Geology and Ground-Water Resources of Fillmore County, Nebraska

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1839-L

Prepared in cooperation with the State of Nebraska, Conservation and Survey Division, University of Nebraska

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By C. F. KEECH *and* V. H. DREESZEN

With a section on CHEMICAL QUALITY OF THE WATER

By L. R. PETRI

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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GEOLOGY AND GROUND-WATER RESOURCES OF FILLMORE COUNTY, NEBRASKA

By C. F. Keech and V. H. Dreeszen

ABSTRACT

Fillmore County, an area 24 miles square, lies in the eastern part of the Nebraska loess plain. Although tributaries of the Big Blue River have eroded valleys into this plain, much of the original surface is intact. Broad flats and numerous shallow undrained depressions characterize the plain.

The county is underlain by unconsolidated deposits of Quaternary age to depths ranging from about 80 to 450 feet. The upper part of this depositional sequence consists largely of wind-deposited clayey silt, and the lower part of stream-deposited sand and gravel. In part of the county, deposits of glacial till also are included. The Quaternary deposits mantle an eroded surface of marine-deposited strata of Cretaceous age.

The lower deposits of Quaternary age are saturated and constitute a highly productive aquifer throughout much of the county. The saturated zone ranges from about 20 to 350 feet in thickness. Replenishment to this aquifer, derived principally from precipitation, is believed to average about 1.4 inches per year. Because the quantity of ground water pumped per year exceeds the average annual quantity of recharge, some of the water used for irrigation is from storage. Consequently, water levels in wells are declining. This trend is likely to continue.

The ground water is of the calcium bicarbonate type and is hard, but it is chemically suitable for irrigation use on most soils in the county.

INTRODUCTION

PURPOSE OF THE INVESTIGATION AND DEVELOPMENT OF GROUND WATER

Lowered water levels in wells and attendant increases in pumping lift have resulted from continued use of ground water for irrigation in parts of Fillmore County. (See fig. 1.) Some county residents are concerned that the ground-water supply is, or will soon be, over-developed. This report, describing the occurrence, chemical character, present use, and potential for development of the ground-water sup-

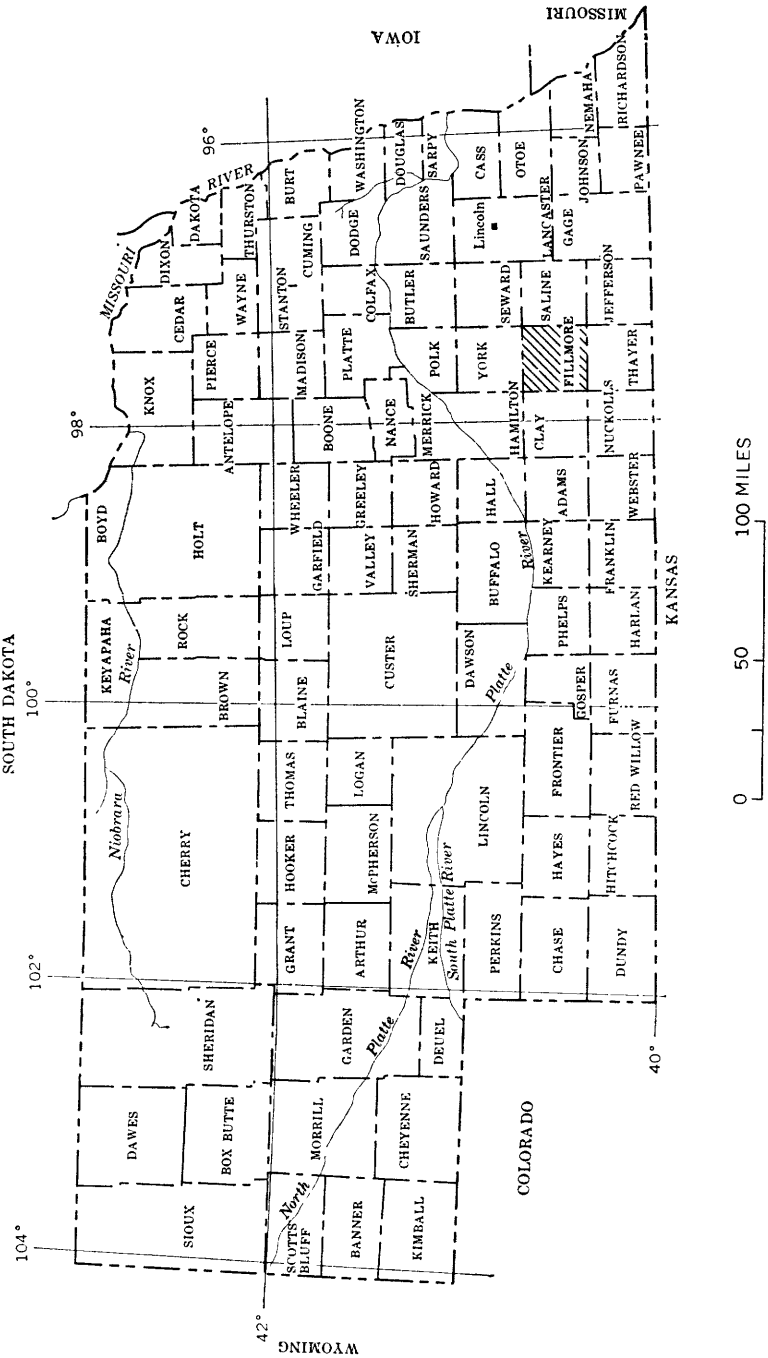

FIGURE 1.—Location of Fillmore County.

plies of the county, provides information that is needed by water managers. Most of the data on which this report is based have been published under the titles "Wells in Fillmore County," "Logs of test holes in Fillmore County," and "Water Levels in Observation Wells in Nebraska," and copies of these reports may be obtained from the Conservation and Survey Division, University of Nebraska, Room 113, Nebraska Hall, Lincoln, Nebr. The collection of data and the writing of this interpretive report together constitute a unit in the program of ground-water studies made cooperatively by the Conservation and Survey Division of the University of Nebraska and the U.S. Geological Survey.

Wide level expanses of fertile soils and a large store of fresh ground water are the principal natural assets of Fillmore County. After Congress in 1862 passed the Homestead Act, which provided for sale of public lands in 160-acre tracts, the soil resources of Fillmore County were developed rapidly; however, for many years after the county had been completely settled, ground water was withdrawn only for domestic and livestock use. Not until the "great drought" of the 1930's caused widespread crop failures were serious attempts made to supplement the deficient precipitation. Even though the first irrigation wells were successful, the drilling of wells for this purpose proceeded at a slow pace, and by 1954 only 100 irrigation wells had been drilled. Then the need for water during a succession of dry years in the mid-1950's prompted the drilling of many additional irrigation wells, and thus the total was raised to nearly 600 by the end of 1957. Although the rate of installation declined in the years that followed, the total number of irrigation wells had increased to 731 by January 1, 1965. (See fig. 2.) The area irrigated during the 1964 growing season was 79,200 acres, or a little more than one-fifth of the county.

Although drought during the middle 1950's undoubtedly was the principal cause of the great increase in the number of irrigation wells, other factors also have influenced the rate of ground-water withdrawal. Among these factors are technical advances in methods of well construction, improvements in drilling equipment and in water-distribution systems, wider availability of natural gas and electricity as sources of power for pumps, and greater use of commercial fertilizers to stimulate crop growth. Future withdrawal rates may be affected also by changes in land management and agricultural practices, greater withdrawals for industrial, public, and domestic uses, and the utilization of surface-water supplies.

