Ground Water in the Republican River Area, Cloud, Jewell, and Republic Counties, Kansas

By Stuart W. Fader

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CONTENTS

ILLUSTRATIONS

TABLES

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ABSTRACT

Both surface and ground water are used for irrigation in parts of Cloud, Jewell, and Republic counties in north-central Kansas. The combination of surface-water irrigation and recharge from precipitation has caused some high ground-water levels in some of the upland areas.

In the lowland areas, alluvial deposits yield as much as 1,400 gallons a minute to wells, and about 12,300 acre-feet of ground water is pumped annually for irrigation and other uses. It is estimated that 710 acre-feet of this quantity was removed from the Republican River in 1963 by the pumping of ground water. Coefficients of transmissibility from 61 well sites were used in making the above estimate.

Ground-water recharge from precipitation in the area was estimated to be 0.6 inch and ground-water losses to evapotranspiration to be less than 0.2 inch.

Chlorides in ground water in northern Cloud County are tabulated and the areas mapped where the ground water might be unfit for use in irrigation.

INTRODUCTION

Purpose of Investigation

Irrigation of the upland areas in northeastern Jewell and western Republic counties began in 1958 with use of surface water from the Harlan County Reservoir in Nebraska and the Lovewell Reservoir in Kansas. Water levels in these areas were shallow prior to irrigation, and because the lateral permeability of the water-bearing material was low, it was expected that seepage from canals and applications of surface water probably would cause temporary detrimentally high water levels. It was necessary to collect data concerning water levels so that areas of present high water levels or potential high water levels could be delineated.

The flow of the Republican River is regulated so that there will be adequate water available for municipal sewage disposal and for navigation. Therefore, information concerning the effects on the flow of the River caused by pumping of ground water from the alluvial deposits in the river valley was needed. In some areas of northern Cloud County ground water in the alluvial deposits is highly mineralized. Information was needed regarding the chloride content of the ground water, the areal extent of the chlorides, and the change of chloride with time, if any, in water from wells.

Location and General Features of the Area

The Republican River area is included in the northern 8 miles of Cloud County, parts of the western 3 ranges of Republic County, and the northeastern part of Jewell County (Fig. 1). The area is part of the "Lower Republican River Unit" as defined by the Kansas Water Resources Board (June, 1961). The lowland area is outlined by the heavy dashed line on Plate 2.

The principal topographic features that are pertinent to the ground water of the area are: the high flat upland plains, similar to those in western Kansas; the gently rolling areas developed on the Dakota Formation; the broad, flat valley of the Republican River; the narrower valleys of Buffalo and White Rock creeks; the broad, flat terraces in the valleys; the deeply dissected area between the uplands and the river valleys; and the salt marshes in northern Cloud County.

There are 1,140 square miles drained by the Republican River between the gages at Hardy, Nebraska, and Concordia, Kansas (Pl. 2). Of this area, 342 square miles is above the gage at Loveland on White Rock Creek, and 330 square miles is above the gage at Jamestown on Buffalo Creek. The remainder of the area is drained by minor streams tributary to the Republican River.

Geologic Setting[1]

Detailed descriptions of the geology of the Republican River area are given by Fishel (1948), Fishel and Leonard (1955), and Bayne and Walters (1959) in reports on the geology and ground-water resources of Republic, Jewell, and Cloud counties, respectively. Because this investigation does not include a detailed study of the geology, only a brief summary is given. The reader is referred to the *Selected References* for more detailed geologic and hydrologic information.

[1] The nomenclature and classification of the geologic units described in the report follow the usage of the State Geological Survey of Kansas and differ somewhat from usage adopted by the U.S. Geological Survey.

The rocks that crop out in the area are sedimentary and range in age from Cretaceous to Recent. A generalized geologic section is given in Table 1. Three geologic sections showing the relationship of the water-bearing materials are shown on Plate 3. Two diagrammatic sections (Fig. 14) showing the relationship of the brackish water to the alluvial deposits are discussed in the section on *Chlorides in Ground Water.*

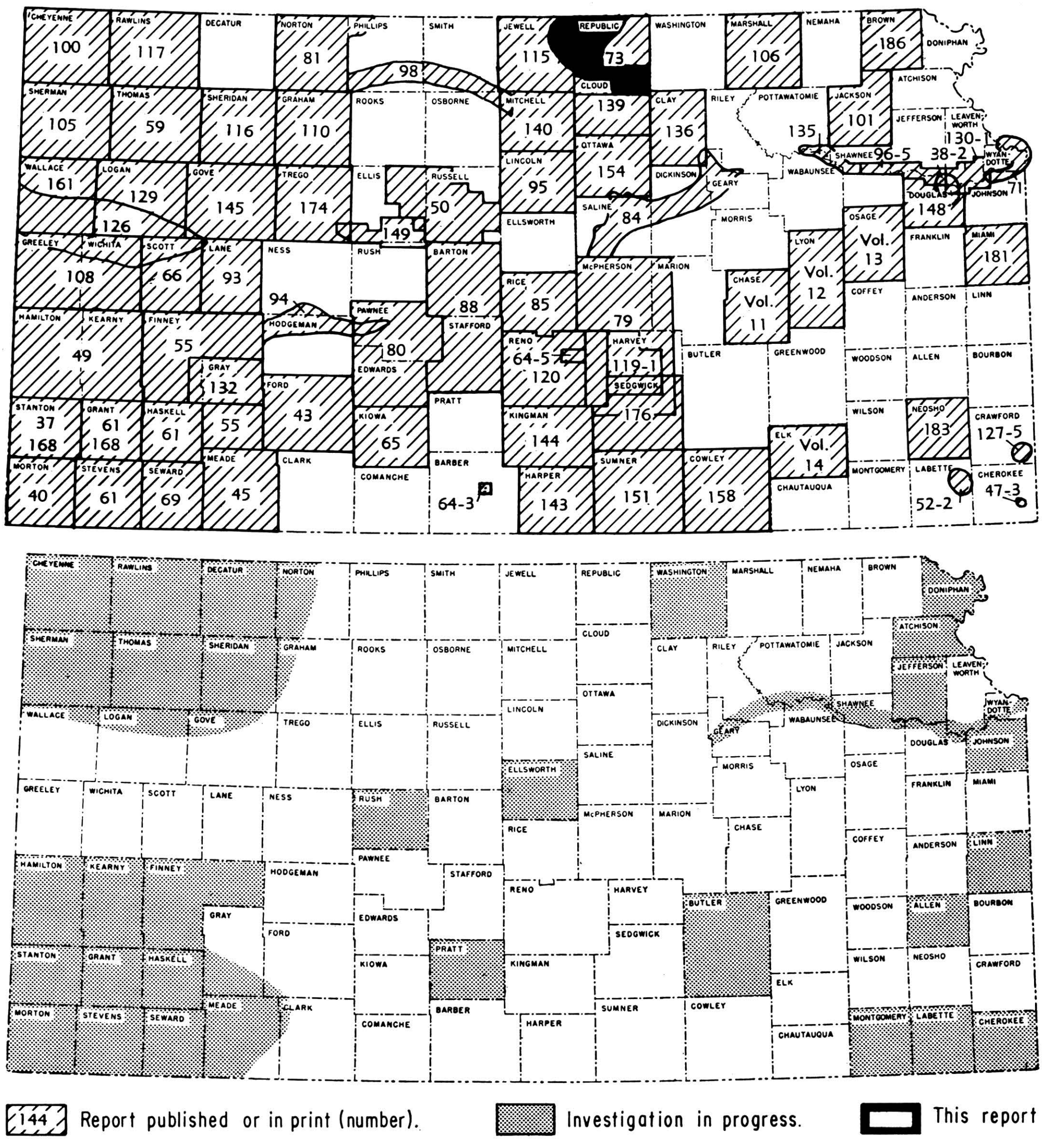

FIGURE 1.—Location of area described in this report, and other areas for which ground-water reports have been published by the State Geological Survey of Kansas or are in preparation.

TABLE 1.—Generalized geologic section in the Republican River area (modified after Fishel, 1948; Fishel and Leonard, 1955; Bayne and Walters, 1959; Jewett, 1959; and Franks, 1966).

System	Series	Stage	Stratigraphic unit	Maximum thickness, ft	Physical character	Remarks
Quaternary	Pleistocene	Recent	Alluvium	130	Clay, silt, sand, and gravel, unconsolidated	Yields up to 1,400 gpm of water
		Wisconsinan	Terrace deposits	125	Clay, silt, sand, and gravel, stream deposited; coarser materials generally in lower part of deposits	Yields large quantities of water
		Wisconsinan and Illinoisan	Eolian silts	20	Silt, mantling upland and older terrace deposits along major streams	Yields no water, but some observation wells screened in this unit
		Illinoisan	Loveland and Crete formations, undifferentiated	75	Silt and clay, waterlaid, containing minor amounts of sand and gravel; generally more gravel near base	Yields small to moderate quantities of water
			Crete Formation	30	Sand, gravel, and silt in terrace position along some major streams. Gravel is principally limestone	Lies generally above water table, but yields small quantities of water where below water table
		Kansan	Sappa Formation	60	Sand and gravel, locally derived, overlain by silt and clay. Occurs in deeper parts of Republican River valley	Yields large quantities of water to wells in northern Republic County; water has high chloride content in part of Cloud County
			Grand Island Formation			
Cretaceous	Upper Cretaceous		Carlile Shale: Blue Hill Shale Member	200	Fissile, noncalcareous, gray to black, marine shale; contains thin sandy zone at top and septarian and discoidal concretions	Yields little or no water, but some observation wells screened in this unit
			Carlile Shale: Fairport Chalk Member	100	Shale, thin-bedded, calcareous	Yields little or no water to wells
			Greenhorn Limestone	90	Limestones and shales, thin-bedded, chalky; thin streaks of bentonite	Yields small quantities of hard water, but some observation walls screened in this unit
			Graneros Shale	40	Clay and fissile shale, noncalcareous, black and olive drab	do
	——?—— Lower Cretaceous		Dakota Formation	300	Clay, shale, siltstone, and sandstone; some lignite	Yields moderate to large quantities of water. High chloride content locally and in lower deposits

Scope of Investigation

The author spent 3 months in the fall of 1962 and 4 months during the summer of 1963 gathering hydrologic data in the field and several months during the winters 1962-64 analyzing both field and published data. Beginning in 1956 the U.S. Bureau of Reclamation measured water levels in about 360 observation wells. These data and data collected by the author were used to prepare hydrographs and water-level maps.

Information concerning the depth, depth to water, diameter, screen and yield was collected for 101 irrigation wells in Cloud County and 86 wells in Republic County. This information, together with geologic information obtained from 25 test holes, 320 well logs furnished by the U.S. Bureau of Reclamation, and previously published information, was used to prepare the map of saturated-thickness of unconsolidated deposits. Three geologic cross sections were prepared using the same data to show the relationship of the geology to the hydrology of the area.

It is planned that a separate report containing the basic data of the area on which this summary report is based will be prepared and will contain the tables of well data and logs of wells and test holes. Table 3 of this report will be updated and new information will be included. This report of basic data will be available to interested readers, for a reasonable fee, upon request from the State Geological Survey of Kansas, Lawrence, Kansas.

Coefficients of transmissibility were computed or estimated from data at 61 well sites. Three detailed aquifer tests using one to four observation wells, 22 step-drawdown (single well) tests, and one single well-recovery test were used at 26 sites. At the remaining 35 sites, estimates were made from specific capacities reported by the owners.

