USE OF A GEOGRAPHIC INFORMATION SYSTEM TO ASSIST WITH STUDIES OF THE AVAILABILITY AND USE OF WATER IN KANSAS

By Kyle E. Juracek

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CONVERSION FACTORS

Multiply	*By*	*To obtain*
inch	2.54	centimeter
foot	0.3048	meter
mile	1.609	kilometer
square mile	2.590	square kilometer
acre	4,047	square meter
acre-foot	1,233	cubic meter
gallon per minute	0.06309	liter per second

USE OF A GEOGRAPHIC INFORMATION SYSTEM TO ASSIST WITH STUDIES OF THE AVAILABILITY AND USE OF WATER IN KANSAS

By Kyle E. Juracek

ABSTRACT

Studies of the availability and use of water resources are difficult because of the spatial complexity and data-intensive nature of the subject. In Kansas, a cooperative effort was undertaken by the Kansas State Board of Agriculture's Division of Water Resources and the U.S. Geological Survey to use a geographic information system (GIS) to (1) integrate their data bases and (2) develop applications that would facilitate and enhance the management and analysis of data regarding the availability and use of water within the State. GIS applications provide assistance to State water-resources managers for decisions regarding ground-water appropriations. Automated GIS procedures perform a variety of computations and can be used to evaluate several location-specific criteria that determine whether or not a ground-water-right application should be approved. GIS applications that are useful to the Geological Survey are oriented toward water-use studies. Automated GIS procedures provide summary information on water use by county and basin.

INTRODUCTION

Water-resources management by the Kansas State Board of Agriculture, Division of Water Resources, and water-use studies by the U.S. Geological Survey can be complicated tasks. Both require compilation of data, analysis, interpretation, and planning. Further complicating the management issue faced by the Division of Water Resources are the ongoing processes of policy formulation, regulation enactment, and enforcement. Water-resources management and water-use studies generally involve large spatial and (or) tabular data bases that need to be maintained and accessed. Unfortunately, access problems are common because the requisite data bases are distributed within the two agencies. Moreover, each agency might not have adequate equipment or personnel to handle the data-management and analytical requirements that their tasks demand. In Kansas, a geographic information system (GIS) is being used to help overcome these obstacles.

Background

The State of Kansas relies extensively on ground water, which provides about 85 percent of the water used. About 93 percent of the ground water withdrawn is used for irrigation (U.S. Geological Survey, 1985). In central and western Kansas, irrigated agriculture depends almost exclusively on ground water from the High Plains aquifer (fig. 1). Increasing concern over the depletion of this resource has led to the creation of five Groundwater Management Districts (GMD's) and numerous Intensive Groundwater Use (or special water-quality) Control Areas (IGUCA's) by the State to help control the development of the resource (fig. 2).

Within the State, the issues of water availability and use are a primary concern of the Kansas Water Office, the Kansas State Board of Agriculture's Division of Water Resources, and the U.S. Geological Survey. The Kansas Water Office is the State agency responsible for water-resources planning. The Division of Water Resources is the State agency responsible for the administration of laws related to water rights, conservation, and use of water resources (U.S. Geological Survey, 1990). U.S. Geological Survey responsibility centers on the systematic collection, analysis, and interpretation of hydrologic data, evaluation of water demands, and water-resources research (Combs, 1989).

In order to better address these responsibilities, the Division of Water Resources and the Geological Survey have undertaken a multiyear study that will use GIS technology to integrate their data bases and improve their data-management and analytical capabilities. This cooperative effort also will contribute to the State's initiative for a GIS-oriented statewide data program.

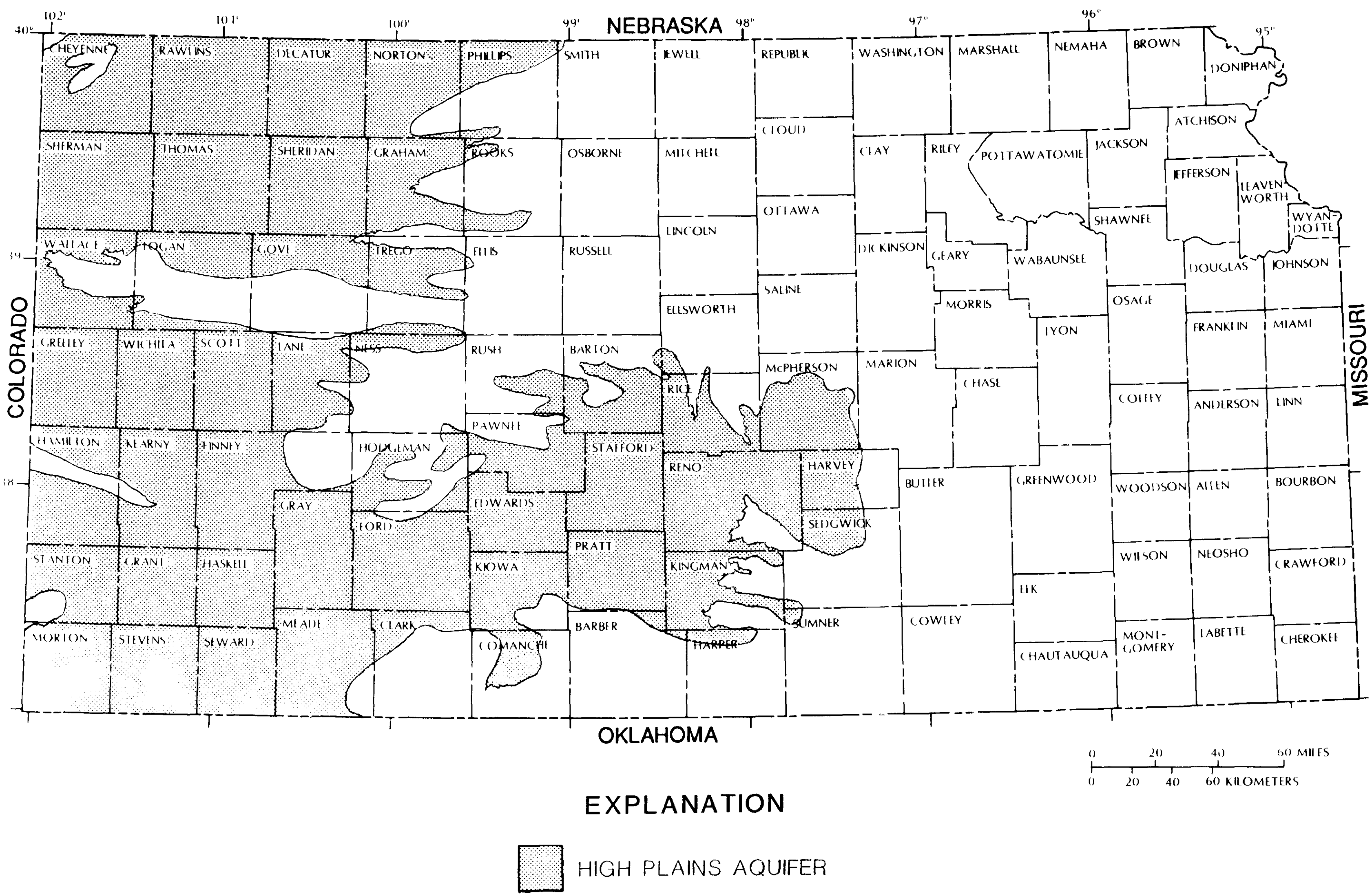


Figure 1. Extent of High Plains aquifer in Kansas (modified from U.S. Geological Survey, 1985).

