ANALYSIS OF STREAM-AQUIFER SYSTEM INTERRELATIONSHIPS IN THE BIG BLUE AND LITTLE BLUE RIVER BASINS IN GAGE AND JEFFERSON COUNTIES, NEBRASKA

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 81-29

Prepared in cooperation with the

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The largest ground-water contributions to streamflow in the Big Blue River occur in the reaches of the river between the mouth of Mud Creek and the dam at Blue Springs (about 13 cubic feet per second) and between the mouth of Turkey Creek and the Beatrice gaging station (about 22 cubic feet per second). Ground-water contributions to streamflow also occur in two tributaries of the Big Blue River: Bear Creek (4.39 cubic feet per second) and Big Indian Creek (6.23 cubic feet per second). In the Little Blue River basin the largest contributions to streamflow occur between the mouths of Big Sandy and Little Sandy Creeks (about 6.5 cubic feet per second) and in the vicinity of Fairbury (about 16 cubic feet per second).

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KANSAS-NEBRASKA BIG BLUE RIVER COMPACT ADMINISTRATION

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UNITED STATES DEPARTMENT OF THE INTERIOR

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SELECTED FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM (SI) METRIC UNITS

Multiply inch-pound units	By	To obtain SI units
foot (ft)	0.3048	meter (m)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	cubic decimeter per second (dm^3/s)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)

DEFINITION OF VERTICAL DATUM

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "mean sea level."

ANALYSIS OF STREAM-AQUIFER SYSTEM INTERRELATIONSHIPS IN THE BIG BLUE AND LITTLE BLUE RIVER BASINS IN GAGE AND JEFFERSON COUNTIES, NEBRASKA

By M. J. Ellis

ABSTRACT

Seepage measurements made during the fall of 1978 at 21 sites in the Big Blue River basin and at 35 sites in the Little Blue River basin were used to determine stream gains or losses in 20 drainage areas in the Big Blue River basin and 31 drainage areas in the Little Blue River basin. Analyses of data from these seepage measurements and of available hydrogeologic data indicate that the most significant ground-water contributions to streamflow in the Big Blue and Little Blue River drainage basins in Gage and Jefferson Counties, Nebr., occur where a direct hydraulic connection exists between a stream and buried coarse-grained deposits of Quaternary age. These deposits occur in two buried bedrock valleys that trend east-northeasterly across the area.

The largest ground-water contributions to streamflow in the Big Blue River occur in the reaches of the river between the mouth of Mud Creek and the dam at Blue Springs (about 13 cubic feet per second) and between the mouth of Turkey Creek and the Beatrice gaging station (about 22 cubic feet per second). Ground-water contributions to streamflow also occur in two tributaries of the Big Blue River: Bear Creek (4.39 cubic feet per second) and Big Indian Creek (6.23 cubic feet per second). In the Little Blue River basin the largest contributions to streamflow occur between the mouths of Big Sandy and Little Sandy Creeks (about 6.5 cubic feet per second) and in the vicinity of Fairbury (about 16 cubic feet per second). A ground-water contribution to streamflow of about 6.5 cubic feet per second also occurs in Rose Creek, a tributary of the Little Blue River.

INTRODUCTION

In July 1974, the U.S. Geological Survey, as part of a.cooperative program with the Kansas-Nebraska Big Blue River Compact Administration (hereinafter referred to as the Administration), began the collection and evaluation of ground-water data for selected parts of the Big Blue and Little Blue River drainage basins in Nebraska. The purpose of this work was to provide the Administration with data for their use in evaluating the effects of ground-water withdrawals on streamflow. The Administration is required to make such an evaluation by Article III, paragraph 3.4 of the Kansas-Nebraska Big Blue River Compact (Kansas-Nebraska Big Blue River Compact Commission 1971) which states:

> "In order to provide a sound basis for carrying out the apportionment provisions of this Compact, the Administration shall cause to be established such stream-gaging stations, ground-water observation wells, and other data-collection facilities as are necessary for administering this Compact; and it shall install such other equipment and collect such data therefrom, for a period of not less than 5 years, as are necessary or desirable for evaluating the effects of pumping of wells on the flows of the Big Blue and Little Blue Rivers at the Kansas-Nebraska State line. The well area to be considered is described in Article V, paragraph 5.2."

Article V, paragraph 5.2 of the compact describes the well area as being the:

> "....alluvium and valley side terrace deposits within one mile from the thread of the river and between the mouth of Walnut Creek and the Kansas-Nebraska State line on the Little Blue River and between the mouth of Turkey Creek and the Kansas-Nebraska State line on the Big Blue River"

The approximate extent of this well area is shown on figure 1.

The Walnut Creek referred to in the Compact was shown as a tributary of the Little Blue River on the 1921 edition of the U.S. Geological Survey's 1:500,000 planimetric map of Nebraska. During the late 1950's and early 1960's, detailed mapping and field studies in the area showed that Walnut Creek is a tributary of Little Sandy Creek. Thus the stream referred to as Walnut Creek in the Kansas-Nebraska Big Blue River Compact is now recognized as Little Sandy Creek.

Initial work done in collecting ground-water data for the Administration consisted of establishing and operating a water-level monitoring network in which both ground-water levels and stream stages were measured. The distribution of the data-collection sites in this network are shown on figure 1. Data collected during the operation of this network were published in the Administration's annual reports (Kansas-Nebraska Big Blue River Compact Administration, 1975, 1976, 1977, and 1978).

EXPLANATION

WELL AREA

DRAINAGE-BASIN BOUNDARY

OBSERVATION WELL
STREAM-STAGE SITE
} Water-level monitoring site in network established for Administration

Figure 1.--"Well area" defined in the Kansas-Nebraska Big Blue River Compact.

During 1977 an evaluation was made of the water-level data that had been collected during the operation of the network and of other hydrogeologic information and data that were readily available. Results of the evaluation indicated that the water-level data from the observation-well network probably would not provide the Administration with the types of information needed for adequate evaluation of the possible effects of ground-water development on streamflow. A decision was then made by the Administration to discontinue operation of the water-level monitoring network and to collect some stream-seepage data (Kansas-Nebraska Big Blue River Compact Administration, 1977, p. 32). This decision was made in the belief that seepage data together with existing hydrogeologic information would provide the information needed to delineate areas where large ground-water contributions to streamflow occur, and thus make it possible to determine areas where ground-water withdrawals might have a significant effect on streamflow.

A seepage survey was planned for the fall of 1977. However, because of widespread heavy rains in the area prior to the scheduled measurement period, the work was postponed until the fall of 1978.

Description of study area

Initial work on the collection of water-level data was limited, for the most part, to the "well area" defined in the Kansas-Nebraska Big Blue River Compact. Changing the scope of the work from the collection and analysis of water-level data to a more detailed analysis of the hydrogeology involved in stream-aquifer system interrelationships, however, made it necessary to expand the study area to include the ground-water basins below the confluence of Little Sandy Creek and the Little Blue River and below the confluence of Turkey Creek and the Big Blue River. For convenience in using available data and information, however, the area described in this report includes all of Jefferson County and that part of Gage County that is in the Big Blue River basin. (See fig. 1.)

Purpose and Scope

The purpose of this report is to describe the hydrogeology of the study area and evaluate the significance of the stream-aquifer system interrelationships. Hydrogeology, as used in this report, is the science that deals with subsurface water and related geologic aspects of surface water. All available hydrogeologic information and data, except those on water-well-registration forms and those resulting from petroleum exploration, were evaluated and used, if applicable. Only selected data from well-registration forms were used; complete use of data for the 859 registered irrigation wells and 35 registered municipal wells in the study area was precluded by funding and time limitations. The hydrogeologic data includes stream-seepage measurements made for this study and stream-seepage and low-flow data collected for other studies.

This report includes a description of the hydrogeologic framework of the aquifer system, a summary of stream-seepage data, and a synthesis of seepage data and other hydrogeologic data that defines areas where large ground-water contributions to streamflow occur. With the exception of seepage data, this report is based entirely on existing data and information contained in reports. Although a considerable amount of hydrogeologic data and information is available, there is not enough to define adequately all aspects of the complex hydrogeologic system that exists in the study area. The major deficiencies in data and information are noted and the constraints and rationale are given for any assumptions that are made.

Previous Investigations

Although many reports contain some information on the hydrogeology of the study area, only six contain specific information on the geology and ground-water hydrology of either Gage or Jefferson Counties. These six are test-hole reports that summarize the results of test holes drilled in Gage and Pawnee Counties (Keech and Schreurs, 1953a) and in Jefferson County (Keech and Schreurs, 1953b), preliminary reports on the ground-water geology of Gage County (University of Nebraska, Conservation and Survey Division, 1956) and Jefferson County (Reed, 1946a), and two theses on the ground-water hydrology of Jefferson County by Veatch (1963 and 1970). Other references that contain hydrogeologic information or data pertinent to the study area or to adjacent areas are listed in the bibliography of this report.

HYDROGEOLOGY

The following description of the hydrogeology of Gage and Jefferson Counties is limited. It has been prepared principally to provide a basis for evaluating probable stream-aquifer system interrelationships and is based entirely on the analysis and synthesis of existing data and on information contained in other reports.

Hydrogeologic Framework

This description of the hydrogeologic framework is limited to the bedrock formations directly overlain by unconsolidated Quaternary deposits and to the Quaternary deposits. Bedrock formations directly overlain by Quaternary deposits are of Permian and Cretaceous age. Although the Permian formations are underlain by more than 1,000 ft of older Paleozoic rocks, no known hydraulic interconnection exists between these older Paleozoic rocks and the aquifer system in the study area; therefore, they are not described in this report.

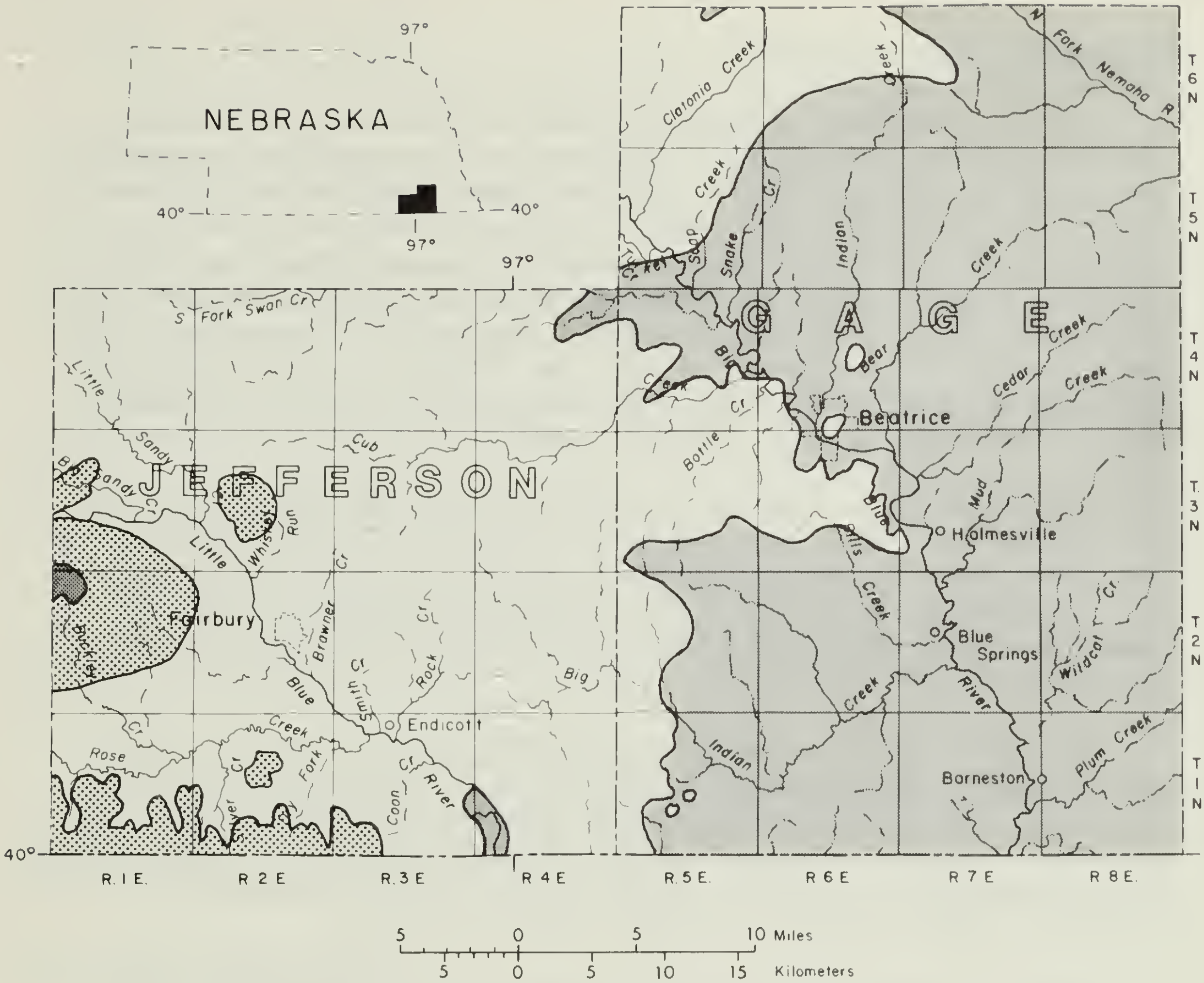
Bedrock Formations

The distribution and stratigraphic sequence of bedrock formations directly overlain by Quaternary deposits in Gage and Jefferson Counties are shown in figure 2. Prior to the deposition of the Cretaceous formations, uplift occurred and the Permian formations were tilted and eroded. The Permian formations dip to the west-southwest at about 8 ft/mi and the Cretaceous formations dip to the west-northwest at about 6 ft/mi. The Dakota Sandstone of Cretaceous age was deposited on the erosional surface formed on the Permian limestones and shales.

Permian limestones and shales, undifferentiated

These deposits consist of the interbedded limestones and shales of the Lower Permian (in ascending order) Admire, Council Grove, and Chase Groups. Most of the individual limestone and shale beds generally range between 1 and 10 ft in thickness; however, the thickest limestone bed is about 30 ft and the thickest shale bed is about 35 ft. Most of the limestones are gray, but some are grayish-buff. The shales are predominantly gray or greenish-gray, but some are black, green, red, or maroon. Total thickness of these interbedded limestones and shales ranges from about 300 ft in eastern Gage County to about 700 ft in southwestern Jefferson County.

