Kansas Geological Survey

UPPER ARKANSAS RIVER CORRIDOR STUDY: INVENTORY OF AVAILABLE DATA AND DEVELOPMENT OF CONCEPTUAL MODELS

A Kansas Water Plan Project

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Donald Whittemore
Study Coordinator
and
Mingshu Tsou and Julie Grauer
Graduate Research Assistants

Kansas Geological Survey Open-File Report 96-19
May 1996

Conducted in cooperation with the
Kansas Water Office
Southwest Kansas Groundwater Management District No. 3
Division of Water Resources, Kansas Department of Agriculture
Division of Plant Health, Kansas Department of Agriculture
Kansas Department of Health and Environment
Southwest Kansas Local Environmental Planning Group

GEOHYDROLOGY

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Lawrence Hathaway and Truman Waugh of the Analytical Services Section of the Kansas Geological Survey (KGS) analyzed the water samples collected for the study. Jeffrey Schloss, Data Manager of the Geohydrology Section at the KGS assisted in obtaining data for the project. Fritz Kessler, a graduate research assistant in the Geohydrology Section produced ArcView maps of the surface geology, soils, water rights locations, and land use for the 5-county region surrounding the study area.

SUMMARY

This is the second report for the first fiscal year funding of the Upper Arkansas River Corridor Study by the Kansas Water Plan. The first report consisted of a presentation to the Technical Advisory Committee for the study, including problem identification, preliminary research, and FY 1996 and FY 1997 plans. This current report includes an overview of the study, inventories and descriptions of available data and references, description of preliminary conceptual models, assessment of data, procedure for obtaining needed information, and FY 1997 and 1998 plans.

The study area comprises approximately 3,560 mi^2 along the Arkansas River corridor in Hamilton, Kearny, Finney, Gray, and Ford counties. The main problem is the recharge of the alluvial aquifer of the Arkansas River valley by saline river waters from Colorado. The saline waters in the alluvial aquifer are also migrating into the Ogallala aquifer. Infiltration of saline river water diverted for irrigation use is also occurring under irrigated fields, although the water is somewhat diluted by conjunctive use of fresh ground water. The river water seepage results from ground-water level declines that have occurred from consumptive use of well water; the decrease in Arkansas River flow from Colorado has also hastened the rate of water-level declines because there has been less water to recharge the alluvial aquifer. The salinity of the river water entering Kansas derives from substantial concentration of low to moderate levels of natural dissolved solids in the river water and alluvial ground waters by consumptive loss of water to evapotranspiration in Colorado. Dissolved solids contents in return flows in Colorado can be over 5,000 mg/L and in Arkansas River water entering Kansas over 4,000 mg/L.

Flow in the Arkansas River does not decrease appreciably from the Colorado state line through the corridor of alluvium resting in the bedrock channel to southwest Kearny County. Thereafter, diversion for infiltration into the alluvial aquifer and then into the underlying Ogallala aquifer, along with diversion for irrigation, decrease the river flow. The river no longer flows past Deerfield in many years except in periods of heavy rains in Colorado and Kansas and snowmelt in Colorado. The high flow of the summer of 1995 was such an event and resulted in the infiltration of a large amount of water along the entire valley. The water was much fresher than low flows but was still slightly saline at its freshest. Flows continued into western Gray County during the first part of 1996. Other than local precipitation and flow from surface and ground water in small tributaries such as Mulberry Creek, the high flow events are now the main source of recharge to the valley in Gray and Ford counties.

Available data for geology, soils, hydrology, water quality, water rights, and land use were obtained and assessed for use in the study. Many of the data sets are in digital form. Maps were prepared of the surficial geology, soil associations, water-rights locations, and land use classifications using geographic information system software. The amount of geologic information in the lithologic logs of water-well records required since 1975 will aid in producing detailed cross sections across and along the river valley. Water-level data is not as numerous in the 1990s as in the 1980s due to a decrease in the number of measured wells,

although the additional measurements collected by the Division of Water Resources along the corridor will supplement the data. River-water quality records are available for low and moderate flows, although not as numerous at present as in the past. The water-quality data collected for this project during the summer of 1995 is the most extensive information available for high river flows. Ground-water quality records exist from 1939 and the 1940s to the present for the area, but range widely in spatial location and frequency. The irrigation water-quality investigations of the Kansas Geological Survey during the 1970s, monitoring by Groundwater Management District No. 3 from 1988 to 1992, recent monitoring by the Southwest Kansas Local Environmental Planning Group, and the sampling for this study comprise most of the ground-water quality data during the last 20 years.

Although there is general information on the areal distribution of saline ground water in the corridor, data is lacking on the subsurface characteristics of the freshwater-saline water interface. Data for well depths is needed for existing water-quality records. Geophysical logging of existing PVC wells and logging and sampling of multi-level monitoring sites proposed for installation in the river valley and below fields irrigated with river water in FY 1997 and FY 1998 will assist in defining the interface. Preliminary work on a stream-aquifer flow and mass transport model has begun for the Garden City area; the work is assisting in identifying data gaps critical to reliable simulation of the system.

INTRODUCTION

Problem

The Arkansas River in southeastern Colorado and westernmost Kansas is one of the most saline rivers in the United States, and contains more than twice the average dissolved-solids concentration of the river near Hutchinson, Kansas, where the river receives saltwater intruding from underlying bedrock. Consumption of water by evapotranspiration in Colorado has substantially decreased the flow and greatly increased the salinity of the river water entering Kansas. Ground-water levels have declined in the High Plains aquifer in southwest Kansas from decreased recharge from the river and consumptive pumping from the aquifer. Not only have ground-water supplies declined, but also Arkansas River flow entering Kansas from Colorado is lost in the river stretch from the state line to Dodge City. The amount of saline river water entering the subsurface is large; during 1988-1990 the mean total annual flow of the river was over 150,000 acre-feet with an approximate average of 3,600 mg/L of total-dissolved solids. In addition to salinity, the concentration of many other dissolved constituents is high. Thus, poor quality water is constantly infiltrating to and contaminating the ground water in the alluvial aquifer.

Mineralized waters also exist in the alluvial aquifer of the Arkansas River corridor downstream of the area where the saline river water is currently infiltrating. Nitrate concentrations have been observed to be increasing in many well waters in the corridor. Ground-water declines in the Ogallala aquifer have decreased the amount of fresh subsurface flow to the alluvium that can dilute salinity and other constituent concentrations. An assessment of the mechanism and present and possible future extent of the ground water contamination is critical for developing plans for minimizing or mitigating water-quality problems in the aquifers.

History and Description of the System

Before settlement of the Great Plains in the 1800's, the Arkansas River carried moderate loads of dissolved solids primarily derived from Cretaceous bedrock in southeastern Colorado and southwestern Kansas. The dissolved solids inputs entered the river from tributaries and ground-water discharge. During low and moderate flows the river waters were probably slightly saline as they entered Kansas. As the flows passed through southwest Kansas, they could either recharge to or receive discharge from the alluvial aquifer, depending on the amount of flow and the ground-water levels in the aquifer. High-flow conditions following dry periods would be times of greater recharge. However, during flood conditions, the Arkansas River waters were more dilute and could have recharged the alluvial aquifer with fresher waters. The bank storage would then have been returned to the river as discharge in later dry periods after partially mixing with waters in the alluvium. Downstream of Garden City, river flows were diluted by fresh ground-water discharge from the Ogallala aquifer.

Beginning in the 1860's, farmers dug small ditches along the Arkansas River in Colorado to divert water for crop irrigation. Larger canals were then constructed for extensive diversion systems starting in the 1870's in Colorado and the 1880's in southwest Kansas. Evapotranspiration of the diverted waters increased the salinity of ground-water recharge from the fields and irrigation return flows. Studies in the 1960's and 1970's indicated that the dissolved-solids content exceeded 1,500 mg/L in the alluvium of the Arkansas River valley from the state line to Gray County and in parts of the Ogallala aquifer adjacent to the alluvium. Part of the dissolved solids in ground waters underlying diversion ditches and the fields irrigated by the ditch waters has been attributed to concentrated river waters. Ground-water levels rose in the vicinity of the canals and ditches due to leakage.

Large increases in ground-water withdrawals from pumping wells began in the 1950's. The consumptive use caused general decreases in subsurface water levels in large areas of southwest Kansas, including those adjacent to the Arkansas River. The Division of Water Resources declared a moratorium on application permits for water appropriations in 1977 along the Arkansas River corridor in southwestern Kansas due to the concern of coupled ground-water table declines and decreasing streamflows. The U.S. Geological Survey investigated the relationships, including simulation with computer models, and published the results in the early- to mid-1980's. In 1986, the Division of Water Resources established an Intensive Groundwater Use Control Area (IGUCA) along the Arkansas River valley from the Colorado state line to the Ford-Edwards county line east of Dodge City.

Irrigation from diversions of Arkansas River water in southeastern Colorado has increased the salinity of the water flowing into Kansas since the 1870's due to evapotranspiration concentration. Regulation of river flows by the John Martin reservoir beginning about 1950 further increased the salinity problem through increased diversions and consumptive loss by evapotranspiration. The reservoir also decreased total flows into Kansas, and especially reduced the amount of more dilute high flows. The evapotranspiration causes increases in many dissolved constituents to undesirable levels for water use. For example, available data indicate uranium concentrations in Arkansas River water entering Kansas often exceed the proposed federal standard for drinking waters.

The total flow volume in the Arkansas River at Coolidge, Kansas, near Colorado state line averaged 152,000 acre-feet during water years 1988-1990 (October, 1987 to September, 1990). At an average total-dissolved-solids concentration of approximately 3,570 mg/L for this period, the mean annual load of dissolved solids is 640,000 metric tons. Essentially all of the saline water contaminates the ground water in southwestern Kansas under present conditions because only during rare events of very high precipitation does water flow past Dodge City. The average annual amount of saline water equates to contaminating a section of the alluvial aquifer that would extend along the river for 95 miles at a width of 1 mile and a saturated depth of 10 feet, assuming a porosity of 25 percent and complete displacement of existing ground water. Over a 10-year period, that amount of saline water could contaminate a corridor of the same length and width to a depth of 100 feet, or a corridor of the same length and 10 foot depth to a width of 10 miles.

The ground water in the alluvial valley is already saline and may be decreasing in quality as suggested by studies of Groundwater Management District No. 3 (GMD3). The average dissolved-solids concentration of ground water at depths less than 150 feet in the IGUCA is in the range 2,000-2,300 based on data of the GMD3 and the KGS. Ground waters in the IGUCA at greater depths average about 1,500-1,700 mg/L. The additional, constant input of water that is more saline than the ground water existing in the IGUCA can only lead to contamination of water supplies as the saline water flows farther outwards and to greater depths in the system.

Depths to water in the alluvium are shallower than in the upland areas of the Ogallala aquifer, resulting in faster response of the ground water to surface contamination than in the Ogallala aquifer. Increasing nitrate concentrations in the alluvial aquifer do not appear to be mainly from infiltration of Arkansas River water entering Kansas because the river nitrate levels are generally lower than the ground-water concentrations. Nitrate contents are also increasing downstream of the area where the river waters have provided substantial recharge in the last twenty years. Thus, nitrate increases are probably related to other surface sources.

Policy or Management Actions Affecting the Ground-Water Contamination

Consumptive use of the water and evaporation from reservoirs will probably continue to occur and concentrate dissolved salts in Colorado. There is a question as to whether increases in flow could recharge the alluvial aquifer enough to allow some of the saline river water to flow far enough downstream to be diluted by recharge in the Great Bend area. Major reductions in irrigation diversions and reservoir storage may be required before restoration of Arkansas River water to a quality that would not contaminate ground waters.

Decreases in pumping along the IGUCA probably would slow the movement of the saline contamination to greater depths and outward from the river. However, long-term management solutions will be needed to protect especially valuable water resources for urban, industrial, and agricultural uses. Creation of areas where reduced or no pumping is allowed between the river and the pumping wells of special value could partially protect the water quality. Other options such as development of ground-water ridges along selected stretches of the river could protect parts of the usable aquifer system while allowing the saline river water to recharge ground waters in areas with relatively high concentrations of existing dissolved solids. Diversion of river waters for irrigation use could be protecting some areas of high-value waters from further additions of saline infiltration. Management of the quantity and location of diversions and the amount of leakage from diversion canals could be included in quantity-quality planning. Determination of the natural contribution of salinity (derived from Cretaceous bedrock and from evapotranspiration without irrigation) in comparison to that generated by past and current irrigation in Kansas is needed to determine the effect of future changes from Arkansas River recharge. Long-term assessment of the rates and patterns of ground-water salinity increases, as well as increases in associated constituents such as uranium, under various streamflow, pumping, and climatic scenarios will be important to both planners and present water users. The plans must also consider nitrate contamination from sources not related to the salinization.

Objectives

Basic Objectives:

The basic objectives comprise major parts of the objectives listed under the water-quality and ground-water decline issues in the subsection on the Arkansas River Corridor Subbasin in the Upper Arkansas Basin section of the Kansas Water Plan:

A. Water-Quality Issue: Document the fate and effects of contaminated Arkansas River flows on the alluvial, Ogallala, and Dakota aquifers in the river valley.

B. Ground-Water Decline Issue: Clearly establish the links among decreased flow in the Arkansas River, increased levels of water contamination in the alluvial, Ogallala, and Dakota aquifers, and lowered ground-water tables.

Component Objectives:

1. Characterize the current water quality of Arkansas River water entering and flowing in southwest Kansas
2. Determine the present extent of ground-water contamination in the Arkansas River corridor from the Colorado-Kansas state line to Dodge City, including the nature and location of the saline-freshwater interface.
3. Determine the salinity sources in past and current Arkansas River waters in the corridor, including natural versus human components.
4. Document the fate of Arkansas River waters currently entering Kansas.
5. Assess the current movement and predict future changes in the movement of the saline-freshwater interface within the alluvial, Ogallala, and Dakota aquifers resulting from ground-water declines.
6. Determine the sources, rate of change, and fate of increasing nitrate concentrations in the alluvial and Ogallala aquifers in the river corridor.
7. Predict changes in the quality of Arkansas River water and the impact of changes in the river quantity and quality on ground-water levels and quality in the alluvial, Ogallala, and Dakota aquifers.
8. Propose and determine the effects of possible management and protection strategies and remediation measures on ground-water levels and quality.

Scope of Work

The study was proposed as a 5-year plan to be conducted in cooperation with the Kansas Water Office, Kansas Department of Health and Environment, Division of Water Resources and Division of Plant Health in the Kansas Department of Agriculture, Southwest Groundwater Management District No. 3, and other appropriate state, local, and/or federal agencies. An Interagency Technical Advisory Committee to be established by the Kansas Water Office will assist in the design and review the program. The Kansas Geological Survey will coordinate the research and conduct and design hydrogeological and geochemical parts of the program investigations. The duration and total scope of the study will depend on the needs and support for the work as determined by the cooperating agencies and funding sources.

First Year of Study

1. Appraisal of existing water-quality and quantity conditions and determination of data needs

The first year of the research program will focus on an appraisal of water-quality and quantity conditions in the upper Arkansas River corridor and development of specific data collection and simulation research efforts. Existing data for river-water quality and flow, ground-water quality and levels, climate, geology, and land and water use and management will be examined to document past and current conditions and determine additional information needed for predicting future changes and developing management and remedial plans. The information will include upstream parts of the Arkansas River valley in Colorado that affect water quality and flow of the Arkansas River. Maps and cross sections will be prepared showing the distribution of saline-water-freshwater interfaces along the corridor. Sampling of river flow and ground waters in the Arkansas River corridor begun in preliminary studies will continue to provide additional information for mapping salinity and characterizing the extent of the problem. Results of the appraisal will be used to design research for subsequent years of the research program to obtain the needed data and develop appropriate hydrogeologic and hydrochemical models for the river corridor.

2. Development of initial conceptual models and selection of appropriate computer model for predictive purposes

Both conceptual and quantitative models will be necessary for determining the future fate of contaminated Arkansas River water and its effects on fresh ground waters in the corridor, and the relationship to ground-water declines from pumping. An initial conceptual model of the hydrogeological and chemical system will be prepared by the end of the first year of study for use in selecting a computer model that is appropriate for predicting the effect of possible future changes. For this selection, ideas must be formulated on what types of changes might occur under different water-use situations. To assist in this process, a preliminary list of possible management, protection, and remediation plans and strategies will be developed during the first year for review by local and state agencies. Preliminary conceptual models of the source, fate, and transport of selected constituents of concern will also be prepared.

3. Assessment of water-quality changes

Appreciable decreases in flow and substantial increases in the salinity of Arkansas River water entering Kansas have been caused by evapotranspiration losses and concentration, respectively, of river and ground water used for irrigation in Colorado. The first year of the comprehensive research program will consider findings obtained and how the research should be further designed to integrate possible changes in Arkansas River flow and quality. A preliminary assessment will be made of the past effect of water-use in Colorado on the quality of Arkansas River water entering Kansas and of the type of information and approach needed for estimating water-quality impacts.

First Year Deliverables

1. Technical Advisory Committee

A Technical Advisory Committee (TAC) was formed to review plans for FY 1996, including the development of an overall plan of study for the project with targeted tasks coordinated and (assigned time lines) scheduled over the next four years, definition of the ground-water decline and water-quality problems within the stream corridor, definition of the stream corridor and study objectives. The TAC comprises the Kansas Water Office (KWO), Kansas Geological Survey (KGS), Division of Water Resources (DWR) and Division of Plant Health (DPH) of the Kansas Department of Agriculture (KDA), Kansas Department of Health and Environment (KDHE), Southwest Groundwater Management District No. 3 (GMD3), Southwest Kansas Local Environmental Planning Group (SWKLEPG), Kansas Conservation Commission, and Kansas Department of Wildlife and Parks (KDWP). In addition, the federal Natural Resources Conservation Service (NRCS, former Soil Conservation Service) assists the TAC in conduction with the membership of the Kansas Conservation Commission.

The first meeting of the TAC was held on October 13, 1995 in Dodge City at the KDHE offices. The main focus of the meeting was a presentation of the study by KGS to inform local, state, and federal agencies of activities and plans in order that agency staff could contribute to the study's objectives through cooperative efforts and advise. The presentation included a discussion of (1) the problems and issues leading to the need for the study, (2) preliminary research work leading to the study plans, (3) the FY 1996 study plans, and (4) the proposed FY 1997 activities. A report was prepared (Whittemore, 1995) and mailed, along with the minutes of the meeting to the TAC members and attendees at the first meeting. An additional meeting is planned for FY 1996 to discuss the results and plans for the next FY as well as for the rest of the project.

2. Report on Inventory of Available Data and Development of Conceptual Models

This is the current report which describes the development of conceptual models of the hydrogeologic system and water quality distribution and pathways, and outlines the establishment of a data collection strategy to fill data gaps within existing databases and to monitor and verify resulting models of the stream corridor system. This report provides an inventory and description of available data and indicates geographic areas lacking water quantity and quality data within the stream corridor.

3. Report on Hydrogeology and Water-Quality Characteristics and Assessment of Flow and Mass Transport Models

This is the report due at the end of FY 1996 which assesses the selected flow and mass transport computer models which can appropriately simulate water exchange between the river and aquifers, allowing for impact analysis of streamflow and water-table effects, sensitivity analysis as to altered conditions stemming from changes in these effects and a predictive capability for evaluation of management options. An interpretative analysis of the existing hydrogeologic and water-quality characteristics of the stream corridor will be reported, along with maps and cross sections of geology, water levels, and water quality.

Description of Study Area

The study area was selected as the Arkansas River corridor from the Colorado-Kansas state line through Hamilton, Kearny, Finney, and Gray counties to the eastern boundary of Ford County (Figure 1). The area includes the Intensive Groundwater Use Control Area (IGUCA) of the upper Arkansas River valley, the ditch irrigation of Hamilton, Kearny, and Finney counties, the Garden City Study Area of the DWR, and a buffer zone outside of these two areas that will allow determination of the transition from saline water in the river valley to freshwater in the Ogallala aquifer. The northern and southern borders of the study area are township boundaries such that there is a buffer of at least 6 miles outside the IGUCA and DWR Garden City Study Area. The study area comprises 97 complete township blocks and half of 4 townships along the western edge of Hamilton County for a total area of approximately 3,564 mi^2. The number of township blocks and total areas by county are approximately 18 and 648 mi^2 in Hamilton, 19 and 684 mi^2 in Kearny, 22 and 756 mi^2 in Finney, 16 and 576 mi^2 in Gray, and 23 and 900 mi^2 in Ford County, respectively.

INVENTORY OF REFERENCES

A data base of references for the study area and the Arkansas River corridor in eastern Colorado was assembled by examination of hard copy publications and computer searches. The computer searches were conducted using bibliographic data bases of the KGS, Georef, and the USGS Selected Water Resources Abstracts (SWRA). The KGS data base used is on a CD-ROM and contains references for geologic, hydrologic, and mineral and energy resources subjects related to Kansas. Georef is an international bibliographic data base for the geological sciences, including hydrogeologic subjects. It was accessed through an on-line connection from the KGS through the University of Kansas library.

The key words used for the searches in the KGS and Georef data bases were Arkansas River, hydrogeology, salinity, water quality, Hamilton County, Kearny County, Finney County, Gray County, and Ford County as associated with Kansas. Selected of these key words were also used in the search of the USGS SWRA. During or after each search, the references retrieved were inspected and all citations not relevant to the study were not selected or were removed from the extracted file, respectively.

A program was written to convert the file of extracted KGS references into a tab-delimited form, with all data fields in a uniform order, that could be imported to EndNote Plus 2. EndNote is a commercial software package for storing, managing, and searching for bibliographic references, and automatically building lists of cited works. The reference data were imported into the Generic reference type, which is the most flexible arrangement of data fields in EndNote for the purposes of this study.

