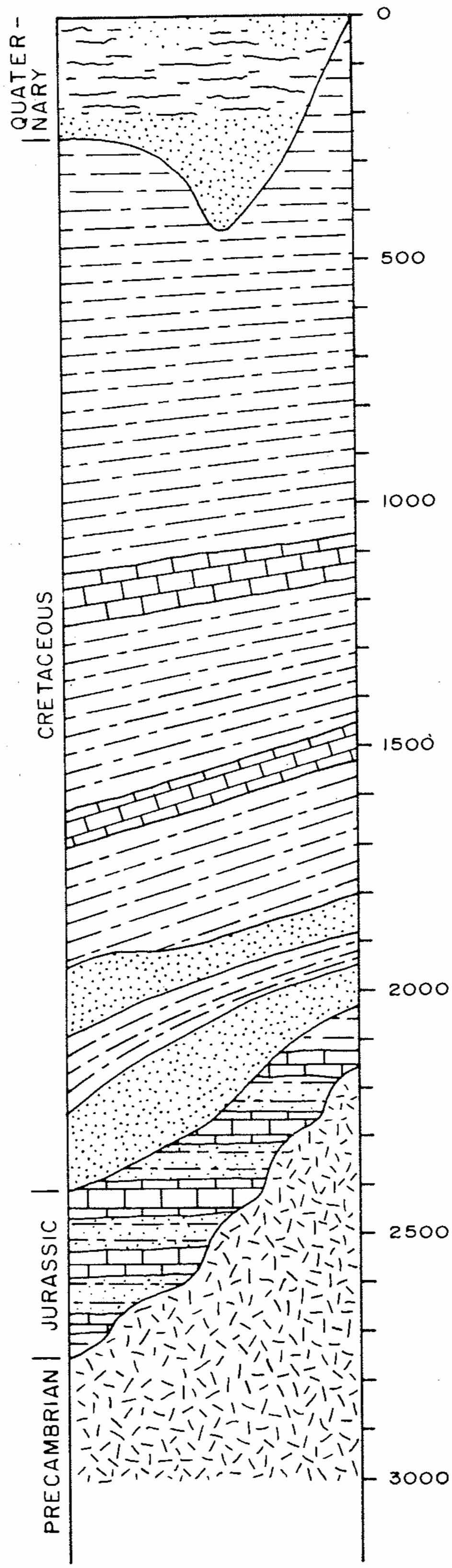

GEOLOGY AND WATER RESOURCES OF CAMPBELL COUNTY SOUTH DAKOTA

Part II – Water Resources

by Neil C. Koch
United States Geological Survey

Bulletin 20
South Dakota Geological Survey

1970

STATE OF SOUTH DAKOTA
Frank Farrar, Governor

SOUTH DAKOTA GEOLOGICAL SURVEY
Duncan J. McGregor, State Geologist

Bulletin 20

GEOLOGY AND WATER RESOURCES OF CAMPBELL COUNTY, SOUTH DAKOTA

PART II: WATER RESOURCES

by
Neil C. Koch
UNITED STATES GEOLOGICAL SURVEY
United States Department of the Interior

Prepared in cooperation with the
South Dakota Geological Survey
and Campbell County

Science Center
University of South Dakota
Vermillion, South Dakota
1970

CONTENTS

Contents—continued

ILLUSTRATIONS

Illustrations—continued

Page

Tables

Water Resources of Campbell County, South Dakota

by

Neil C. Koch

ABSTRACT

Campbell County, an area of 763 square miles, is in the north-central part of South Dakota and is bounded on the west by the Missouri River and on the north by North Dakota. The county is nearly covered by glacial drift and lake deposits of Pleistocene age, and alluvium and colluvium of Holocene age. These sediments range in thickness from a thin veneer to more than 475 feet and overlie the Pierre Shale and Fox Hills Formations of Cretaceous age.

A deep-glacial aquifer, composed mostly of outwash, underlies about 20 percent of the county, averages 100 feet in thickness, and contains about 2½ million acre-feet of water in transient storage. This aquifer supplies about 11 percent of the water used in the county. A transmissivity of 100,000 gpd per ft (gallons per day per foot) and a storage coefficient of 0.003 were obtained from a 22-hour aquifer test on an irrigation well south of Pollock.

The deep-glacial aquifer averages about 70 feet in thickness from Pollock to Mound City and has a transmissivity of 50,000 to 100,000 gpd per ft. East and south of Mound City the average thickness is about 150 feet with a transmissivity of 100,000 to 200,000 gpd per ft. Water levels range from 25 feet below land surface east of Mound City to 50 feet below land surface at Pollock. Recharge occurs from infiltration of ground water in T. 125 N., R. 75 and 76 W., and from subsurface inflow from McPherson County and downward percolation through till. Natural discharge occurs as subsurface outflow to the Missouri River near Pollock and into Walworth County.

Shallow-glacial aquifers cover 40 percent of the county and yield as much as 500 gpm (gallons per minute) to wells. There is about 1 million acre-feet of water in transient storage. Recharge to the aquifers is by precipitation, seepage from Spring Creek, and ground-water inflow from Walworth County.

