Ground-Water Resources of Hamilton County Nebraska

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1539-N

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

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

Keech—GROUND-WATER RESOURCES OF HAMILTON COUNTY, NEBR.—Geological Survey Water-Supply Paper 1539-N

Ground-Water Resources of Hamilton County Nebraska

By C. F. KEECH

With a section on the CHEMICAL QUALITY OF THE WATER

By P. G. ROSENE

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1962

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C.

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GROUND-WATER RESOURCES OF HAMILTON COUNTY, NEBRASKA

By C. F. Keech

ABSTRACT

Hamilton County includes an area of about 538 square miles and in 1960 had a population of 8,665. The general physiography of the county is that of an almost level eastward-sloping depositional plain, the original surface of which has been slightly modified by stream erosion and wind action. The West Fork of the Big Blue River is the only perennial stream in the county. Ephemeral streams, which flow only during and after heavy rains, are the Big Blue River, Lincoln Creek, and Beaver Creek. The Platte River, which forms the northwest boundary of the county, flows during the winter months but usually is dry during the summer. The climate is subhumid, the normal annual precipitation being about 24 inches. Agriculture is the principal industry in the county; corn is the most important crop. More than 113,000 acres was irrigated with water pumped from 1,196 wells in 1957.

Hamilton County is in the southeastern part of the loess-plains region of Nebraska, just west of the glaciated region. Sand and gravel, and associated silt and clay deposits of Quaternary age, mantle the area. The parts of these deposits that are below the water table are saturated and yield large quantities of water to wells.

The deposits of Quaternary age rest on an eroded bedrock surface of rocks of Cretaceous age, except in one small area in the southwestern part of the county where they rest on a remnant of deposits of Tertiary age. The deposits of Tertiary age are partly consolidated fine-textured sand, silt, and clay. These deposits are saturated and may yield water to some wells. The rocks of Cretaceous age have little significance as potential source of ground water in Hamilton County.

The water that is available to wells in the county is derived principally from precipitation; the recharge through the soil is believed to average about 40,000 acre-feet per year. Some recharge is also obtained from the Platte River when it is in flood stage, but the amount thus received is relatively small compared to that received from precipitation.

The use of ground water for irrigation has increased greatly since 1952, and analyses of the hydrologic data indicate that the ground-water discharge exceeds the recharge. The natural recharge is about equal to the amount of water required to irrigate one-ninth of the land. Development in 1957 had reached the point where almost one-third of the land in the county was being irrigated with ground water.

The ground water is generally of relatively low mineralization and in most of the county is of the calcium bicarbonate type. Near the north and west borders of the county, the relatively high mineralization and high concentrations of sulfate in the ground water probably are due in part to recharge from the Platte River. The continued lowering of the water table may cause the more mineralized water in the western part of the county to move into the areas where the water is now the least mineralized. The water is suitable for irrigation, domestic, and many industrial uses.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

The investigation of which this report is based is part of a long-term cooperative program of study of the ground-water resources of Nebraska that was begun in 1930 by the U.S. Geological Survey and the Conservation and Survey Division, University of Nebraska. It is sixth of a series of detailed local investigations that have been made under that program. Logs of test holes in Hamilton County have been duplicated and may be obtained on request from the Conservation and Survey Division of the University of Nebraska (Keech, 1960a). Water-level measurements obtained in Hamilton County prior to 1957 are on open file at the U.S. Geological Survey, Lincoln, Nebr.; measurements made during and after 1957 are available from the Conservation and Survey Division, University of Nebraska, as Nebraska Water Survey Papers 4 to 6.

In 1945, the ground-water investigations in Nebraska were intensified by the Geological Survey as part of the program by the U.S. Department of the Interior for the development of the Missouri River basin. Several reports which describe hydrologic conditions in the state have been prepared under this program. One of these (Johnson and Keech, 1959), which describes the Big Blue River basin above Crete, Nebr., contains considerable geologic and hydrologic data on Hamilton County.

Before the end of World War II, the chief use of ground water in Hamilton County was for domestic, stock, and public supplies, and demands for large amounts of water were few. However, since about 1946 many farmers have begun irrigating with ground water, and the progressive increase in its use for irrigation in Hamilton County has caused concern among residents as to the possibility of depletion of the available supply. This investigation was made to provide a better understanding of the quantity and quality of the available supply, the probable safe yield of the ground-water reservoir, and the possibility of developing additional supplies. The report includes basic data that should prove useful in future studies, because the pumping of large quantities of ground water is certain to raise many quantitative problems. Records of wells in Hamilton County have been published as Nebraska Water-Survey Paper 7 (Keech, 1960b). Ground-water draft in part of the county as of 1958 had reached a stage where further increase of pumpage would lower the regional water table to the extent that, in localities where the saturated deposits are thin, the supply would be inadequate for irrigation.

As part of the investigation, the ground water was also studied to determine the chemical quality and type, to relate its quality to the geology and hydrology, and to evaluate its suitability for use.

LOCATION AND EXTENT OF THE AREA

Hamilton County is in southeastern Nebraska (fig. 1), about 65 miles due west of Lincoln, Nebr. The bordering counties are Merrick on the north, Polk and York on the east, Clay and Adams on the south, and Hall on the west. The Platte River, flowing in a northeasterly direction, forms the 32-mile northwestern boundary; the western boundary is about 12 miles long, the southern boundary, 24 miles, and the eastern boundary, about 32½ miles. The county includes an area of 538 square miles, or 344,320 acres.

PREVIOUS INVESTIGATIONS

The earliest investigation of the ground-water resources of the area was made by Darton (1898), who described the physiography, geology, and ground water in a portion of southeastern Nebraska that included Hamilton County. As part of an investigation of the ground-water resources of south-central Nebraska, Lugn and Wenzel (1938) studied the western half of Hamilton County and the portion of the county that lies in the Platte River valley. Unpublished geologic and hydrologic data compiled by E. C. Reed, which consists of maps showing types of land, configuration of the water table, depth to water, thickness of the saturated materials, and geologic cross sections, are available in the open file at the University of Nebraska. Test drilling was done in Hamilton County during several periods from 1931 through 1949 by the Conservation and Survey Division of the University of Nebraska, in cooperation with the U.S. Geological Survey. The logs of these test holes are available from the Conservation and Survey Division, University of Nebraska (Keech, 1960a). Johnson and Keech (1959) studied Hamilton County as part of the investigation of the geology and ground-water hydrology of the Big Blue River basin above Crete, Nebr. Keech and Dreeszen (1959) reported on the geology and ground-water hydrology of Clay County, which is adjacent to Hamilton County on the south border.

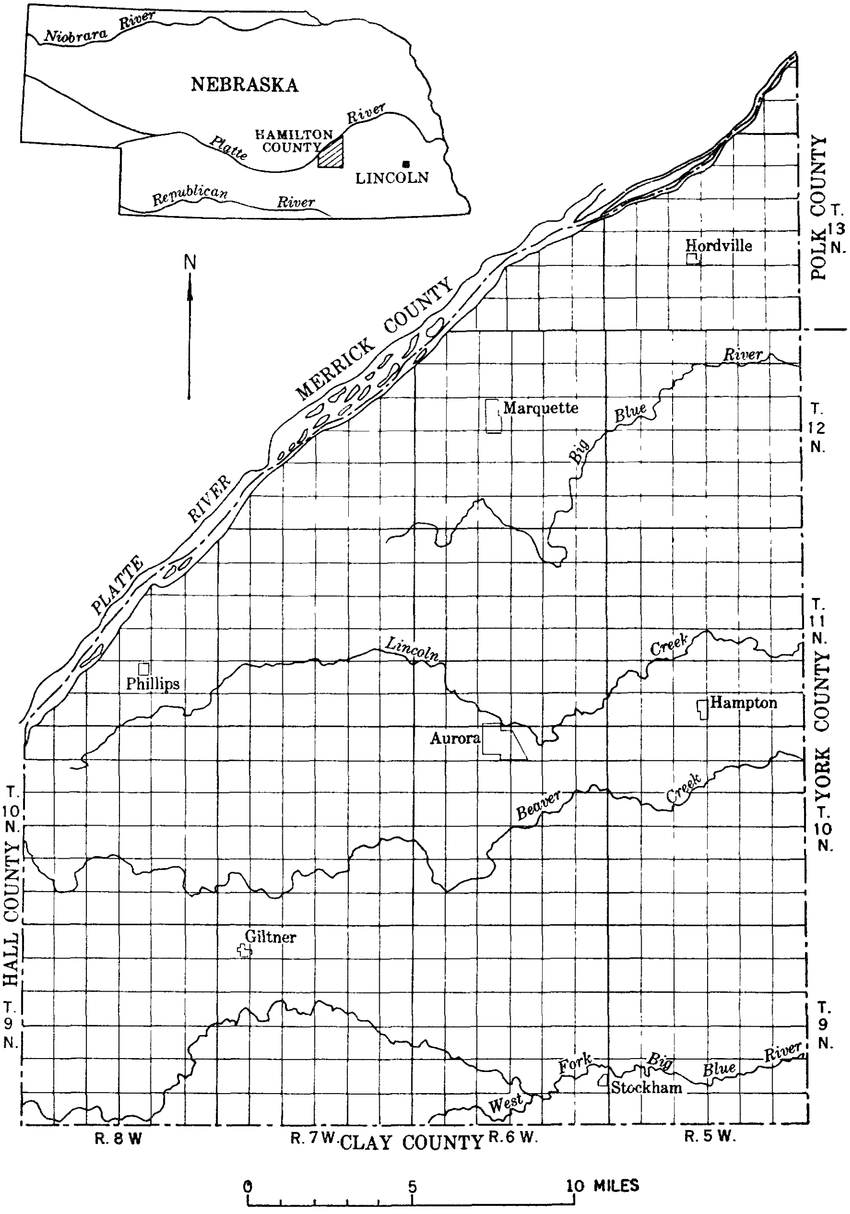

FIGURE 1.—Index map of Hamilton County, Nebr.

METHODS OF INVESTIGATION

The field data on which this report is based were collected during the summers of 1956 to 1958. All irrigation and public-supply wells were visited in the field, and well schedules were written giving the following information where available: well numbers, owner or user, year drilled, depth of the well, type of pump and power, diameter and type of casing, a description of the measuring point, depth of water, date of measurement, yield and drawdown, use of the water, and availability of chemical analyses and water-level measurements (Keech, 1960b). Water samples collected from 34 representative wells were analyzed in the laboratory of the U.S. Geological Survey, Lincoln, Nebr., by standard Survey methods (Rainwater, 1960).

Well drillers, farmers, soil conservationists, and superintendents of public water supplies were interviewed to obtain information on the use of water in the county, and all available well and test-hole records were collected. Farmers using ground water for irrigation were interviewed concerning irrigation practices, present and past water use, type of crops grown, and plans for additional wells or increased use of ground water.

Periodic depth-to-water measurements have been made at irregular intervals for a number of years in eight wells. (See figures 10–12.)

WELL-NUMBERING SYSTEM

Wells and test holes are numbered in this report according to their location within the system of land subdivision of the U.S. Bureau of Land Management. The first numeral in the number 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 160-acre and 40-acre subdivisions of the section are lettered *a*, *b*, *c*, and *d* in a counterclockwise direction, beginning in the northeast quarter. Figure 2 illustrates this well-numbering system.

PERSONNEL AND ACKNOWLEDGMENTS

Many persons have gathered parts of the information upon which this report is based, but special credit is due Thomas R. Bischof, who collected most of the information on irrigation wells, and to James W. Nelson, who made many of the depth-to-water measurements and participated in other fieldwork. Messrs. Bischof and Nelson were employed by the U.S. Geological Survey.

E. C. Reed, State Geologist and Director of the Conservation and Survey Division of the University of Nebraska, reviewed the manu-

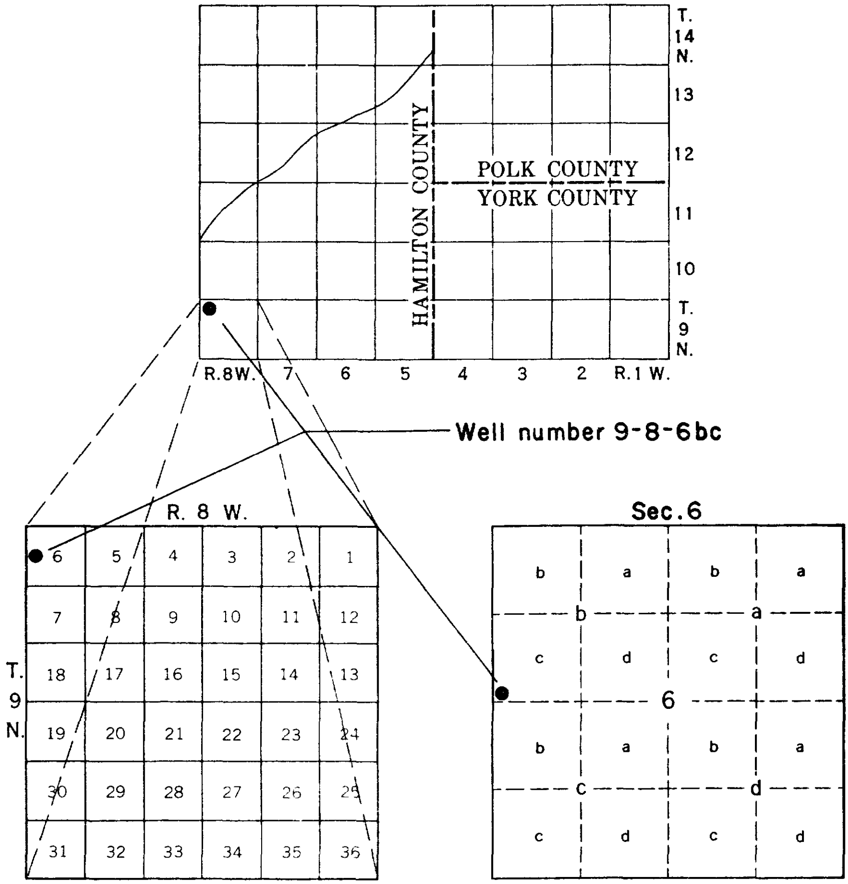

FIGURE 2.—Sketch showing well-numbering system.

script and supplied many unpublished data that have been included in the report. Special acknowledgment is due V. H. Dreeszen, Assistant Director of the Conservation and Survey Division, for the preparation of the geologic sections and assistance in many phases of the field investigations.

Appreciation is also expressed to the many farm operators, well drillers, and other persons who cooperated and assisted in the collection of field data. C. M. Mead, county agricultural extension agent, and Gilbert Barnell, representative of the Hamilton County Irrigation Association, furnished data for many irrigation wells. Personnel of the U.S. Soil Conservation Service at Aurora, Nebr., provided much information regarding names of well owners and locations of wells.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

Hamilton County is in the physiographic region of the state known as the Nebraska Plain (Lugn, 1935, p. 16). The general physiography of the county is that of an almost level eastward-sloping plain that has been slightly modified by stream erosion and wind action. Most of the county is an upland surface; the remainder consists of narrow terraces and flood plains along the streams. The Platte River, which forms the northwest boundary of the county, has eroded a broader and deeper valley than has been eroded by other large streams in the county. This valley lies at an average depth of about 100 feet below the general level of the upland. To the south it is bordered by steep bluffs, which are sharply dissected by deep ravines except where the deposits are very sandy. The surface on the higher part of the slopes is highly dissected, whereas the surface on the sandy areas on the lower part is relatively smooth. The floor of the Platte River valley, as viewed from the upland, appears to be a level plain that stretches from the foot of the bluffs to the river. Actually, however, the surface of the valley floor ranges from level to undulating, and the bottom lands include both well-drained and poorly drained areas. The terraces bordering the flood plain are mostly well drained.

The larger streams within the county are bordered by belts of alluvium, most of which are well drained.

Drainage of Hamilton County is chiefly through the Big Blue River and its tributaries; the Platte River drains only a narrow strip less than 3 miles wide along the north border of the county. The West Fork of the Big Blue River and the lower reaches of Beaver Creek flow perennially; all the other streams are dry most of the year and flow only during and for a short time after rains. A few small basins occur on the level uplands where drainage is not established. These depressions, because of their fine-textured surface soil and subsoil, hold water for long periods after heavy rains, although during long dry periods they dry up.

CLIMATE

The climate of Hamilton County is characterized by great seasonal extremes typical of southeastern Nebraska. The winters are long and cold; the summers are hot. The normal spring is cool and rainy; the fall is long, and characterized by moderate temperature and occasional periods of rainy weather.

More than half the annual precipitation normally falls as thunder showers from May to August. The spring and early summer rains usually are well distributed, though droughts are not uncommon. In dry spring seasons there is sometimes considerable wind, resulting in much blowing dust. The late summer droughts frequently occur when corn, the principal crop, is tasseling. Because this is a critical time in corn growth, irrigation is almost always needed for full crop development. This is true even in years when the total annual precipitation is greater than normal. The average annual snow fall is about 27 inches, about half of which comes during February and March.