The reference data in Georef is formatted with two-character tags preceding each field. The extracted reference file was imported to EndNote using the companion software EndLink

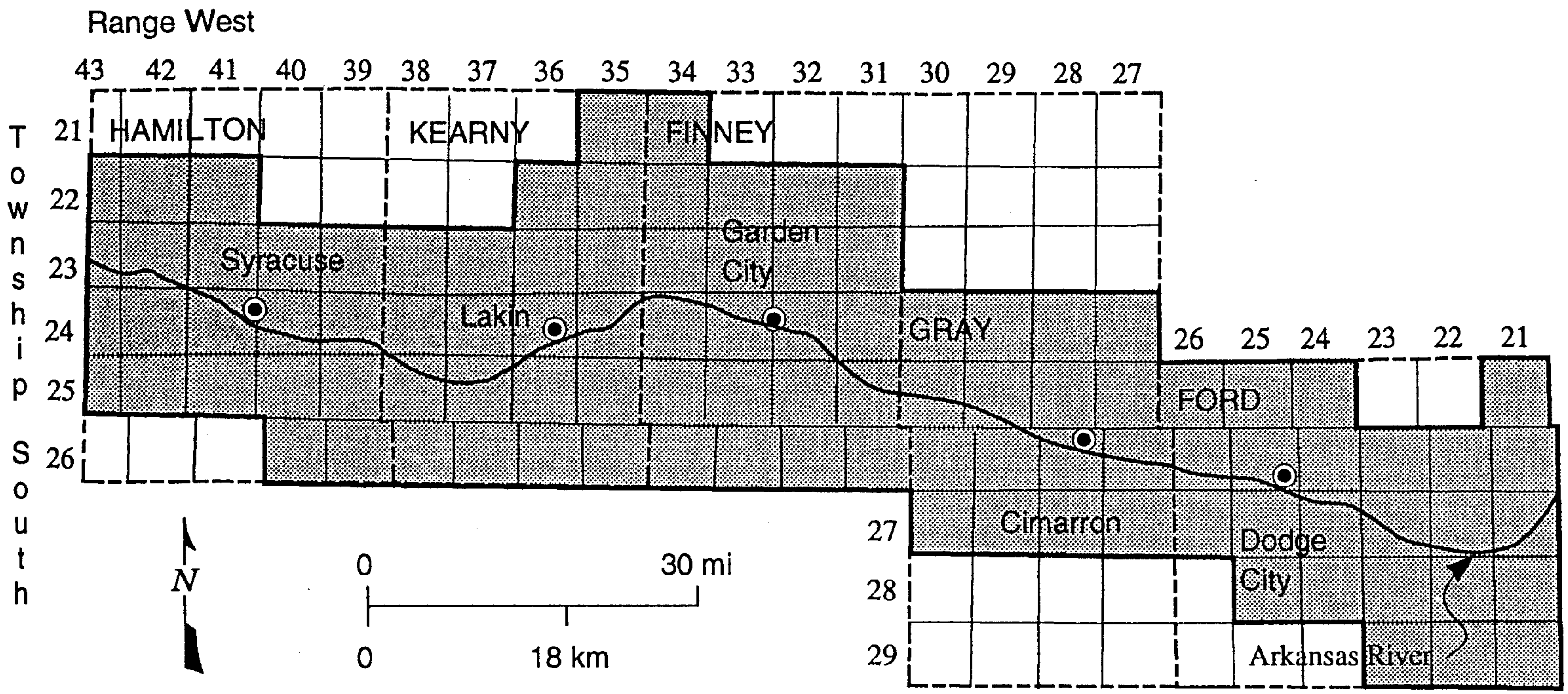

Figure 1. Location of the area of the Upper Arkansas River Corridor Study within the 5-county region. The study area boundary is the bold line.

2. EndLink 2 is an import module that enables EndNote to import data files saved from a variety of on-line services, CD-ROMs, and library data bases. The Silver Platter filter in EndLink was used to interpret the tags of the information fields in the Georef data base. The data were imported into the same reference type (Generic) used for the KGS references.

References were selected from the SWRA via the USGS World Wide Web pages available on the internet. The references were typed into the Generic reference files in the EndNote data base. The number of the additional references found in the SWRA that were not duplicated in the KGS and Georef data bases was relatively small and made this approach to input appropriate at the time.

All of the references were assembled into one data base in EndNote. The references can be searched and subsets of the bibliography based on keywords can be extracted using EndNote. The entire bibliography was also exported to a Microsoft Word file for formatting for printing. The printed data base appears at the end of this report under the section "Bibliographic Data Base".

INVENTORY AND DESCRIPTION OF AVAILABLE DATA

Geology

Surficial Geology

Information on the surficial geology of the study area is needed for assessing the character of materials which would affect land use and infiltration of rainfall at the land surface, and delineating the surface exposure of different types of aquifers. The KGS has prepared a digitized map of the surficial geology of the state. The geology coverage for the area of Hamilton, Kearny, Finney, Gray, and Ford counties was extracted and used to prepare a colored map at a scale of 1:500,000 for the Upper Arkansas River Corridor (UARC) Study. The geographic information software (GIS) package ArcView on a Sun Unix workstation was used to generate the map. A more detailed coverage of the surficial geology of Finney County as mapped at a 1:50,000 scale by W. Johnson and Arbogast (1993a, 1993b) has also been digitized by the KGS. The coverage has been transferred to the Geohydrology Section for use in this project.

Subsurface Geology

Characterization of the subsurface geology of the river corridor is required for improving delineation of the boundaries of the Ogallala aquifer with the overlying alluvial aquifer and underlying Dakota aquifer or confining layer, and estimating the relative flow properties of different layers in the alluvial and Ogallala aquifers. For example, it is known that in the Garden City area there is an upper and lower aquifer in the High Plains aquifer with a less permeable zone separating the two. However, the extent and continuity of this zone is not well known.

The depth to the bedrock surface is needed for saturated thickness calculations. The geology of the bedrock underlying the High Plains aquifer is important for determining hydrologic connections with bedrock aquifers. Most of the bedrock underlying the High Plains aquifer or surface loess in the study area is either Upper Cretaceous shales and chalks or Lower Cretaceous shales and sandstones.

Published information

Most of the subsurface geologic data for the High Plains aquifer in the study area is contained in the following publications: McLaughlin (1943) [Hamilton and Kearny counties]; Lobmeyer, and Sauer (1974) [Hamilton County]; Gutentag, et al. (1972) [Kearny County]; Dunlap et al. (1985) [Kearny and Finney counties]; Meyer et al. (1969, 1970) [Finney County]; Gutentag et al. (1972) [Finney County]; Latta (1944) [Finney and Gray counties]; McGovern (1974) [Gray County]; Waite, (1942) [Ford County]; Spinazola, and Dealy (1983) [Ford County]; Gutentag et al. (1981) [southwest Kansas]. Most of these publications include geologic cross sections, although many of the cross sections do not include information on different lithologies in the High Plains aquifer but only the thickness of the aquifer and the different underlying bedrock units.

The subsurface geologic information for the Dakota aquifer in the area of the upper Arkansas River corridor is either contained in reports and papers of the Dakota Aquifer Program or in publications cited in the Program documents. Relevant references were included in the bibliographic inventory listed at the end of this report and in the reference list of a Dakota Aquifer Program report such as Macfarlane et al. (1994). Maps of the Dakota Aquifer Program show the boundary between the Dakota aquifer subcrop beneath the High Plains aquifer, where the Dakota aquifer is in contact with the High Plains aquifer, and the confined portion of the Dakota aquifer where overlying Upper Cretaceous rocks separate the High Plains from the Dakota aquifer.

Water well records

Since 1975, Kansas regulations have required that anyone drilling a water or monitoring well file a water well record (WWC-5) form. The form includes information on the location, use, and construction of the well, and geologic strata encountered during drilling (lithologic log). Hard copies of the forms are kept at the KGS and the Kansas Department of Health and Environment (KDHE). The KDHE also digitizes the records for use as a computer data base. The KGS has obtained the computer data base and receives updates every half-year. The data is in the relational data-base management program called Microsoft Access on a PC microcomputer.

The well records for Hamilton, Kearny, Finney, Gray, and Ford counties were extracted from the state-wide data base and transferred to another microcomputer for use in this project. The data set represents the latest digital update (November 1995) available from the KDHE. The much smaller data base for the project specific area of the upper Arkansas River corridor allows much faster queries than from the state-wide data base. The data were then transferred from the project data base by county into the spreadsheet program Microsoft Excel for processing.

The well locations are present in legal form (township, range, section) on the WWC-5 form. The location within a section are designated by letters for compass directions for quarters, halves, and/or corners. Sometimes a "near center" designation may also be given. The section locations were converted to the "A, B, C, D" method for identifying quarters used by the U.S. Geological Survey (USGS) and the KGS. A Fortran computer program was written to perform the operation on all common designations and identify all non-standard representations. The non-standard designations were converted manually. After this conversion was complete, the well locations were then also converted into latitude and longitude coordinates using the computer program LEO211 of the KGS. The latitude and longitude coordinates are required for location for mapping purposes in the GIS software packages Arc/Info and ArcView.

The totals of well records in the WWC-5 forms within the study area of the upper Arkansas River corridor by counties are Hamilton 192, Kearny 726, Finney 2,040, Gray 1,003, and Ford 1,763. A computer program was written to sort the well-record files and determine the number of records per township. Figure 2 is a map of the distribution of wells in the WWC-5 forms by township. The map shows graphically that, in general, there are appreciably more wells associated with the cities and towns in the study area within the 5 counties than in areas distant from the towns. The distribution is also related to the presence or absence of sufficient saturated thickness in the High Plains aquifer to yield adequate supplies of water to wells. Another factor is that the WWC-5 forms were not required until 1975, therefore, the areas with more wells in Figure 2 represent relatively recent locations of wells and ground-water development. The densities of well records for the portion of each county in the study area are 0.3 per mi^2 in Hamilton County, 1.1 per mi^2 in Kearny County, 2.7 per mi^2 in Finney County, 1.7 per mi^2 in Gray County, and 2.0 per mi^2 in Ford County.

<u>Geophysical logs</u>

Exploration for oil and gas has occurred across much of the study area. Newer boreholes drilled during petroleum exploration generally will be logged using geophysical equipment. Although the upper geologic layers are not always logged, some logs are run to near the surface. The gamma-ray and resistivity records from such logs could be of value to the study for determining the depths and thicknesses of major clay and aquifer units in the Arkansas River corridor. The KGS has a repository of a large number of geophysical logs run by the oil and gas industry.

Soils

The Soil Conservation Service (now the National Resources Conservation Service [NRCS]) has published soil surveys for all of the 5 counties within the study area: McBee et al. (1961) Hamilton County, Salee et al. (1963) Kearny County, Harner et al. (1965) Finney County, Tamasu and Roth (1968) Gray County, and Dodge et al. (1965) Ford County. The NRCS has also digitized data and boundaries for all soil associations in Kansas. There are 35 soil associations within the Hamilton, Kearny, Finney, Gray, and Ford counties region. The [redacted] [redacted]

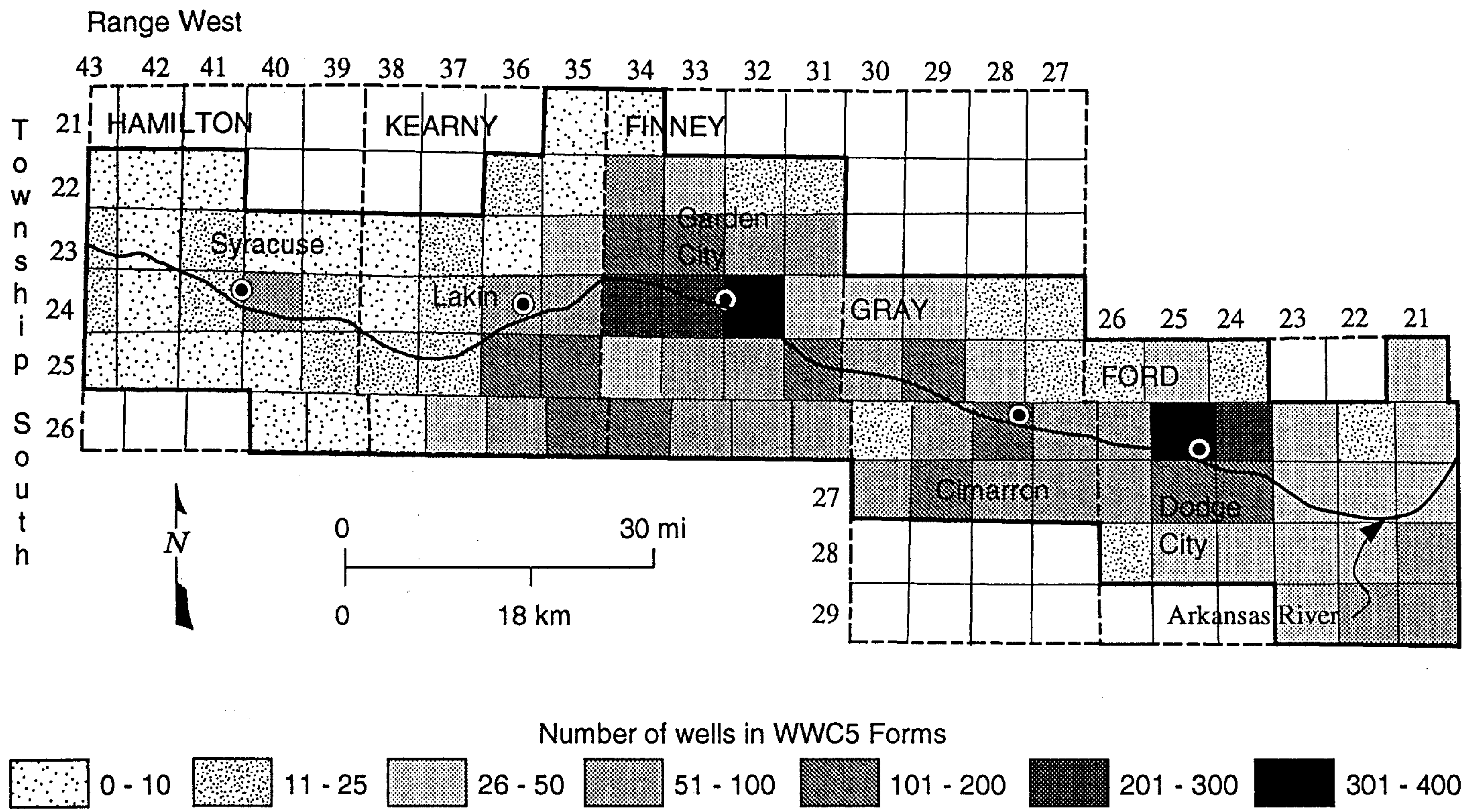

Figure 2. Number of wells in WWC5 forms per township in the Upper Arkansas River Corridor Study area. The study area boundary area is the bold line.

associations are named according to the three soil series comprising the greatest acreages within each association, for example, Spearville-Harney-Richfield.

A colored map for the soil associations in the 5-county region encompassing the study area was prepared at a scale of 1:500,000 using ArcView. The soil associations were ordered according to generally increasing permeability on the basis of increasing sand and decreasing clay content. The association order was used for grouping associations with similar textures. The association groups include silty clay loams to silt loams, clay loams to loamy sands, silt loams to silty clay loams, silt loams, silt loams to fine sandy loams, find sandy loams to silty loams, and loamy fine sands to fine sands, in order or increasing permeability. The groups and textures within groups were used to select the color schemes for the ArcView map. The same color was used for different associations with the same textures for the three main soil series in an association. The associations were numbered and the numbers used on a smaller reference map to assist in identifying different associations.

Hydrology

Characterization and quantification of aspects of the hydrology of the study area are necessary for both conceptual and mathematical models of the water flow and budget in the system, including determination of the link between the Arkansas River and ground-water-level declines, and the transport of salinity and other dissolved contaminants. Information on inputs to the system include data on precipitation and surface recharge, Arkansas River flow from the Colorado-Kansas state line, and subsurface flow of water from the High Plains and bedrock aquifers into the study area. Water outputs comprise evapotranspiration, river flow, and ground-water discharge.

Precipitation and Evapotranspiration

Precipitation data for Kansas are available at the KGS in digital format on a CD and hard disk computer files. There are several observation sites within the study area (Figure 3). Although most of these are for precipitation and temperature, Garden City and Dodge City include measurements of humidity that may be used in calculations of evapotranspiration and climatic indices. Data for climatic indices, such as the Palmer drought severity index, are also in computer files at the KGS and can be useful for examination of soil moisture and recharge characteristics.

Surface Water

Arkansas River

Essentially all of the surface water in the study area comprises flows in the Arkansas River and irrigation ditches. There are currently 4 stations that gage Arkansas River flow; these stations are located near Coolidge, at Syracuse, Garden City, and Dodge City. Table 1 gives information on these stations and available data, as well as other stations at which discharge has been measured within the last 20 years. Data is available from the Water Resources Division of the USGS in Lawrence. Selected sets of digital data have been

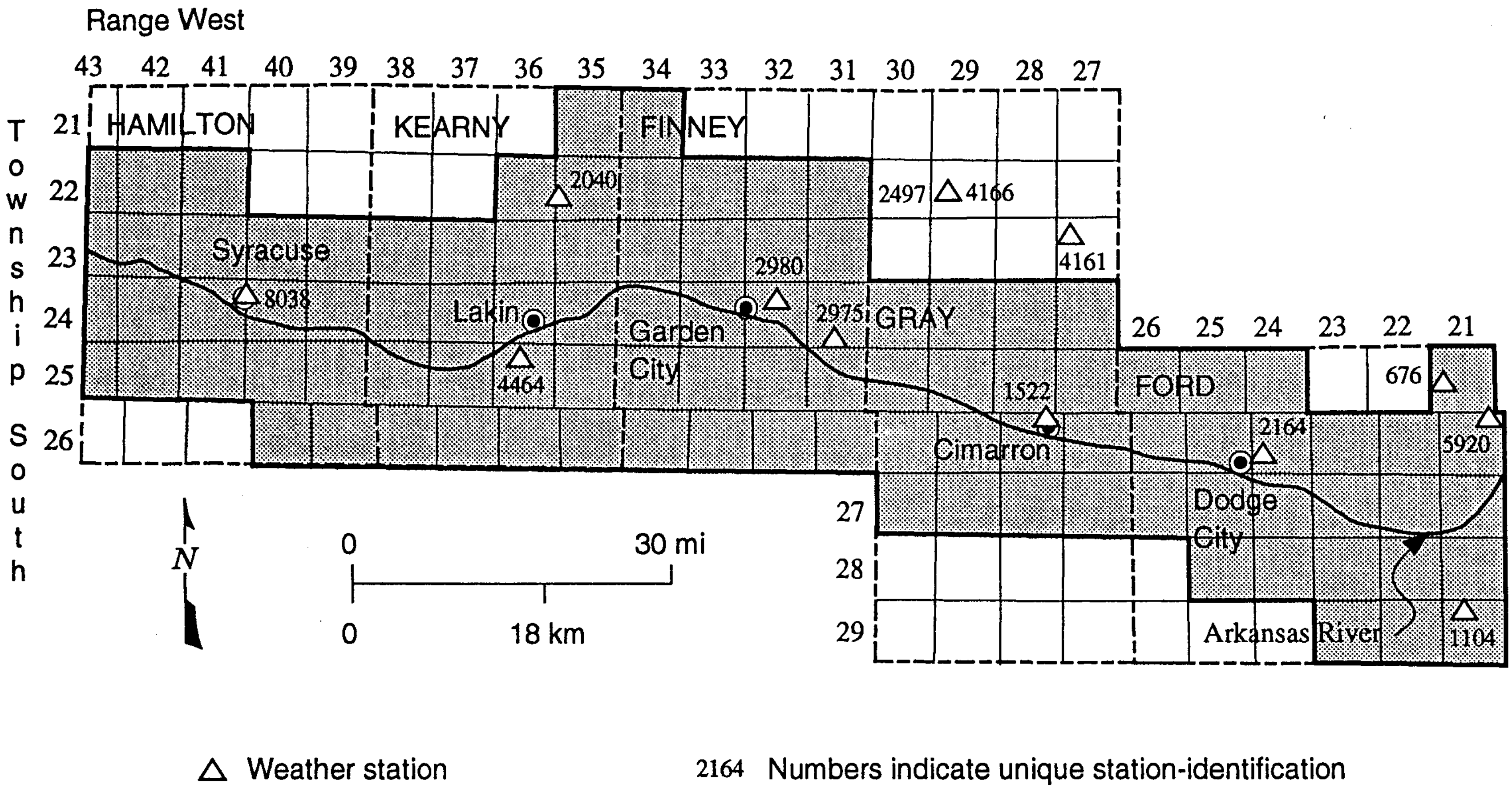

Figure 3. Location of precipitation stations in the 5-county region enclosing the Upper Arkansas River Corridor Study. The study area boundary is the bold line.

transferred by FTP from the USGS data-base files after extracting the data using their ADAPTS system via TELNET. One limitation with recent data is that the flow values may not available at some stations until corrected for new rating curves such as after the large flows of the summer of 1995.

Table 1. Characteristics of federal gaging stations with flow records during some period within the last 20 years in the Arkansas River corridor study area.

Station name	Station number	Legal location	River mile	Period of record
Frontier Ditch near Coolidge	07137000	23S-43W-21ADC	-	Oct 1950 - present
Arkansas River near Coolidge	07137500	23S-43W-26BAB	1099.3	May 1903 - Oct 1903 Mar 1921 - May 1921 Oct 1950 - present
Arkansas River at Syracuse	07138000	24S-40W-18BDB	1080.9	Aug 1902 - Sep 1906 Oct 1920 - present
Arkansas River at Kendall	07138020	24S-39W-25DCC	1066.7	Apr 1979 - Sep 1982
Arkansas River below Amazon diversion	07138062	25S-38W-12BBB	1059.7	Apr 1977 - Sep 1982
Arkansas River at Lakin	07138065	24S-36W-34ADB	1044.9	Apr 1978 - Sep 1982
Arkansas River at Garden City	07139000	24S-32W-19BDB	1024.2	Jun 1922 - Jun 1970 Oct 1986 - present[a]
Arkansas River at Dodge City	07139500	26S-25W-35BCC	970.9	Oct 1902 - Sep 1906 Sep 1944 - present[b]
Mulberry Creek near Dodge City	07139800	28S-25W-24B	-	Mar 1968 - Sep 1990

[a] July 1970 to September 1986, flood hydrograph record.
[b] Gage-height records collected at same site at different datum 1909-1932 are contained in reports of U.S. Weather Bureau.

Irrigation ditches

There were 8 irrigation ditches or canals diverting water from the Arkansas River prior to 1966 (Balsters and Anderson, 1979). The ditches were started in the early to mid 1980s (Sherow, 1990). Use of the ditches varied greatly during the late 1800s because of poor maintenance, flooding that destroyed headgates, and mismanagement related to inexperience and financial difficulties. Introduction of sugar beet growing to the area after 1900 resulted in a revitalization of the ditches. However, damage from floods and maintenance and management problems continued to make operations difficult. In the early 1900s, pumping of ground water into the ditches started which made water supplies more reliable for irrigation. The joint use of water diverted from the Arkansas River and well water for irrigation in the areas served by the ditches continues today. The locations of the main canals and ditches are marked on USGS 7.5 minute topographic quadrangles.