Water samples collected prior to 1960 were analyzed for several constituents by chemists in the Sanitary Engineering Laboratory of the Kansas State Department of Health under the supervision of H. A. Stoltenberg. Samples collected after 1960 were analyzed in the field for chlorides only. The analyses of the samples collected prior to 1960 are published in Kansas Geological Survey bulletins 73, 139, and 155, and those collected after 1960 are given in this report.

The altitudes of measuring points of wells and test holes were determined by the U.S. Bureau of Reclamation and by the Kansas District Office of the U.S. Geological Survey and the State Geological Survey of Kansas.

Well-Numbering System

The locations of wells and test holes in this report (Fig. 2) are designated according to the General Land Office Surveys in the following order: township, range, section, quarter section, quarter-quarter section, and quarter-quarter-quarter section (10-acre tract). The quarter sections, quarter-quarter sections, and quarter-quarter-quarter sections are designated *a, b, c,* or *d* in counterclockwise direction beginning in the northeast quarter section.

If more than one well or test hole is located in the same 10-acre tract, the location letters are followed by a serial number.

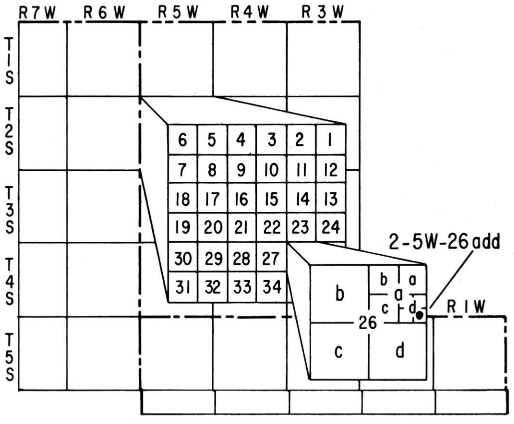

FIGURE 2.—Well-numbering system used in this report. The well is in SE SE NE sec. 26, T 2 S, R 5 W.

The locations of these wells and test holes and the locations of the surface-water gaging stations are shown on Plate 3.

Precipitation

The annual precipitation at Concordia, Belleville, and Burr Oak is shown in Figure 3. The normal monthly precipitation at Concordia is shown in Figure 4.

HYDROLOGY OF THE AQUIFERS

Aquifer Tests

The quantity of water that an aquifer will yield to wells depends upon the hydrologic properties of the materials in the aquifer. The ability of an aquifer to transmit water is measured by its coefficient of transmissibility. The *coefficient of transmissibility (T)* of an aquifer is defined as the number of gallons of water that will move in 1 day through a vertical strip of aquifer 1 foot wide and the full thickness of the aquifer, under a hydraulic gradient of 100 percent or 1 foot per foot, at the prevailing temperature of the water. The *coefficient of permeability (P)* is expressed as the rate of flow, in gallons per day, through a cross-sectional area of 1 square foot under a hydraulic gradient of 1 foot per foot. The coefficient of permeability can be computed by dividing the coefficient of transmissibility by the thickness *(m)* of the aquifer. The *coefficient of storage (S)* of an aquifer is defined as the volume of water it releases or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. Under water-table conditions the coefficient of storage is practically equal to the *specific yield,* which is defined as the ratio of volume of water a saturated material will yield to gravity in proportion to its own volume.

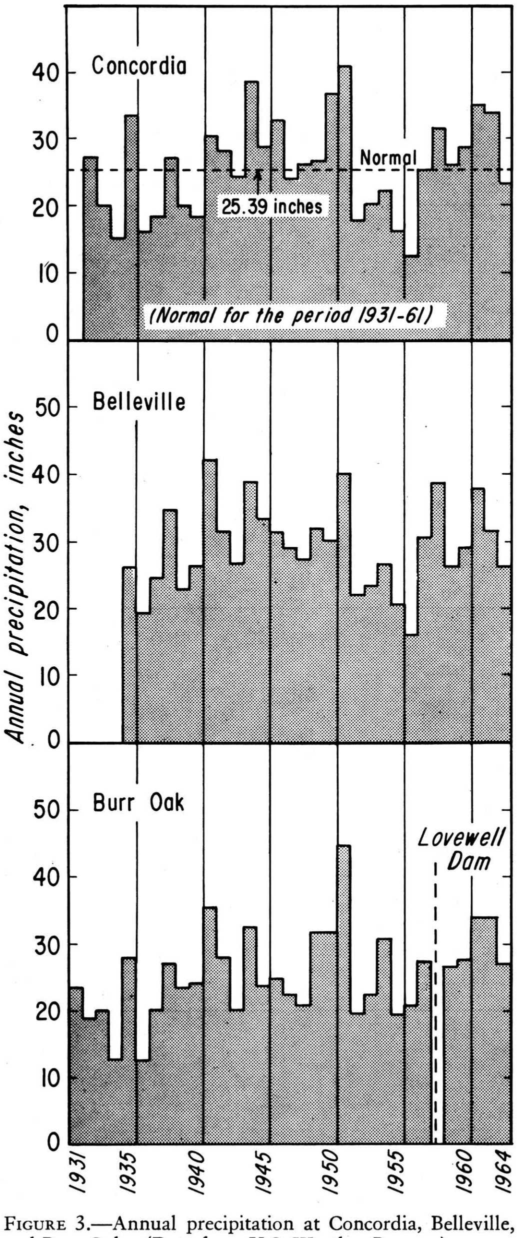

FIGURE 3.—Annual precipitation at Concordia, Belleville, and Burr Oak. (Data from U.S. Weather Bureau.)

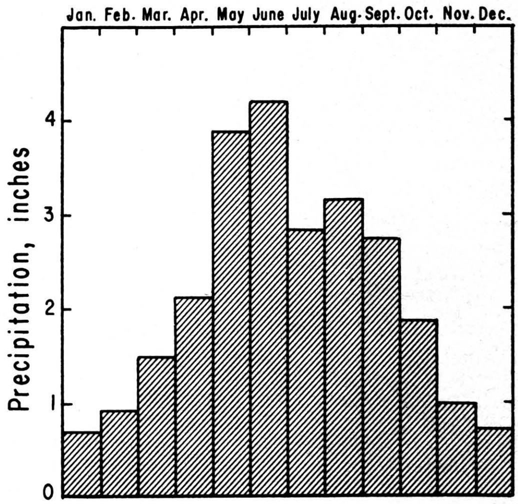

FIGURE 4.—Normal monthly precipitation at Concordia, Kansas, for the period 1931-61. (Data from U.S. Weather Bureau.)

The step-drawdown tests were analyzed by the following Theis (1935) equation:

$$\frac{Q}{s} = \frac{T}{264 \log_{10} \frac{Tt}{187 r_w^2 S} - 65.5},$$

where Q=discharge of pumped well, in gpm;
s=drawdown, in feet (corrected for well loss);
T=coefficient of transmissibility, in gallons a day per foot;
S=coefficient of storage;
r_w=radius of well, in feet;
t=time, in days after pumping started.

The results of the tests are given in Table 2.

Water Levels

Water levels in the area are shown by hydrographs (Fig. 5-10), by water-level contours (Pl. 2 and 3), and by the depth to water (Pl. 1). The areas of zero water level (corresponding

TABLE 2.—Results of pumping tests in the Republican River area, Kansas.

Well number	Geologic source*	Coefficient of transmissibility, in gpd/ft	Coefficient of permeability, in gpd/ft²	Type of test†
REPUBLIC COUNTY				
1-3W-3bc	Qd	320,000	4,000	SC
5aa	Qd	190,000	4,200	SC
1-4W-17ab	Qd	288,000	5,500	SC
1-5W-18ab	Qd	50,000	1,500	SC
2-4W-31bc	Qd	60,000	2,200	SC
3-4W-8ccb	Qa	100,000	2,500	OW
17bd	Qa	72,000	2,400	SC
17db	Qa	45,000	1,000	SC
20aa	Qa	60,000	1,500	SC
32da	Qa	110,000	2,700	SC
4-4W-4bc	Qa	50,000	1,560	SC
4db	Qw	175,000	4,260	SDD
4dc2	Qw	130,000	3,000	OW
8ad	Qa	75,000	1,500	SC
8db	Qa	65,000	2,200	SC
8dd	Qa	75,000	1,700	SC
9ab	Qw	125,000	2,500	SC
9ca	Qa	150,000	3,750	SC
15cd2	Qi	10,000		SC
17da	Qa	200,000	4,000	SC
17dd	Qa	90,000	1,800	SC
21caa	Qw	170,000	3,600	SDD
21cab	Qw	120,000	3,000	SDD
22ca	Qi	60,000	2,200	SC
22cc	Qi	95,000	2,500	SC
27ddc	Qw	70,000	2,000	SDD
29db	Qa	80,000	2,000	SC
33aa	Qw	140,000	3,500	SC
34baa	Qw	120,000	3,200	SC
CLOUD COUNTY				
5-1W-21cd	Qw	60,000	1,500	SC
30aac	Qa	160,000	4,000	SC
31bd	Qw	185,000	3,400	SC
32bc	Qw	80,000	1,600	SDD
5-2W-19bc	Qw	62,000		SC
21ad	Qa	110,000	2,750	SC
21dd	Qa, Qk	40,000	800	SDD
25cb	Qw	100,000	2,000	SC
25cc	Qw	270,000	5,700	OW
31cc	Qd	20,000	1,000	SC
32cb	Qw	100,000	3,200	SDD
32db	Qw	190,000	6,300	SDD
34aab	Qw	140,000	2,400	SDD
36ab	Qw	300,000	6,300	SC
36bc	Qw	30,000	1,800	SC
5-3W-21ca	Qa	150,000	4,000	SDD
22bc1	Qw	280,000	3,700	R
35abc	Qa	130,000	2,600	SDD
36bb	Qa	190,000	3,400	SDD
5-4W-3abd	Qw	130,000	3,200	SC
3dd	Qw	90,000	2,600	SDD
8dad	Qw	100,000	2,600	SC
9cca	Qw	330,000	5,000	SDD
13dad	Qw	140,000	4,800	SDD
15da	Qa	260,000	4,300	SDD
16dd	Qw	93,000	2,300	SDD
17aa	Qw	160,000	3,800	SDD
21ba	Qw	93,000	2,200	SDD
22ab	Qw	125,000	2,400	SC
6-1W-2ca	Qw, Kd	50,000	1,700	SDD
4bc2	Qw	55,000	1,400	SDD
12ab	Qw	190,000	5,100	SDD

* *Qd*, Pleistocene deposits, undifferentiated; *Qa*, Recent alluvium; *Qw*, Wisconsinan terrace deposits; *Qi*, Illinoisan terrace deposits; *Qk*, Kansan deposits; *Kd*, Dakota Formation.
† *SC*, specific capacity; *OW*, observation wells; *SDD*, step drawdown; *R*, recovery.

closely to areas of waterlogging) are shown by blue lines on Plate 1 for part of the area.

Water levels in wells fluctuate in response to additions to or withdrawals from the aquifers. In general, the hydrographs show a downward trend of water levels for the period of deficient precipitation, 1953-56 (Fig. 3), and the rise after 1956 is owing to an increase in precipitation. After 1958 irrigation from surface sources has contributed to the rise in water level in some areas.

