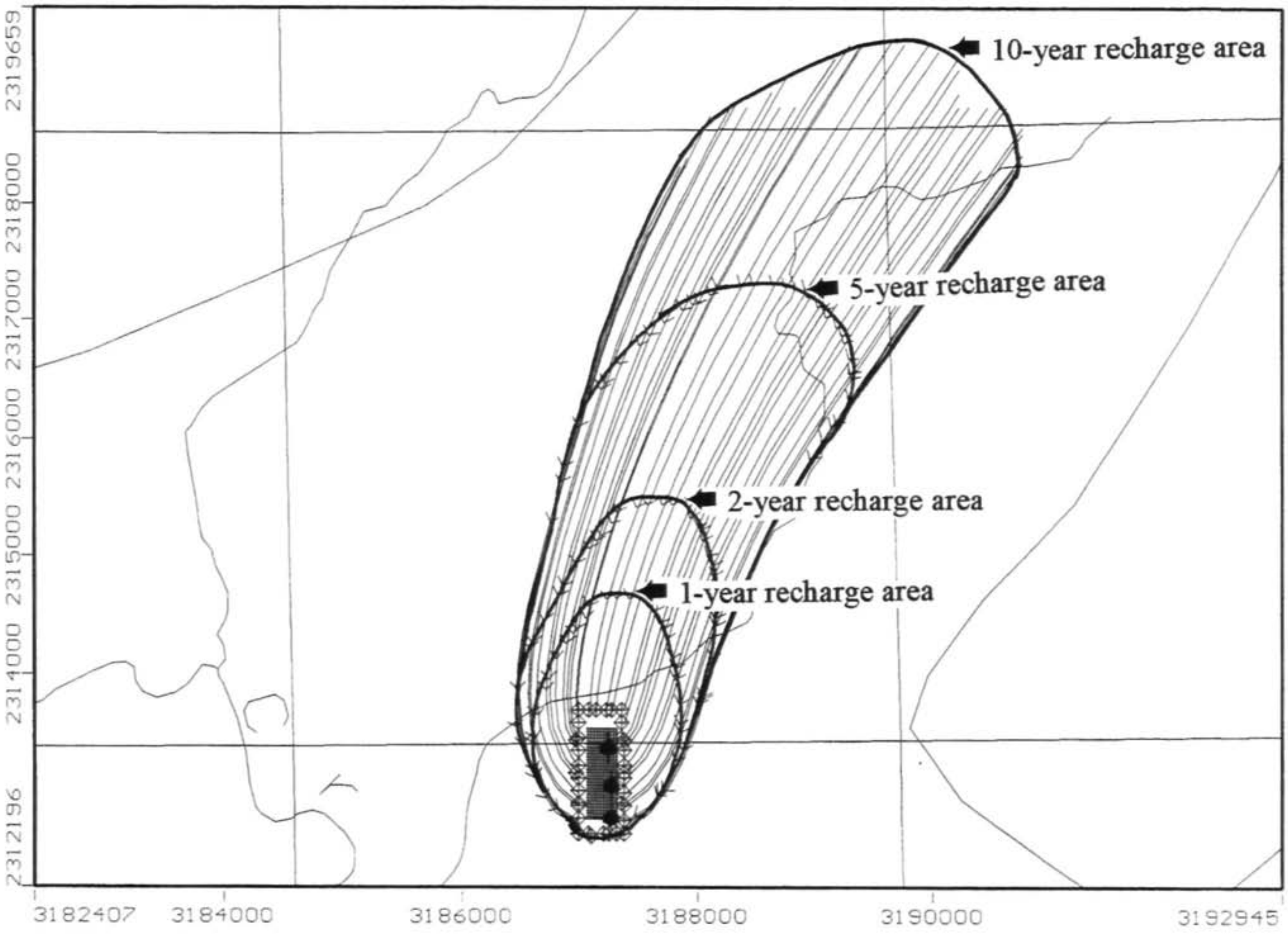


Figure 24b. 1-, 2-, 5-, and 10-year recharge areas for ground-water withdrawal of 400,000 gpd at north well field

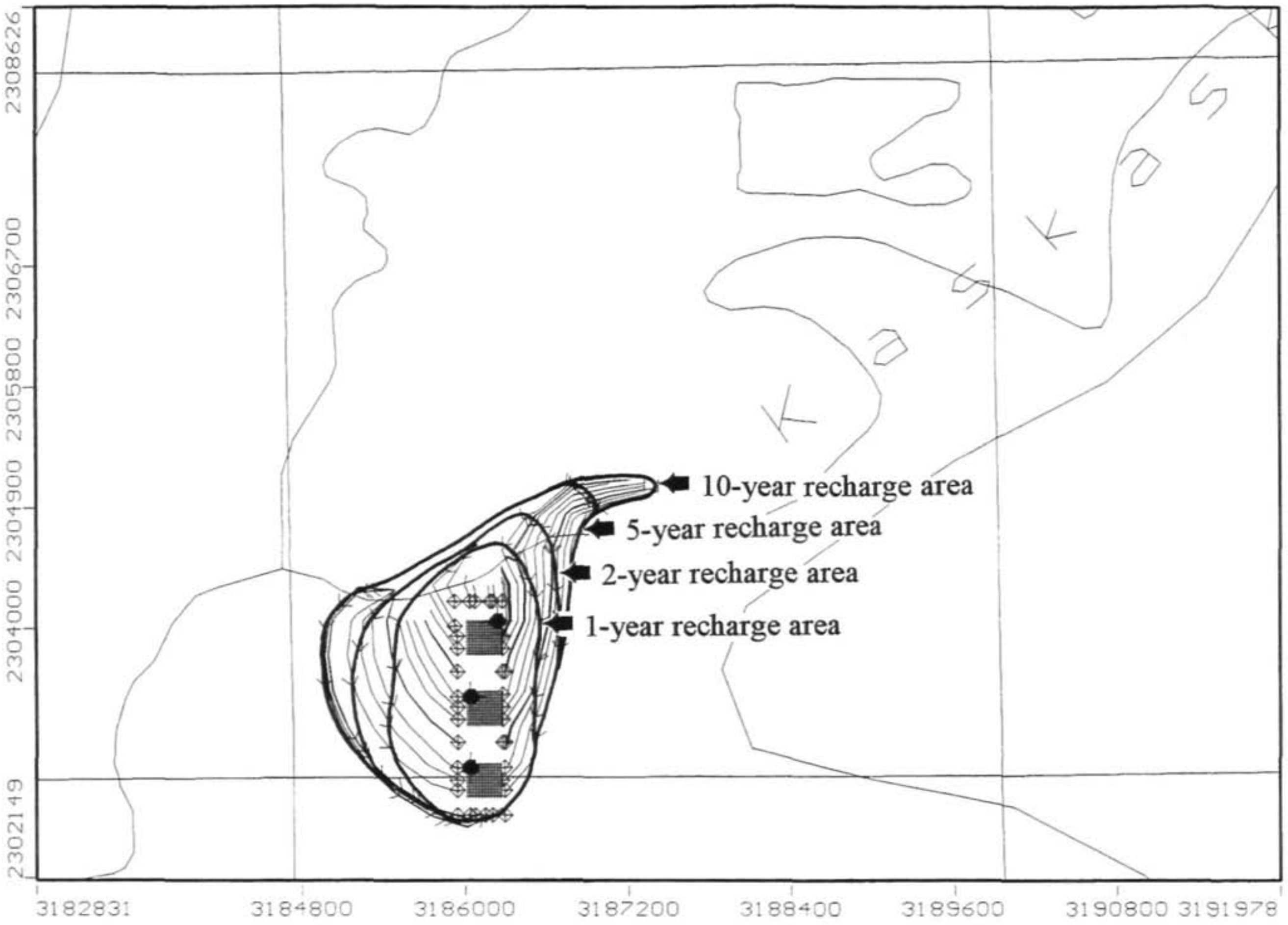


Figure 24c. 1-, 2-, 5-, and 10-year recharge areas for ground-water withdrawal of 400,000 gpd at south well field