Precipitation has been recorded at Aurora, Nebr. since 1880, except for the years 1882–94 and 1915–22. The record is continuous since 1923. Figure 3 shows the annual precipitation and the cumulative departure from average precipitation at Aurora for the period of 1923–57. The graph indicates that the annual precipitation follows a cyclic pattern in that periods of greater than average precipitation alternate with periods of less than average precipitation, and it shows that the precipitation was deficient during the 1930's. During the period 1940–51 the precipitation was greater than average, but this wet period was followed by another drought. Crop failures, however, often result from poor distribution of the precipitation during the

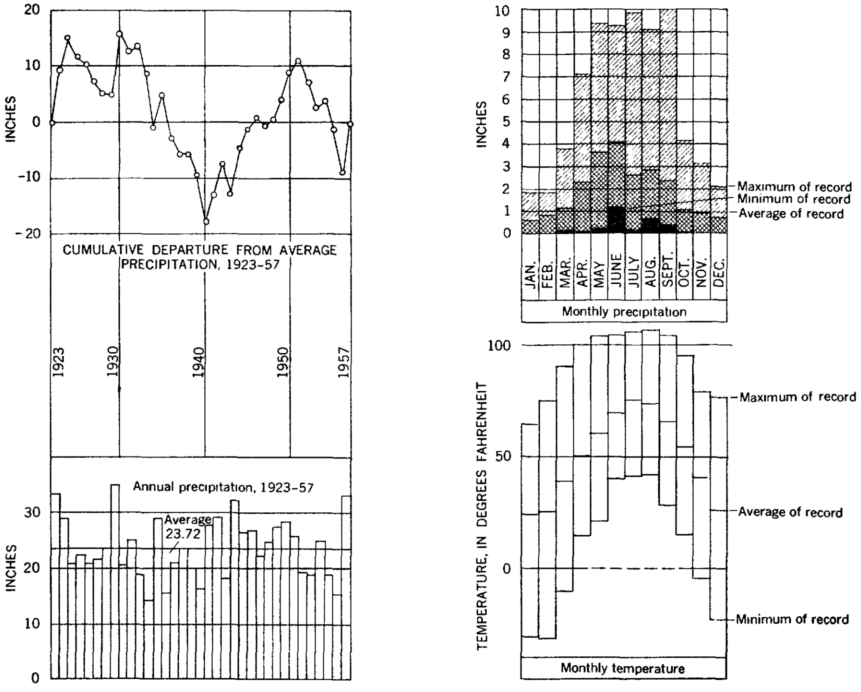

FIGURE 3.—Precipitation and temperatures recorded at Aurora, Nebr., 1923–57 (from records of the U.S. Weather Bureau).

year; occasionally crop production is good in a dry year in localities that happen to receive precipitation at favorable times.

The mean annual temperature in Hamilton County is about 51.5°F. The temperature commonly exceeds 100°F. in midsummer, and in the winter often drops to below zero; lows of —25°F. have been recorded.

POPULATION

The first permanent settlements in Hamilton County were made in 1866, and 4 years later the county was organized, as the result of a general election on May 3, 1870. The 1920 census showed that the population had increased to 13,237, but since the late twenties the population has been decreasing. The 1960 census showed the county to have 8,665 residents, 2,560 of whom lived in Aurora, the county seat and largest town.

TRANSPORTATION

Transportation facilities in Hamilton County are good. There are direct railroad connections from Aurora to Lincoln, Omaha, Grand Island, and other markets important for farm products.

U.S. Highway 34 crosses the county from east to west through Aurora, and State Route 14, which is hard surfaced south of Aurora, crosses the county from north to south. Improved roads are laid out on nearly all section lines and many of these roads are gravel surfaced. Most farmers own trucks in which they transport grain and other produce to rail terminals or directly to market. Livestock is normally trucked directly from the farms to the Omaha livestock market.

SOILS AND AGRICULTURE

Farms occupy about 98 percent of the land area of Hamilton County; with few exceptions, they range in size from 160 to 240 acres. Corn, wheat, alfalfa, grain sorghums, and oats are the principal crops.

Except on the slopes and the flood plain of the Platte River valley, where much of the land is in pasture or hay, the soils of Hamilton County are suited to all crops common to the region. Most of the soils of Hamilton County are excellent for cultivation and are particularly well suited to growing of corn. The subsoils and the topsoils are friable and well developed but are underlain by a heavy claypan (a term used locally to indicate soils that are clayey and poorly drained) at a depth of 8 to 20 inches below the land surface. During abnormally wet seasons fields underlain by claypan are too wet for cultivation; during very dry weather the surface soils above the claypan layer dry out and crops growing on them soon suffer from lack of moisture because the plant roots, having been limited in their depth of penetration by the almost impervious claypan, are shallow. Where cultivated, these soils are generally used for small grain.

The soils of well-drained terraces in the stream valleys are well adapted to the growing of corn. They are generally sandy and are easily tilled. The sandier of these soils require careful management to prevent severe wind erosion when cultivated.

MINERAL RESOURCES

Except for ground water, Hamilton County has no known mineral resources of economic significance. Sand and gravel, used principally for road cover, are obtained from deposits of Pleistocene age along the Platte River.

GEOLOGY

STRATIGRAPHIC UNITS AND THEIR WATER-BEARING PROPERTIES

The stratigraphic units at and near the surface in Hamilton County consist of a mantle of silt, clay, sand, and gravel of Quaternary age. These unconsolidated sediments were deposited on a relatively uneven, eroded bedrock surface underlain by rocks of Cretaceous and Tertiary age. (See fig. 4.)

The Ogallala formation, a stream deposit of Tertiary age, is the youngest bedrock in Hamilton County; it immediately underlies the Quaternary deposits locally in the western part of the county. Rocks of Cretaceous age, which underlie the Pleistocene and Tertiary strata, are, from youngest to oldest: the Niobrara formation, Carlile shale, Greenhorn limestone, Graneros shale, and Dakota sandstone.

The Cretaceous rocks consist of beds of shale, chalky limestone, and sandstone, which dip gently to the northwest. These were eroded to an eastward-sloping surface prior to the deposition of rocks of Tertiary age, which were subsequently mostly reworked during Pleistocene time. The Cretaceous rocks are underlain by a considerable thickness of older sedimentary rocks of Permian, Pennsylvanian, Mississippian, Devonian, Silurian, Ordovician, and Cambrian age, and these rocks are underlain by igneous or metamorphic rocks of Precambrian age.

Large supplies of ground water are obtained throughout Hamilton County from the Quaternary deposits; however, the possibilities of developing water from wells in the older rocks are limited. To date

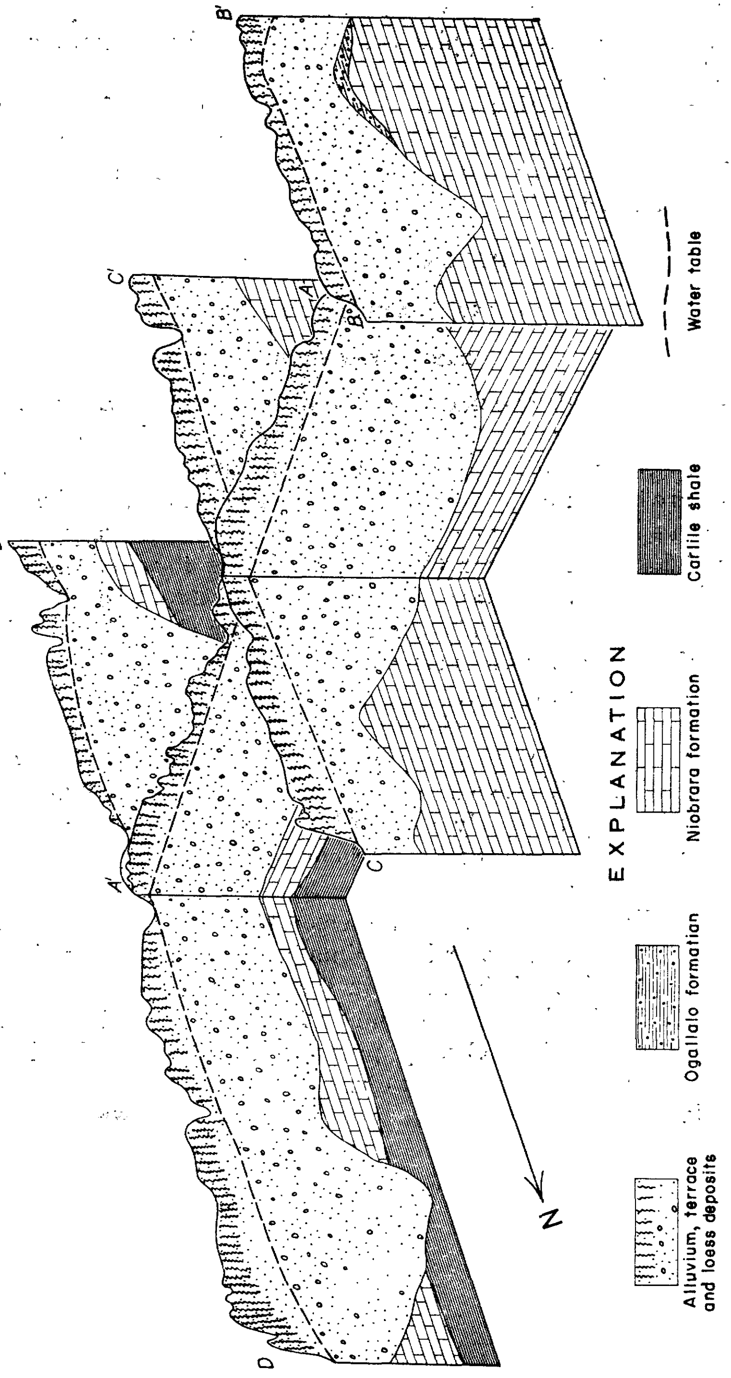

FIGURE 4.—Fence diagram of Hamilton County, Nebr., showing generalized geologic sections.

no attempt has been made to obtain water from the Tertiary and older deposits because ample supplies are available in the shallower aquifers of Pleistocene age.

A generalized section of the stratigraphic units of Quaternary, Tertiary, and Cretaceous age in Hamilton County is shown by table 1, which gives their range in thickness and lithologic character and their importance as sources of ground water.

CRETACEOUS SYSTEM

LOWER CRETACEOUS SERIES

DAKOTA SANDSTONE

The Dakota sandstone underlies Hamilton County at a considerable depth. It consists of a series of interbedded layers of shale and sandstone. Although no test holes or wells sufficiently deep to reach the Dakota are known to have been drilled in the county, tests drilled for oil and gas in adjoining counties indicate that the average thickness of the Dakota in Hamilton County probably is about 350 feet. The formations of Cretaceous age dip westward, and the depth to the upper surface of the Dakota sandstone increases from about 600 feet below land surface in the southeastern corner of the county to about 900 feet in the southwestern corner.

In general, less than half the total thickness of the Dakota sandstone in the vicinity of Hamilton County is sandstone—the rest is clay shale and sandy shale. The sandstone generally is fine to medium grained and is moderately to loosely cemented. The quality of the water contained in the sandstone of the Dakota in Hamilton County is not known. However, analyses of water from the Dakota sandstone in Seward, Saline, Lancaster, and Jefferson Counties, which are southeast of Hamilton County, and at points in western Nebraska indicate that mineralization of the water in the Dakota sandstone increases westward and with depth below land surface. The water in the Dakota sandstone in Hamilton County probably is too mineralized to be suitable for irrigation or domestic use, or even for drinking water for livestock.

TABLE 1.—*Generalized section of the geologic formations and their water-bearing properties, Hamilton County*

System	Series	Stratigraphic unit	Thickness (feet)	Character and distribution	Water supply
Quaternary	Recent	Surficial alluvium, loess, and soil.	0–5±	Widespread soils; flood-plain deposits of clay, silt, sand, and gravel; isolated windblown deposits of silt and clay.	Significant only in that it transmits water to recharge the ground-water reservoir.
	Pleistocene	Unconsolidated deposits, undifferentiated.	30–430	Wind deposits of clay and silt; water-laid and windblown stratified deposits of silt, clay, sand, and gravel; stream-deposited sand and gravel containing layers of clay and silt of wind and stream origin; underlies the entire county.	Principal source of water to wells in the county; yields abundant supplies about in proportion to the saturated thickness of the sand and gravel deposits. Those deposits above the water table are significant principally as a transmitting media in recharge of the ground-water reservoir.
Tertiary	Pliocene	Ogallala formation	0–40	Brownish-gray and gray silt, sandy silt and clayey silt containing lenses of sand and locally a basal gravel; partly cemented but principally unconsolidated.	Not a known source of water supply; may yield water to some domestic wells.
Cretaceous	Upper Cretaceous	Niobrara formation	0–380	Yellow and light- to dark-gray marine chalky shale and chalk; underlies much of the county.	Not a source of water supply to wells.
		Carlile shale	130–285	Medium- to dark-gray marine shale, calcareous in the lower part; underlies all of the county.	Do.
		Greenhorn limestone	25–30	Gray fossiliferous limestone interbedded with calcareous shale; underlies the entire county.	Do.
		Graneros shale	40–65	Dark-gray shale, calcareous in the upper part; underlies all the county.	Do.
	Lower Cretaceous	Dakota sandstone	300–400	Interbedded clay shale, sandy shale, and sandstone; underlies all the county.	Contains mineralized water. Wells in Hamilton County are not sufficiently deep to reach this formation.

UPPER CRETACEOUS SERIES

GRANEROS SHALE

The Graneros shale lies immediately above the Dakota sandstone and is present beneath all of Hamilton County. The depth to the top of the Graneros increases progressively northward and westward. The Graneros shale consists of about equal thicknesses of an upper dark-gray calcareous shale containing thin limestone layers and of a lower noncalcareous dark-gray shale. The average thickness of the Graneros shale is probably about 60 feet. The shale is relatively impervious and does not yield water to wells in the county.

GREENHORN LIMESTONE

A sequence of interbedded gray fossiliferous limestone and calcareous shale named the Greenhorn limestone immediately overlies the Graneros shale throughout Hamilton County. Its thickness averages between 25 and 30 feet; however, the formation was not reached by any of the test holes and no wells are known to penetrate it in Hamilton County. The limestone and shale of the Greenhorn is relatively impervious and is not considered a potential aquifer in the county.

CARLILE SHALE

The Carlile shale overlies the Greenhorn limestone in all of Hamilton County. The formation was penetrated by the drill in all the test holes drilled along the Hamilton-York county line. It ranges in thickness from about 130 feet to about 285 feet in Hamilton County.

The lower 70 to 90 feet of the Carlile shale, known as the Fairport chalky shale member, consists of dark-gray calcareous shale interbedded with thin layers of fossiliferous limestone. The Blue Hill shale member of the Carlile overlies the Fairport chalky shale member. It is principally a medium- to dark-gray noncalcareous clay shale; its thickness in Hamilton County ranges from about 195 to about 215 feet. Locally, a fine-grained sand is present in the upper few feet of the Carlile shale.

The Carlile shale is very fine textured and therefore almost impervious. It does not yield water to wells in Hamilton County.

NIOBRARA FORMATION

The Niobrara formation is a yellow and light- to dark-gray chalky shale and chalk. Owing to oxidation the upper part of the Niobrara formation is yellow, white, orange, and yellow gray over the buried ridges and the side slopes of buried valleys. It immediately overlies the Carlile shale and is the youngest Cretaceous formation in Hamilton County. During early Tertiary time, streams cut through the Niobrara formation into the Carlile shale locally in the deeper parts of the now buried channels. (See geologic section *D–D′*, pl. N-1.) Elsewhere in the county a part of the Niobrara was removed by erosion in late Cretaceous or Tertiary time. The Niobrara formation is thickest in the western part of Hamilton County, where it is estimated to be as much as 380 feet thick.

The Niobrara formation has been subdivided into two members in other parts of Nebraska, the Fort Hays limestone member below and the Smoky Hill chalk member above, but no attempt is made to differentiate them in this area.

No wells in Hamilton County are known to obtain water from the Niobrara formation, and it is not considered to be a potential source of water for wells; however, records on file at the Conservation and Survey Division, University of Nebraska, show that significant yields are obtained from this formation in Nuckolls County and in a few other areas in the state. The water in the formation is believed to be contained in crevices and solution channels, principally in the upper few feet. Crevices or solution channels are more common in the highly weathered shale, but they are not everywhere present. The water in the Niobrara formation probably is more mineralized than water in the overlying formations of Tertiary and Pleistocene age.

TERTIARY SYSTEM

PLIOCENE SERIES

OGALLALA FORMATION

The Ogallala formation of the Pliocene series is the only formation of Tertiary age present, and it underlies only a small part of Hamilton County. It is of continental origin, having been laid down by streams, and consists of interbedded hard and soft layers of sand, silt, and clay. Some layers are cemented by calcium carbonate, but others are relatively unconsolidated. Gradations, both lateral and vertical, from one lithologic type to another are characteristic of the formation. Because some beds of the Ogallala formation are so like some of the Quaternary deposits, it is not always possible to determine, when drilling, the exact depth at which the bit first enters the Ogallala formation. Generally, the first cemented continental bed encountered is considered to be the top of the Ogallala. Only one test hole—9–8–19cc, near the southwest corner of Hamilton County—definitely penetrated cemented beds of the Ogallala formation, where it capped a buried ridge of Niobrara formation (section *B–B′*, pl.

N-1). Elsewhere in Nebraska the Ogallala is an important aquifer, but because of its limited thickness and extent it is not an important source of ground water in Hamilton County.

QUATERNARY SYSTEM

PLEISTOCENE SERIES

The land surface at the end of Tertiary time presumably was a relatively flat constructional plain. During early Pleistocene time, the surface of the Tertiary deposits was eroded and reworked in Hamilton County, leaving only scattered remnants of the deposits in place.