The Frontier Ditch is currently operable and diverts water from the drainage of Cheyenne Creek about 0.3 mile west or from the Arkansas River approximately 3 miles west of the Colorado-Kansas border. The Holly Drain in eastern Colorado conveys irrigation return flow to the Cheyenne Creek drainage which forms part of the water that flows into the Frontier Ditch. The source of water in the Frontier Ditch at a given time depends on the flow in the Cheyenne Creek drainage from Colorado return flows or precipitation runoff; when these are low, a greater proportion of Arkansas River water is used. Water from the ditch is used to irrigate cropland overlying the floodplain and terraces along the north side of the river in Kansas for about 6 miles to the east of its headgate. The USGS maintains a gaging station on Frontier Ditch within Kansas just 0.3 miles from the Colorado-Kansas border (Table 1).

The Alamo and Fort Aubrey canals formerly diverted water from the river several miles west of Syracuse and carried water for irrigation along the northern side of the river to several miles east-southeast of Syracuse. The Alamo Canal was abandoned in 1974 (Sherow, 1990). Part of the water rights of the Fort Aubrey Canal have been transferred to the Frontier Ditch (M. Rude, personal communication).

Most of the ditches in Kansas serve eastern Kearny County and the area to the west and northwest of Garden City. The Amazon Ditch currently diverts the largest quantity of water from the Arkansas River in Kansas. The headgate of the Amazon Ditch is in central Kearny County; the canal extends in a northeast direction before irrigating cropland north of Deerfield and into westernmost Finney County. Water from the Amazon Ditch also serves the Great Eastern Ditch. The Great Eastern headgate first diverted water from the Arkansas River in 1882 (Sherow, 1990). Altercation among developers resulted in construction of the Amazon Ditch, with a headgate upstream of the headgate of the Great Eastern Ditch. In 1955 the operators of the Great Eastern and Amazon ditches entered into an agreement to jointly operate (M. Rude, personal communication). The Amazon Ditch was widened to accommodate increased flow to allow it to serve the irrigation areas for both ditch systems. Water is diverted from the Amazon Ditch into Lake McKinney to the northeast of Lakin. The Great Eastern Ditch system now obtains its water from Lake McKinney and irrigates land in western Finney County to the northwest of Garden City. The portion of the Great Eastern canal between Lake McKinney and the original headgate on the Arkansas River has been abandoned.

The Southside Ditch diverts water from the southern bank of the Arkansas River about 3 miles downstream of the Amazon Ditch headgate; the headgate formerly operated in conjunction with that of original headgate of the Great Eastern Ditch. Southside Ditch water irrigates land along its extent before ending near the Kearny-Finney counties line. There generally has been some diversion into the ditch system each year but the amount of water has substantially decreased in the last 10 years. Part of the decrease has resulted from conversion of about half of the irrigable land in the system to the Conservation Reserve Program. The ditch did not divert water during the highest flow of the summer of 1995, but diverted at the end of the high flow about the beginning of August (M. Rude, personal communication). The return flow from the Southside Ditch enters the Arkansas River near Deerfield.

The headgate of the Farmers' Ditch is a couple miles east of Deerfield. The headgate of the Garden City Ditch was originally about a mile farther downstream. Both ditch systems later entered into a cooperative arrangement involving the use of the headgates of the Farmers Ditch as the diversion from the Arkansas River. Water for the Garden City Ditch is now diverted from the Farmers Ditch near the Kearny-Finney counties line. These ditches carry water to irrigate land to the west and northwest of Garden City. The irrigation area of the Garden City Ditch appears to have formerly included cropland that has now been converted to other uses in western Garden City. The amount of water available for use in recent years has been variable due to the relatively small flow in the river.

Flow data for the Kearny and Finney counties ditches are not as readily available as the federally maintained gaging stations on the Arkansas River and Frontier Ditch. There are some USGS discharge measurements on the Great Eastern Canal diversion near Lakin during a limited period for research studies. The irrigation companies have probably kept some flow records as a part of their management. Other data from which flows could be estimated include water use reports made to the DWR by the companies.

Ground Water

Water-level data

The KGS maintains a data base of water-levels in the State well network. The KGS also publishes a hardcopy report each year for the data, for example, Woods et al. (1995). The water levels have been measured every winter (usually January) by the USGS and the DWR; the DWR also measures some wells quarterly. Data for the study area exist primarily for wells screened in the alluvial aquifer of the Arkansas River valley and the Ogallala aquifer although levels have also been measured in several Dakota aquifer wells. The number of wells monitored generally increased until the mid-1980s, then declined after reassessment of the information and cost of the program. Figure 4 illustrates these changes for wells in the Ogallala aquifer in the Garden City Study area of the DWR; the number of alluvial wells measured for this area remained about the same during the period.

The DWR has also been measuring water levels in additional wells in the upper Arkansas River corridor since the mid 1980s. Many of these wells appear to be the same wells formerly in the State water-level network but which were dropped from the network due to the program assessment and cost. The DWR has sent hand-written sets of the additional data which the KGS will digitize for this study.

Aquifer characteristics

Information on aquifer characteristics, including maps of water-table surface and saturated thickness, for the High Plains aquifer in the upper Arkansas River corridor are

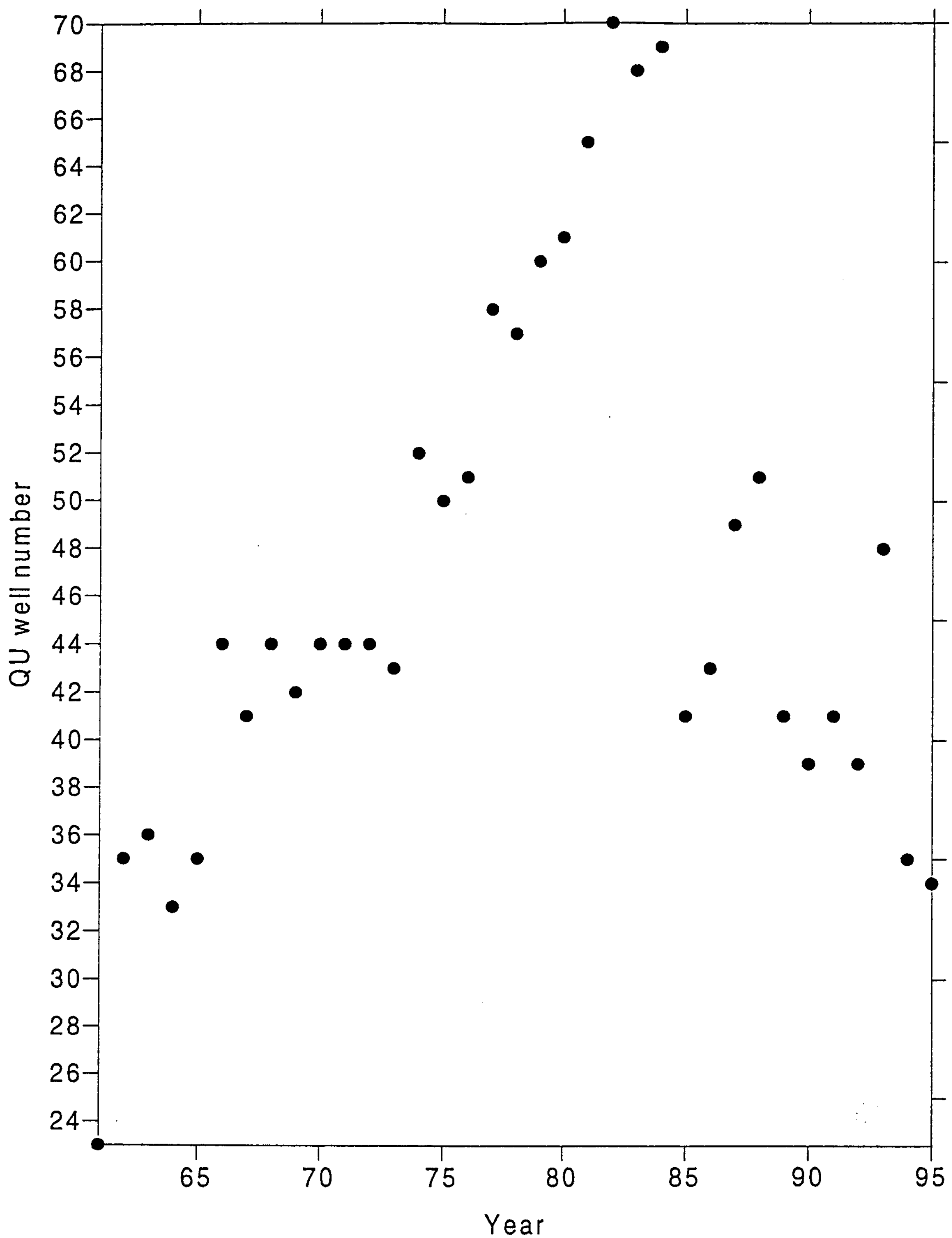

Figure 4. Number of wells for which there are measured water levels in the Kansas water-level data base within the Garden City Study Area of the DWR.

included in geohydrologic studies by McLaughlin (1943) [Hamilton and Kearny counties]; Lobmeyer, and Sauer (1974) [Hamilton County]; Gutentag, et al. (1972) [Kearny County]; Gillespie et al., (1977) [Kearny County]; Dunlap et al. (1985) [Kearny and Finney counties]; Meyer et al. (1969, 1970) [Finney County]; Gutentag et al. (1972) [Finney County]; Prill et al. (1977) [Finney County]; Latta (1944) [Finney and Gray counties]; McGovern (1974) [Gray County]; Waite, (1942) [Ford County]; Spinazola, and Dealy (1983) [Ford County]; Pabst and Jenkins (1976) [southwestern Kansas]; Pabst and Gutentag, (1979) [southwestern Kansas]; Gutentag et al. (1981) [southwestern Kansas]; Stullken (1988) [southwestern Kansas]. Other reports and maps are available for the entire High Plains aquifer in the Great Plains or for other large-scale studies but the prior referenced documents generally contain the data which was used in the large-scale publications.

Information on the geohydrology of the Dakota aquifer, including maps, are referenced in reports and papers of the Dakota Aquifer Program or in publications cited in the Program documents. Relevant references were included in the bibliographic inventory listed at the end of this report and in the reference list of a Dakota Aquifer Program report such as Macfarlane et al. (1994).

Water Quality

Ground-water quality and its link to Arkansas River water quality and declining water tables is the main focus of this study. Water-quality data for the Arkansas River and the alluvial, Ogallala, and Dakota aquifers is needed for different time periods to determine the present concentration distribution and origin of salinity and constituents of concern and to assess variations in and migration of natural and anthropogenic sources of the salinity and other contaminants.

Surface Water

Nearly all the surface waters sampled in the study area comprise Arkansas River water. The USGS has collected samples for chemical analysis from the Arkansas River near Coolidge for many years (Table 2). However, the number of samples has generally decreased since 1981 such that now only about 4 or 5 samples are currently each year. The Coolidge site is maintained as a National stream-quality accounting network station; samples are analyzed for major chemical properties, major, minor, and selected trace inorganic constituents, and sediment. Some water samples from the Coolidge station were also analyzed for many pesticides for a few years. Chemical-quality data were also periodically collected for Arkansas River waters at Dodge City for a period of about 16 years that ended in 1977. Specific conductance was measured in one or more water samples per year at some discharge gaging stations in Table 1, for example, at Frontier Ditch in 1991 and 1994, Syracuse during 1975-1980, 1985, 1987, and 1990-1994, Kendall in 1979 and 1982, Garden City in 1964 and 1965, and at Mulberry Creek near Dodge City during 1976-1979 and in 1981. River discharge values accompany the chemical-quality and specific conductance data.

The KDHE also has collected samples from the Arkansas River for many years (Table 3); chemical analyses include determination of pesticides as well as inorganic constituents. A

Table 2. U.S. Geological Survey stations in the study area with chemical-quality data for Arkansas River waters.

Station name	Station number	Legal location	River mile	Period of record for water samples[a]
Arkansas River near Coolidge[b]	07137500	23S-43W-26BAB	1099.3	Nov 1963 - present[c]
Arkansas River at Syracuse	07138000	24S-40W-18BDB	1080.9	Sep 1969 Oct 1970 May 1971 Oct 1971 Jun 1974 - Oct 1974
Arkansas River at Garden City	07139000	24S-32W-19BDB	1024.2	Jun 1964 Jun 1965
Arkansas River at Dodge City[d]	07139500	26S-25W-35BCC	970.9	Oct 1961 - May 1977 Apr 1987 - May 1987

[a] If a period is not indicated, only one sample was collected for the month.
[b] Specific conductance was measured daily November 1963 to September 1968 and January 1976 to September 1981.
[c] Only one or two samples were analyzed during a few of these years.
[d] Specific conductance was measured daily October 1974 to June 1977 when the river was flowing.

water sample is currently collected by KDHE every two months when water is flowing at the sampling station. The data exist in digital form in the STORET system of the U.S. EPA. The surface water data for the 5-counties in which the study area is located were transferred electronically to the KGS. The STORET data also include the USGS chemical-quality determinations for the stations listed in Table 2 and described above. USGS discharge values accompany the USGS chemical quality data in STORET. Discharge measurements for the KDHE sampling dates can be obtained by using the USGS data for a gaging station at or nearby the sampling site.

The KGS, GMD3, SWKLEPG, DPH, and the KDHE have sampled Arkansas River waters during the last two and one-half years preliminary to and as a part of the UARC Study (Table 4). The Analytical Services Section of the KGS analyzed the samples for inorganic constituents. The samples represent both low-flow conditions before and after the high flow event of the summer of 1995 as well as sample profiles along the river during the 1995 high discharge in July and August. The profile during the latter part of the high-flow event, when the Arkansas River was flowing completely through Kansas, included samples collected within the study area and downstream to just east of Hutchinson.

Table 3. Kansas Department of Health and Environment stations in the study area with chemical-quality data for Arkansas River waters.

Station name	KDHE station no.	Legal location	Period of record for water samples
Arkansas River near Coolidge	000223	23S-43W-26BAB	Jul 1967 - Sep 1981 May 1983 - present
Arkansas River near Deerfield	000598	24S-35W-14ACB	Apr 1990 - present
Arkansas River at Pierceville	000286	25S-31W-13CCC	Dec 1973 - Apr 1977 Aug 1979 Apr 1980 Apr 1986 Oct 1987 - Jun 1990 Jul 1995 - present
Arkansas River near Garden City[b]	002009	25S-31W-13CCC	Jun 1972[c] Apr 1975[c]
Arkansas River near Dodge City[d]	000285	27S-24W-13BCC	Jun 1972[a] Apr 1975[a] Dec 1973 - Sep 1981 May 1983 - May 1987[e] May 1987 - Nov 1989
Mulberry Creek near Dodge City	000700	27S-22W-32BDD	Oct 1994
Arkansas River near Ford	000594	27S-22W-31DCD	Apr 90 - present

[a] If a period is not indicated, only one sample was collected for the month unless otherwise noted.

[b] The sample location is essentially the same as the Pierceville station. The difference in the latitude-longitude location from the Pierceville location suggests that the sample site may have been downstream of the bridge south of Pierceville rather than upstream.

[c] Several samples were collected during the month.

[d] The sample location is at the bridge two miles southeast of Fort Dodge.

[e] Only one sample per year.

Ground Water

Ground-water quality records were assembled for the study area from a number of federal, state, and local agency sources. These include data from the USGS, US EPA, KDHE, KGS, GMD3, and SWKLEPG. Distribution of the records accumulated to date for this study are listed by county and decade in Table 5 and displayed by township in Figures 5-11. Many of the records are for multiple samples from the same site, thus the number of wells represented is substantially smaller than the number of samples.

The USGS computer data base includes the oldest of the digital records, which extend back to 1939 for the study area. Some older data exist in USGS publications (Slichter, 1906;

Table 4. Locations of Arkansas River water samples collected in the study area by Kansas and local agencies and analyzed by the Kansas Geological Survey.

Station name	Legal location	Period of record for water samples
Arkansas River near Coolidge	23S-43W-26BAB	Jun 1993 Jan, Apr, Aug 1994 Jul, Aug 1995 Jan 1996
Arkansas River at Syracuse	24S-40W-18BDB	Jun 1993 Jan, Apr, Aug 1994 Jul, Aug 1995
Arkansas River at Kendall	24S-39W-25DCC	Jun 1993 Jan, Apr, Aug 1994 Jul 1995
Arkansas River at Amazon Ditch headgate	25S-38W-12BBB	Aug 1995 Jan 1996
Arkansas River at Lakin	24S-36W-34ACA	Jun 1993 Jan, Apr, Aug 1994 Jul, Aug 1995
Arkansas River at Deerfield	24S-35W-14ACB	Jun 1993 Jan, Apr, Aug 1994 Jul 1995
Arkansas River at Holcomb	24S-33W-7CCB	Jun 1993 Jan, Apr 1994
Arkansas River at Garden City	25S-31W-19BDB	Jul, Aug 1995 Jan 1996
Arkansas River at Pierceville	25S-31W-13CCC	Jan 1996
Arkansas River at Charleston	25S-30W-25BDD	Jul, Aug 1995 Jan 1996
Arkansas River at Ingalls	26S-29W-02ACA	Jan 1996
Arkansas River at Cimarron	26S-28W-11DCB	Jul, Aug 1995 Jan 1996
Arkansas River at Howell	26S-26W-21BCB	Jul, Aug 1995
Arkansas River at Dodge City	26S-25W-35BCC	Jul, Aug 1995
Arkansas River near Dodge City[a]	27S-24W-5BBD	Jul, Aug 1995
Arkansas River near Ford	27S-22W-31DCD	Jul, Aug 1995

[a] The sampling location is between Dodge City and Fort Dodge.

Table 5. Chemical records for well waters by county and decade for the study area.

Decade	County					Total
	Hamilton	Kearny	Finney	Gray	Ford	
1939-1949	21	24	21	21	51	138
1950-1959	2	20	24	14	38	98
1960-1969	34	61	46	15	27	183
1970-1979	18	38	82	95	80	313
1980-1989	43	58	69	35	47	252
1990-1995	29	145	182	114	111	581
Total	147	346	424	294	354	1565

Parker, 1911) but only a few of these have legal locations. However, some of these old data include descriptive locations and names which may allow estimation of the location by research on landowners in historical records. Most of the early data were collected as a part of USGS and KGS cooperative studies of the ground-water resources of the 5 counties. Well-water samples were collected in the summer of 1939 for the Ford County investigation (Waite, 1942), in November 1940 for the Hamilton and Finney counties study (McLaughlin, 1943), and during September 1940 to January 1941 in Finney and Gray counties. These 3 studies account for essentially all the samples collected during the 1939-1949 period in Table 5 and Figures 5-11. Some additional wells were sampled during 1956 for a study of the Arkansas River valley for irrigation waters in Gray and eastern Finney counties (Stramel, et al., 1958).

Starting in the 1950s the USGS collected samples as part of a ground-water monitoring program in cooperation with the KDHE. In 1990 the KDHE took over this program and now collects water from wells across the state generally on a biennial basis with approximately half of the wells sampled each year. These data are also stored in the US EPA STORET system. Currently the wells in the monitoring program within the study number 14 (Hamilton 3, Kearny 4, Finney 3, Gray 3, and Ford County 1 well).

The KGS conducted investigations of the quality of irrigation waters in the High Plains aquifer in Kansas during the mid-1970s to 1980. Most of the chemical records for wells within the UARC Study area are included in Hathaway et al. (1977, 1978a); several records for the northern Gray County part of the upper Arkansas River corridor are listed in Hathaway et al. (1978b). The wells in the corridor area were sampled during the summer irrigation seasons of 1975-1977. The large number of well waters collected largely explain the great increase in records for the 1970s in comparison with early decades.