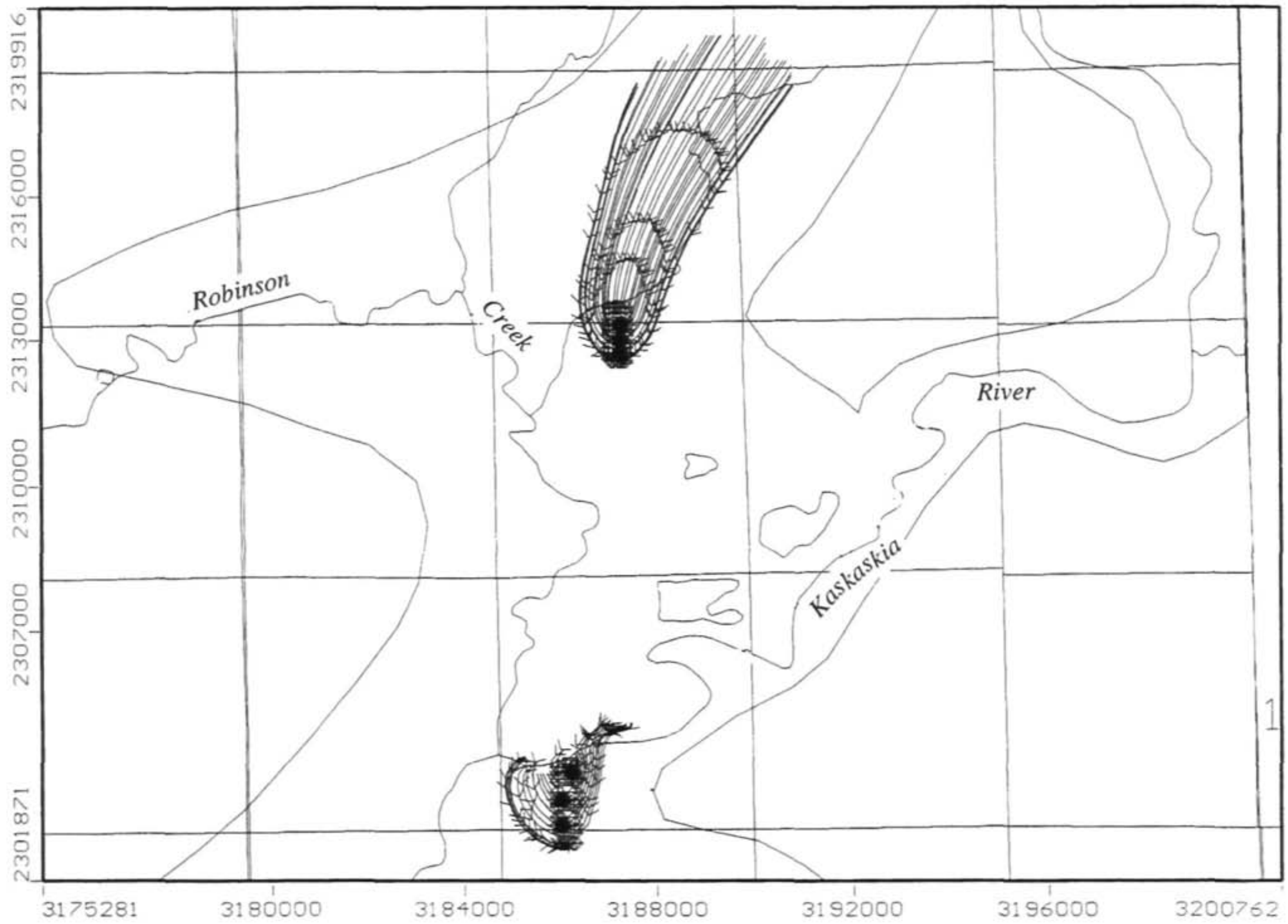


Figure 25a. 1-, 2-, 5-, and 10-year recharge areas for total ground-water withdrawal of 900,000 gpd

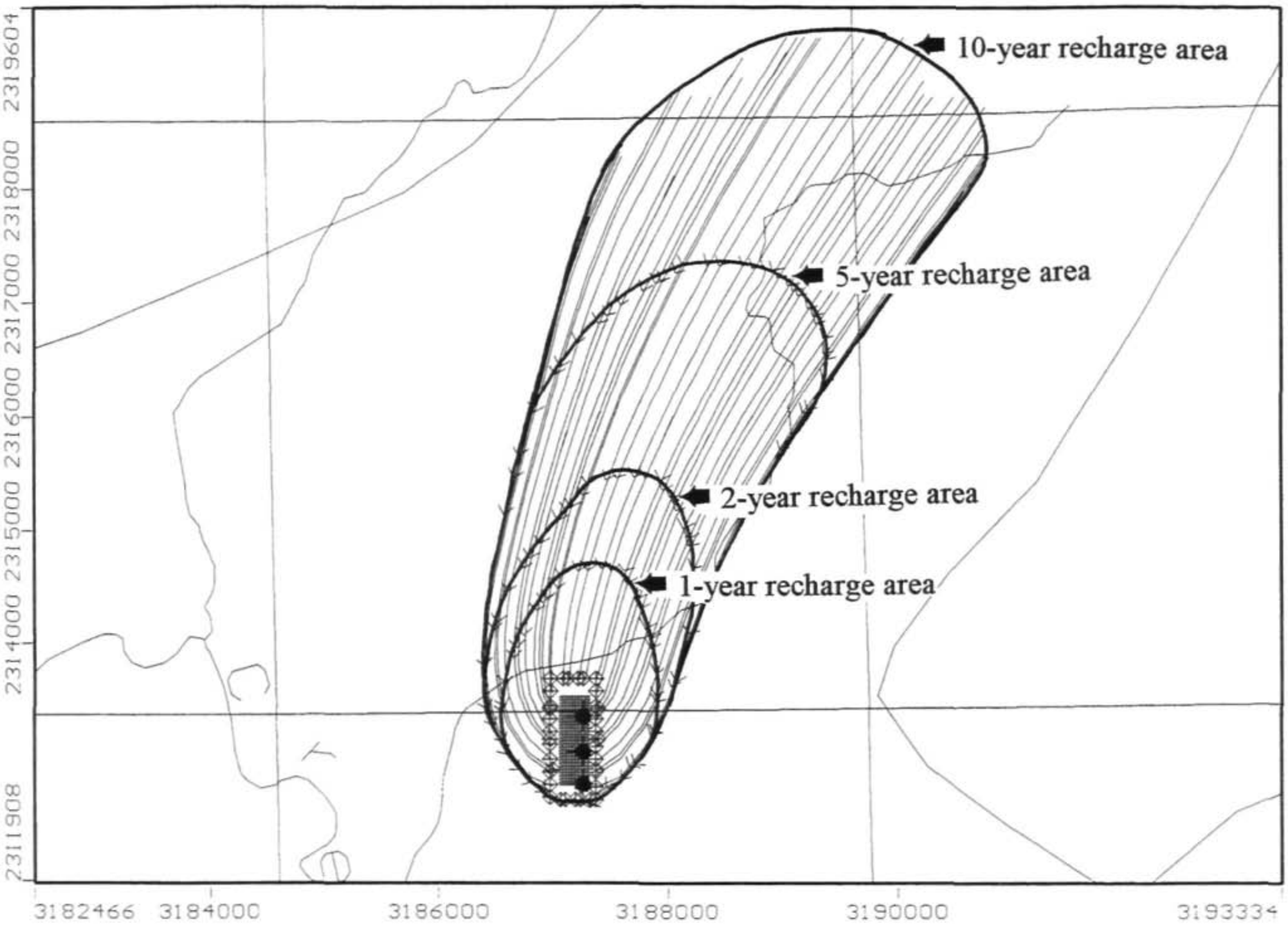


Figure 25b. 1-, 2-, 5-, and 10-year recharge areas for ground-water withdrawal of 450,000 gpd at north well field