In the upland areas of western Republic and eastern Jewell counties, water levels rise during the summer months (see Fig. 5, 6, and 7) and fall during the winter months. In addition to the higher normal monthly precipitation in May and June (Fig. 4), water is applied for irrigation starting in May or June. Thus, a rise of ground-water levels would be expected during the summer months along with some detrimentally high ground-water levels in areas of normal shallow-water levels (Pl. 1, 2, 3).

In the lowland areas, water levels are generally related to the local recharge from precipitation and the discharge rate of the Republican River (Fig. 8, 9, and 10). Where pumping of ground water occurs, the water level is lowered during the dry summer months. Evapotranspiration also tends to lower the water levels in the lowland area.

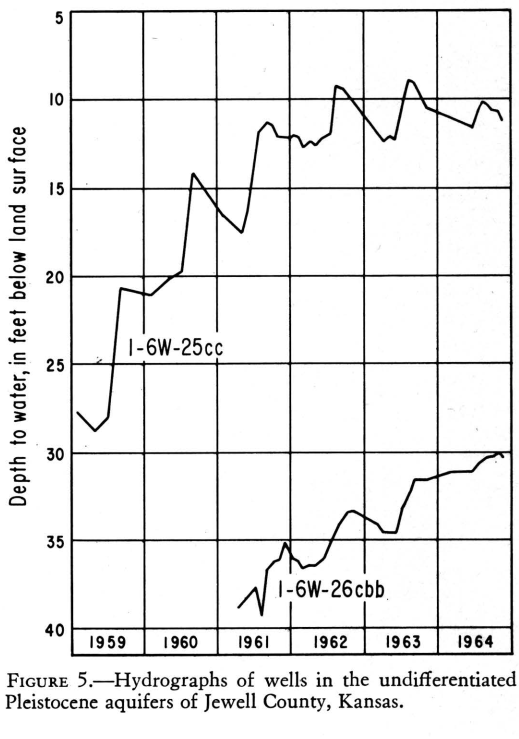

FIGURE 5.—Hydrographs of wells in the undifferentiated Pleistocene aquifers of Jewell County, Kansas.

Ground Water in Storage

In 1963, the alluvial deposits, excepting those of Kansan age, along the lowland area of the Republican River (Pl. 4) contained about 580,000 acre-feet of water. This estimate is based on the volume of saturated material above the Kansan deposits (which is generally a poor aquifer and contains brackish water in northern Cloud County) and an assumed coefficient of storage of 0.2. However, not all of this water in storage is available for irrigation use, and should the water levels decline, the yields of the wells will decline, and a time may be reached when yields will no longer be adequate for irrigation, but yields will continue to be adequate for stock, domestic, or other uses. Because of the dissection of the upland areas, no attempt was made to compute the ground water in storage in the upland.

Recharge and Discharge

The recharge to the ground-water reservoir is by direct infiltration from precipitation in the area, by seepage from streams and ponds, and by seepage from surface-water irrigation. Most of the precipitation falling on the eroded upland areas runs off, returns to the atmosphere by evapotranspiration either locally from soil moisture or after reaching the water table and moving laterally to the confluence of the water table and the upland streams and drains, or by seeping

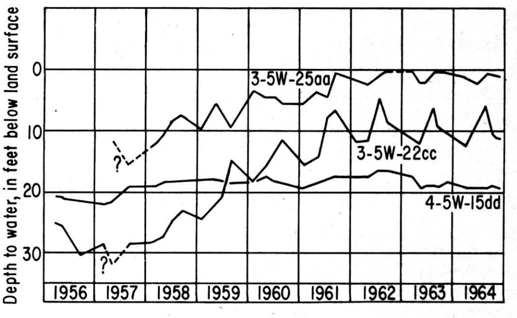

FIGURE 6.—Hydrographs of wells in undifferentiated Pleistocene aquifers (3-5W-25aa) and Cretaceous (Greenhorn) aquifers (3-5W-25aa; 3-5W-22cc; and 4-5W-15dd) of upland Republic County, Kansas.

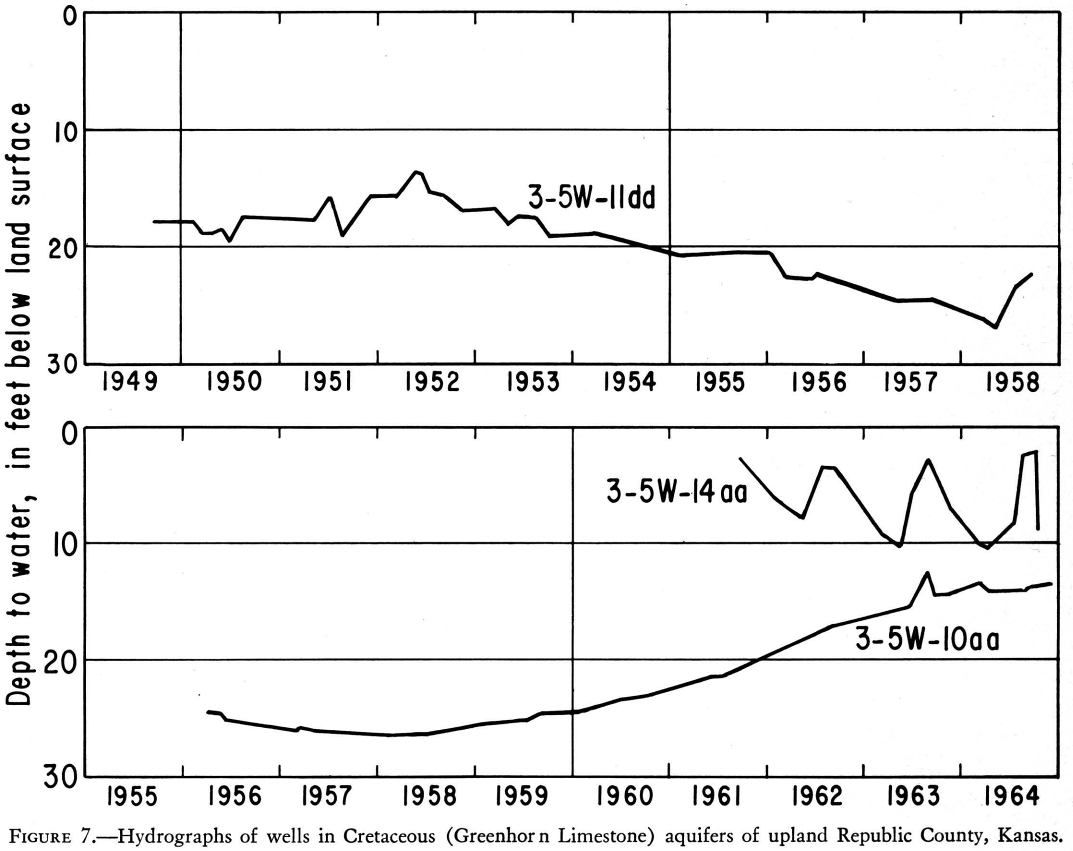

FIGURE 7.—Hydrographs of wells in Cretaceous (Greenhorn Limestone) aquifers of upland Republic County, Kansas.

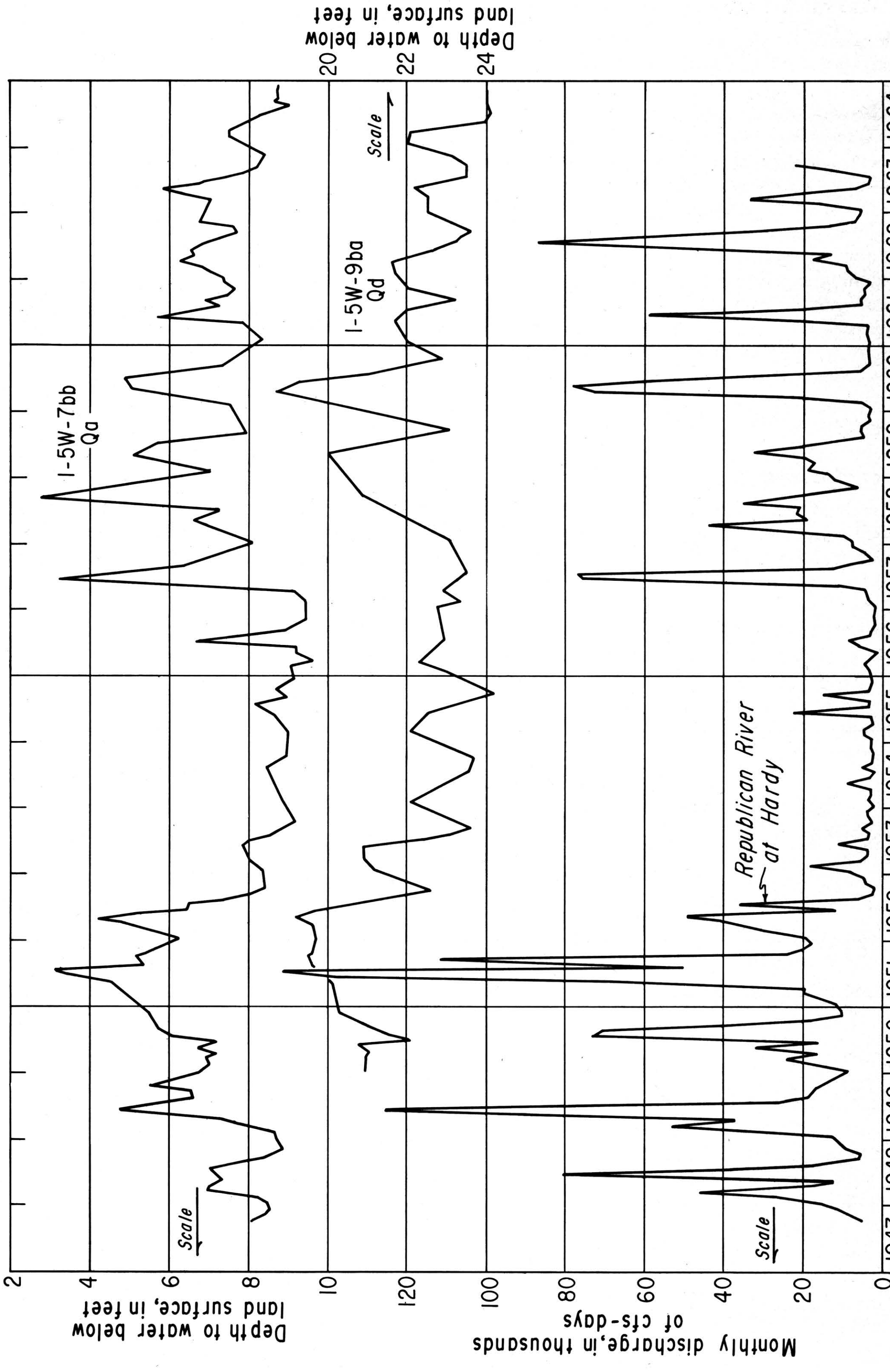

FIGURE 8.—Hydrographs of wells in the Pleistocene aquifers and monthly flow in the Republican River near Hardy, Nebraska. (*Qd*, undifferentiated Pleistocene deposits; *Qa*, Recent alluvium.)

downward into the Cretaceous aquifers where it moves laterally to the streams or drains. As evapotranspiration is less in the winter than the summer months, small amounts of this discharge should reach the streams to be gaged but might be delayed for as long as 6 months. When precipitation is above normal on the non-irrigated areas of the uplands, recharge is increased and a rise in water level is expected together with a slight increase of evapotranspiration and a slight increase in the lateral flow to streams. When precipitation is below normal the discharge to evapotranspiration and streams is more than the recharge and a decline of water levels results. After 1958, irrigation using surface water has resulted in additional recharge in the irrigated areas of northwestern Republic County and the adjacent areas of Jewell County (Fig. 5-7).