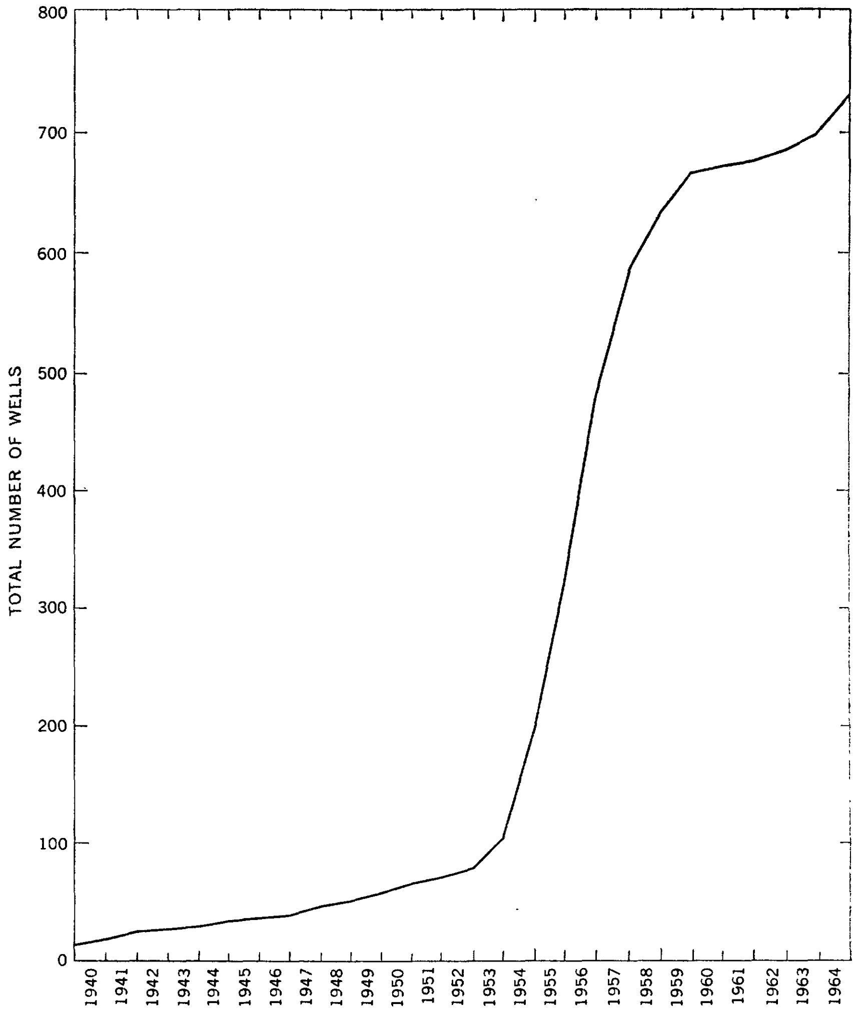

FIGURE 2.—Cumulative total of irrigation wells.

GENERAL FEATURES OF THE AREA

Fillmore County is 24 miles square and lies in the eastern part of the Nebraska loess plain, a southeastward-sloping tableland between the Platte and Republican Rivers in the south-central part of the State. Much of the county consists of broad upland flats characterized by numerous shallow undrained depressions that are mostly less than 40 acres in extent but which may be as much as 500 acres. Rolling or rough land is restricted to the side slopes of the more deeply incised drainageways. The principal streams are bordered by narrow bottom lands and by valleyside terraces. All the streams in the county are part of the drainage systems of the Big and Little Blue Rivers.

WELL-NUMBERING SYSTEM

Wells and test holes are numbered in this report according to their location within the land subdivisions of the General Land Office Survey of the county (fig. 3). The first numeral in the well-location num-

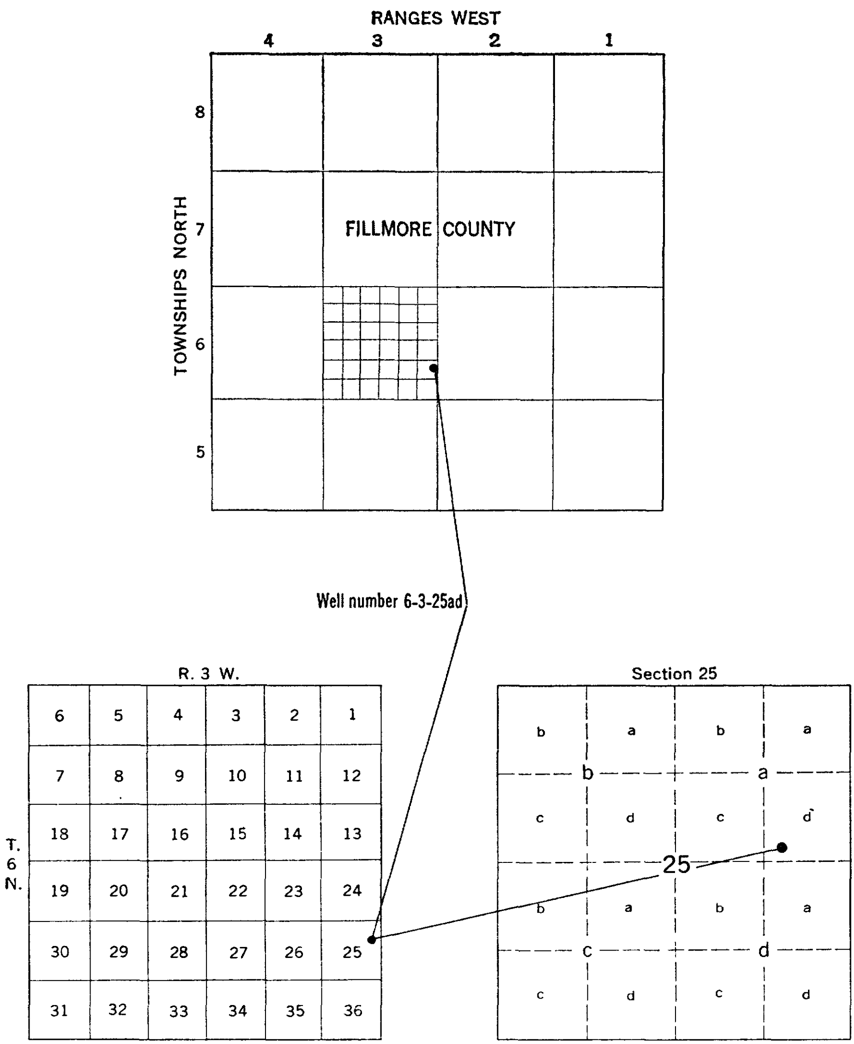

Figure 3.—Well-numbering system.

ber indicates the township, the second the range, and the third the section. The lowercased letters that follow the section number indicate the position of the well within the section; the first indicates the quarter section, and the second the quarter-quarter section. These letters are applied in a counterclockwise direction beginning with "a" in the northeast quadrant. A number following the lowercased letters indicates the number of the well in sequence as inventoried within the tract of land delineated by the last letter; if only one well is within this tract, no numeral is shown.

ACKNOWLEDGMENTS

Appreciation is expressed to the residents of Fillmore County who provided information concerning irrigation operations and practices. Soil Conservation Service personnel provided much information regarding names of well owners and locations of irrigation wells in the county, and municipal-supply officials furnished information concerning wells, pumps, reservoirs, and distribution systems of municipal supplies.

CLIMATE

The climate of Fillmore County is subhumid. During 70 years of record at Fairmont and Geneva, annual precipitation has ranged from as little as 14.85 inches to as much as 42.58 inches and has averaged about 27 inches per year. Whereas fall, winter, and early spring precipitation results mostly from widespread storms, that in late spring and summer more commonly results from local thunderstorms. Winters ordinarily are very cold with many days of clear skies; there are occasional blizzards, but heavy snowfalls are rather uncommon. The mean average temperature is 51.5°F. The lowest recorded temperature is −32°F, and the highest is 118°F. As the average date of the last killing frost is May 5 and that of the first killing frost September 30, the average growing season is about 150 days.

POPULATION

The frequent economic setbacks resulting from poor crops, particularly during the drought of the 1930's, caused many of the earlier residents to move out of the county. At its peak, about 1910, the population was nearly 15,000, but by 1960 it had declined to about 9,400.

SOILS AND AGRICULTURE

The upland soils in Fillmore County have developed from the upper few feet of the thick layer of loess which mantles the tableland. Where well drained, the soils are fertile and friable but require rather careful management if good tilth is to be maintained. Because the soils absorb and release water slowly, they generally respond favorably to most irrigation practices and are suitable for a variety of crops. The numerous depressions on the upland surface are floored with fine-grained material washed in from the surrounding area. As this material is nearly impermeable, most of the depressions become ponds during wet weather and dry out only during extended rainless periods. If adequately drained, the soils in the depressions can be made friable through tilling and then can be successfully irrigated. The subsoils of the upland area are less friable and less permeable than the soils. The upper part of the subsoil generally is dark colored and leached of calcium carbonate, whereas the lower part is light colored and enriched with lime dissolved from overlying dark-colored materials. The soils on the valleyside terraces and the bottom land are similar surficially to the upland soils but are underlain by more permeable subsoils.