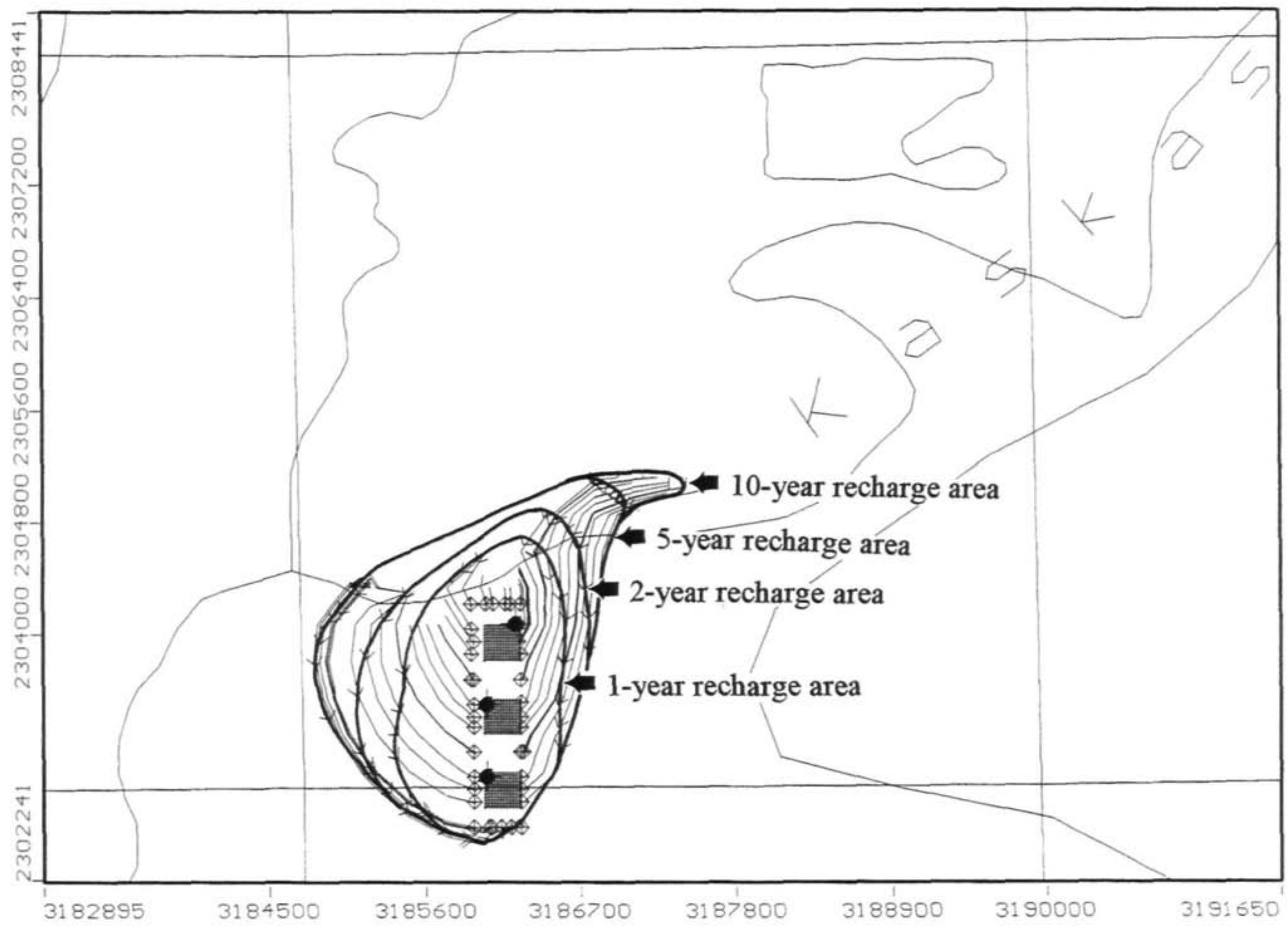


Figure 25c. 1-, 2-, 5-, and 10-year recharge areas for ground-water withdrawal of 450,000 gpd at south well field

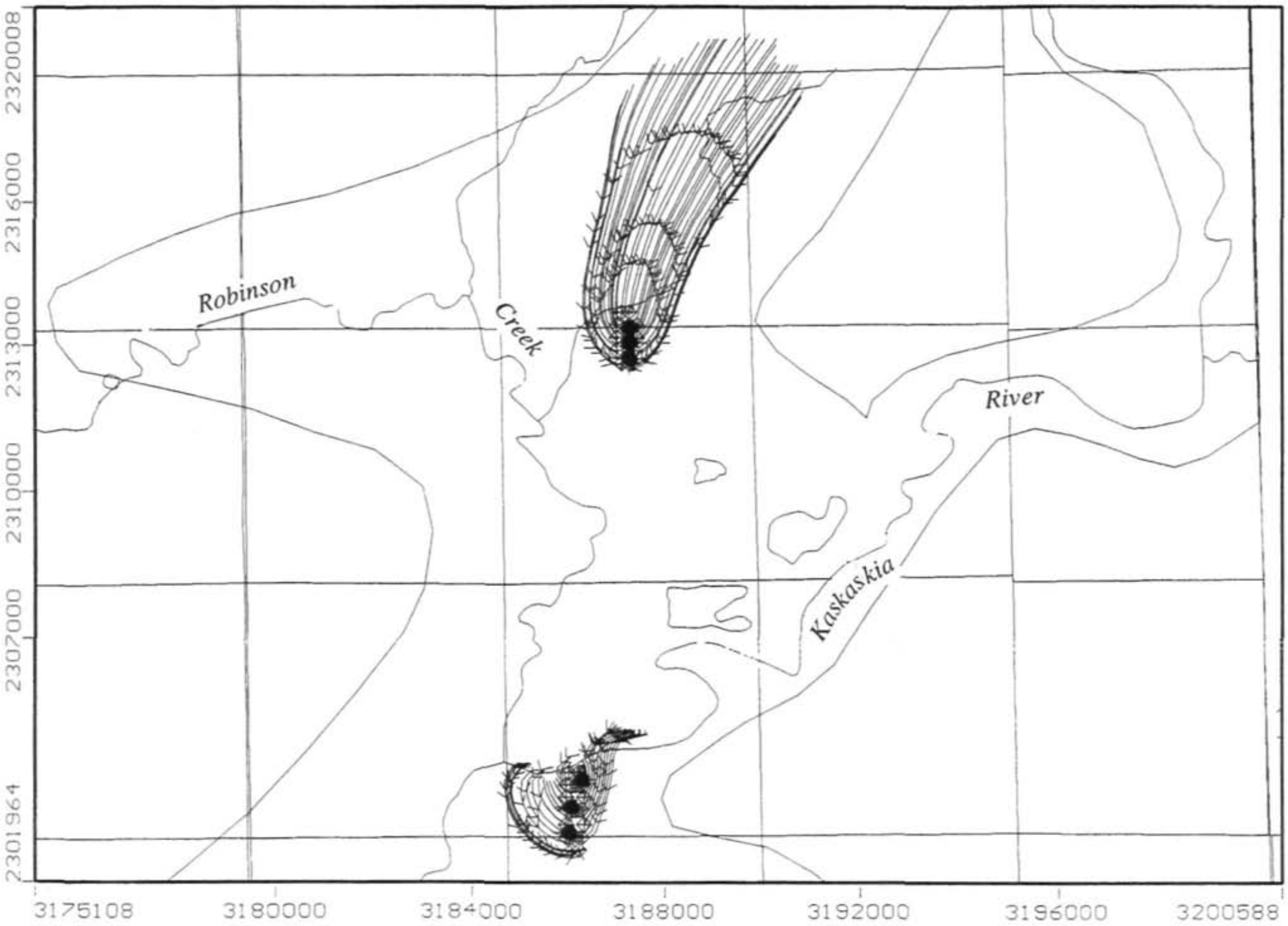


Figure 26a. 1-, 2-, 5-, and 10-year recharge areas for total ground-water withdrawal of 1 mgd