The ridges and valleys that were features of the land surface during early Quaternary time now lie below the thick mantle of unconsolidated deposits of Pleistocene age and the present topography has very little resemblance to that of the bedrock surface. In Hamilton County the material filling the buried channels and in lesser thickness mantling the bedrock hills is largely silt and clay. (See pl. N-1.) A considerable amount of coarse-grained sediment overlies the fine-grained deposits. These are the deposits that yield copious supplies of water to wells.

Three major buried valleys of the drainage system on the surface of the Cretaceous bedrock extend across Hamilton County from west to east (fig. 5). The centerline of the southernmost buried channel passes about 2 miles south of the city of Aurora. (See test hole 10-7-24aa, section *C-C′*, pl. N-1.) The northernmost buried valley passes beneath the village of Hordville. (See test hole 13-4-19cc, section *D-D′*, pl. N-1.) A shallower buried valley that extends across the county south of the village of Marquette was drilled at test hole 12-7-13dd (section *C-C′*, pl. N-1).

Glacial ice sheets that advanced outward from the centers of snow accumulation in Canada were responsible for great changes in the environment of the area of Hamilton County; and, although they did not reach the area, they were responsible directly or indirectly for the accumulation of the tremendous quantities of sand, gravel, silt, and clay that now blanket the area.

When the first of the continental glaciers, the Nebraskan ice sheet, advanced southward into eastern Nebraska, it dammed the eastward draining valleys and caused them to fill with impounded water and eventually to overflow. The overflow followed the ice margin southward until the water reached a valley draining to the Gulf of Mexico. Meanwhile, the blocked valleys were being filled with the sediment that was dropped by the streams as they entered the body of ponded water. During the backward melting of the glacier, the older de-

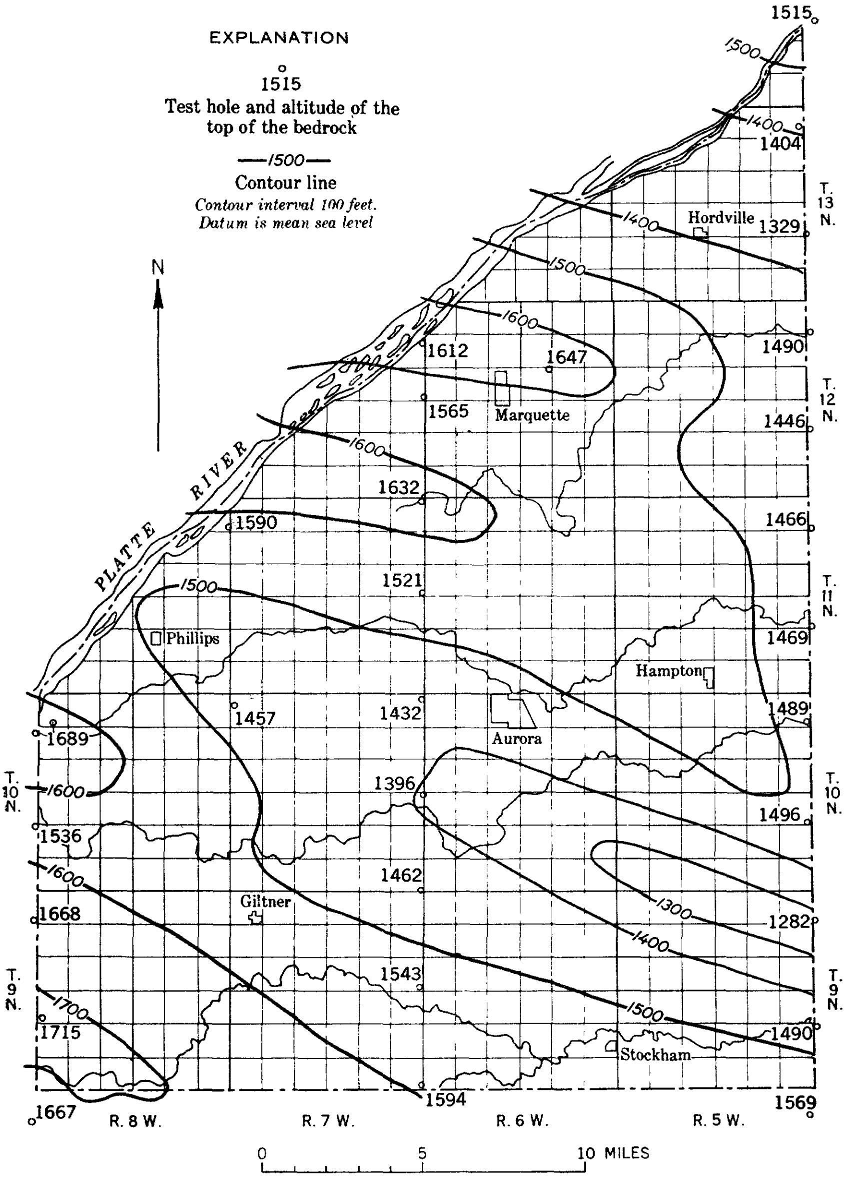

FIGURE 5.—Map of Hamilton County, Nebr., showing configuration of the surface of the Cretaceous rocks.

posits were mantled by fine-grained materials that were partly wind deposited and partly stream deposited. During the interglacial stage that followed, the streams again entrenched and broadened their valleys; thus, they removed much of the material that had been deposited during the Nebraskan glacial stage. When the second continental glacier, the Kansan ice sheet, advanced into eastern Nebraska, ice again blocked the valleys and caused them to be filled with coarse sediments. These coarse sediments also were mantled with fine-grained material during the waning phase of the Kansan glaciation.

There were four major glaciations—Nebraskan, Kansan, Illinoian, and Wisconsin, each having a similar cycle of erosion and deposition (see fig. 6). Each glaciation was followed by a period in which the climate became warmer and the ice front melted back. River flats,

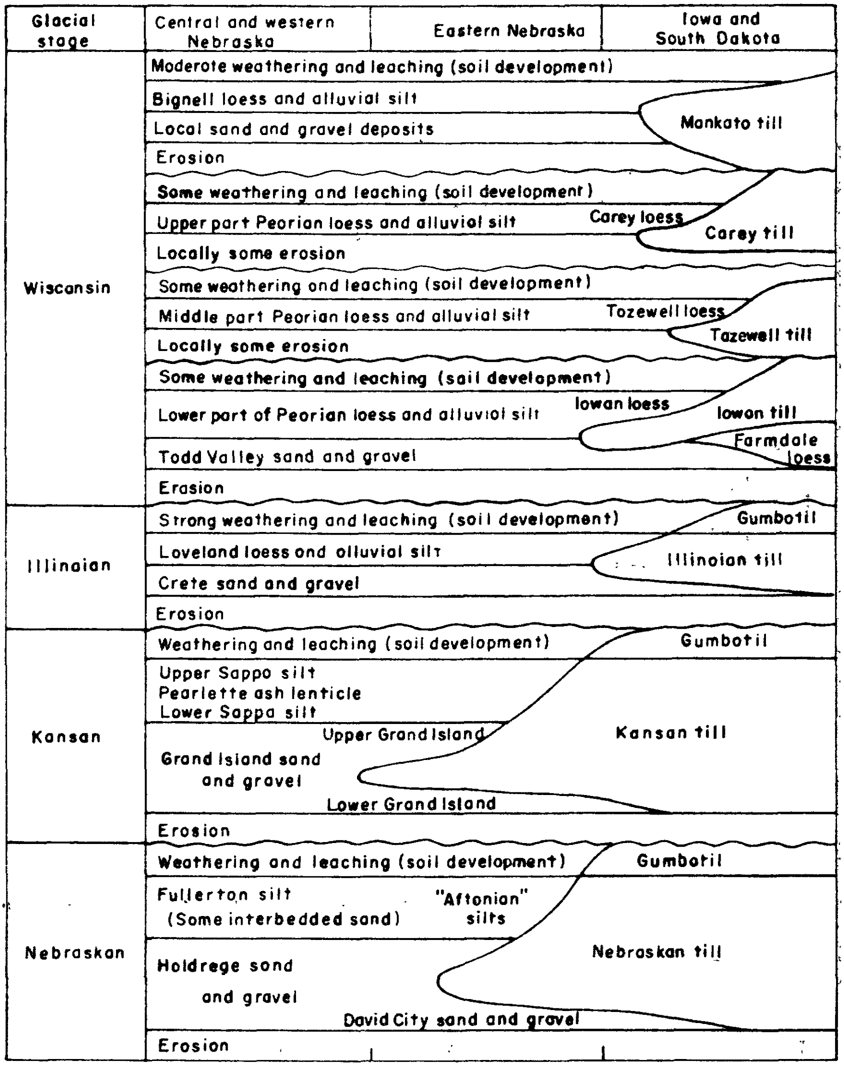

FIGURE 6.—Correlation table showing the relation of the Pleistocene formations to continental glaciation in Nebraska (after Condra, Reed, and Gordon, 1950).

kept free of vegetation by frequent flooding, were subject to wind erosion, and great quantities of silt were blown into the uplands bordering the valleys to form the loess deposits that mantle much of Hamilton County. During the longer pauses in deposition, soils developed. Such fossil soils can be seen in road cuts at some places in Hamilton County.

Figure 6 is a correlation table after Condra, Reed, and Gordon (1950), showing the stratigraphic units of the Pleistocene as used by the Nebraska Geological Survey. The deposits of Pleistocene age have not been differentiated in this report but are considered as a single stratigraphic unit.

The sand and gravel deposits of Pleistocene age are the principal aquifers in the county. Wells of moderately large to large yield may be obtained from these deposits in all parts of the county.

RECENT SERIES

The deposits of late Pleistocene age grade into those of Recent age with no sharp line of demarcation. The topsoil, surficial wind-blown loess, and stream and slope-wash clay, silt, sand, and gravel constitute the deposits of Recent age. The wind-blown and slope-wash deposits generally are thin, commonly only a few inches thick in their maximum development over the uplands. Stream-laid material consisting of reworked sediments of Pleistocene age may be as much as 5 feet thick in the major valleys.

GROUND WATER

PRINCIPLES OF OCCURRENCE

All water beneath the surface of the earth is termed subsurface water. Below some level beneath the land surface, the permeable rocks generally are saturated with water under hydrostatic pressure. The subsurface water in the zone of saturation is termed "ground water," whereas subsurface water above the zone of saturation is termed "suspended subsurface water," or vadose water. Ground water is the part of subsurface water that is available through wells or springs, and its upper surface is known as the water table. The depth to the water table below the land surface and the thickness of the zone of saturation differ greatly in different localities. In some areas the zone of saturation is overlain by relatively impervious material that confines the ground water under pressure, and in other areas water is suspended above the main water table because of relatively impervious material that hinders the downward movement of water to such an extent that it forms an upper or perched zone of saturation.

Water that is confined under pressure is known as artesian water, and an upper zone of saturation separated from the principal ground water by unsaturated deposits is called perched water.

Some of the ground water in Hamilton County may be under slight artesian pressure, but perched water is found only in a few isolated areas, and it is not known in quantities large enough to furnish water supplies to wells.

The ground water available through wells in Hamilton County is derived almost entirely from precipitation that falls as rain or snow within the area or in areas to the west. Part of the water that falls as rain or snow is carried away as surface runoff, and part of it evaporates or is transpired by growing vegetation. The part that is not disposed of as runoff, evaporation, and transpiration infiltrates the soil and underlying strata and eventually joins the body of ground water in the zone of saturation.

The rocks that form the crust of the earth generally are not solid throughout but contain numerous open spaces called voids or interstices. These spaces are the receptacles that contain ground water. They range in size from microscopic openings to the large caverns developed in limestones. The ratio, expressed as a percentage, of the volume of the open spaces or voids to the total volume of the rock is the porosity of the rock. When considering problems of ground-water supply, knowledge of the porosity of the water-bearing materials is desirable; however, the permeability of the materials rather than their porosity controls the rate at which water can move through them. The permeability of a rock—its capacity for transmitting water under pressure—is governed by the size, shape, and arrangement of the openings. For example, a bed of fine silt or clay may have a relatively high porosity, but because of the small size of the rock particles each opening is very small. Because molecular attraction holds a thin layer of water on the surface of each grain, these layers of water are not free to move and may fill or almost fill the

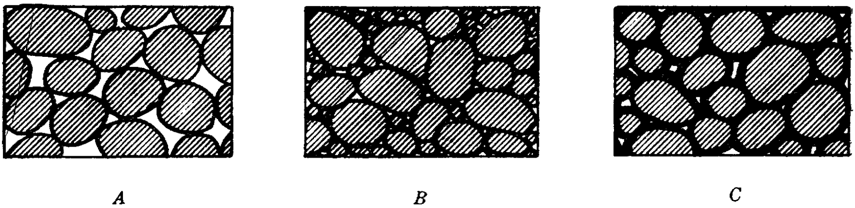

FIGURE 7.—Diagram showing three types of rock interstices and the relation of rock texture to porosity. *A*, Well-sorted sedimentary deposits having a high porosity; *B*, poorly sorted sedimentary deposits having low porosity; *C*, well-sorted sedimentary deposits whose porosity has been diminished by the deposition of mineral matter in the interstices (after Meinzer, 1923).

openings of fine-textured sediments. Thus, the permeability, or water-transmitting capacity of the material, is very low even though its porosity, or water-holding capacity, is very high. Likewise, larger openings that are not connected may produce a high porosity and a low permeability. Water moves most freely through a rock that has relatively large and well-connected openings.

Three common types of openings, or interstices, and the relation of rock texture to porosity are shown by figure 7.

THE WATER TABLE AND DIRECTION OF GROUND-WATER MOVEMENT

Ground water moves slowly through the voids in the rocks and in the direction of the slope of the water table (see fig. 8) ; the slope of the water table is controlled by the permeability and thickness of the water-bearing materials, the topography, local variations in the quantity of recharge and discharge, and the stratigraphy and structure of the rock formations. The ground water is eventually discharged through springs or wells, through seeps into streams, or by evaporation and transpiration.

The water table is defined as that surface, within the zone of saturation, over which the pressure everywhere is atmospheric. It is not level but generally is a sloping surface having many irregularities, which are caused by several factors. In places where the amount of recharge is exceptionally high, the water table may rise and form a mound or low ridge from which the water slowly spreads out. In material of low permeability these mounds or ridges may be pronounced, but in very permeable material they generally are of small relief. Depressions in the water table may indicate places where the ground water is discharging, as along streams that are below the normal level of the water table or in places where water is withdrawn by wells or vegetation.

The water table follows in a general way the configuration of the land surface. Thus, in Hamilton County the ground water moves from the uplands towards the streams and, if not intercepted by transpiration, it discharges to the streams. The water table in Hamilton County is in most places a few feet below the streambeds. With the exception of the Platte River and the West Fork of the Big Blue River, the streams generally receive no ground-water seepage.

Plate N–2 shows the shape and slope of the water table in Hamilton County by contour lines that connect points of equal altitude on the water table. The contours are based on altitudes of static water levels in 140 wells, obtained by subtracting the measured depths to water in the wells from the altitudes of the measuring points. The altitudes of the measuring points of wells and of the land surface at the test-

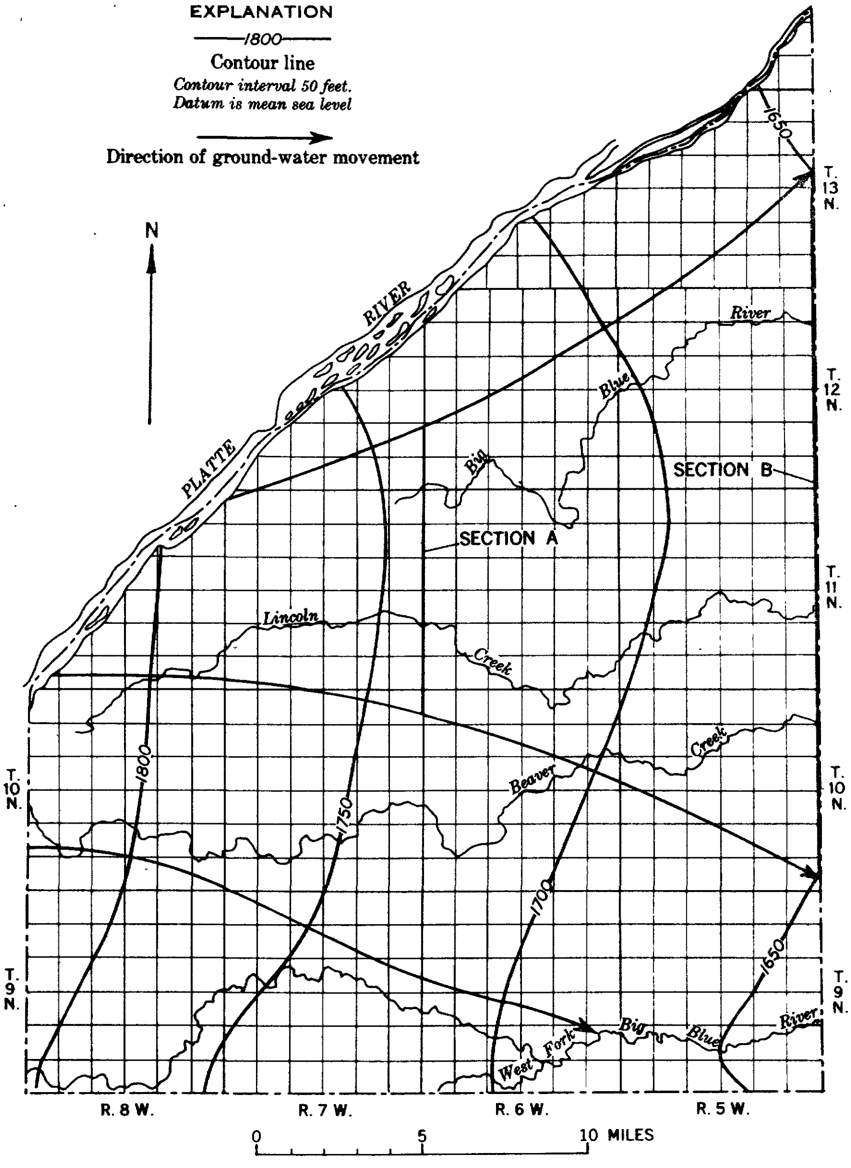

FIGURE 8.—Map of Hamilton County, Nebr., showing configuration of the water table and the direction of ground-water movement, June 1958.

hole sites were determined by means of altimeter surveys or by spirit leveling from points of known altitude.