The shallow and deep-glacial aquifer waters are suitable for irrigation under certain soil conditions. Shallow aquifer water is more suitable for irrigation than deep aquifer water. Both aquifers contain water that is high in bicarbonate and sulfate. The shallow-glacial water is generally high in calcium, whereas the deep-glacial water is always high in sodium.

The artesian Dakota and Fall River aquifers underlie all of Campbell County at a depth of about 2,000 feet. These aquifers furnish water of sufficient quantity for domestic and farm needs by flowing wells. Because of excessive mineralization this water is not suitable for irrigation.

Surface-water resources are increasing in importance as the supply becomes more readily available through construction of dams. The Oahe Reservoir on the Missouri River and Lake Pocasse are being used for irrigation at the present time and Spring Creek has potential.

INTRODUCTION

In July 1964, a 3-year study was begun to determine the geology and water resources of Campbell County. This report is an appraisal of the water resources of the county. The geology of the county is described in a report by Hedges (in preparation). The basic data collected and used in the preparation of these reports are available in a third report (Hedges and Koch, 1970) which consists of well records, quality-of-water data, and logs from test drilling. The basic-data report is of supplemental benefit to the reports on geology and water resources.

County studies, such as this, are made cooperatively by the South Dakota Geological Survey and the U. S. Geological Survey (see fig. 1).

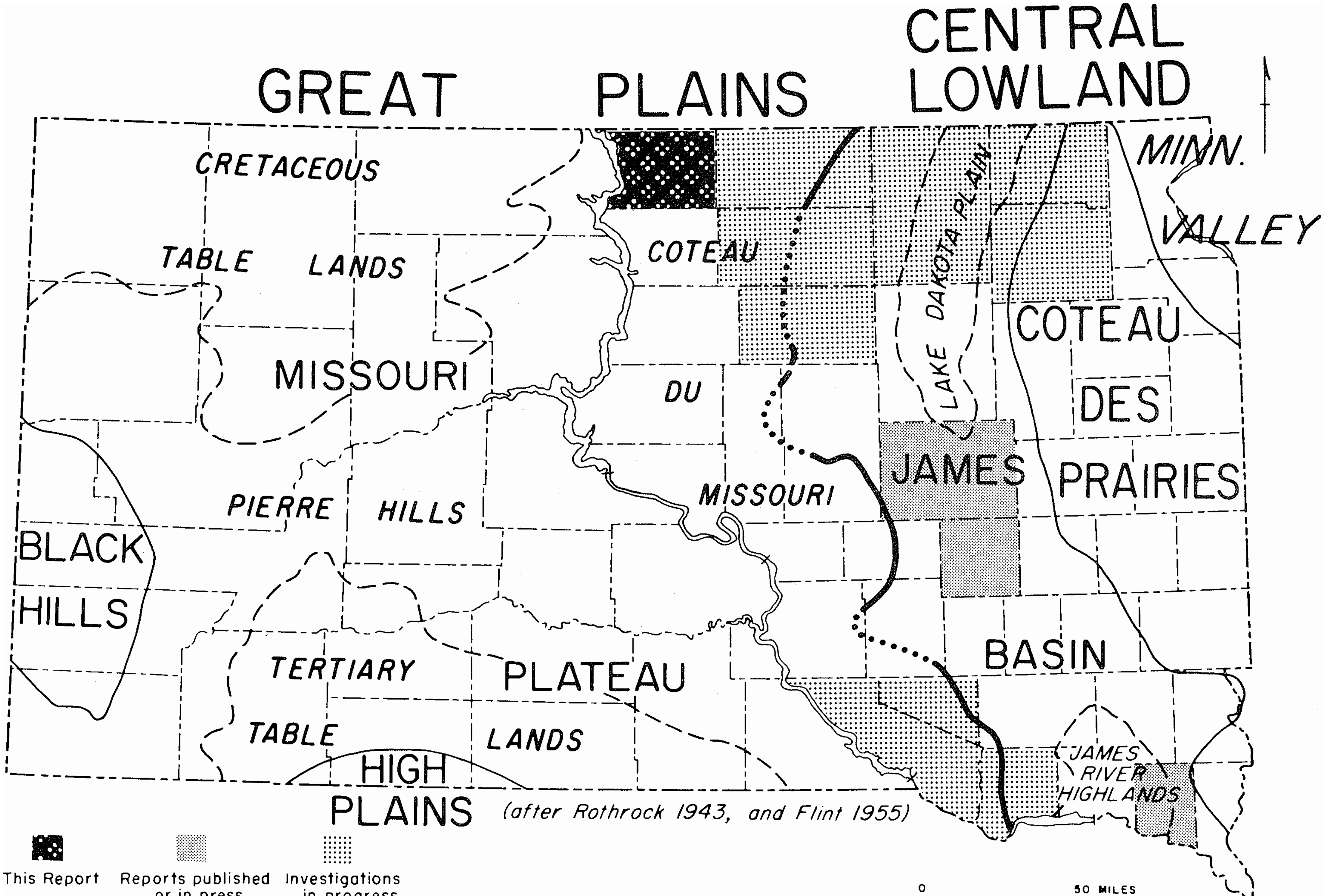

Figure I. Index map of South Dakota showing area of report, status of county investigations, and major physiographic divisions of South Dakota.

It should be emphasized that this is a general appraisal of water resources; any large-scale ground-water development should be preceded by local test drilling and determination of aquifer characteristics.