Principal crops in Fillmore County are grain sorghum, winter wheat, corn, and alfalfa. Most grain is marketed, but some is used locally as feed for livestock. Corn is the principal cash crop, and about two-thirds of the corn acreage is irrigated. The average yield of the irrigated corn is about 85 bushels per acre but that of the dryland corn is considerably less and varies from year to year depending on the amount and distribution of rainfall during the growing season. About one-sixth of the alfalfa acreage and one-eighth of the grain sorghum acreage is irrigated; wheat is a dryland crop. Irrigation has strengthened the economy greatly. If the water and soil resources are conserved and used efficiently, the economy likely will continue to trend upward.

Although, in some years, precipitation during the growing season is ample for production of moderately good crops without irrigation, the growing season in many years is characterized by one or more dry spells in which hot winds seriously damage the nonirrigated crops and greatly reduce their yields. Almost every year crop yields can be increased substantially through application of irrigation water to supplement the precipitation.

GEOLOGY

STRATIGRAPHIC UNITS AND THEIR WATER-BEARING PROPERTIES

Because ground water is both stored in and transmitted through openings (interstitial voids, open fractures, and solution channels) in rocks, the lithologic characteristics, thickness, and areal distribution of the water-bearing rock units must be known if the occurrence, availability, and quality of the ground water are to be understood. Rocks differ greatly in ability to transmit water; some will transmit large quantities, others will yield little, and many are so nearly impermeable that they will yield no water and instead act as barriers to ground-water movement. The mineral constituents of the rocks with which ground water comes in contact and the degree to which those minerals are soluble in water determines the chemical quality of the water and the uses for which the water is suitable.

Rock strata of sedimentary origin underlie Fillmore County to a depth of nearly 3,500 feet. The oldest and deepest of these strata are of Paleozoic age, those next above are of Cretaceous (Mesozoic) age, and the uppermost and youngest are of Quaternary (Cenozoic) age. The Paleozoic and Cretaceous strata consist of consolidated marine or nearshore deposits and together constitute about 95 percent of the total thickness of sedimentary rock. The Quaternary strata, which constitute the remainder, consist of unconsolidated sediments of fluvial, eolian, or glacial origin.

The consolidated strata are referred to collectively as bedrock, and their upper surface, which is buried beneath the mantling Quaternary deposits, consists of hills and valleys. (See pl. 1.) The relief of the bedrock surface is somewhat greater than that of the present-day surface and is the most important factor governing the thickness of the overlying deposits.

Currently the bedrock is of very minor importance as a source of ground-water supply. However, as the rocks of Cretaceous age are tapped by three wells and each of the Cretaceous rock units is in direct contact with the overlying water-bearing Quaternary deposits, they are included in the following description of the geology as related to the availability of ground water. They also are included in the generalized geologic section (table 1).

CRETACEOUS SYSTEM

LOWER CRETACEOUS SERIES

DAKOTA SANDSTONE

The Dakota Sandstone underlies all Fillmore County and is in direct contact with the Quaternary sediments filling the deeper part of the bedrock valleys in the eastern part of the county. (See pls. 1 and 2.) The Dakota is the oldest formation of Cretaceous age in Nebraska, and although it is called a sandstone, more than half of it consists of interbedded siltstone, clayey shale, and sandy shale. Much of the sandstone is fine grained and generally only moderately to loosely cemented. Two tests in the county, drilled by the petroleum industry in exploring for oil and gas, penetrated the Dakota Sandstone. In one, the thickness of the formation was found to be about 385 feet; in the other, about

TABLE 1.—*Generalized description of the geologic formations of Cretaceous and Quaternary age and their water-bearing characteristics*

System	Series	Stratigraphic unit		Thickness (feet)	Texture and areal distribution	Water supply
Quaternary	Recent	Undifferentiated flood-plain alluvial, colluvial, and eolian deposits.		0–5±	Clay, silt, sand, and fine gravel; generally humic. Mostly limited to valley areas.	Generally above water table.
	Pleistocene	Wisconsin	Peorian Loess	0–30	Mostly yellowish-gray clayey silt; generally highly humic in uppermost part. Surficial deposit throughout nearly entire upland area.	Generally above water table. Where saturated, yields water to wells at slow rate.
			Undifferentiated fluvial deposits	0–30	Clay, silt, sand, and fine gravel; underlie valley-side terraces and valley floor of principal drainage courses.	Generally saturated. Yield water to wells at moderate rate.
		Illinoian	Loveland Formation	0–160	Mostly brown clayey silt; contains lenses of sand; locally is sandy at base; capped by fossil soil in many places; underlies nearly the entire upland area.	Generally above regional water table, but contains perched ground water where underlain by glacial till. Sand lenses yield water to wells at slow rate.
			Undifferentiated fluvial, lacustrine, and eolian deposits		Silt, sand, and gravel. Areally restricted to broad valleys that existed at beginning of Illinoian time; underlie most of southwest half of county and parts of northeast half.	Generally saturated. Where thick and coarse textured, yield water to wells copiously.
		Kansan	Sappa Formation[1]	0–50	Mostly light-yellowish-gray to light-gray clay and silt; contains lenses of sand and gravel; contains and is capped by fossil soil in some places. Underlies much of northeast half of county and small parts of southwest half.	Generally saturated in lower part. Sand lenses yield water to wells at slow rate.
			Glacial till	0–65	Silty, sandy clay containing scattered pebbles and a boulder zone; underlies large area in northeastern and north-central parts of county and small area in T. 6 N., R. 1 W.	Yields very little water or no water to wells. In places is nearly impervious and has above it a perched water body.
			Undifferentiated fluvial, lacustrine, and eolian deposits	0–200	Clay, silt, sand, and gravel; underlie much of county but are absent beneath large area in southeastern part of county and in small areas in northwestern and west-central parts.	Saturated. Where thick and coarse-textured, yield water to wells copiously.
		Nebraskan	Undifferentiated fluvial, lacustrine, and eolian deposits	0–200	Clayey silt, sand, and gravel; underlie much of county but locally are absent in northeastern, south-central, and west-central parts.	As above.

See footnote at end of table.

TABLE 1.—*Generalized description of the geologic formations of Cretaceous and Quaternary age and their water-bearing characteristics*—Continued

System	Series	Stratigraphic unit	Thickness (feet)	Texture and areal distribution	Water supply
Cretaceous	Upper Cretaceous	Niobrara Formation	0–70	White, yellow, and gray chalky shale; mostly weathered. Underlies two small areas in western part of county.	Saturated. Where creviced, yields water to wells moderately freely. Known to be tapped by only two wells in county.
		Carlile Shale	0–280	Medium- to dark-gray shale; calcareous in part; contains thin layers of limestone; underlies all but the deeper parts of the bedrock valleys.	Does not yield water to wells.
		Greenhorn Limestone	0–25	White and gray limestone and calcareous shale; underlies all but the deeper parts of the bedrock valleys.	As above.
		Graneros Shale	0–70	Dark-gray shale; calcareous in upper part; underlies all but the deepest part of the bedrock valleys.	As above.
	Lower Cretaceous	Dakota Sandstone	250–385	Clay, silty and sandy shale, siltstone, and sandstone; underlies entire county.	Saturated. Water is moderately to highly mineralized. Sandstone layers yield water moderately freely to wells. Known to be tapped by only one well in county.

[1] As defined by Condra, Reed, and Gordon (1950, p. 22).

360 feet. In these tests the sampling interval through the Cretaceous section was too great to permit accurate evaluation of the lithology of the Dakota.

Four ground-water survey test holes were drilled a short distance into the Dakota, and it has been reported that a commercially drilled test hole for the Village of Ohiowa penetrated about 175 feet into the formation. Only one well in the county is known to be producing water from the Dakota Sandstone. It is a domestic and stock well about 1½ miles south of Milligan in the NE¼NE¼ sec. 23, T. 6 N., R. 1 W., and is reported to be 344 feet deep. Sandstone aquifers were reported from 339 to 340 and 342 to 343 feet. Water from the well is of relatively poor quality and is of the sodium bicarbonate type. The chemical characteristics of water from this well are discussed in the chemical quality section of this report.

Water supplies from deep wells (350–400 ft) tapping the Dakota Sandstone, which would yield water satisfactory for livestock use, could be developed in the Milligan-Ohiowa area where water is difficult to obtain from the Quaternary deposits. Water from the Dakota Sandstone should be analyzed for chemical quality to determine its suitability for human consumption.