Ground water in the lowlands is recharged by local precipitation along the valley bottoms and terraces, by lateral flow from the Republican River, by seepage from the shales, sandstones, and limestones along the valley walls, and in the Hardy to Scandia area by irrigation with surface water. The discharge from the lowland areas is by evapotranspiration, by pumpage of ground water for irrigation, municipal, domestic, and stock uses, and by seepage to some reaches of the streams.

Estimate of Recharge

The recharge to the aquifers along the Republican River can be estimated if it is assumed that base flow in the river is from ground water and that base flow (Q_{80}) is about 80 percent time on the flow-duration curves. From the curves (Furness, 1959) the Q_{80} at Hardy is 202 cfs (cubic feet per second) and at Concordia 235 cfs. If this base flow is assumed to be equal to recharge over the area of 1,140 square miles between the gages, the recharge would be about 0.4 inch per year. Because trees and other vegetation along the streams obtain part of their water supply from ground water, the recharge must be greater than 0.4 inch to supply both the streams and vegetation.

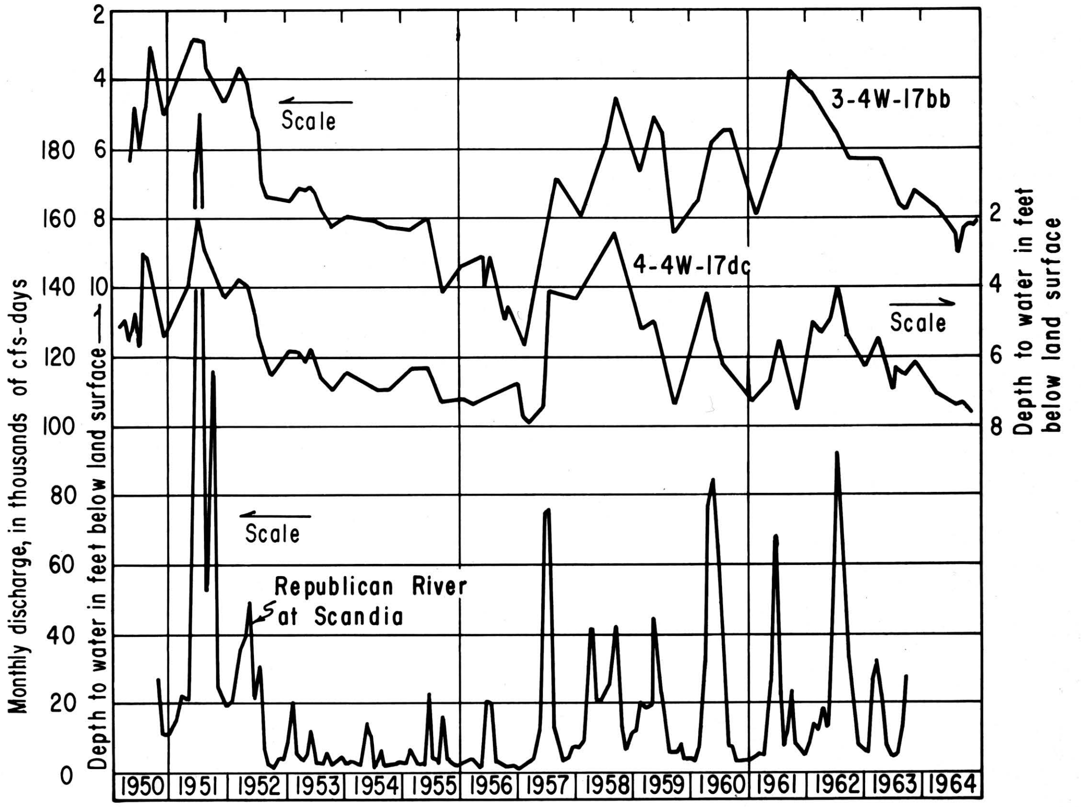

Figure 9.—Hydrographs of wells in the alluvial aquifers (Recent) and monthly flow in the Republican River at Scandia, Kansas.

The recharge can also be estimated from the Base Flow Data (Busby and Armentrout, 1965). The recharge to the area would be the base flow in the streams draining the area. During the growing season, the water lost to evapotranspiration along the valley walls and streams would not reach the gage to be measured; therefore, recharge in the area would be larger than gaged on the stream. The maximum recharge to the area would approach the base flow during the non-growing season, but as factors other than evapotranspiration are involved, the recharge is between the base flow in the streams during the growing season and during the non-growing season. In this report the mean of record for the year (from Base Flow Data) was used to estimate the recharge.

The mean of record base flow for the year (Busby and Armentrout, 1965) for White Rock Creek at Lovewell, Kansas, was 7.10 cfs for an area of 342 square miles or 0.30 inch. In the Little Blue River near Endicott, Nebraska, the basin immediately northeast of the area, the base flow was 157 cfs for an area of 2,340 square miles or 0.84 inch. In the Solomon River, south of the area, the difference in base flow between Beloit and Niles, Kansas, was 61 cfs for an area of 1,240 square miles or 0.62 inch. The average of these was 0.59 inch and includes some loss to evapotranspiration.

An examination of the aerial photographs for the area indicated that there were about 6 square miles of cottonwood and willow trees along the valley bottom of the Republican River. About 4 square miles were between the Hardy and Concordia gages and 2 square miles between Concordia and the Clay county line. According to Blaney (1957, p. 129), the evapotranspiration rate for cottonwood trees in California was 1.15 times the pan evaporation rate for a water level of 4 feet below the land surface. The water levels under the lowland area along the Republican River are in most localities from 3 to 12 feet below the land surface, and therefore the above coefficient was reduced to 1.0. U.S. Weather Bureau Climatological Data show that the average pan evaporation for the growing season in

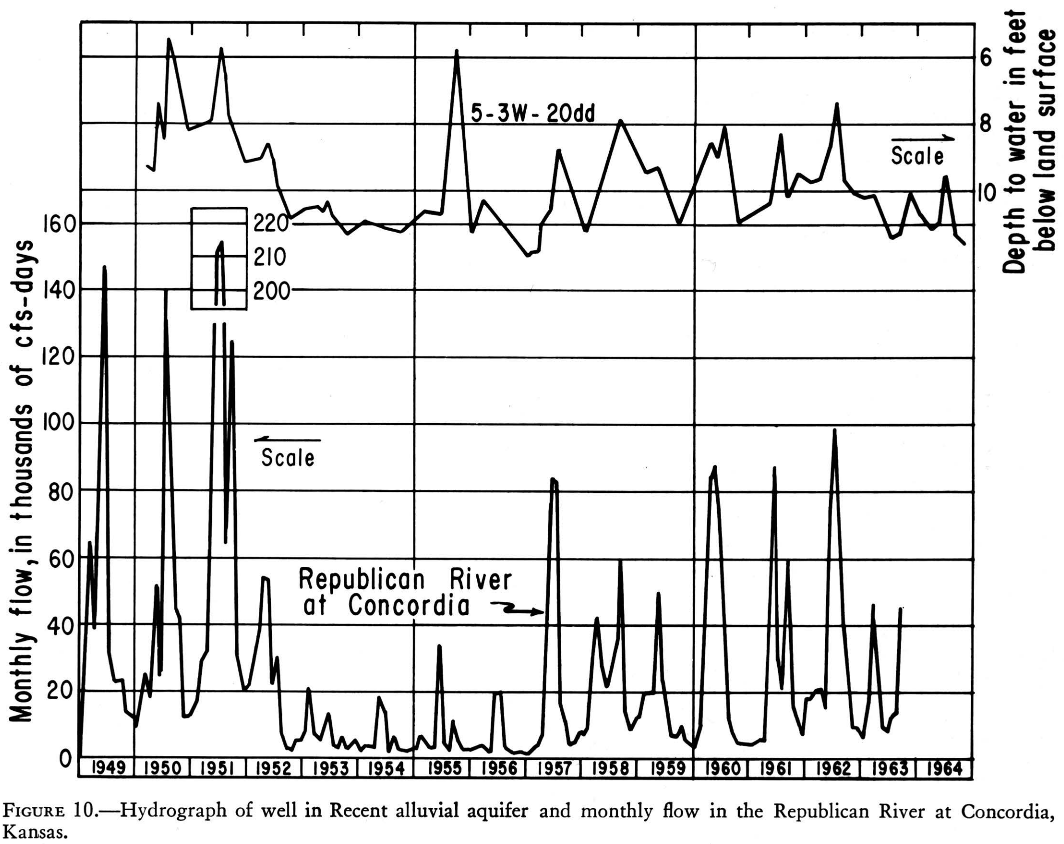

FIGURE 10.—Hydrograph of well in Recent alluvial aquifer and monthly flow in the Republican River at Concordia, Kansas.

north-central Kansas was 56 inches for the period 1959-63.

If the above figures are reasonable for north-central Kansas, there would be about 12,000 acre-feet of water used annually by trees along the river between Hardy and Concordia. There are as many trees along the upland drainages as there are along the river lowlands, so that the total estimated evapotranspiration by trees in the area is about 25,000 acre-feet or 0.4 inch annually between Hardy and Concordia. Because the trees obtain part of their water supply from soil moisture that never reaches the water table, only part of the 0.4 inch can be considered recharge.

Another estimate of the losses to evapotranspiration can be made from the base-flow data, considering that the effects of evapotranspiration are delayed in reaching the stream gage by 3 or 4 months and the difference in mean base flow between the growing and non-growing seasons might be the maximum losses to evapotranspiration in the basin. The base flow (mean of record) at Lovewell for the months of August through January averaged 5.81 cfs and for the months of February through July averaged 11.07 cfs. This difference, 5.26 cfs (or 0.2 inch), is the maximum loss. The difference at Endicott, Nebraska was 0.25 inch. Therefore, possibly 0.2 inch should be added to the 0.4 inch (Q_{80}) recharge between Hardy and Concordia. The recharge rate in the Republican River area, then, is probably 0.6 inch, as indicated by both methods.

It should be noted that the above computations are for near natural conditions and for the total drainage area. The recharge potential along the valley bottoms is greater than the upland areas because of more sandy soils in the valley bottoms. Therefore, the recharge is probably greater than 0.6 inch in the lowland areas and less than that figure in the upland areas.

Withdrawals of Water

In 1963 there were 86 irrigation wells in Republic County and 101 in Cloud County. There were 12,300 acre-feet of ground water pumped in the Republican River drainage area for irrigation and municipal use in 1963 (Fig. 11). Eight thousand acre-feet were withdrawn above the gage at Concordia. A small amount was pumped from the Kansan deposits in north-central Republic County, but most of the pumpage was from the alluvial deposits in the lowlands along the river.