Campbell County, an area of 763 square miles, is located in the north-central part of the State. The county is bounded on the west by the Missouri River, on the north by North Dakota, on the east by McPherson County, and on the south by Walworth County. It is in the Coteau du Missouri (Missouri Hills) division of the Great Plains province and can be divided topographically into the rolling glacial hills in the eastern part, large flat areas in the central part, and the rugged river "brakes" in the western part of the county (see fig. 2).

The area has a subhumid climate. Precipitation is quite variable but averages 16 inches a year. The occurrence of drought conditions is the major factor limiting further development of an agricultural economy.

Acknowledgements

Many residents of Campbell County and several well drillers provided valuable information about the water-bearing zones. The cooperation and helpfulness of County Extension Agent, Michael Madden, and the County Commissioners is greatly appreciated. Appreciation is expressed to Myron Johnson for permitting and assisting with the test of his irrigation well and to the drillers of Empire Irrigation and Drilling Company for their assistance during the test.

Previous Investigations

Lee (1956) described briefly the amount of ground water available near Mound City. See Hedges (in preparation) for a listing of previous geologic investigations.

Well-numbering System

Wells and test holes are located according to a numbering system based on the Federal land-survey system used in South Dakota (fig. 3). The location number consists of township, range, and section numbers separated by hyphens, followed by a maximum of four letters that indicate, respectively, the 160, 40, 10, and 2½-acre tract in which the well is located. A serial number following the last letter is used to distinguish between wells in the same tract. Thus, well 126-76-15daaa (fig. 3) is in the NE¼NE¼NE¼SE¼, sec. 15, T. 126 N., R. 76 W.

SURFACE WATER

Surface water development, other than for wildlife and recreation, started in 1958 when the Oahe Reservoir was completed on the Missouri River. Another surface water reservoir, Lake Pocasse, on Spring Creek, was completed in 1961. These reservoirs provide surface water for agricultural uses and may provide water for municipal and industrial uses in Campbell County in the future.

Surface drainage in Campbell County is poorly developed except for Spring Creek which receives runoff from the northern half of the county and discharges it into the Missouri River. The Spring Creek drainage area as shown in figure 2 is divided into the contributing area, where most of the surface runoff reaches Spring Creek, and the noncontributing area, where most of the surface runoff enters local closed basins and seldom reaches a stage to overflow into Spring Creek. In these poorly developed drainage areas, runoff evaporates or seeps into the drift.

Streamflow records for Spring Creek are available from March 1960 to 1968. Little to no flow occurs from July or August to about February or March. Much of the spring flow is caused by snowmelt with March 1966 recording the largest runoff during the period of record. See figure 6 for monthly streamflow in Spring Creek. The recharge-discharge discussion of the Spring Creek aquifer section of this report discusses the surface-ground water relationship.