The limestone beds yield water to wells in areas where secondary porosity has developed due to fracturing, solution, or both. Most wells completed in these limestones yield less than 25 gal/min. Insufficient data are available to delineate areas where secondary porosity has developed in the limestone beds and no data are available on the hydrologic properties of these beds. Available data indicate that all the shale beds virtually are impermeable.



EXPLANATION

CARLILE SHALE	Upper Cretaceous	CRETACEOUS	MESOZOIC
GREENHORN LIMESTONE AND GRANEROS SHALE, UNDIVIDED			
DAKOTA SANDSTONE	Lower Cretaceous		
Unconformity			
UNDIFFERENTIATED LIMESTONES AND SHALES	Lower Permian	PERMIAN	PALEOZOIC
CONTACT			

Figure 2.--Bedrock geology (from Burchett and others, 1972).

Cretaceous Dakota Sandstone

In the study area, as in most of eastern Nebraska, the Dakota Sandstone can be divided into three parts--a lower sandstone, a middle shale, and an upper sandstone. The lower sandstone consists of very fine to medium-grained grayish-buff sandstone interbedded with gray shale and some variegated clay. Generally, the sandstones are poorly cemented; however, some thin lenses of sandstone are well cemented by iron oxide. Data to define, adequately, the spatial distribution of the sandstones are not available. Within the study area, the thickness of the lower sandstone ranges from 0 to almost 150 ft, and it is probably present throughout all of the Dakota Sandstone area shown in figure 2.

The middle shale consists of clay shales and variegated clays that are mottled pale red to dark red by iron oxide. Thin, discontinuous sandstones occur but account for less than 10 percent of the thickness of the sequence. The middle shale is present throughout most of the Dakota Sandstone area shown in figure 2 and ranges in thickness from 0 to about 100 ft.

The upper sandstone consists of very fine to fine-grained, poorly consolidated, thin sandstones interbedded with gray shale. Individual sandstones are generally less than 20 ft thick. Available data are not adequate to define the spatial distribution of sandstones in this sequence. The upper sandstone, which is present only in the western one-half of Jefferson County, ranges in thickness from 0 to 100 ft.

Total thickness of the Dakota Sandstone in the study area ranges from 0 to more than 350 ft. The thickest known occurrence of the formation in the study area is in southwestern Jefferson County.

Because of the lack of cementation and the relatively uniform grain-size distribution, the sandstones in the Dakota generally are good sources of water. Yields from wells completed in the formation vary considerably, depending upon the methods used in well completion and upon the thickness of saturated sandstone. Several of the irrigation wells in Gage and Jefferson Counties, that are completed in the formation, yield 500 to 800 gal/min. Available data indicate that the average hydraulic conductivity of sandstones in the basal unit of the formation is about 25 ft/d. Geologic data indicates that the hydraulic conductivities of sandstones in the middle and upper units are approximately the same as those of the lower unit. Shales in the formation are relatively impermeable, and depending upon their thickness, distribution, and composition, may be either confining or semiconfining layers.

Cretaceous Graneros Shale

The Graneros is a medium to dark gray shale. The basal part of the formation, which is about 25 ft thick, consists of noncalcareous shale that contains thin layers of silt and very fine-grained sandstone. However, some of the shales near the base of the formation are carbonaceous. In the upper part of the formation, which is about 40 ft thick, the shales are very calcareous and are interbedded with thin limestone layers. The Graneros is very soft and easily eroded, thus it is generally present only where it is overlain by the more resistant Greenhorn Limestone.

Total thickness of the Graneros Shale, which is relatively impermeable and is not a source of water in the study area, ranges from 0 to about 65 ft.

Cretaceous Greenhorn Limestone

The Greenhorn is a gray limestone containing interbedded shaley limestone, marl, and calcareous shale. Most of the marl and shale beds occur in the middle part of the formation. Total thickness of Greenhorn Limestone ranges from 0 to about 30 ft.

Where secondary porosity has developed because of solution, fracturing, or both, the formation yields small amounts of water to wells. The spatial distribution of secondary porosity in the study area is unknown, and no data are available on the hydrologic properties of the formation.

Cretaceous Carlile Shale

A map by Burchett and others (1972) indicates that probably only the basal part of the Carlile is present in the study area. The basal part of the Carlile is a medium-gray calcareous shale that contains thin and thin-bedded fossiliferous shaley limestones and calcareous shales. No information is available on the thickness and hydrologic properties of the formation in the study area.

Quaternary Deposits

All the Quaternary deposits in the study area are unconsolidated and consist of Holocene and Pleistocene clays, silts, sands, and gravels. Holocene deposits generally are very thin and occur only as part of the alluvium along stream valleys. Most of the Quaternary deposits are of Pleistocene age. These Pleistocene deposits are complex in nature and distribution, reflecting a varied history of erosion and sedimentation related to the advance and retreat of continental ice sheets.

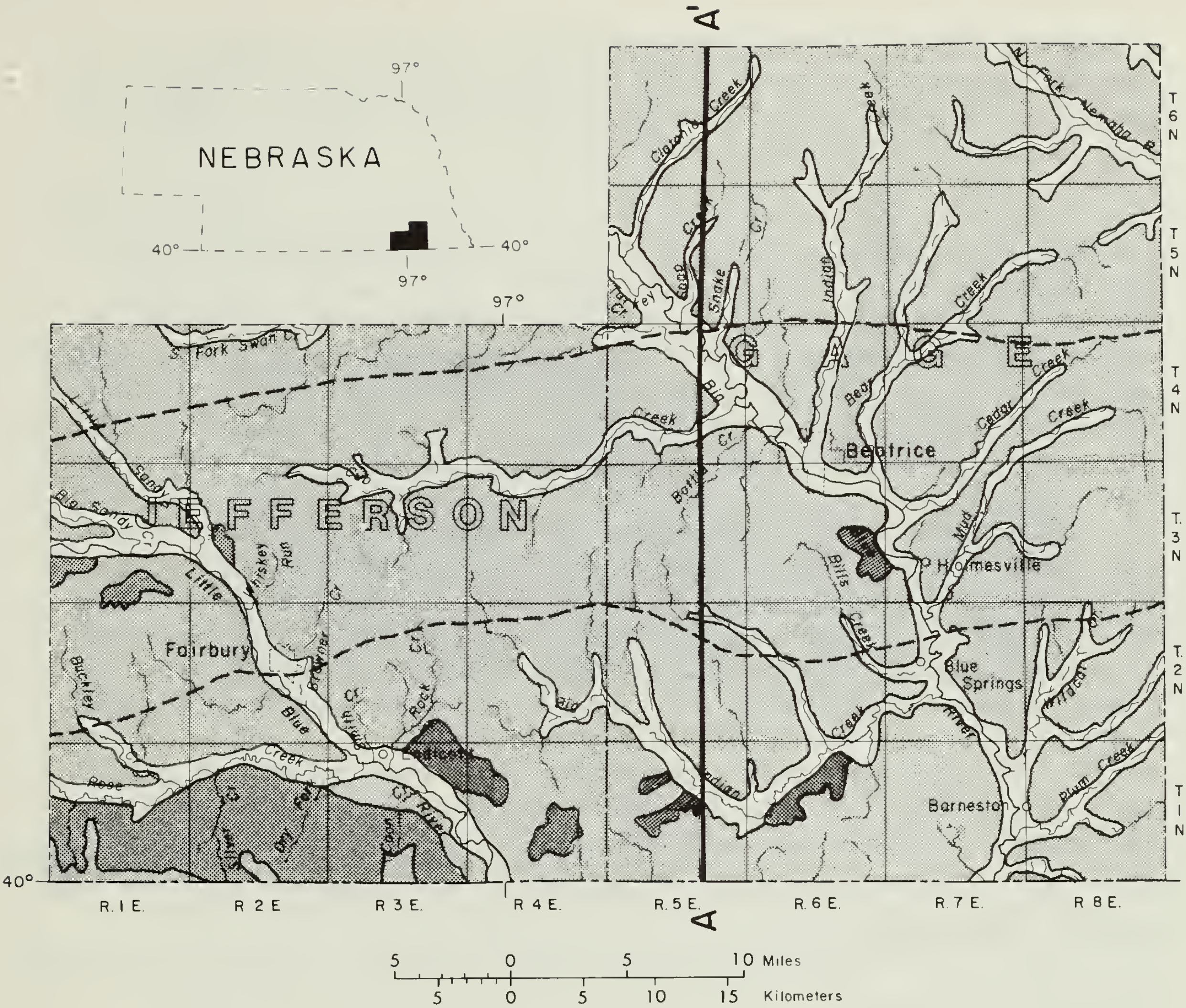
In order to facilitate the description of the Quaternary deposits in this report, they have been divided into three categories: Exposed coarse-grained deposits, fine-grained deposits, and buried coarse-grained deposits. The division of the Quaternary deposits into these categories is based partly on the hydrologic properties of the sediments and partly on their areal distribution. This approach to describing the Quaternary deposits is based primarily on the assumption that the hydrologic properties of all sediments in each category are relatively uniform. For the purposes of the study, this assumption is probably valid; however, a more detailed hydrogeologic study should include thorough analysis and evaluation of the distribution of hydrologic properties within and among the various Quaternary deposits.

Uplift and subaerial erosion of the bedrock surface occurred after deposition of the Cretaceous formations and prior to the deposition of the Quaternary deposits. The configuration of the resultant bedrock surface strongly influenced the thickness and composition of sediments deposited during the early part of the Quaternary Period. Paleotopographic maps, showing the configuration of the bedrock surface (Veatch, 1970, p. 50, and Burchett and Carlson, 1966, fig. 2) indicate that the bedrock surface generally slopes to the east-northeast. The most noteworthy paleotopographic features are two deeply incised valleys that trend east-northeasterly. (See figure 3.) Total relief of the bedrock surface within the study area is about 600 ft.

Exposed coarse-grained deposits

Exposed coarse-grained deposits in the study area consist of fluvial sediments along the Big Blue and Little Blue Rivers and along their major tributaries. Sediments that form low terraces adjacent to the streams and the alluvium along the streams are the most hydrogeologically significant exposed coarse-grained deposits, and their approximate areal extent is shown on figure 3. Discontinuous small remnants of exposed coarse-grained deposits associated with high terraces along the Big Blue and Little Blue River valley are generally unsaturated and have not been shown on figure 3.

Along the Big Blue and Little Blue Rivers the deposits in the low terraces and alluvium consist of silt, sand, and gravel. Available data indicate that large vertical and lateral differences in the composition of these deposits are common. Logs of test holes and wells drilled in the river valleys indicate that the deposits generally consist of 5-15 ft of slightly sandy silt that overlies 10-15 ft of silty and clayey sand, and that in turn overlies 0-10 ft of silty sand and gravel. Generally the total thickness of these deposits along the Big Blue and



EXPLANATION

(white box)	EXPOSED COARSE-GRAINED DEPOSITS	QUATERNARY
(light shaded box)	FINE-GRAINED DEPOSITS	
(dark shaded box)	BEDROCK, UNDIFFERENTIATED	MESOZOIC AND PALEOZOIC, UNDIFFERENTIATED
————	CONTACT	
- - - - - -	AXIS OF BURIED BEDROCK VALLEY	
A——A'	TRACE OF HYDROGEOLOGIC SECTION SHOWN IN FIGURE 4	

Figure 3.--Surficial geology (adapted from soil association maps by Beesley and others, 1964, and by Pollock and Davis, 1975).

Little Blue River valleys is less than 20 ft, but is as much as 40 ft. Along the major tributaries to the Big Blue and Little Blue Rivers, the deposits in the low terraces and alluvium consist mostly of silty sand that is generally less than 10 ft thick.

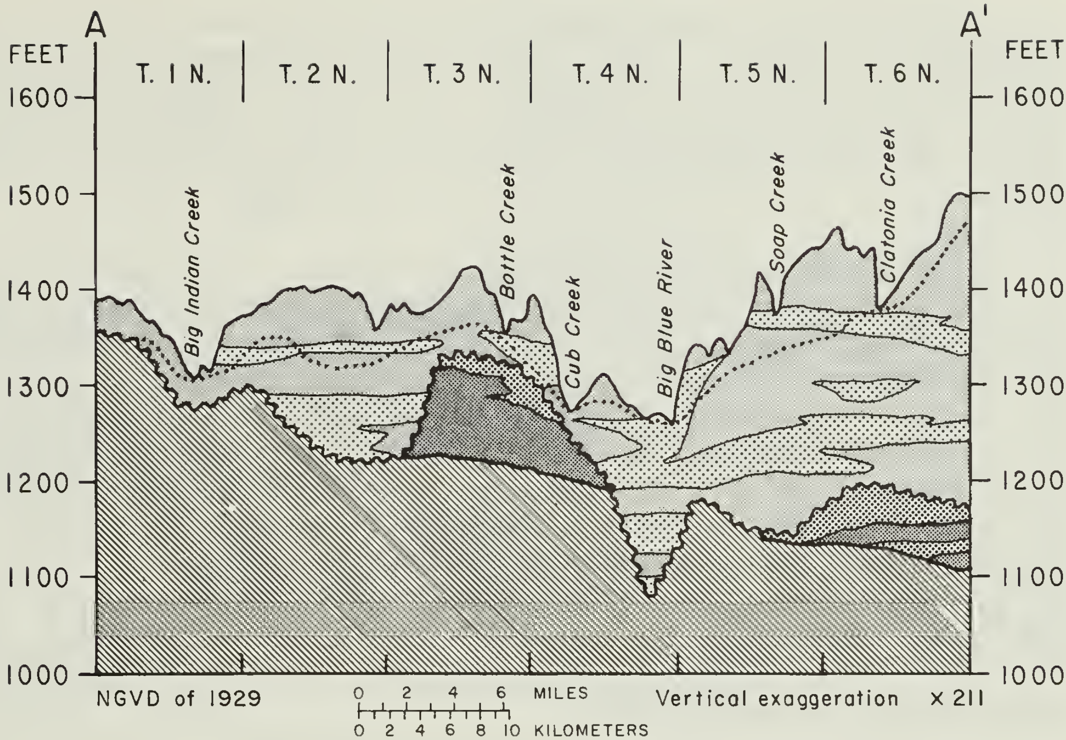
Yields from wells completed in the low terraces and alluvium usually are less than 100 gal/min. An evaluation of available test-hole and well-log data, using methods modified after those described by Emery (1966a), indicates that the hydraulic conductivity of the deposits probably ranges between 10 and 75 ft/d and averages about 25 ft/d. The saturated thickness of the deposits along the Big Blue and Little Blue River valleys is less than 20 ft most places, and the saturated thickness along the major tributaries to the rivers generally is less than 5 ft.