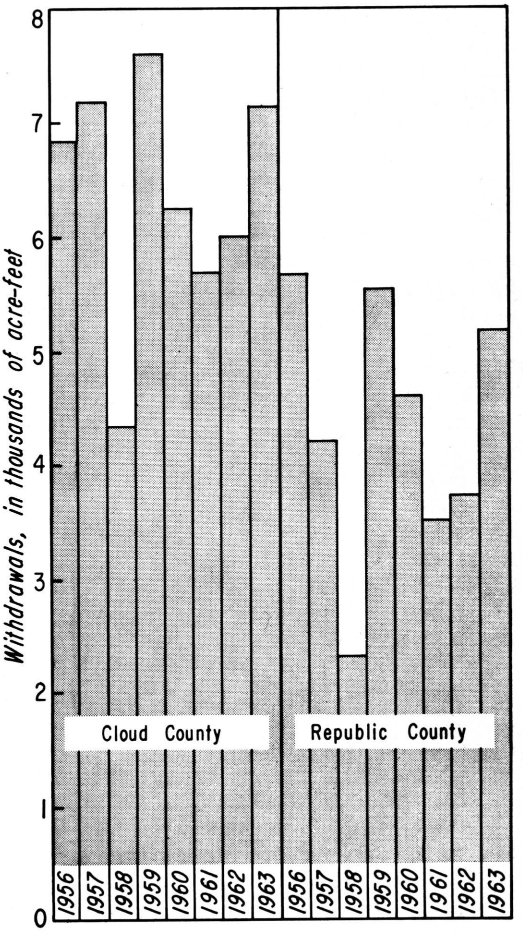

Figure 11.—Withdrawals of ground water in the Republican River drainage basin.

Effects of Pumping of Ground Water on Streamflow

In Kansas there is considerable ground water available along most of the major stream valleys. Several periods of deficient rainfall have prompted farmers in these areas to develop irrigation systems utilizing ground water. Some of the water pumped from the valley aquifers would have been naturally discharged to the streams, and where the pumping level has been lowered to a point below the level of the stream, water moves directly from the stream into the aquifer. Pumping from wells has resulted in the interception of water moving toward the stream and has caused the surface water to move into the aquifer, thus affecting the flow of the stream. The following is an estimate of this effect on the flow of the Republican River.

Theis (1941) presented a method of estimating the effect of pumping a well on the flow of a nearby stream. The formula originally given contains a complex series. Conover (1954) devised a chart (Fig. 12) that allows a simple graphical solution of the formula. The estimates given later are based on data obtained from field tests in the area as applied to the chart.

The following assumptions are necessary in the use of the above method: (1) that the aquifer is homogeneous and isotropic; (2) that the aquifer and the stream are in free communication with each other (the river bed contains a minimum of silt so that ground-water flow from the stream is not retarded); (3) that constant pumping rates are maintained throughout the periods of time chosen; (4) that the lowering of the water level does not change the transmissibility; and (5) that there is sufficient flow in the river to satisfy the demands of pumping during the periods of time chosen.

The information needed to use the chart (Fig. 12) is as follows: (1) the coefficient of transmissibility *(T)*, in gallons per day per foot, from Table 2; (2) the coefficient of storage *(S)*, assumed to be 0.2; (3) the distance *(a)* between the well and the stream, scaled from well-location map; (4) the time of pumping *(t)* in years, assumed; and (5) the pumping rate *(Q)*, in gallons per minute for each well reduced from the measured or reported rate by an assumed 20 percent to allow for return seepage from irrigation.

To use the diagram (Fig. 12), enter it either at the left or right with the distance from the stream *(a)*. Proceed upward to the right or downward to the left parallel to the diagonal lines to the intersection with the S/T ratio (top of diagram), then proceed horizontally across the diagram to the intersection with the time (bottom of diagram). Read the percent from the diagonal lines, interpolating between lines if necessary. For example: If a=0.15 mile, $S/T= 2\times10^{-6}$, and t=1 year, percent=91.

Using field data and the chart (Fig. 12), the percent of each well pumping rate supplied by the river was estimated at the end of 10, 20, 62, 124, 224, and 365 days. These percentages were entered in a table (not shown) and multiplied by the pumping rate of each well. The total quantities, in gallons per minute, obtained from the stream at the assumed times were computed and plotted on Figure 13.

In summary, if all the irrigation wells in the river valley between Hardy and Concordia were pumped continuously at a constant rate of 66,000 gpm, the quantities supplied by the river would be:

7,500 gpm at the end of 10 days;
12,200 gpm at the end of 20 days;
21,900 gpm at the end of 62 days;
and 38,500 gpm at the end of 1 year.

Between Concordia and the Clay county line, if the total pumping rate were 38,000 gpm, the quantities supplied by the river would be:

4,200 gpm at the end of 10 days;
6,900 gpm at the end of 20 days;
13,300 gpm at the end of 62 days;
and 24,700 gpm at the end of 1 year.

In 1963, a year of below-normal rainfall, the average time irrigators pumped was 22 days. Figure 13 shows about 13,000 gpm or 29 cfs was being removed from the stream between Hardy and Concordia at the end of 22 days.

The area under the curves in Figure 13 is the volume pumped from the river. This would be 710 acre-feet between Hardy and Concordia and 420 acre-feet between Concordia and the Clay county line, or a total of 1,130 acre-feet if all the wells were pumped for 22 days. If these figures are correct, about 7,000 acre-feet of the 8,000 acre-feet (page 13) pumped above the gage at Concordia was removed from ground-water storage during the irrigation season. Figures 8, 9, and 10, show a decline of water level in the lowlands since 1960. However, as the aquifer was assumed to be full and water rejected for the estimate of recharge (page 13), it is estimated that the 7,000 acre-feet will be replaced by precipitation and seepage from the river during periods of higher precipitation.

CHLORIDES IN GROUND WATER

Because of the history of high chloride content in water from irrigation wells in Cloud County, a sampling program has been established to determine any changes in amount of chloride (Table 3). The chloride content increases in one or two wells during the pumping season, but there is very little change in chloride content from year to year. However, seven or more wells have been abandoned for irrigation use, owing to high chloride content. Because the abandoned wells were not pumped, comparable water samples were not available, and the changes in chloride content are not known.

The Dakota Formation in most of northwestern Cloud County contains water high in chloride, 250 ppm (parts per million) or higher (Pl. 4). The water in the Dakota Formation moves into the Kansan and alluvial deposits (Fig. 14) in the subsurface, and therefore most of the Kansan deposits and the basal part of the alluvial deposits along the Republican River in Cloud

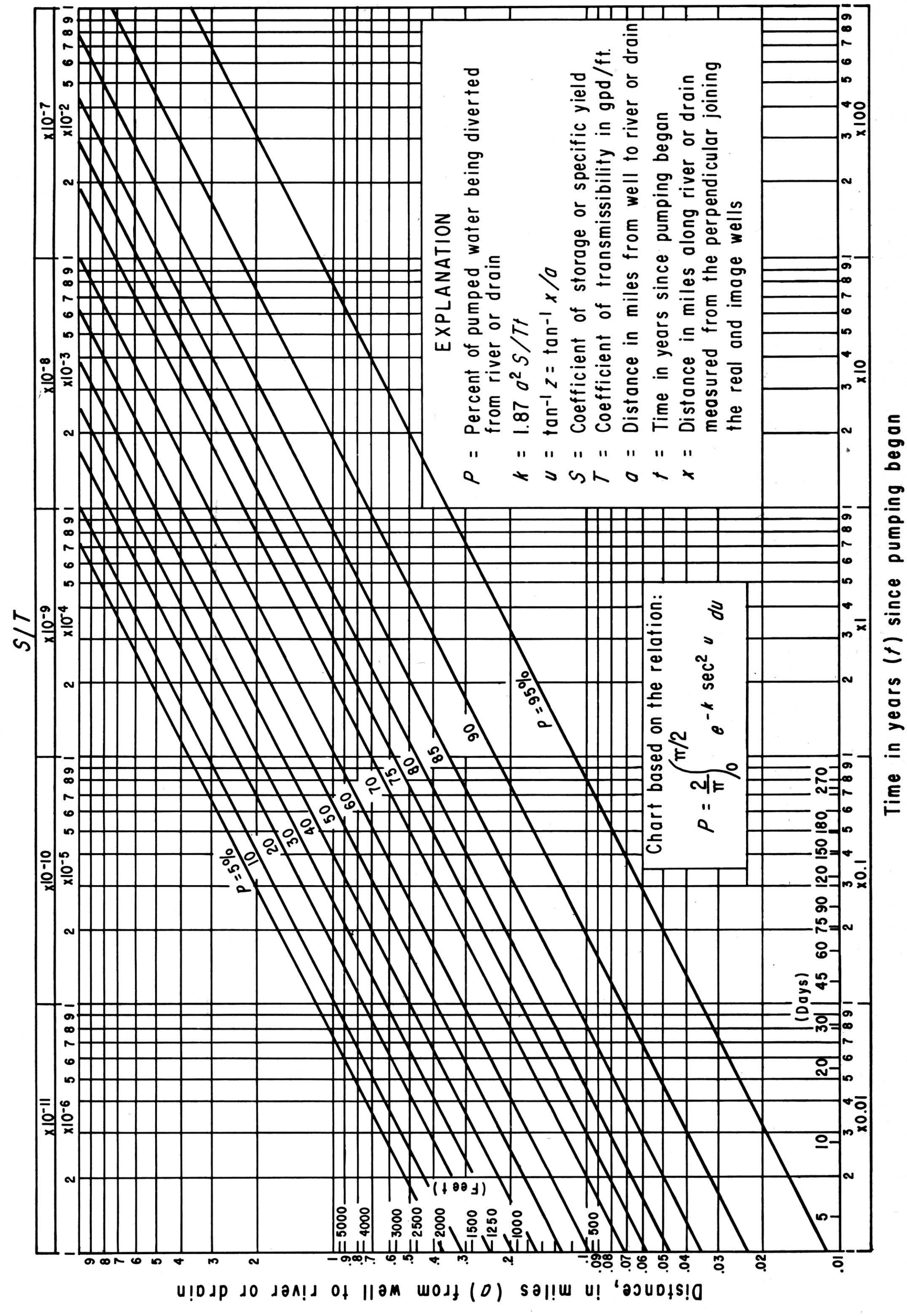

FIGURE 12.—Determination of percentage of pumped water being diverted from a river or drain. For explanation of terms see page 14. (After Conover, 1954.)

TABLE 3.—Chlorides in water from wells and springs in the Republican River area, Kansas.