UPPER CRETACEOUS SERIES

GRANEROS SHALE

The Graneros Shale, except where removed by erosion, directly overlies the Dakota Sandstone and consists of a lower noncalcareous dark-gray shale about 25–30 feet thick and an upper dark-gray calcareous shale about 35–40 feet thick. Where not eroded, the Graneros is about 65 feet thick. Test drilling indicates that all Graneros Shale has been removed by erosion in the deepest part of buried valleys in the eastern part of the county and that its upper part has been removed along the slopes of buried valleys in the central, eastern, and extreme southwestern parts of the county. (See pls. 1 and 2.) No test hole was drilled completely through the formation. Because it is relatively impervious, the Graneros is not a source of ground water.

GREENHORN LIMESTONE

The Greenhorn Limestone directly overlies the Graneros Shale and is about 25 feet thick in areas where it has not been eroded. It consists of interbedded white and gray fossiliferous limestone and calcareous shale. The limestone layers of the Greenhorn are thicker and the shale layers thinner and more calcareous than those of either the underlying Graneros Shale or the overlying Carlile Shale. The formation has been removed by erosion in the deeper part of the buried valleys but is present beneath the remainder of the county. (See pls. 1 and 2.) The Greenhorn Limestone is not known to be tapped by any wells in the county. In the Ohiowa area, however, pre-Quaternary weathering probably produced crevices that may contain enough water for domestic or stock wells.

CARLILE SHALE

The Carlile Shale is the uppermost bedrock formation in much of the western half of the county and caps some of the buried hills and ridges in the eastern half. In the deeper buried valleys it has been completely removed by erosion; elsewhere, with the exception of two buried hills, it has been partly removed. The two buried hills are in the west-central and northwestern parts of the county and are capped by the Niobrara Formation. (See pls. 1 and 2.) In these areas, the Carlile is about 280 feet thick. Nowhere in the county is it a source of water.

NIOBRARA FORMATION

The Niobrara Formation is the youngest bedrock unit in Fillmore County. It probably covered the entire county at one time but later was completely removed by erosion except for the two buried hills in the west-central and northwestern parts. (See pls. 1 and 2.) It consists of white, gray, and yellow chalky shale and chalk. Originally probably more than 300 feet thick, the formation now is no more than about 70 feet thick anywhere in the county.

Three test holes, 6–4–6cc, 7–4–19cc, and 8–5–1dd, were drilled through the Niobrara Formation and into the Carlile Shale; another test hole, 8–5–24dd, was drilled 5 feet into chalky shale but could not be drilled deeper because circulation of drilling fluid could not be maintained. Apparently the drilling fluid was seeping into either a cavity or a crevice. Circulation was lost also in test hole 8–5–1dd near the base of the formation. Almost all the Niobrara Formation explored by test drilling was weathered. The maximum thickness of weathered shale drilled was 56.5 feet in test hole 6–4–6cc.

In some places, many crevices were produced by weathering, and where tapped by wells, they yield small to large quantities of water. Two irrigation wells, 6–4–8db and 6–4–8dc, are reported to derive water from creviced chalk. One is said to yield about 200 gpm (gallons per minute), and the other about 300 gpm. Mr. Frank Kamler, owner of the wells, reported that 20 exploratory test holes were drilled prior to selection of the well sites. Where unweathered, the Niobrara Formation generally will not yield water.

QUATERNARY SYSTEM

Throughout Fillmore County the Cretaceous rocks are mantled by unconsolidated sediments of Pleistocene and Recent age. These deposits not only fill valleys eroded into the bedrock during pre-Pleistocene and very early Pleistocene time but also cover the highest hills between those valleys; thus their aggregate thickness differs widely from place to place. (See pl. 1.) For example, they are as much as 450 feet thick in the northern part of T. 7 N., R. 1 W., but only 60 feet thick in the northwestern part of T. 6 N., R. 4 W.

Deposition of the Quaternary sediments was not a continuous process: alluvial plains were alternately built up by sediment accumulation and torn down by erosion. The Quaternary Period was characterized by widespread climatic changes accompanied by the expansion and subsequent melting of continental ice sheets; probably the alternating aggradations and degradations in this area were related to the successive glaciations of the north-central and northeastern parts of the United States.

Of the four generally recognized glaciations, ice sheets of the first two, the Nebraskan and the Kansan, invaded eastern Nebraska and, by disrupting the drainage pattern and blocking the existing valleys, caused those valleys to be filled with sediment. Although the later ice sheets (Illinoian and Wisconsin) did not block the drainageways that crossed Fillmore County, the climatic changes that caused the glaciations (together with sea-level changes, possible crustal adjustments to the weight of the ice, and other factors) were great enough to cause streams to aggrade and degrade alternately.

Some of the unconsolidated sediments occupying the buried valleys consist largely of brown and gray silt and clay; locally these deposits include some sand and gravel. For several years after being discovered by test drilling, they were regarded to be of Pliocene (Tertiary) age. Condra, Reed, and Gordon (1950) named them the Seward Formation and considered them to be a fine-textured facies of the Ogallala Formation, which rests on the Cretaceous bedrock and underlies Quaternary deposits throughout a large area in central Nebraska. Although correlative deposits in Clay County, which borders Fillmore County on the west, were assigned to the Seward Formation by Dreeszen (Keech and Dreeszen, 1959), subsequent work and evaluation of additional subsurface data in eastern and central Nebraska prompted him to conclude that at least some, if not most, of the beds that he and others previously identified as Seward Formation are Pleistocene, not Pliocene, in age and therefore younger than the Ogallala Formation. The currently available evidence indicates that deposits previously identified as Seward also may include side-valley or hilltop remnants of clays either older than or of the same age as the Ogallala. The following arguments support the conclusion that the Seward, in its entirety, is not an eastern equivalent of the Ogallala: (1) The texture, color, and degree of induration of the Seward differs from that of the Ogallala in central Nebraska, and (2) the Seward more commonly occupies the floor and side slopes of buried bedrock valleys, whereas definitely identified outliers and eastward-extending tongues of the Ogallala generally occupy buried bedrock divides. On the geologic sections of Fillmore County (pl. 2), the deposits equivalent to the Seward as originally defined are included with the sedimentary rocks of Nebraskan age. The remainder of the deposits of Nebraskan age consist partly of fluvial sand and sandy gravel and partly of clayey silt that may be of fluvial, lacustrine, or eolian origin.

The subsurface presence of glacial till in the vicinity of Geneva, Fairmont, Exeter, and Milligan indicates that at least one of the major ice sheets, the Kansan, advanced into Fillmore County. The remainder of the Kansan deposits generally consist of coarse-grained fluvial sediments in the lower part and of fine-grained fluvial and eolian sediments in the upper part; the till, where present, lies between the two. Although the fluvial deposits consist largely of rock debris transported into the county by streams that drained unglaciated areas, they include some debris carried in by meltwater from the glacier. The fine-grained sediments constituting the upper part of the Kansan deposits are considered to be the Sappa Formation.

The Illinoian deposits consist of fine to coarse interbedded fluvial and eolian sediments that are capped by the laterally continuous Loveland Formation, which is composed partly of loess. Most of the fluvial sediments were transported into the area by streams that drained unglaciated areas, and they were derived largely from older Pleistocene deposits. Some of the fluvial sediments, particularly those in the eastern part of the county, may have been deposited by southward-flowing meltwater from the Illinoian ice sheet which overrode northeastern Nebraska. The capping loessial deposits generally are brown, whereas the similarly fine-grained sediments interbedded with the coarse-textured fluvial sediments are brown to greenish gray. Fossil soils occur both within and at the top of the Illinoian deposits.

The Wisconsin deposits consist largely of eolian sediments that are similar in texture to the upper part of the Loveland Formation but are lighter in color, less brownish, and generally less clayey. These eolian sediments comprise the Peorian Loess on which the soils of the present-day upland surface have developed. Fluvial sediments of Wisconsin age are restricted to the present-day valleys, where they underlie the terraces and bottom lands; they are mantled with fine-grained sediments washed into the valleys from the bordering uplands.

The geologic sections on plate 2 reveal that the thickness of the Nebraskan, Kansan, Illinoian, and Wisconsin deposits differs widely from place to place. The differences in thickness are due partly to the irregularities of the surface on which they rest and partly to erosion subsequent to their deposition.

The deposits of Recent age consist of surficial alluvial, colluvial, and eolian sediments. Because, for the most part, they have been derived from local sources, they are similar in texture and composition to the parent materials and are difficult to distinguish from them. Small in areal extent, they generally are less than 5 feet thick.