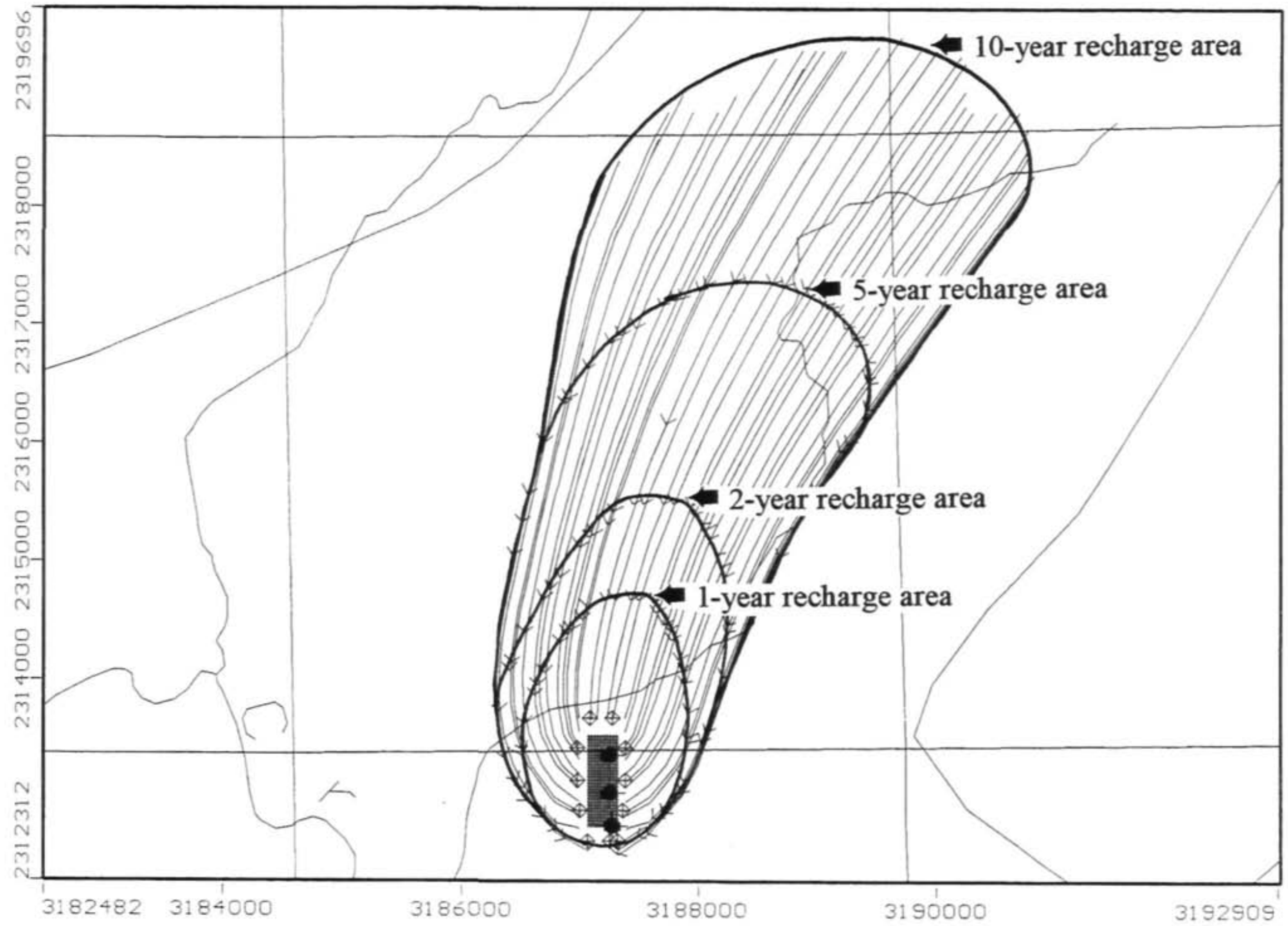


Figure 26b. 1-, 2-, 5-, and 10-year recharge areas for ground-water withdrawal of 500,000 gpd at north well field