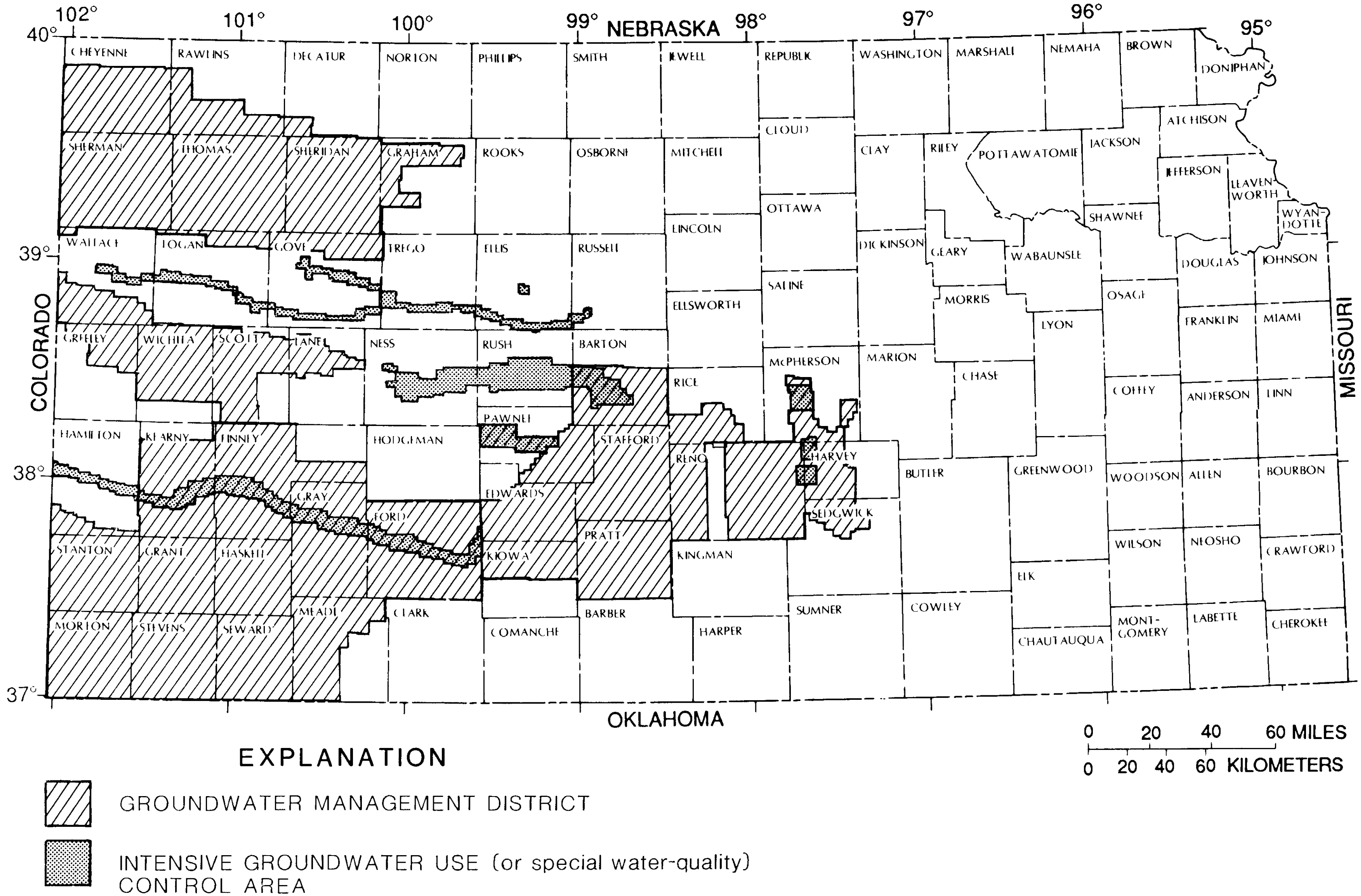


Figure 2. Location of State-designated Groundwater Management Districts and Intensive Groundwater Use (or special water-quality) Control Areas (modified from U.S. Geological Survey, 1990).

Purpose and Scope

This report describes the results of a study to develop a prototype, automated, water-resources information management and analysis system that will facilitate and enhance the analytical capabilities of the Division of Water Resources and the Geological Survey regarding the availability and use of water for irrigated agriculture in the Kansas High Plains. Specific study objectives were to:

- Develop a system that integrates data bases of the Division of Water Resources and the Geological Survey;

- Develop an applications-oriented system that will offer data retrieval, analysis, and display capabilities that can be used by State personnel confronted with the task of managing the State's water resources; and

- Develop an applications-oriented system that will offer data retrieval, analysis and display capabilities to assist Geological Survey personnel in studies of, or related to, water availability and use.

This report provides an overview of the prototype GIS application that has been developed to meet the aforementioned objectives. Topics addressed include (1) justification for GIS, (2) system development, and (3) system applications.

JUSTIFICATION FOR THE GEOGRAPHIC INFORMATION SYSTEM

The Division of Water Resources and the Geological Survey independently maintain large data bases that are of mutual interest. Specifically, the Division of Water Resources maintains tabular data bases that provide information on points of diversion (that is, wells and surface-water intakes from which withdrawal of water is authorized), authorized water use, and reported water use. The Geological Survey maintains spatial data bases that provide information on boundaries (for example, county, township, basin) and hydrography. Together, these data bases represent an enormous quantity of information.