In 1988, GMD3 started a program to monitor ground-water quality. Wells were sampled by GMD3 staff up to 1992 and submitted to a private laboratory for analysis. A digitized set of the chemical records were obtained from GMD3 and examined for estimated accuracy on the basis of charge balance calculations and comparison of measured and computed total dissolved solids (TDS) concentration. The assessment showed that the analyses are very good in comparison with most private laboratories; the chemical data will be

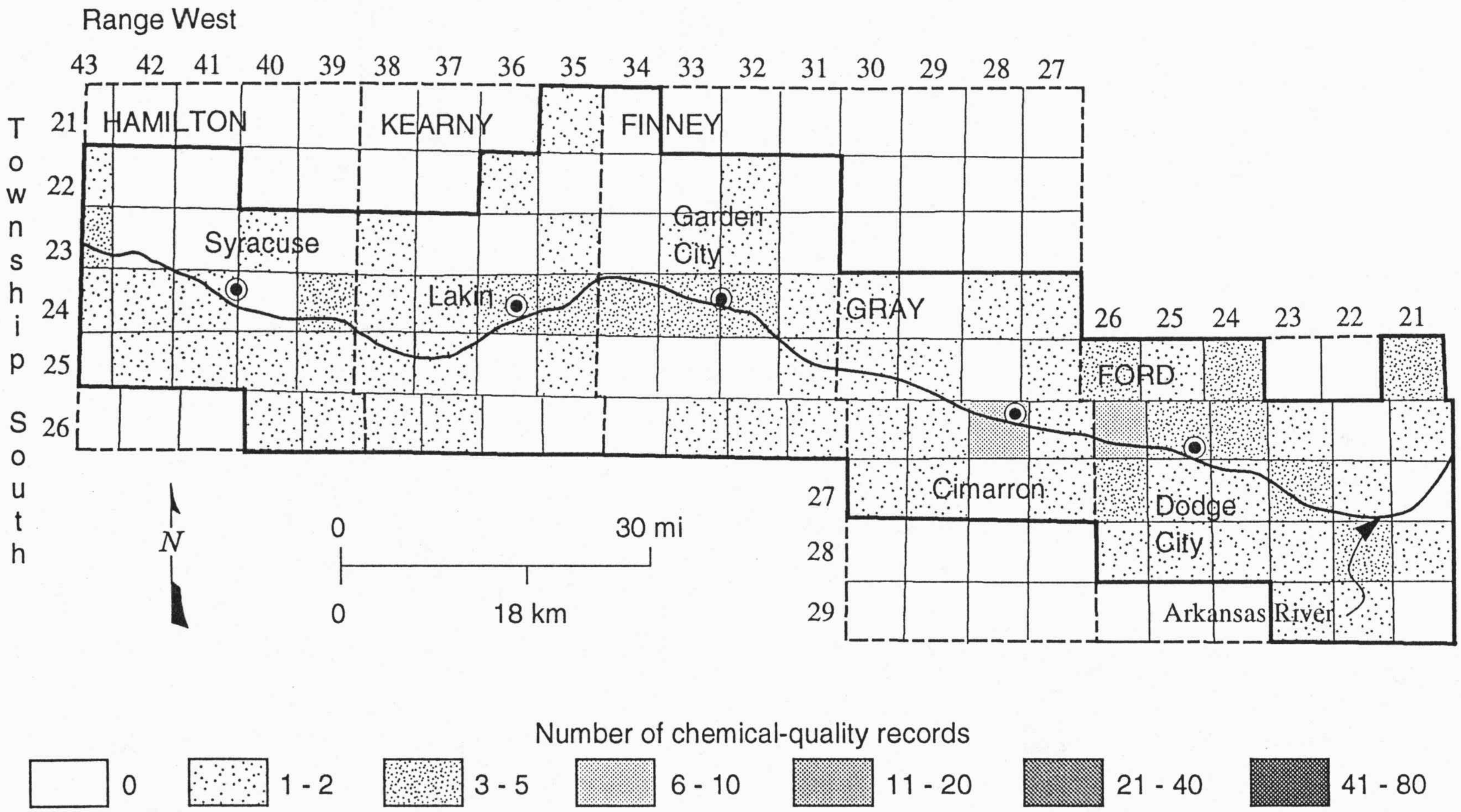

Figure 5. Number of chemical-quality records per township for well waters in the Upper Arkansas River Corridor Study area, 1939 - 1949. The study area boundary is the bold line

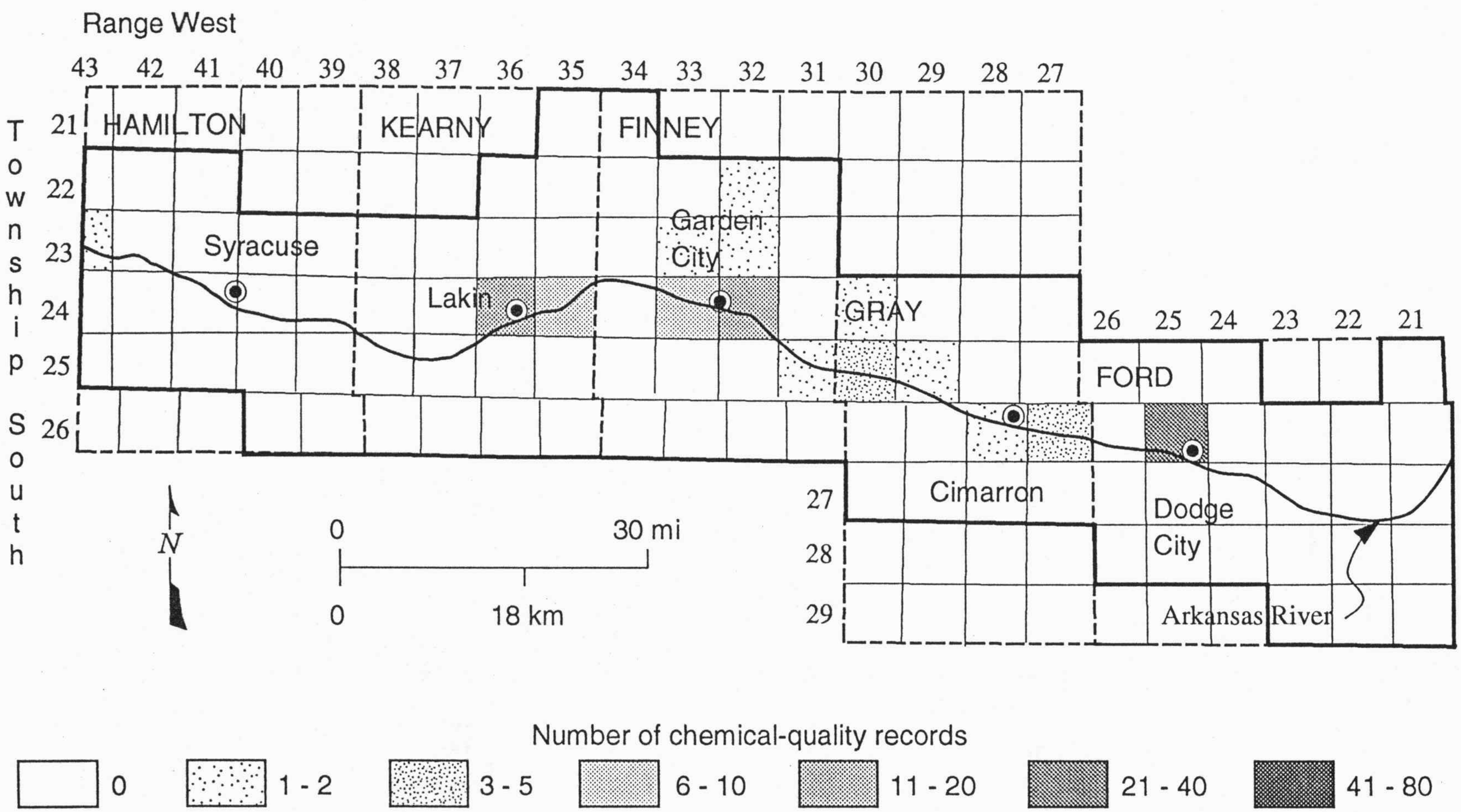

Figure 6. Number of chemical-quality records per township for well waters in the Upper Arkansas River Corridor Study area, 1950 - 1959. The study area boundary area is the bold line

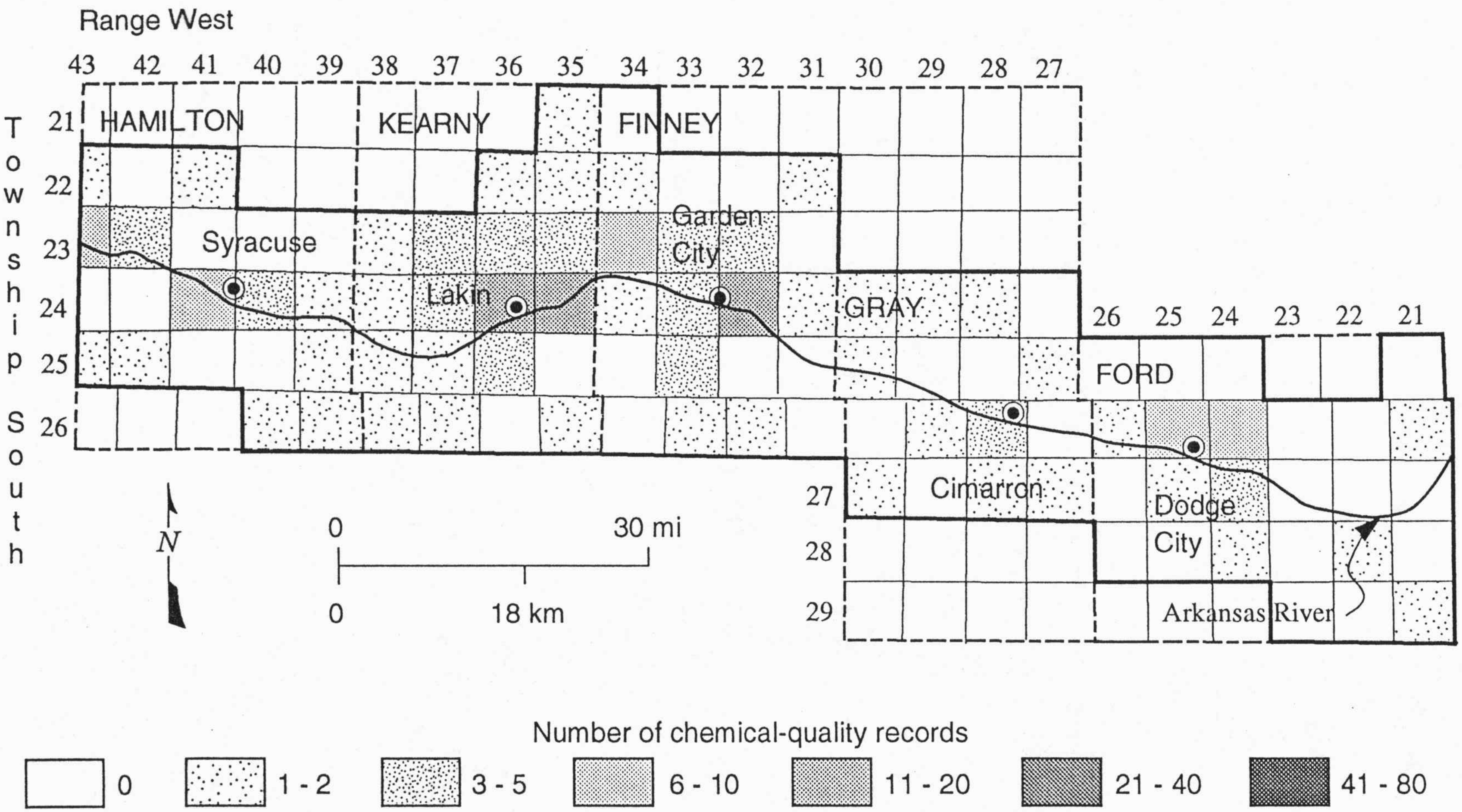

Figure 7. Number of chemical-quality records per township for well waters in the Upper Arkansas River Corridor Study area, 1960 - 1969. The study area boundary is the bold line.

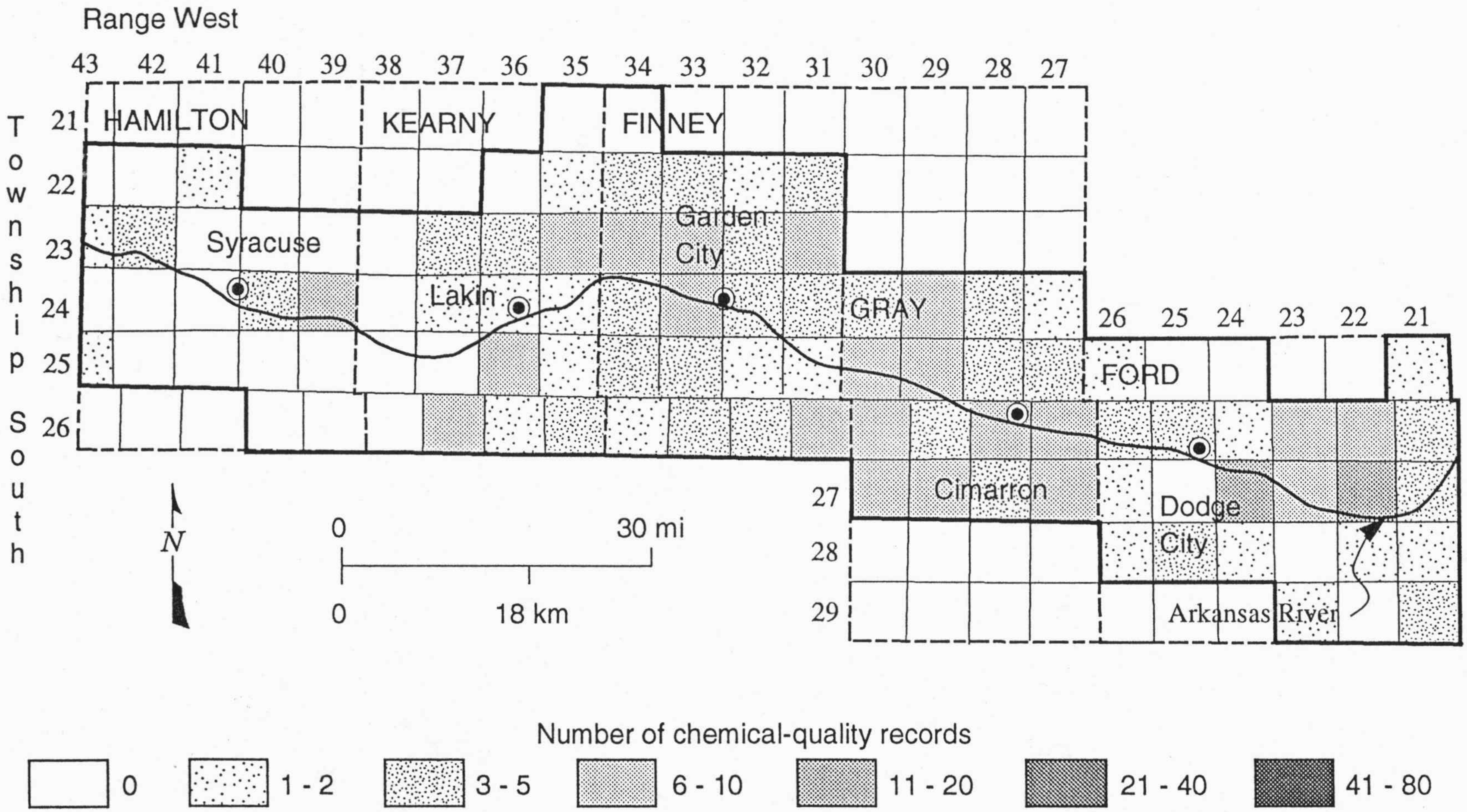

Figure 8. Number of chemical-quality records per township for well waters in the Upper Arkansas River Corridor Study area, 1970 - 1979. The study area boundary is the bold line.

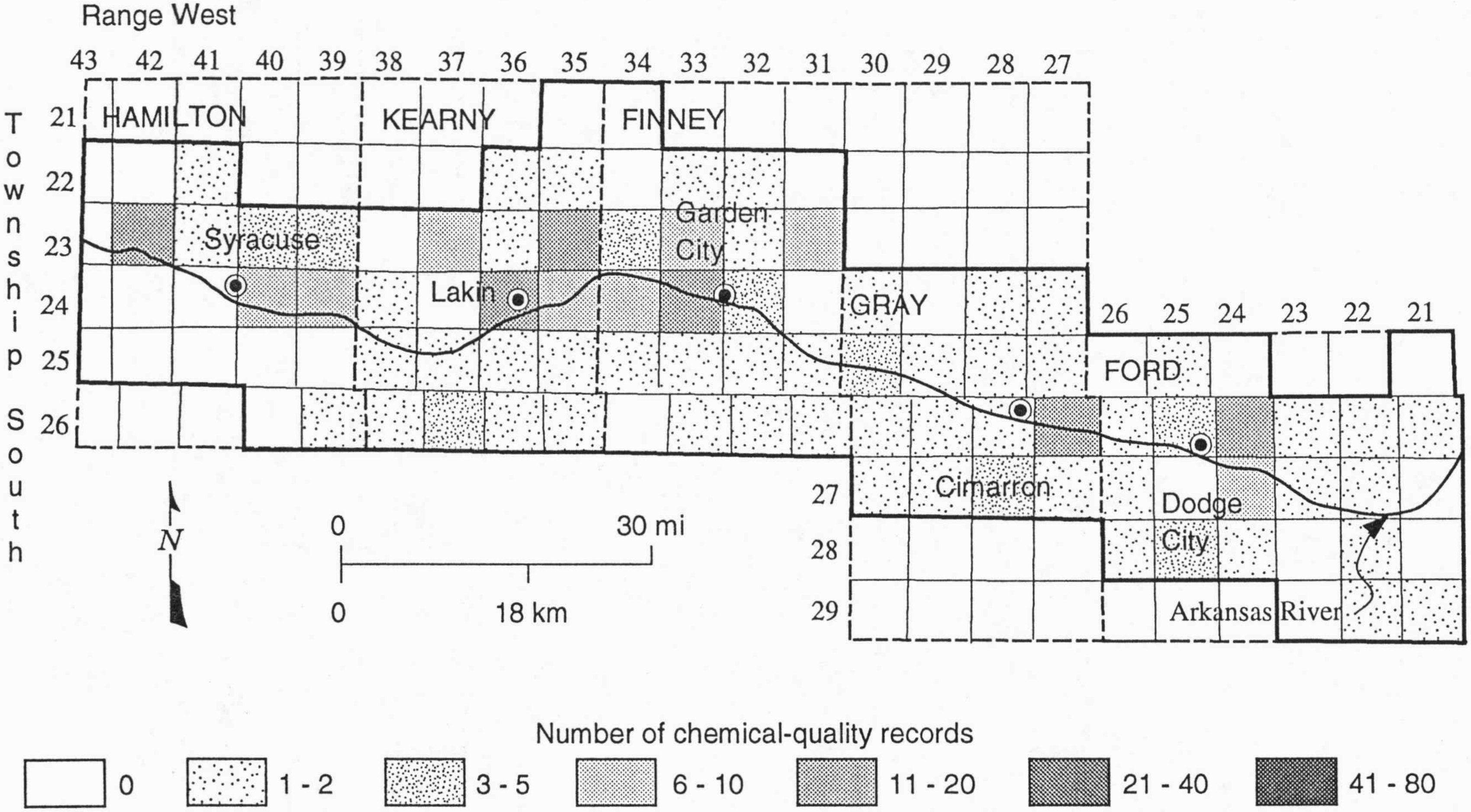

Figure 9. Number of chemical-quality records per township for well waters in the Upper Arkansas River Corridor Study area, 1980 - 1989. The study area boundary is the bold line.

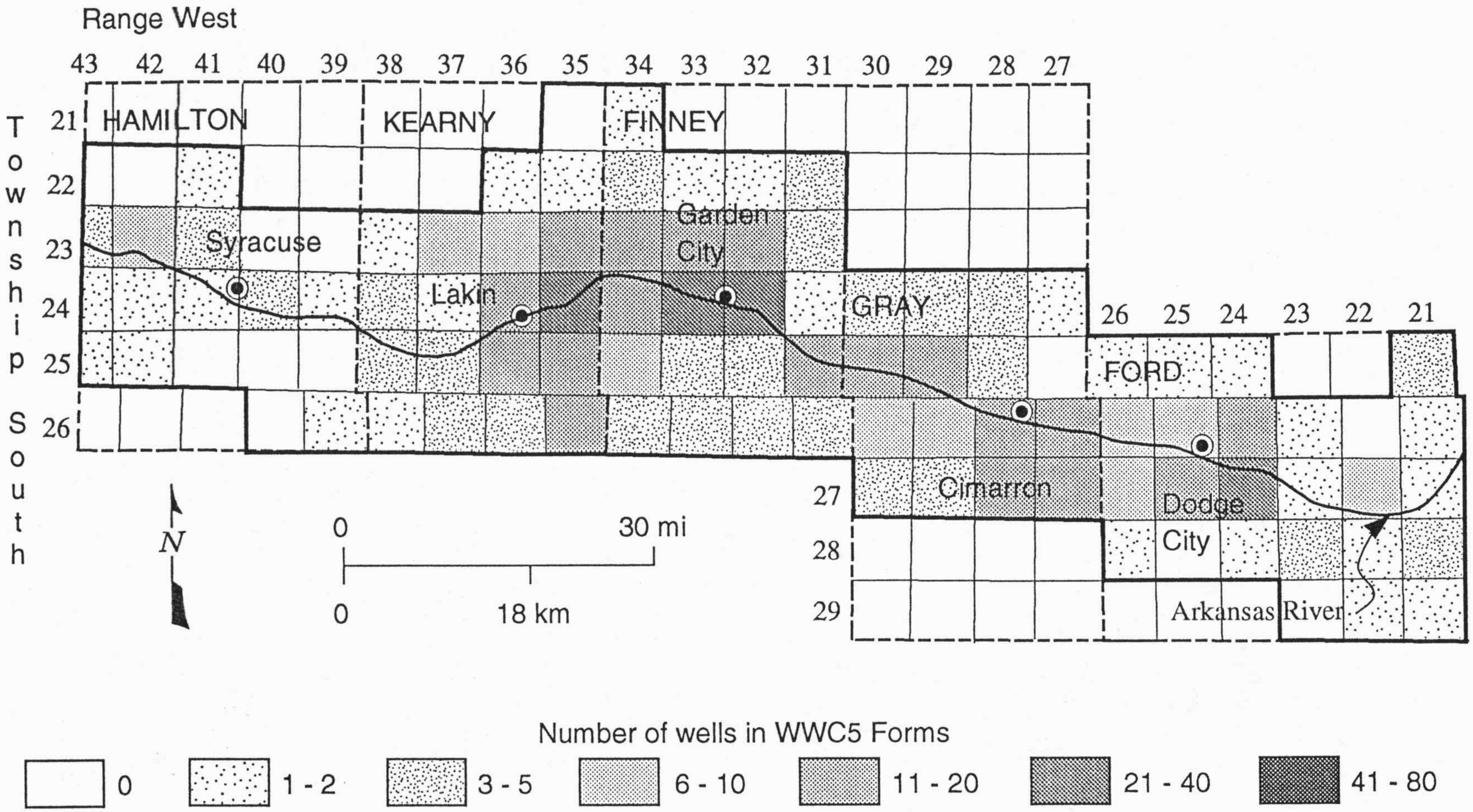

Figure 10. Number of chemical-quality records per township for well waters in the Upper Arkansas River Corridor Study area, 1990 - 1995. The study area boundary is the bold line.