The water table in Hamilton County slopes generally eastward at an average gradient of about 7 feet to the mile. Contours that bend upgradient or toward the west indicate depressions or troughs in the water table. The most pronounced trough occurs in the valley of the West Fork of the Big Blue River and is due to the discharge of ground water into the river (see section *D—D′* pl. N–1). The contours that are spaced far apart indicate a relatively gentle slope, whereas the contours that are spaced close together indicate a steep gradient.

HYDROLOGIC PROPERTIES OF THE WATER-BEARING MATERIALS

POROSITY AND SPECIFIC YIELD

The amount of ground water that can be stored in an aquifer (a water-bearing material or rock) depends on the porosity of the aquifer. A rock is said to be saturated when all its interstices are filled with water.

Ground-water storage within an aquifer may be construed to be one of two quantities: (a) The total amount of water within the aquifer; or (b) the amount of the stored water that will move out of the pore spaces under the force of gravity—the storage that is available to wells, springs, and streams. Part of the water in all rocks is held by the force of molecular attraction, which in fine-grained rocks such as silt and clay is great enough to retain most of the water against the force of gravity.

The proportion of water in an aquifer that will drain by gravity is expressed by the term "specific yield." The specific yield of an aquifer is defined by Meinzer (1923, p. 28) as the "ratio of (a) the volume of water which, after being saturated, it will yield to (b) its own volume." This means that if 1 cubic foot of saturated water-bearing material will yield under the force of gravity a volume of water of 0.20 cubic foot, the specific yield of that material is 0.20 or 20 percent, and under natural conditions, recharge of 0.20 foot of water will produce a rise of the water table of 1 foot. Conversely, a decline of the water table in this aquifer of 1 foot indicates the loss of water equivalent to a depth of water of 0.20 foot distributed over the area of decline.

The term "coefficient of storage" or "storage coefficient" often is used in describing hydrologic properties of aquifers. By definition, the coefficient of storage of an aquifer is the volume of water it releases from 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 it is generally equal to the specific yield.

PERMEABILITY AND TRANSMISSIBILITY

The amount of water a given rock can hold is determined by its porosity, but the rate at which it will transmit water is determined by its permeability. The permeability of a water-bearing material is measured by the rate at which the formation will transmit water through a given cross section under a given difference in head per unit of distance. The coefficient of permeability in Meinzer's units may be expressed as the rate of flow of water in gallons per day (gpd) through a cross-sectional area of 1 square foot under a hydraulic gradient of 1 foot per foot at a temperature of 60°F (Wenzel, 1942, p. 7). The field coefficient of permeability is the same except that it is not corrected for temperature.

Gravel is the most productive water-yielding material in Nebraska. Gravel deposits are highly permeable and have high specific yields. Well-sorted sand ranks next to gravel as an ideal aquifer. However, in sand the voids or interstices between grains are smaller, hence it conducts water less readily and yields a smaller proportion of its water to wells. Fine sand particles are readily carried into wells by water and may create difficult problems during the drilling, development, and pumping of wells.

Of the ground water used in Hamilton County, nearly all is pumped from sand and gravel deposits of Pleistocene age. Most of these beds consist of relatively well sorted sand and gravel, and where they are sufficiently thick they are capable of supplying large amounts of water to properly constructed wells.

The permeability of water-bearing materials may be determined directly by laboratory tests of samples of the materials or indirectly from determinations of ground-water velocity in the field, and from observations of the fluctuations of water levels in nearby wells when a well is pumped. The physical properties of the geologic formations in the Platte River valley were reported by Lugn and Wenzel (1938, p. 96). These strata extend under Hamilton County and are believed representative of the water-bearing materials tapped by all the large wells in the county. The average coefficient of permeability as computed in a 48-hour pumping test in a well in the NW¼, sec. 17, T. 11 N., R. 8 W., across the Platte River from Phillips, was 997 gpd per square foot (Lugn and Wenzel 1938, p. 101). The average coefficient of permeability, as measured in the laboratory, of 19 samples of the water-bearing material obtained during the drilling of a well at the location of the test was 1,200 gpd per square foot (Lugn and Wenzel 1938, p. 91).

The coefficient of transmissibility is similar to the coefficient of permeability; it is defined as the number of gallons of water per day transmitted through a strip of the aquifer 1 mile wide and extending the height of the water-bearing formation (aquifer) under a hydraulic gradient of 1 foot per mile. The coefficient of transmissibility is equal to the field coefficient of permeability multiplied by the thickness of the aquifer, in feet (Theis, 1935, p. 520).

To approximate the coefficient of transmissibility, E. C. Reed, state geologist of Nebraska, devised a system that is based on many tests made in Nebraska and has proved reliable in predicting yields of many wells developed in the unconsolidated sand and gravel of Pleistocene age. Each lens or layer of material in a test hole is closely examined, classified, and assigned a coefficient of permeability within a range as follows:

Material	*Gallons per day per square foot*
Clay and silt	0– 100
Sand, very fine, silty	100– 300
Sand, fine to medium	300– 400
Sand, medium	400– 600
Sand, medium to coarse	600– 800
Sand, coarse	800– 900
Sand, very coarse	900–1, 000
Sand and gravel	1, 000–2, 000
Gravel	2, 000–5, 000

After each lens or bed of material of similar physical characteristics is assigned a coefficient of permeability, each coefficient is multiplied by the thickness, in feet, of that material. This number is an estimate of the coefficient of transmissibility for that unit of material. Then, the rounded sum of the coefficients of transmissibility of all saturated beds is considered to be the coefficient of transmissibility for the aquifer. (See fig. 9.)

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 a 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 to range between 20,000 and 50,000 gpd per foot in figure 9, wells generally will yield adequate supplies for household and farm use but will not yield supplies sufficient 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 having 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

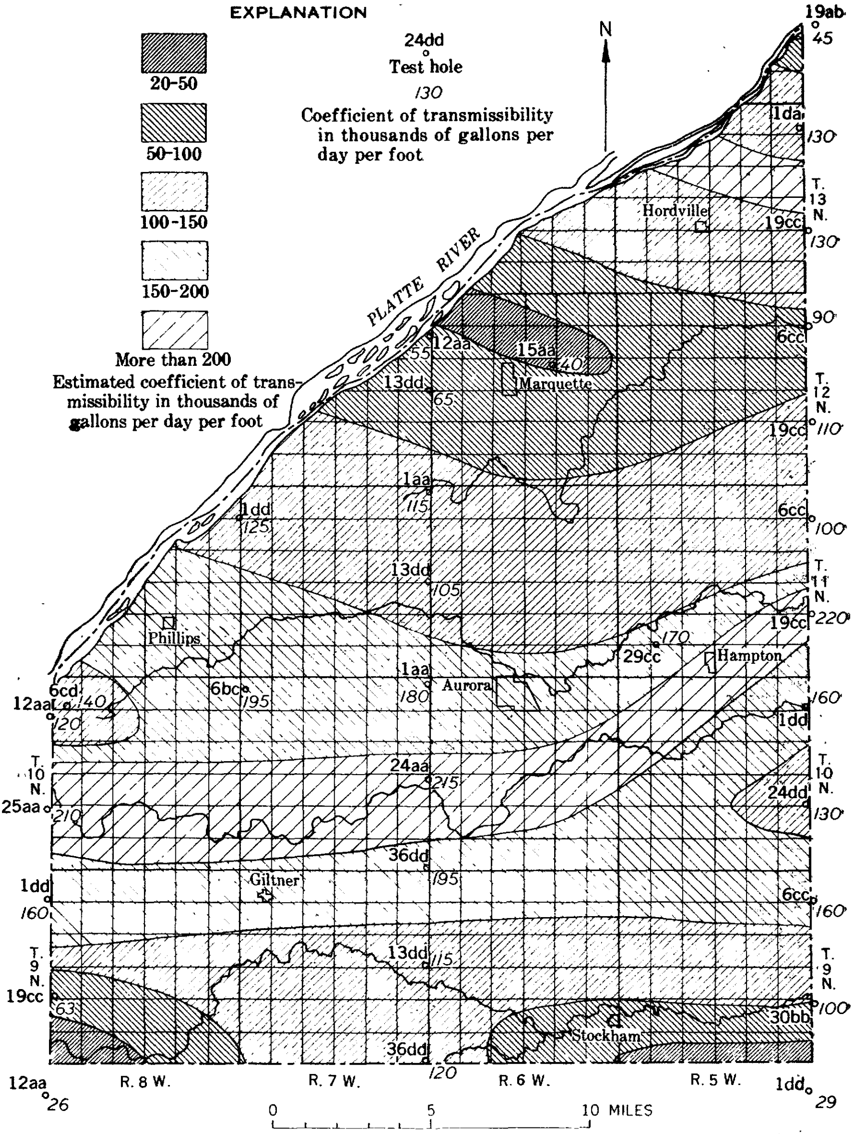

FIGURE 9.—Map of Hamilton County, Nebr., showing the estimated coefficient of transmissibility of the saturated deposits.

wells probably will not be significantly reduced in yield by a lowering of the water table of a few feet.

RATES OF MOVEMENT OF GROUND WATER

The rate of movement of ground water depends on two factors: the permeability of the water-bearing medium, and the slope or gradient of the water table. In saturated sand and gravel, the water is contained in the voids between the grains of rock. Obviously, if water is to move through the sand and gravel, the voids must be interconnected and there must be a different hydrostatic pressure from one void to the next to cause the water to move. As of 1958, the water table in Hamilton County was nearly flat, having an average gradient of only about 7 feet in a mile; therefore, the pressure difference between the interstices (voids) in the sand and gravel was very small and as a result the ground water moved very slowly. Lugn and Wenzel (1938, p. 136) computed the velocity of ground-water movement northwest of Phillips in the Platte River valley to be 0.63 foot a day or approximately 230 feet per year. The rate of flow of ground water in Hamilton County may be considered to be in about the same magnitude of that in the Platte River valley, because the permeability of the water-bearing materials and the slope of the water table were about the same as those in the Platte River valley at the time of Lugn and Wenzel's work. Velocities of only a few hundred feet a year are common for sand and gravel aquifers in Nebraska; although the velocity of ground-water movement is very slow when one considers that this movement has been going on under natural conditions for many centuries, the amount of water involved becomes very significant. Discharge by wells in recent years, however, has superimposed a new or artificial discharge upon the previously stable system and has, by lowering the water table, changed the gradient of the water table in places and caused ground water to move more rapidly in local areas. When a well is pumped, a depression in the water table is formed around the well and a hydraulic gradient is established toward the well from all directions. This gradient is steep near the well and causes the water to move toward the well much more rapidly than under natural rates of ground-water movement.

DEPTH TO WATER

The depth to water in Hamilton County ranges from less than 5 feet in the alluvium near the Platte River to about 135 feet beneath the upland divide northeast of Hordville (pl. N–2). Depths to water of 80 to 100 feet are typical of most of the upland. At Marquette and Phillips the depth to water is about 95 feet, at Hordville about 90 feet, at Hampton about 80 feet, at Giltner about 75 feet, at Aurora about 70 feet, and at Stockham about 25 feet (see pl. N–2).

The depth to water and the probable drawdown of the water level in a well are important factors to consider when planning to pump water from the well for irrigation, because the cost of pumping a given quantity of water varies directly with the height the water must be lifted. Much more power is required to pump water from wells on the uplands than from wells on the valley floors where the water table is shallow. Likewise, pumping water from an improperly developed well, in which the drawdown is excessive, is uneconomical.

FLUCTUATIONS OF THE WATER TABLE

The stage of the water table is an indication of the quantity of water in the ground-water reservoir. In general, the water table rises when the recharge exceeds the discharge and declines when the discharge exceeds the recharge.

Precipitation that filters through the soil to the water table, seepage that reaches the underground reservoir from surface streams whose channels are above the water table, and underflow from adjoining areas to the west and northwest cause the water table to rise when the recharge exceeds the rate at which ground water is discharged from the county.

Discharge of water from the ground-water reservoir by evaporation, transpiration by growing vegetation, pumping from wells, outflow into surface streams, and underflow into adjacent areas depletes the ground-water storage and causes a decline of the water table when it exceeds the recharge. The rate and magnitude of the fluctuations of the water table are governed by the rate and magnitude at which the underground reservoir is replenished or depleted.

In places where wells are not heavily pumped, the fluctuations of the water table generally correlate with variations in the climatic factors of precipitation, temperature, and evaporation.

In some of the heavily pumped irrigated areas, however, the fluctuations of the water table are influenced to a larger degree by the artificial withdrawal of water than by the natural fluctuations of discharge and recharge. In these areas water may be removed from the ground-water reservoir at a rate faster than it is naturally replenished, and where this occurs a general decline of the water table takes place. Thus, in the heavily pumped areas each season of pumping begins with a lower water table and a smaller amount of water in storage than the previous season. In such heavily pumped areas, the storage depleted by lowering the water table can be refilled only when recharge exceeds discharge. This may be accomplished by decreasing the pumping or by increasing the recharge by natural or artificial means.

Hydrographs of six wells are presented in figure 10 and one well in figure 11 to illustrate the character and magnitude of water-level fluctuations in the county during the period 1949–58. The depths to water in three of the wells, 9–6–34bb, 9–8–9dc, and 11–6–13cb1, were

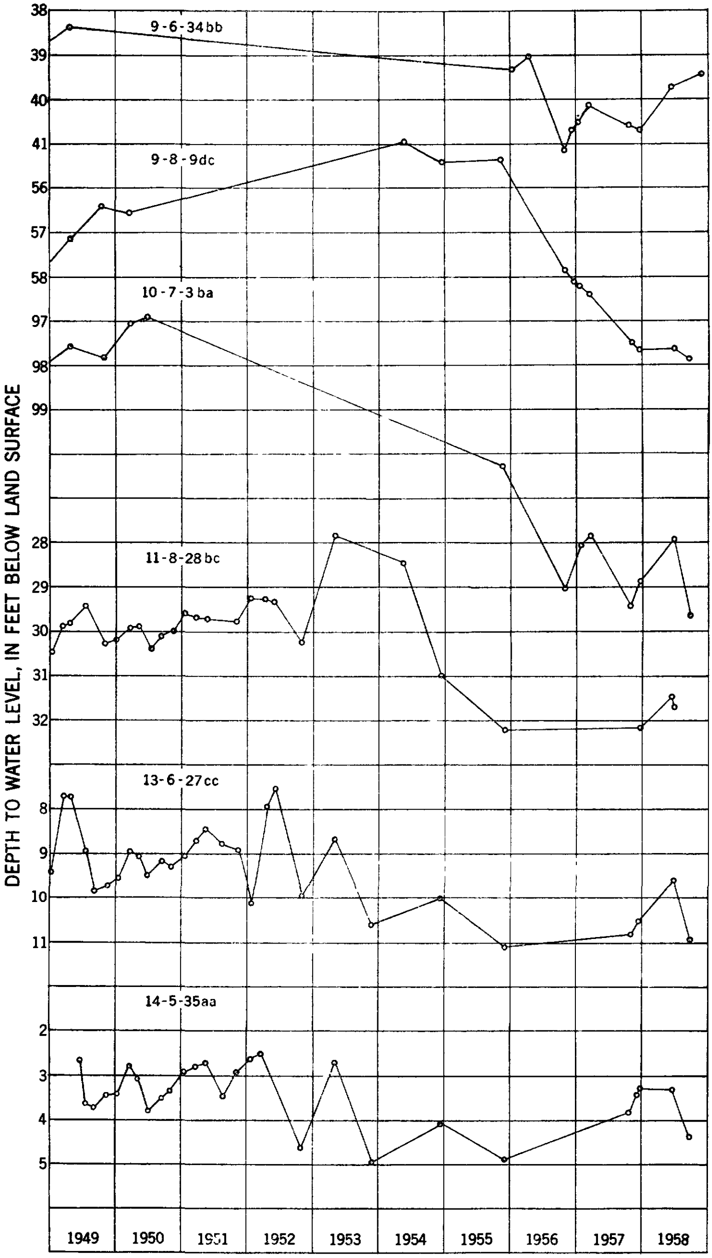

FIGURE 10.—Hydrographs of six wells in Hamilton County, Nebr., 1949–58.