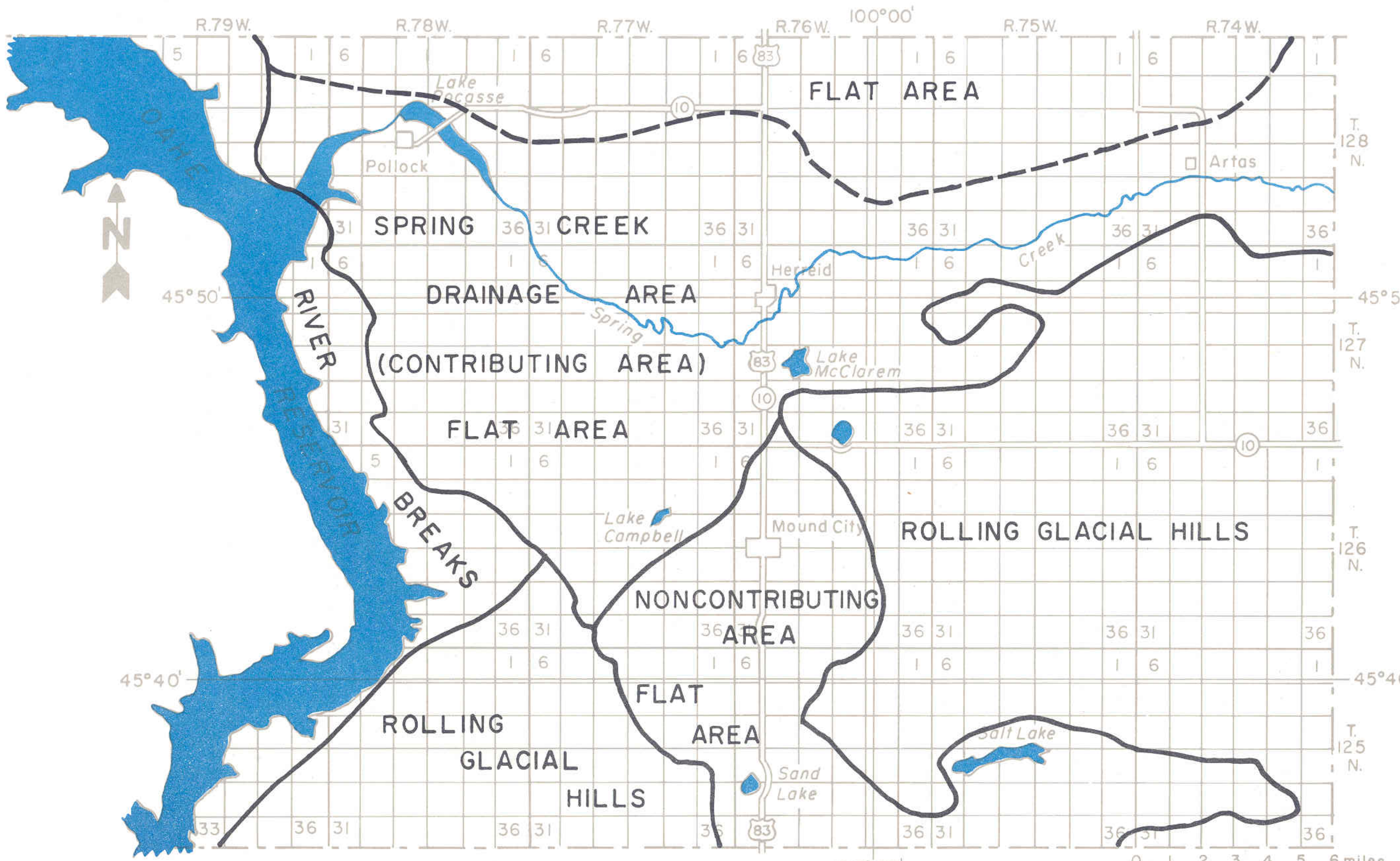

Figure 2. Index map of Campbell County showing major topographic features and Spring Creek drainage area.

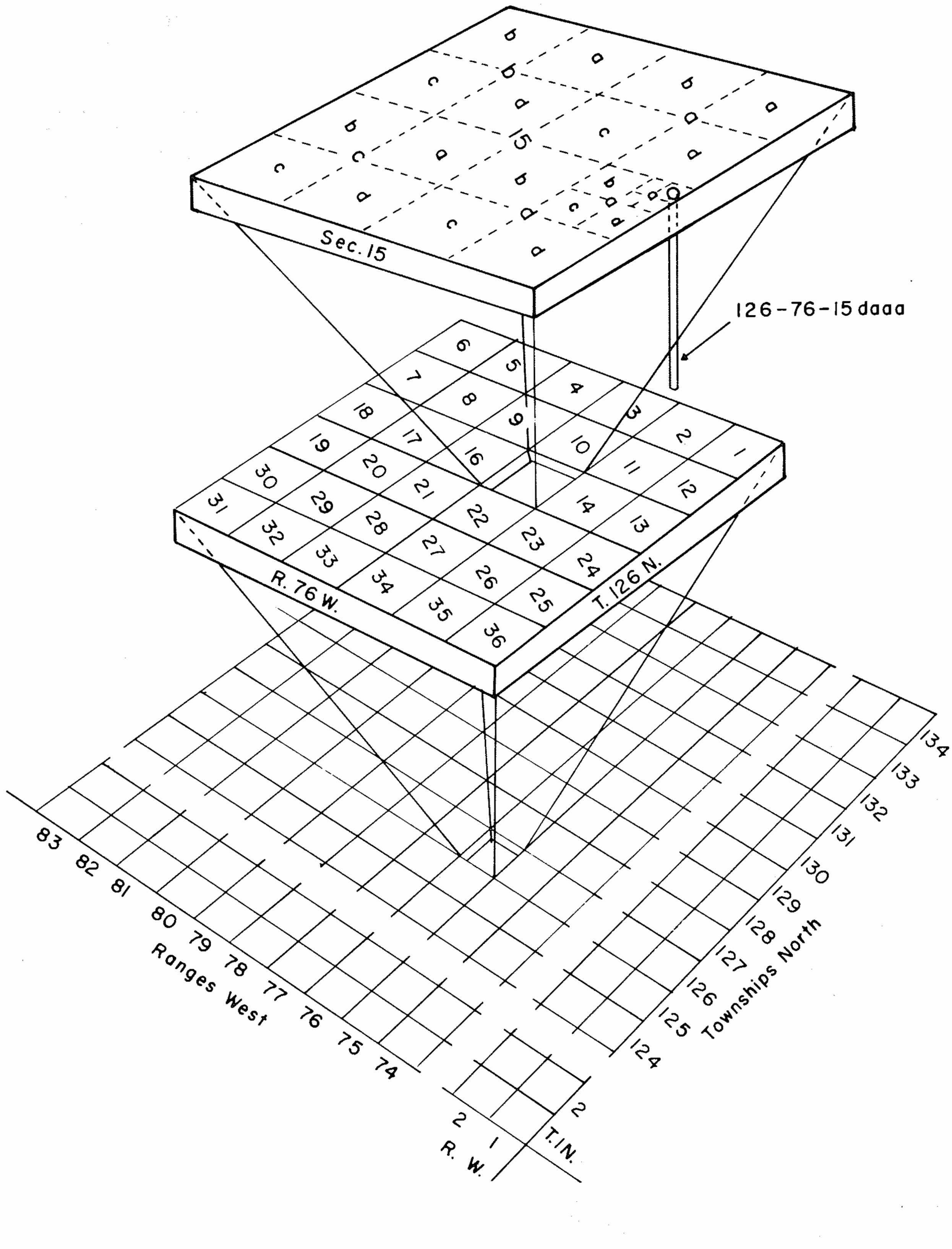

Figure 3. Well-numbering diagram.