The two agencies differ with regard to their specific analysis needs. A common denominator, however, is the importance of, and necessity for, spatial analysis. Spatial analysis refers to questions for which location is a fundamental component. In water-resources-management activities of the Division of Water Resources, a typical spatial query is the following: "On the basis of water availability within a 2-mile radius of the site and the distance to the nearest well, should a ground-water-rights application be approved or denied?" An example of spatial analysis related to water use is the following query: "Within a basin, what is the total number and distribution of wells and what is the total annual water withdrawal?" Obtaining the answers to these and other questions can be cumbersome, particularly when the solution is attempted manually.

Many problems related to the management and utilization of large, complex, spatial data bases, either singly or in combination, can be overcome with GIS technology. A GIS is a powerful, computer-based tool for the storage, organization, retrieval, manipulation, analysis, and display of spatial, and associated tabular, data. Some specific advantages of using a GIS include (1) improved data access; (2) the ability to perform complex spatial queries; (3) the ability to access multiple data bases simultaneously; (4) more consistent, and reproducible, results (as compared to a manual solution); (5) the ability to facilitate and enhance existing analysis procedures; and (6) the potential to pursue new applications that previously were unfeasible.

The use of GIS technology, however, is by no means problem-free. Initially, the cost of the hardware and software might be a deterrent. Additional concerns include the availability and reliability of the data to be used. A GIS solution might appear attractive until the time and expense of data acquisition, data-base creation, editing, and maintenance are factored in. Moreover, the quality of geographical data bases might be compromised by several factors, including the age of the data, source-map scale, density of observations, positional accuracy, and measurement error. A related concern is the likelihood of further data-quality deterioration due to error accumulation as layers of the data base are manipulated and combined (Burrough, 1986). These points emphasize that much care should be taken in the data-base development process and that caution should be exercised in analyses and use of the results.

SYSTEM DEVELOPMENT

The prototype system, referred to as the Water Information Management and Analysis System (WIMAS), was developed by the U.S. Geological Survey on a Data General AViiON[1] workstation using ARC/INFO geographic-information-system software. A schematic diagram of the system is given in figure 3.

Data-Base Development

The WIMAS data base consists of a combination of Division of Water Resources and Geological Survey data. Structurally, the data

[1] The use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

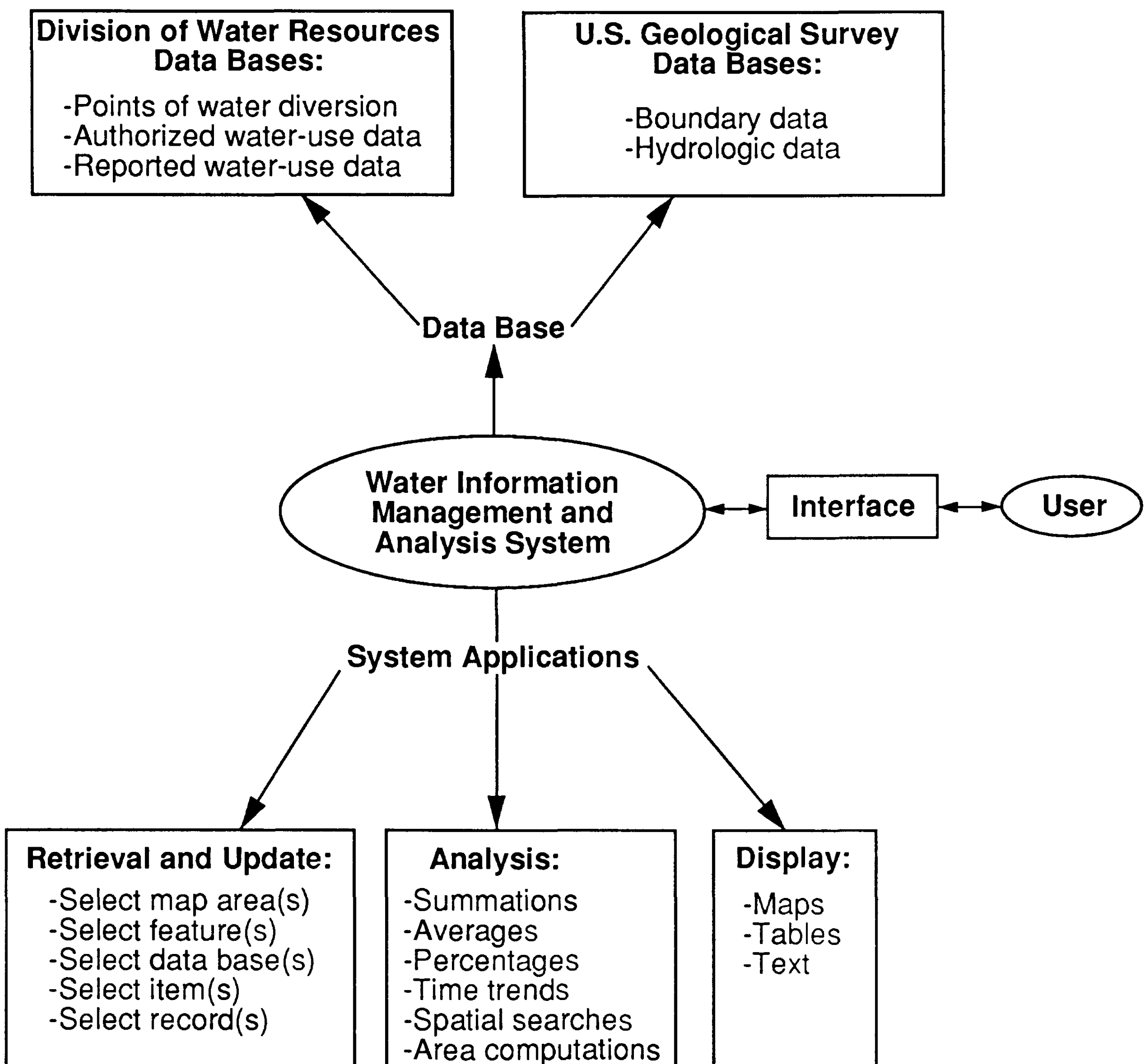


Figure 3. Water Information Management and Analysis System (WIMAS).

base is organized into a series of "coverages" (also known as "data layers" or "data themes"). A coverage is the basic unit of data storage used by ARC/INFO. A coverage is a digital version of a map that contains both the locational and thematic-attribute information for map features in a particular area. Map features are stored as points (for example, irrigation wells), arcs (for example, linear features, such as roads or streams), or polygons (for example, lakes). The associated thematic information (for example, feature name) is stored in feature-attribute tables (ESRI, 1987).