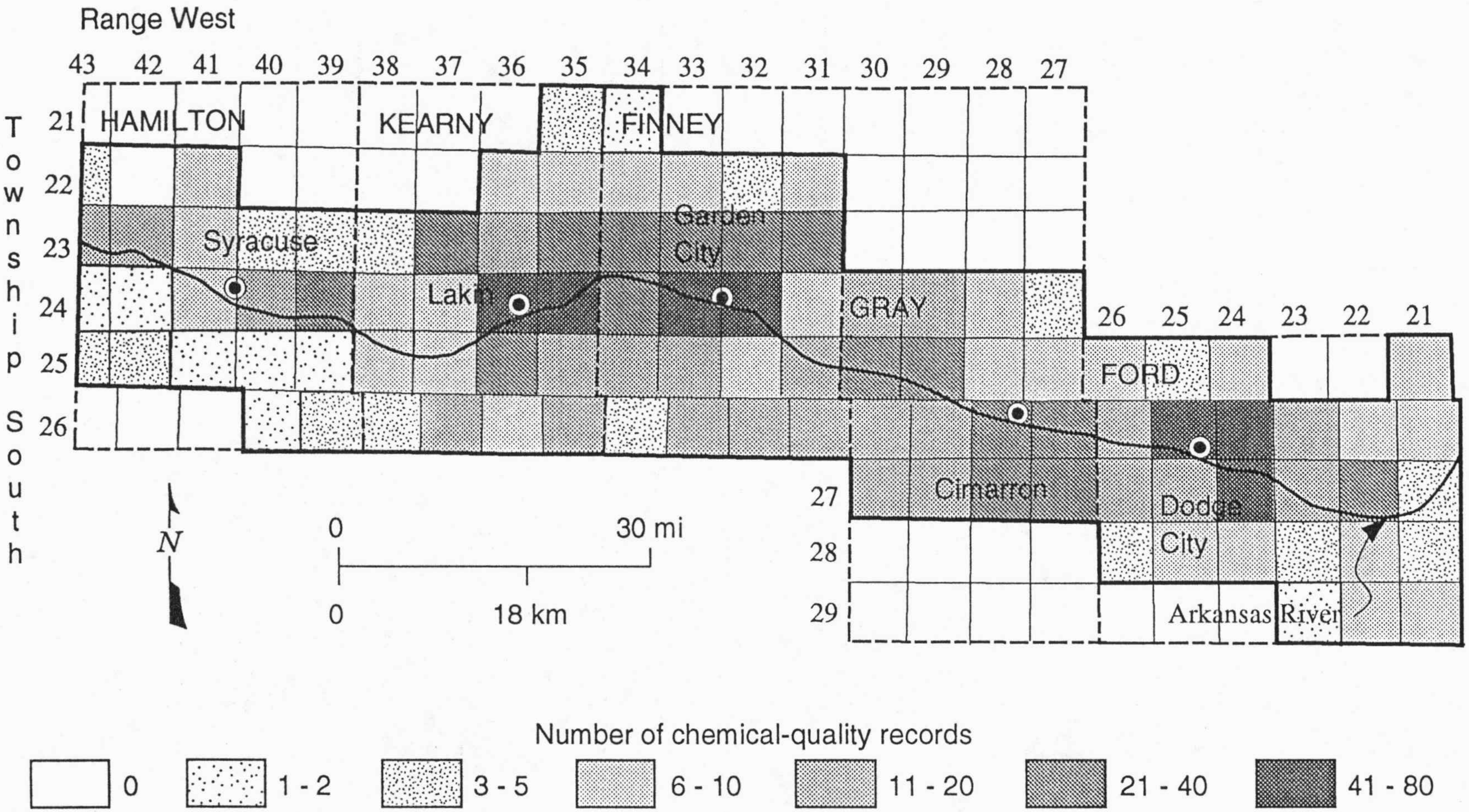

Figure 11. Number of chemical-quality records per township for well waters in the Upper Arkansas River Corridor Study area, 1939 - 1995. The study area boundary is the bold line.

valuable for this study. The GMD3 data comprise a large number of the records of the 1980s decade.

The SWKLEPG started a ground-water monitoring program in 1992. Staff of the SWKLEPG collected the samples and either analyzed the waters themselves or submitted the samples to the same private laboratory utilized by the GMD3. The digitized data were obtained from the SWKLEPG for this study. The analyses do not include all major constituent concentrations, therefore an assessment of the error in the data could not be made. The error in the private laboratory values is assumed to be the same as for the GMD3 data. The SWKLEPG data will be assessed for accuracy by discussion with the staff; based on preliminary conversation, the data should be accurate enough for use in maps of constituent concentration distribution and examination of temporal changes. Many of the data have no accompanying legal location but are identified by landowner. It may be possible to attach legal locations to some of these data. Records with legal location generally only include identification down to a section. More precise locations within sections might also be possible by using landowner descriptions.

The SWKLEPG provided a digital set of water-quality records as a part of monitoring for the Center for Disease Control. The number of records are few in comparison with the GMD3 and SWKLEPG data sets. The chemical determinations are limited to bacteria, nitrate, lead, and atrazine. The legal locations for the wells are only to the section number. However, the nitrate values should be useful for assessing the general distribution of this constituent in the study area.

Several samples from the Dakota Aquifer Program were collected from wells within the UARC Study area by the KGS and analyzed at its laboratories.

In the last few years, the DPH has sampled waters from irrigation wells to determine the effects of chemigation on ground-water quality. The DPH has determined pesticide concentrations and the KGS has analyzed the samples for inorganic nutrients. In 1994, the KGS also analyzed the samples for complete major and selected minor constituents. The DPH also cooperated with the KGS in the preliminary work for the UARC Study by collecting waters in 1994 from irrigation wells that were sampled by the KGS in the mid-1970s or that are very near to these wells. During 1995, the first year of this study, the DPH sent samples of waters from the wells that they visited as a part of their program, and which are in the study area, to the KGS for determination of inorganic substances.

The combination of the GMD3, SWKLEPG, and joint DPH and KGS sampling and analysis programs account for the great increase in the number of chemical quality records during the 1990s in comparison with earlier decades (Table 5). The areal distribution of the sample record locations is related both to the presence of substantial saturated thicknesses in the High Plains aquifer and to the density of population (Figures 5-11). The 1939-1949 data are relatively evenly distributed over the study area because the general assessment character of the ground-water studies in which sampling was included (Figure 5). The 1950s data are sparse and are mainly located in the Garden City and Dodge City areas (Figure 6). The 1960s data include many samples in the city locations but also are distributed, except for eastern Ford

County, across rural areas (Figure 7). Records for the 1970s are distributed mainly across the High Plains portion of the study area; the number of records are much fewer for Hamilton and westernmost Kearny County (Figure 8). Many of the data in the 1980s are concentrated along the townships within the Arkansas River valley as well as more populated locations (Figure 9). The 1990's data provide a relatively good distribution across the upper Arkansas River corridor, primarily from eastern Kearny through western Ford counties (Figure 10).

Although the total number of records appears to be great (Figure 11), the variability in the areal and temporal distribution, the number of constituents determined, and the details in location identification will limit the assessment of ground-water quality for particular time periods and at different depths. However, the data provide an adequate basis for analysis of salinity distribution and changes in the system. Some additional sampling will be needed at the same locations to determine recent quality changes. Other wells need to be sampled to characterize changes in quality with depth in the aquifer system.

Water Rights and Use

Water rights and use data are maintained by the DWR in their WIMAS system; the data are also available from the Data Access and Support Center (DASC) office at the KGS. The data for the 5 counties in the upper Arkansas River valley area have been transferred for use in this study.

Locations of the water rights were extracted and converted into a form that could be used in ArcView. A map was then created showing the locations for the 5-county region enclosing the study area. The map was photoreduced for display in this report (Figure 12). Nearly all the water rights are for wells, however, some of those in the figure are probably also for the few surface water rights to diversions from the Arkansas River. Most of the wells with water rights are used for irrigation, although some of the wells supply water for public supplies, industry, and stock yards.

The distribution of the well locations in Figure 12 largely indicates the presence of sufficient saturated thickness in the High Plains aquifer (alluvial and Ogallala aquifers) for large capacity pumping. The areas with few or no well locations represent the absence of or very thinly saturated parts of the High Plains aquifer. In these areas, the few wells are completed in the Dakota sandstone aquifer underlying the High Plains aquifer. The alluvial aquifer of the Arkansas River in Hamilton County stands out clearly in the map as a band of wells along the river; the Ogallala aquifer is either not present or too thin to provide large supplies of water in the region just to the north and south of the bedrock channel of the river. The thinner alluvial deposits in western Kearny County are reflected by very few water rights.

The pattern of the water-right locations in Figure 12 is noticeably grid-like in the area south of the Arkansas River in southern Kearny and Finney counties and central Gray County in comparison with the generally more random pattern elsewhere. The grid-like pattern is associated with center-pivot irrigation as indicted by land-use discussed in the next section. There is a high correlation of the location of the grid-like area with the distribution of Quaternary dune sand indicated in the geologic map of the region. The development of the

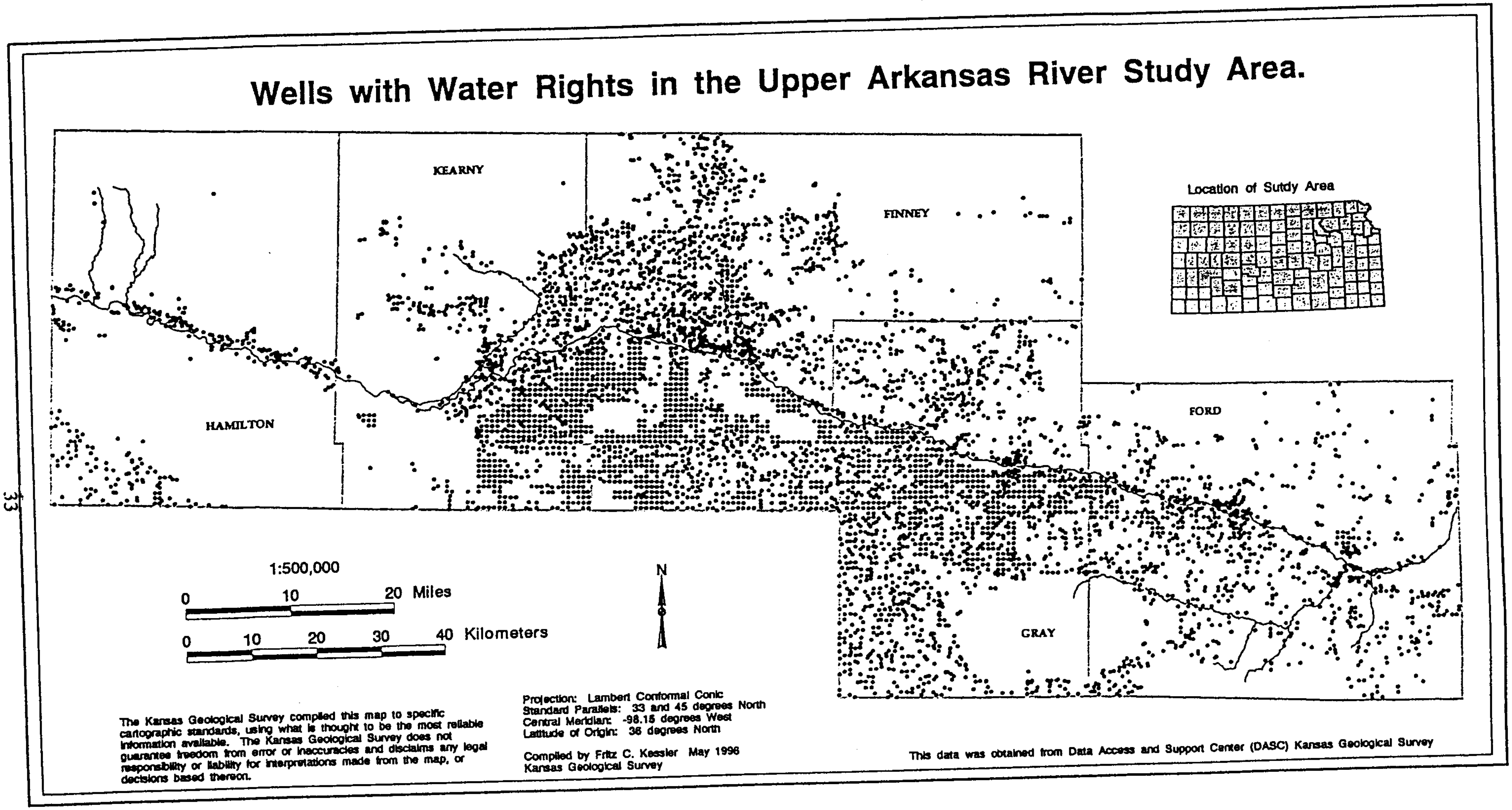

Figure 12. Photocopy reduction of ARCVIEW map showing location of water rights in the 5-counties enclosing the UARC Study area. A few of the water rights locations plotted are not for wells but represent rights for diversions from the Arkansas River.

center-pivot irrigation in the sand dune area generally came later that of irrigation in the other locations and occurred as wells mainly centered in quarter sections arranged in a regular pattern in sections. Center-pivot systems are also used elsewhere, but the water well right may have originally been obtained for flood irrigation and thus is not necessarily located in the center of a section.

Land Use

Digital information for land use was obtained as Landsat Thematic Mapper data for 1990/1991 from the Kansas Applied Remote Sensing Program. A colored map of land-use classifications in the 5-county region encompassing the study area was prepared using ArcView. The land-use classifications comprise residential, commercial and industrial, grassland, urban grassland, woodland, urban woodland, cropland, water, and other. Major highways are also shown on the map. Cropland and grassland comprise most of the land uses, with cropland covering an appreciably larger area than grassland. The next greatest land use types are residential and roads, however the total area in these uses is only a few percent.

The pattern of center-pivot irrigation is noticeable in the area south of the Arkansas River in eastern Kearny, Finney, and central Gray counties as small diamond shapes of grassland among the circles of cropland. The major grasslands within the study area occur mainly along the south side of the Arkansas River in Hamilton and western Kearny counties, although substantial acreages also exist to the north of the Arkansas River in the same region. Remnants of grasslands that formerly covered the sand dunes are still present south of the Arkansas River in southeast Kearny and southern Finney counties. Some grasslands also exist in the study area along the Arkansas River valley in Gray and Ford counties, with the largest contiguous mass in easternmost Ford County. One of most important factors that would affect the accuracy of the land-use map today relative to the 1990, 1991 date of the image collection would be the presence of fields that have been in the Conservation Reserve Program for multiple years and which have developed a substantial stand of grass.

The pattern of grassland and cropland correlates fairly well with the distribution of wells with water rights (Figure 12). Locations with water rights nearly always are shown as cropland. Dryland farming is used in many areas, thus much of the areas without points for water rights in Figure 12 are used for cropland. However, the areas without water rights in the sand dune region south of the Arkansas River in eastern Kearny County and Finney County are mainly grasslands.

PRELIMINARY CONCEPTUAL MODELS

The following descriptive conceptual models were developed to assist in assessing the types of water-resource problems in the study area, determining the data needed for examination of the character and extent of the problems, guiding the construction of quantitative computer simulations, and considering possible management and protection plans. Some facets of the conceptual models are factual whereas other aspects are hypothetical and will require further testing by acquisition and analysis of appropriate data.

Hydrology

Surface-Water and Ground-Water Interaction

Flow in the Arkansas River crossing into western Kansas in recent years has typically averaged between 100 and 200 cfs. John Martin Reservoir regulates the flow, although during the irrigation season little flow may be released from the reservoir and most of the river water entering Kansas comprises return flows and seepage from the alluvial aquifer. During some years unusually heavy local rainfall downstream of the reservoir can briefly increase the flow in the river in southwest Kansas. In other years, heavy snowmelt and/or rainfall above the John Martin Reservoir and other upstream reservoirs can fill the storage capacity such that large flows may be released. The latter situation occurred during the summer of 1995 and resulted in a large increase in river flow in Kansas for about one month.

Arkansas River flows between Coolidge and Syracuse do not change substantially during most periods. Some declines may be due to river losses to the alluvium caused by consumptive use of ground water for irrigation in the valley, although seepage and return flow from Frontier Ditch waters on the north side of the river may moderate these losses. The alluvium in this valley reach is in a bedrock cut which extends downstream to western Kearny County. There appear to be enough irrigation wells in the alluvium downstream of Syracuse that consumptive use might cause some infiltration of river waters and loss of flow before the river reaches the Amazon Ditch headgates.

Just before the Arkansas River enters the area where the Ogallala aquifer underlies the alluvium, the Amazon Ditch diverts a substantial amount of water. The diverted water is conveyed in a canal downstream past Lakin before being used for irrigation in its service area and that of the Great Eastern Ditch system. The Southside Ditch headgates about 3 miles downstream divert variable amounts of water (although smaller volumes than the Amazon Ditch) during the irrigation season. The canals of these systems probably lose a small amount of seepage that recharges the alluvium and Ogallala aquifer. Some of the water used from the ditches for irrigation also infiltrates to the subsurface to recharge the ground water below the fields. Ground water is also used for irrigation on most of the same fields serviced by the ditch water. The wetter conditions of the soils in the irrigated areas could result in more infiltration of water from substantial rainfall because there would be more soil moisture than in non-irrigated fields, thereby increasing the probability that the rain could saturate the soils sufficiently to drive recharge below the root zone.

Ground-water levels in the Ogallala aquifer have become lower than those in the overlying alluvial aquifer downstream from central Kearny County. As a result, the Arkansas River loses water by seepage to the alluvium. Near Deerfield further river losses occur at the Farmers Ditch headgates when water is diverted during the irrigation season. The combined natural seepage to the alluvium caused by ground-water-level declines and the removal of water by ditch diversions have resulted in little or no river flow reaching Garden City during most of the last 20 years. The exceptions have been 1987 to 1988 and 1995 to 1996. During these years the river flowed for a period through the entire state. Even after the complete through flow ceased, the river continued to flow much farther downstream than usual. The flow front advances and retreats over short periods largely in response to the amount of ditch diversions. The reason for the further extension of the river front after large flow events could be smaller seepage losses as a result of the large amount of infiltration to the alluvial aquifer during the flow peak, as well as greater flows entering the state from Colorado.

Large snow melt from the Rocky Mountains and much rainfall in eastern Colorado filled the reservoirs of the Arkansas River and tributaries in the early summer of 1995. Colorado began to substantially increase the volume of water released from John Martin Reservoir from about July 1 to the latter part of July. Figure 13 shows the large peak flow at the Coolidge gaging station in July relative to the flows from April 1 to the end of October. The two narrow flow spikes in the latter part of May could represent runoff from heavy rains in eastern Colorado. The river flow at Coolidge in early April was in the typical range of about 100-200 cfs. Flows in early April at Great Bend were very low and difficult to discern on Figure 13. Rainstorms in May produced 3 flow peaks of increasing heights at Great Bend. There was no flow at Dodge City during the spring.

Figure 14 is an expanded view of a portion of the period in Figure 13. The figure illustrates the great increase in discharge of the Arkansas River at Coolidge once flow releases from John Martin Reservoir reached Kansas. The flows fluctuated between 2,000 and 2,300 cfs before reaching a peak of about 2,900 cfs on July 29, 1995. Although some flows were probably diverted by irrigation ditches, flows soon became large past Deerfield. The river entered the portion of the channel that had been dry most of the time since the latter part of 1988. Large amounts of the flow infiltrated to the alluvial aquifer. The river front slowly advanced down the valley and finally reached the gaging station at Dodge City on July 19. During this time the flow at Great Bend was low because there were no substantial rains contributing enough runoff to appreciably affect the discharge. The Arkansas River flow continued to advance downstream, but the higher stage and dry river bed resulted in large seepage losses to the alluvium. Finally, on August 1, a full month after the start of the high flow at Coolidge, water from Colorado in the flow front reached Great Bend and the Arkansas River once again flowed completely through Kansas.

Reservoir releases from the John Martin Reservoir were sharply reduced after July 29, 1995, causing a large drop in discharge at Coolidge (Figure 14). The flow at Dodge City increased until August 3 then declined, probably as a result of the decreased discharge into Kansas reaching the city by that date. Thus, the time for a change in the flow wave to be transmitted from Coolidge to Dodge City appears to have been about 5 days. By comparison, the seepage loss during the advance of the river in the dry bed resulted in a travel time of 18 days for the flow front to cover the same distance. The flow at Dodge City briefly increased a small amount during August 7 and 8, which may reflect the temporary leveling off of flow at Coolidge during August 1 and 2 before large declines started again. This suggests that the rate of seepage losses were declining sufficiently to allow more efficient transfer of discharge downstream. The reduction in flow at Coolidge appeared at Great Bend after August 6.

After the flow at Coolidge dropped below 600 cfs, the discharge at Dodge City declined appreciably (Figure 14). By August 21, 1995 the flow at Dodge City had ceased,

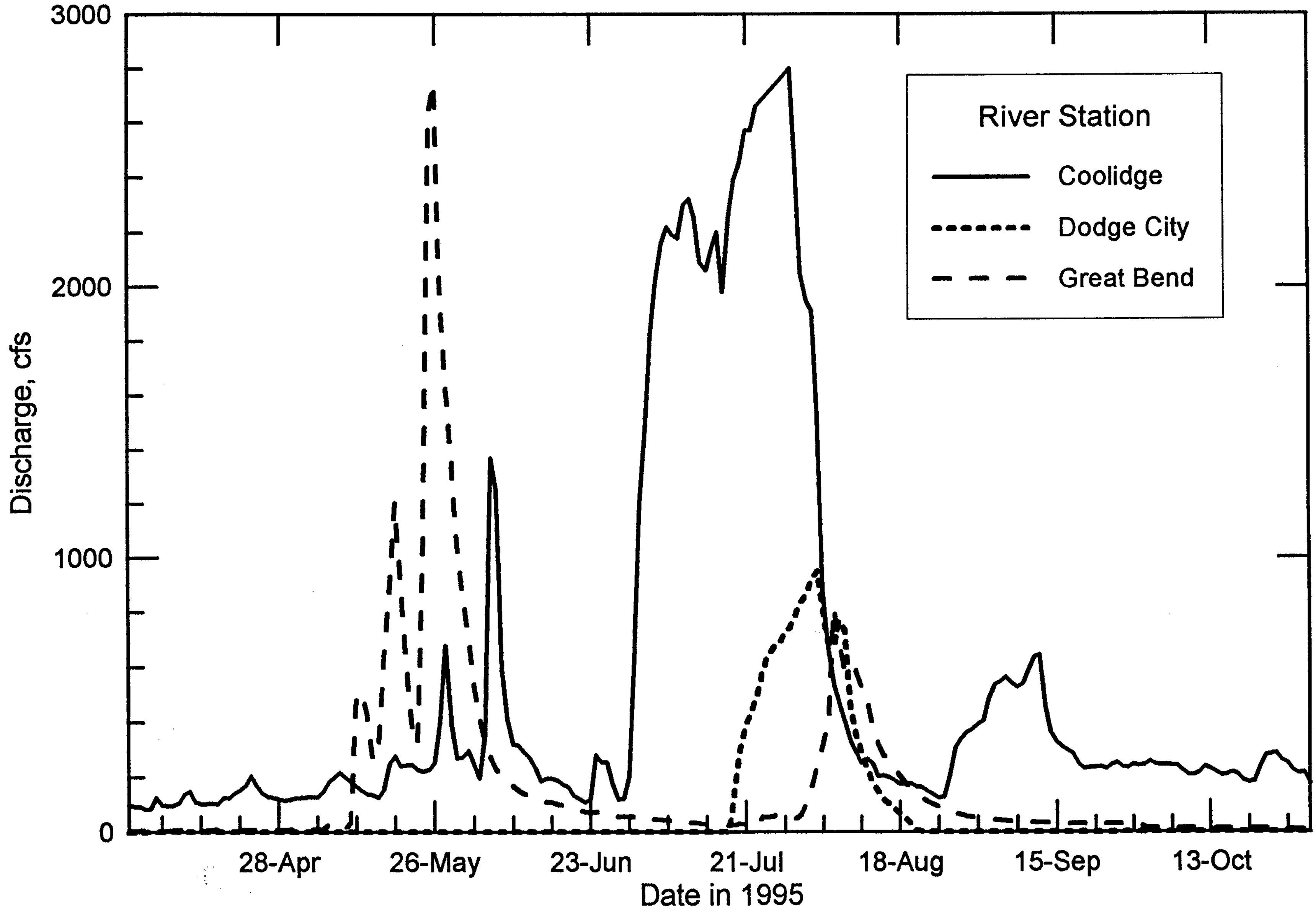

Figure 13. Discharge of the Arkansas River at Coolidge, Dodge City, and Great Bend during April 1 to October 30, 1995.