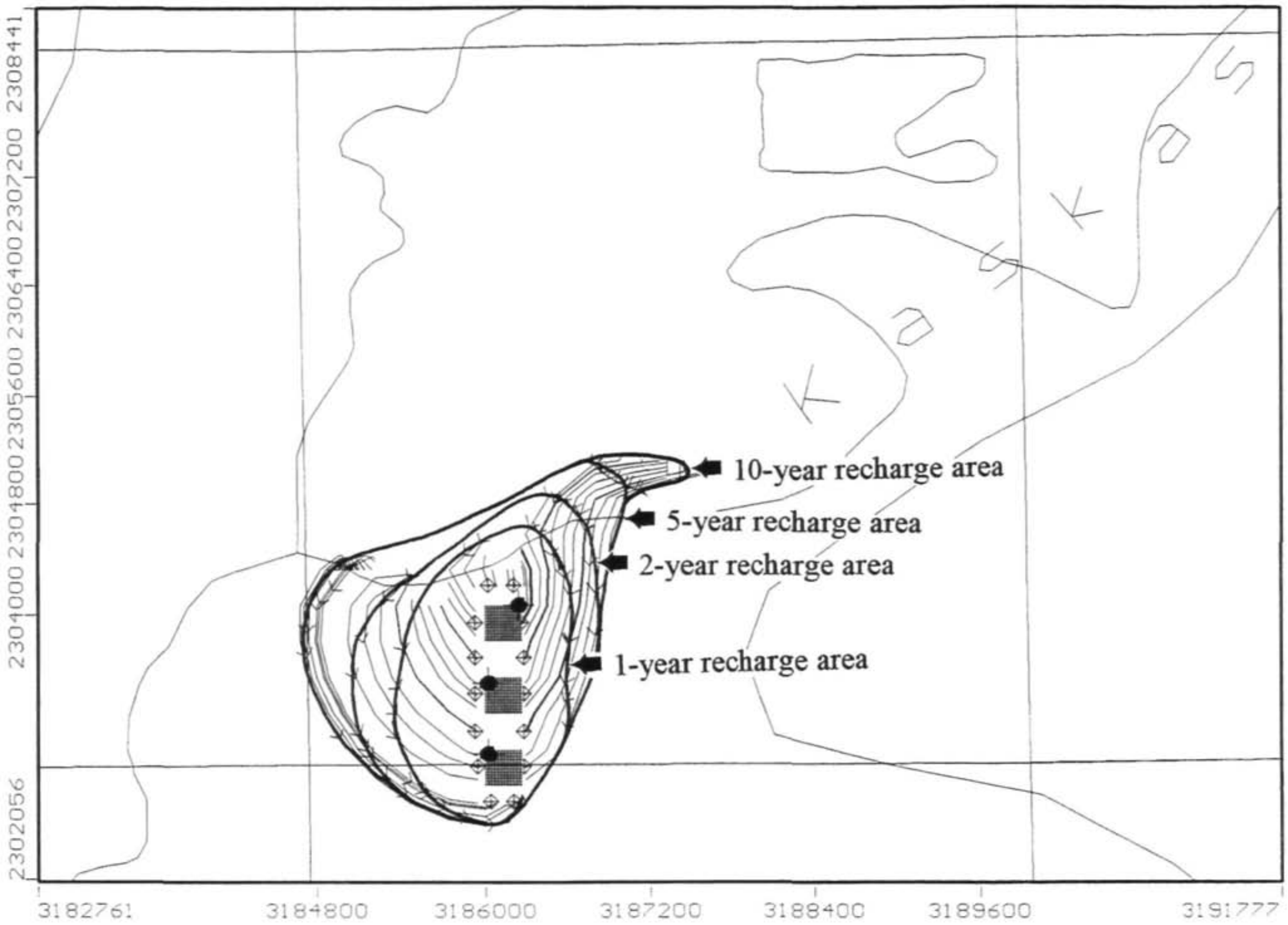


Figure 26c. 1-, 2-, 5-, and 10-year recharge areas for ground-water withdrawal of 500,000 gpd at south well field

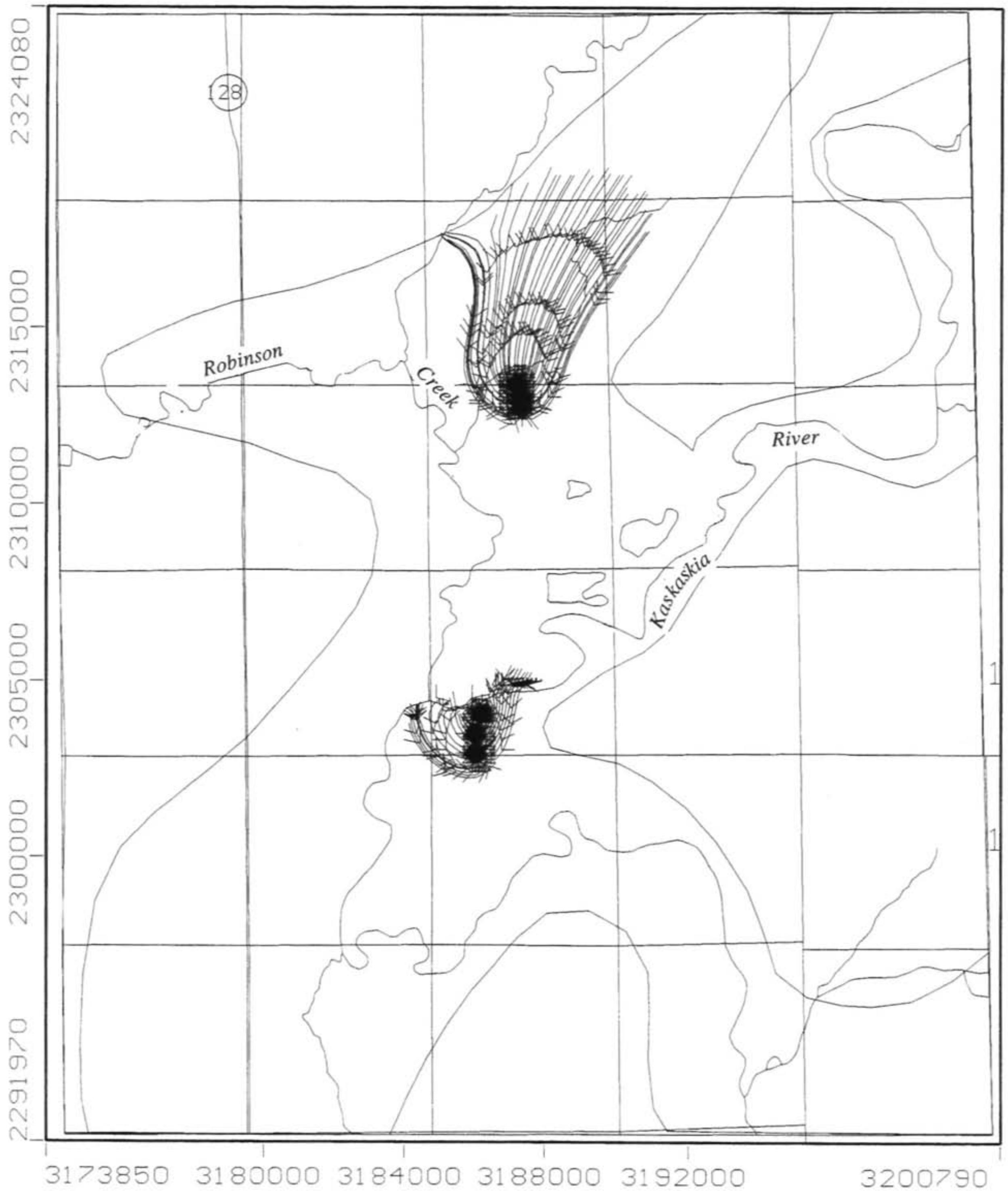


Figure 27a. 1-, 2-, 5-, and 10-year recharge areas for total ground-water withdrawal of 1.5 mgd