The top surfaces of the remnants of exposed coarse-grained deposits associated with the high terraces along the Big Blue and Little Blue River valleys generally are 60 to 90 ft above the valley floors. These deposits consist of medium and coarse sand intermixed with fine gravel. In most places, the thickness of the deposits is less than 20 ft but locally may be as much as 50 ft. Because of their topographic position and high permeability most of the deposits drain rapidly and are unsaturated. A few of the larger remnants are water bearing; however, the saturated thickness of sand and gravel in these remnants is commonly less than 5 ft. It is estimated that the hydraulic conductivity of these deposits ranges between 150 and 200 ft/d. Few data are available on the composition and the spatial distribution of sediments that comprise the low terraces, alluvium, and high terraces.

Fine-grained deposits

The fine-grained deposits in the study area consist of undifferentiated loess and till. Most of the loess is composed of silt and slightly clayey silt and most of the tills are composed of silty clay. Figure 3 shows the approximate areal distribution of these deposits. It should be noted, however, that the fine-grained deposits also underlie most of the exposed coarse-grained deposits along the tributaries to the Big Blue and Little Blue Rivers.

The depositional and erosional history of the fine-grained deposits is complex, and the deposits are not considered as being of a single "blanket-type". Detailed studies by Veatch (1970) indicate that in Jefferson County the fine-grained deposits comprise as many as 13 recognizable stratigraphic units. Many of the individual beds that make up the fine-grained deposits interfinger with the buried coarse-grained deposits, as is shown in figure 4.



EXPLANATION

FINE-GRAINED DEPOSITS--Loess and other deposits of silt, clayey silt, silty clay, and clay

COARSE-GRAINED DEPOSITS--Sand, sand and gravel, and gravel. No distinction is made between exposed and buried coarse-grained deposits.

QUATERNARY — CENOZOIC

DAKOTA SANDSTONE--Sandstone facies

DAKOTA SANDSTONE--Shale facies

Lower Cretaceous — CRETACEOUS — MESOZOIC

UNDIFFERENTIATED LIMESTONES AND SHALES — Lower Permian — PERMIAN — PALEOZOIC

CONTACT

APPROXIMATE WATER TABLE

BEDROCK SURFACE

Figure 4.--Generalized hydrogeologic section A — A'.

Generally, the total thickness of the fine-grained deposits ranges between 75 and 125 ft. There are no fine-grained deposits along the Big Blue and Little Blue River valleys nor where the Permian or Cretaceous bedrock formations crop out (fig. 3). The thickest sequence of fine-grained deposits (almost 250 ft) occurs in the northern part of Gage County.

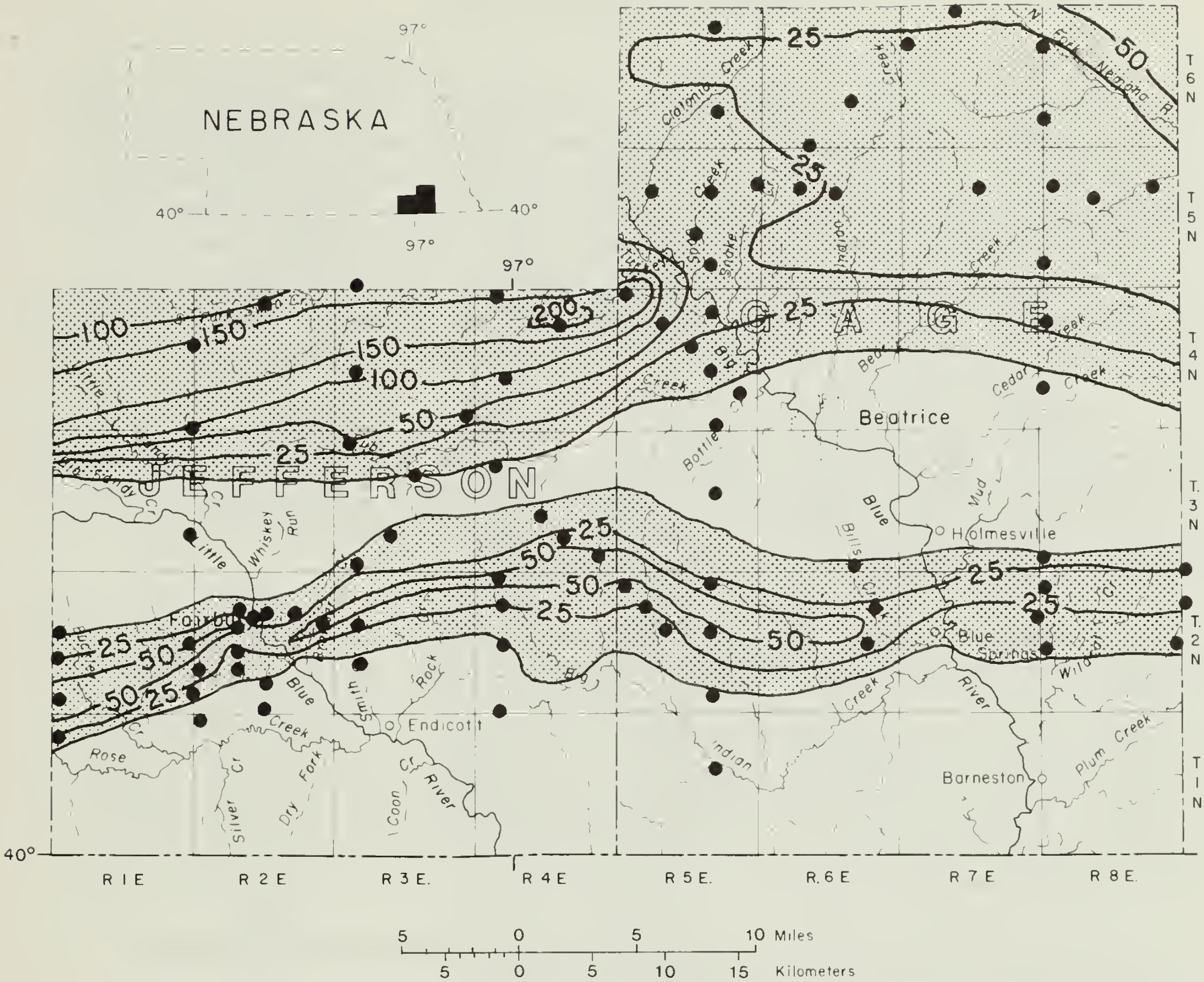
In areas where no other aquifers are present, a few domestic and stock wells have been completed in the fine-grained deposits. Yields from these wells commonly are less than 10 gal/min. No attempt has been made to determine the saturated thickness of the deposits, but it probably ranges from 0 to 125 ft. Based on the available data on the lithologies of the deposits, the hydraulic conductivities are estimated to range between 2 and 10 ft/d. Data available from test-hole logs and drillers' logs probably would be adequate for defining the spatial distribution of these sediments for most of the study area. Information on the composition of the sediments, however, is available only from test-hole logs.

Buried coarse-grained deposits

Buried coarse-grained deposits in the study area consist of fluvial sediments which occur in the two bedrock valleys that trend east-northeasterly across the area. These deposits are variable in composition, ranging from silty sands to slightly sandy gravels. Most of the deposits, however, consist of medium to very coarse sand intermixed with fine gravel. The approximate areal extent of these deposits is shown in figure 5.

The thickest known sequence of buried coarse-grained deposits occurs in the northeastern part of Jefferson County, where as much as 210 ft of sand and gravel were found in a test hole located in the SE¼SE¼ sec. 10, T. 4 N., R. 4 E. (Keech and Schreurs, 1953b, p. 13.)

These buried coarse-grained deposits are the most productive aquifers in the study area. It is estimated that more than 800 irrigation wells have been completed in the deposits. Yields from these irrigation wells generally range between 700 and 1,000 gal/min, but yields of as much as 1,800 gal/min have been reported. The saturated thickness of these sand and gravel deposits in the study area ranges from 0 to more than 200 ft (fig. 5). Evaluation of data from test-hole logs indicate that the hydraulic conductivity of the deposits probably ranges between 160 and 200 ft/d. Use of data from test-hole logs and drillers' logs would make it possible to define accurately the spatial distribution of the deposits, and to define adequately major variations in lithologies.



EXPLANATION

APPROXIMATE EXTENT OF AREAS UNDERLAIN BY BURIED COARSE-GRAINED DEPOSITS

—50— LINE OF EQUAL SATURATED THICKNESS OF BURIED COARSE-GRAINED DEPOSITS; INTERVALS, 25 AND 50 FEET

● TEST HOLE

Figure 5.--Extent of Quaternary buried coarse-grained deposits and their saturated thickness.

Surficial Aquifer System

All the stratigraphic units that have been described in this report are hydrogeologically interrelated. Conceptually, these deposits can be thought of as forming either a single unconfined aquifer in which there are large lateral and vertical differences in thickness and hydrologic properties, or as an unconfined aquifer system composed of hydraulically interconnected aquifers and local confining or semiconfining beds. In this report, the conceptualization of an unconfined aquifer system is used because it facilitates description of the hydraulic interrelationships among the deposits and between the deposits and the stream system.

Although ground water in some of the bedrock formations in the western part of Jefferson County may be confined by relatively impermeable shales, in those parts of the study area where ground-water contributions to streamflow from the bedrock formations may occur, ground water in the formations is virtually unconfined.

Throughout almost all the study area, the relatively impermeable shales and limestones of Permian age form the base of the unconfined aquifer system. In some parts of central and western Jefferson County, however, the Graneros Shale, shales in the Dakota Sandstone, or both, may be the effective base. The top of the aquifer system is the water table. Locally, where the relatively impermeable bedrock formations that form the base of the aquifer system are exposed at the land surface, the unconfined aquifer system is absent.

Veatch (1970, p. 80) states that local perched water tables may occur in the Quaternary fine-grained deposits.

All deposits below the water table are saturated and each saturated deposit is hydraulically connected to adjacent saturated deposits. However, the permeabilities of most of the shales and some of the limestones are so low that there is almost no movement of water through or from them. Hydrologic relationships among the various stratigraphic units and between the stratigraphic units and the stream system are summarized in table 1.

Water-Table Configuration

A water-level contour map, which is a graphic representation of the areal distribution of hydraulic gradient (dh/dl), can be of considerable assistance in developing an understanding of the occurrence and movement of ground water. The contour lines on a water-table map, which are drawn by extrapolation between point values combined with judgment as to

Table 1.--Summary of unconfined-aquifer system

Stratigraphic unit	Relationship to other deposits	Relationship to streamflow	Remarks
Quaternary			
Exposed, coarse-grained deposits	Direct hydraulic interconnection with Dakota Sandstone and undifferentiated Permian formations along the valleys of the Big Blue and Little Blue Rivers, Quaternary fine-grained deposits along tributaries to the Big Blue and Little Blue Rivers, and Quaternary buried coarse-grained deposits where the river valleys intersect these deposits.	Only deposits that have a direct relationship to streamflow. All ground-water contributions to streamflow move through these deposits.	Minor aquifer. Lowering of ground-water levels in these deposits could significantly affect streamflow; however, potential for large-scale development exists only in areas where these deposits directly overlie Quaternary buried, coarse-grained deposits.
Fine-grained deposits	Direct hydraulic interconnection with all deposits, except the Quaternary exposed coarse-grained deposits along the Big Blue and Little Blue Rivers.	No direct relationship to streamflow, but is hydraulically interconnected with Quaternary exposed coarse-grained deposits along most tributaries to Big Blue and Little Blue Rivers.	Generally not an aquifer. Greatest hydrogeologic significance is that recharge to most of the unconfined aquifer system moves through these deposits.
Buried coarse-grained deposits	Direct hydraulic interconnection with all of the bedrock formations, except the Carlile Shale; Quaternary fine-grained deposits; and Quaternary exposed coarse-grained deposits.	No direct relationship to streamflow; however, significant amounts of ground water move from these deposits into the Quaternary exposed coarse-grained deposits and thence into the streams.	Major aquifer. Lowering of ground-water levels in these deposits could significantly affect streamflow in the Big Blue and Little Blue Rivers, Rose Creek, and Big Indian Creek.
Cretaceous			
Carlile Shale	Direct hydraulic interconnection with Greenhorn Limestone and with Quaternary fine-grained deposits.	No direct or significant indirect relationship to streamflow.	Not an aquifer--may be a confining bed to ground water in Greenhorn Limestone.
Greenhorn Limestone	Direct hydraulic interconnection with Carlile Shale, Graneros Shale, and Quaternary fine-grained deposits.	----do----------------------------------	Minor aquifer in areas where secondary porosity has developed.
Graneros Shale	Direct hydraulic interconnection with Greenhorn Limestone, Dakota Sandstone, and Quaternary fine-grained deposits.	----do----------------------------------	Not an aquifer--is a confining bed to ground water in any permeable beds that underlie it.

Table 1.--Summary of unconfined-aquifer system--Continued

Stratigraphic unit	Relationship to other deposits	Relationship to streamflow	Remarks
Cretaceous--Continued			
Dakota Sandstone	Direct hydraulic interconnection with Graneros Shale, undifferentiated Permian formations, and all Quaternary deposits.	No direct relationship to streamflow. Along the valleys of the Big Blue and Little Blue Rivers, however, some ground water probably moves from the sandstone facies of the formations into the Quaternary exposed coarse-grained deposits and thence into the streams.	Sandstone facies are major aquifers. Large-scale development of ground water from formation would have some effect on streamflow, but probably would be relatively insignificant. Shale facies are not aquifers and are confining beds.
Permian			
Undifferentiated limestones and shales	Direct hydraulic interconnection with Dakota Sandstone and all Quaternary deposits.	No direct relationship to streamflow. Along the valleys of the Big Blue and Little Blue Rivers, however, some ground water may move from zones of secondary porosity in the limestones into the Quaternary exposed coarse-grained deposits and thence into the streams.	Limestones are minor aquifers where secondary porosity has developed. Shales and limestones with no secondary porosity form base of aquifer system.

the probable effects of hydrogeology, represent lines of equal potential. Ground water moves, in accordance with the hydraulic gradient, from a higher level or potential toward a lower level or potential. Because the contour lines on a water-level map are lines of equal potential, the direction of ground-water movement generally is downgradient at right angles to the contour lines.

Ground-water divides (ridges in the water table on each side of which the water table slopes downward in a direction away from the ridge) can also be delineated by the the use of water-table contour maps. A ground-water divide is analogous to the divide between two drainage basins on the land surface and generally ground-water divides closely parallel surface-drainage divides. In some localities, however, there may be little relation between these two divides because of hydrogeologic controls, changes caused by man's activities, or both.