Within ARC/INFO, the feature-attribute tables are maintained by a relational data-base management system (RDBMS). In a RDBMS, the data are stored as simple records where each record contains the thematic-attribute information for a single coverage feature (ESRI, 1987). The RDBMS is advantageous in that, given that each feature in the coverage has a unique identifier, additional feature-attribute tables (that is, data files) can be created and "related" to the original coverage using common or "shared" attributes (for example, the unique feature identifier). The ability to "relate" attribute tables requires that the records in the related tables contain at least one attribute that is also contained in the records of the original coverage. Relational data bases afford the user considerable flexibility as multiple data files can be accessed simultaneously. Moreover, searches can be performed by using any attribute(s), singly or in combination, from any of the related attribute tables. An example of a relational data-base structure is provided in figure 4.

Information obtained from the Division of Water Resources consisted of tabular data files that provide information on points of diversion, authorized water use, and reported water use within the State. Data from the Division of Water Resources was used to develop a coverage for the State, entitled DWRPD, that included 37,854 active points of diversion. Creation of the coverage required two steps. First, a Fortran program was used to convert the locational information from its original format (public-land-survey designation and, in many cases, feet north and west of the southeastern corner of the section) to latitude and longitude coordinates. Subsequently, the resultant coordinate file was used as input to an ARC/INFO routine that automatically generated the coverage. The associated feature-attribute table included such attributes as permit number, county code, basin code, location (township, range, and section

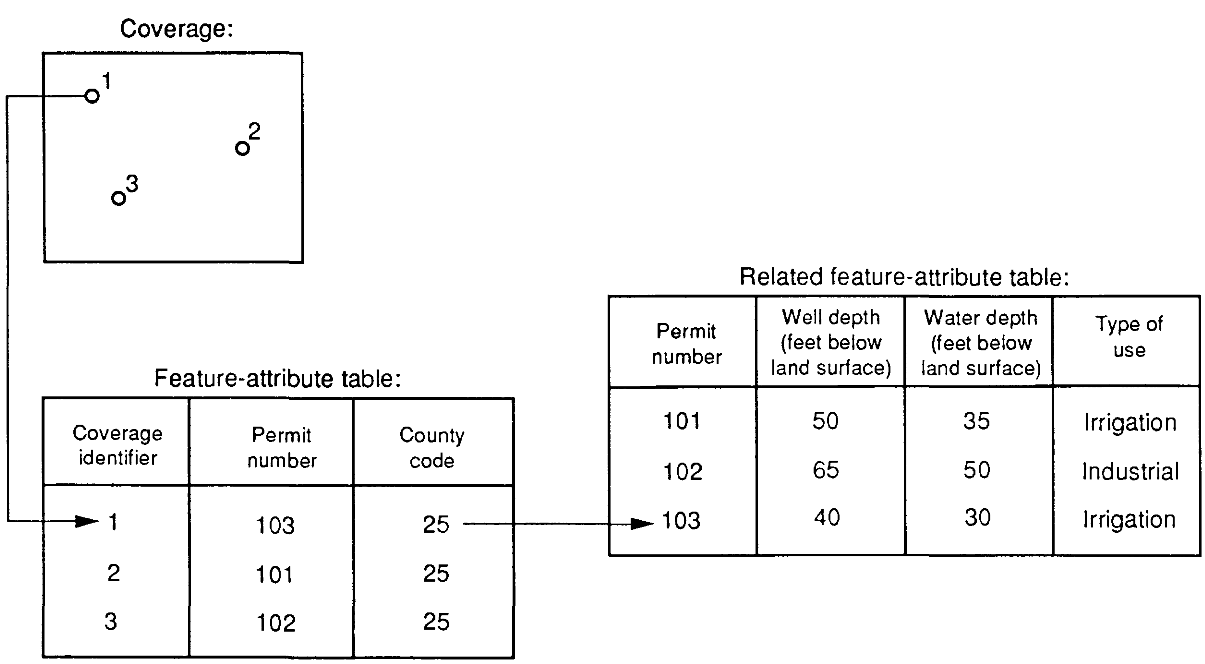


Figure 4. Relational data-base structure.

qualifiers), status code (for example, active or pending), source (surface or ground water), type of use, GMD code, and IGUCA code.

Three additional feature-attribute tables, entitled RATE, QUANT, and DWRWU, also were created and related to the DWRPD coverage using a newly created, unique feature identifier that combined the permit number with the locational information. The creation of the unique identifier was required given the presence of the following situations in the Division of Water Resources' data files: (1) a single permit might have multiple points of diversion, and (2) a single point of diversion might have multiple permits. Thus, in order to assign a unique identifier to each feature, a hybrid attribute was necessary.

The RATE table contains information on authorized water use in terms of permitted rate. Specific attributes include permit number, location, record code (that is, whether the rate applies to a single point of diversion or to a permit that includes several points of diversion), authorized pumping rate (gallons per minute), and the unique identifier. The QUANT table contains information on authorized water use in terms of permitted annual quantity. Specific attributes include permit number, location, record code (as previously defined), authorized annual quantity (acre-feet), and the unique identifier. The DWRWU table contains the reported water-use information. Among the attributes included are permit number, location, address code of the permit holder, report year, hours pumped, pumping rate (gallons per minute), total annual quantity (acre-feet), acres irrigated (when applicable), well depth, water depth, and the unique identifier.

Available coverages incorporated from Geological Survey data bases provided the remainder of the requisite spatial information. A coverage entitled STATE provides the boundary data for the State of Kansas. A coverage entitled COUNTY provides the boundary data for all the counties in the State. In addition, COUNTY includes attributes for county code, county name, and total area, in square miles and acres. A coverage entitled TOWNSHIP provides the boundary data, as well as the township-and-range numbers, for all the townships in the State. A coverage entitled SECTIONS provides the point data for all the section corners in the State. Two coverages, entitled CITIES and PPL, provide information on the cities and towns within the State. CITIES provides the polygon data and proper names for the large cities, and PPL provides the point data and proper names for the majority of the populated places (large and small) in the State.

The remainder of the Geological Survey coverages are water oriented. A coverage entitled RRFILE provides the hydrography data for the State. Specifically, RRFILE provides the arc data, as well as the proper names for all the rivers, streams, and lakes in the State. A coverage entitled HUC provides the boundary data for all the basins in the State. Additionally, HUC includes attributes for basin code, basin area (square miles and acres), and basin name. A coverage entitled GMD provides the boundary data, identification codes, and names for all the GMD's in the State. Finally, a coverage entitled IGUCA provides the boundary data, identification codes, and names for all the IGUCA's in the State.

Software Development

An applications-oriented system, WIMAS is menu-driven and includes numerous on-screen prompts and instructions for ease of use. The applications developed for the prototype system focus solely on the issues of ground-water availability and use. The programming was done exclusively within the ARC/INFO environment by using the ARC Macro Language (AML).