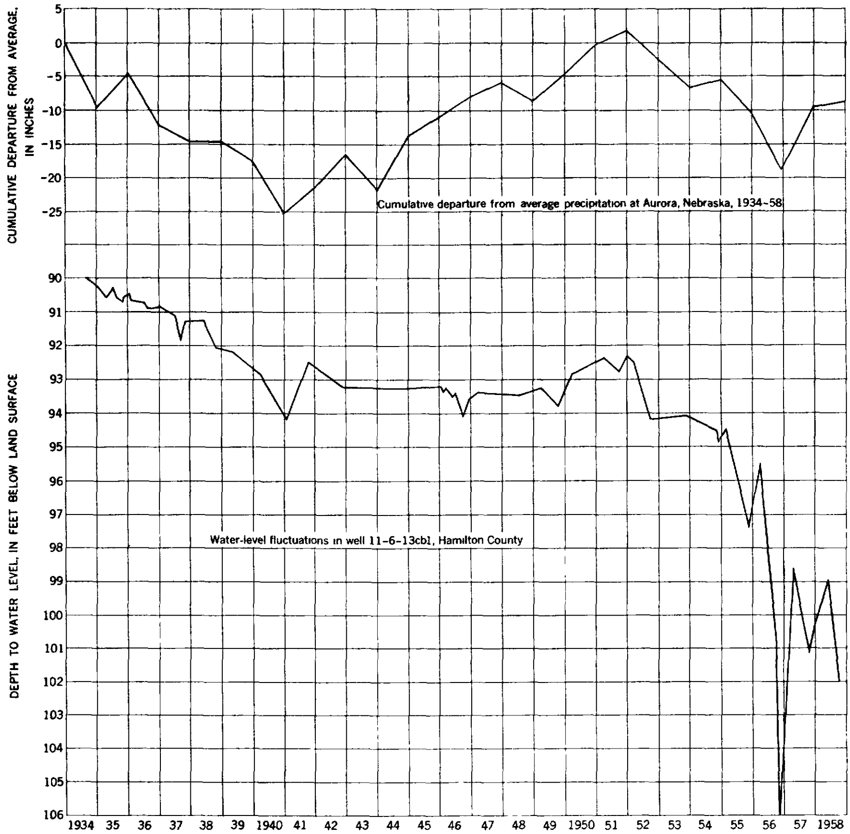

FIGURE 11.—Fluctuations of the water level in a well near Aurora, Nebr., and cumulative departure from long-term average precipitation at Aurora, 1934–57.

first measured in 1934 and have been measured at irregular intervals since that time. Water levels in well 13–6–27cc have been observed at irregular intervals since 1935, in well 11–8–28bc since 1946, in well 10–7–3ba since 1948, and in well 14–5–35aa since 1949.

Well 10–6–26bc was drilled and equipped with a recording gage in April 1956 (fig. 12). Since the date of installation, a continuous record of all fluctuations of the water level in the well has been obtained except for a few short intervals when the clock, which moves the chart, failed to function.

Since the spring of 1956, the Hamilton County Irrigation Association has made measurements of the depth to water each spring and fall in a group of irrigation wells. The association began the program with a network of 58 wells in 1956 and later added more wells; in the spring of 1958, about 100 wells were included in their observation-well program. These depth-to-water measurements are on open file and are available on request from the Conservation and Survey Division of the University of Nebraska or the office of the U.S. Geological Survey at Lincoln, Nebr.

The hydrograph for well 14–5–35aa shows typical fluctuations of the water level in a well where the water table is shallow. The water level fluctuates in response to recharge by precipitation and discharge by evapotranspiration. It stood only a fraction of a foot lower in December 1957 than it stood in June 1949, the beginning of record. Thus, during the period of record in this part of the county, the recharge has been nearly equal to the discharge and the total amount of water in storage remained about the same except for the seasonal periods when recharge and discharge were temporarily out of balance.

During dry periods of several years' duration the water table may register successive declines, but during subsequent wet years the water table may return to its previous maximum or to even a higher level. Therefore, decline of the water table during a dry year does not necessarily indicate an excessive withdrawal of water from the ground-water reservoir. However, some of the hydrographs show significant net changes in the water level since heavy development of ground water for irrigation began. The hydrograph for well 10–7–3ba and 11–6–13cb1 indicates a persistent decline of the water table after 1955. It is significant that these hydrographs are of wells in heavily pumped areas. The decline of the water table in these areas has resulted from the pumping of ground water from the aquifer at an annual rate that is greater than the average annual recharge.

A hydrograph for well 11–6–13cb1 and a graph of cumulative departure from average precipitation at Aurora are shown in figure 11. Comparison of the two graphs shows that for the period prior to 1945 the precipitation was the dominant factor influencing the water table at the site of the well, but that beginning in the late forties when the rate of withdrawal of ground water for irrigation was increased, the fluctuation of the water table began to show increasingly the influence of the pumping on the ground-water reservoir.

The hydrograph for well 10–6–26bc, which is equipped with the recording gage, shows the seasonal effect of heavy pumping of ground water upon the stage of the water table (see fig. 12). Each summer, when pumping of ground water for irrigation began, the water level in the observation well declined at a relatively rapid rate until pumping stopped. In 1956, heavy pumping began about June 15 and continued into August, except for a short interval in July. Immediately after pumping ceased, the water level began to recover, rapidly at first, then more slowly until pumping was resumed in July 1957. The graph shows that the water level did not recover to its original

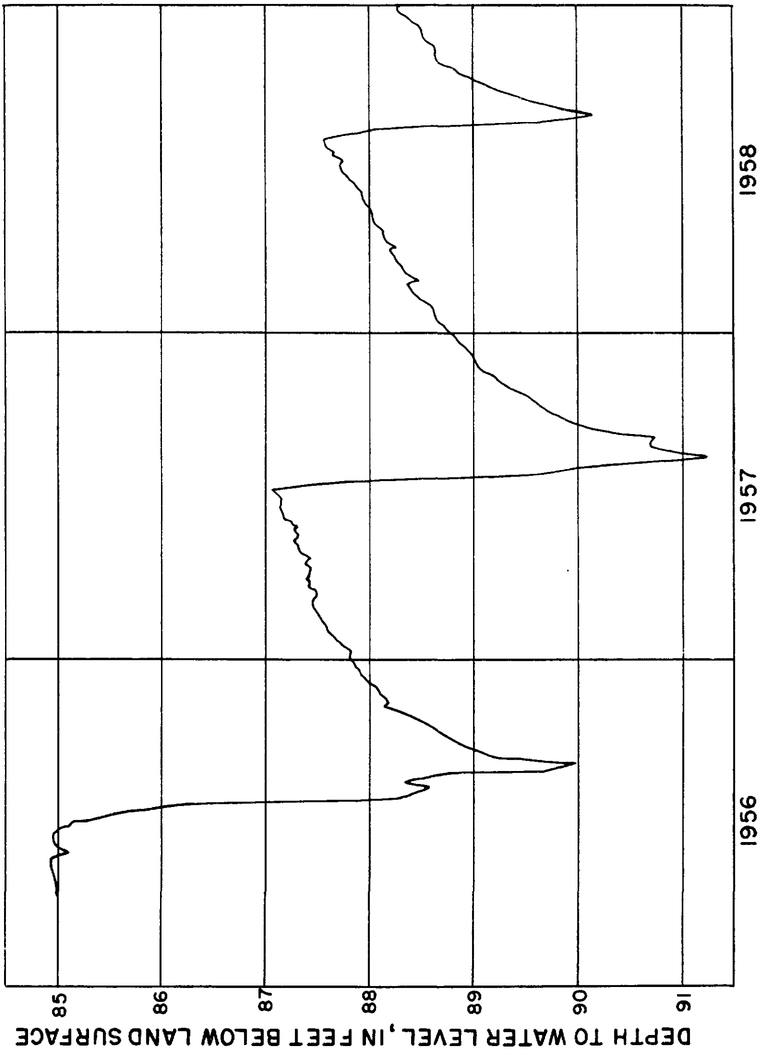

FIGURE 12.—Hydrograph of the water level in well 10–6–26bc, from recording gage.

level before pumping was resumed in 1957. The period of pumping during 1957 was shorter than that during 1956 and the water level declined less than in 1956. The water level began to recover after the pumping ceased in 1957 and continued to rise until pumping was resumed in 1958; but, as before, the water level did not recover to the highest level of the previous season before the pumping was resumed. Thus, each year pumping began before the water table could completely recover. This fact is significant because it suggests that more water was removed from storage each year than was replaced by natural recharge. If this trend continues for 20 or more years, the decline will become significant and may eventually seriously deplete the ground-water supply.

GROUND-WATER STORAGE

Reservoirs have been constructed on many streams in Nebraska to reduce flood crests and to store water for release as needed for power or irrigation. The term "reservoir" as applied to the storage of surface water can be applied in similar fashion to underground storage. Both types of reservoirs have the same general purpose in that they tend to smooth out the daily, seasonal, and annual fluctuations of the amount of water supplied by precipitation. Nature has provided beneath Hamilton County a vast natural ground-water reservoir that absorbs water chiefly during periods of surplus supply, and gradually releases it to seeps, springs, wells, and areas of evapotranspiration. The ground-water reservoir is the source of all natural streamflow in the county during rainless periods.

The ground-water reservoir in Hamilton County contains thick deposits of unconsolidated saturated sand and gravel that average more than 130 feet in thickness. The saturated unconsolidated deposits are not known to contain water under appreciable artesian pressure, and it is assumed that watertable conditions prevail nearly everywhere. If it is assumed that the specific yield of the sand and gravel is 20 percent,[1] the unconsolidated deposits would contain about 9 million acre-feet of available water or more than twice as much as the combined storage in all the larger surface-water reservoirs in Nebraska. Thus, enough water is stored in the ground-water reservoir in Hamilton County to form a lake more than 26 feet deep the size of the county. This large ground-water reservoir is affected only to a small extent by variations in the rate of precipitation; for this reason it is especially desirable as a source of water for irrigation.

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[1] Wenzel (in Lugn and Wenzel, 1938, p. 91, 96) reported the average specific yield of 17 samples collected in the vicinity of a pumping test in Merrick County to be 24 (determined by laboratory analyses) and the specific yield from the pumping test to be about 22. The location of the pumping test is 2 miles northwest of Phillips.

The amount of water in storage in a ground-water reservoir is, however, no indication of that reservoir's capabilities for sustained yield to wells and springs. The perennial yield is limited by the average annual recharge to the reservoir, just as the useful yield of a surface reservoir is limited by the inflow into it.

GROUND-WATER RECHARGE

The ground-water reservoir beneath Hamilton County is recharged primarily by infiltration of local precipitation through the soil. Other sources of recharge are seepage from streams and from water ponded in depressions from underflow from adjoining areas and from water spread on the land for irrigation. Some ground-water recharge is derived from the Platte River when it is flowing; this recharge is greatest when the river is at flood stage. Much of the time, however, the Platte River is dry or has a very small flow, and at these periods it is probably draining the ground-water reservoir.

RECHARGE BY UNDERFLOW

The movement of ground water in Hamilton County is, in general, from west to east (fig. 8). Part of the water that enters the county by underflow crosses the Hall-Hamilton county line, and part of the underflow originates as seepage from the Platte River when the river is at high stage. It is unlikely that any of the underflow beneath Hamilton County originates from areas across the Platte River to the north and west, because heavy pumping for irrigation in the lower Platte River valley has resulted in the depletion of a large amount of ground-water storage beneath the valley. This ground-water reservoir would have to be replenished before it could transmit ground water to Hamilton County.

The configuration of the water table adjacent to the Platte River, east of the 1,800-foot contour on the water table, shows that the direction of movement of ground water is toward the northeast, parallel to the river (pl. N-2). The water table in this part of the county is essentially in equilibrium with the Platte River. Thus, when the river is at high stages, some water moves from the river to the ground-water reservoir; conversely, when the river is at low stages, water is drained from the ground-water reservoir to the river. Because of this balanced condition, the net recharge to the ground-water reservoir from the Platte River is probably small.

Of the water that enters the county by underflow from the west, part may originate in the Platte River. The amount of water that enters the county from the west can be estimated by use of the formula $Q=TIL$, in which Q represents the quantity of water that moves through the aquifer in gallons per day; T is the coefficient of transmissibility in gpd per ft.; I is the hydraulic gradient of the water table; and L is the length of the aquifer being considered, in feet. In order to arrive at an estimate of the underflow from the west, it is assumed that the amount is about equal to that quantity moving through the saturated section at the location of the 1,800-foot contour line on the water table (see pl. N–2).

From an analysis of the materials encountered in drilling test holes along the west border of the county, the average coefficient of transmissibility (T) is estimated to be about 118,000 gpd per foot along the 1,000-foot contour line. The hydraulic gradient (I) is about 0.0002, about 10.5 feet per mile, and the length of the aquifer being considered is about 94,000 feet. Therefore

$$Q = 118{,}000 \times 0.002 \times 94{,}000 = \text{approximately 22 mgd (million gallons per day), or 25,000 acre-feet per year.}$$

Although water is moving into Hamilton County by underflow, the water thus obtained does not add to the average net amount in storage in the county because ground water is moving out of the county by underflow to the east and south, and the outflow is estimated to be about 8,000 acre-feet per year more than the inflow (see p. N–39).

RECHARGE FROM PRECIPITATION

Of the average annual precipitation (about 24 inches) in Hamilton County, only a small part reaches the zone of saturation; most is lost through evaporation, transpiration by plants, and as surface runoff without ever reaching the water table.

Inspection of the configuration of the water table in plate N–2 shows rather conclusively that water enters the county by lateral percolation from the Platte River and areas to the west. The bending of the contour line on the water table also indicates that the water table is somewhat mounded, with the nose of the mound toward the east. These facts are illustrated by figure 8, which shows 50-foot contours on the water table, somewhat generalized to fit the reduced scale, and flow lines at right angles to the contours. The two flow lines originating on the Platte River boundary of the county diverge as they cross the county from west to east. Inasmuch as the physical characteristics of the aquifer are similar from west to east, this spreading of the flow lines must result from mounding of the water table in response to recharge to the aquifer by water infiltrating from the land surface.

If the hydraulic gradient, the direction of ground-water movement, and the transmissibility of the water-bearing materials are known, the quantity of water moving through the aquifer can be computed. The amount of water contributed by recharge from the land surface was estimated for that part of the county bounded by two ground-water flow lines and two north and south lines labeled "section A" and "section B" in figure 8. Sections A and B were selected along geologic sections *C–C′* and *D–D′* (pl. N–1); they intersect two flow lines that have been drawn along the maximum slope of the water table. Because the flow lines diverge from west to east, section B is much longer than section A; thus, if the transmissibility and slope of the water table at each section are about equal, more water must be moving through section B than through section A. The transmissibility of the saturated water-bearing formation at each section was estimated from analyses of materials obtained from the test holes. Examination of the test-hole samples indicates that the average coefficient of transmissibility of the aquifers in both sections A and B is about 130,000 gpd per foot. The gradient of the water table at sections A and B is about the same, about 7 feet per mile, which is about the average gradient of the water table in the county. The quantity of water crossing each section within a given time may be computed by the formula $Q=TIL$ (p. N–35).

The length of section A is about 46,500 feet and the length of section B is about 112,000 feet.

Thus, the quantity of water crossing section A each day may be estimated as follows:

$Q=TIL$

$$Q=130{,}000\times\frac{7}{5{,}280}\times 46{,}500$$

$Q=8$ mgd

Similarly, the quantity of water crossing section B may be estimated as follows:

$$Q=130{,}000\times\frac{7}{5{,}280}\times 112{,}000$$

$Q=19$ mgd, or 11 mgd more than the quantity flowing through section A

The 11 mgd represents the recharge between sections A and B that necessarily originated on the land surface of the area between the sections. This amount is equal to almost 13,000 acre-feet per year; the area included by the sections and the flow lines is about 110,000 acres; therefore, the average annual rate of recharge over the area is about 1.4 inches per year.

The area between sections A and B may be considered to be typical for the county with respect to precipitation and soil conditions; hence, the annual ground-water recharge is probably typical for all the county. On the basis of this assumption, the annual recharge by infiltration of precipitation in the county is estimated to be about 40,000 acre-feet per year.

The amount of water that filters into the soil and recharges the ground-water reservoir is in large part dependent on the permeability of the soil. Nearly all soils in Hamilton County have been derived from the Peorian loess, which has fairly uniform physical and chemical properties; therefore, the soils of the county are relatively uniform.

By applying an estimated infiltration rate to the soils of Hamilton County, E. C. Reed (oral communication, 1958) computed annual recharge to be about 37,000 acre-feet. Both these figures are only estimates, but their close agreement indicates they are in the right order of magnitude.

One may speculate that with the change in land treatment from original prairie to dryland farming to irrigation farming that some changes might occur in the physical characteristics of the soil. For example, the increase in the amount of water added to the soil under irrigation may even decrease the ability of the soil to transmit water by the translocation of clay into the subsoils. Also, the application of ground water to the soil together with evapotranspiration of the applied water may cause an accumulation of salts in the soil that may in time decrease the permeability.

RECHARGE FROM STREAMS AND PONDS

Recharge to the ground-water body from ephemeral streams whose beds are above the water table occurs during the brief period when streams are flowing after rains. In this report, the recharge from ephemeral streams is treated as part of the recharge from precipitation discussed in the preceding pages.

Most of the upland plain is well drained, although a few shallow basinlike depressions occur on the flatter uplands. In these places the surface drainage is poorly established and rainwater collects in the depressions; however, a claypan subsoil retards infiltration of water to the water table. Water that accumulates in the depressions after rains disappears slowly, principally by evapotranspiration.