Analysis of conditions revealed by water-level contours is made in accordance with the empirical law formulated by Darcy in 1856. In general terms, Darcy's law may be stated as:

$$Q = -KA\, dh/dl$$

where Q is the rate at which water flows through a cross section of area A, composed of material having a hydraulic conductivity of K, and in which the hydraulic gradient is dh/dl. The cross-sectional area A may be expressed as the saturated thickness of the material (b) times its width (w). Thus,

$$A = bw$$

and

$$Q = -K\, bw\, dh/dl$$

By rearranging the equation to solve for the hydraulic gradient

$$\frac{dh}{dl} = -\frac{Q}{Kbw}$$

it can be seen that changes in hydraulic gradient are directly proportional to changes in Q and, inversely, proportional to changes in K, b, and w.

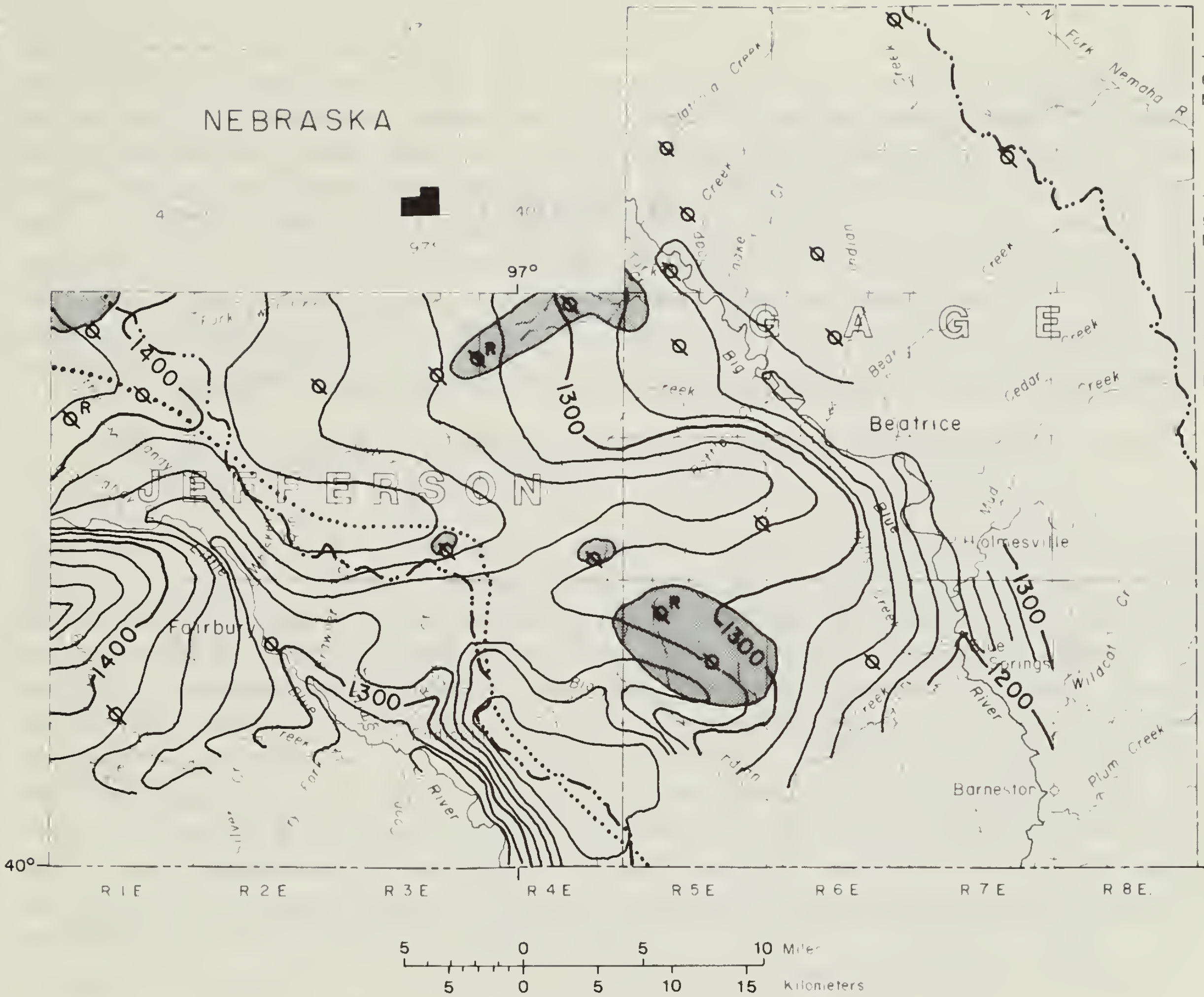
Changes in the spacing of contours on a water-level map represent changes in hydraulic gradient. According to Darcy's law, changes in hydraulic gradient must be caused by changes in discharge Q, hydraulic conductivity K, saturated thickness b, or aquifer width w. If continuity of the flow rate is assumed, the spacing depends only on aquifer width, thickness, hydraulic conductivity, or both. Generally, most changes in hydraulic gradient are caused by changes in saturated thickness, hydraulic conductivity, or both. Changes in hydraulic gradient caused by changes in aquifer width are most common in alluvial aquifers along streams. Interpretations of water-table contour maps need to be made carefully, considering all possible combinations of factors which may affect hydraulic gradient.

The approximate configuration of the water table in the unconfined aquifer system is shown in figure 6 for most of the study area. The term "approximate" is used in describing this map because the quantity and quality of the combined water level and hydrogeologic data used in preparing this map range from fair to nonexistent. Contours were not drawn in areas for which no water-level data are available and for which there are few hydrogeologic data. Although this map is not an exact portrayal of the configuration of the water table, it is adequate for determining the general directions of ground-water movement and for delineating the approximate locations of ground-water divides.

Water-Level Fluctuations

Water-level fluctuations are indications of changes in the amount of ground water stored in an unconfined aquifer. In general, the water table rises when the amount of recharge exceeds the amount of discharge and declines when the converse is true. Prior to development by man, the ground-water system generally was in a state of equilibrium; recharge to the aquifers approximately equaled discharge from the aquifers and only minor fluctuations in ground-water levels occurred. Data for 22 observation wells for which there are 10 or more years of record, indicate that the large-scale development of ground water for irrigation supplies has significantly altered this natural equilibrium in some parts of the study area, and water-level declines of 5 ft or more have developed. (See figure 6.)

Hydrographs of the water level in the three observation wells equipped with continuous recorders are shown in figure 7. An explanation of the major water-level fluctuations shown on these hydrographs is given by Pederson and Johnson (1979, p. 16 and 20). The locations of these wells and the 20 other wells in which water levels were measured during 1979 are shown in figure 6. All three wells equipped with recorders are completed in Quaternary buried coarse-grained deposits.



EXPLANATION

AREAS WHERE GROUND-WATER LEVELS HAVE DECLINED MORE THAN 5 FEET FROM PREDEVELOPMENT LEVELS

—1300— WATER-TABLE CONTOUR--Shows altitude of water table, spring 1979. All contours are approximately located. Contour interval, 20 feet. (National Geodetic Vertical Datum of 1929.)

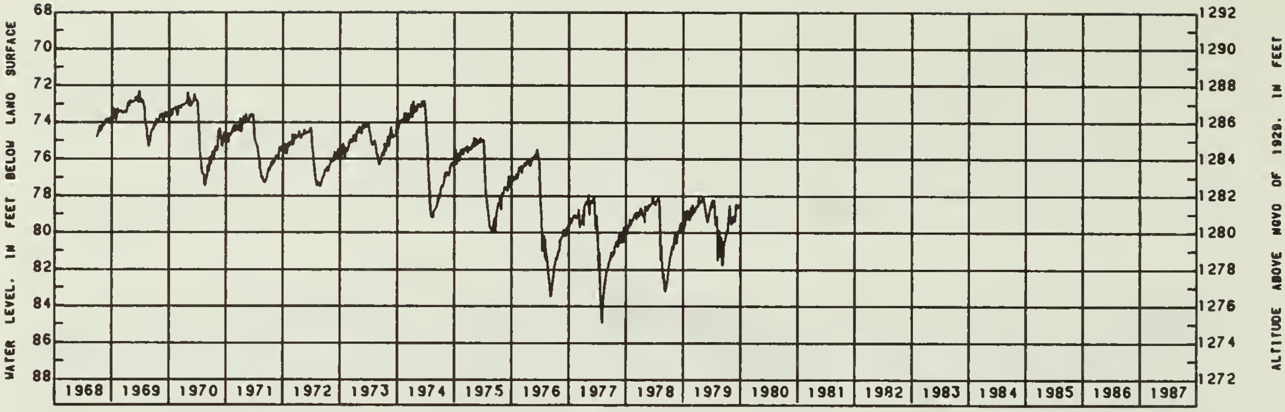
GROUND-WATER DIVIDE

DRAINAGE-BASIN BOUNDARY

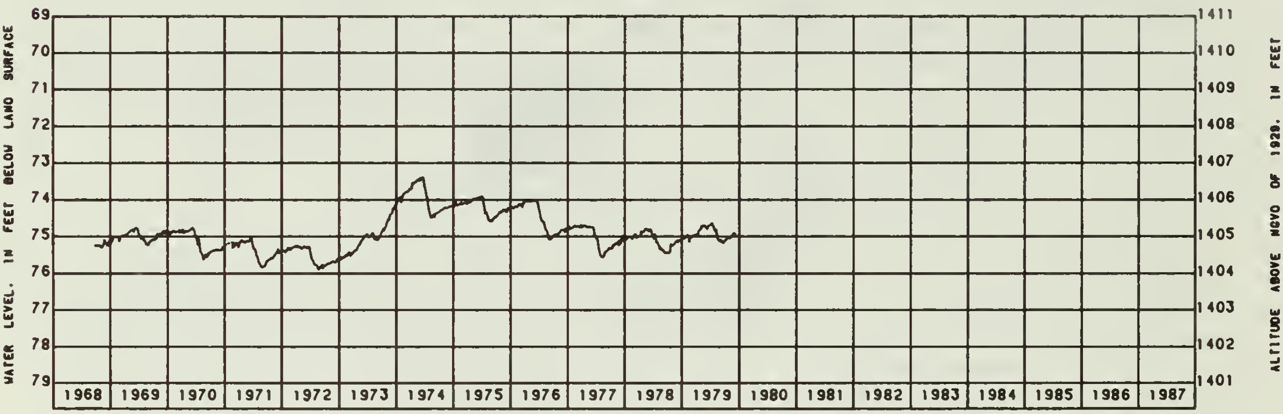
OBSERVATION WELL

R OBSERVATION WELL EQUIPPED WITH A RECORDER

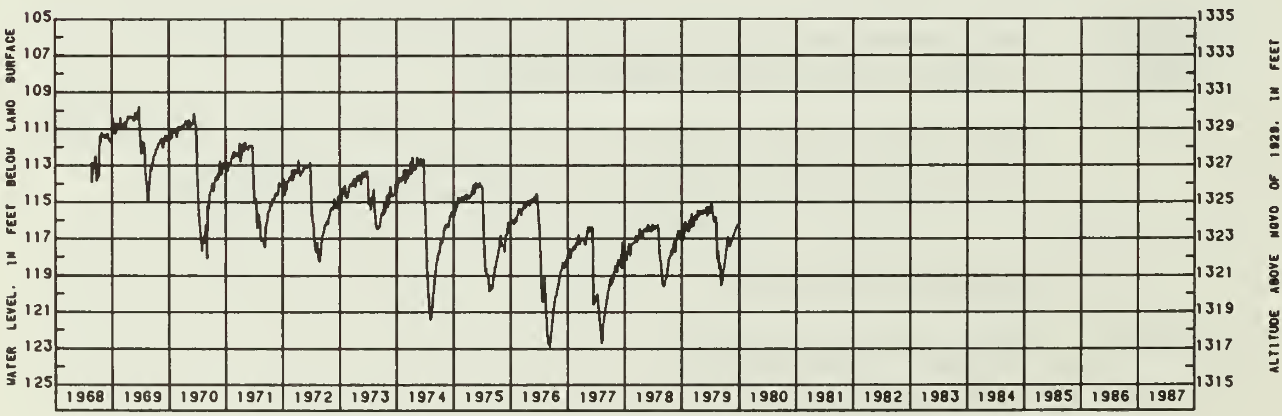
Figure 6.--Approximate configuration of the water table.



ELLIS RECORDER WELL, SE¼SE¼ SEC. 8, T.2 N., R.5 E., GAGE COUNTY



DAYKIN RECORDER WELL, NE¼NE¼ SEC. 31, T.4 N., R.1 E., JEFFERSON COUNTY



PLYMOUTH RECORDER WELL, NE¼SE¼ SEC. 13, T.4 N., R.3 E., JEFFERSON COUNTY

Figure 7.--Water levels in observation wells equipped with recorders.

Use of Ground Water

Although ground water is used for all domestic and municipal supplies and for most livestock supplies in Gage and Jefferson Counties, the greatest use of ground water is for irrigation supplies. As shown on figure 8, the number of irrigation wells in the Big Blue River basin in Gage and Jefferson Counties has increased significantly during the past 25 years. The increase in the number of irrigation wells in the Little Blue River basin located in Jefferson County has not been as great, because the areal extent of aquifers capable of yielding large amounts of water is smaller.

Most of the irrigation wells are completed in the Quaternary buried coarse-grained deposits. Approximately 30 wells, located in Tps. 1 through 3 N., R. 4 E. (Jefferson County) and R. 5 E. (Gage County), are completed in the Dakota Sandstone. Some of the older wells located northwest of Beatrice may be completed in both the Quaternary exposed coarse-grained deposits and the buried coarse-grained deposits. Only one irrigation well, located in T. 3 N., R. 1 E. (Jefferson County), is known to be completed only in the Quaternary exposed coarse-grained deposits.

As has been noted in the discussion of water-level fluctuations, some local declines in ground-water levels that are attributable to irrigation pumpage have developed in parts of Gage and Jefferson Counties, mostly in the Big Blue River basin. The largest areas of decline, as delineated by Pederson and Johnson (1979, p. 5), are in western Gage County (T. 2 N., R. 5 E.) and northeastern Jefferson County (T. 4 N., R. 4 E.). (See fig. 6.) Whether or not declines in these areas have had or will have a significant effect on streamflow is not known.