SYSTEM APPLICATIONS

WIMAS was designed to meet the unique data-management and analytical needs inherent in studies of water availability and use. The applications developed are discussed by type.

Water-Availability Applications

System capabilities were developed to provide assistance to State water-resources managers regarding ground-water- appropriations questions. Decisions as to whether a ground-water-right application is approved or denied are based largely on information collected within a 2-mile radius of the application site (M.A. Scherer and L.E. Stullken, Kansas State Board of Agriculture, Division of Water Resources, oral commun., 1991). Accordingly, system capabilities are oriented toward the selection, display, and query of circular, 2-mile-radius areas.

Initially, WIMAS provides the user with the option of either first viewing the entire county or proceeding directly to the township within which the application site is located. If the county option is chosen, the user is prompted to either point to the desired county (on a map of the State) or enter the county name. WIMAS responds with a display that includes the county boundary, hydrography, populated places, wells, and township-and-range boundaries and numbers. The system then instructs the user to point to the desired township.

Alternatively, the user can proceed directly to the township by entering the township-and-range identifiers. WIMAS responds with a display that consists of the township boundary, hydrography, populated places, wells, and section corners. The user then is instructed to specify the application site, which provides the requisite center location for the ensuing 2-mile-radius query and analysis. The application site is specified by its location (that is, feet north and west) relative to the southeastern corner of the section containing the site. The township display then is replaced with an enlarged view of the targeted circular area. The 2-mile-radius circle is drawn with the desired attribute information (that is, hydrography, populated places, wells, and section corners) displayed out to a radius of 3 miles. Additionally, the system displays and identifies any restricted-use areas (GMD's and IGUCA's) that include the application site.

WIMAS then generates a summary report for the 2-mile-radius circle. The report begins with a complete listing of all wells, by permit number, that are located within the circle. Additional attributes listed include the status code, location (township, range, and section qualifiers), authorized annual withdrawal (acre-feet), and the reported annual water use (acre-feet).

The report then gives an evaluation of specific spacing and water-availability criteria that provide guidance on whether or not a ground-water-right application should be approved. Spacing criteria define the minimum allowable distance between an application site and any existing wells that is required. The spacing criterion varies depending on which GMD, if any, the application site is located within. For most locations, the minimum-spacing requirement is 1,320 feet. Within certain GMD's, however, more restrictive spacing requirements are enforced (for example, in one GMD, the minimum-spacing requirement can be as great as 2 miles). Typically, GMD's use a site-specific approach in which the minimum-spacing requirement is directly related to such factors as estimated aquifer-depletion percentage or the requested quantity (acre-feet per year) (M.A. Scherer and L.E. Stullken, Kansas State Board of Agriculture, Division of Water Resources, oral commun., 1991). The summary report indicates whether or not the spacing criterion is satisfied. If it is not satisfied, the report indicates how many wells are located within the minimum allowable distance.

Water-availability criteria impose additional restrictions, which include the maximum allowable ground-water yield (acre-feet per year) for a 2-mile-radius circle. Maximum allowable water yields are GMD-specific. Some are constant, but others are computed by means of a formula. Factors used in the computation include the area of consideration (acres), average saturated thickness (feet), storage coefficient, and average annual recharge (inches per year). Depending on the GMD, the area of consideration might or might not be adjusted to account for those parts of the 2-mile-radius circle that are outside of the GMD boundaries. In all cases, areas of consideration for circles that extend beyond the State boundary are adjusted to include only those parts located within the State (M.A. Scherer and L.E. Stullken, Kansas State Board of Agriculture, Division of Water Resources, oral commun., 1991).

On the basis of maximum allowable water yield, net water availability is computed for the circle. All prior appropriations (including the current application) are totaled and subtracted from the maximum yield to determine the net water availability. In certain GMD's, the application will not be recommended for approval if net water availability is less than zero. The summary report provides the maximum allowable water yield, total prior appropriations, and net water availability for the circle. Finally, the report lists the GMD (that is, the regulations) on which the calculations were based. The start-to-finish progression through the 2-mile-radius-circle analysis is depicted in figure 5. Examples of a computer-screen display and a summary report for a 2-mile-radius-circle analysis are provided in figure 6 and table 1, respectively.

Water-Use Applications

In response to the Geological Survey's interests, WIMAS capabilities oriented toward water-use studies were developed. The prototype system includes county and basin applications.

Initially, the user selects either the county or the basin option from a menu. The user then is prompted to select a specific county or basin by either pointing to it (on a map of the State) or entering the county name or basin number. WIMAS responds with a display that consists of the unit boundary (that is, county or basin), hydrography, major cities, and points of diversion.

Analysis capabilities are accessed through a submenu. Options available include the ability to select, display, and summarize subsets within a county or basin. For example, the user can query for points of diversion that draw from ground water, are used for irrigation, or use ground water for irrigation. In response, WIMAS displays the desired points, computes the total number of points in the subset, computes the percentage of all points represented by the subset, and computes the density of the subset in points per square mile.

A second group of options provides summary information on ground-water withdrawals. The user can query for total withdrawal, as well as use-specific withdrawal, for a county or basin. For example, in response to a request for information on ground water used for irrigation, the system would provide the total volume of irrigation withdrawal (acre-feet per year) and compute the percentage of all ground-water withdrawals represented by that use.

A third group of options provides summary information on annually irrigated lands. The user can query for total, as well as source-specific, acres irrigated in a county or basin. For example, in response to a request for information on acres irrigated by ground water, the system would compute the total acres irrigated by ground water, the percentage of all irrigated acres that are irrigated by ground water, and the percentage of the county or basin that is irrigated by ground water.