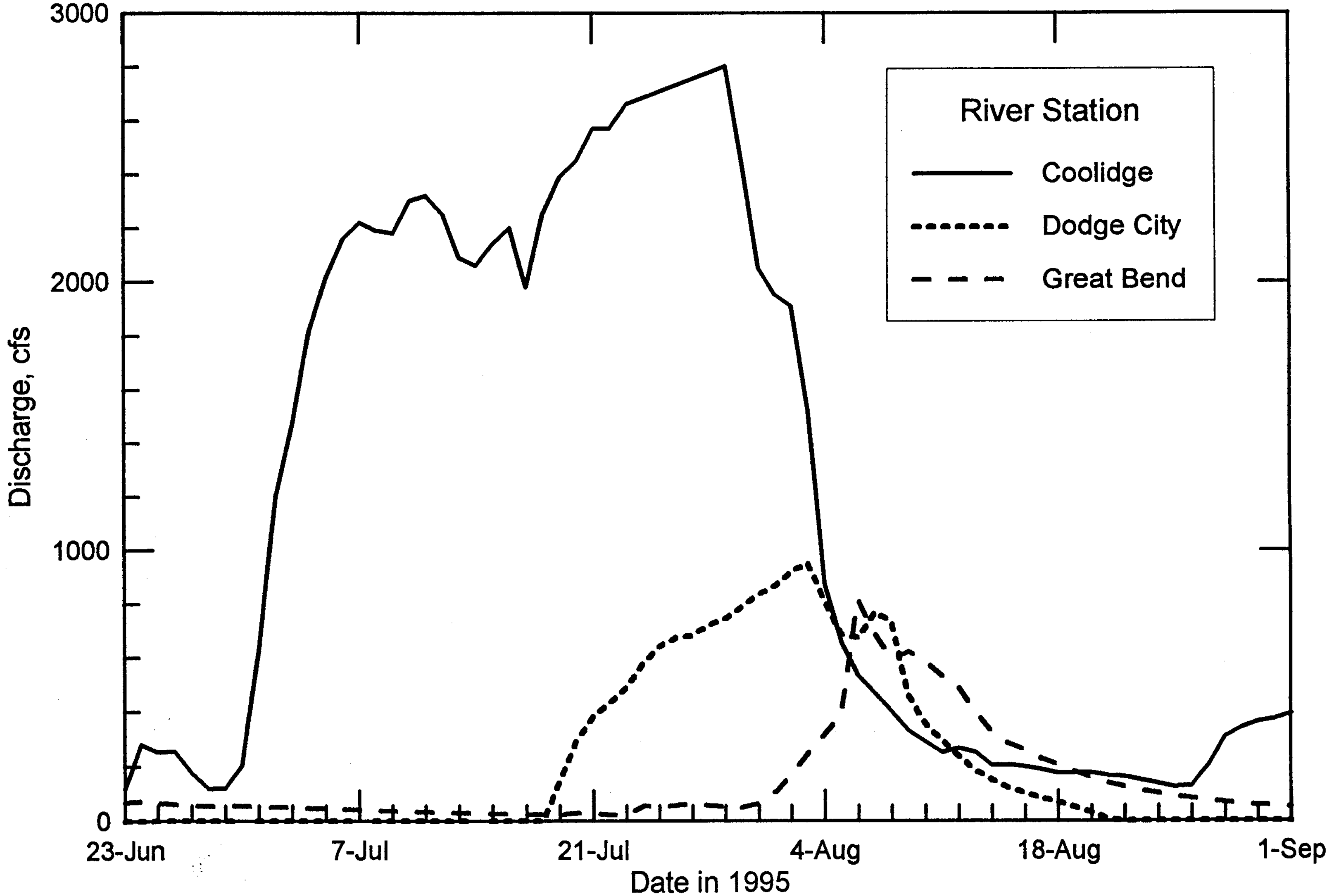

Figure 14 Discharge of the Arkansas River at Coolidge, Dodge City, and Great Bend during June 23 to September 1, 1995.

reflecting the effect of both the ditch diversions and bed seepage losses in Kansas. The approximately two week increase in flow at Coolidge during the first part of September did not result in flows reaching Dodge City (Figure 13). Flows at Great Bend also decreased to very low levels by the beginning of September.

Comparison of the area under the 3 flow peaks at Coolidge, Dodge City and Great Bend (Figure 14) could be used to estimate the seepage losses to the river bed. Information on the flows diverted by irrigation ditches in Kansas would allow improvement of the estimates of flow losses from Coolidge to Deerfield. When the discharge data calculations from gage height measurements at Garden City become available from the USGS, estimates of seepage losses from Garden City to Dodge City could be computed. Visual inspection of Figure 14 indicates that there were substantial seepage losses between Dodge City and Great Bend. Combining the portion of these losses that would have occurred in Ford County with the difference between the Coolidge and Dodge City flow peaks indicates that most of the water that entered Kansas during the summer of 1995 recharged various parts of aquifers in the UARC Study area.

Flows in the Arkansas River after the summer 1995 peaks have continued to be larger in Finney and part of Gray counties than during the period of 1989 to early 1995. The flow front has generally extended into central Gray County as far downstream as Cimarron during the first third of 1996. The flow front is expected to retreat as more of the water in the alluvial aquifer infiltrates deeper into the alluvium to the Ogallala aquifer.

Ground-Water System

Ground water generally flows from west to east in the High Plains aquifer in the upper Arkansas River corridor. Figures 15-19 are black and white printouts of larger maps generated using ArcView. The data for the figures represent the alluvial aquifer in the bedrock valley from the state line to western Kearny County and the Ogallala aquifer from central Kearny County to central Finney County. Figure 15 displays the predevelopment water-level surface in the High Plains aquifer in the western portion of the UARC Study area (known as the Garden City Study Area by the DWR). Water-level contours did not bend appreciably at the Arkansas River indicating an approximate equilibrium between recharge from and discharge to the river.

Water-level declines in the Ogallala aquifer have been substantial since the large increase in ground-water use for irrigation in the 1950s. Water levels also declined in the alluvial aquifer overlying those areas of the Ogallala with large water-level drops. Although the general north-south nature of the water-table contours remain during 1985 (Figure 16) and 1994 (Figure 17), noticeable bends in some of the contours occur near the Arkansas River, especially just west of Garden City. These bends indicate the recharge of the Ogallala aquifer from the alluvium in the vicinity of the river valley; the source of the water is seepage from the Arkansas River.

A map of saturated thickness changes for the same area from predevelopment to 1985 (Figure 18) shows that the greatest decreases are to the north and south of the Arkansas River

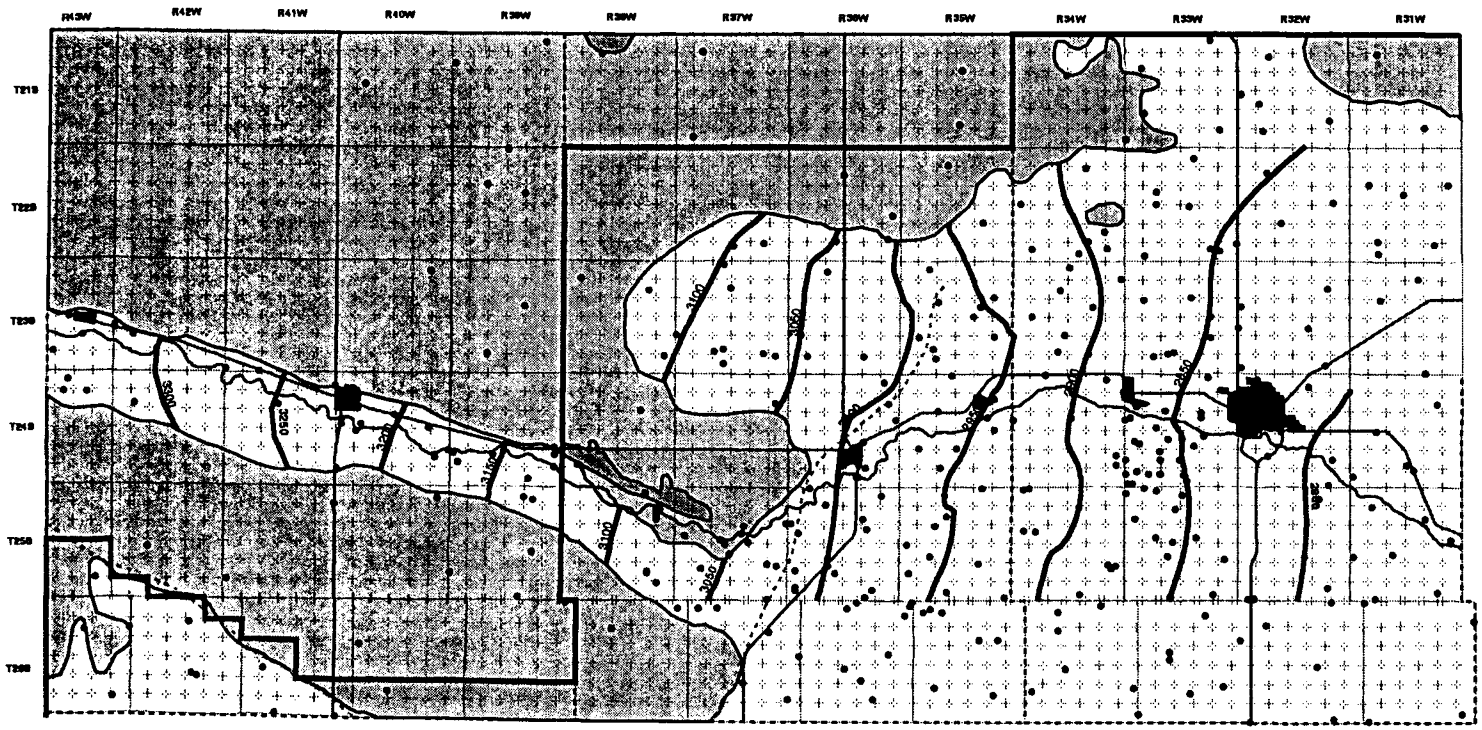

Figure 15. Elevation of the predevelopment water-level surface for the High Plains aquifer in the Garden City Study Area. Contour intervals are in ft above sea level.

[redacted]

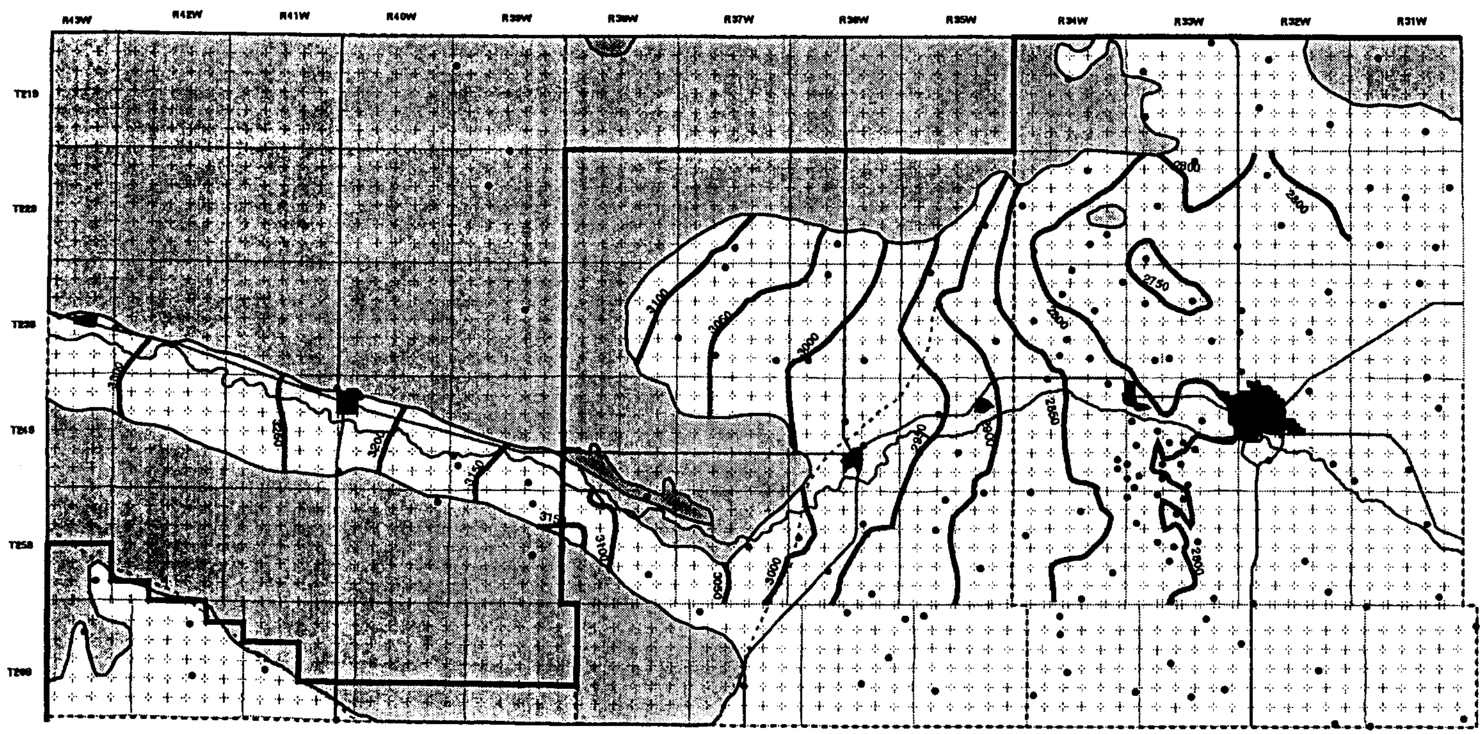

Figure 16. Elevation of the 1985 water-level surface for the High Plains aquifer in the Garden City Study Area. The data represent averaged values for 1984-1986. Contour intervals are in ft above sea level.

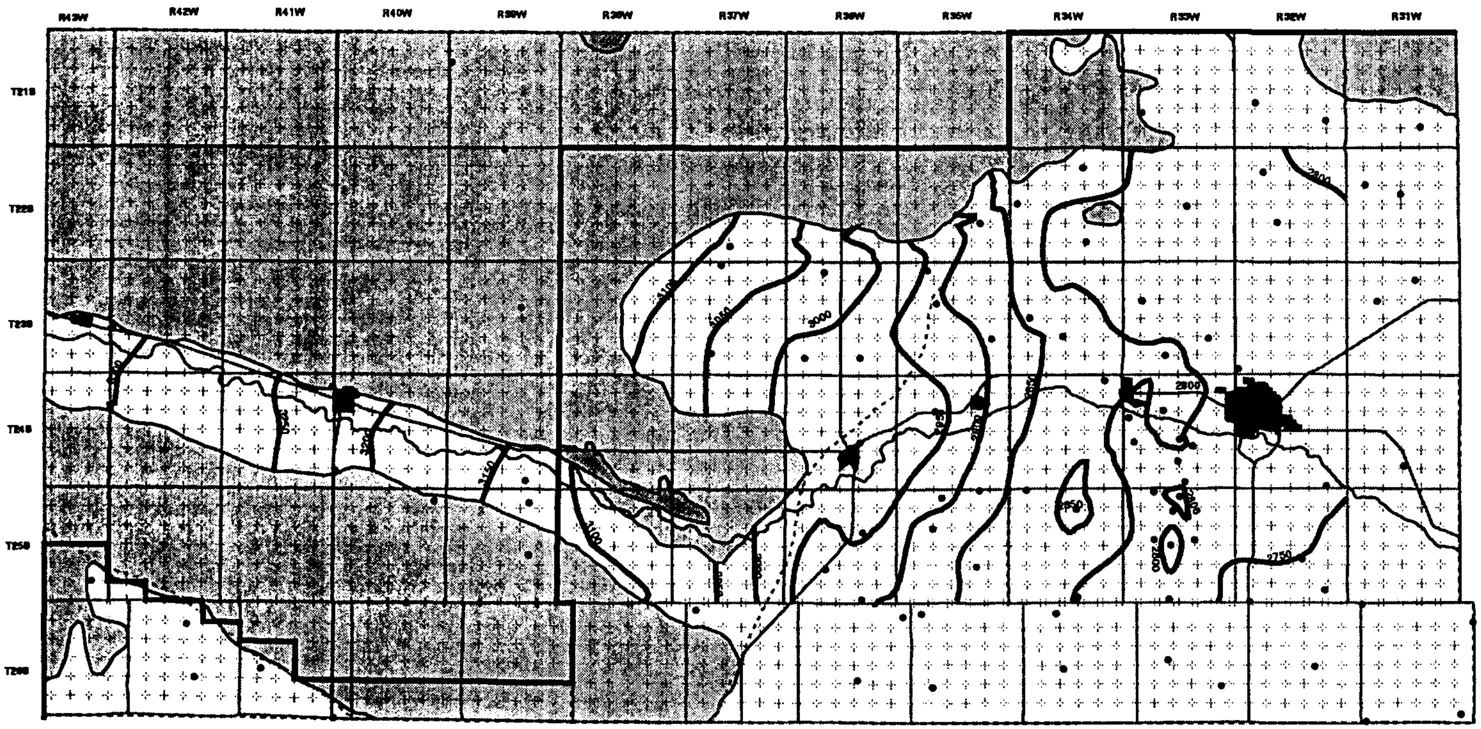

Figure 17. Elevation of the 1994 water-level surface for the High Plains aquifer in the Garden City Study Area. The data represent averaged values for 1993-1995. Contour intervals are in ft above sea level.

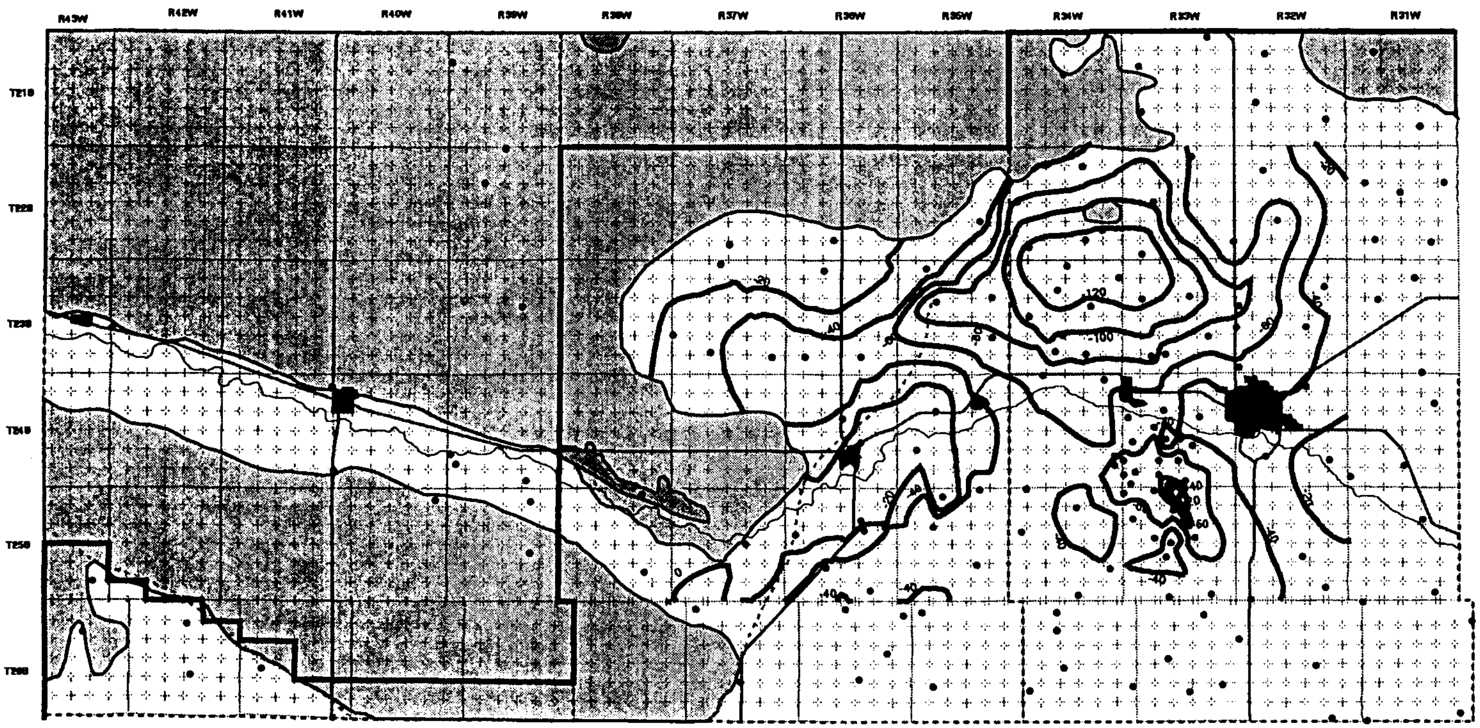

Figure 18. Change in saturated thickness from predevelopment to 1985 (averaged 1984-1986 values) for the High Plains aquifer in the Garden City Study Area. All contours are negative indicating decreasing saturated thickness, except for the zero contour in southwest Kearny County. Contour intervals are in ft.