GROUND WATER

DEPTH TO WATER

The depth to the water table below land surface is the depth to which wells must be drilled to reach water. As shown on plate 1 (also pl. 2), the depth is greatest beneath upland areas and least beneath the floor of stream valleys. The greatest depths—a little more than 100 feet—occur north of Fairmont and near the county line northwest of Shickley.

DIRECTION OF GROUND-WATER MOVEMENT

The configuration of the water table in 1964 is shown by the contour lines on plate 1. The high point on the water table is on the west county line southwest of Grafton and has an altitude of nearly 1,650 feet, and the low point is at the southeast corner of the county and has an altitude of about 1,435 feet. From the high point the water table slopes northeastward, eastward, and southeastward throughout the county except in an area of about 42 square miles in the vicinities of Milligan and Ohiowa; there the water table slopes away from a subsidiary high point on the county line southeast of Milligan. The water table is mounded in this area because the water-bearing sediments are much less permeable than elsewhere in the county and therefore retard movement of water toward the discharge areas. Water accumulates until enough pressure is built up to overcome the resistance of the sediments to water movement.

Ground water percolates in the direction of the steepest hydraulic gradient—that is, at right angles to the water-table contours. Representative flow lines on plate 1 show that ground water is percolating into Fillmore County along its entire west boundary and that it is percolating out of the county along the entire south boundary and along most of its east and north boundaries. Because the hydraulic gradients are extremely low in most of the area the rate of percolation probably does not exceed 1 foot per day in any part of the county. At this slow rate about 4,200 years would be required for a molecule of water to percolate across the full width of the county.

PHYSICAL PROPERTIES OF THE WATER-BEARING QUATERNARY DEPOSITS

The saturated Quaternary deposits are considered in this report to constitute a single aquifer even though they consist of a variety of textural types and were laid down during several different cycles of deposition. The base of the zone of saturation is the irregular surface of the underlying bedrock, and the top is the regional water table. The saturated zone ranges in thickness from as little as 20 feet (over the highest bedrock hill) to as much as 350 feet (in the deepest bedrock valley). If the average thickness is assumed to be 175 feet and the average effective porosity to be 20 percent, the total volume of water in the Quaternary deposits in Fillmore County is about 13 million acre-feet.

The diameter of the voids and the degree to which they are interconnected determine the capacity of a rock material to transmit water. The coefficient of transmissibility is a measure of this capacity and may be expressed as the rate of flow of water, at the prevailing temperature, in gallons per day through a cross-sectional area 1 mile wide and extending the full thickness of saturated rock material under a hydraulic gradient of 1 foot per mile. Values of the coefficient of transmissibility, as estimated from examination of rock cuttings obtained in the drilling of test holes and from logs of irrigation wells, are shown on plate 1; they range from 3,000 to 249,000 gallons per day per foot. The coefficients of transmissibility plotted on plate 1 were the basis for estimating the areal distribution of different ranges in the transmissibility of the aquifer. To obtain maximum yield, a well must be designed, constructed, and developed according to the physical characteristics of the aquifer as the capacity of an aquifer to yield water to wells is related directly to the transmissibility of the aquifer; moreover, the pump must be designed to take full advantage of the capacity of the well.

Inasmuch as the coefficient of transmissibility is a characteristic of the ability of the aquifer to yield water to wells and is proportional to the specific capacity (gallons per minute per foot of drawdown), those areas in the county having the lowest values for the coefficients of transmissibility will be areas where the yields of wells generally will be small, and those areas having the highest values will be areas where large-capacity wells may be obtained. For example, in the zone showing the coefficient of transmissibility of the deposits as less than 50,000 gpd per foot, wells generally will yield adequate supplies for household and farm use but not for irrigation of field crops. Fair to good yields from irrigation wells may be expected in the zone of deposits indicated as having a coefficient of transmissibility of 50,000 to 100,000 gpd per foot; however, lowering of the water table a few feet in this zone may significantly reduce the yields of wells. Irrigation wells properly designed and developed in the zones of deposits indicated to have coefficient of transmissibility of more than 100,000 gpd per foot may be expected to yield more than 1,000 gpm (gallons per minute); these wells probably will not be significantly reduced in yield by a lowering of the water table of a few feet.

RECHARGE

Precipitation that infiltrates the soil zone and that escapes both evaporation and transpiration by plants is the principal source of recharge to the zone of saturation. Precipitation is far more likely to become available for recharge in the early spring or late fall than when the ground is frozen or when vegetation is flourishing. Exactly how the transfer of water from the zone of soil moisture to the zone of saturation takes place is not fully understood. That it occurs is manifest, however, by rising water levels in wells.

Probably a small part of the water pumped for irrigation infiltrates below the reach of roots and thereby becomes a source of recharge. Return from irrigation, however, merely replaces a fraction of the water that was withdrawn from the zone of saturation and so does not constitute, as does precipitation, an addition to the supply.

Divergence of the flow lines on plate 1 is the result of changes in the transmissibility of the aquifer and recharge (addition of water to the zone of saturation by infiltration from the land surface). Therefore, if the quantity of flow through successive sections that extend from one to the other of a given pair of flow lines is known, the increase in flow from one section to the next is a measure of the quantity of recharge within the area bounded by the flow lines and the lines of section. The approximate quantity of water (Q) moving through sections A, B, and C on plate 1 was computed from the equation

$$Q=TIL,$$

in which

T is the coefficient of transmissibility, in gallons per day per foot,
I is the hydraulic gradient, in feet per mile, and
L is the length of the section, in miles.

The results of the computations—900,000 gpd (gallons per day) for A, 4,000,000 gpd for B, and 9,500,000 for C—indicate that the average rate of recharge must be 1.4 inches per year to account for the increase in flow from section to section.

The closer spacing of the contour lines and the reversed direction of the water-table slope in the Ohiowa-Milligan area is partly the result of locally high bedrock that is mantled by both glacial till and fine-grained eolian deposits; it does not indicate, as is true of some water-table mounds, that the rate of recharge is greater here than in other parts of the county. Instead, the rate of recharge probably is somewhat less than the average for the remainder of the county, and the water-bearing zone consists of materials having such a low coefficient of transmissibility that a steeper hydraulic gradient is necessary for water to drain away from the central part of the mound.

DISCHARGE BY WELLS

Before wells were drilled in Fillmore County, the ground water that percolated into the county plus the recharge from precipitation on the county eventually was discharged by evapotranspiration in the valley areas where the water table was within a few feet of the land surface, by outflow into the few streams that had incised their channels below the water table, and by subsurface percolation into adjoining counties on the north, east, and south. Current pumping from wells intercepts ground water that otherwise would be discharged naturally at some later time.

The number of wells is only one of the factors governing the amount of ground water pumped from year to year. Weather conditions are far more important because withdrawals for irrigation in dry years may be double or even triple those in wet years. The annual recharge from precipitation is estimated to be about 39,000 acre-feet on the irrigable lands underlain by productive aquifers. Thus, if 460 wells were to be pumped at yearly rates of 1 acre-foot per acre on an average of 85 acres each, the total amount of water pumped would be equal to the annual recharge from precipitation.

Because irrigation wells are not evenly distributed throughout the county, withdrawals in areas where wells are more numerous generally exceed the quantity of recharge and, as a result, the water table is declining at a significant rate. The effect of pumping for irrigation is illustrated by the 8-year water-level record for a well at Shickley. (See fig. 4.) During each of the eight irrigation seasons, the water level was lowered sharply—almost 2 feet in 1964, but lesser amounts in each of the preceding 7 years; during the remainder of each year, it rose but not enough in any nonirrigation season to balance the decline of the preceding irrigation season. Consequently, the water level at the end of 1964 was a little more than 5 feet lower than at the end of 1956. The trend of the hydrograph indicates that the decline is likely to continue unless precipitation for a succession of years is sufficient during the growing season to curtail withdrawals for irrigation.