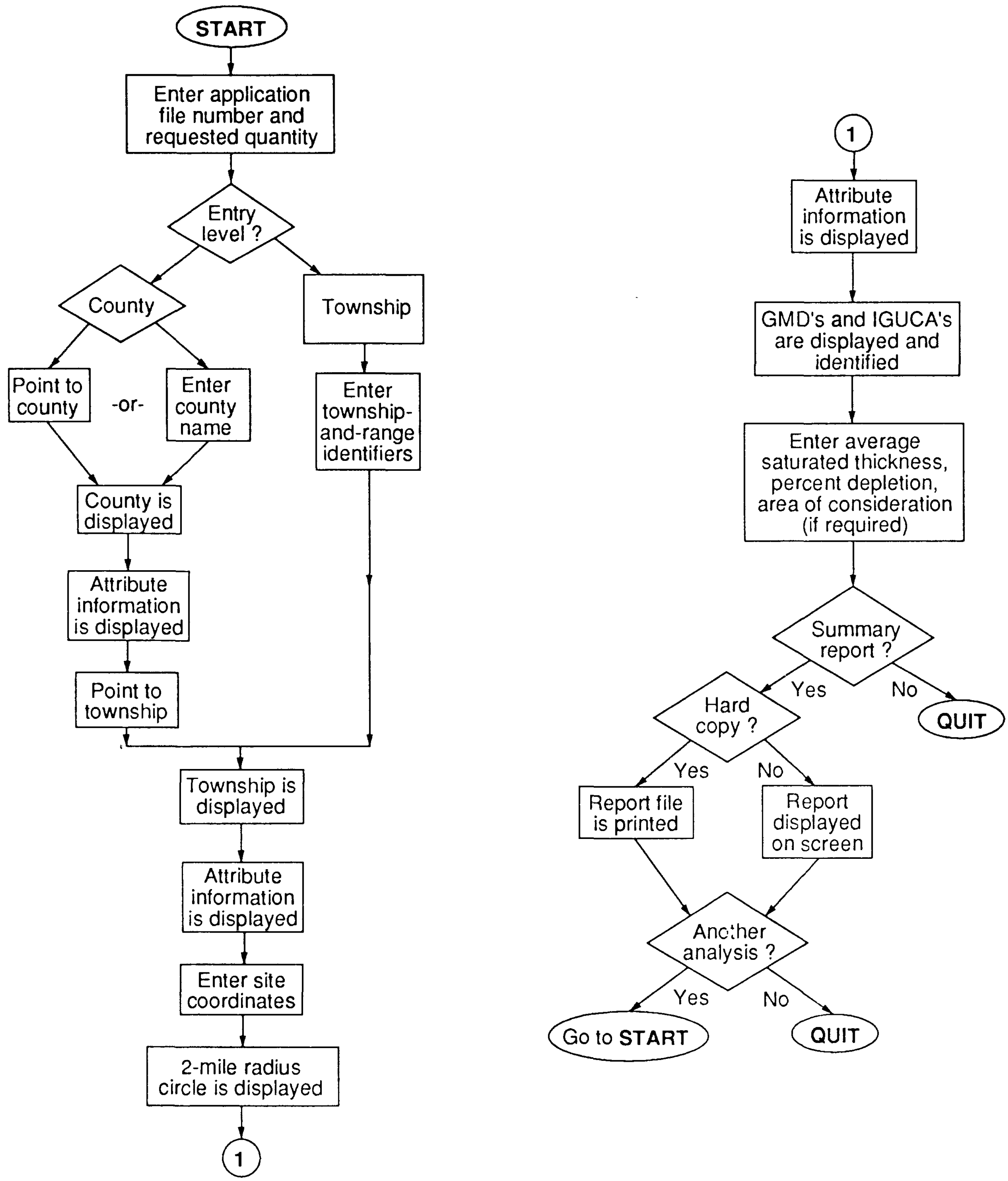
A final option provides information on the annual intensity of ground-water use for irrigation within a county or basin. Intensity is an application rate computed as a ratio of total acre-feet of ground water used for irrigation to total number of acres irrigated by ground water.

The start-to-finish progression through the county-basin analysis is depicted in figure 7. Examples of computer-screen displays for county and basin analyses are provided in figures 8 and 9, respectively.

Future Enhancements

Priorities for future system development include the addition of a surface-water component and the ability to perform various aquifer computations. Concerning the latter, specific examples of applications include the ability to compute mean ground-water level and changes in ground-water level.

System enhancements for the water-availability applications could include the ability to perform computations for GMD's, IGUCA's, and interactively defined areas (for example, boxes, irregular polygons) that might cross existing political and hydrologic boundaries. The selection, display, and query of such areas would provide information regarding the necessity for, and areal extent of, existing and future GMD's, IGUCA'S, and other restricted-use areas. An essential enhancement would be the integration of numerous additional State, regional, and local restrictions on water use that the prototype system does not yet address. Further, information on geology,



EXPLANATION

GMD	GROUNDWATER MANAGEMENT DISTRICT
IGUCA	INTENSIVE GROUNDWATER USE (or special water-quality) CONTROL AREA

Figure 5. Start-to-finish progression through a 2-mile-radius-circle analysis.