Well number	Depth, ft	Water-bearing unit*	Date of sampling	Chloride, ppm
REPUBLIC COUNTY				
1-3W-3bc	212	Qd	8-30-62	12
4dd	111	Qd	7-30-42	26
10dd	80	Qd	7-30-42	18
18cc	171	Qd	7-30-42	14
1-4W-4ba	160	Qd	7-31-42	34
17dc	55	Qd	7-30-42	3
31bc	63	Qd	3-10-42	24
34ad	115	Qd	7-30-42	23
1-5W-6bb	?	Qa	7-30-42	18
14dc2	61	Qa	7-30-42	20
18ab	49	Qd	7- 1-63	30
18bb	75	Qd	7-30-42	25
20ab	160	Qd	6-27-63	36
2-4W-7dd	42	Qa	7-31-42	26
2-5W-2bd1	19	Qa	7-30-42	39
3-4W-9dd	69	Kg	7-31-42	57
17db	43	Qa	4-17-42	46
29da	13	Qa	7-31-42	118
32da	47	Qa	7-10-63	138
3-5W-13dd	56	Kg	7-31-42	78
16dd	67	Kc	8- 7-44	168
25bb	64	Kc	7-31-42	640
32bb	116	Kd	7-31-42	1,320
4-4W-4db	59	Qa	8-28-63	48
8ad	60	Qa	7- 9-63	90
8db	40	Qa	7- 9-63	30
8dd	51	Qa	7- 9-63	42
9ab	72	Qa	7-10-63	54
9ca	49	Qa	7- 9-63	90
10cb	44	Qi	7- 2-63	48
16dab	52	Qw	7- 9-63	36
17da	54	Qa	7- 2-63	66
4-4W-17dd	60	Qa	7- 9-63	72
21caa	66	Qw	7-10-63	42
21cab	66	Qw	7- 9-63	54
22ca	50	Qi	7- 2-63	30
22cc	56	Qi	7- 9-63	24
27ddc	59	Qw	6-19-63	43
			5-25-64	50
			7-20-64	24
29db	53	Qa	7-10-63	30
			7- 8-64	36
32cc2	35	Qa	7-31-42	18
33aa	53	Qa	7-10-63	42
			7- 8-64	48
33da	63	Qa	7-20-64	42
33dc	65	Qa	7-20-64	84
34baa	52	Qw	8-25-60	75
			7-10-63	30
			7- 8-64	36
34dbb	49	Qw	8-25-60	31
			8-25-61	40
			5-25-63	33
			7-20-64	36
4-5W-7cb	42	Kg	7-31-42	96
23bc	128	Kd	7-31-42	1,655
30ba	84	Kd	7-31-42	65
CLOUD COUNTY				
5-1W-15cc	200	Kd	7-21-64	54
26ad2	158	Kd	8- 4-54	19
30bc	-	Qa	6-18-63	24
30dcb1	71	Qa	8-15-61	645
30dcb2		Qa	5-25-64	126
			7-21-64	423
31ac	80	Qw	7-21-64	135
32bc	74	Qw	8-16-63	132
			5-25-64	51
			7-21-64	113
5-1W-32dc	90	Qw	8-16-63	54
			7-21-64	63
34ddd	60	Qw	1943	212
	100	Kd	1943	450
5-2W-15cb	40	Kd	6-18-63	46
19bc	93	Qw	6-20-63	243
			5-25-64	94
			7-21-64	243
19cbb	71	Qa	1943	2,450
20cca	45	Qa	7-21-64	45
21ad	50	Qa	8-27-63	182
21dd	64	Qa, Qk	8-27-63	510
			5-25-64	610
			7-21-64	370
22ca	55	Qa	7-21-64	144
25cb	65	Qw	8-15-61	65
25cc	72	Qw	1- -55	212
26add	80	Qw	1943	210
	99	Qw	1943	3,450
28daa	42	Qa	1943	23
	65	Qa	1943	1,300
	72	Qa	1943	1,340
	80	Qk	1943	2,650
28da1	57	Qa	5-25-64	572
			7-21-64	576
28da2	48	Qa	5-25-64	352
			7-21-64	387
29ddb	57	Qa	5-25-64	572
			7-21-64	576
29db	48	Qa	5-25-64	352
			7-21-64	387
30bcd	40	Qa	6-12-54	368
			8-15-61	765
			5-25-64	136
			7-21-64	792
31cc	43	Qd	8-15-63	18
32cb	50	Qw	8-16-63	30
			5-25-64	36
			7-21-64	45
5-2W-32db	54	Qw	8-16-63	24
			5-25-64	34
			7-21-64	41
34aab	81	Qw	8-29-63	90
			5-25-64	50
			7-21-64	99
36bc	40	Qw	6-18-63	26
5-3W-15ab	341	Kd	10-18-55	16,000
17abc	100	Qi	8-25-60	468
			8-15-61	390
			7- 6-64	138
			7-20-64	372
18bbb	100	Qi	6-18-54	44

TABLE 3.—Chlorides in water from wells and springs in the Republican River area, Kansas *(continued)*.

Well number	Depth, ft	Water-bearing unit*	Date of sampling	Chloride, ppm	Well number	Depth, ft	Water-bearing unit*	Date of sampling	Chloride, ppm
19bb1	90	Kd	1943	19	5-4W-7bd1	110	Kd	6-27-63	660
	121	Kd	1943	850	7dd	39	Qw	6-25-63	120
	127	Kd	1943	1,900	8ad	20	Qw	6-20-63	238
19cb	67	Qa	9- 8-54	17	8bc	40	Qw	6-25-63	198
19ddd	52	Qa	1943	21	8cc	25	Qw	6-25-63	144
	67	Kd	1943	26	8dad	60	Qw	8-15-61	200
20bbc	70	Qa	1943	58				8-14-63	210
	80	Qk	1943	413				7-21-64	198
	107	Qk	1943	3,760	8dda	60	Qw	8-15-61	80
21ca	50	Qa	8-29-63	24				7-21-64	150
21cbc	50	Qw	1943	59	9cca	75	Qw	5-13-60	35
	71	Qw	1943	880				8-25-60	13
21dd	47	Qw	1943	48				8-24-63	30
	63	Qw	1943	89				5-25-64	32
	84	Qk	1943	2,880	10ba	54	Qw	8-25-60	31
22bad	35	Qi	1943	230	11ad1	39	Qw	7-20-64	18
	71	Qi	1943	2,335	11ad2	38	Qw	7-20-64	36
22bcc	45	Qw	1943	167	13bbb	39	Qw	1943	25
	50	Qw	1943	388		44	Qw	1943	43
	60	Qw	1943	1,160	13bd	40	Qw	8-15-61	35
	87	Qk	1943	13,750				5-25-64	18
22dcb	35	Qa	1943	331				7- 8-64	24
	65	Qa	1943	6,350				7-20-64	38
24dc	55	Qa	7-21-64	63	13dad	53	Qw	8-15-61	85
25db	48	Qa	5-25-64	108				8-23-63	90
			7-21-64	63				7- 7-64	60
								7-20-64	90
5-3W-28bac	36	Qa	1943	21	14aa	33	Qw	7-20-64	30
	70	Qk	1943	86	14abb	56	Qw	1943	47
	103	Qk	1943	4,360	14da	48	Qw	5-25-64	27
28bb	51	Qa	5-24-43	23				7-20-64	36
28bbb	50	Qa	1943	22	15aba	69	Qa	5-13-60	95
28bbc	50	Qa	1943	27				8-25-60	75
28bbd	42	Qa	1943	20				8-15-61	78
	52	Qa	1943	30				5-25-64	112
	74	Qa	1943	228				7-21-64	72
	107	Qk	1943	5,040	15cad	72	Qa	5-13-60	287
28bbd2	20	Qa	1943	14				8-25-60	200
	40	Qa	1943	22				8-15-61	300
	51	Qa	1943	27				7-10-63	390
	76	Qk	1943	1,400				8-11-63	414
29aac	94	Qk	1943	3,500					
29bbc	61	Qa	1943	45	5-4W-15cad			5-25-64	336
31bb	37	Qa	6- 3-54	80				7-21-64	420
32aa1	50	Qa	1- 2-45	72	15da	70	Qa	8-25-60	144
32aa2	50	Qa	1945	80				8-15-61	170
32aa3	50	Qa	8- 4-54	110				7-18-63	152
35abc	65	Qa	8-15-61	85				7-21-64	270
			8-25-63	72	15ddd	65	Qw	1943	450
			5-25-64	30		117	Qk	1943	1,240
			7-21-64	90	16bd	83	Qw	5-13-60	100
36ab	85	Qa	8-15-61	65				8-25-60	94
			8-16-63	85				8-15-61	100
			5-25-64	50				7-21-64	90
			7-21-64	54	16ca	85	Qw, Qi	5-13-60	435
36bb	74	Qa	8-15-61	110				8-25-60	440
			8-25-63	84				8-15-61	485
			5-25-64	34				7- -63	378
			7-21-64	81				7- -63	498
								7- -63	696
5-4W-2bb	....	Qw	7-20-64	18				5-25-64	680
2ca1	48	Qw	6- 9-64	30	16cb	45	Qw	5-13-60	75
3abd	59	Qw	8-25-60	44				8-25-60	75
			8-15-61	40				8-15-61	125
3dd	68	Qw	8-23-63	24				8-24-63	84
4aac	64	Qw	7-20-64	72				5-25-64	76
5cb	33	Qw	6-25-63	42				7-21-64	96

TABLE 3.—Chlorides in water from wells and springs in the Republican River area, Kansas *(concluded)*.

Well number	Depth, ft	Water-bearing unit*	Date of sampling	Chloride, ppm	Well number	Depth, ft	Water-bearing unit*	Date of sampling	Chloride, ppm
16dc	25	Qw	8-20-63	42	21bd2	24	Qw	6-25-63	354
			7-21-64	60				7-21-64	432
16dd	60	Qw	5-13-60	37	21db	....	Qw	6-25-63	450
			8-25-60	75	22ab	68	Qw	5-13-60	100
			8-15-61	145				8-25-60	167
			8-22-63	78				8-15-61	155
17aa	64	Qw	5-13-60	81				8-14-63	150
			8-25-60	100				7-21-64	150
			8-15-61	130					
			8-24-63	132	5-5W-4aab	80	Kd	11- 5-53	205
			5-25-64	100		160	Kd	11-17-53	16,400
			7-21-64	138		402	Kd	11-17-53	17,800
18bb1	54	Qi	6-25-63	132	4bb	53	Qk	10-30-53	9,310
18bb2	60	Kd	6-25-63	282	7cc	55	Qk	5-18-54	1,150
18bc	47	Qi	6-25-63	138	11ad	168	Kd	6-27-63	60
					12ad	130	Kd	6-28-63	300
5-4W-18cb	60	Qi	6-25-63	78	12bc1	40	Qi	6-28-63	96
18dd	48	Kd	6-25-63	498	22da	140	Qi	7- 7-53	43
19ad	50	Qi	6-25-63	474	24dd	57	Qk	5-20-54	28
19da	36	Qi	6-25-63	564					
20bb	49	Qi	6-25-63	552	6-1W-2ca	84	Qw, Kd	8-26-63	18
21ba	59	Qw	5-13-60	112	3aa	41	Qa	6-15-54	21
			8-25-60	206		77	Qk	6-15-54	19
			8-15-61	260	4bc2	86	Qw	8-27-63	42
			8-22-63	282	10cc	87	Kd	3- 4-54	13
			5-25-64	70	12ab	63	Qw	8-26-63	24

* *Qd*, Pleistocene deposits, undifferentiated; *Qa*, Recent alluvium; *Qw*, Wisconsinan terrace deposits; *Qi*, Illinoisan terrace deposits; *Qk*, Kansan deposits; *Kd*, Dakota Formation; *Kg*, Greenhorn Limestone; *Kc*, Carlile Shale.

County contain brackish water. In some areas (Pl. 4) along the Republican River, water from some wells contains more chloride than is tolerable for irrigation and other uses.

Diagrammatic sections for an area west of Concordia are presented in Figure 14. The brackish water is flowing into the area from the west almost parallel to cross section E-E′. As the wells in sec. 16, 17, and 20, T 5 S, R 4 W, are pumped, the brackish water moves northward and upward into the wells, and the chloride content of water from the southernmost wells in section D-D′ will increase. However, the Republican River, which normally contains water of low chloride content, recharges the aquifer when the water level in wells is lowered below the river level. This provides water of low chloride content to the wells near the river; whereas, the water from the river is intercepted by pumping wells before reaching the southernmost wells. Thus, the southernmost wells pick up the brackish water from the lower parts of the aquifers.

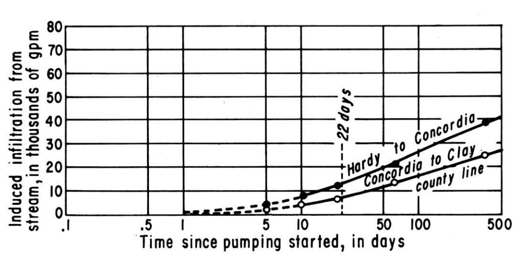

FIGURE 13.—Quantity of water supplied by streams to wells in the valley alluvium.