Reports by Emery (1965 and 1966a) contain the only published information on the probable effects of ground-water development on streamflow in Gage and Jefferson Counties. However, some of the assumptions that were used by Emery, most notably the rate at which ground-water development would occur, have proved to be incorrect. His assumption that the total number of irrigation wells located in the areas of the Big Blue and Little Blue River basins in Nebraska would increase 50 percent during the period 1962-82 was far too conservative. Based on Nebraska well-registration data, the total number of registered irrigation wells in the basins increased by 151 percent between January 1, 1963, and December 31, 1979. The number of registered irrigation wells in that part of Gage County that is in the Big Blue River basin increased by 363 percent, and the number in Jefferson County increased by 325 percent. Figure 9 shows for each township in the study area the total number of registered irrigation wells drilled before January 1, 1963, and the total number of registered irrigation wells as of January 1, 1980.

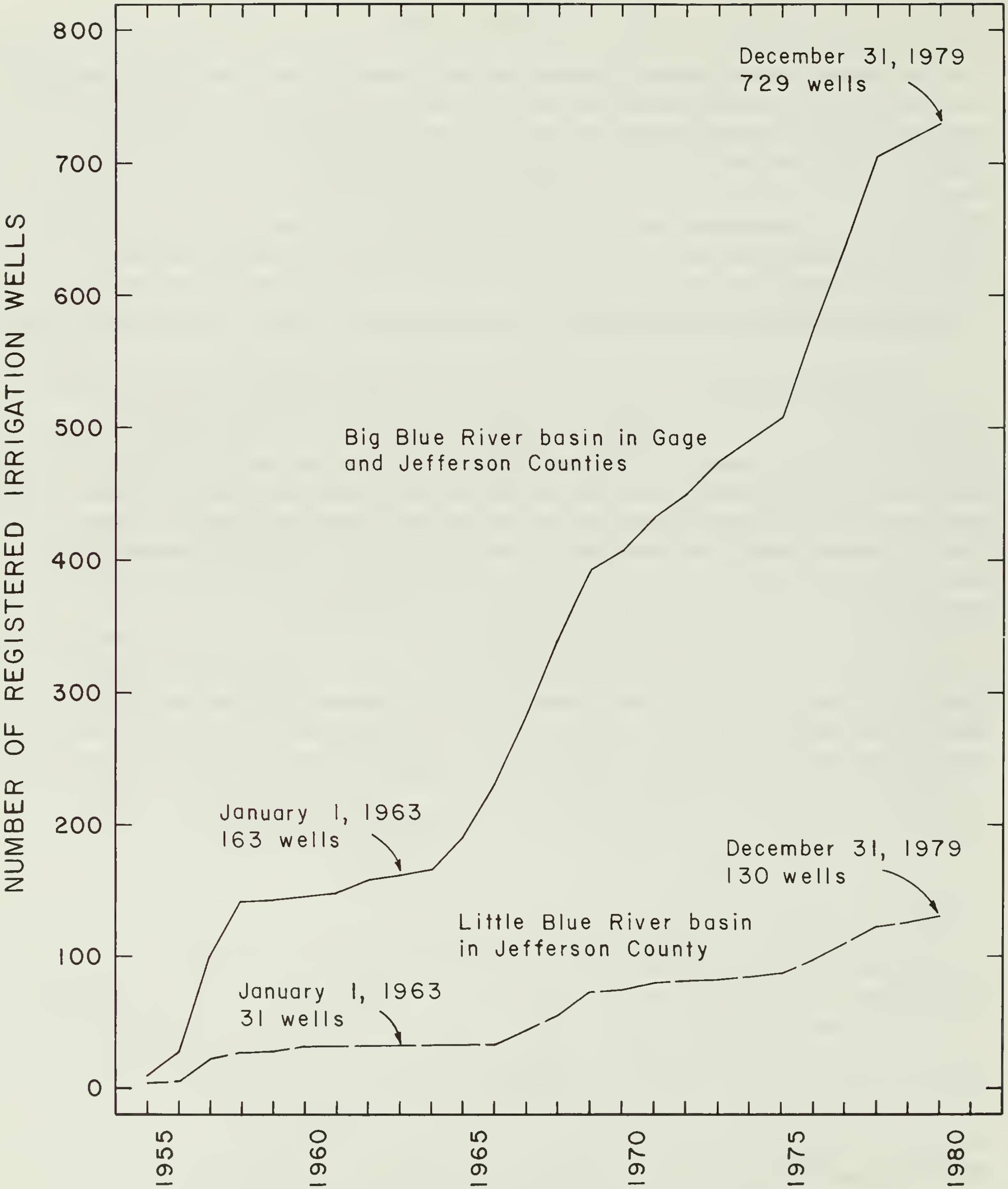
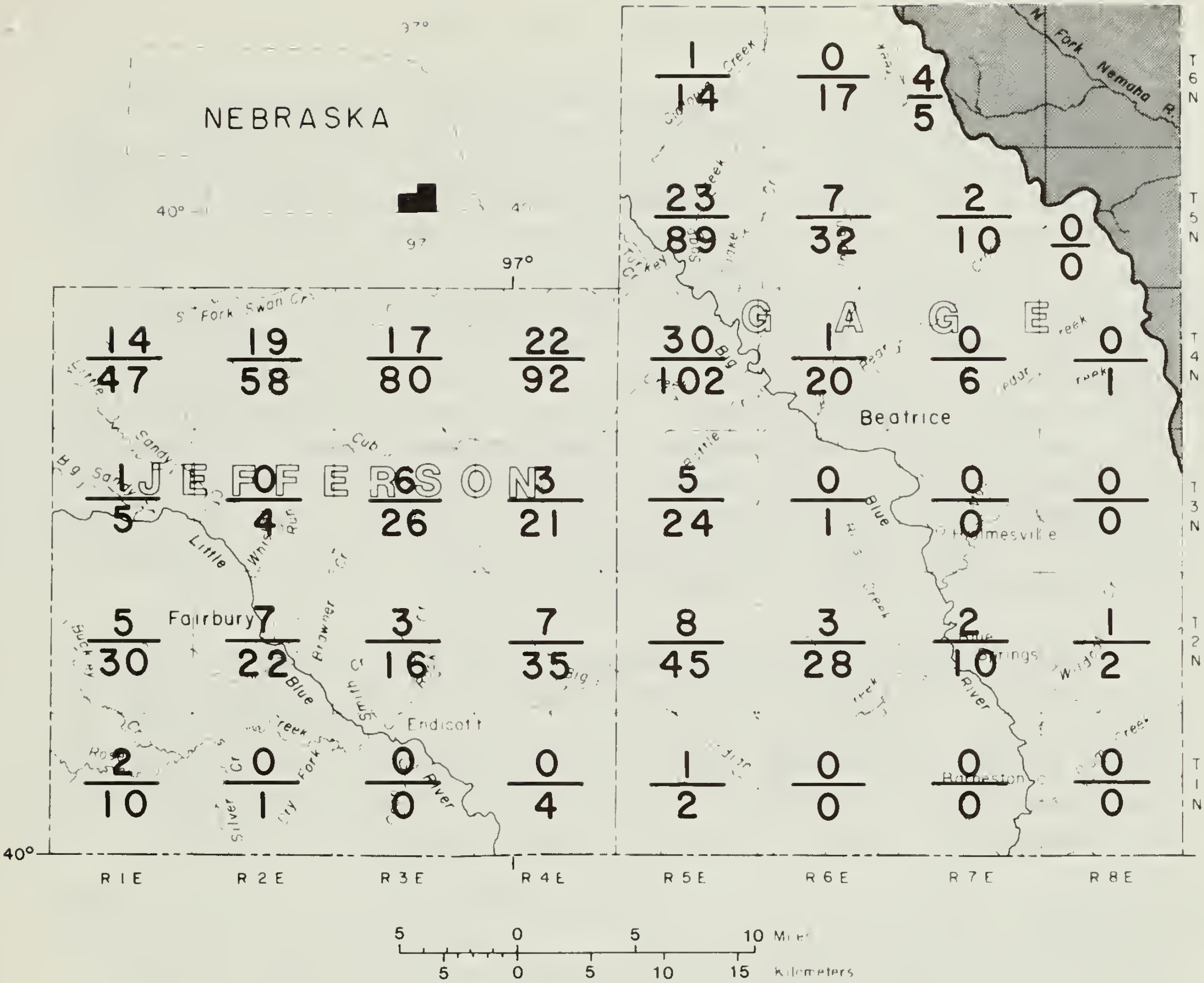


Figure 8.--Cumulative totals of registered irrigation wells in study area, January 1, 1955, through December 31, 1979.



EXPLANATION

7/35	NUMBER OF REGISTERED IRRIGATION WELLS DRILLED PRIOR TO JANUARY 1, 1963 / NUMBER OF REGISTERED IRRIGATION WELLS DRILLED PRIOR TO JANUARY 1, 1980
(shaded box)	PART OF GAGE COUNTY THAT IS NOT IN THE BIG BLUE RIVER BASIN

Figure 9.--Comparison of the numbers of registered irrigation wells drilled prior to January 1, 1963, with those prior to January 1, 1980.

Seepage Survey, Fall 1978

Data from a seepage survey, supplemented with other hydrogeologic data and with records of streamflow from recording gaging stations, can be used to define areas where significant channel gains or losses occur. A seepage survey consists of measuring discharge at intervals along a channel reach during a period of base flow. Such a seepage survey was made in the study area between October 24 and November 2, 1978. The survey consisted of 37 measurements made as part of this study, and 19 measurements made in the Little Blue River basin as part of the data-collection effort for the U.S. Geological Survey's High Plains Regional Aquifer System Analysis project. In order to facilitate discussion of the seepage data, the measurement sites have been sequentially numbered in downstream order. Measurement sites 1 through 21 are in the Big Blue River basin, and sites 22 through 56 are in the Little Blue River basin. Results of this seepage survey are given in table 2 and the locations of the measurements sites are shown in figure 10.

In determining from seepage surveys where gains or losses in flow occur along a stream, it is important that flow in the stream during the entire period of the survey be as nearly uniform as practicable. Accordingly, seepage measurements usually are made during periods of base flow when variations in flow due to precipitation, snowmelt, evapotranspiration, stream diversions, and ground-water pumping are minimal.

Base flow is the sustained or fair-weather flow of a stream, whether affected by the works of man or not. It is composed chiefly of effluent ground water but may include runoff delayed by slow passage through lakes and wetlands. Even base flow, however, is not constant, because both ground-water inflow and streamflow itself are nonsteady or transient. Ground-water inflow may be variable because of time-dependent changes in recharge to and discharge from the ground-water system. Streamflow may be variable during base flow because of time- and location-dependent changes in amounts of diversion from the stream, changes in channel storage, and runoff into the stream.

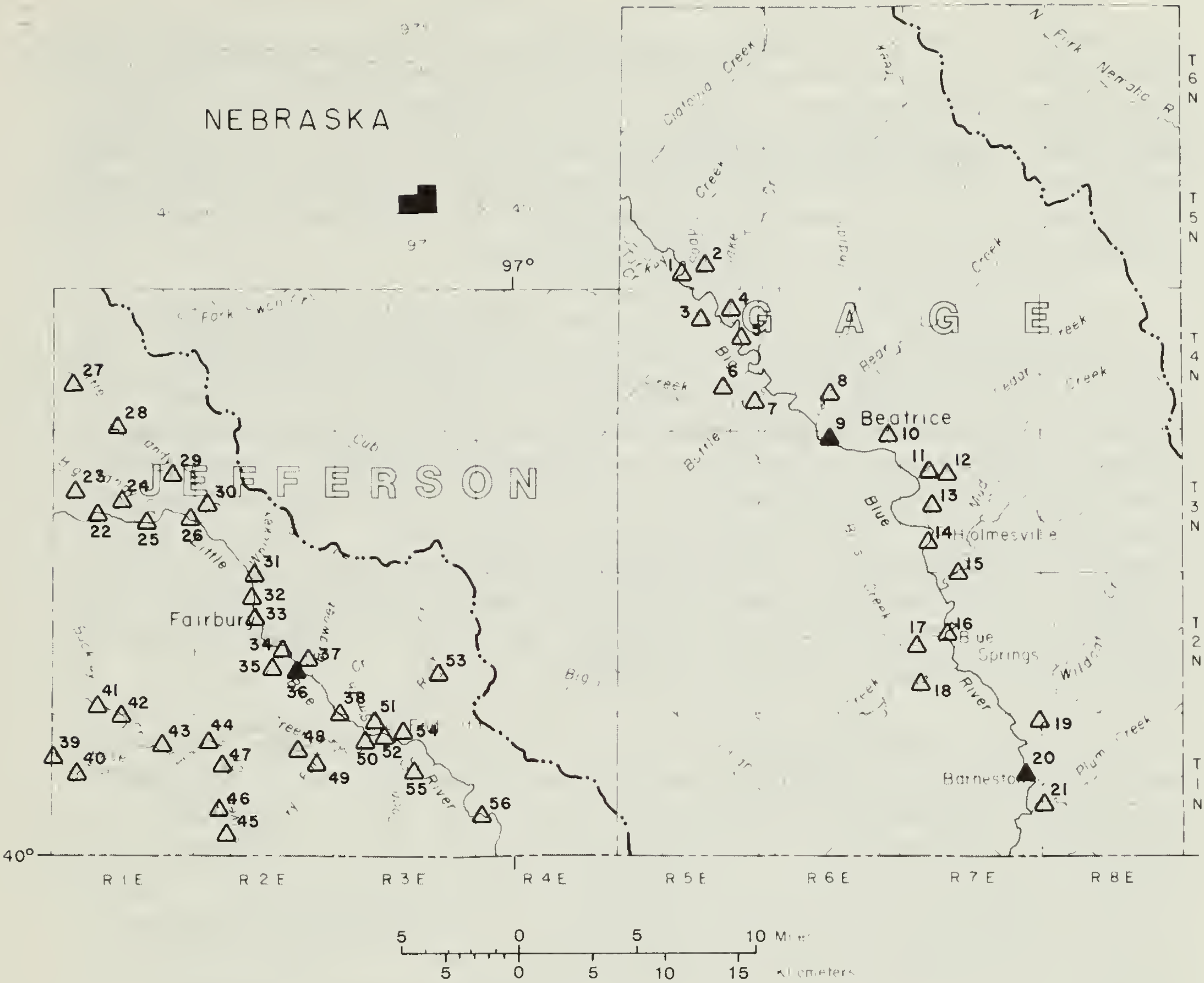
Seepage surveys should also be limited to periods of low to moderate streamflow and to streams of small to moderate size, in order that the percentage errors that are inherent in streamflow measurements may be small compared to the magnitude of seepage gain or loss in a given reach. The percentage error in streamflow measurements usually is less than ± 5 percent. This means that if the measured discharge of a stream is 1.00 ft^3/s, the actual discharge is between 0.95 and 1.05 ft^3/s; and if the measured discharge is 100 ft^3/s, the actual discharge is between 95 and 105 ft^3/s.