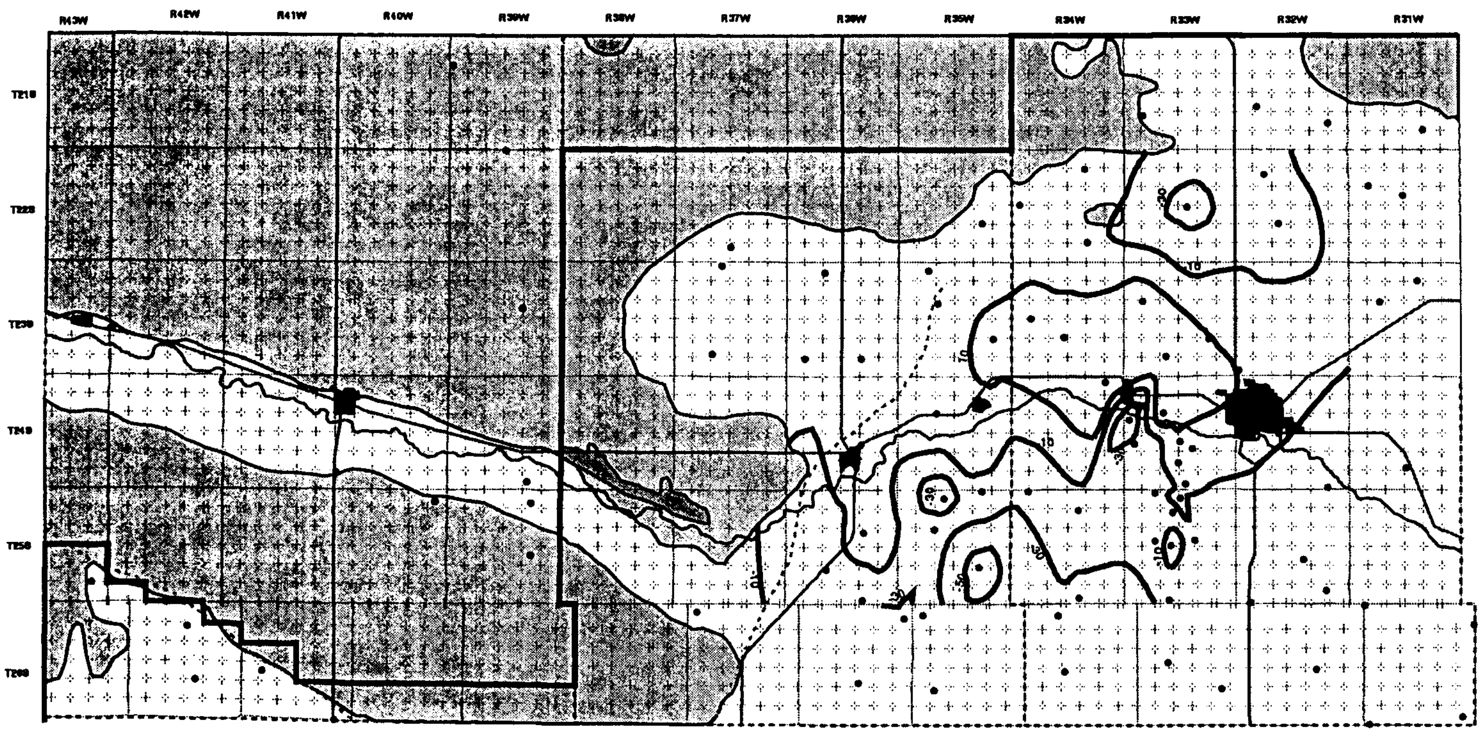

Figure 19. Change in saturated thickness from 1985 to 1994 (averaged 1984-1986 and 1993-1995 values) for the High Plains aquifer in the Garden City Study Area. All contours are negative indicating decreasing saturated thickness, except for the plus 10 contour just west of Garden City. Contour intervals are in ft.

valley, and from 1985 to 1994 (Figure 19) to the south of the valley. Decreases of over 120 ft occurred to the northwest of Garden City by 1985. Saturated thickness changes have been generally less than 10 ft in the bedrock valley from the state line to western Kearny County, indicating there have not been substantial enough changes between the alluvium and the underlying Dakota aquifer to appreciably alter water levels. The constant flow of the Arkansas River through the bedrock channel area must help maintain the saturated thickness in that stretch of the valley. A nose of smaller declines in saturated thickness in the Ogallala aquifer is visible in eastern Kearny County in Figure 18. This observation and the nose-like shapes in the water-level surface just west of Garden City in Figures 16 and 17 indicate the importance of the river flows to recharge in the aquifer.

Water diverted from the Arkansas River in the Amazon, Great Eastern, Farmers, and Garden City ditches is used for irrigation on the north side of the river from north of Deerfield to west and northwest of Garden City. Water-level and saturated thickness declines are large in this area, and generally become greater the farther to the north. Although some recharge might be expected to occur from recharge of ditch irrigation waters, the net loss from ground-water pumping has apparently greatly exceeded the recharge.

Water Quality

Source and Character of Salinity

The Arkansas River is very fresh as it enters the Great Plains from the Rocky Mountains. The concentration of sulfate is relatively high (often about 100 mg/L) in comparison with that of chloride (usually less than 10 mg/L) in the freshwater. Discharge of ground water from Cretaceous bedrock to tributary streams in eastern Colorado increases the dissolved solids of the river water somewhat; the sulfate/chloride ratio is also generally high in these waters. However, the major increase in salinity today is due to the great losses of water by evaporation from water surfaces in reservoirs and the discharge to the river of saline return flow and ground water in the alluvial aquifer affected by evaporation from ditches and irrigation furrows, evaporation of soil moisture brought near the surface by capillary action, and transpiration by plants. Increase in the salinity of Arkansas River water caused by ditch irrigation systems in Colorado was noticeable as early as 1895 (Sherow, 1990). Historical records of water-quality data for the Arkansas River suggest that TDS and sulfate concentrations appear to have approximately doubled from 1906 to 1973. The TDS and sulfate contents of low flows have remained within the same approximate range from 1973 to the present. A bar graph of these changes is shown in the first report for the UARC Study (Whittemore, 1995).

The chemistry of Arkansas River water in eastern Colorado and southwestern Kansas is characterized primarily by high contents of the cations sodium, calcium, and magnesium (in order of decreasing equivalent concentrations), and the anion sulfate. Concentrations of sodium can reach 600 mg/L, calcium nearly 400 mg/L, magnesium over 200 mg/L, sulfate 2,400 mg/L, and total dissolved solids over 4,000 mg/L in river water in Kansas during low flows. Although chloride concentrations also increase with the other major constituents, concentrations do not generally exceed 160 mg/L in low flows. The sulfate/chloride mass ratio remains between 10 and 20 in both low and high flows in the Arkansas River in eastern Colorado and southwestern Kansas. High sulfate content would be the main concern for contamination of drinking waters by seepage of Arkansas River water. Although the current sulfate limit of 250 mg/L is only a recommended standard for drinking water, the federal government has proposed 400 mg/L as a maximum contaminant limit.

Water in the irrigation return flows from Colorado form much of the Arkansas River flow entering Kansas during the irrigation season. Concentrations of sodium, calcium, magnesium, sulfate, and chloride have been observed as high as 1,100, 410, 290, 3,700, and 290 mg/L, respectively, in ditch return flows in eastern Colorado (Cain, 1985); the highest specific conductance measured in the study by Cain was 6,940 µS/cm (µmho/cm) and the largest TDS content computed from these data is 5,800 mg/L. Water also seeps from the alluvium in eastern Colorado to form part of the Arkansas River flow. The ground waters in the alluvial aquifer underlying ditch irrigation in Colorado have also become saline. Cain (1985) reported dissolved sodium, calcium, magnesium, sulfate, and chloride contents as large as 1,000, 360, 320, 3,400, and 290 mg/L, respectively in ground waters in irrigated areas; the specific conductance and computed TDS concentration were as great as 6,410 and 5,500 mg/L, respectively. These data indicate how saline waters could become in some localities in the future in Kansas if current conditions continue.

The highly mineralized surface and ground waters are usually saturated with respect to the minerals calcite ($CaCO_3$) and gypsum ($CaSO_4 \cdot H_2O$). Chemical precipitation of these minerals limits the maximum calcium and sulfate concentrations. Some magnesium is probably also incorporated into the calcium carbonate formed, thus it is somewhat limited as well. Chloride concentration is generally the best indicator of the degree of concentration of the water by loss of water to evapotranspiration. For example, the chloride concentrations increase about an order of magnitude in low Arkansas River flows from the most western irrigation ditches diverting river water in Colorado to the gaging station at Coolidge, Kansas. The other constituents increase in similar degree until the concentrations of calcium and sulfate reach levels where chemical precipitation occurs. The increase in sodium content generally parallels that of chloride, although cation exchange with calcium and magnesium on clays in river sediments and soils can alter its concentration.

Increases in minor and trace constituent concentrations in the Arkansas River and irrigation return flows also occur. The increases in dissolved contents of many constituents are limited by chemical precipitation and adsorption reactions. Boron, selenium, and uranium concentrations were found as high as 2 mg/L, 68 µg/L, and 220 µg/L, respectively in surface waters collected from the Arkansas River valley in eastern Colorado during April, 1991 (Zielinski et al., 1995). The dissolved concentrations of all of these constituents were well correlated with one another, and were also well correlated with sodium, sulfate, and chloride contents (coefficients $\geq$0.82). Boron, selenium, and uranium contents in waters from the Arkansas River and Lake McKinney in Kansas were observed to be as high as 0.64 mg/L, 10 µg/L, and 47 µg/L, respectively, in samples collected in 1988 (Mueller et al., 1991). These values compare with the maximum contaminant limit of 50 μg/L for selenium and the proposed limit of 20 μg/L for uranium.

Source of Nitrate

Nitrate concentrations have generally increased in ground waters in the upper Arkansas river valley within the last 20 years. This observation is based on the 1994 sampling of the same irrigation wells or wells very close to wells sampled in 1975. Of the 16 well waters collected, the nitrate content increased in 13 and decreased in only 3 samples. One of the well waters collected in 1994 was at the maximum contaminant limit for drinking waters and another contained nitrate appreciably greater than the standard of 10 mg/L nitrate-N. The magnitude of the average nitrate increase in the well waters was larger than the average decrease (Whittemore, 1995).

The nitrate concentrations in low flows of the Arkansas River in eastern Colorado and southwest Kansas typically range from 1 to 3 mg/L nitrate-nitrogen. High flows contain smaller concentrations; nitrate-N contents are usually <2 mg/L and commonly <1 mg/L. All samples collected along the river from Coolidge to Dodge City on July 25, 1995 (during the peak flow period) contained <0.5 mg/L nitrate-N. The average nitrate concentration in the river water is substantially less than the average content in ground waters in the High Plains aquifer in the river valley. The data suggest that leaching of nitrate derived from fertilizer and oxidation of nitrogen in soil organic matter is the source of the contamination.

Fate of Contaminants

Nearly all of the saline waters that flow in the Arkansas River today infiltrate to the High Plains aquifer in southwest Kansas. During unusually high flow events, some river water flows out of the upper Arkansas River corridor but this water is generally less saline than the river water that flows into the state most of the time. Some of the contaminants in the saline water may accumulate as precipitated salts or adsorbed constituents in the soils of fields irrigated by the river water. A small amount of constituents also leaves the area in the plants and animals that feed on the plants grown with the saline water. However, overall the net effect on the ground-water quality in the upper Arkansas River corridor is the constant influx and infiltration of mineralized river water into the aquifers and migration vertically and away from the river as ground-water pumping causes water-level surfaces to slope away from the valley. Likewise, seepage of river water diverted for irrigation use will continue to add saline water to the aquifer underlying the irrigated fields.

Before irrigation ditch systems were constructed in the 1870s in Colorado, the Arkansas River flowed enough during most periods to maintain shallow water tables in the alluvium in the vicinity of the river. Some discharge from Cretaceous bedrock and the Ogallala aquifer to the river valley also helped to keep water tables shallow. The river channel was much broader and shallower than today; human impacts decreasing the river flow have caused deepening and narrowing of the channel. During extended dry periods the shallow ground water in the floodplain probably became very slightly saline because evaporation of moisture from the sediment could occur as capillary action pulled water up above the water table. Transpiration by plants growing at elevations of the floodplain above the active river channel could also increase salinity during dry periods. As the river stage continued to fall during drought, some of the shallow, saline ground water in the alluvium underlying the floodplain would move along curved flow lines downward and towards the river and then upwards and to the river channel as discharge. This would result in moving the slightly saline water deeper into the alluvium before discharge to the river.

High flow events with fresh river water would have caused some infiltration of water into the floodplain sediments, thereby diluting the upper part of the slightly saline water but also driving some of the saline water deeper into the alluvium. When the high stage receded to low flows, the diluted ground water would then flow towards the river. Heavy atmospheric precipitation would have also infiltrated to the shallow alluvial waters and caused dilution.

Ground water in the Dakota aquifer underlying the Arkansas River valley in eastern Colorado and southwestern Kansas is fresh but contains relatively high sulfate concentrations (usually 50-300 mg/L) in comparison with other constituent contents (Macfarlane et al, 1994). Before drilling of wells, the Dakota aquifer was artesian along the Arkansas River valley from southeastern Colorado into Hamilton County. The Dakota aquifer probably also discharged water to the river valley along other stretches downstream of Hamilton County through the study area. Some natural discharge of this water into the Arkansas River would have added fresh water of calcium-bicarbonate, calcium-sulfate, or mixed cation-anion type, with sulfate/chloride mass ratios from somewhat less than 10 to near 15. The higher sulfate concentrations of the bedrock discharge would have partly balanced dilution by surface recharge and Ogallala discharge to the alluvial aquifer and river water. Thus, moderate concentrations of sulfate would have been expected in waters in the alluvium near the river and in lower river flows. Concentration of this water in the shallow alluvium and in the river by evapotranspiration would then have produced even higher sulfate contents.

Before human impacts, the combined effects of the evapotranspiration concentration of shallow ground waters during dry periods, dilution by flooding and infiltration of rainwater, and bedrock discharge would have reached a state of approximate equilibrium about which salinity from climatic changes would vary. Ground waters with somewhat elevated dissolved solids, but not the levels observed today, would be expected in the alluvial aquifer below the floodplain. In general, the farther downstream in the Arkansas River valley, the less saline the water in the alluvium would be because the increase in mean annual rainfall would cause increased dilution from direct infiltration and greater ground-water discharge from the Ogallala aquifer to the valley.

After irrigation started in Colorado in the 1870s, the Arkansas River flow entering Kansas was reduced in quantity and became more saline. After the 1870s, the Kansas diversions would have also decreased flow somewhat, although the amounts used in Kansas have always been substantially less than those in Colorado. The more saline river waters would not have affected the alluvial ground waters much during low flow periods except in the local areas of the broad river channel, because ground-water discharge to the river from bedrock, alluvium underlying higher terraces in the valley, and the Ogallala aquifer, where present, would have prevented movement away from the channel zone. High flow events, however, would result in water infiltrating into the shallow alluvium covered by the flood waters that would have been more saline than expected before irrigation began. The greater salinity of the high flow could have been derived from locally heavy rainfall flushing salts from irrigated fields and saline water from return-flow ditches. In addition, the front of a flood event caused by rains or snowmelt in the Rocky Mountains or locally heavy rain would mix with the saline low-flow water to produce a mixture which would have been the first water to seep into the alluvium as the river stage rose.

After ground-water use in the alluvial aquifer started near the turn of the century, water-level surfaces near the pumping wells would produce local cones of depression that could cause some of the slightly saline ground water in the shallow alluvium to migrate farther from the river. In addition, pumping from the Dakota aquifer in southeastern Colorado and far southwestern Kansas began to reduce the artesian head to levels such that today they are below the river channel. Thus, discharge of freshwater from the underlying Dakota aquifer to the river valley decreased. Continued pumping of the alluvial aquifer and development of the Ogallala aquifer later caused further declines in ground-water levels. Once the water levels in the alluvium away from the river declined enough that river-water seepage became substantial, the alluvial water began to become appreciably more saline from the high TDS river water.

The saline water diverted from the Arkansas River for irrigation use in Kansas became more saline from further evapotranspiration. Some of the saline water seeped from below canals and irrigated fields to the alluvial aquifer or Ogallala aquifer. The infiltrating water would have been most saline in the period before water was pumped from the alluvial or Ogallala aquifer and added to the ditches for use with the river water for irrigation. Some areas did not add ground water to the ditches or fields; salinity increases below these irrigated areas should be expected to be greater than where fresh ground water has been used.

Ground water is used today on most of the fields irrigated by surface water. In the past, this was often accomplished by placing the pumping well near the ditch and pumping water into the ditch to mix with the Arkansas River water. Locations of some of the wells next to the ditches can be seen on USGS 7.5 minute topographic maps for the area. Currently, there are 3 main methods in which the ground water is used: a field is flooded with river water then ground water is added to the field via a gated pipe; ground water is pumped into a pit into which the river water is added from a tap from the diversion ditch and the mixture is used for irrigation; river water and pumped ground water both enter a pipe that is used to distribute the water to the irrigated field (M. Rude, personal communication). A small number of fields apparently still have only river water applied for irrigation.

As ground-water level declines in the Ogallala aquifer became more pronounced in eastern Kearny County eastward through the study area, saline waters in the alluvial aquifer began to migrate farther from the river. Saline water infiltration from fields irrigated with river water could also penetrate to greater depths into the Ogallala aquifer. The migration pathway of the saline water is affected by the heterogeneity of the aquifer. Both the alluvial and

Ogallala aquifers contain layers and lenses of sediments of greatly differing permeability. Clayey layers would slow the downward movement of saline waters but allow more lateral flow within overlying permeable sands; the saline water would be perched on the less permeable zone. Such a situation appears to exist to the west and south of the Garden City area. The USGS study of Dunlap et al. (1985) indicates that a confining zone separates permeable zones into an upper and a lower aquifer from southeastern and east-central Kearny County to southern and west-central Finney County.

The ground-water levels present in the alluvial aquifer near the river are substantially higher than in the Ogallala aquifer. However, leakage from the alluvial aquifer has produced a ridge of higher water levels below the river valley, especially in eastern Kearny and southern Finney counties where seepage from the Arkansas River is an important source of recharge. The slope of the water-level surface is currently greater towards the north but projections of water-level declines made by Dunlap et al. (1985) indicate that future declines will be greater south of the river. Thus, saline water from the river and alluvial aquifer could be expected to not only move downward but farther away from the river towards freshwater supplies.

In the areas where Arkansas River water is used for irrigation nearer the Arkansas River, the downward infiltration of increasingly saline water to the alluvial and Ogallala aquifers will eventually meet the saline water migrating outward from the river. In irrigated areas both close to and farther from the river, recycling of saline water by pumping of ground water affected by infiltration below fields irrigated with river water will slowly increase the salinity of the subsurface waters.

The eastern part of the upper Arkansas River corridor no longer receives significant recharge from the river during most periods. However, when heavy local rainfall or influxes of water released from Colorado reservoirs filled by much snowmelt and precipitation create river flow through the area, most of the flow will infiltrate to the alluvium. Ground-water levels have also declined in the alluvial and Ogallala aquifers in Gray and Ford counties, resulting in conditions that favor such river-water loss. The water-level declines in the alluvial aquifer below the floodplain could result in reducing the amount of evapotranspiration of shallow subsurface water, thereby decreasing the concomitant generation of salinity from natural processes.

Large flow events that have occurred during recent years in the Arkansas River result in appreciably less saline river water than during low flows. Despite input of very fresh snowmelt and rain on occasion in Colorado, mixing with the great amount of saline water in reservoirs, ditch systems, and shallow aquifers, and flushing of readily leachable salts in soils of irrigated fields, produce slightly saline river water in Colorado by the time the water reaches Kansas.

During the summer of 1995, the freshest water observed entering Kansas (July 25 at Coolidge) during the flow peak had a specific conductance of 1,680 µS/cm (or µmho/cm), a TDS content of about 1,220 mg/L, and a sulfate concentration of 708 mg/L (Figure 20). (See Whittemore, 1995, for a figure of specific conductance for the same sites and dates shown in Figure 20.) The salinity of the river water on July 25 was higher at locations downstream of

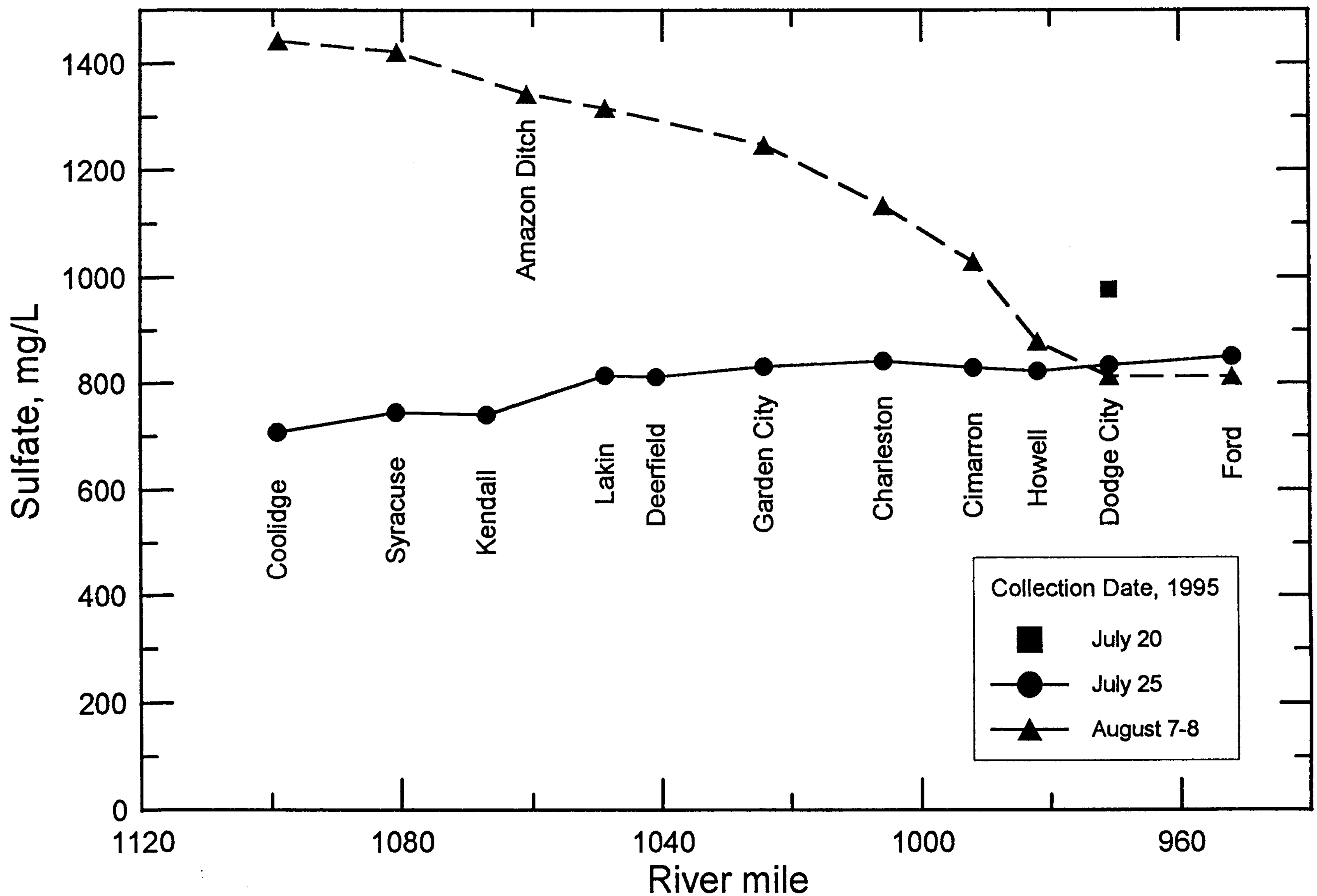

Figure 20. Sulfate concentration for water samples collected from the Arkansas River during the high-flow event of the summer of 1995. The river mile location of the sites is either from data for USGS gaging stations or estimated between stations.