In the area northeast of Concordia, brackish water from the Dakota Formation moves from the north into the alluvial deposits in the subsurface. This underflow accounts for the high chloride content in the alluvial deposits in T 5 S, R 3 W. East of Salt Creek the underflow is less brackish. As the brackish water moves eastward along the bottom of the valley alluvium, recharge from rainfall and the less brackish underflow from the north and south dilutes the brackish water, and only a small amount of brackish water occurs as a narrow strip in T 4 S, Rs 1 and 2 W. In general, most of the Kansan deposits in the Republican River valley in Cloud County contain brackish water. Thus, very few irrigation wells are drilled into these deposits. Thin clay layers in the lower parts of the alluvial deposits above the Kansan deposits may retard the upward movement of brackish water, provided the wells do not penetrate the clay layers.

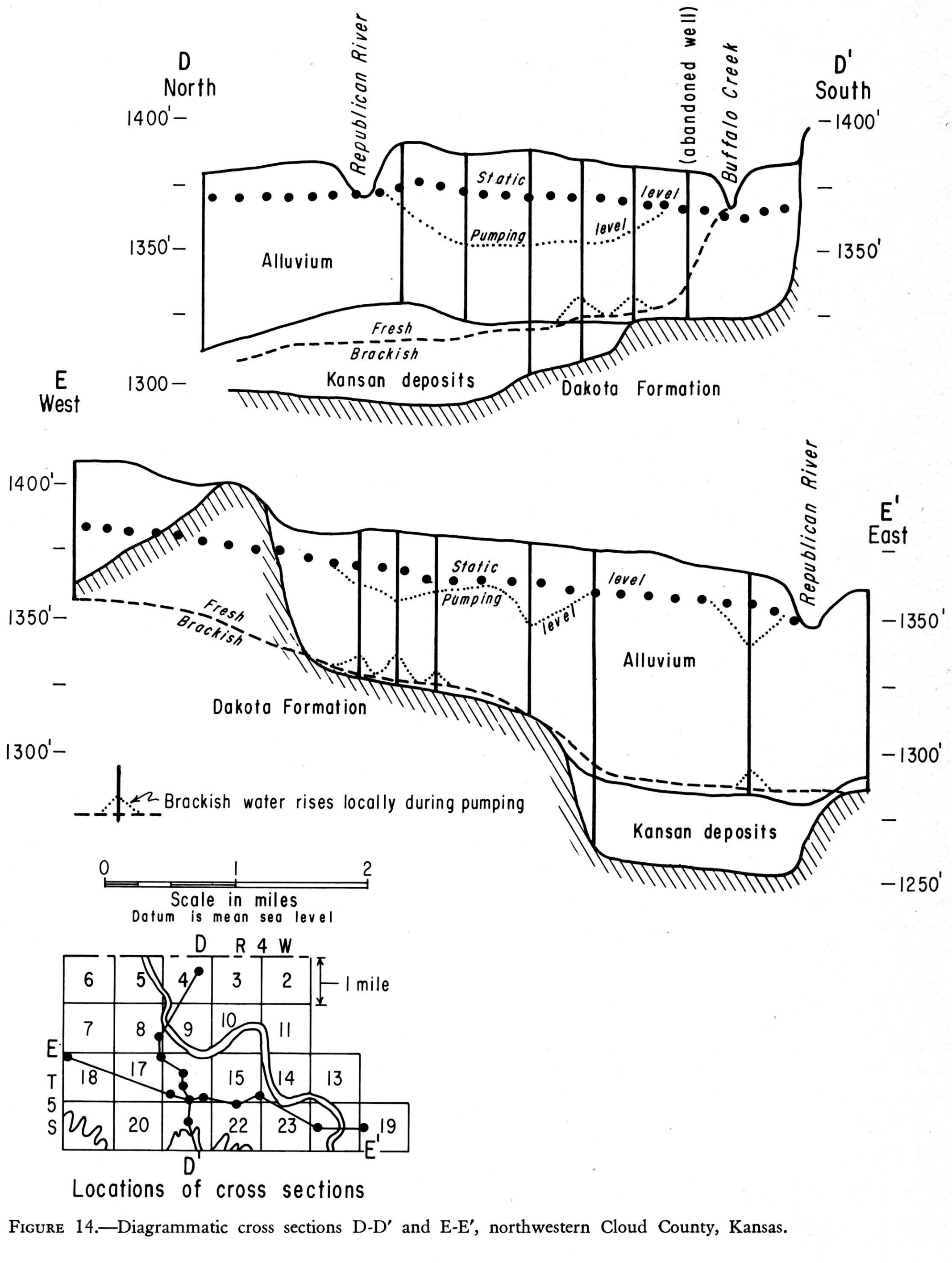

FIGURE 14.—Diagrammatic cross sections D-D′ and E-E′, northwestern Cloud County, Kansas.

SUMMARY AND CONCLUSIONS

The Republican River area is divided into two general categories in relationship to the ground-water aquifers. In the lowland areas, large quantities of water are available from the alluvial deposits. In the upland areas, water can be obtained from silts, clays, and silty gravels of Pleistocene age overlying the Cretaceous rocks or from the Cretaceous rocks. However, the application of surface-water irrigation has raised the water level in some of the upland areas causing flooding of pump pits at well sites and waterlogging of fields. Only the upper part of the Cretaceous material yields water suitable for most uses, as the water becomes more saline with depth.

Data from aquifer tests indicate that the coefficient of transmissibility ranges from 10,000 to 320,000 gpd/ft and the coefficient of permeability ranges from 800 to 6,300 gpd/ft^2. Coefficient of storage was not determined from the short aquifer tests but was assumed from experience in other areas.

Water levels dropped in the upland areas during the period 1953-56, rose with increased precipitation during the period 1956-58, and rose considerably in the areas irrigated by surface water after 1958. Waterlogging has occurred in some of those areas. Water levels in the lowland areas fluctuate with the rate of discharge of the Republican River and with the local pumping rate.

The alluvial deposits above the Kansan deposits contain about 580,000 acre-feet of water in storage. If water levels are drawn down due to pumping, the aquifers become thin and no longer yield sufficient water for irrigation. Therefore, part of the water in storage is unavailable for irrigation.

Recharge from precipitation was computed from streamflow records to be about 0.6 inch per year over the area. An estimated 0.2 inch is lost to evapotranspiration before reaching the streams. Recharge in the lowland areas is probably greater than in the upland areas.

Withdrawal of ground water in the lowlands was 7,600 acre-feet in 1958 and 12,300 acre-feet in 1963. The theoretical quantity of water removed from the Republican River by the pumping of ground water between Hardy and Concordia was computed to be 710 acre-feet in 1963.

Chlorides in irrigation water are a problem in northern Cloud County. However, suitable water can be obtained from aquifers, which are stratigraphically higher than Kansan deposits, in most of the lowland areas.

RECOMMENDATIONS

The following recommendations are included so that sufficient data will be available for future analyses of the hydrology of the area, either by the digital computers, electronic analog models, or other methods. These types of analyses were beyond the scope of this report or the need for additional data was recognized too late to be included in the study.

The measurement of water levels in the area should be continued at the present intervals with the same areal coverage. However, four or five additional observation wells should be drilled along the upland on the east side of the Republican River for the purpose of comparing fluctuations of water levels in similar geologic formations outside the area of influence of the irrigation by surface water. The approximate locations of these wells, depending on the geology found when drilled, should be:

NW sec. 34, T 1 S, R 4 W;
NW sec. 16, T 2 S, R 4 W;
NW sec. 10, T 3 S, R 4 W;
and SE sec. 2, T 4 S, R 4 W.

The measurement program of the low flows of the Republican River between Hardy and Concordia should be extended so that more accurate estimates of gains or losses in this reach are available. This may include an investigation by statistical methods as to the type or types of field data needed.

The collection of data on the chlorides in water should be continued on the present annual monitoring basis.

LOGS OF WELLS AND TEST HOLES

Logs of 22 test holes drilled in the Republican River area were selected to represent the different types of materials encountered. Eleven of these test holes were drilled by the State and Federal Geological Surveys and are headed "Sample log of test hole augered. . . ." These test holes were logged by the author during drilling. Nine of the test holes were drilled and logged by the U.S. Bureau of Reclamation; these are headed "Log of test hole drilled by U.S. Bureau of Reclamation. . . ." The remaining test holes were drilled and logged by commercial well drillers and are headed "Driller's log of test hole drilled by. . . ."

1-3W-5bc.—Driller's log of test hole in SW NW sec. 5, T 1 S, R 3 W near center of NW¼ sec.; drilled by Don Barney for Edwin Tientjen, June 1958. Altitude of land surface, 1,662 feet.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series, undifferentiated		
Loam	2	2
Clay, yellowish-brown	7	9
Clay, brown	8	17
Sand, brown, clay	6	23
Clay, brown	39	62
Sand, fine	23	85
Clay	1	86
Sand, fine	7	93
Clay, gray	14	107
Clay, brown, soft	6	113
Clay, brown	9	122
Sand, fine, and gravel	96	218
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Carlile Shale		
Shale, black	2	220

1-4W-31cc (U.S.B.R. 164).—Log of test hole in SW SW sec. 31, T 1 S, R 4 W, 50 feet north and 350 feet east of SW cor. sec.; drilled by U.S. Bureau of Reclamation, October 1957. Altitude of land surface, 1,496 feet.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series		
Illinoisan Stage		
Crete and Loveland formations		
Silt	5	5
Sand, fine, slight amount silt	3	8
Silt	12	20
Silt and fine sand	2	22
Sand, fine, clean; loose	4	26
Sand, fine to coarse; loose	10	36
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Carlile Shale		
Shale, blue; firm	2+	38+

1-4W-31dc.—Sample log of test hole in SW SE sec. 31, T 1 S, R 4 W, 20 feet north and 100 feet east of S¼-cor. sec.; augered, November 29, 1962. Altitude of land surface, 1,514 (estimated) feet.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series		
Illinoisan Stage		
Crete and Loveland formations, undifferentiated		
Topsoil, black	4	4
Clay, bluish-black	2	6
Clay, tan	5	11
Clay, silty, tan	9	20
Kansan Stage		
Grand Island and Sappa formations, undifferentiated		
Clay, silty, dark-brown	4	24
Sand, fine to medium, tannish-brown	2	26
Clay, brownish-red	3	29
Gravel and clay strips	6	35
Sand, coarse, tan	5	40
Sand, coarse, and pea-sized gravel	4	44
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Carlile Shale		
Shale, bluish-black, hard	1	45

1-5W-9ddd.—Sample log of test hole in SE SE SE sec. 9, T 1 S, R 5 W, 20 feet north and 30 feet west of SE cor. sec.; augered, June 1963. Altitude of land surface, 1,501 feet.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series		
Recent Stage (alluvium)		
Sand, fine, silty, tannish-brown	5	5
Sand, coarse, tan	5	10
Sand and gravel, bluish-gray	8	18
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Carlile Shale		
Shale, black; drilled hard	1+	19+