RECHARGE FROM IRRIGATED LANDS

All irrigation on the upland in Hamilton County is done with water pumped from wells. Water from the wells is commonly conveyed to the crop area in metal tubes from which no losses occur, although many farmers use the open earth-bed ditches, which may lose a considerable amount of water by seepage. The water is applied to the crop by means of ditches or sprinklers and some of that probably seeps below the reach of plant roots to return to the ground-water reservoirs. This water may be considered to be a source of recharge. It is estimated that the amount returned to storage is small, however, and probably does not exceed 10 percent of the water applied to the land.

GROUND-WATER DISCHARGE

Ground water is discharged in Hamilton County chiefly by pumpage and ground-water outflow to the east, and to a lesser extent by evapotranspiration and to streams. The rate at which it is discharged varies principally with the differences in the precipitation and the season of the year.

The rate at which ground water is pumped for irrigating crops varies greatly from day to day and season to season. During dry periods in the growing season nearly all pumps are in operation and as much as 3,500 acre-feet each day may be pumped out of the ground-water reservoirs. In contrast none is pumped in midwinter. Similarly the amount of ground water that is discharged naturally fluctuates considerably from time to time depending on the season and atmospheric conditions. The rate at which ground water is discharged at any given time is largely controlled by the demand for water by growing vegetation both in the irrigated areas and in the shallow water areas where the water table is within the reach of plant roots.

DISCHARGE BY TRANSPIRATION AND EVAPORATION

In the areas where the water table is within the reach of plant roots, water can be taken into the roots of plants directly from the zone of saturation or from the capillary fringe extending upward from it and discharged from the plants by transpiration (Meinzer, 1923, p. 48). Except in a few small areas in the Platte River valley and the valley of the West Fork of the Big Blue River, the depth to water in Hamilton County is so great that there is no transpiration or evaporation from the zone of saturation or from the capillary fringe. Plants growing on the upland where the water table is too deep to be reached by the roots obtain water from the zone of soil moisture, not from the zone of saturation.

Discharge of ground water from the zone of saturation is mostly limited to areas along the Platte River and the lower reaches of the West Fork of the Big Blue River where the water table stands close to the land surface (see pl. N–1).

The amount of ground water used by plants in the Platte River valley probably is quite large. Wenzel (1938) postulated that about one acre-foot of ground water per acre was transpired annually by plants growing in an area of about 600 square miles in the Platte River valley between Chapman and Gothenburg. However, only a small amount of this type of discharge occurs in Hamilton County because the depth to the water table is greater than 10 feet in most of the valley south of the Platte River. A total of only about 4,000 acres of land is included in the areas of shallow ground water where plants consume ground water.

DISCHARGE BY UNDERFLOW

As discussed earlier, ground water moves generally from west to east across Hamilton County. Ground water that is not used within the county or is not intercepted by streams percolates into adjacent counties to the east; a very small amount probably moves southward. The total amount of water that moves out of the county by underflow is estimated from the average gradient and average transmissibility to be about 33,000 acre-feet per year.

DISCHARGE BY SPRINGS AND SEEPS

The configuration of the water table, as shown in plate N–2, indicates that ground water is discharging into the West Fork of the Big Blue River. A number of small springs having discharges of less than a gallon per minute were observed along the bank of the stream, and it was noted that the discharge of the stream was considerably greater where it leaves the county than where it enters; the increase probably is somewhat less than 10 cfs (cubic feet per second). An estimate based on the average gradient of the water table and the estimated coefficient of transmissibility of the aquifer adjacent to the river indicates that more than 6,000 acre-feet of ground water per year is discharged to the stream. Diffused seepage of water into the Platte River is also a factor of discharge, but the total amount is relatively small.

DISCHARGE BY WELLS

The largest form of discharge of ground water in Hamilton County is through wells. More than 245,000 acre-feet of water is estimated to have been pumped for irrigation during 1956 and about 100,000 acre-feet in 1957. In addition, all domestic water supplies and most stock-water supplies were pumped from wells, though the amount pumped for these purposes is relatively small.

The irrigation season in Hamilton County usually begins in June and ends in September, but its length varies from year to year depending on the distribution of precipitation.

When wells are pumped the water table declines around each of the pumped wells and assumes a form similar to an inverted cone. This depression in the water table is known as the cone of depression, and the distance that the water level is lowered in the well is called the drawdown. The greater the pumping rate in a well, the greater is the drawdown. When pumping stops, the cone of depression gradually refills with water that moves into it from areas adjacent to the limits of the cone of depression, and the regional water table declines slightly. Most wells are pumped intermittently, and while a cone of depression is being formed in one part of the area another cone may be filling in some other part of the area. After the end of the pumping season, the regional water table gradually assumes a form similar to the form it had before the pumping season began; however, the regional water table is likely to be lower than it would have been if there had been no pumping.

When a well is pumped, the water level in the well is lowered; the amount of lowering from the static water level is called the drawdown. The amount of drawdown necessary to obtain a given rate of yield from a well is a direct function of the permeability of the water-bearing formations, and the frictional entrance resistance of the well screen. If other pumping wells are nearby, they may cause the drawdown to be increased. This condition is called interference between wells. Interference between wells may reduce the capacity of wells to yield water.

The capacity, expressed in gallons per minute, can be defined as the maximum rate at which the well will yield water after the pumping water level becomes approximately stabilized.

The specific capacity of a well is its rate of yield per unit of drawdown and is computed by dividing the capacity in gallons per minute by the drawdown in feet. Thus, for example, if a well is pumped at a rate of 1,000 gpm and the water level in the well is drawn down 10 feet below the static water level, the well has a specific capacity of 100.

WELL CONSTRUCTION

Most of the wells in Hamilton County are drilled by the jetting or hydraulic-rotary methods, except for a few driven wells in the Platte River valley. Livestock and domestic water supplies commonly are obtained from small-diameter wells that are jetted or "washed" into the aquifer. The large-diameter wells required for irrigation and public supplies are drilled by hydraulic-rotary methods.

All the wells in Hamilton County obtain water from unconsolidated deposits. Wells in these deposits must be cased to the bottom to prevent caving of the walls, and the casing below the water table is perforated to allow water to enter. The selection of the proper size of perforations is very important and may determine the capacity and life of a well. If the perforations are too large, fine material may filter through and fill the well; if the perforations are too small, they may become clogged and prevent the free entrance of water. The coarse particles that remain around the perforated casing as a well is developed form a natural gravel envelope that increases the effective diameter and the capacity of the well.

Most of the irrigation and municipal wells in Hamilton County are artificially gravel packed. To construct a well of this type, a hole about 36 inches in diameter is drilled and a well screen of perforated steel or concrete casing, having an inside diameter of 18 inches, is centered opposite the water-bearing beds; unperforated casing extends to land surface. The annular space between the casing and the hole is filled with uniformly screened gravel whose grain size is slightly larger than that of the water-bearing material. The envelope of gravel that surrounds the well increases the effective diameter of the well. Because the effective diameter is larger than it would have been if the well were drilled only large enough to accommodate the screen or perforated casing, the velocity of the water entering the gravel pack is less and movement of sand from the formation into the well is less. If the water-bearing formation is relatively coarse and uniform in texture, addition of a gravel pack around the well may not increase the yield appreciably. It is even possible that in some places the yield of a well might be reduced by the addition of a gravel pack.

Irrigation wells in Hamilton County generally are drilled to penetrate 50 feet or more of saturated sand and gravel. If the thickness of the saturated sand and gravel is less than 50 feet, the wells are drilled through the entire aquifer. Commonly, a concrete platform is placed around the top of the casing for support of the pumping equipment and many installations are protected by a small building constructed over the well and platform.

The depths of the irrigation wells in Hamilton County range from 42 to 315 feet. The following table shows the ranges in depth of 967 irrigation wells in Hamilton County:

Depth range (feet)	*Number of wells*
25– 50	2
50– 75	24
75–100	15
100–125	35
125–150	61
150–175	307
175–200	401
200–225	104
225–250	13
250–275	4
275–300	0
300–325	1

METHOD OF LIFT AND TYPES OF PUMPS

Most domestic and stock wells in Hamilton County are equipped with cylinder pumps operated by windmills, electric motors, or gasoline engines, but a few are pumped by hand. The cylinders or working barrels of most cylinder pumps are below the water level and are of the lift type, which discharge water at the land surface or into storage tanks. A few wells are equipped with jet pumps.

With few exceptions, the irrigation and public supply wells are equipped with deep-well turbines having two to five stages; they are belt, gearhead, or direct driven and are powered by electric motors or internal combustion engines, the latter using propane, butane, diesel fuel, natural gas, or gasoline. Stationary propane, tractor-fuel, and natural-gas powerplants are the most common, though some pumps are powered by farm tractors.

Wells also furnish nearly all the public water requirements in Hamilton County. The city of Aurora and the villages of Giltner, Hampton, Hordville, Marquette, and Phillips have municipal water supply wells, storage reservoirs, and distribution systems. All the towns obtain water from deep wells; none of the water is chlorinated or softened.

GROUND WATER PUMPED FOR IRRIGATION

The principal use of ground water in Hamilton County is for irrigation. The water is pumped from wells by turbine pumps and is most commonly distributed by gravity in pipe or unlined ditches. When the open ditch is used, a canvas dam in the ditch raises the water level above the level of the field, and the water is siphoned from the ditch with curved plastic or metal tubes. The water then flows by gravity through furrows down the length of the crop rows. Distribution by gated pipe is becoming popular and may soon be the most common type of distribution because less labor is required by its use than by the open-ditch method. Sprinklers are coming into common use to irrigate rolling land; they are particularly adapted for irrigating alfalfa and pasture, but their use for row crops, especially corn, is difficult because much labor is necessary to move the sprinklers in tall-growing crops.

The principal irrigated crops in Hamilton County are corn, grain sorghums, and alfalfa. During the canvass made in 1956–57 (Keech, 1960b), 1,196 irrigation wells were visited and pertinent information concerning each was obtained from the owners or operators. Farm operators interviewed in 1956 reported an average of 85.6 acres irrigated per well. In 1956 about 75 percent of the acreage was planted to corn, the remaining 25 percent to grain sorghums, alfalfa, soybeans, pasture, and miscellaneous crops. Nordquist and Logan (1958) estimated that a total of about 90,000 acres in 1956 and 113,500 acres in 1957 was irrigated by ground water in Hamilton County.

The amount of water pumped for irrigation varies considerably from year to year because of variations in the amount and distribution of the precipitation received during and before the growing season; in general, however, more land each year is being irrigated with ground water. The increase in use of ground water has resulted from two principal causes: one is the increasing number of irrigation wells, and the other is the increased water requirements of the crops, stimulated into accelerated growth by fertilizers.

The field inventory indicates that about 1,000 irrigation wells were pumped in 1956. The average rate of pumping per well was about 850 gpm and the average pumping time was about 65 days or 1,560 hours. Thus, the total amount of water pumped by all irrigation wells was about 245,000 acre-feet. This is more than double the estimated 100,000 acre-feet used in 1955 when the total number of irrigation wells was about 700 and the average pumping time was about 48 days.

It is estimated that less than 100,000 acre-feet was pumped in 1957, and a much smaller amount was pumped in 1958. Thus, it is not possible at this time to estimate the average annual use of water per irrigated acre or the total average annual withdrawal. The annual use of water varies with the climatic factors and changes in farming practices, but doubtless as more and more land is irrigated increasing amounts of water will be used each year. The rate of installation of irrigation wells in Hamilton County is shown in figure 13.

The number of irrigation wells installed during any year is, in part, related to the amount and distribution of the precipitation. In drought years, especially if the year is preceded by a dry year or fall, the interest in irrigation is at a high level and many more wells are constructed than during a wet or near-normal year. The adverse effect of subnormal precipitation on the economy of a nonirrigated farm may be partly reduced by tilling practices that conserve moisture in the soil, but irrigation is the only means by which high crop yields can be maintained throughout a prolonged drought.

Most irrigators report that irrigation produces greater crop yields in years of above-normal precipitation as well as in dry years. Very few farmers expressed dissatisfaction in the results obtained from irrigation; most believe that it stabilizes farm economy. The amount and distribution of rainfall in the future will not affect irrigation practices as much as it has in the past because farmers likely will tend to gear all farm operations to irrigation. As farmers gain more experience in irrigation, they may make more economical use of the water.

At the time of this investigation (1957) poorly controlled application of water to the land was the cause of much wastage.

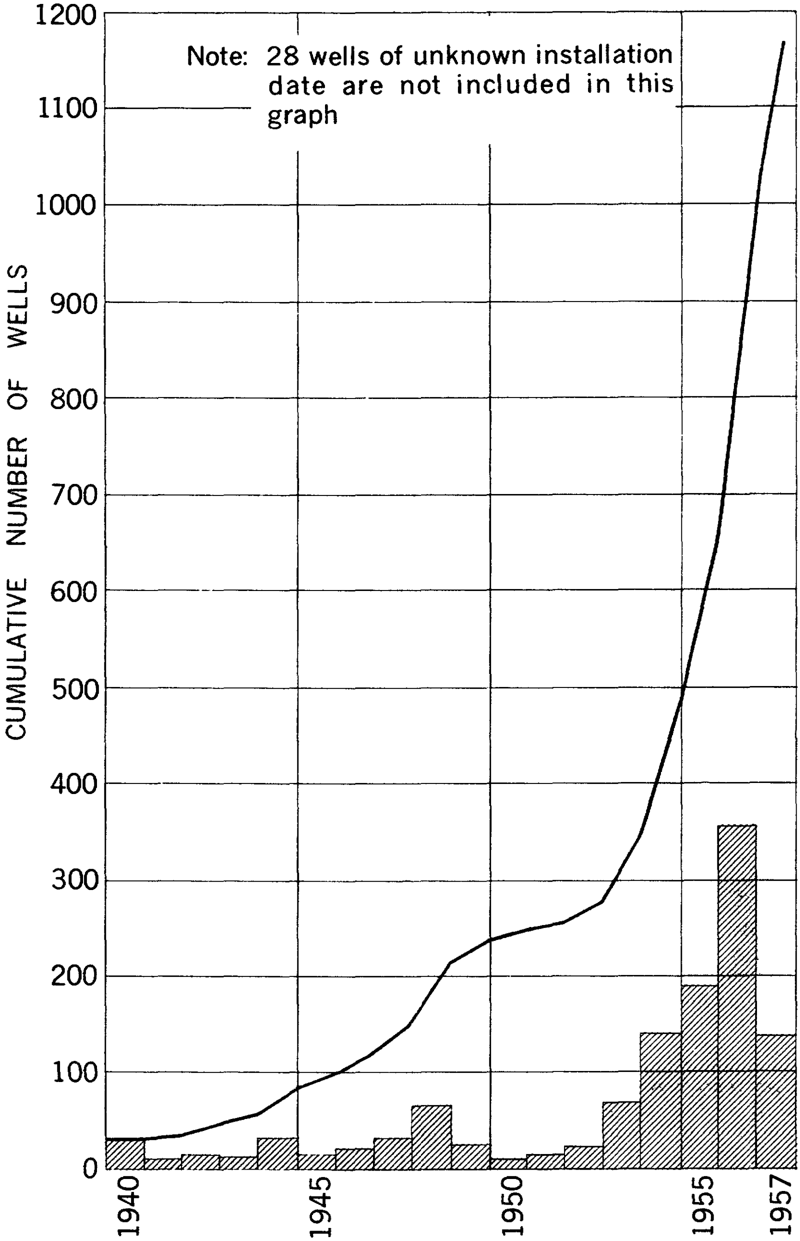

FIGURE 13.—Rate of installation of irrigation wells in Hamilton County, Nebr.

EFFECT ON GROUND-WATER STORAGE

Under natural conditions the discharge of ground water equals the natural recharge, and the ground-water reservoir is said to be in equilibrium. When water is pumped from the ground-water reservoir, the discharge is increased by the amount of water pumped until such time as the removal from storage of pumped water reduces the natural discharge by an equal amount. Because the artificial withdrawal of ground water in Hamilton County is already greater than the natural discharge, an equilibrium can not, under present conditions, be effected. Therefore, the use of ground water will continue to deplete the supply. Equilibrium of the ground-water reservoir can in the future be effected either by reducing the withdrawal or by increasing the recharge, or both.

CHANGES IN GROUND-WATER STORAGE SINCE THE SPRING OF 1953

Changes in ground-water storage, based on fluctuations of water levels in observation wells, for the period from the spring of 1953 to the spring of 1957 are shown in figure 14.

The collection of supplemental water-level data by the Hamilton County Irrigation Association was begun in the spring of 1956. The association now measures depth to water in about 100 irrigation wells each spring before the irrigation season is begun and each fall after most of the irrigation has ceased. These data have also been used in the determination of the change in ground-water storage for the period from the spring of 1956 to the spring of 1958.

Since the middle 1940's, withdrawals of ground water have increased each year except during years when precipitation was above normal and demand for irrigation was relatively light, principally 1951, 1957, and 1958. Owing to drought conditions during 1952–56, withdrawals of ground water for irrigation increased almost sevenfold from an estimated 30,000 acre-feet in 1952 to about 200,000 acre-feet in 1956.

Figure 14, which shows the net changes in water level, spring of 1953 to spring of 1957, indicates an average lowering of the water table of about 4.5 feet during that period. On the basis of the average decline computed by the zones shown in this figure, the net amount of material unwatered was computed to be 1,540,000 acre-feet. The depletion of ground-water storage, assuming a storage coefficient of 20 percent, is 308,000 acre-feet of water.