Surface water is also discussed in the quality of water and water use sections.

GROUND WATER

Ground water in Campbell County is derived from precipitation and ground-water inflow. Part of the precipitation flows into streams and lakes as direct runoff, part returns to the atmosphere by evaporation and transpiration (evapotranspiration), and the remainder seeps downward through the soil and rocks to the saturated zone. The surface of the saturated zone is called the water table. In the saturated zone, all openings between the sand and clay particles or in the joints and fractures in consolidated bedrock deposits are filled with water.

Ground water moves through the pores, cracks, and other openings in the soil and rock below the water table. The size, shape, and distribution of these openings may vary considerably from place to place and control the storage and movement of water. Rock or soil which yields sufficient water to be of importance as a source of supply is called an aquifer.

The permeability of a rock material is its capacity for transmitting a fluid. The degree of permeability is determined by the size and amount of interconnection of the openings. For example, an aquifer composed of coarse-grained, well sorted material will normally yield more water than one composed of finer grained, poorly sorted material. The hydraulic conductivity is the rate of flow of water in gallons a day through a cross section of 1 square foot under a unit hydraulic gradient or a 1 to 1 slope of the ground water surface. Transmissivity is equal to the hydraulic conductivity multiplied by the saturated thickness of the aquifer in feet.

When an aquifer is confined by an overlying, relatively impermeable material such as clay or shale and the water in wells rises above the top of the aquifer, the water is said to be under artesian pressure. Some aquifers are under sufficient pressure so that water flows from the well at the land surface.

A major part of the study was the drilling of test wells to determine the physical characteristics of the rock materials beneath the ground surface. The rock material has been divided into two groups, the glacial deposits and the bedrock deposits. Water-bearing characteristics of the principal rock materials are given in table 1.[1]

Glacial Deposits

Glacial drift includes all rock material transported by glacier ice even though subsequently affected by wind or water (Thwaites, 1961, p. 30). It is divided into till, the unstratified and unsorted drift deposited by the ice without subsequent movement by wind and water; and the stratified drift of which outwash is that material deposited by melt water as it flowed on and away from the ice. The drift generally ranges in thickness from a few feet in areas north of Pollock (fig. 2), north of Artas, along Spring Creek in Rs. 74 and 75, and along the Missouri River, to about 200 feet in a buried valley which extends from Pollock eastward to Herreid then south along State Highway 83 to the county line. However, the thickest area (more than 400 feet) is in the main channel of the ancient Grand River (fig. 15) where it crosses the southeast corner of the county.

Till consists of clay, silt, sand, and a heterogeneous mixture of rock fragments which range in size from clay to large boulders. About 70 percent of the surficial deposits in the county are till. Because of the heterogeneous mixture of rock fragments in till and large percent of clay content, it has low permeability and, in general, is not a good source for water.

Outwash consists of sorted gravel, sand, and silt. It is the most permeable surficial deposit in Campbell County. This report will be primarily concerned with determining the

[1] Stratigraphic nomenclature and classification used in this report are those of the South Dakota Geological Survey. They differ somewhat from usage adopted by the U. S. Geological Survey.

Table 1.--Principal rock units and their water-bearing characteristics in Campbell County, South Dakota

Age		Rock unit	Description	Maximum thickness (feet)	Water-bearing characteristics
Quaternary	Holocene	Alluvium	Clay, silt, sand and gravel, sorted and stratified.	10	Permeable, yields small amounts of water to wells along Spring Creek.
Quaternary	Pleistocene	Drift			
Quaternary	Pleistocene	Outwash	Sand and gravel, well sorted and stratified.	220	Forms major aquifers. Yields 25 to 1,000 gpm.
Quaternary	Pleistocene	Till	Clay with unsorted mixtures of silt, sand, and gravel. Some sand lenses.	100	Acts as a confining layer over deeper outwash deposits. Yields 1 to 5 gpm of poor-quality water.
Quaternary	Pleistocene	Lacustrine	Clay and silt, stratified.	140	Not known to yield water to wells.
Cretaceous	Upper	Fox Hills Formation	Sandstone	20	Does not contain sufficient water for wells.
Cretaceous	Upper	Timber Lake Member	Sand and sandstone		Does not contain sufficient water for wells.
Cretaceous	Upper	Trail City Member	Sandy shale		Does not contain sufficient water for wells.
Cretaceous	Upper	Pierre Shale	Shale	700	Yields small amounts of poor-quality water to shallow wells.
Cretaceous	Upper	Niobrara Marl	Shale, calcareous	200	Unknown.
Cretaceous	Upper	Carlile Shale	Shale	450	Does not yield water.
Cretaceous	Upper	Greenhorn Limestone	Shale, calcareous	190	Unknown.
Cretaceous	Upper	Graneros Shale	Shale	290	Does not yield water.
Cretaceous	Lower	Dakota Formation	Sandstone	250	Yields water to flowing wells.
Cretaceous	Lower	Skull Creek Shale	Shale	170	Does not yield water.
Cretaceous	Lower	Fall River Sandstone (Inyan Kara Group)	Sandstone	350	Yields water to flowing wells.
Jurassic		Unknown rock units	Shale	580	Does not yield water.
Pennsylvanian		Lower Minnelusa	Shale and limestone		Yields water at base.
Mississippian		Madison Group	Limestone	?	Unknown.
?		Unknown rock units		?	

areal extent, thickness, and water-bearing properties of the outwash.