Table 2.--Results of seepage survey in the Big Blue and Little Blue River basins
[ft^3/s = cubic foot per second; mi = mile]

Measurement site	Stream	Location of measurement site	Date measured	Discharge (ft^3/s)	Remarks
		Big Blue River basin			
1	Big Blue River---------	NW¼NE¼ sec. 33, T.5 N., R.5 E.	Nov. 2, 1978	100	9.5 mi northwest of Beatrice gage.
2	Soap Creek-------------	SW¼SE¼ sec. 27, T.5 N., R.5 E.	-----do-----	.30	-----------------
3	Unnamed tributary to Big Blue River-------	SW¼NE¼ sec. 10, T.4 N., R.5 E.	-----do-----	0	-----------------
4	Snake Creek------------	SE¼SE¼ sec. 2, T.4 N., R.5 E.	-----do-----	0	-----------------
5	Big Blue River---------	NW¼NW¼ sec. 13, T.4 N., R.5 E.	-----do-----	106	5.9 mi northwest of Beatrice gage.
6	Cub Creek--------------	NE¼NW¼ sec. 26, T.4 N., R.5 E.	Nov. 1, 1978	1.19	-----------------
7	Bottle Creek-----------	NW¼SW¼ sec. 30, T.4 N., R.5 E.	-----do-----	trace	-----------------
8	Indian Creek-----------	SW¼NW¼ sec. 27, T.4 N., R.6 E.	-----do-----	.98	-----------------
9	Big Blue River---------	SW¼NW¼ sec. 3, T.3 N., R.6 E.	Oct. 31,1978	125	Beatrice gage
10	Bear Creek-------------	SW¼SE¼ sec. 36, T.4 N., R.6 E.	Nov. 1, 1978	4.39	-----------------
11	Unnamed tributary to Cedar Creek----------	NW¼SW¼ sec. 8, T.3 N., R.7 E.	Nov. 2, 1978	.43	-----------------
12	Cedar Creek------------	SE¼SE¼ sec. 8, T.3 N., R.7 E.	-----do-----	.66	-----------------
13	Unnamed tributary to Big Blue River-------	SW¼NW¼ sec. 20, T.3 N., R.7 E.	Nov. 1, 1978	0	-----------------
14	Big Blue River---------	NE¼SW¼ sec. 29, T.3 N., R.7 E.	-----do-----	130	6.0 mi southeast of Beatrice gage, below the dam at Holmesville.
15	Mud Creek--------------	SW¼SE¼ sec. 33, T.3 N., R.7 E.	-----do-----	1.74	-----------------
16	Big Blue River---------	NE¼SE¼ sec. 7, T.2 N., R.7 E.	Oct. 31,1978	215	6.9 mi north-northwest of Barneston gage, below dam at Blue Springs.
17	Bills Creek------------	NE¼NE¼ sec. 19, T.2 N., R.7 E.	-----do-----	0	-----------------
18	Big Indian Creek-------	NW¼SW¼ sec. 29, T.2 N., R.7 E.	-----do-----	6.23	-----------------
19	Wildcat Creek----------	NE¼NE¼ sec. 12, T.1 N., R.7 E.	-----do-----	0	-----------------
20	Big Blue River---------	SE¼NW¼ sec. 13, T.1 N., R.7 E.	-----do-----	194	Barneston gage.
21	Plum Creek-------------	NW¼SW¼ sec. 19, T.1 N., R.8 E.	-----do-----	2.28	-----------------
		Little Blue River basin			
22	Little Blue River------	NE¼SE¼ sec. 20, T.3 N., R.1 E.	Oct. 27,1978	56.2	10.8 mi northwest of Fairbury gage.
23	Big Sandy Creek--------	SW¼NW¼ sec. 17, T.3 N., R.1 E.	-----do-----	24.0	-----------------
24	Big Sandy Creek--------	NE¼NE¼ sec. 21, T.3 N., R.1 E.	-----do-----	26.9	-----------------
25	Little Blue River------	SW¼SW¼ sec. 23, T.3 N., R.1 E.	-----do-----	83.6	8.9 mi northwest of Fairbury gage
26	Little Blue River------	SE¼SE¼ sec. 24, T.3 N., R.1 E.	-----do-----	90.1	7.7 mi northwest of Fairbury gage.
27	Little Sandy Creek-----	NW¼NW¼ sec. 29, T.4 N., R.1 E.	Oct. 25,1978	0	-----------------
28	Little Sandy Creek-----	SE¼SE¼ sec. 33, T.4 N., R.1 E.	-----do-----	.08	-----------------
29	Little Sandy Creek-----	SW¼SW¼ sec. 12, T.3 N., R.1 E.	-----do-----	.38	-----------------
30	Little Sandy Creek-----	SE¼SW¼ sec. 18, T.3 N., R.2 E.	Oct. 25,1978	1.14	-----------------

Table 2.--Results of seepage survey in the Big Blue and Little Blue River basins--Continued

Measure-ment site	Stream	Location of measurement site	Date measured	Discharge (ft^3/s)	Remarks
		Little Blue River basin--Continued			
31	Whiskey Run------------	NW¼NE¼ sec. 4, T.2 N., R.2 E.	-----do-----	0.32	------------------
32	Little Blue River------	SW¼SE¼ sec. 4, T.2 N., R.2 E.	-----do-----	91.1	3.7 mi northwest of Fairbury gage.
33	Little Blue River------	SE¼SE¼ sec. 9, T.2 N., R.2 E.	-----do-----	93.6	2.7 mi northwest of Fairbury gage, at U.S. Highway 136 bridge.
34	Little Blue River------	NE¼NE¼ sec. 22, T.2 N., R.2 E.	-----do-----	103	1.2 mi northwest of Fairbury gage, below the dam at Fairbury.
35	Unnamed tributary to Little Blue River----	NE¼SW¼ sec. 22, T.2 N., R.2 E.	Oct. 27,1978	0	------------------
36	Little Blue River------	NW¼NE¼ sec. 26, T.2 N., R.2 E.	Oct. 25,1978	98.6	Fairbury gage.
37	Brawner Creek----------	NE¼SE¼ sec. 23, T.2 N., R.2 E.	-----do-----	0	------------------
38	Little Blue River------	SE¼SW¼ sec. 31, T.2 N., R.3 E.	-----do-----	107	2.7 mi southeast of Fairbury gage, site of discontinued Endicott gage.
39	Rose Creek-------------	SE¼SW¼ sec. 7, T.1 N., R.1 E.	Oct. 26,1978	8.72	------------------
40	Rose Creek-------------	NE¼SE¼ sec. 18, T.1 N., R.1 E.	-----do-----	8.83	------------------
41	Buckley Creek (tributary to Rose Creek)--	NW¼SW¼ sec. 33, T.2 N., R.1 E.	-----do-----	0	------------------
42	Buckley Creek (tributary to Rose Creek)--	SE¼SE¼ sec. 33, T.2 N., R.1 E.	-----do-----	.06	------------------
43	Buckley Creek (tributary to Rose Creek)--	NE¼SE¼ sec. 11, T.1 N., R.1 E.	-----do-----	.81	------------------
44	Rose Creek-------------	NE¼NE¼ sec. 7, T.1 N., R.2 E.	-----do-----	11.5	------------------
45	Silver Creek (tributary to Rose Creek)--	NE¼NW¼ sec. 32, T.1 N., R.2 E.	-----do-----	trace	------------------
46	Silver Creek (tributary to Rose Creek)--	SW¼SW¼ sec. 20, T.1 N., R.2 E.	-----do-----	.15	------------------
47	Silver Creek (tributary to Rose Creek)--	SE¼SW¼ sec. 17, T.1 N., R.2 E.	-----do-----	.53	------------------
48	Rose Creek-------------	SW¼NE¼ sec. 11, T.1 N., R.2 E.	Oct. 24,1978	12.3	------------------
49	Dry Branch of Rose Cr.-	SW¼SE¼ sec. 12, T.1 N., R.2 E.	-----do-----	0	------------------
50	Rose Creek-------------	SW¼SE¼ sec. 5, T.1 N., R.2 E.	-----do-----	15.2	------------------
51	Smith Creek------------	SE¼NE¼ sec. 5, T.1 N., R.3 E.	-----do-----	.26	------------------
52	Little Blue River------	SE¼SW¼ sec. 4, T.1 N., R.3 E.	-----do-----	118	4.7 mi southeast of Fairbury gage.
53	Rock Creek-------------	SE¼SW¼ sec. 23, T.2 N., R.3 E.	-----do-----	.06	------------------
54	Rock Creek-------------	NW¼SE¼ sec. 4, T.1 N., R.3 E.	-----do-----	.56	------------------
55	Coon Creek-------------	NW¼NE¼ sec. 15, T.1 N., R.3 E.	-----do-----	.26	------------------
56	Little Blue River------	NW¼NW¼ sec. 30, T.1 N., R.4 E.	-----do-----	110	9.8 mi southeast of Fairbury gage.



EXPLANATION

▲20 CONTINUOUS-RECORD GAGING STATION.--Number is measurement-site number used in this report.

△53 MEASUREMENT SITE WITHOUT A GAGE.--Number is measurement-site number used in this report.

—··——··— DRAINAGE-BASIN BOUNDARY

Figure 10.--Locations of sites where streamflow measurements were made for the fall 1978 seepage survey.

Because of transient variations in streamflow and because of the percentage error in streamflow measurements, some of the apparent seepage gains and losses determined from the discharge measurements made during the fall of 1978 may not be real. This is especially true of seepage gains and losses in the Big Blue and Little Blue Rivers. Seepage gains and losses for parts of the Big Blue and Little Blue River basins within the study area are summarized in table 3. The locations of the drainage areas given in table 3 are shown in figure 11.

An evaluation of discharge data and the factors that might affect its significance indicate that most of the streamflow measurements made as part of the seepage survey probably are representative of base flow. Some of the streamflow measurements on the Big Blue and Little Blue Rivers probably were affected to some extent by channel storage behind dams, runoff from precipitation in the river basins upstream from the study area, and the percentage error in measurements. Only two measurements are considered to be of no value for determining seepage gains or losses. These two measurements were made on the Big Blue River at site 16 (6.9 mi north-northwest of Barneston gage, below the dam at Blue Springs) and at site 20 (Barneston gage).

The dam at Blue Springs is used for intermittent power generation; water is stored until there is sufficient hydraulic head to run the generators. Because of the manner in which this dam is operated, the average daily discharge at the Barneston gage may vary by as much as 25 percent and instantaneous discharges by an even larger amount. Thus, it is not possible to use seepage-survey data for determining gains and losses in the reach of the Big Blue River between the Kansas-Nebraska State line and the dam at Holmesville (drainage areas 15 and 19 on figure 11.

Records of previous streamflow measurements that were made at sites measured as part of the seepage survey were also considered in the evaluation of data. These records are summarized in table 4. Many of these measurements were made at times when evaporation and runoff from precipitation significantly affected streamflow and are not representative of base flow. However, all measurements made at the sites are included in table 4 to show the possible variations in discharge that might occur. Measurements made on tributaries to the Big Blue and Little Blue Rivers during November 1977 are probably representative of base flow for the conditions that existed at that time.

Table 3.--Apparent seepage gains and losses for drainage areas in the Big and Little Blue River basins
[mi^2 = square mile; ft^3/s = cubic foot per second]

Drainage area	Stream	Area (mi^2)	Inflow		Outflow		Apparent seepage gain(+) or loss(-) (ft^3/s)
			Measurement site	Discharge (ft^3/s)	Measurement site	Discharge (ft^3/s)	
			Big Blue River basin				
1	Soap Creek	13.1	Divide	0	2	0.30	+ 0.30
2	Unnamed tributary to Big Blue River	[1]27.6	Divide	0	3	0	0
3	Snake Creek	11.2	Divide	0	4	0	0
4	Big Blue River	6.2	1	100			
			2	.30			
			3	0			
			4	0			
					5	106	+ 5
5	Cub Creek	135.2	Divide	0	6	1.19	+ 1.19
6	Bottle Creek	6.4	Divide	0	7	Trace	+ Trace
7	Indian Creek	[1]75.0	Divide	0	8	.98	+ .98
8	Big Blue River	43.6	5	106			
			6	1.19			
			7	0			
			8	.98			
					9	125	+ 16
9	Bear Creek	75.8	Divide	0	10	4.39	+ 4.39
10	Unnamed tributary to Cedar Creek	3.1	Divide	0	11	.43	+ .43
11	Cedar Creek	27.8	11	.43	12	.66	+ .23
12	Unnamed tributary to Big Blue River	1.7	Divide	0	13	0	0
13	Big Blue River	24.0	9	125			
			10	4.39			
			12	.66			
			13	0			
					14	130	0
14	Mud Creek	56.5	Divide	0	15	1.74	+ 1.74
15	Big Blue River	21.4	14	130			
			15	1.74			
					16	215	+ 83
16	Bills Creek	14.7	Divide	0	17	0	0
17	Big Indian Creek	207.4	Divide	0	18	6.23	+ 6.23