The heaviest withdrawals of ground water during this period occurred in 1956. The dry year of 1956, which followed several years of drought, was one of the most severe on record. The last 3 months

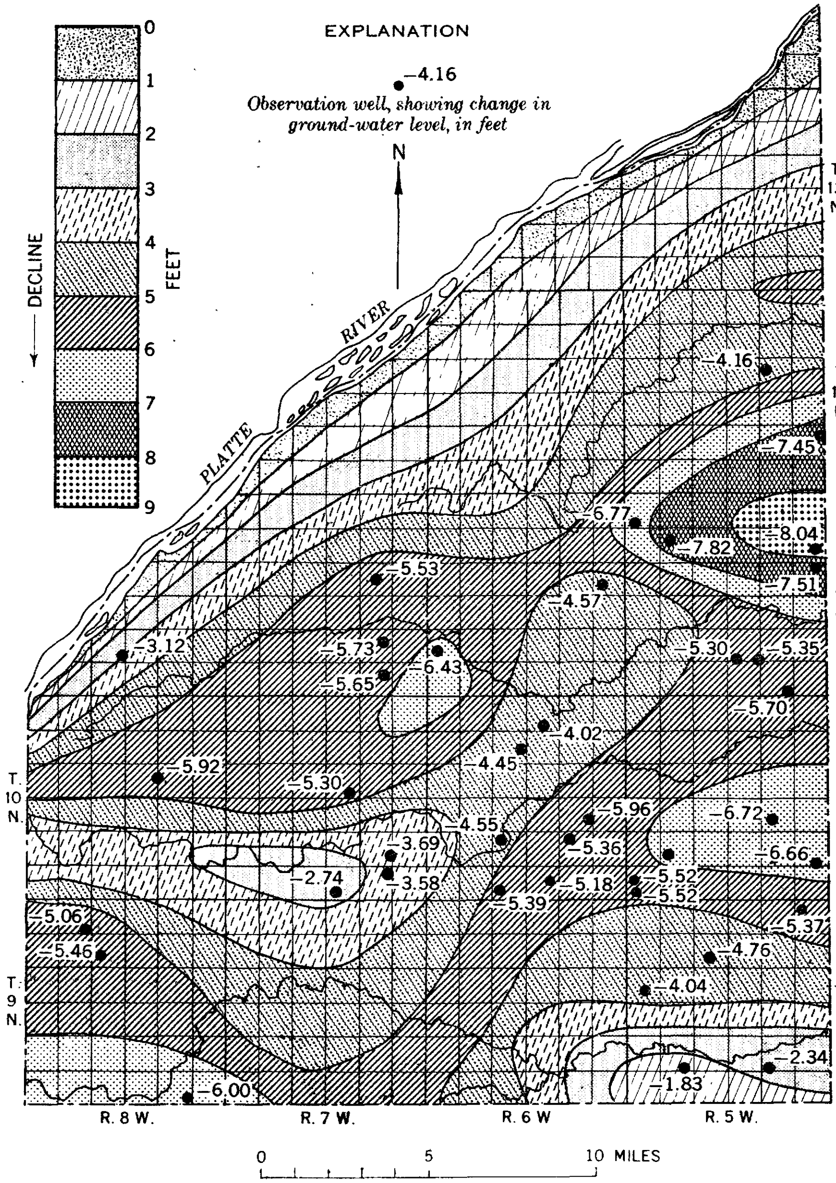

FIGURE 14.—Map of Hamilton County, Nebr., showing net changes in ground-water levels, spring of 1953 to spring of 1957.

of 1955 were very dry also, and irrigation began in 1956 much earlier than normal. The depletion of ground water in storage during 1956 was about 187,000 acre-feet, based on the average water-level decline of 2.7 feet in wells between the spring of 1956 and spring of 1957 as observed by the Hamilton County Irrigation Association. This amount of depletion checks reasonably close to the estimated pumpage. The depletion is somewhat smaller than the pumpage, however, because rains that began in March 1957 had partly recharged the ground-water reservoir by the time the 1957 spring measurements of water levels in wells were obtained. As a result of the heavy spring rains, pumping was not resumed on a large scale until late in July 1957, and thus the ground-water reservoir received substantial recharge before the beginning of the 1957 pumping season. However, the withdrawals in 1957 were greater than the recharge, according to analyses of the depth to water in wells in the spring of 1958, which, when compared with measurements made in the spring of 1957, showed that the net amount of water in storage had declined about 3,000 acre-feet during the period.

CHEMICAL QUALITY OF THE WATER

By P. G. Rosene

The chemical quality of water depends on the kinds and concentrations of the mineral constituents dissolved in the water. Water condensing in the atmosphere dissolves gases, such as oxygen and carbon dioxide, the solution of which greatly increases the ability of the water to dissolve certain minerals in the earth's crust. As the water penetrates the soil, its solvent ability is further increased by the solution of additional carbon dioxide and other substances.

The kinds and concentrations of mineral constituents dissolved in water depend on many factors, the most important of which are the kinds, amounts, and surface area of minerals available for solution; the length of time the water is in contact with the minerals; the gases dissolved in the water; and the temperature of the water. Because the rock materials through which water moves are heterogeneous both chemically and physically, the chemical quality of the ground water differs from place to place.

Some of the terms used herein are defined as follows:

Equivalent per million (*epm*).—A unit for expressing the concentration of chemical constituents in terms of the relative combining power of the electrically charged particles, or ions, in solution. In chemical reactions, 1 epm of a cation reacts with exactly 1 epm of an anion.

Part per million (ppm).—A unit for expressing the concentration of chemical constituents by weight. Parts per million are computed as one million times the ratio expressed, as a decimal, of the weight of constituents to the weight of the solution.

Parts per million are converted to equivalents per million by multiplying by an appropriate factor.

Cations	*Conversion factor*	*Anions*	*Conversion factor*
Calcium (Ca^{++})	0.04990	Carbonate (CO_3^{--})	0.03333
Magnesium (Mg^{++})	.08224	Bicarbonate (HCO_3^-)	.01639
Sodium (Na^+)	.04350	Sulfate (SO_4^{--})	.02082
Potassium (K^+)	.02558	Chloride (Cl^-)	.02820
		Fluoride (F^-)	.05263
		Nitrate (NO_3^-)	.01613

Percent sodium.—The ratio, expressed as a percentage, of sodium to the sum of calcium, magnesium, sodium, and potassium—all ions in equivalents per million.

Specific conductance.—A measure of the ability of the water to conduct an electrical current, expressed in micromhos ($mho \times 10^{-6}$) per centimeter at 25°C. It varies with the concentrations and types of ions in solution and can, therefore, be used to estimate the degree of mineralization of the water.

Water from 34 wells, which are distributed uniformly throughout Hamilton County (fig. 15), was analyzed to determine its chemical quality and type. The wells were pumped immediately prior to collection of samples so that the water sampled would be representative of the water in the aquifer. Results of the analyses are given in table 2.

The mineralization of the water is relatively low; the specific conductance ranged from 365 to 863 micromhos per centimeter, and dissolved-solids concentration ranged from 231 to 603 ppm. The water having the highest mineralization is near the north and west borders of the county, and the water having the lowest mineralization is in the west-central part of the county (see fig. 15).

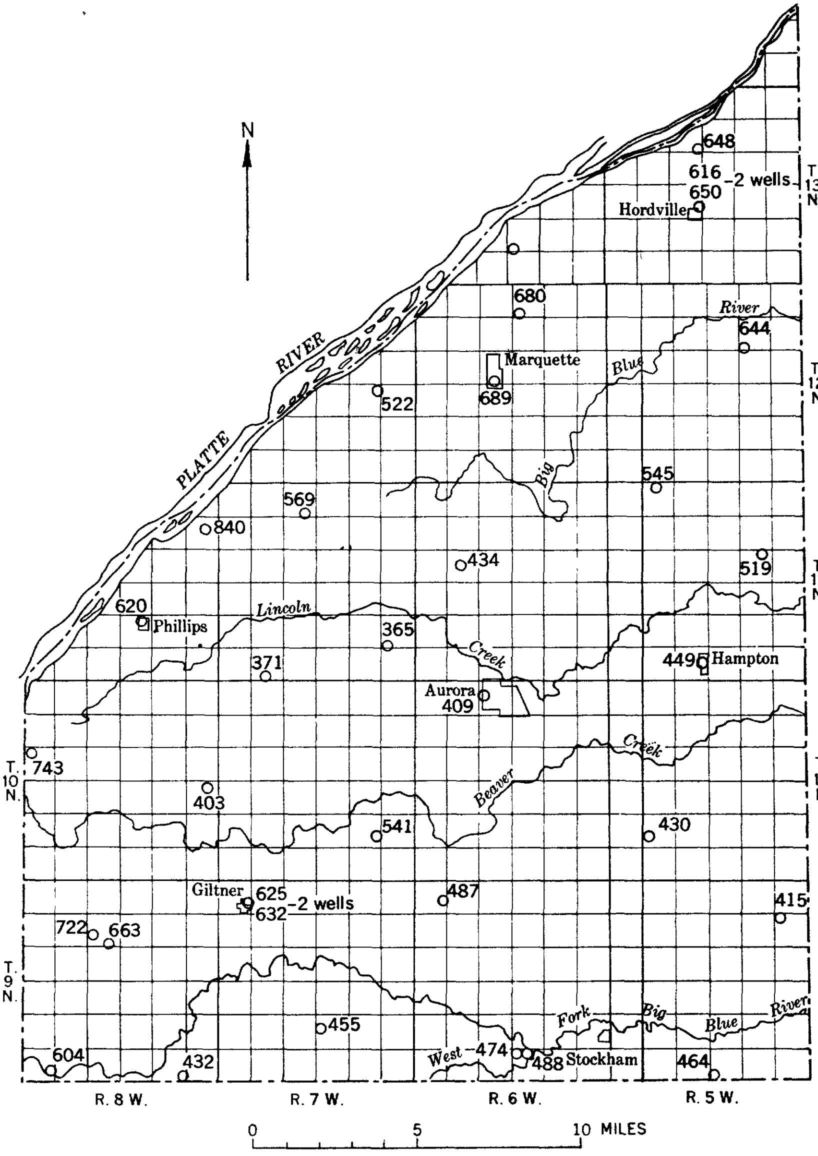

FIGURE 15.—Map showing chemical-quality sampling sites and specific conductance, in micromhos per centimeter, of ground water.

TABLE 2.—*Chemical analyses of*

[Use of water: I, irrigation; PS, public supply, S, stock.

Well	Depth or well (feet)	Use of water	Date of collection	Temperature (°F)	Silica (SiO₂)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)
9-5-12bb	181	I	Aug. 23, 1958	53	32	0.02	-------	56	7.7	20	6.4
9-5-34cc	153	I	do	53	37	.03	-------	65	9.5	18	5.4
9-6-6da	175	I	do	54	30	.13	0.02	68	9.4	21	5.8
9-6-34ba	103	I	do	53	39	.03	-------	65	11	22	5.8
9-6-34bb	86.9	I	Oct. 31, 1936	------	-------	------	-------	63	12	21	
9-7-6dad1	120	PS	Aug. 23, 1958	54	29	.34	1.3	85	15	28	5.2
9-7-6dad2	260	PS	Sept. 25, 1952	56	24	.38	1.2	88	15	26	4.8
9-7-27bc	183	I	Aug. 22, 1958	53	39	------	-------	60	10	20	5.2
9-8-9cb	170	I	do	54	33	1.2	.99	103	17	31	6.0
9-8-9dc2	93	S	Oct. 31, 1936	------	-------	.31	-------	96	17	24	
9-8-31da	105	I	Aug. 23, 1958	53	41	.08	-------	86	13	22	6.7
9-8-35dd	158	I	do	------	45	------	-------	60	8.6	15	5.9
10-5-29cb	196	I	do	54	28	.02	-------	56	7.9	22	5.3
10-6-4bc	170	PS	Apr. 3, 1957	54	31	.03	.00	53	7.8	19	5.4
10-7-26da	155	I	Aug. 22, 1958	53	29	.03	-------	69	10	30	6.3
10-8-18bb	169	I	do	53	19	.02	-------	84	16	53	5.8
10-8-24ab	185	I	do	54	22	.04	-------	50	7.5	22	5.4
11-5-5ba	158	I	do	53	33	.01	-------	70	10	30	8.0
11-5-14ab	169	I	Aug. 21, 1958	53	35	.00	-------	72	10	22	6.1
11-5-33ad1	120	PS	May 28, 1953	55	41	.01	.03	62	10	18	6.7
			Aug. 21, 1958	54	38	.02	.02	59	10	17	6.4
11-6-17bd	205	I	Aug. 22, 1958	54	30	.01	-------	59	7.8	21	5.1
11-7-4dc	180	I	do	54	23	.02	-------	74	14	28	5.7
11-7-25cc	182	I	do	54	25	.01	-------	44	7.8	20	4.5
11-7-32cd	177	I	do	54	22	.02	-------	45	7.9	19	4.5
11-8-12ac	188	I	do	54	22	.01	-------	102	21	50	5.8
11-8-27ab	170	PS	June 11, 1953	56	24	.44	.02	76	15	25	5.4
			Aug. 22, 1958	54	23	.05	.01	79	16	28	5.6
12-5-11cc	170	I	Aug. 21, 1958	53	27	.01	-------	91	14	29	5.7
12-6-3cc	-------	I	do	54	24	.01	-------	90	15	34	7.9
12-6-16cd	145	PS	May 20, 1953	57	24	.05	.02	119	15	44	12
			Aug. 21, 1958	54	19	.04	.07	97	13	33	10
12-7-23aa	-------	I	do	54	19	.01	-------	66	12	27	5.6
13-5-9dd	-------	I	do	53	32	.02	-------	94	13	27	7.3
13-5-21da1	160	PS	May 14, 1953	55	32	.01	.04	92	13	26	7.4
13-5-21da2	262	PS	Aug. 21, 1958	------	41	.02	.08	84	12	32	9.0
13-6-27cc	61	I	Dec. 15, 1936	------	-------	------	-------	50	9.8	21	

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[1] Estimated.

ground water, Hamilton County

Results in parts per million except as indicated]

Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids (residue on evaporation at 180°C)	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Sodium-adsorption ratio	Specific conductance (micromhos per cm at 25°C)	pH
206	26	11	0.4	2.6	0.12	269	171	2	20	0.7	415	7.0
226	30	15	.3	4.2	.04	303	201	16	16	.6	464	6.9
218	66	7.5	.4	1.0	.03	319	208	29	17	.6	487	6.9
233	44	13	.3	2.7	.03	324	208	17	18	.7	488	7.0
236	40	8.0	.6	4.0	-------	----------	207	13	18	.6	[1] 474	----
236	123	9.0	.3	1.8	.05	420	274	80	18	.7	625	7.0
244	132	10	.2	1.8	.03	434	281	81	16	.7	632	7.2
202	48	12	.3	3.6	.04	302	192	26	18	.6	455	7.0
262	152	13	.4	2.5	.05	499	326	111	17	.7	722	7.0
266	105	23	.4	1.7	-------	----------	310	92	15	.6	[1] 663	----
234	98	11	.3	15	.05	434	270	78	15	.6	604	6.9
184	45	8.0	.3	13	.03	314	185	34	14	.5	432	6.8
199	36	11	.4	2.8	.03	276	172	9	21	.7	430	7.1
201	31	8.0	.4	3.9	-------	259	164	0	19	.6	409	7.3
253	30	16	.3	23	.15	344	215	8	23	.9	541	6.8
199	181	22	.4	8.7	.11	497	275	112	29	1.4	743	7.2
191	33	7.5	.3	3.3	.03	249	156	0	23	.8	403	7.0
269	38	7.5	.4	16	.05	349	216	0	22	.9	545	6.9
243	41	14	.3	8.0	.04	337	222	23	17	.6	519	7.0
235	21	12	.1	12	.03	307	196	3	16	.6	472	7.0
226	15	11	.3	11	.05	289	190	5	16	.5	449	7.0
221	27	9.0	.4	1.6	.04	273	179	0	20	.7	434	7.2
235	90	6.0	.5	8.1	.05	371	241	48	20	.8	569	7.2
164	37	8.0	.4	.6	.04	236	142	8	23	.7	365	7.3
165	34	9.0	.5	2.6	.03	231	145	10	22	.7	371	7.1
205	253	25	.4	1.2	.05	603	341	173	24	1.2	840	7.1
190	132	14	.5	4.5	.03	399	251	95	17	.7	604	7.4
205	133	13	.4	8.3	.05	413	264	96	18	.7	620	7.1
316	70	10	.3	4.2	.04	412	286	27	18	.7	644	7.1
263	108	8.5	.4	28	.14	456	288	72	20	.9	680	7.1
319	162	13	.8	27	.07	583	358	96	20	1.0	863	7.2
289	116	7.5	.3	5.0	.05	456	297	60	19	.8	689	7.1
217	73	8.0	.4	9.3	.06	333	214	36	21	.8	522	7.2
305	73	14	.3	3.5	.05	425	289	39	16	.7	648	7.2
302	76	13	.2	3.2	.04	414	282	34	16	.7	650	7.3
322	46	10	.3	3.9	.06	403	257	0	21	.9	616	7.3
184	50	5.0	.4	.8	-------	----------	165	14	22	.7	----------	----

The chemical composition of the water is illustrated diagrammatically (Stiff, 1951) in figure 16. Differences in water composition are readily apparent by differences in the shapes of the diagrams. The chemical type of a water is determined by the relative proportions of the cations and anions present (Piper, Garrett, and others, 1953, p. 26). In most of Hamilton County the water is of the calcium bicarbonate type, but in the west and northwest parts it is of the