Shallow Aquifers

Spring Creek aquifer

In Campbell County the Spring Creek aquifer (fig. 4) is composed mainly of outwash and alluvium, underlies an area of about 100 square miles (13 percent of the county), and is found at or near land surface. Water is within 10 feet of the land surface in most wells and may occur under water table or artesian conditions. Using an average saturated thickness of 25 feet and an estimated porosity of 20 percent, it is calculated that the aquifer contained 320,000 acre-feet of water in transient storage in 1966.

The main part of the aquifer lies in the north-central part of the county (fig. 4). To the east of this area (toward Artas along Spring Creek) the aquifer narrows and thins. To the west, in Rs. 78 and 79 W., the aquifer narrows slightly and decreases in thickness. The thickness and distribution of sand and gravel in the aquifer are shown on figure 4 and on 10 lithologic sections on figure 5.

Recharge-discharge.—Spring Creek aquifer is hydraulically connected to Spring Creek in many places. In most years there is streamflow from March through July (see fig. 6), as a result of snowmelt and rainfall. During the rest of the year there is little or no flow. When the water table is below the stream surface, some of the streamflow will enter the aquifer where there is a hydraulic connection. When the water table is above the level of the stream surface, water will discharge from the aquifer to the creek. Since the project started in 1964, water has been discharging into Spring Creek from springs in T. 126 N., R. 77 W., sections 6 and 8, but there is insufficient ground-water discharge to maintain base flow during the drier summer months. Figure 6 shows that above normal rainfall is required to maintain streamflow in the summer months. When above normal rainfall occurs following several dry months, much of the rainfall enters the soil zone and is held as soil moisture. The balance percolates down to the water table, or is removed by evapotranspiration. For example, in September 1961 and July and August 1963, above normal rainfall failed to produce streamflow.

Hydrologic characteristics.—The water table slopes downstream toward Spring Creek at a similar gradient to that of the creek (fig. 7). Between Artas and Herreid, the gradient of the ground-water surface is about 7 to 20 feet per mile and between Herreid and Pollock about 6 feet per mile. This water-surface slope limits the area of the aquifer available to supply water to a given well. For example, a well at Artas could obtain water from all of the aquifer to the east but it could draw water in the aquifer from only about a mile to the west. This amounts to about 3 square miles, or about 2,000 acre-feet of water in 1966. Beyond this point the water level in the aquifer would be below the bottom of the well. (See fig. 4.) Development of the aquifer for irrigation should not be considered without further study because the Artas area is dependent on this aquifer for domestic water supply. Recharge is entirely from precipitation which percolates down to the water table. During dry years the recharge rate decreases while the evapotranspiration rate remains about the same, resulting in a lowering of the water table. A 3-foot drop in the water table reduces the available water in the 3 square mile area to 1,000 acre-feet. Irrigation wells would further lower the water table which could result in lowered water levels and reduced well yields along the edges and in the eastern part of the aquifer. Available data indicate that it may not be possible to remove large quantities of water from the Spring Creek aquifer east of R. 76 W. without greatly affecting other wells in the area.

Well yields are dependent on transmissivity and well construction. Properly constructed wells in the areas where medium- to coarse-grained sand is greater than 25 feet in thickness (fig. 8) may yield as much as 300 gpm. However, one group of wells in the area which averaged 27 feet in depth and 7 feet in diameter, only yielded 40 to 175 gpm. Well development in very fine to fine-grained sand is very difficult and not always successful.