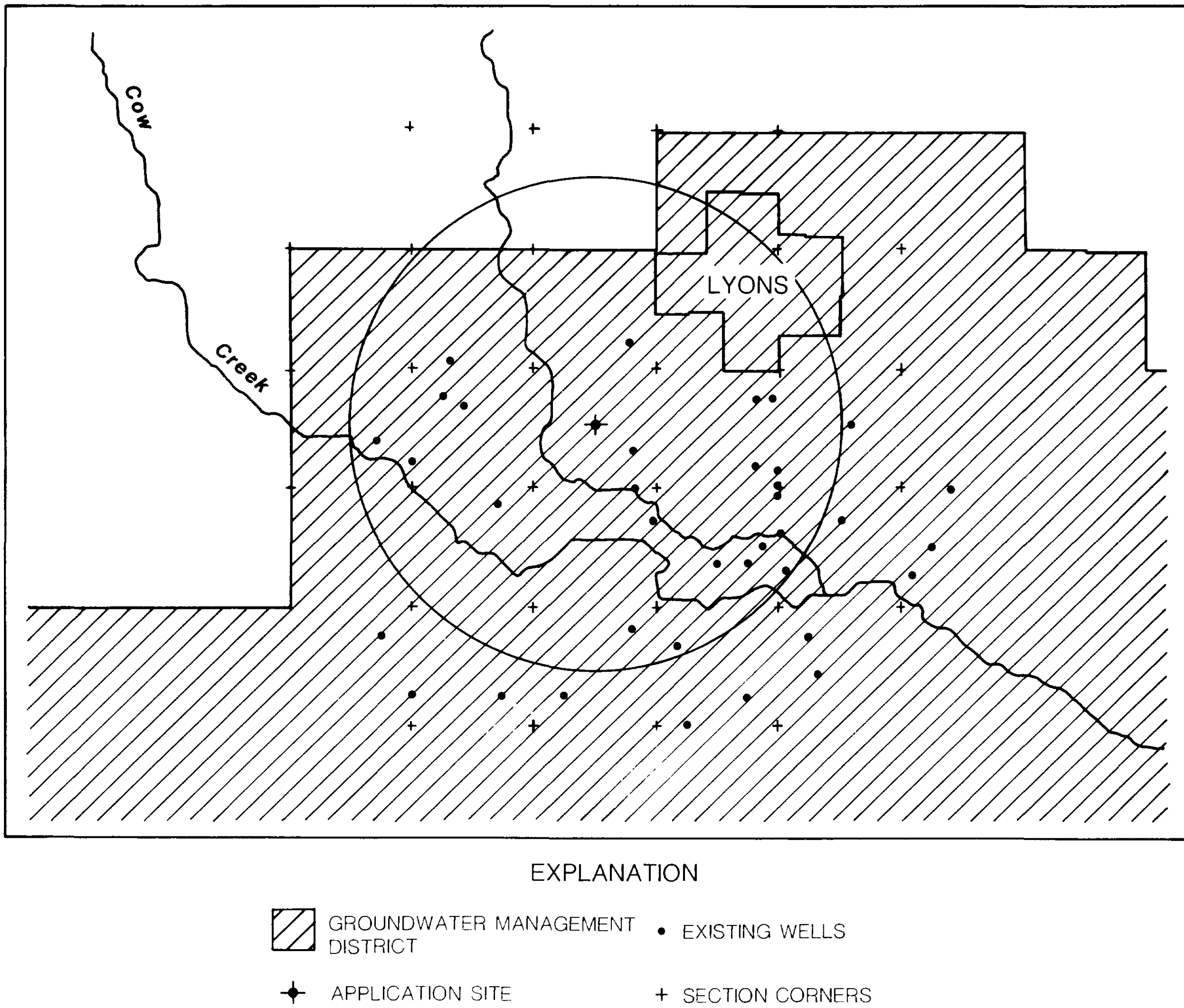


Figure 6. Example of a computer-screen display for a 2-mile-radius-circle analysis.

critical-habitat areas, wetlands, contaminated sites, feedlots, regulated dams, and chemigation licensees ideally could be incorporated into the system (M.A. Scherer and L.E. Stullken, Kansas State Board of Agriculture, Division of Water Resources, oral commun., 1991).

Enhancements for the water-use applications could include the ability to perform use-specific computations. In addition to irrigation, capabilities could be developed to assist in other types of water-use studies, including municipal and industrial withdrawals. Also, the possibility of developing the ability to perform source-specific (for example, river, reservoir, aquifer), water-availability computations could be explored.

SUMMARY

To facilitate and enhance the management and analysis of data concerning water availability and use for irrigation in the Kansas High Plains, the Kansas State Board of Agriculture's Division of Water Resources and the U.S. Geological Survey have undertaken a multiyear study involving the use of geographic information system (GIS) technology. A prototype GIS application, referred to as WIMAS, was developed to provide data retrieval, analysis, and display capabilities that could assist in water-availability and water-use studies. The development of WIMAS involved an integration of data bases independently maintained by the two agencies.

Table 1. *Example of a summary report for a 2-mile-radius-circle analysis*

File no.	Status	Authorized quantity (acre-feet per year)	Reported use (acre-feet per year)	Location
A00520400	NK	209	93	SESWSW 33 03S 42W
A00520400	NK	209	46	SE 33 03S 42W
A00847000	NK	312	51	SWSWNW 33 03S 42W
A00903100	NK	208	170	SE 04 04S 42W
A00869100	NK	126	69	NESWNW 33 03S 42W
A00869100	NK	126	51	NWSWNW 33 03S 42W

This application site satisfies the 1,400-foot spacing requirement.

Maximum yield from circle:	1,430 acre-feet per year
Total approved volume*:	1,290 acre-feet per year
Amount still available:	140 acre-feet per year

*NOTE: The total approved volume includes the requested quantity.

Restricted-use areas: Northwest Kansas GMD #4

GIS applications developed for water-availability studies are oriented toward the selection, display, and query of circular, 2-mile-radius areas and are designed to provide assistance to State water-resources managers for decisions regarding ground-water appropriations. Automated GIS procedures perform a variety of computations and evaluate location-specific spacing and water-availability criteria that help determine whether or not a ground-water-right application should be approved.

Other GIS applications are oriented toward water-use studies. Capabilities provide for the selection, display, and query of individual counties and basins. Automated procedures provide summaries of annual water-use data. Available summary options include total ground-water withdrawals, total acres irrigated by ground water, and intensity of ground-water use for irrigation.