Even if the irrigation wells were evenly distributed and the consumptive withdrawals and the recharge were kept in balance, the

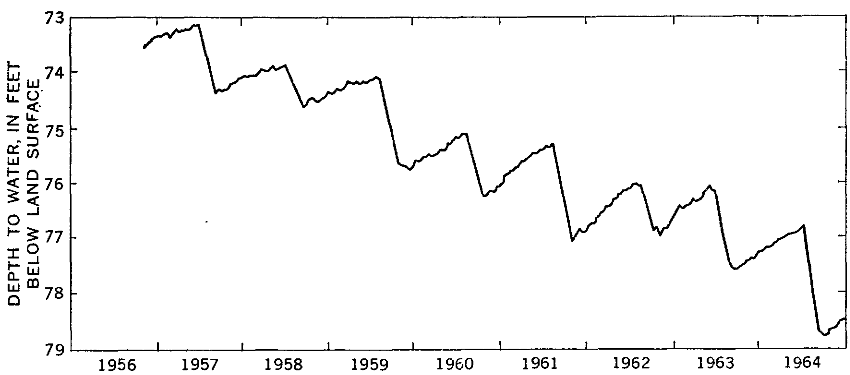

FIGURE 4.—Fluctuation of water level in well at Shickley, Nebr.

water table would decline until the water-table gradient toward areas of natural ground-water discharge reverses. Then, natural ground-water discharge would cease, a state of equilibrium would be established at the lowest water-table position, and the decline in the water table would come to a halt. Because consumptive ground-water withdrawals are likely to increase, at least for several more years, water levels will probably not stabilize in the near future.

Recently the Geological Survey constructed an electric analog model of the Blue River drainage basin and used it to determine the effect of ground-water pumping on streamflow and ground-water levels by imposing on the model a reasonable simulation of predicted ground-water developments (Emery, 1965). As Fillmore County is wholly within that drainage basin, the results of the study are pertinent to this report. It was assumed that annual consumptive ground-water withdrawals will continue to increase until 1982, at which time they will be 50 percent greater than in 1962. Then, because the water table will have been lowered to the extent that the specific capacities of wells will have been reduced significantly, the rate of withdrawal will begin to decline and by 2022 will have returned to the 1962 level. The results of imposing these predictions on the model indicate that in 1982 the water level in the southwestern part of Fillmore County will be a little more than 20 feet lower than it was in 1948 and that by 2022 it will be more than 40 feet lower. Elsewhere in the county the declines will have been less but significant.

As shown by plate 1, the saturated Quaternary deposits beneath more than half of Fillmore County are capable of yielding water to wells at rates of more than 1,000 gpm; however, the potential for development of the ground-water resources is limited by the low rate of recharge. The water table is declining even at the current rate of withdrawal, and the prospect is that the rate of withdrawal will increase and cause it to decline even faster. As was assumed for the analog model study, yields of wells will diminish, and additional wells will be required to maintain the irrigation supply; consequently, the cost of obtaining water will increase as the water table declines. Although ground water is a renewable resource, withdrawal at a rate exceeding the potential for recharge results in a diminution of the supply, but unless such diminution occurs, the ground-water resources of Fillmore County never will be utilized to their fullest extent. From the present view, therefore, pump irrigation will have its heyday and then slowly decline. The date that the decline will begin obviously will depend on the rate at which ground-water development proceeds.

PERCHED WATER

Beneath an area of about 150 square miles in the northeastern part of Fillmore County, a layer of nearly impervious clay inhibits transfer of moisture from the soil zone to the main body of ground water to such a degree that the more permeable sediments directly overlying the clay have become saturated. This perched, or suspended, zone of saturation, the upper surface of which is labeled "perched water table" on the geologic sections (pl. 2), is called the first water by local drillers. A few domestic and livestock wells tap the perched zone of saturation, but the water is of poor quality.

The water table of the perched water body fluctuates independently and with greater amplitude than the deeper regional water table. (See fig. 5.) As the perched water table is nearer to the land surface than the regional water table, it is the first to be reached by infiltrating precipitation, and its rises, therefore, can be correlated with wet periods. Moreover, because the perched water table is within the reach of deep-rooted plants, it declines in response to vegetal withdrawals during the growing season. Also contributing to the declines, but less significantly, are the effects of pumping from low-capacity wells and slow seepage to the regional ground-water body. Fluctuations of the regional water table are due, on the other hand, mostly to pumping for irrigation. If not for the effects of irrigation withdrawals, fluctuations

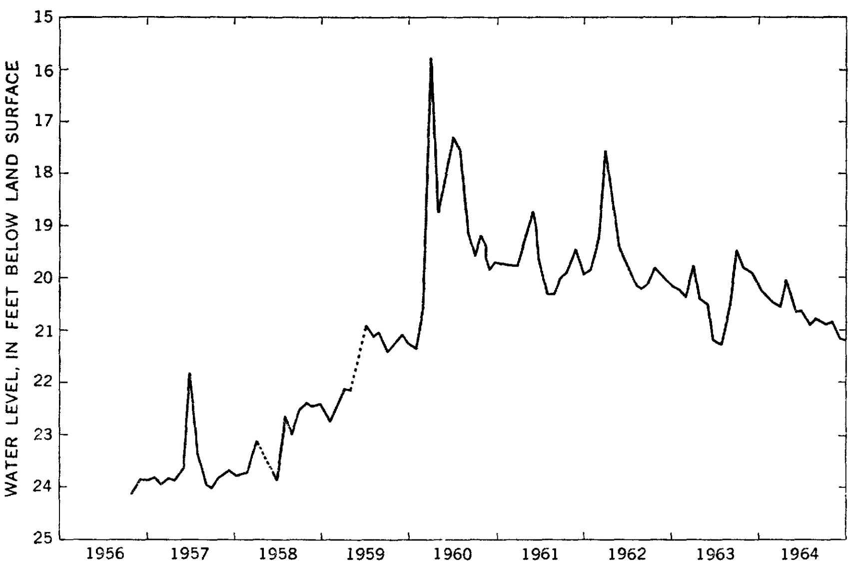

FIGURE 5.—Water-level fluctuation in wel 8-2-26ad1 in the perched water body.

of the regional water table would be due only to changes, ordinarily slight, in the ratio of natural recharge to natural discharge.

If water were to be imported and spread on land underlain by the perched water zone, the additional recharge might raise the perched water table enough to cause waterlogging unless preventive measures are taken. Water pumped from the deep regional aquifer and spread on the land would also have the same result as importing water from outside the area.

CHEMICAL QUALITY OF THE WATER

By L. R. PETRI

The suitability of water for a particular use is determined in part by its chemical quality. To define the chemical quality of the ground water in Fillmore County, a study was made of analyses of water from 87 wells, 86 of which tap Quaternary deposits and 1 of which taps the Dakota Sandstone. Most of the samples for analysis were obtained from irrigation and public-supply wells. In general, water from domestic wells was sampled only in parts of the county where no large-supply wells exist. Water from School Creek and a branch of Turkey Creek was also analyzed.

To insure that each ground-water sample was representative of the available supply in a particular location, none was collected until the well had been pumped long enough to exhaust from the casing and its immediate vicinity any water not typical of that naturally in the aquifer. Fifty-six of the samples were collected using standard sampling procedures and sample containers. The rest were collected by farmers and others and although neither the sampling procedures nor sample containers used were standard, the analytical results are considered to be fairly reliable. All the analytical work was done in the Geological Survey laboratory in Lincoln, Nebr.

All the analytical results are given in tables 2 and 3 and those for water in the Quaternary deposits are represented on plate 1 by four-sided diagrams that show the concentrations of the principal mineral constituents in equivalents per million. The shapes of the diagrams indicate differences in the chemical composition of the water, and differences in the length of the horizontal sides are a function of the concentrations of the various chemical constituents.

Water in Quaternary deposits that consist largely of fluvial sand and gravel is of either the calcium bicarbonate or calcium sulfate type and generally contains less than 400 ppm (parts per million) of dissolved minerals. Its hardness as $CaCO_3$ ranges from 140 to 200 ppm and is almost wholly of the carbonate type. This kind of hardness is