1-5W-10aaa.—Sample log of test hole in NE NE NE sec. 10, T 1 S, R 5 W, 40 feet south and 35 feet west of NE cor. sec.; augered, June 1965. Altitude of land surface, 1,550 (estimated) feet.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series		
Wisconsinan and Illinoisan stages		
Peoria and Loveland formations, undifferentiated		
Topsoil, brown	1	1
Clay, silty, black	5	6
Clay, silty, brown	2	8
Pleistocene fluvial deposits, undifferentiated		
Sand, coarse, brownish-tan; hard to drill	13	21
Sand and pea-sized gravel, tannish-brown	4	25
Clay, gravel, and sand layers, blue	2	27
Sand, coarse, and gravel, blue; with some clay	15	42
Gravel, and blue clay; drilled hard	21	63
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Carlile Shale		
Shale, black	2+	65+

1-5W-16ccc.—Log of test hole in SW SW SW sec. 16, T 1 S, R 5 W, near SW cor. sec.; drilled by U.S. Bureau of Reclamation, May 1961. Altitude of land surface, 1,510 feet.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series, undifferentiated		
Silt, dark-brown; drilled easy	5	5
Silt, light-brown; drilled easy	4	9
Clay, silty, dark-gray; drilled easy	3	12
Clay, silty, light-gray; drilled easy	3	15
Sand, very fine, gray; loose	8	23
Sand, fine to medium, gray; loose	10	33
Sand, fine to coarse, bluish-gray; loose	5	38
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Carlile Shale		
Shale, blue; firm	2+	40+

1-5W-36dc (U.S.B.R. 163 F).—Log of test hole in SW SE sec. 36, T 1 S, R 5 W, 100 feet north and 1,180 feet west of SE cor. sec.; drilled by U.S. Bureau of Reclamation, January 1958. Altitude of land surface, 1,486 feet.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series		
Illinoisan Stage		
Crete and Loveland formations		
Silt	4	4
Sand, fine, silty; loose	2	6
Silt	1	7
Sand, fine, silty; loose	1	8
Silt; small amount fine sand	9	17
Silt	1	18
Clay, silty, compact	1	19
Sand, fine; small amount silt	1	20
Silt	2	22
Sand, fine, silty	3	25
Sand, fine to coarse; loose	3	28
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Carlile Shale		
Shale, blue; firm	2	30

1-5W-35dd (U.S.B.R. 162 B).—Log of test hole in SE SE sec. 35, T 1 S, R 5 W, 100 feet north and 160 feet west of SW cor. sec.; drilled by U.S. Bureau of Reclamation, 1957. Altitude of land surface, 1,478 feet.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series		
Recent Stage (alluvium)		
Sand, very fine, silty; loose	2	2
Sand, very fine, some silt; loose	2	4
Sand, fine	7	11
Sand, fine to coarse; loose	6	17
Sand, fine to coarse; silty, small pieces weathered shale	7	24
Sand, fine to coarse, some small gravel, small pieces weathered shale	2	26
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Carlile Shale		
Shale, blue; firm	2	28

2-4W-5bbb.—Sample log of test hole in NW NW NW sec. 5, T 2 S, R 4 W, 20 feet south and 15 feet east of NW cor. sec.; augered, June 1963. Altitude of land surface, 1,545 (estimated) feet.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series		
Wisconsinan and Illinoisan stages		
Peoria and Loveland formations, undifferentiated		
Silt, tan	10	10
Clay, silty, tannish-yellow	6	16
Sand, very fine, tannish-white; drilled hard	9	25
Sand, medium, tan	9	34
Sand, medium, silty; grayish-tan	5	39
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Carlile Shale		
Shale, sandy, black; drilled hard	2+	41+

2-5W-1ba (U.S.B.R. 163).—Log of test hole in NE NW sec. 1, T 2 S, R 5 W, 10 feet south and 1,300 feet east of NW cor. sec.; drilled by U.S. Bureau of Reclamation, 1957. Altitude of land surface, 1,476 feet.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series		
Recent Stage (alluvium)		
Sand, very fine, silty; loose	5	5
Sand, fine; loose	3	8
Sand, fine to medium; loose	11	19
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Carlile Shale		
Shale, blue; firm	2	21

2-5W-20aa.—Log of test hole in NE NE sec. 20, T 2 S, R 5 W, near NE cor. sec.; drilled by U.S. Bureau of Reclamation, 1955. Altitude of land surface, 1,554 feet.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series		
Wisconsinan and Illinoisan stages		
Peoria and Loveland formations, undifferentiated		
Silt, clayey, dark-brown	2	2
Clay, silty, brown	1	3
Silt, light-gray, rusty streaks	8	11
Silt, dark-brown	5	16
Clay, silty, light grayish-brown	9	25
Clay, silty, brown	4	29
Pleistocene deposits, undifferentiated		
Clay, light-yellow, and weathered shale	11	40

3-4W-8cc3.—Sample log of test hole in SW SW sec. 8, T 3 S, R 4 W, 100 feet northeast of well 8cc1; augered, November 1962. Altitude of land surface, 1,437 feet.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series		
Recent Stage (alluvium)		
Topsoil, black	2	2
Sand, coarse, brown	20	22
Sand, coarse, and gravel, bluish-gray	27	49
Clay, blue	1+	50+

3-5W-16bb.—Log of test hole in NW NW sec. 16, T 3 S, R 5 W, near NW cor. sec.; drilled by U.S. Bureau of Reclamation, 1956. Altitude of land surface, 1,511 feet.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series		
Wisconsinan and Illinoisan stages		
Peoria and Loveland formations, undifferentiated		
Clay, dark-brown	2	2
Clay, dark-gray	2	4
Silt, light rusty-brown	7	11
Pleistocene deposits, undifferentiated		
Clay, dark-gray	5	16
Clay, light-brown	12	28
Clay, silty, light-brown	7	35
Clay, yellowish-brown	13	48
Chalk, weathered, yellow	18	66
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Carlile Shale		
Shale, blue	1+	67+

3-5W-20ad.—Log of test hole in SE NE sec. 20, T 3 S, R 5 W, near E¼ cor. sec.; drilled by U.S. Bureau of Reclamation, 1961. Altitude of land surface, 1,499 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
Wisconsinan and Illinoisan stages		
Peoria and Loveland formations, undifferentiated		
Clay, silty, dark-brown	4	4
Silt, light grayish-brown, rusty streaks	6	10
Clay, silty, reddish-brown	25	35
Clay, yellow, and chalk fragments	1	36
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Greenhorn Limestone		
Chalk, weathered, yellow	1+	37+

4-4W-4dc2.—Sample log of test hole in SW SE sec. 4, T 4 S, R 4 W, 0.1 mile north and 0.1 mile east of S¼ cor. sec.; augered, November 1962. Altitude of land surface, 1,431 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
Wisconsinan Stage (terrace deposits)		
Topsoil	5	5
Clay, silty, black	9	14
Clay, silty, tan	2	16
Silt, tan, and fine sand	7	23
Sand, fine, silty, grayish-tan	7	30
Sand, medium to coarse, silty, gray	10	40
Sand, coarse, gray	5	45
Sand, coarse, and fine gravel, gray	5	50
Gravel and coarse sand, gray	17	67
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Graneros Shale		
Shale, yellowish-brown; drilled hard	6+	73+

4-4W-21cab.—Driller's log of test hole in NW NE SW sec. 21, T 4 S, R 4 W; drilled by Ben Lervold, at irrigation well for Lloyd Blosser, April 1954. Altitude of land surface, 1,412 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
Wisconsinan Stage (terrace deposits)		
Loam	8	8
Clay and sand	14	22
Gravel, medium, and sand	8	30
Gravel, coarse	38	68
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Graneros Shale		
Clay, blue	22	90+

4-4W-30cc.—Sample log of test hole in SW SW sec. 30, T 4 S, R 4 W, 160 feet north and 30 feet east of SW cor. sec.; augered, November 1962. Altitude of land surface, 1,424 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
Recent Stage (alluvium)		
Topsoil (and road fill), black	10	10
Clay, brown	2	12
Clay, silty, brown	8	20
Clay, brown, and silty clay layers	7	27
Sand, fine, brown	1	28
Clay, brown, and silty clay layers	11	39
Clay, silty, brown	27	66
Clay, silty, brown; drilled hard	4	70
Clay, silty brown; layers of fine yellow sand	8+	78+

4-5W-16cc.—Log of test hole in SW SW sec. 16, T 4 S, R 5 W, near SW cor. sec.; drilled by U.S. Bureau of Reclamation, 1956. Altitude of land surface, 1,500 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
Wisconsinan and Illinoisan stages		
Peoria and Loveland formations, undifferentiated		
Silt, brown	5	5
Clay, silty, brown	3	8
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Greenhorn Limestone		
Chalk, weathered, yellow; some hard layers	14+	22+

4-5W-19bbb.—Sample log of test hole in NW NW NW sec. 19, T 4 S, R 5 W, 30 feet south and 35 feet east of NW cor. sec.; augered, June 1963. Altitude of land surface, 1,396 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series, undifferentiated		
Topsoil, black	2	2
Clay, tan, silty; drilled hard	8	10
Clay and fine silty sand layers	9	19
Clay, blue	3	22
Silt, bluish-gray, clayey	12	34
Clay and silt, bluish-gray	7	41
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Graneros Shale		
Sandstone and shale, blue	2+	43+

4-5W-32da.—Sample log of test hole in NE SE sec. 32, T 4 S, R 5 W, 35 feet south and 35 feet west of E¼-cor. sec.; augered, June 1963. Altitude of land surface, 1,395 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series, undifferentiated		
Topsoil, black	2	2
Clay, silty, gray	3	5
Silt, sandy, brown	3	8
Silt, gray	4	12
Sand, very fine, gray	4	16
Silt, gray	4	20
Silt, brown, and fine sand layers	7	27
Clay, brown	5	32
Silt and very fine sand	6	38
Sand, very fine, silty, brownish-tan	14	52
Silt, gray	7	59

	Thickness, feet	Depth, feet
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
Graneros Shale		
Shale, blue; drilled hard	4+	63+

5-4W-26bc.—Sample log of test hole in SW NW sec. 26, T 5 S, R 4 W, 60 feet east of W¼ -cor. sec.; augered, November 1962. Altitude of land surface, 1,375 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
Wisconsinan Stage (terrace deposits)		
Topsoil, black	5	5
Sand, fine, brown	3	8
Clay, gray	2	10
Sand, fine, brown	8	18
Clay, silt, and fine sand, gray	5	23
Silt and fine sand, gray	7	30
Sand, very fine, silty, brown	5	35
Sand, very fine, silty, bluish-gray	13	48
Sand, coarse, and fine gravel	3	51
CRETACEOUS SYSTEM		
Lower (?) Cretaceous Series		
Dakota Formation		
Shale, weathered, blue	4	55
Shale, blue	2+	57+

5-5W-2cd.—Sample log of test hole in SE SW sec. 2, T 5 S, R 5 W, 30 feet north and 0.45 mile west of SE cor. sec.; augered, June 1962. Altitude of land surface, 1,432 (estimated) feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
Wisconsinan Stage (terrace deposits)		
Topsoil, black, and silty clay loam	3	3
Clay, silty, tan	8	11
Sand, very fine, silty, clayey; some sandstone chips, tannish-white	7	18
Clay, brown, hard	1	19
Silt and sand, very fine, tan	8	27
Clay and silt layers	3	30
Silt and very fine sand, tan	3	33
Silt and very fine sand, tan; some layers drilled hard	4	37
CRETACEOUS SYSTEM		
Lower (?) Cretaceous Series		
Dakota Formation		
Clay, blue, and tan sandstone stringers	5+	42+

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INDEX