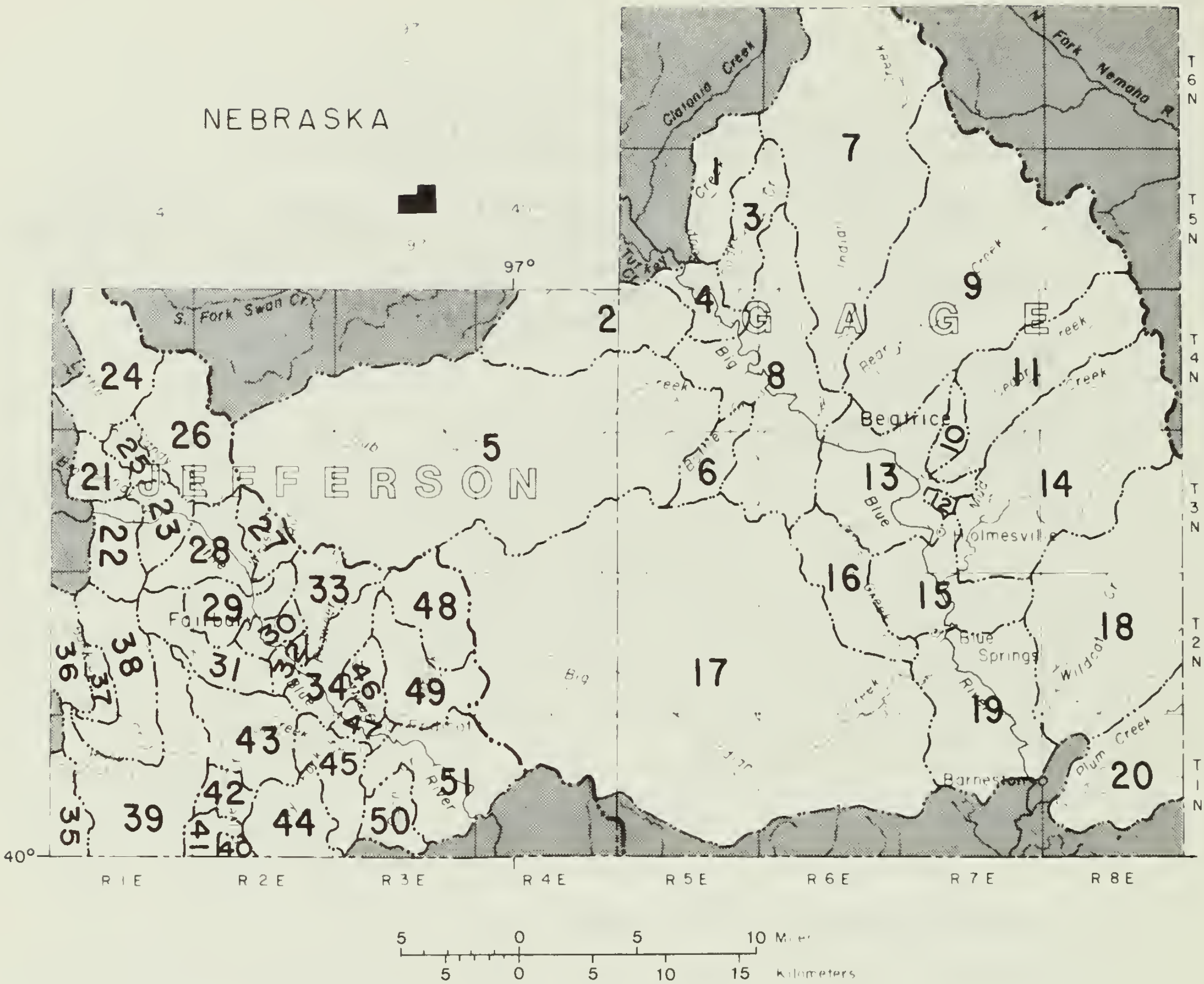
Table 3.--Apparent seepage gains and losses for drainage areas in the Big and Little Blue River basins--Continued

Drainage area	Stream	Area (mi²)	Inflow Measurement site	Inflow Discharge (ft³/s)	Outflow Measurement site	Outflow Discharge (ft³/s)	Apparent seepage gain(+) or loss(-) (ft³/s)
			Big Blue River basin--Continued				
18	Wildcat Creek----------------	[1]102.2	Divide	0	19	0	0
19	Big Blue River----------------	29.3	16	215	------	------	------
			17	0	------	------	------
			18	6.23	------	------	------
			19	0	------	------	------
					20	194	- 27
20	Plum Creek--------------------	[1]68.6	Divide	0	21	2.28	+ 2.28
			Little Blue River basin				
21	Big Sandy Creek---------------	5.1	23	24.0	24	26.9	+ 2.9
22	Little Blue River-------------	9.1	22	56.2	------	------	------
			24	26.9	------	------	------
					25	83.6	+ .5
23	Little Blue River-------------	6.4	25	83.6	26	90.1	+ 6.5
24	Little Sandy Creek------------	[1]17.9	27	0	28	.08	+ .08
25	Little Sandy Creek------------	3.9	28	.08	29	.38	+ .30
26	Little Sandy Creek------------	17.4	29	.38	30	1.14	+ .76
27	Whiskey Run-------------------	5.0	Divide	0	31	.32	+ .32
28	Little Blue River-------------	11.9	26	90.1	------	------	------
			30	1.14	------	------	------
			31	.32	------	------	------
					32	91.1	- .4
29	Little Blue River-------------	10.3	32	91.1	33	93.6	+ 2.5
30	Little Blue River-------------	3.0	33	93.6	34	103	+ 9.4
31	Unnamed tributary to Little Blue River-----------------	9.5	Divide	0	35	0	0
32	Little Blue River-------------	2.5	34	103	------	------	------
			35	0	------	------	------
					36	98.6	- 4
33	Brawner Creek-----------------	8.0	Divide	0	37	0	0
34	Little Blue River-------------	11.0	36	98.6	------	------	------
			37	0	------	------	------
					38	107	+ 8
35	Rose Creek--------------------	[1]7.5	39	8.72	40	8.83	+ .11
36	Buckley Creek (tributary to Rose Creek)----------------	[1]9.1	Divide	0	41	0	0

Table 3.--Apparent seepage gains and losses for drainage areas in the Big and Little Blue River basins--Continued

Drainage area	Stream	Area (mi^2)	Inflow: Measurement site	Inflow: Discharge (ft^3/s)	Outflow: Measurement site	Outflow: Discharge (ft^3/s)	Apparent seepage gain(+) or loss(-) (ft^3/s)
	Little Blue River basin--Continued						
37	Buckley Creek (tributary to Rose Creek)	3.4	41	0	42	0.06	+0.06
38	Buckley Creek (tributary to Rose Creek)	16.0	42	.06	43	.81	+ .75
39	Rose Creek	[1]29.9	40	8.83			
			43	.81			
					44	11.5	+ 1.8
40	Silver Creek (tributary to Rose Creek)	[1]2.4	Divide	0	45	Trace	+ Trace
41	Silver Creek (tributary to Rose Creek)	[1]4.6	45	Trace	46	.15	+ .15
42	Silver Creek (tributary to Rose Creek)	4.0	46	.15	47	.53	+ .38
43	Rose Creek	13.3	44	11.5			
			47	.53			
					49	12.3	+ .2
44	Dry Branch Rose Creek	[1]14.0	Divide	0	49	0	0
45	Rose Creek	13.3	48	12.3			
			49	0			
					50	15.2	+ 2.9
46	Smith Creek	4.2	Divide	0	51	.26	+ .26
47	Little Blue River	2.8	38	107			
			50	15.20			
			51	.26			
					52	118	- 4
48	Rock Creek	12.4	Divide	0	53	.06	+ .06
49	Rock Creek	14.5	53	.06	54	.56	+ .50
50	Coon Creek	5.6	Divide	0	55	.26	+ .26
51	Little Blue River	20.2	52	118			
			54	.56			
			55	.26			
					56	110	- 8

[1]Includes some area in county or counties adjacent to study area.



EXPLANATION

17 DRAINAGE-AREA NO.

DRAINAGE-BASIN BOUNDARY

DRAINAGE-SUBBASIN BOUNDARY

AREA NOT INCLUDED IN SEEPAGE SURVEY

Figure 11.--Drainage areas defined by seepage data.

Table 4.--Records of previous streamflow measurements made at sites measured during fall 1978
[ft^3/s = cubic foot per second]

Measurement site	Stream and station No.	Date measured	Discharge (ft^3/s)
		Big Blue River basin	
1	Big Blue River 06-8814.20	May 14, 1968	241
		June 12, 1968	500
		Sept. 2, 1968	201
		Oct. 2, 1968	72
		Apr. 15, 1969	606
		Apr. 17, 1969	1,130
		June 23, 1969	275
6	Cub Creek 06-8814.30	June 12, 1968	74.1
		Sept. 9, 1968	6.43
		Oct. 2, 1968	1.2
		Oct. 29, 1968	2.8
		June 23, 1969	3.1
		Sept.11, 1969	1.5
		Nov. 7, 1977	.62
8	Indian Creek 06-8814.50	Aug. 20, 1968	13.1
		Oct. 2, 1968	.14
		Oct. 29, 1968	.28
		June 23, 1969	.35
		Sept.11, 1969	.15
		Nov. 17, 1977	1.5
10	Bear Creek 06-8815.20	Aug. 20, 1968	19.3
		Oct. 3, 1968	.86
		June 24, 1969	3.5
		Sept.12, 1969	1.9
		Nov. 7, 1977	3.7
12	Cedar Creek 06-8815.50	June 12, 1968	.20
		Aug. 20, 1968	10.5
		Oct. 3, 1968	0
		June 24, 1969	1.5
		Sept.12, 1969	.42
		Nov. 7, 1977	.06

Table 4.--Records of previous streamflow measurements made at sites measured during fall 1978--Continued

Measurement site	Stream and station No.	Date measured	Discharge (ft^3/s)
		Big Blue River basin--Continued	
15	Mud Creek 06-8816.50	Aug. 2, 1968	57.2
		Oct. 3, 1968	.13
		June 24, 1969	4.4
		Sept. 12, 1969	1.2
		Nov. 7, 1977	1.0
18	Big Indian Creek 06-8817.50	May 10, 1968	3.66
		June 12, 1968	3.10
		Aug. 21, 1968	10.5
		Oct. 3, 1968	2.1
		June 24, 1969	11
		Sept. 12, 1969	4.2
19	Wildcat Creek 06-8820.50	Aug. 21, 1968	8.89
21	Plum Creek 06-8820.50	Aug. 21, 1968	1.37
		Oct. 3, 1968	.28
		June 24, 1969	10
		Sept. 12, 1969	2.1
		Little Blue River basin	
24	Big Sandy Creek 06-8839.50	May 17, 1968	22.5
		June 14, 1968	29.4
		Aug. 7, 1968	39.1
		Sept. 26, 1968	242
		Oct. 22, 1968	61
		June 17, 1969	33
		Sept. 26, 1969	26
		Nov. 3, 1977	30
30	Little Sandy Creek 06-8839.60	Aug. 7, 1968	.62
		Sept. 27, 1968	6.26
		Oct. 23, 1968	3.53
		June 17, 1969	2.94
		Sept. 26, 1969	.73
		Nov. 3, 1977	2.2

Table 4.--Records of previous streamflow measurements made at sites measured during fall 1978--Continued

Measurement site	Stream and station No.	Date measured	Discharge (ft^3/s)
		Little Blue River basin--Continued	
33	Little Blue River 06-8839.95	May 15, 1968	132
		Aug. 7, 1968	76.3
		Sept.27, 1968	341
		Oct. 23, 1968	265
		June 17, 1969	279
		Sept.26, 1969	258
		Nov. 3, 1977	185
50	Rose Creek 06-8840.10	May 15, 1968	15.5
		Aug. 8, 1968	9.80
		Sept.27, 1968	28.5
		Oct. 23, 1968	41
		June 17, 1969	28
		Sept.26, 1969	12
		Nov. 3, 1977	18
52	Little Blue River 06-8840.20	May 14, 1968	186
		June 14, 1968	238
		Aug. 8, 1968	102
		Sept.27, 1968	455
		Oct. 23, 1968	372
		June 17, 1969	355
		Sept.26, 1969	305
		Nov. 3, 1977	224

SYNTHESIS OF SEEPAGE DATA AND OTHER HYDROGEOLOGIC DATA

Ground-water contributions to streamflow occur where the direction of ground-water movement is toward the stream. The quantity of ground water that enters any given reach of stream is controlled by the area of hydraulic connection, the hydraulic gradient between the aquifer and stream, and the hydraulic conductivity of the streambed and the aquifer. Stream losses to the ground-water system occur only where the direction of ground-water movement is away from the stream. Thus, within the study area, the most significant ground-water contributions to streamflow would be expected where the streams are hydraulically connected with the Quaternary buried coarse-grained deposits. Only very small ground-water contributions to streamflow would be expected where the streams are hydraulically connected with relatively impermeable beds, such as the undifferentiated Lower Permian limestones and shales and the Quaternary fine-grained deposits. Because available data indicate that all ground-water movement is toward the streams, no seepage losses would be expected. Generally, data collected during the seepage survey support these assumptions. (See table 3.)

In the following discussion of seepage data and other hydrogeologic data, explanations are given for those drainage areas for which the apparent seepage gain or loss listed in table 3 is at variance with what would be expected from evaluation of other hydrogeologic data.

Big Blue River Basin

Drainage area 1 - Soap Creek drainage basin.--The stream is hydraulically connected with Quaternary fine-grained deposits and the apparent seepage gain of 0.30 ft^3/s is reasonable.

Drainage area 2 - unnamed tributary to Big Blue River.--Available data indicate the stream is not hydraulically connected with the aquifer system (Quaternary fine-grained and buried coarse-grained deposits). Thus, the determination of no flow in the stream is reasonable.

Drainage area 3 - Snake Creek drainage basin.--Available data indicate a very small seepage gain might occur in this basin; however, having no flow at the time the seepage survey was made is not unreasonable.

Drainage area 4 - Big Blue River 9.5 to 5.9 mi northwest of Beatrice gage.--The river is hydraulically connected with both Quaternary buried coarse-grained and exposed coarse-grained deposits, and the apparent seepage gain of about 5 ft^3/s is reasonable.

Drainage area 5 - Cub Creek drainage basin.--The stream is hydraulically connected with Quaternary fine-grained deposits and the apparent seepage gain of 1.19 ft^3/s is reasonable.

Drainage area 6 - Bottle Creek drainage basin.--Available water-level data indicate that throughout most of its length the stream bed is above the water table, and the determination of almost no flow in the stream is reasonable.

Drainage area 7 - Indian Creek drainage basin.--Throughout most of its length, the stream is hydraulically connected with Quaternary fine-grained deposits. The apparent seepage gain of 0.98 ft^3/s is reasonable.

Drainage area 8 - Big Blue River 5.9 mi northwest of Beatrice gage to Beatrice gage.--The river is hydraulically connected with both Quaternary buried coarse-grained and exposed coarse-grained deposits and the apparent seepage gain is reasonable. However, inflow measurements in the Big Blue River were made 2 days after outflow measurements and the apparent seepage gain of about 16 ft^3/s should be considered as being an approximation of the actual seepage gain.

Drainage area 9 - Bear Creek drainage basin.--Available data indicate that, at least locally, the stream is hydraulically connected with Quaternary buried coarse-grained deposits. The apparent seepage gain of 4.39 ft^3/s is reasonable.