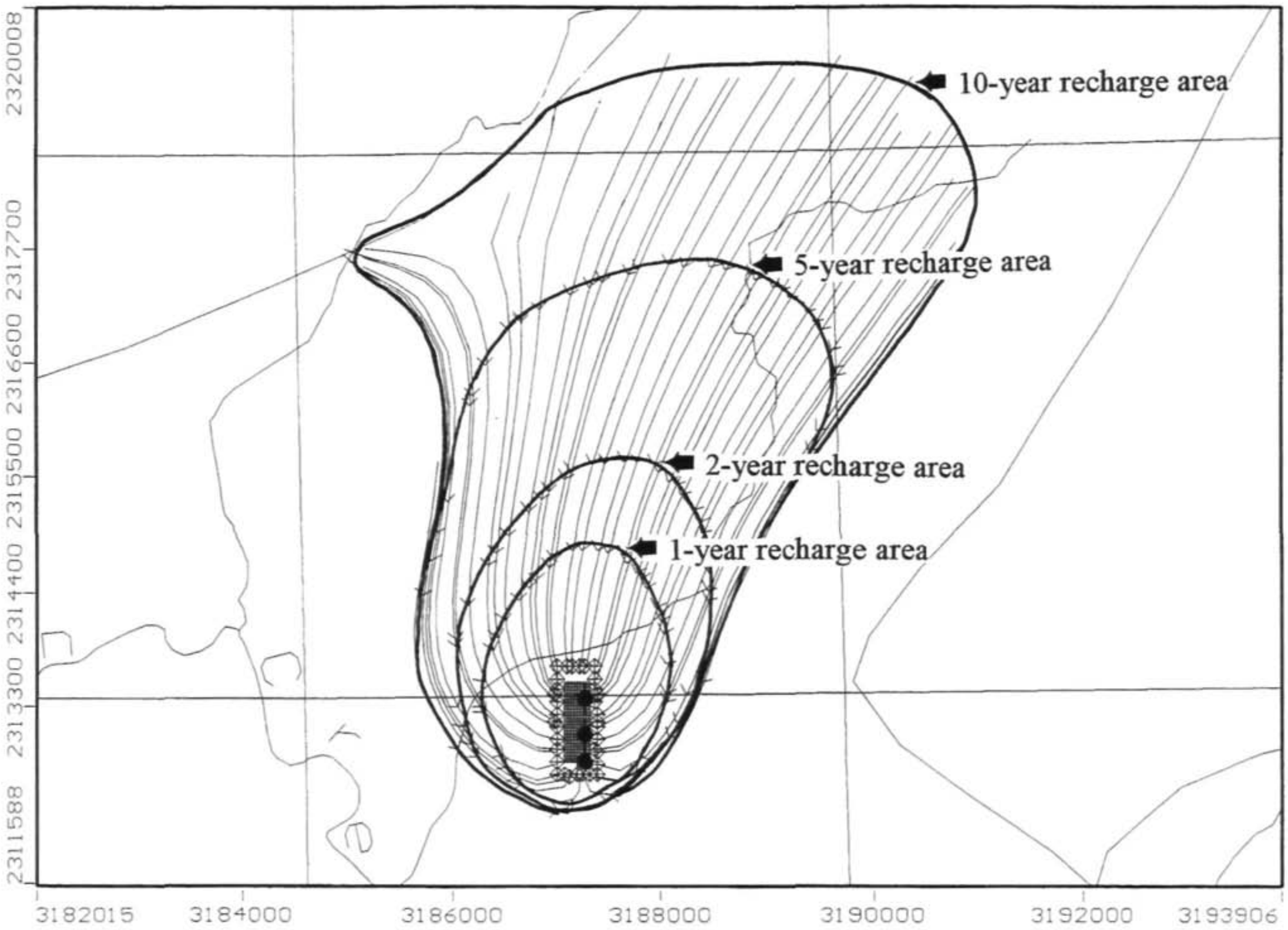


Figure 27b. 1-, 2-, 5-, and 10-year recharge areas for ground-water withdrawal of 750,000 gpd at north well field

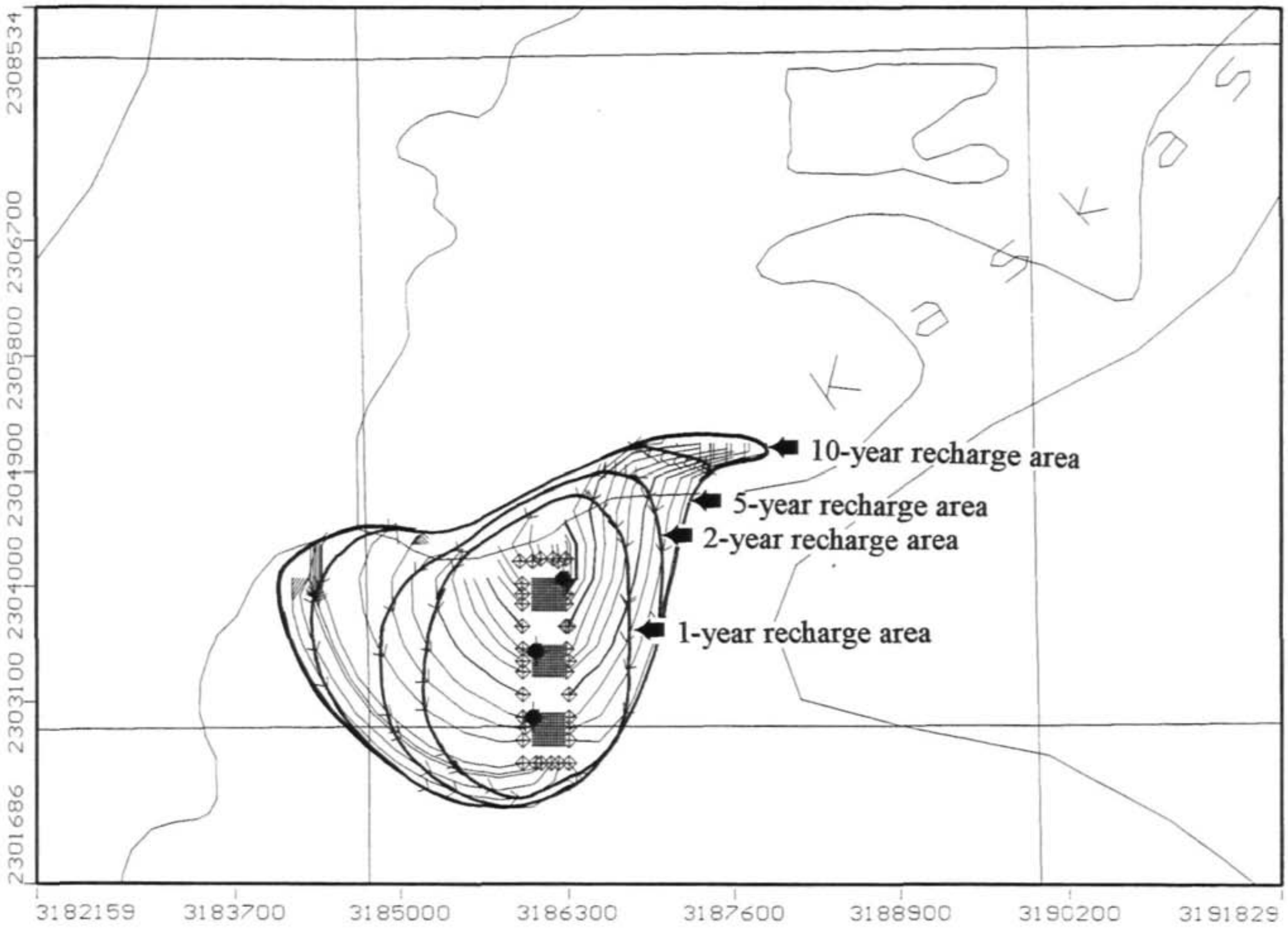


Figure 27c. 1-, 2-, 5-, and 10-year recharge areas for ground-water withdrawal of 750,000 gpd at south well field

The ground-water flow model was then run several times to generate a series of time-based recharge areas for various pumping scenarios at each well field. During this process, it was observed that for the pumping rates used in these simulations, the effects seen at each well field were independent of the operation of the other well field. In other words, the recharge areas delineated at one well field are constant even if pumping rates at the other well field are changed.

Delineating the 5-year recharge area for each well field, which was the primary goal of this study, revealed the north well field's recharge area encompasses a significant portion of the land to the north-northeast of that well field. This oval-shaped recharge area extends upgradient approximately 0.87 mi from the center of the well field and attains a width of approximately 0.35 mi at its northern "reach". The 5-year recharge area at the south well field encompasses a smaller oval-shaped area, approximately 0.4 mi (north to south) by approximately 0.3 mi (east to west) and centered roughly over the well field. Recharge from the Kaskaskia River significantly limits the areal extent of this recharge area.

It is our hope that the several simulations conducted and displayed herein will allow Shelbyville officials and their consultants to proceed with ground-water protection management activities. Specifically, the recharge area delineations displayed in figures 21-27 for the varying pumping conditions should prove especially useful.

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APPENDIX A.

GROUND-WATER LEVEL RECORD SHEET

APPENDIX A.