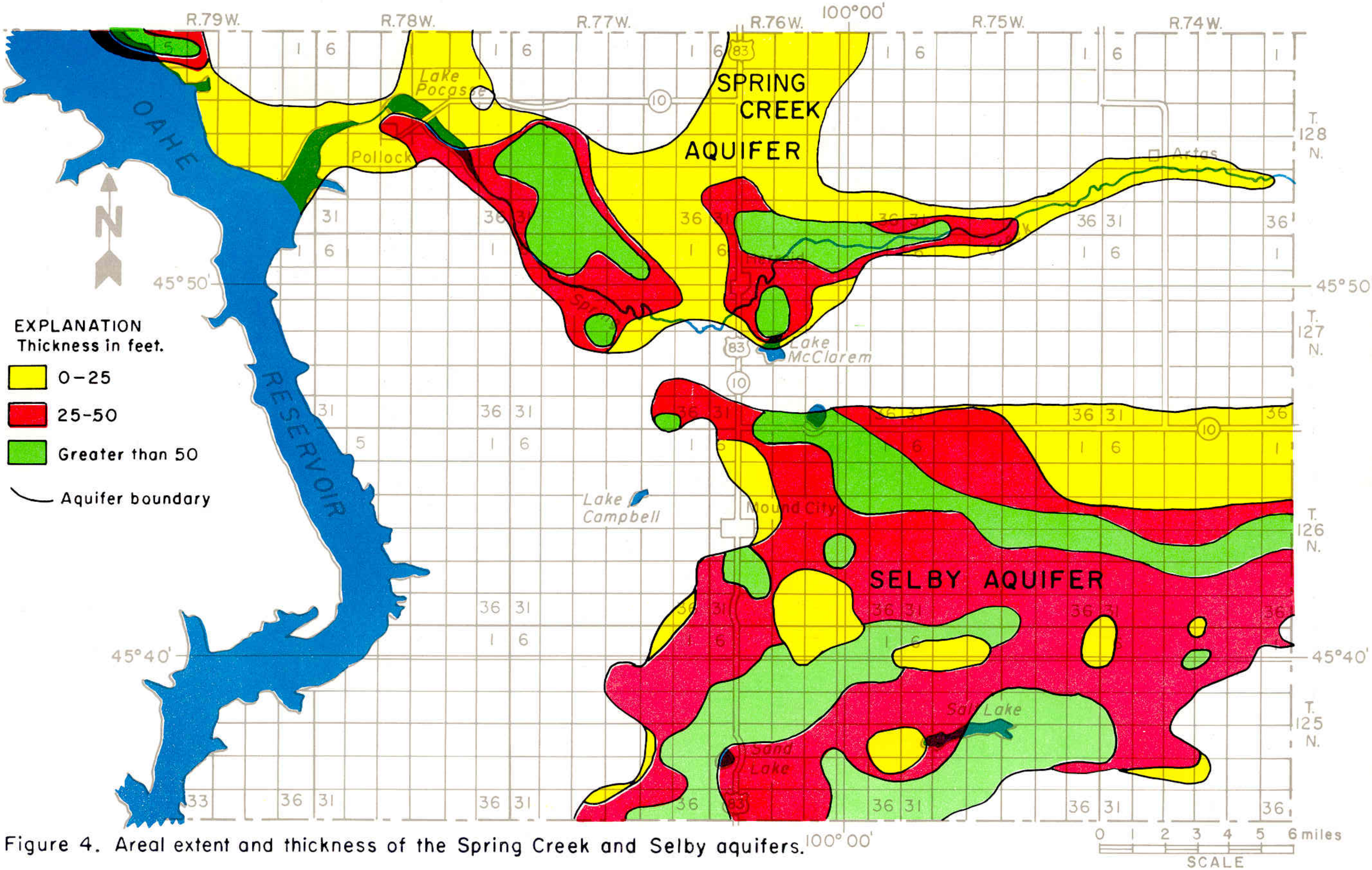

Figure 4. Areal extent and thickness of the Spring Creek and Selby aquifers.