Drainage areas 10 and 11 - Cedar Creek drainage basin.--Main aquifers in the basin are undifferentiated Lower Permian limestones and shales and Quaternary fine-grained deposits. Topographic maps indicate that the stream is not hydraulically connected with the aquifer system in the upper part of the basin. The apparent seepage gain of 0.66 ft^3/s is reasonable.

Drainage area 12 - unnamed tributary to Big Blue River.--Topographic maps indicate that most of the stream is not hydraulically connected to the aquifer system, and the determination of no flow is reasonable.

Drainage area 13 - Big Blue River, Beatrice gage to 6.0 mi southeast of Beatrice gage.--Evaluation of other hydrogeologic data indicates that little or no seepage gains or losses should occur, and the apparent seepage loss seems to verify this evaluation. Outflow from the area was measured on November 1, 1978, and inflow at the Beatrice gaging station on October 31, 1978.

Drainage area 14 - Mud Creek drainage basin.--Available data indicate that for much of its length the stream probably is not in direct hydraulic connection with the aquifer system; however, the stream locally may be hydraulically connected with Quaternary buried coarse-grained deposits near its confluence with the Big Blue River. The apparent seepage gain of 1.74 ft^3/s is reasonable.

Drainage area 15 - Big Blue River, 6.0 mi southeast of Beatrice gage to 6.9 mi north-northwest of Barneston gage.--Although a significant seepage gain should occur in this drainage area between the dams at Holmesville and Blue Springs because the Big Blue River probably is hydraulically connected to Quaternary buried coarse-grained deposits in the reach between the mouth of Mud Creek and the dam at Blue Springs, the apparent seepage gain of 83.26 ft^3/s is not reasonable. This apparent seepage gain is due to the manner in which the dam at Blue Springs is operated for power generation, which causes large transient variations in streamflow to occur.

The approximate ground-water contribution to streamflow in this reach can be determined if it is assumed (1) that the mean monthly discharges at the Barneston and Beatrice gaging stations for the month of October 1978 are representative of base flow, and (2) that, as other hydrogeologic data indicate, the only significant direct ground-water contribution to streamflow in the reach at the Big Blue River between the Barneston and Beatrice gaging stations occurs between the mouth of Mud Creek (measurement site 15) and the dam at Blue Springs (measurement site 16). Inflow at Beatrice is 131 ft^3/s, outflow at Barneston is 157 ft^3/s, and inflow from Big Indian, Mud, Cedar, and Bear Creeks is 13.02 ft^3/s. Thus a seepage gain of approximately 13 ft^3/s probably occurs in this drainage area.

Drainage area 16 - Bills Creek drainage basin.--Although topographic maps indicate that the several miles of the stream are hydraulically connected to the aquifer system, available water-level data indicate that throughout most of its length the streambed is above the water table and that little or no seepage gains should occur. The determination of no flow in the stream is reasonable.

Drainage area 17 - Big Indian Creek drainage basin.--As shown in figures 4 and 6, there is some movement of ground water toward the stream from the part of the basin where Quaternary buried coarse-grained deposits occur, and the determined seepage gain of 6.23 ft^3/s seems reasonable. With the available data, it cannot be determined whether a significant amount of the ground water moves directly into Big Indian Creek or if most ground water moves into tributaries of Big Indian Creek.

Drainage area 18 - Wildcat Creek drainage basin.--Topographic maps indicate that the stream has a relatively steep gradient, and it is probable that there is little or no direct hydraulic interconnection between the stream and the ground-water system. Thus, the determination of no flow in the stream is reasonable.

Drainage area 19 - Big Blue River, 6.9 mi northwest of Barneston gage to Barneston gage.--The apparent seepage loss of about 27 ft^3/s for this area between the dam at Blue Springs and the Barneston gage is not reasonable. This apparent seepage loss is due to the manner in which the dam at Blue Springs is operated for power generation, which causes large transient variations in streamflow to occur. Based on an evaluation of available hydrogeologic information, it is probable that there is no stream loss in this area, and that any stream gain in the area would be small.

Drainage area 20 - Plum Creek drainage basin.--The main aquifers in this basin are undifferentiated Lower Permian limestones and shales and Quaternary fine-grained deposits. The apparent seepage gain of 2.28 ft^3/s is reasonable, because topographic maps indicate that stream gradient is relatively low and, therefore, the stream probably is hydraulically connected to the ground-water system for most of the length of the stream.

Little Blue River Drainage Basin

Drainage area 21 - lower part of Big Sandy Creek drainage basin.--Available data indicate that a good hydraulic connection exists between the stream and Quaternary buried coarse-grained deposits. The apparent seepage gain of 2.9 ft^3/s is reasonable.

Drainage area 22 - Little Blue River, 10.8 to 8.9 mi northwest of Fairbury gage.--The apparent seepage gain of 0.5 ft^3/s is not unreasonable. Available hydrogeologic data indicates that both the hydraulic conductivity and cross-sectional area of the alluvial deposits increase below the mouth of Big Sandy Creek; thus it is possible that there is also some ground-water contribution to the underflow that leaves the area.

Drainage area 23 - Little Blue River, 8.9 to 7.7 mi northwest of Fairbury gage.--The apparent seepage gain of 6.5 ft^3/s is reasonable. Available hydrogeologic data indicate that a hydraulic connection exists between the stream system and the Quaternary buried coarse-grained deposits that occur north of the river. However, differences in underflow into and out of the area may also account for some of the gain.

Drainage areas 24-26 - lower part of Little Sandy Creek drainage basin.--Available hydrogeologic data indicate that some hydraulic connection exists between the stream and the Quaternary buried coarse-grained deposits. The configuration of water table (fig. 6), however, indicates that the ground-water and surface-water divides for this area do not tend to parallel each other, and that movement of ground water in much of the area of the surface-water drainage basin probably is toward the Big Blue River rather than the Little Blue River. Thus, the apparent seepage gain of 1.14 ft^3/s is reasonable.

Drainage area 27 - Whiskey Run drainage basin.--Main aquifers in the area are Quaternary fine-grained deposits, Greenhorn Limestone, and Dakota Sandstone. The apparent seepage gain of 0.32 ft^3/s is reasonable.

Drainage area 28 - Little Blue River, 7.7 to 3.7 mi northwest of Fairbury gage.--The apparent seepage loss of 0.4 ft^3/s may be caused by differences in underflow at measuring sites on the river or by percentage errors in measurement. Other hydrogeologic data indicate that little or no gain should occur in area.

Drainage area 29 - Little Blue River, 2.7 to 3.7 mi northwest of Fairbury gage.--Quaternary buried coarse-grained deposits are hydraulically connected with the river and the apparent seepage gain of 2.5 ft^3/s is reasonable.

Drainage area 30 - Little Blue River, 1.2 to 2.7 mi northwest of Fairbury gage.--Quaternary buried coarse-grained deposits are hydraulically connected with river, and apparent seepage gain of 9.4 ft^3/s is reasonable. Differences in underflow of measuring sites, however, may affect streamflow; therefore, the gain should be considered an approximation.

Drainage area 31 - drainage basin of unnamed tributary to Little Blue River.--Topographic and water-level data indicate that the stream channel in this basin is not hydraulically connected with the aquifer system, and a determination of no flow is reasonable.

Drainage area 32 - Little Blue River, 1.2 mi northwest of Fairbury gage to Fairbury gage.--The apparent seepage loss of about 4 ft^3/s probably is related to differences in amounts of underflow at measuring sites. Effects of the dam at Fairbury on streamflow and on underflow into the area cannot be determined with available data. Other hydrogeologic data indicate that some ground-water contribution from Quaternary buried coarse-grained deposits which are hydraulically connected with the river should occur in this drainage area. If the inflow at measuring site 34 (103 ft^3/s) is subtracted from the outflow of measuring site 38

(107 ft^3/s), a gain of 4 ft^3/s for drainage areas 32 and 34 can be determined. This gain probably approximates the ground-water contribution to streamflow that occurs in drainage area 32.

Drainage area 33 - Brawner Creek drainage basin.--Available topographic and water-level data indicate that almost all of the basin is above water table. Determination of no flow is reasonable.

Drainage area 34 - Little Blue River, Fairbury gage to 2.7 mi southeast of Fairbury Gage.--The apparent seepage gain of 8 ft^3/s in this drainage area is probably due to differences in the amount of underflow at the measuring sites. (See discussion of drainage area 32.) Data to support this assumption are not available.

Drainage areas 35-45 - Rose Creek, Jefferson County line to mouth.--Main aquifers throughout most of the area are Quaternary fine-grained deposits and Dakota Sandstone; however, Quaternary buried coarse-grained deposits underlie the northern parts of drainage areas 39 and 43 and most of drainage areas 36, 37, and 38 (Buckley Creek drainage basin). Available data indicate that there is ground-water movement from the Quaternary buried coarse-grained deposits toward Rose Creek, but data are not adequate for determining where the most significant ground-water contributions to streamflow occur. Apparent seepage gains for these drainage areas (table 3) are reasonable, and a total seepage gain of about 6.5 ft^3/s for drainage areas 35-45 also is reasonable.

Drainage area 46 - Smith Creek drainage basin.--The apparent seepage gain of 0.26 ft^3/s is reasonable for this basin where Quaternary fine-grained deposits and the Dakota Sandstone are the main aquifers.

Drainage area 47 - Little Blue River, 2.7 to 4.7 mi southeast of Fairbury gage.--Evaluation of hydrogeologic data indicates that little or no seepage gain or loss should occur in this drainage area. Thus, the apparent seepage loss of 4.46 ft^3/s is not considered reasonable. This apparent loss probably is the result of transient variations in streamflow. Inflow to the area, at site 38, was measured on October 25, 1978, and outflow from the area, at site 52, was measured on October 24, 1978, and data for the Fairbury gage indicate that amount of flow into the area was larger on October 25, 1978, than it was on October 24, 1978 (U.S. Geological Survey, 1980, p. 377). The apparent seepage loss may also be due in part to percentage errors in measurements, differences in the amount of underflow into and out of the area, or both.

Drainage areas 48 and 49 - Rock Creek drainage basin.--Main aquifers in this basin are Quaternary fine-grained deposits and sandstones in the lower part of the Dakota Sandstone. The apparent seepage gain of 0.56 ft^3/s is reasonable.

Drainage area 50 - Coon Creek drainage basin.--The shaly middle part of the Dakota Sandstone crops out throughout much of this basin and very little or no seepage gains would be expected. The apparent seepage gain of 0.26 ft^3/s is not reasonable, but could be the result of runoff from rain showers in the area the day before the seepage measurement was made.

Drainage area 51 - Little Blue River, 4.7 to 9.8 mi southeast of Fairbury gage.--Evaluation of other hydrogeologic data indicate that no seepage gains or losses should occur in this area. Thus, the apparent seepage loss of 8.82 ft^3/s is not considered reasonable. Although some apparent seepage loss may be attributable to the transient effects of increased channel storage, most of the apparent seepage loss probably is the result of percentage errors in measurement.

SUMMARY AND CONCLUSIONS

Significant ground-water contributions to streamflow occur in the parts of the Big Blue and Little Blue River basins that are in the study area. The largest seepage gains occur where streams are hydraulically connected with buried coarse-grained deposits. Lack of data has made it necessary to make some assumptions in the interpretation of seepage and other hydrogeologic data.

In the Big Blue River basin, the largest ground-water contributions to streamflow occur in the reaches of the river between the mouth of Turkey Creek and the Beatrice gaging station (less than 22.5 ft^3/s) and between the mouth of Mud Creek and the dam at Blue Springs (approximately 13 ft^3/s). The gain in the reach between the mouth of Turkey Creek and the Beatrice gage cannot be determined exactly because there is considerable underflow at the upstream end of the reach and almost no underflow at the Beatrice gaging station. Significant ground-water contributions to streamflow also occur in two tributaries of the Big Blue River: Bear Creek (4.39 ft^3/s) and Big Indian Creek (6.23 ft^3/s).

In the Little Blue River basin the largest ground-water contributions to streamflow in the river occur in the vicinity of Fairbury (about 16 ft^3/s) and between the mouths of Big Sandy and Little Sandy Creeks (about 6.5 ft^3/s). A ground-water contribution to streamflow of about 6.5 ft^3/s also occurs in that part of the Rose Creek drainage basin that is in the study area. Lack of data to define probable differences in the amount of underflow at measurement sites makes it impossible to quantify seepage gains for some reaches of the river.

Seepage gains indicated by data from the seepage survey made during the fall of 1978 are representative of base flow during a period when transient effects on streamflow and ground-water inflow are minimal. During the growing season the effect of evapotranspiration, stream diversions, and ground-water pumping probably cause the ground-water contribution to streamflow to be somewhat less. Existing ground-water development for irrigation probably has, as yet, had no significant effect on streamflow. However, even at the current degree of development, it is probable that irrigation pumpage of ground water will cause some diminishment of the ground-water contribution to streamflow in the future. The main areas of ground-water development likely to have the greatest effect on streamflow are located where Quaternary buried coarse-grained deposits occur in the Big Indian and Rose Creek drainage basins, in the vicinity of Fairbury, and northwest of Beatrice.

ADDITIONAL DATA NEEDS

This analysis of stream-aquifer interrelationships is mostly qualitative; probably the only way in which an adequate quantitative evaluation of the interrelationships between ground water and streamflow in the study area can be made is by use of deterministic-modeling techniques. Before valid models can be developed, however, additional data need to be collected. If such techniques are to be applied, the boundaries of the area should be selected so that they coincide, as much as possible, with natural hydrologic and hydrogeologic boundaries. Data collection in anticipation of a model study could be initiated at any time, and the early collection of water-use and water-level data would tend to enhance modeling efforts. Data to correct major deficiencies before the stream-aquifer interrelationships can be modeled are:

1. Sufficient water-level data for accurate definition of the configuration of the water table at different time periods so that the effects of stresses on the aquifer system can be determined. Collection of this data would probably require the measurement of water levels in 200 to 300 wells at least twice and possibly three times.

2. Data to use in quantifying the amount of underflow that occurs at selected streamflow measurement sites. These data would be collected by drilling test-hole transects to determine the cross-sectional area of the alluvial deposits and to provide a basis for estimating the hydraulic conductivity of the deposits. Also, some observation wells would need to be installed along these transects in order that the relationship between water levels and stream stage can be defined.

3. Additional seepage data to quantify better the gains that occur in some parts of the basin and to aid in evaluation of the significance of ground-water contributions to streamflow during periods when evapotranspiration rates are high and when large amounts of ground water are being pumped for irrigation.

4. Data on the distribution in time and space of water use within the study area. Such data are virtually nonexistent, but are essential in any modeling effort.

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