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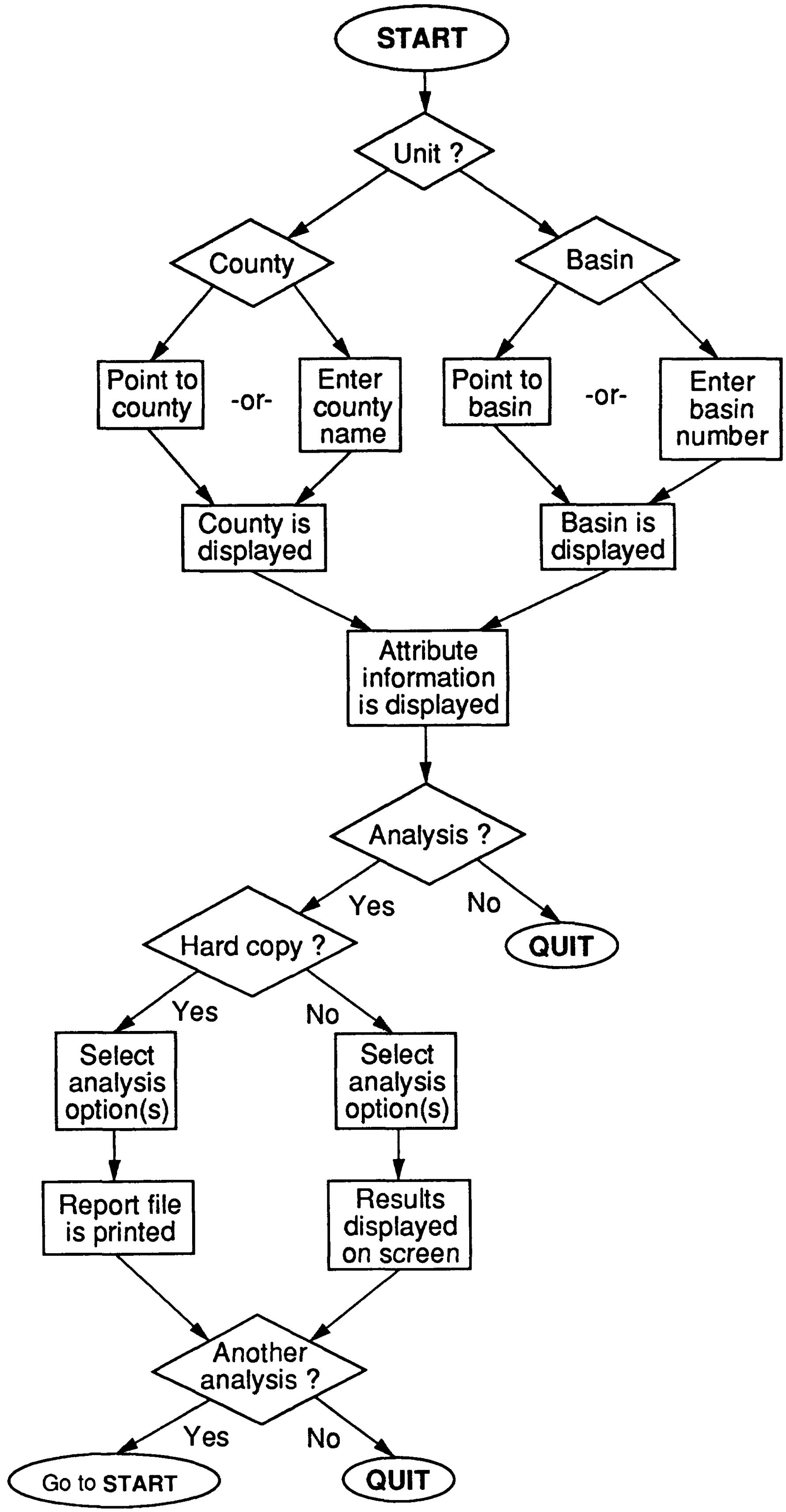
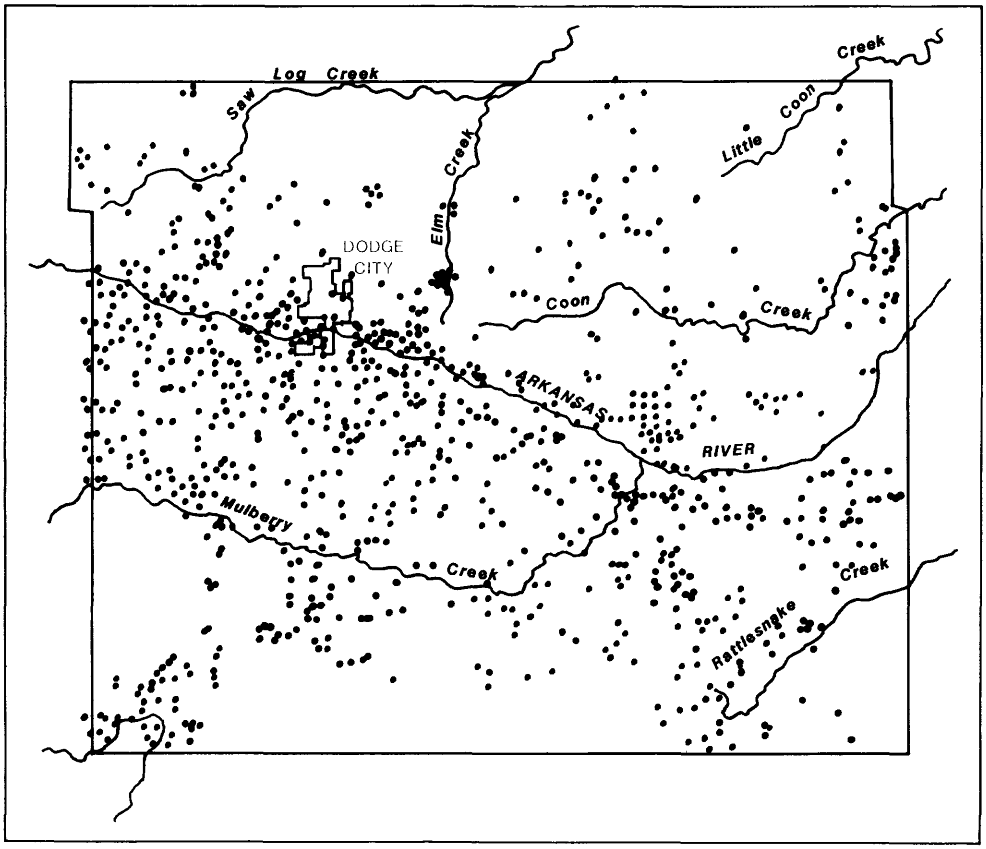


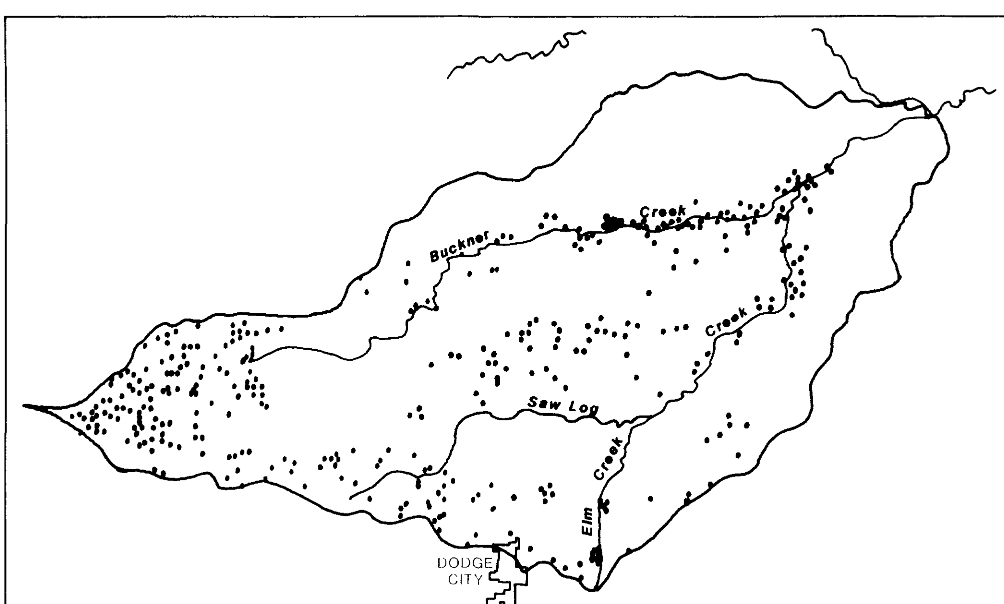
Figure 7. Start-to-finish progression through county-basin analysis.



EXPLANATION

• EXISTING WELLS

Figure 8. Example of a computer-screen display for a county analysis.



EXPLANATION

• EXISTING WELLS

Figure 9. Example of a computer-screen display for a basin analysis.