Coolidge. On July 20, when the flow front was just past Dodge City, the sulfate concentration was 977 mg/L. As fresher water continued to reach Dodge City, the sulfate content dropped to 835 on July 25, then to 813 mg/L on August 8. The last of these three collection dates was during the recession portion of the flow at the gaging station. The last sample collected (August 15) before flow ceased (August 21) at Dodge City contained a much higher sulfate concentration of 1317 mg/L.

The lowest salinity of the river at any given location probably occurred close to the end of the flow peak at that site. A few days after the flow peak passed, the salinity rose steadily. This is indicated by the increasing sulfate content in an upstream direction for the August 7-8 samples (Figure 20). The July 25, 1995 sample at Coolidge was collected 4 days before the end of the flow peak at that station. The August 7 sample at Ford was collected about 4 days after the peak flow had passed. Samples were also collected earlier on August 7 at Kinsley and Larned; the sulfate concentrations were 810 and 752 mg/L, respectively. The flow peak at Larned was probably only about a day earlier. The sample at the Larned site on the Arkansas River could have been somewhat diluted by Pawnee River water. Based on this data the sulfate content probably did not drop substantially below 800 mg/L at any time during flow through Ford County.

The chemical quality of the high flow event of the summer 1995 indicates that another important mechanism for introducing slightly saline water into the alluvial aquifer near the river is by infiltration of flood waters. The large amount of the river recharge could have an important affect on water quality even though flooding events could be spaced by as much as 10 years apart. The results also confirm that there is a large reserve of salinity in Colorado that can increase the TDS of waters entering Kansas during high flows. Although any reduction in water use in Colorado that might occur as a result of resolution of the Arkansas River Compact case would be expected to result in water of decreased salinity, stored salts in the system will probably moderate those decreases.

Very high sulfate concentrations are present in some ground waters in the Arkansas River valley, especially in the alluvial aquifer. For example, sulfate concentrations in two of the 3 wells that the KDHE monitors in Hamilton County on a biennial basis have ranged from 2,440 to 2,990 mg/L; these are both irrigation wells. The sulfate content of the third well, used for public water supply for Syracuse, has increased from 119 to 161 mg/L during 1990 to 1994. Wells with multiple-year records in some of the other counties in the study area with high sulfate concentrations show relatively constant, fluctuating, or increasing values. For example, an irrigation well in Finney County, which has been yielding water with sulfate concentrations in the range of 150-340 mg/L over the decade, produced water with a much greater sulfate content (660 mg/L) in 1994.

A preliminary investigation for the UARC Study was conducted to determine water quality changes in irrigation wells sampled in 1975 along the Arkansas River valley. In cooperation with the KGS, the DPH collected waters in 1994 from the same irrigation well or a well very close to an irrigation well sampled in 1975 by the KGS. Inorganic constituents were analyzed in the samples at the KGS. The results for sulfate are shown in Figure 21.

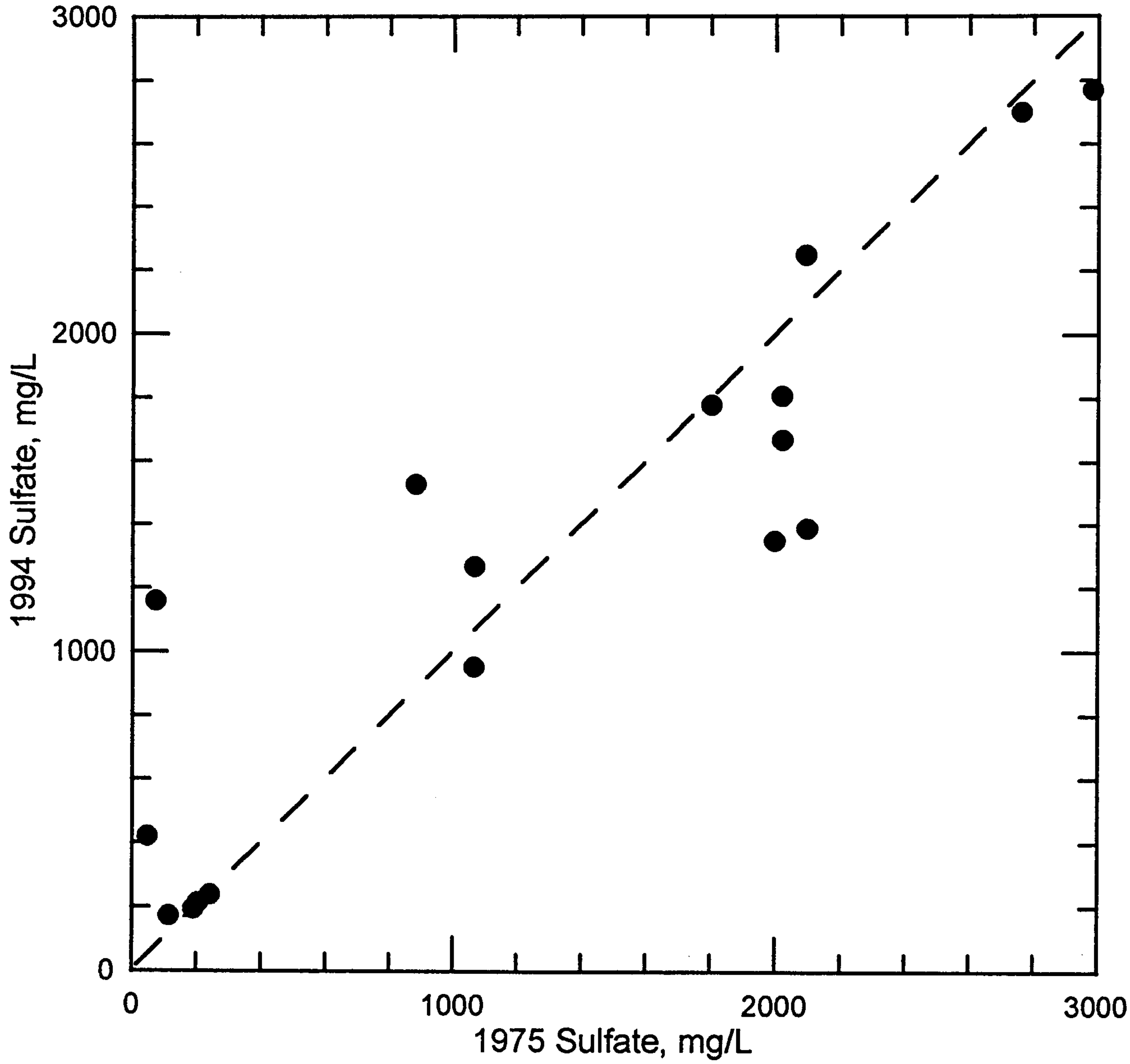

Figure 21. Sulfate concentration for water samples collected from irrigation wells in 1975 and from the same or very nearby wells in 1994. The dashed line represents concentrations that were the same in 1975 as in 1994.

These are the same samples discussed under the section on "Sources of Nitrate" above. The dashed line in Figure 21 represents the condition in which concentrations were the same for 1994 and 1975. Points above the dashed line indicate an increase in sulfate during the period; points below the line a decrease for the same period. The figure shows that there were both increases and decreases in sulfate contents. The sulfate level at locations with lower to moderate concentrations in 1975 either increased or remained about the same, whereas the levels at locations with high concentrations in 1975 either decreased or remained about the same. The percentage increases in sulfate concentrations tended to be greater than the percentage decreases.

The fluctuations and increasing and decreasing trends in different locations indicate that there are multiple factors controlling salinity variations in the aquifers. Although the general or average trend will be increasing salinity in the ground waters close to the river and under areas irrigated with river water, changes in water use and, thus, alteration of hydraulic gradients, could result in local salinity decreases. For example, the substantial decreases in sulfate in Figure 21 were mainly in one area of Kearny County and might possibly be related to locations with a substantial percentage of land in the Conservation Reserve Program. Shallow waters in the alluvial aquifer could also become temporarily fresher from infiltration of rainwater during unusually wet years. Even though the high flow of 1995 was slightly saline, the sulfate concentrations were still a third of those in some alluvial waters. Similar, less saline waters are expected to have been present in the river during the high flows that occurred during 1987. Seepage of the high flow could also temporarily freshen saline alluvial ground water.

Declines in the potentiometric surface of the Dakota aquifer where it immediately underlies alluvium of the Arkansas River valley in western Hamilton and western Kearny counties could cause migration of saline water downwards. The thickness and continuity of shale units within the Dakota strata above sandstone bodies and below the alluvium would control the rate of saline water influx. Although movement of alluvial water into the Dakota aquifer would be expected to be a slow process, it could eventually affect local water quality in the vicinity of pumping wells.

Increase in nitrate concentration in the High Plains aquifer could accompany an increase in salinity below croplands in the alluvial valley near the river and in the Ogallala aquifer below fields irrigated with river water. Nitrate increase with time could also be expected under fertilized and irrigated fields in locations without river water use and far enough away from areas of river water irrigation and the valley that saline ground water has not yet reached the location. In general, the nitrate increase probably will not be as fast in areas farther from the river because the depth to the water table is generally greater than near the river.

Minor and trace constituents concentrated in saline river waters could either largely travel with the saline water during subsurface flow or be adsorbed or precipitated on soil and sediment particles. If accumulation of such constituents as uranium can occur within certain layers of soils below fields irrigated with river water, and the accumulated substances can be mobilized by extraction into plant roots, the concentrated constituents could be of concern. This potential problem will be investigated later as a separate study.

ASSESSMENT OF DATA AND INFORMATION NEEDS

Geology

Surficial geology and soil maps are adequate for the needs of the study. W. Johnson of the KU Geography Department is working with the KGS to produce more detailed surficial geology of the Hamilton and Kearny counties region.

The raw data for subsurface geology are generally sufficient as a starting point for analysis for the study. However, the amount of interpreted information is not great enough for determining the stratigraphy of the aquifer systems for use in conceptual and quantitative models of ground-water flow. In addition, boreholes in the aquifer with both detailed characterization of the lithology and gamma-ray geophysical logs are very few and are needed to better interpret the aquifer stratigraphy.

Hydrology

The amount of climatic and weather data, including information on evapotranspiration, being collected and currently available appear to be adequate for inputs into hydrologic models.

Enough flow stations are maintained on the Arkansas River that additional gaging sites are not needed for this project. The data for diversion flows from the Arkansas River in Kansas need to be assessed to determine whether additional flow measurements will be needed for determining the current distribution of saline river waters over croplands. Although the USGS 7.5 minute topographic quadrangles display the major diversion canals and ditches, additional information is needed on the present and historic location of water use from ditch irrigation in Kansas. The locations of the ditches and the diversion flow data will need to be digitized for use in maps and flow models if not in electronic form.

Preliminary development of the information for use in a ground-water flow and saline water transport model in the Garden City area has revealed that additional water-level measurements are needed to fill in geographic gaps without data. Many wells formerly included in the water-level program were removed in the late 1980s. Measurements for some of these wells or nearby wells are needed to reduce error in the flow and transport model. More information is needed on the screened intervals for the different wells measured for water levels to better determine which particular permeable strata the levels represent. If this data is not in the GWSI (Ground Water Site Information) files of the USGS, other sources of this information will be pursued.

The rate of response of water levels at different levels in the High Plains aquifer at the same location within the river valley and in areas irrigated by river water is needed for conceptual and quantitative models of ground-water flow and salinity migration. Additional data on aquifer parameters are needed for better characterization of river-aquifer interactions and ground-water flow across less permeable horizons that separate aquifer layers. Such information would also reduce error in flow and transport models.

Water Quality

The available chemical data for the Arkansas River in Kansas are adequate for general characterization of river-water during low and moderate flows. A limited number of additional samples are needed to characterize the chemistry during the course of this study. The additional samples that the KDHE will collect as a part of their monitoring program should serve to provide much of this additional low to moderate flow data. The amount of past data for high flows is sparse; the collection of chemical data for the high flow event of 1995 as a part of this study provided much more information than previously available for the chemical variations during high-flow conditions.

The relatively recent program of GMD3 and SWKLEPG for monitoring ground-water quality has greatly increased the data available for this study. Additional samples are needed from the same wells to better determine the recent migration of salinity in the aquifers near the Arkansas River and within areas crossed by diversion ditches and irrigated by river water. Many of the SWKLEPG water-quality data do not have specific locations for the wells within sections. These need to be better located. There are also many additional SWKLEPG analyses without any legal location. Detailed identification of the well would make this data useful for the study.

There are many chemical records in the GMD3 data file for which no depth information is available for the well sampled and there are no depths in the SWKLEPG data file. Depth and screened interval information is also needed for the irrigation wells that were sampled by the KGS in the mid-1970s and by the DPH in the 1990s. Although Figures 5-11 show the distribution of ground-water quality data by township, detailed mapping of data containing TDS or sulfate concentrations is required before more specific gaps in areal and depth coverage can be assessed.

Although the number of ground-water quality records is large, there is insufficient information to determine the character and location of the interface between the freshwater and saline water in the alluvial and Ogallala aquifers. Variations in the interface with changes in pumping, river stage, and irrigation use of river water are not known.

Management and Protection Plans

Policy or management actions that could affect the ground-water contamination were discussed under a section in the introduction to this report. Possible management and protection plans need to be developed that fit the information being assembled and the conceptual models developed as a part of this study and that are feasible for the area and local and state agencies. As the distributions of the salinity and nitrate in the study area are better delineated and models of the hydrogeology and contaminant transport are improved, the management plans can be adjusted and tested using quantitative simulation. Information on existing management and protection regulations and policies exist in documents of the GMD3, DWR, and KDHE. Other state agency policies may also be relevant to the area, such as those in the KDWP, Kansas Conservation Commission, and additional divisions in the KDA besides the DWR.

PROCEDURE FOR OBTAINING NEEDED INFORMATION

Geology

Lithologic data in the WWC-5 forms for water wells are being analyzed to improve cross sections of aquifer stratigraphy in the study area. The first sections being constructed are for the Garden City area. Records for wells within a mile of the cross section line are being examined for this purpose. The results indicate that the number of clayey and silty units in the High Plains aquifer are numerous and could be important for limiting the downward movement of saline water, and causing perching and more rapid migration within permeable zones.

Geophysical logging of available PVC wells formerly used for oil-field water supply is proposed as a method for better characterization of the stratigraphy of aquifer units. Staff of the DPH believe that there are some of these wells present in the study area. The KGS has the equipment necessary for gamma-ray logging of these wells. Better interpretation of the aquifer materials could be made using boreholes for which detailed logging of the cuttings is available.

Two multi-level well sites are proposed to be installed in the Arkansas River valley in FY 1997 in the initial flow and mass transport model area described below under "Hydrology". Geological, geophysical, hydrological, and water-quality data will be collected from the sites. An additional multi-level well site is proposed for construction in the river valley between Cimarron and Dodge City, and two sites are planned within areas irrigated by river water west of the Garden City area for FY 1998. The wells will be screened in permeable zones in the alluvium and Ogallala aquifers. The intervals in the Ogallala aquifer will be selected to be above and below the saline water migrating from the alluvium. These wells will be logged for cuttings and gamma-ray for detailed geology and will serve as control points to help guide proper interpretation of gamma-ray logs run in existing water wells. Procedures developed during the GMD5 Mineral Intrusion study will be applied during the work.

Geophysical records for oil and gas wells will be examined to select those that were run through the High Plains aquifer. The gamma-ray and resistivity logs for those records will be interpreted to assist in the determination of aquifer stratigraphy.

Hydrology

GIS maps will be prepared of the present system of river diversion ditches and areas irrigated by river water. If data are sufficient, digital maps will be prepared of areas irrigated by river water in the past. Flow data at the diversion headgates, for the distribution of the water for irrigation use, and in return flows will be obtained from the DWR, ditch companies, and other sources to the extent that it exists or may be available for use in the study.

A river-aquifer and ground-water flow model is being developed for a 644 mi^2 area (23 mi N-S by 28 mi E-W) that lies within T. 22 N. to T. 25 S and R. 31 W. to R. 36 W., in western Finney and eastern Kearny counties. The Arkansas River passes through the center of the model rectangle and the irrigation service areas of the ditch systems west of Garden City, as well as the city, are included in the rectangle. The flow model program (MODFLOW) has a link to a chemical mass transport model (MT3D) which will be used to simulate saline water movement in the system. Work on the model has begun to shown what information is needed and lacking for simulating flow and mass transport. Simulation of the more detailed area will assist in better guidance of model development for the entire corridor of the Upper Arkansas River later in the UARC Study.

Information will be obtained from the USGS or DWR for the screened interval of wells used for the water-level program of the state and for the additional measurement program of the DWR in the Garden City Study Area. Water-levels will be measured during the next winter in wells that are located in areas lacking data and for wells that were previously in the state network. Water levels will also be measured in the multi-level well sites to be constructed as described in the "Geology" section immediately above. Slug and pumping tests will be run on the multi-level wells to obtain data on hydraulic parameters of aquifer units.

Water Quality

Contour maps and cross sections will be prepared for the areal and vertical distribution of TDS, sulfate, and nitrate concentrations in the ground waters in the alluvial and Ogallala aquifers for different time periods. The available data suggest that no more than 3 periods will be justified because the number of sample records including concentrations of these constituents (or specific conductance from which TDS content can be estimated) are not sufficient for greater temporal detail. The time periods planned for use in the maps are 1939-1965, 1966-1985, and 1986-present. The maps and sections will show where additional data are critical for the mass transport model in the Garden City area, as well as along the entire upper Arkansas River corridor.

The KGS will work with the GMD3, SWKLEPG, DPH, and KDHE for obtaining additional ground-water quality in wells in the study area. Resampling of wells from which waters were previously collected will be especially valuable for determining the migration of salinity in the corridor. Information on the location and depth of wells previously sampled by these agencies and the KGS will be obtained where available through cooperative work with staff of the agencies and from landowners. The old USGS chemical data for well waters in Parker (1911) will be examined to determine their quality; location information will be sought for chemical data deemed reliable and valuable to the study by research in historical records.

The KGS geophysical logging equipment will be used to obtain an induction log, in addition to gamma-ray logs described above, in the multi-level wells to be installed and in existing PVC wells drilled for oil-field water supply. Procedures developed in the GMD5 Mineral Intrusion Study will be applied to separate out the conductive effects of different geologic strata by correlating the gamma-log results with the conductivity profile in wells in parts of the aquifer without saline water. The correlation will allow better interpretation of the conductivity profiles for discerning saline water from freshwater in the permeable zones of the aquifer. These procedures will be especially critical for use of the conductivity logs in the UARC Study area because the salinity contrast is not as great as the freshwater-saltwater transition in portions of the aquifer in the Great Bend Prairie.

Data for minor element concentrations are being analyzed to determine the degree of evapotranspiration concentration of constituents in water from Colorado and Kansas for different river conditions. The approach includes examination of changes in dissolved bromide and boron concentrations relative to the contents of major constituents (especially chloride, sulfate, and magnesium). Geochemical equilibria models will be run to assess the conceptual model that saturation with respect to calcite and gypsum control calcium and sulfate concentrations once the river or irrigation water becomes saline enough. This will aid in assessing the removal and storage of mineralization in the soils in areas irrigated by river water and return flows, and in predicting how saline waters can become in the future in areas where saline ground waters are recycled to the surface as irrigation waters.

Management and Protection Plans

The KGS will examine the existing management and protection policies of the GMD3 and appropriate state agencies to determine what types of plans could be formulated that would use present procedures. Approaches that are currently not applied to the area will be formulated based on published literature and new ideas that fit the data for the area and predictions from the computer simulations of water flow and contaminant transport. The possible plans will be presented to the members of the TAC for their examination and input. Revised plans will be produced for assessment by staff and boards of local and state agencies.

OUTLINE OF FY 1997 AND 1998 PLANS

FY 1997 Proposed Activities

Present FY 1996 results to the Interagency Technical Advisory Committee and incorporate Committee guidance into research plans

Establish data-collection network for water-levels and water-quality for use in conceptual and quantitative modeling, including data from current networks and new measurements from existing water wells and two multi-level monitoring well sites to be installed across the saline-freshwater transition zone

Assess down-hole geophysical methods for determining saline-freshwater transition zone in the Arkansas River valley

Initiate determination of hydrogeology and salinity distribution in areas between existing data and observation network locations, including geophysical logging of available water wells and use of available lithologic logs

Begin identification of the sources and fate of salinity and other chemical constituents of concern, including nitrate

Revise preliminary maps and cross sections of salinity, selected chemical constituents, and aquifer stratigraphy, and use to revise conceptual models developed in FY 1996

Continue development of ground-water and river-aquifer interaction model of Garden City area and add salinity transport component for use in assessing effects of water-use patterns on ground-water quality

Begin modeling of water-level declines, river-aquifer interactions, and water quality along the entire Arkansas River corridor for predicting effects of natural and human factors

Develop possible management, protection, and remediation plans and strategies for research guidance in Garden City area and along the entire corridor

FY 1998 Proposed Activities

Present FY 1997 results to the Interagency Technical Advisory Committee and incorporate Committee guidance into research plans

Continue data-collection necessary for conceptual and quantitative models

Continue identification of the sources and fate of salinity and other chemical constituents of concern, including nitrate

Continue determination of hydrogeology and salinity distribution in areas between existing data and observation network locations, including geophysical logging of available wells and installation of additional multi-level monitoring well sites to be installed across the saline-freshwater transition zone in the river valley and underlying areas irrigated with river water

Revise maps and cross sections of salinity, selected chemical constituents, and aquifer stratigraphy based on additional data collected, and apply to improving conceptual flow and water-quality models

Complete ground-water and river-aquifer interaction model for salinity transport in the Garden City area and assess impact of possible management and protection alternatives for reducing salinity impact

Continue modeling of water-level declines, river-aquifer interactions, and water quality along the entire Arkansas River corridor for predicting effects of natural and human factors

Assess practicality of management and protection strategies considered in the Garden City model area and use to guide data collection and modeling along the entire corridor

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