TABLE 2.—*Chemical*

[Analytical results in parts per

Location	Depth (feet)	Date of collection	Temperature (°F)	Silica (SiO_2)	Total iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)
5-1-3dc	43	Apr. 30, 1954		22	0.41		195	27	86	6.0
8cb		Aug. 16, 1955		45	.19	0.42	105	30	17	6.0
		Apr. 11, 1956	55						17	
24cd	125	Aug. 3, 1955	53						27	
32ad	196	Aug. 2, 1955	53						26	
5-2-6bb	116	Aug. 3, 1955	53						39	
7db	206	Aug. 16, 1955	52	28	.07	.00	62	9.8	26	4.2
13bb	90	Aug. 3, 1955	54						41	
28dc	161	July 20, 1955	54	29	.39		50	10	24	4.3
5-3-6cb	150	July 1954[a]							23	
6db	150	do.[a]							24	
10da	160	do.[a]							22	
21cc	154	do.[a]							22	
22ab	165	July 26, 1955	53						20	
22bb	150	July 1954[a]							22	
26aa	185	do.[a]							23	
28ac	180	do.[a]							22	
5-4-1bd	150	do.[a]							24	
2cb	180	do.[a]							28	
4cd	162	do.[a]							24	
9bc	180	do.[a]							22	
11bb	180	do.[a]							24	
12bd	132	Aug. 16, 1955	50	40	.00	.00	49	8.4	23	7.1
	132	Mar. 23, 1956	54							
12dd	154	July 1954[a]							24	
13aa	160	do.[a]							22	
16ad	150	do.[a]							19	
20dd	150	do.[a]							15	
28dc	136	do.[a]							17	
29bb	150	do.[a]							16	
32bb	190	do.[a]							19	
35aa	162	do.[a]							19	
6-1-2da2	140	Aug. 17, 1955		42	.02	.00	107	26	35	4.3
2db	185	Aug. 3, 1955	53						28	
6cc	183	July 29, 1955	53						27	
22aa	65	Aug. 3, 1955	53						86	
22dd	58	Aug. 16, 1955							50	
23aa	344	Aug. 25, 1957[a]	55	10	.16		2.2	.6	325	2.3
6-2-4dc	212	July 29, 1955	53						34	
7bb	170	July 26, 1955	54						31	
21ba	85	Aug. 3, 1955	53						39	
23bb	210	Apr. 13, 1956	55						25	
25cb	70	July 26, 1955	54						23	
6-3-9dc	185	July 1954							25	
13da	138	Apr. 30, 1954	55	21	.88		63	13	28	5.0
30dc	173	July 28, 1955	52						27	
31dd	160	July 1954[a]							19	
6-4-5bb	125	July 28, 1955	53						36	
12cc	195	July 29, 1955	53						22	
16ca	200	do.							23	
19ab	162	July 1954[a]							22	
19dc	183	do.[a]							24	
20bb	165	do.[a]							25	
23bb	195	do.[a]							26	
27cc	140	do.[a]							27	
30ab	185	do.[a]							25	
	185	Jan. 10, 1955					59	8.8	23	
32cb	180	July 1954[a]							25	
33cc	172	do.[a]							24	
34dc	160	do.[a]							24	
35aa	165	do.[a]							25	
7-1-15ad	253	Aug. 4, 1955	52						18	
30ba	261	Mar. 23, 1956	54						20	
32cd	100	do.	54						20	
7-2-13bb1	60	Aug. 4, 1955							89	
13bb2	225	Aug. 17, 1955							22	
13cc	265	Apr. 11, 1956	55						30	
18dd	265	Aug. 4, 1955	51						23	
7-3-16dd	183	do.	52						22	
36cd1	180	Aug. 15, 1955		31	.10	.02	62	12	26	5.0
	180	Apr. 11, 1956	54						26	
36cd2	180	Mar. 23, 1956	54						21	

See footnotes at end of table.

analyses of ground water

million except as indicated]

Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids (residue on evaporation at 180°C)	Hardness as $CaCO_3$		Percent sodium	Specific conductance (micromhos per cm at 25°C)	pH
								Calcium, magnesium	Noncarbonate			
442	0	398	7.0	0.2	4.8	0.10	1,000	596	234	24	1,320	7.4
387	0	84	9.0	.3	5.1	.06	492	386	69	9	754	7.4
385	0	------	------	------	------	----	--------	374	58	9	755	7.3
380	0	------	------	------	------	.06	--------	352	40	14	754	7.6
211	0	------	------	------	------	----	--------	176	3	24	458	7.4
155	0	------	------	------	------	----	--------	273	146	24	731	7.1
209	14	45	12	.2	.4	.04	301	195	1	22	481	8.5
367	0	------	------	------	------	----	--------	386	85	19	877	7.4
197	0	41	14	.4	.5	.05	283	168	6	23	434	7.6
168	8	------	------	------	------	----	--------	148	0	25	391	8.6
165	10	------	------	------	------	----	--------	152	0	25	403	8.6
173	10	------	------	------	------	----	--------	152	0	24	393	8.6
173	12	------	------	------	------	----	--------	164	2	23	404	8.6
229	0	------	------	------	------	.04	--------	186	0	19	462	7.5
196	8	------	------	------	------	----	--------	174	0	22	429	8.5
166	8	------	------	------	------	----	--------	154	5	25	402	8.5
176	8	------	------	------	------	----	--------	164	7	23	412	8.5
164	10	------	------	------	------	----	--------	152	1	25	409	8.6
176	20	------	------	------	------	----	--------	164	0	27	432	8.8
166	10	------	------	------	------	----	--------	156	3	25	414	8.6
160	8	------	------	------	------	----	--------	152	8	24	391	8.6
168	12	------	------	------	------	----	--------	158	1	25	406	8.6
194	0	26	15	.1	9.7	.05	267	157	0	23	424	7.3
-------	------	------	------	------	------	----	--------	------	------	------	427	----
179	0	------	------	------	------	----	--------	150	3	26	414	7.5
164	9	------	------	------	------	----	--------	150	1	24	383	8.6
162	4	------	------	------	------	----	--------	156	17	21	393	8.5
114	4	------	------	------	------	----	--------	124	24	21	324	8.3
147	10	------	------	------	------	----	--------	146	9	20	365	8.5
144	7	------	------	------	------	----	--------	142	12	20	354	8.5
158	9	------	------	------	------	----	--------	146	2	22	364	8.6
156	10	------	------	------	------	----	--------	144	0	22	361	8.5
314	0	162	17	.1	10	.06	561	374	117	17	830	7.4
364	0	------	------	------	------	.05	--------	322	24	16	712	7.3
239	0	------	------	------	------	----	--------	238	42	20	575	7.4
301	0	------	------	------	------	.07	--------	644	397	23	1,440	7.3
374	0	------	------	------	------	----	--------	604	297	15	1,240	7.4
609	20	141	10	6.3	2.0	3.9	839	8	0	98	1,310	8.6
246	0	------	------	------	------	----	--------	258	56	22	646	7.5
205	0	------	------	------	------	.05	--------	205	37	25	548	7.3
178	0	------	------	------	------	----	--------	208	62	29	592	7.3
221	0	------	------	------	------	----	--------	203	22	21	501	7.5
340	0	------	------	------	------	----	--------	360	81	12	767	7.3
204	16	------	------	------	------	----	--------	206	12	21	483	8.7
225	0	70	15	.3	.0	.04	332	209	24	22	520	7.4
228	0	------	------	------	------	----	--------	181	0	24	483	7.4
135	7	------	------	------	------	----	--------	104	0	29	295	8.4
292	0	------	------	------	------	.06	--------	361	122	18	836	7.3
216	0	------	------	------	------	----	--------	186	9	21	461	7.4
230	0	------	------	------	------	----	--------	230	43	18	550	7.6
190	12	------	------	------	------	----	--------	178	3	21	423	8.6
200	14	------	------	------	------	----	--------	196	9	21	474	8.7
258	0	------	------	------	------	----	--------	218	6	20	520	8.2
212	0	------	------	------	------	----	--------	186	12	23	479	7.7
182	12	------	------	------	------	----	--------	168	0	26	443	8.7
188	14	------	------	------	------	----	--------	178	1	23	445	8.7
220	0	------	14	------	------	----	289	183	3	21	453	7.4
166	9	------	------	------	------	----	--------	150	0	27	401	8.5
164	10	------	------	------	------	----	--------	152	1	25	404	8.6
166	10	------	------	------	------	----	--------	152	0	25	398	8.6
172	14	------	------	------	------	----	--------	164	0	25	427	8.6
222	0	------	------	------	------	----	--------	179	0	18	423	7.7
267	0	------	------	------	------	----	--------	199	0	18	460	7.4
186	0	------	------	------	------	----	--------	150	0	22	384	7.1
206	0	------	------	------	------	.11	--------	770	601	20	1,690	7.2
219	0	------	------	------	------	----	--------	186	6	21	465	7.6
230	0	------	------	------	------	----	--------	235	46	22	577	7.4
220	0	------	------	------	------	----	--------	202	22	20	505	7.7
218	0	------	------	------	------	----	--------	184	5	21	457	7.7
212	0	59	15	.2	8.7	.04	318	202	28	21	513	7.5
207	0	------	------	------	------	----	--------	230	60	20	558	7.3
206	0	------	------	------	------	----	--------	183	14	20	449	7.4