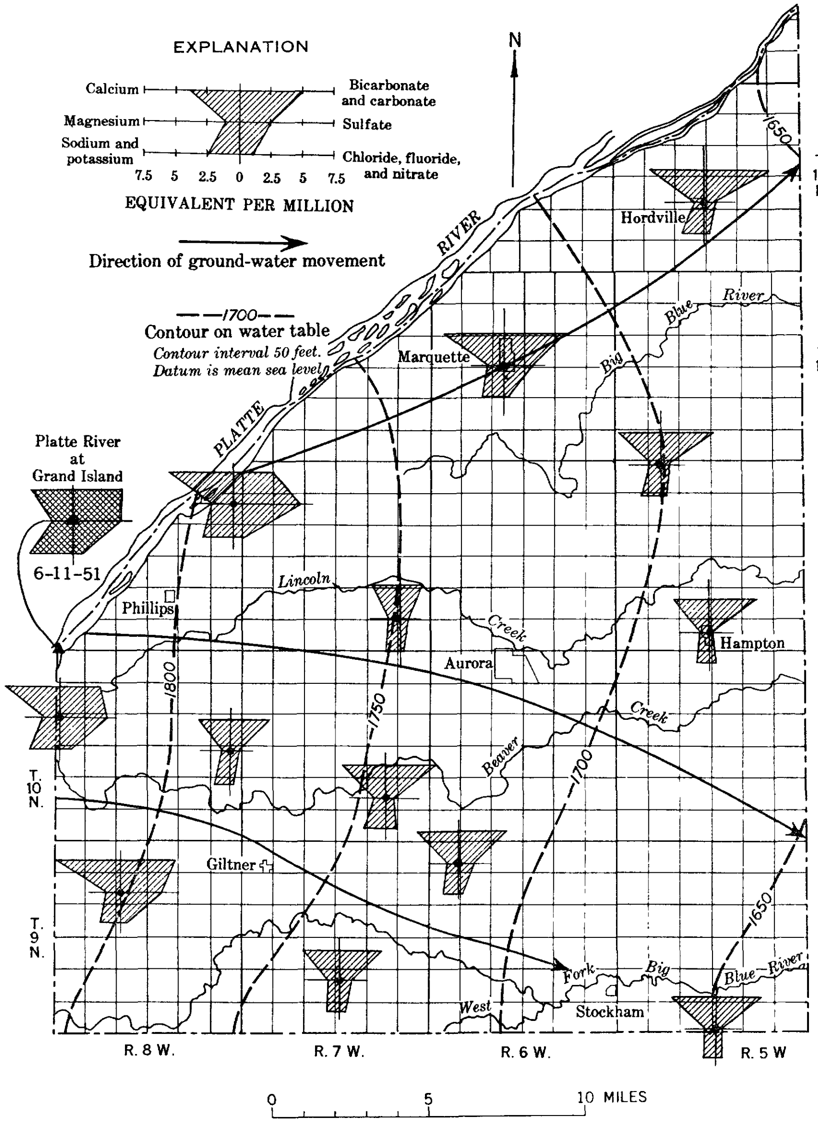

FIGURE 16.—Map showing the chemical composition of selected samples of water.

calcium sulfate bicarbonate type. In relative proportion to the other major constituents present, sulfate is the only one that differs significantly.

For comparison, a diagram representing the composition of water in the Platte River at Grand Island, Nebr., at high stages, is also shown in figure 16. Results of chemical analyses of water from the Platte River at Grand Island have been published by the U.S. Geological Survey (1956, 1957).

Concentrations of potassium, fluoride, and boron in the ground water are relatively uniform and low (see table 2). In most of the county, concentrations of iron plus manganese were less than 0.2 ppm; but in parts of T. 9 N., Rs. 7 and 8 W., they exceeded 0.3 ppm. The concentration of iron in water from well 11–8–27ab was 0.44 ppm in 1953, but it was only 0.05 ppm in 1958; the higher concentration may have been due to contamination of the sample with rust particles from the well casing. Sodium, magnesium, chloride, and nitrate concentrations are generally low; nitrate is not so uniform in concentration as the other three constituents. The temperature of the water at the times of collection ranged from 53° to 57°F.

Change in mineralization with time was generally insignificant. Mineralization of the water from wells 11–5–33ad1 and 11–8–27ab changed only slightly during a 5-year interval, and that from wells 9–8–9cb and 9–8–9dc2, adjacent to each other, changed very little during a 22-year interval. An exception was water from well 12–6–16cd, which changed significantly in mineralization during 5 years.

WATER QUALITY IN RELATION TO GEOLOGY AND HYDROLOGY

The extensive beds of sand and gravel that yield water to wells in most of the county are composed principally of quartz and feldspars. These minerals are only slightly soluble and, therefore, contribute a relatively small amount of dissolved material to the ground water.

Water generally increases in mineralization as it moves downgradient through an aquifer, because the length of time the water is in contact with soluble minerals increases. However, in parts of Hamilton County the water decreases in mineralization as it moves downgradient, presumably because of dilution by local recharge to the ground-water reservoir from precipitation.

The relatively high mineralization and high concentrations of sulfate in the ground water near the west and north borders of the county probably are due in part to recharge from the Platte River. The similarity in composition of the ground water near these borders to that of the water in the Platte River at Grand Island is apparent in figure 16.

The effect of the recharge from the Platte River extends only a relatively short distance into Hamilton County. The proportion of recharge entering the ground-water reservoir from local precipitation is much greater that that from the Platte River; the greater proportion is evidenced by the decrease, within about 5 miles, of sulfate concentrations from 4 to 1 epm in wells 10–8–18bb and 10–8–24ab, respectively.

The difference in the chemical quality of the water from the upper and the lower parts of the saturated deposits of Quaternary age is insignificant. This fact is apparent from a comparison of the quality of the water from well 9–7–6dad1, which taps the upper part, with the quality of the water from well 9–7–6dad2, which taps the lower part (see table 2). A similar comparison of water quality may be made between wells 13–5–21da1 and 13–5–21da2. (Wells 9–7–6dad1 and 9–7–6dad2 are only about 50 feet apart, and wells 13–5–21da1 and 13–5–21da2 are only about 300 feet apart.) The insignificant difference in the quality of the water from the upper and lower parts of the saturated deposits indicates that the quality of the water in the deposits of Quaternary age is probably influenced only slightly by the underlying formations.

The least mineralized water is generally in the areas where the estimated coefficient of transmissibility of the saturated deposits exceeds 150,000 gpd per foot (see pl. N–2 and fig. 16). Some of the areas where the water table has been lowered appreciably by the increased use of water for irrigation coincide with the areas where the water is the least mineralized (see figs. 14 and 16). Although no significant changes in water quality are apparent to date, continued lowering of the water table may cause the more mineralized water in the western part of the county to move into the areas where the water is now the least mineralized.

WATER QUALITY AND USE

Water is one of the most widely used natural resources of our Nation. The chemical quality of the water, however, may limit the utilization of a water supply. In this report, only three major uses are discussed.

DOMESTIC USE

Water for domestic use should be not only bacteriologically safe, but free of objectionable taste and odor, and should not contain excessive amounts of harmful substances. Standards for drinking and culinary water used by carriers subject to the Federal Quarantine Regulations, established by the U.S. Public Health Service (1946), have been adopted by the American Water Works Association as criteria of quality for all public water supplies. The standards that pertain to the chemical constituents are reproduced, in part, in table 3.

With only one exception, the water used for public supplies in Hamilton County meets the recommended standards. The exception is the public water supply at Giltner, which contains 1.6 ppm of iron plus manganese (see table 3). Concentrations of iron plus manganese higher than 0.3 ppm may cause reddish-yellow to black stains on plumbing fixtures and laundry and may contribute an objectionable astringent taste to the water. Iron and manganese can be removed by many processes, including the zeolite water-softening process.

TABLE 3.—*Chemical constituents and physical properties relating to suitability of the water for domestic use*

[Results in parts per million except as indicated]

Constituent or property	Recommended maximum concentration [1]	Public Supply							
		Aurora	Giltner		Hampton	Hordville		Marquette	Phillips
			120 ft well	260 ft well		160 ft well	262 ft well		
Arsenic (As)	[2] 0.05	[3] 0.02	[3] 0.0		[3] 0.008	[3] 0.01		[3] 0.001	[3] 0.01
Lead (Pb)	[2] .1	[3] .0	[3] .011		[3] .0	[3] .04		[3] .0	[3] .0
Magnesium (Mg)	125	7.8	15	15	10	13	12	13	16
Iron plus manganese (Fe+Mn)	.3	.03	1.6	1.6	.04	.05	.10	.11	.06
Sulfate (SO_4)	250	31	123	132	15	76	46	116	133
Chloride (Cl)	250	8.0	9.0	10	11	13	10	7.5	13
Fluoride (F)	[2] 1.5	.4	.3	.2	.3	.2	.3	.3	.4
Nitrate (NO_3)	[4] 44	3.9	1.8	1.8	11	3.2	3.9	5.0	8.3
Dissolved solids	500	259	420	434	289	414	403	456	413
Hardness as $CaCO_3$	(5)	164	274	281	190	282	257	297	264
Color (platinum-cobalt scale)	20	0	--------	2	----------	--------	--------	----------	--------
Turbidity (silica scale)	10	--------	--------	2	----------	.6	--------	----------	--------

[1] By U.S. Public Health Service (1946) unless otherwise noted.
[2] Mandatory maximum.
[3] Analysis by Nebraska State Dept. Health of samples collected in 1952, 1953, or 1954.
[4] By Maxcy (1950).
[5] See p. 55–56.

Mineral substances that cause hardness of water combine with soap to produce an insoluble curd. Hardness is caused principally by calcium and magnesium, but it may also be caused by iron, manganese, barium, aluminum, and free mineral acids. Calcium and magnesium contribute to scale formation in steam boilers and pipes. Specific limits for hardness have not been established, but the following gradations are generally recognized and are convenient for classification and description of water supplies:

Hardness as $CaCO_3$ (ppm)	*Rating*	*Suitability*
< 60	Soft	Suitable for many uses without further softening.
60–120	Moderately hard	Usable except in some industrial applications.
121–200	Hard	Softening required by laundries and some other industries.
> 200	Very hard	Requires softening for many uses.

In Hamilton County the water from 12 of the wells sampled is hard, and the water from the rest of the wells is very hard. The effects of hard water can be minimized by the use of water softeners and synthetic detergents.

IRRIGATION

Irrigation has become an essential and integral part of the agricultural economy of Hamilton County. The success of irrigation programs is dependent on many factors, of which an important one is the chemical quality of the irrigation water. Several methods of evaluating water for irrigation have been used in the past; the one used in this report was developed by the U.S. Salinity Laboratory Staff (1954).

The suitability of water for irrigation is determined principally from four characteristics:

1. Total concentration of dissolved salts.
2. Relative proportion of sodium to other cations in solution.
3. The bicarbonate concentration as related to the calcium plus magnesium concentration.
4. Concentration of toxic elements such as boron.

The total concentration of dissolved salts is represented by the specific conductance of the water. In general, water having a specific conductance of less than 750 micromhos per centimeter is suitable for irrigating plants that have a moderate salt tolerance. Water having a specific conductance between 750 and 2,250 micromhos per centimeter should not be used on soils having restricted drainage; even with adequate drainage, special management for salinity control of the soil solution is required, and plants having good salt tolerance should be selected.

A part of the irrigation water must drain through the root zone to prevent salt buildup in the soil. The percentage of the irrigation water that must drain through the root zone to control soil salinity at any specified level is defined as the leaching requirement. It is recommended that for sensitive crops the soil-salinity level, as represented by the specific conductance of the drainage water at the bottom of the root zone, be kept below 4,000 micromhos per centimeter. At this soil-salinity level, the leaching requirement for the ground water sampled in Hamilton County ranges from 9.1 to 21 percent.

High concentrations of sodium relative to the concentration of calcium plus magnesium in irrigation water can adversely affect soil structure. A measure of the ability of a water to produce the adverse effect on the soil structure is termed the "sodium hazard" of the water. An index for predicting the sodium hazard is the sodium-adsorption-ratio (SAR), which is defined by the equation

$$\mathrm{SAR}=\frac{\mathrm{Na}^{+}}{\sqrt{\dfrac{\mathrm{Ca}^{++}+\mathrm{Mg}^{++}}{2}}}$$

where the concentrations of the designated cations are expressed in equivalents per million. In the method for determining the suitability of water for irrigation (U.S. Salinity Laboratory staff, 1954), the classification of the water depends on the SAR and the specific conductance of the water. The water in Hamilton County has an SAR of 5 or less and a specific conductance of 863 micromhos per centimeter or less; therefore, it has a low sodium hazard and can be used for irrigation on almost all soils.

The relation of bicarbonate concentration to calcium plus magnesium concentration may affect the suitability of a water for irrigation. The amount in equivalents per million of bicarbonate in excess of calcium plus magnesium is termed "residual sodium carbonate." Water containing residual sodium carbonate will increase in percent sodium and in alkalinity as calcium and magnesium precipitate from the soil solution. Alkaline water dissolves organic matter, and the increase in percent sodium deteriorates the tilth of the soil; thus a soil condition known as "black alkali" may result. Wilcox, Blair, and Bower (1954) concluded that water containing less than 1.25 epm of residual sodium carbonate is probably safe for use. In Hamilton County the water contains less than 0.15 epm of residual sodium carbonate; therefore, it can be used without injury to the soil structure.

Boron is essential to the normal growth of all plants; however, if present in concentrations above optimum, it may be highly toxic to some plants. The boron limit for the most sensitive plants is 0.3 ppm (Scofield, 1936). Boron concentrations for the samples analyzed were less than 0.16 ppm; therefore, no toxic effects due to boron are to be expected.

INDUSTRIAL USE

Water-quality requirements for industry differ considerably. Generally, however, water that is suitable for domestic use is also suitable for most industrial uses or can be made suitable by treatment. For all industrial applications, water of constant composition is of primary importance. The water sampled in Hamilton County is satisfactory for most industrial uses; however, hardness or iron and manganese concentrations may require treatment of the water for some uses.

SUMMARY AND CONCLUSIONS

The amount of water stored in the ground-water reservoir at any given time is controlled by the rate of replenishment and withdrawal or, in other words, the recharge to and discharge from the aquifer. In order to evaluate the ability of the ground-water reservoir to sustain the yield of wells it is essential first to evaluate the factors of recharge and discharge. It is essential also to separate the natural factors from the artificial factors induced by man. For example, when water levels in wells decline, it is important to know how much of the lowering is the result of natural factors and how much is attributable to withdrawals of water from wells. Otherwise, an overdeveloped area may not be recognized in its early stages of overdevelopment and, thus, water users cannot be informed of areas where overdevelopment is likely to occur in time to apply remedial measures.

Analyses of the hydrologic data from Hamilton County indicate that current development of the ground-water resources exceeds recharge. The data indicate that the annual natural recharge is about equal to the amount required to irrigate one-ninth of the land, and some of the recharge is destined to be naturally discharged and cannot be used for irrigation. Development of irrigation in Hamilton County in 1957 had reached the point where more than one-third of the county was being irrigated. Where, then, is the source of the additional water required for irrigation? To this question there is at present only one answer—storage within the aquifer, storage that has accumulated through centuries of time. It is evident that this storage is adequate for several decades of withdrawals at the present rate, but even so, eventually the reservoir will be seriously depleted if withdrawals continue at the present rate of development and no progress is made toward increasing the replenishment.

The most direct method of reducing the draft from the reservoir would be by the reduction of pumping from wells. This is actually what happens if nature takes its course, because, as the water level declines, the saturated thickness of the water-bearing materials becomes smaller and the yields of wells are correspondingly reduced.

Artificial replenishment of the ground-water reservoir in order to reduce the disparity between draft and natural replenishment might be accomplished by spreading imported surplus surface water on the land. Implementation of this kind of development would have a twofold stabilizing effect because it would supplement the irrigation supply and at the same time recharge the ground-water reservoir by percolation from the water spread on the land. The practice of artificial recharge by spreading water on the land is being accomplished in many places in the West, notably in California, and also in areas heavily pumped for industrial and municipal use in the East.

Some progress is being made in the development of means by which imported water can be directly injected into the ground-water reservoir through the use of recharge wells. Much experimentation in regard to artificial recharge through wells is in progress, but to date many problems remain to be solved.

Any significant effort toward the conservation of ground water must be based on a comprehensive understanding of the geology and hydrology of the area as well as knowledge of land management and the agricultural practices. The magnitude of the forces affecting the available supply of ground water is always changing; thus, if ground water is to be properly managed, a constant evaluation of the ground-water conditions is necessary.

The ground water is generally of relatively low mineralization, and in most of the county it is of the calcium bicarbonate type. The water having the highest mineralization is near the north and west borders of the county and is of the calcium sulfate bicarbonate type. Sulfate is the only major constituent that differs significantly throughout the county. Change in mineralization with time and depth was generally insignificant.

The relatively high mineralization and high concentrations of sulfate in the ground water near the west and north borders of the county probably are due in part to recharge from the Platte River. The continued lowering of the water table may cause the more mineralized water in the western part of the county to move into the areas where the water is the least mineralized.

The water in most of the county is of good quality for domestic use except that it is hard. Because mineralization, sodium hazard, residual sodium carbonate, and concentrations of boron are low, the water is suitable for irrigation on almost all soils. The water is of satisfactory quality for many industrial uses.

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