Well Inventory No: ____________

ILLINOIS STATE WATER SURVEY

GROUND-WATER LEVEL RECORD SHEET

SHELBYVILLE

OWNER/RESIDENT: ____

ADDRESS: ____

____ PHONE: ____________________

SECTION . plot: ______________ TWP: ______________ RGE: ______________ CO: ______________

FT from Section Corner: ____

DEPTH: ______________________________ WELL BOTTOM ELEVATION: ____________________

CASING DIAMETER/LENGTH: ____

S/G AQUIFER INTERVAL(S): ____

AQUIFER NAME: ______________________________ DATE DRILLED: ____________________

MEASURING POINT: ____

____________________ AT __________ feet above LAND SURFACE ELEV: ____________________

NOTES: ____

INVENTORY DATE: ______________________________ FIELD ASSISTANT: ______________________________

DATE	NONPUMPING WATER LEVEL, feet					REMARKS
	Held	Wet	Depth	MP Ht	Elevation	

APPENDIX A. Concluded

Well Inventory No: ____________

OWNER/RESIDENT:____

SECTION . plot:______________**TWP:**______________**RGE:**______________**CO:**______________

APPENDIX B.

INFORMATIONAL FLYER DISTRIBUTED DURING PROJECT FIELD WORK

DELINEATION OF THE GROUND-WATER RECHARGE AREA FOR SHELBYVILLE'S MUNICIPAL WELL FIELDS

Conducted by:	*In cooperation with:*
Hydrology Division	SHELBYVILLE WATER DEPARTMENT
ILLINOIS STATE WATER SURVEY	City of Shelbyville

The City of Shelbyville operates two well fields southwest of the city which withdraw ground water from water-bearing sand-and-gravel deposits (aquifers) associated with an ancient bedrock valley as well as alluvial deposits of the Kaskaskia River. In recent years there has been increased interest in this aquifer system and its potential for continued use as a viable and safe source of water. This increased awareness has resulted in an expressed desire to learn more about the resource and to be better able to address future resource development and management plans. An important step in this process is the delineation of the 5-year time-of-travel recharge area(s) for the two municipal well fields which the city operates. The City of Shelbyville has contracted with the Illinois State Water Survey (ISWS) for this 12-month study.

Field efforts related to this study will begin this spring in the study area (shown below) around the municipal well fields and will conclude in the summer or fall of this year with a "mass measurement" of ground-water levels. The first task of the project is to establish a network of existing wells in which to measure ground-water levels in the summer or fall of this year. This network is being established during the spring and early summer of this year, as field staff from the ISWS begin contacting residents in the study area seeking their possible assistance with this study.

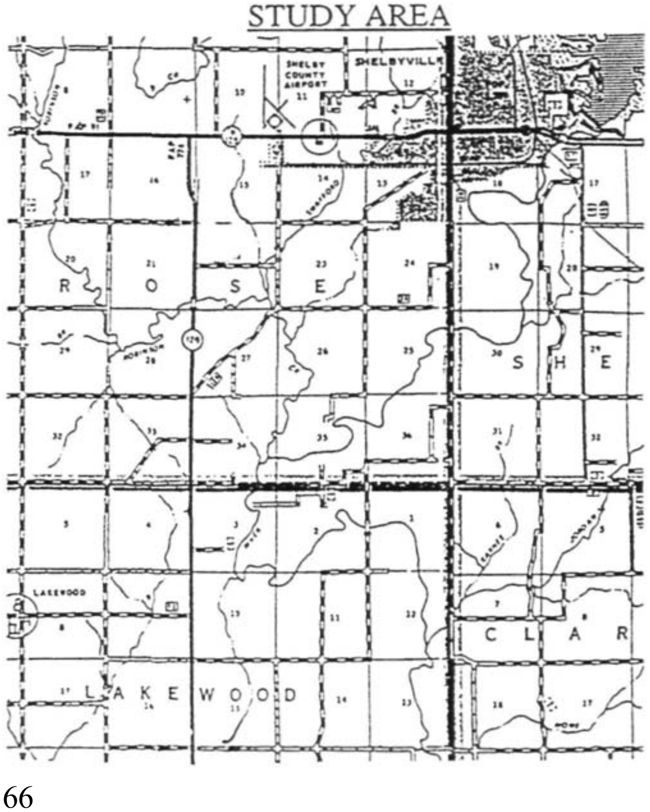
We request your permission to allow us to determine if the water level in your well can be measured and, if so, to include your supply well in this network of wells for the mass measurement. Your help will contribute to the understanding of the aquifer system and better allow effective management and utilization of this important resource.

If you have any questions, please contact:

Mr. Mark Anliker
Assistant Hydrologist
Illinois State Water Survey
2204 Griffith Drive
Champaign, EL 61820
Phone: 217-333-5383

or

Mr. Brent Shull
Water Superintendent
City of Shelbyville
P.O. Box 346
Shelbyville, IL 62565
Phone:217-774-2621



APPENDIX C.