TABLE 2.—*Chemical analyses*

[Analytical results in parts per

Location	Depth (feet)	Date of collection	Temperature (°F)	Silica (SiO_2)	Total iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)
7-4-20da1	139	Apr. 30, 1954	------	29	0.23	------	66	13	27	4.4
23aa1	--------	Aug. 4, 1955	54	------	------	------	------	------	19	------
8-1-10ad	253	Aug. 5, 1955	51	------	------	------	------	------	22	------
20da	250	Mar. 15, 1953	56	34	.23	0.40	77	16	21	5.1
	250	Aug. 15, 1955	56	36	.17	.68	73	17	21	5.0
25ca	260	Aug. 5, 1955	53	------	------	------	------	------	22	------
8-2-1cc	110	Aug. 19, 1955	------	------	------	------	------	------	32	------
1da	100	Aug. 5, 1955	------	------	------	------	------	------	37	------
5bc	115	----do------	------	------	------	------	------	------	27	------
25cb	65	----do------	53	------	------	------	------	------	68	------
26ab	50	Aug. 17, 1955	------	------	------	------	------	------	75	------
26ad1	40	Oct. 12, 1956	------	25	.99	.00	298	87	91	9.2
30bd1	245	Sept. 26, 1952	56	30	.43	.03	71	11	23	3.9
	245	Aug. 15, 1955	------	37	.01	.42	64	13	24	4.5
8-3-3ad	--------	Aug. 5, 1955	------	------	------	------	------	------	29	------
27dc	120	----do------	54	------	------	------	------	------	36	------
8-4-2bc	140	----do------	49	------	------	------	------	------	19	------
7ac	130	----do------	53	------	------	------	------	------	20	------
25cc	190	Aug. 4, 1955	50	------	------	------	------	------	24	------
25dd1	160	Aug. 15, 1955	------	40	.03	.00	59	11	24	5.2
32cb	--------	Aug. 5, 1955	------	------	------	------	------	------	24	------

[a] Not collected by Geological Survey personnel.
[b] Sum of determined constituents.

sometimes called temporary hardness because boiling the water will cause the calcium carbonate to precipitate.

In the Milligan-Ohiowa area, where the Quarternary deposits consist mostly of fine-grained sediments, the water is of the same general type but is more mineralized (500–1,000 ppm) and much harder (200–650 ppm). Water from one well due west of Geneva and near the county line is chemically similar to water in the Milligan-Ohiowa area. There the saturated Quaternary deposits also are mostly fine grained but are much thinner than in the Milligan-Ohiowa area.

The most mineralized water in the Quaternary deposits in Fillmore County, of which water from well 8–2–25cb is an example, is that in the perched zone of saturation in the general vicinities of Fairmont and Exeter. This water is of the calcium sulfate type and hardness exceeds 700 ppm.

TABLE 3.—*Chemical analyses of water from School Creek and unnamed branch of Turkey Creek*

Location	Date of collection	Temperature (°F)	Sodium (Na)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Specific conductance (micromhos per cm at 25°C)	pH
7-1-31dd	Apr. 11, 1956	74	11	75	0	53	0	31	165	7.3
8-4-16cb	Apr. 13, 1956	50	24	251	0	202	0	20	487	7.9

of ground water—Continued

million except as indicated]

Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids (residue on evaporation at 180°C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Specific conductance (micromhos per cm at 25°C)	pH
232	0	61	21	0.3	0.0	0.05	338	219	29	21	525	7.4
206	0	------	------	------	------	----	--------	181	12	19	441	7.5
258	0	------	------	------	------	----	--------	255	43	16	580	7.5
272	0	73	9.0	.3	.4	.06	376	258	35	15	579	7.3
271	0	62	8.5	.2	.2	.08	358	253	31	15	567	7.6
256	0	------	------	------	------	.08	--------	216	6	18	517	7.5
377	0	------	------	------	------	----	--------	546	237	11	1,100	7.6
345	0	------	------	------	------	.06	--------	495	212	14	1,050	7.4
191	0	------	------	------	------	.05	--------	129	0	31	377	7.4
376	0	------	------	------	------	.04	--------	976	668	13	1,830	7.3
446	0	------	------	------	------	----	--------	594	228	22	1,360	7.4
497	0	865	6.5	.3	11	.12	[b]1,640	1,100	692	15	2,030	7.3
265	0	39	19	.2	1.1	.04	342	224	7	18	511	7.3
260	0	29	17	.1	.0	.04	320	212	0	19	510	7.3
174	0	------	------	------	------	----	--------	289	146	18	697	7.0
329	0	------	------	------	------	----	--------	402	132	16	926	7.5
249	0	------	------	------	------	----	--------	195	0	18	470	7.5
289	0	------	------	------	------	----	--------	224	0	16	524	7.6
248	0	------	------	------	------	.03	--------	200	0	21	496	7.6
244	0	23	15	.1	1.4	.04	302	192	0	21	473	7.3
242	0	------	------	------	------	----	--------	185	0	22	475	7.4

Water from well 6–1–23aa (table 2), which taps the Dakota Sandstone, is of the sodium bicarbonate type and is about as mineralized as the perched water in the Quaternary deposits. It is extremely soft, having a hardness of only 8 ppm. This water, however, contains 6.3 ppm of fluoride, which is considerably more than the 1.5 ppm limitation recommended by the American Water Works Association (1950). Reportedly, children reared in the household that obtains water from this well are afflicted with dental fluorosis (mottled enamel), which is a condition caused by drinking water with excess fluoride during the period of tooth formation. Water from this well also contained 3.9 ppm boron. This concentration is considerably more than permissible limits (0.33 ppm) for boron-sensitive plants.

Where supplies for irrigation in the county are obtained from deposits of Quaternary age, the water is quite suitable for application to crops. The total mineral concentration is low; sodium is present in small quantities, bicarbonate concentrations are balanced by calcium and magnesium, and boron is present only in negligible amounts. Except that the water is hard and may contain objectionable concentrations of iron and manganese, it is satisfactory for public supplies and for rural domestic use. Water from wells in areas where only small supplies can be obtained generally is not of good quality for domestic purposes but can be used for watering lawns and gardens and for livestock supplies.

The analytical results for water from School Creek indicate that at the time and place of sampling, the water was largely base flow that is derived from fluvial sand and gravel of Quaternary age. The sample from the branch of Turkey Creek was so much more dilute and soft that it must have consisted either largely or wholly of overland runoff.

CONCLUSIONS

The vast quantity of water stored in the ground-water reservoir beneath Fillmore County is a valuable resource. It can bring economic well being and prevent desolation during the severe droughts that are likely to occur in the county. The amount of water in storage, however, is no indication of a reservoir's capacity to yield water on a sustained basis. A small ground-water reservoir, for example, may have a higher sustained yield than a large one if the small reservoir is recharged more efficiently. The limit of the sustainable yield of any reservoir is set by the recharge to it.

The ground-water development in Fillmore County is relatively new, and it has been rapid. In some localities withdrawals may already exceed the ability of the aquifer to sustain yields to wells.

It is estimated that the annual recharge to the ground-water reservoir is about equal to the average annual withdrawal of 460 evenly distributed irrigation wells. At the end of 1965, 731 irrigation wells had been installed in the county, and no doubt many more will be installed in the future. Thus, the potential rate of withdrawal of ground water is much greater than the annual rate of replenishment. When ground water is withdrawn at a more rapid rate than it is replenished, the deficit is removed from storage, and the water table declines at a rate proportional to the rate of the excessive withdrawal of water.

A declining water table inevitably results in reduced yields of wells. Moreover, reduced yields may occur in a short time in the places where the aquifer is thin and where wells are already being pumped to the maximum of the water-yielding capacity of the aquifer. In places where the aquifer is thick and highly permeable, many years may elapse before the decline of the water table will seriously affect well yields because lowered water levels may be compensated for by deepening wells, lowering pumps, and increasing power in proportion to lift.

The following quotation by Thomas (1952, p. 74) is applicable to the effective use of ground water in Fillmore County:

> Most men would like to have security in their water sources; they would like, in other words, to be assured that their wells or springs or streams or reservoirs or what not will provide the water they need year after year. Even a lifetime is not enough, for they would like to pass that security on to succeeding generations.

Most water sources can provide this security to some degree, because they are renewed or replenished naturally. Man, in his development and use of the water resources, may elect to limit that use to the quantity that nature is capable of replenishing. Or, as an alternative, he may improve or expand the natural facilities for replenishment. Effective use of an aquifer for sustained yield can be achieved by either method. But either method requires an adequate knowledge of the limitations imposed by nature. The quantity of water yielded by "mining"—withdrawing it at rates greater than it is replenished—cannot be sustained perennially.

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