WELLS IN MASS MEASUREMENT NETWORK

			— Legal	Location- -				Estimated	——Inventory (Apr-May	1996)——		——Mass Measurement——			
Inv No	x	y	Twp	Rge	Sec. Plt	Owner/Resident	Well Depth (ft)	Land Surface Elevation (ft-msl)	MP Height (ft)	Depth to Water, below MP (ft)	Ground-water Elevation (ft-msl)	MP Height (ft)	Depth to Water, below MP (ft)	Ground-water Elevation (ft-msl)	Well Typ
1	3189317	2303553	11N	3E	35.2a	Charles W. Furr	20	594	0	14.44	579.56	0	8.53	585.47	U
2	3189704	2304301	11N	3E	35. 1b	Donald Rogers	30	600	0	19	581	0		600	U
3	3193622	2307402	11N	3E	36. 3g	Julia Myers	20	601	0	4.58	596.42	0	2.12	598.88	U
4	3190335	2298837	10N	3E	1 8g	Jack Mars	27	565	1.8	16.77	550.03	1.8	13	553.8	U
5	3186657	2302770	10N	3E	2.6h	Alice Larimore		550				0	2.13	547.87	N/A
6	3191387	2310962	11N	3E	25. 7e	Tony Weishaar	51	565	2	26.48	540.52	2	23.48	543.52	L
7	3188410	2313361	11N	3E	26. 3h	Owen Shull (well #1)	20	565	0	2.73	562.27	0	2.1	562.9	U
8	3187929	2313095	11N	3E	26. 3h	Owen Shull (well #2)	20	561	0	1.86	559.14	0	0	561	U
9	3187845	2312768	11N	3E	26. 3h	Owen Shull (well #3)	20	561	0	1.5	559.5	0	0.1	560.9	U
10	3189269	2307586	11N	3E	35. 1h	Maury Weishaar	25	542	0.8	12.7	530.1	0.8	10.02	532.78	L
11	3187276	2302093	10N	3E	2.5g	Marion & Ferd Herreid	55	580	0.8	24.47	556.33	0.8	22.95	557.85	U
12	3184476	2316752	11N	3E	22. 1f	William Pettry	41	550	3	4.2	548.8	3	4.53	548.47	L
13	3184013	2315919	11N	3E	22. 1d	James Thompson	24	550	0.3	4.75	545.55	0.3	2.82	547.48	L
14	3180199	2309049	11N	3E	27.7b	Kimble Foor/J. Miller	30	601	0	6.85	594.15	0	3	598	U
15	3179492	2308896	11N	3E	27.8b	Kimble Foor	80	604	0.8	17.82	586.98	0.8	11.4	593.4	U
16	3183161	2303734	11N	3E	34. 3b	James Endris	30	595	3	22	576	3	18.04	579.96	U
17	3182877	2303494	11N	3E	34.4a	Daniel Lochbaum	43	600	0.7	21.74	578.96	0.7	20.63	580.07	U
18	3179396	2303524	11N	3E	33. 1b	Roger Fitzgerald (well #1)	15	596	0.5	3.53	592.97	0.5	3.47	593.03	U
19	3179359	2303650	11N	3E	33. 1b	Roger Fitzgerald (well #2)	22	593	1.1	0	594.1	1.1	0	594.1	U
20	3193316	2314539	11N	3E	24.3b	Rob Hennings		611	1.3	6.29	606.01	1.3	4.8	607.5	U
21	3193503	2317432	11N	3E	24. 3f	Larry Graham	21	598	1.8	2.89	596.91	1.8	3.17	596.63	U
22	3187294	2319013	11N	3E	14.5a	James Hampton (well #1)		579	0	3.23	575.77	0	3.3	575.7	U
23	3178206	2315009	11N	3E	21 .2c	Roger Wicker	27	557	2	3.24	555.76	2	4.05	554.95	L
24	3189692	2312516	11N	3E	26. 1g	unknown		602	0.8	3.43	599.37	0.8	4.1	598.7	U
25	3189770	2310230	11N	3E	26. 1d	James Prosser		557	2.3	22.13	537.17	2.3	20.23	539.07	L
26	3182167	2305828	11N	3E	34 . 4e	Vera Lu Jeffers (Well #1)	30	602	0	5.29	596.71	0	5.25	596.75	U
27	3182166	2305732	11N	3E	34. 4e	Vera Lu Jeffers (Well #2)	15	605	0.3	4.1	601.2	0.3	5.13	600.17	U
28	3182074	2305615	11N	3E	34. 4e	Vera Lu Jeffers (Well #3)	52	600	1.2	2.2	599	1.2	2.48	598.72	U
29	3198712	2308146	11N	4E	31 ,3h	Harold McKittrick		590	1.6	7.84	583.76	1.6	7.29	584.31	U
30	3194918	2309954	11N	3E	25. 1c	Joe Woodall	50	603	1.8	8.26	596.54	1.8	7.1	597.7	U
31	3195175	2303650	11N	4E	31 ,8b	James Hedderman	30	602	0.3	5.57	596.73	0.3	6.39	595.91	U
32	3188362	2297675	10N	3E	2.3a	Paul Corley (well #1)	65	613	0	10.2	602.8	0	10.44	602.56	U
33	3187554	2294794	10N	3E	11 .4d	Paul Corley (well #2)		606	0	1.67	604.33	0	1.82	604.18	U
34	3188594	2318518	11N	3E	23. 2h	Hyink estate		577	2.6	28	551.6	2.6	25.14	554.46	L
35	3188554	2309547	11N	3E	26.2c	Ray Buhrmester (well #1)	22	590	0.35	2	588.35	0.35	1.59	588.76	U
36	3188346	2308311	11N	3E	26.3a	Ray Buhrmester (well #2)	55	564	1.2	21.9	543.3	1.2	22.08	543.12	L
37	3189813	2319459	11N	3E	13.8b	Joe Toll (well #1)	24	585	0.3	4.38	580.92	0.3	2.99	582.31	U
38	3189680	2319387	11N	3E	13.8b	Joe Toll (well #2)	30	582	0.5	1.91	580.59	0.5	3.39	579.11	U
39	3179653	2298456	10N	3E	3.8b	Darrell Nohren	25	602	0.6	2.91	599.69	0.6	2.77	599.83	U
40	3182500	2292550	10N	3E	10.4a	Mike Langan	30	580	2	7.75	574.25	2	7.93	574.07	U
41	3195240	2298541	10N	4E	6.8b	Carl Borders	57	593	1.6	19.3	575.3	1.6	33.19	561.41	U
42	3196601	2294811	10N	4E	7.6d	James Beals	30	580	1.7	17.69	564.01	1.7	17.49	564.21	U
43	3200475	2294943	10N	4E	7. 1e	Jerald Hieronymus	30	590	1.6	10.7	580.9	1.6	11.18	580.42	U
44	3179648	2295663	10N	3E	10 . 8f	Jerry Martz	32	590			590	1.9	10.22	581.68	U
45	3181941	2297556	10N	3E	3.5a	Nelda Koontz	38	540		2.94	537.06	1	4.51	536.49	L
46	3175485	2318989	11N	3E	16.6a	Kevin Campbell	30	612	1	4.93	608.07	1	6.07	606.93	U
47	3185199	2321674	11N	3E	14. 7e	Gene & Carol Davis	27	605	1.5	3.97	602.53	1.5	4.06	602.44	U
48	3176117	2307999	11N	3E	33. 5h	unknown		607	0	4.77	602.23	0	8.62	598.38	U
49	3177324	2295007	10N	3E	9 4e	Everett Matheny	15	590	3	3.27	589.73	3	3.76	589.24	U

			— Legal	Location—				Estimated	——Inventory (Apr-May	1996)——		——Mass Measurement——			
Inv No.	x	y	Twp	Rge	Sec. Plt	Owner/Resident	Well Depth (ft)	Land Surface Elevation (ft-msl)	MP Height (ft)	Depth to Water, below MP (ft)	Ground-water Elevation (ft-msl)	MP Height (ft)	Depth to Water, below MP (ft)	Ground-water Elevation (ft-msl)	Well Type
50	3181806	2291828	10N	3E	15. 5h	Kevin Sheils		592	1.1	7.05	586.05	1.1	13.21	579.89	U
51	3182314	2291811	10N	3E	15. 4h	Mrs. Nolan H. Sheils		591	1.6	4.48	588.12	1.6	7.98	584.62	U
52	3174413	2301249	10N	3E	4. 8f	Mr. Robert J. Miller		620		3.72	616.28	1	4.74	616.26	U
53	3200120	2315878	11N	4E	20. 8d	Pat Macklin	48	608	1.7	45.91	563.79	1.7	44.6	565.1	U
54	3193207	2321886	11N	3E	13. 3E	Lester M. Reynolds (well #1)	23	613	0	4.72	608.28	0	5.1	607.9	U
55	3193200	2322116	11N	3E	13. 3E	Lester M. Reynolds (well #2)	26	616	0.8	2.83	613.97	0.8	2.94	613.86	U
56	3180005	2315860	11N	3E	22. 7d	Hester M. Rincker	30	600	0.2	3.43	596.77	0.2	3.37	596.83	U
57	3186027	2313345	11N	3E	26. 6h	unknown (yellow concrete ob well)		543	3.1	7.13	538.97	3.1	7.37	538.73	L
58	3189731	2315473	11N	3E	24.8c	Lillie M. Forbes	90	596	1.2	34.08	563.12	1.2	31.99	565.21	U
59	3191920	2311926	11N	3E	25.5f	Stan Grygiel	25	605				0.4	6.05	599.35	U
60	3187322	2319155	11N	3E	14.5a	James Hampton (well #2)	78	580	0.9	30.67	550.23	0.9	29.7	551.2	L
61	3197119	2320294	11N	4E	18.5c	Leroy Harris (Well#1)	23	545				1.9	10.04	536.86	L
62	3196792	2319177	11N	4E	18. 5a	Leroy Harris (Well#2)	25	550				2.6	6.71	545.89	L
63	3187271	2313318	11N	4E	26. 4h	Shebyville – N. obs well at N. well field		555	2.4	16.67	540.73	2.4	16.33	541.07	L
64	3187282	2312717	11N	4E	26. 4g	Shebyville – S. obs well at N. well field		559				1.8	22.8	538	L
65	3186159	2303635	11N	4E	35.6b	Shebyville – obs well at S. well field		549	3.2	25.35	526.85	3.2	22.7	529.5	L
66	3187503	2290778	10N	3E	14. 4f	Kendall Snyder	50	595				2.8	8.02	589.78	U

Notes:

MP = measuring point
U = upland
L = lowland (i.e., in Shebyville's a(quifer)

ILLINOIS
DEPARTMENT OF
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