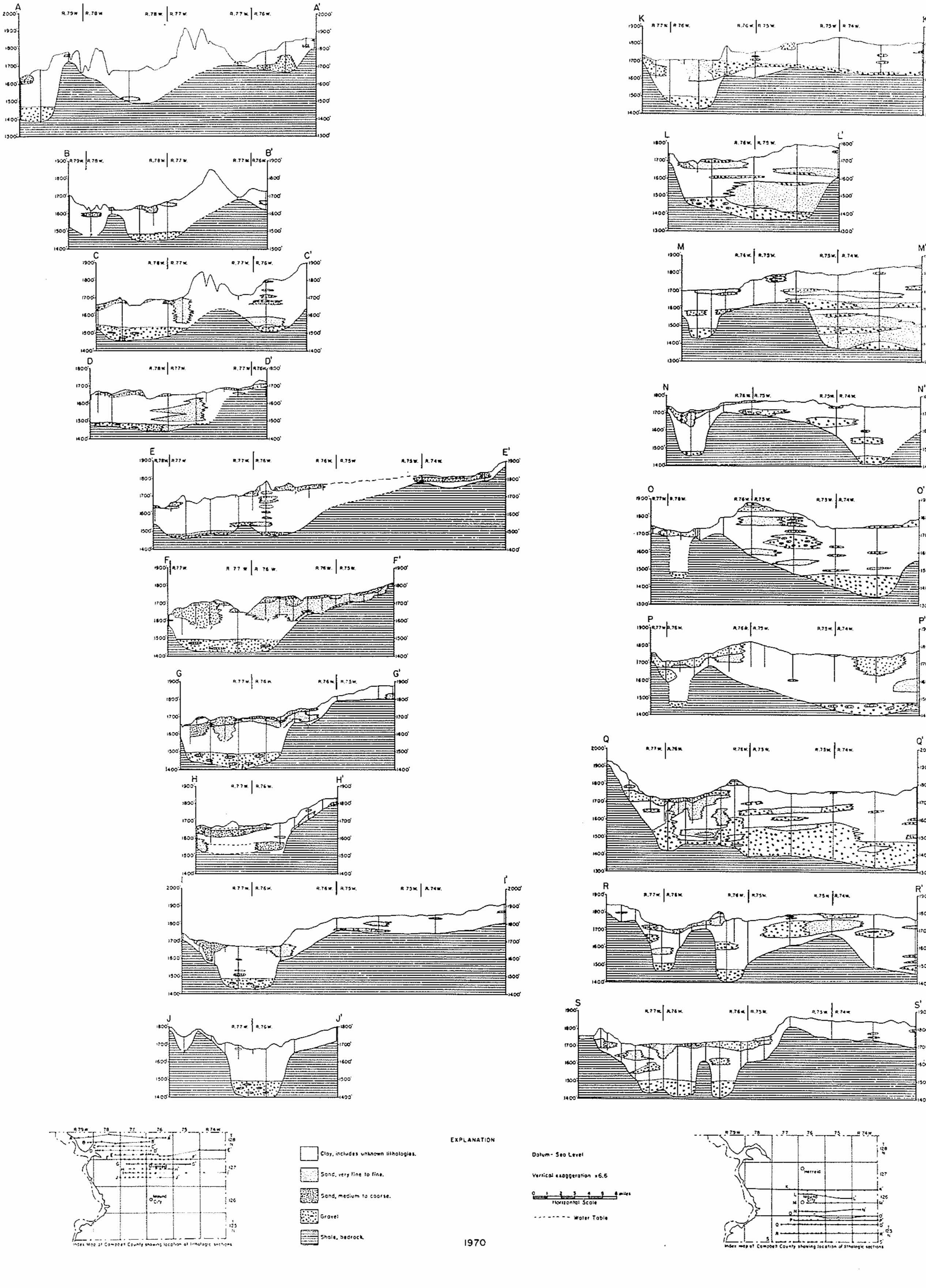

Figure 5. Profile A-A' to S-S'.

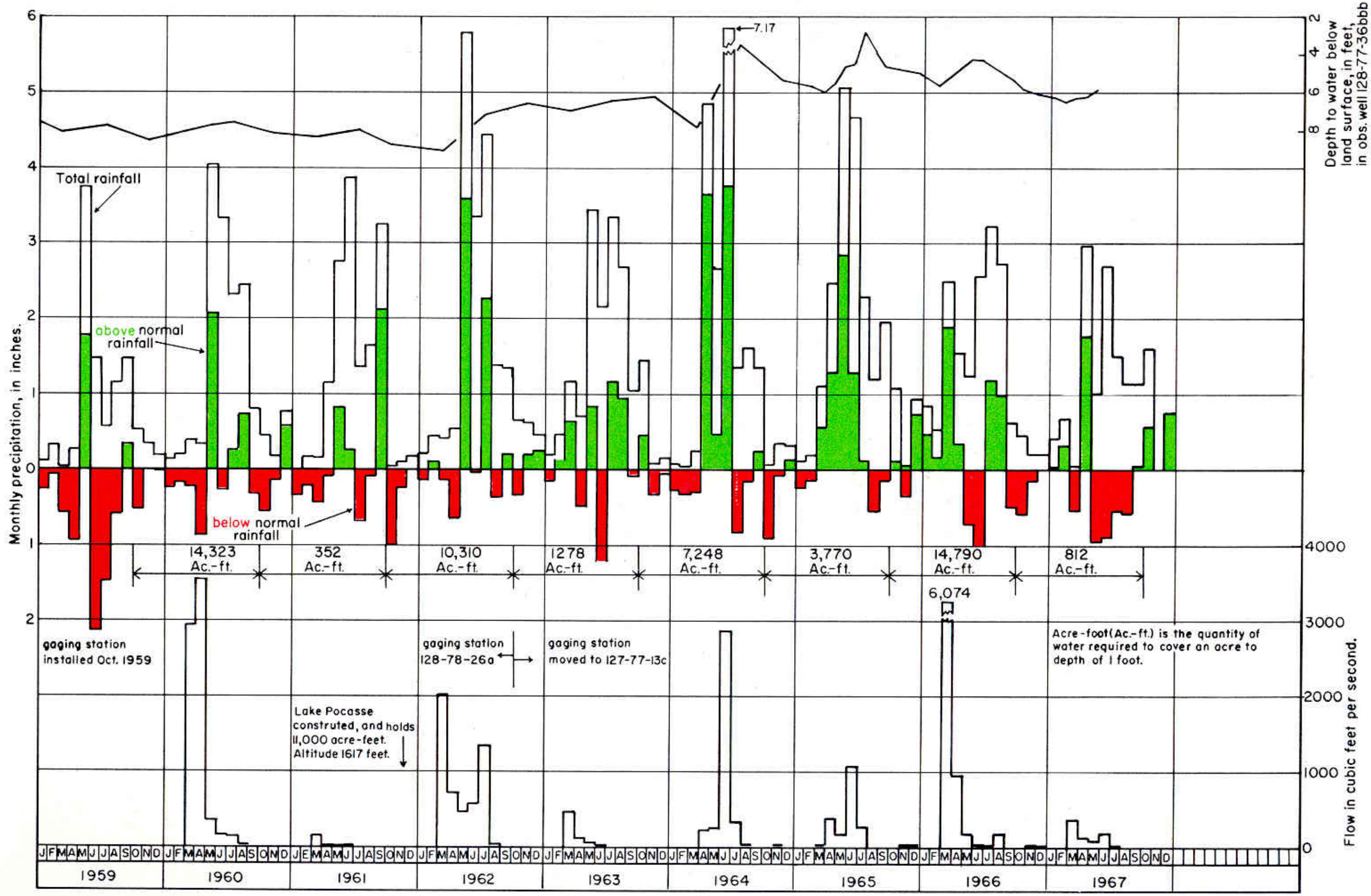

Figure 6. Monthly flow in Spring Creek, precipitation at Pollock, and water-level changes in well 128-77-36 bbbb.

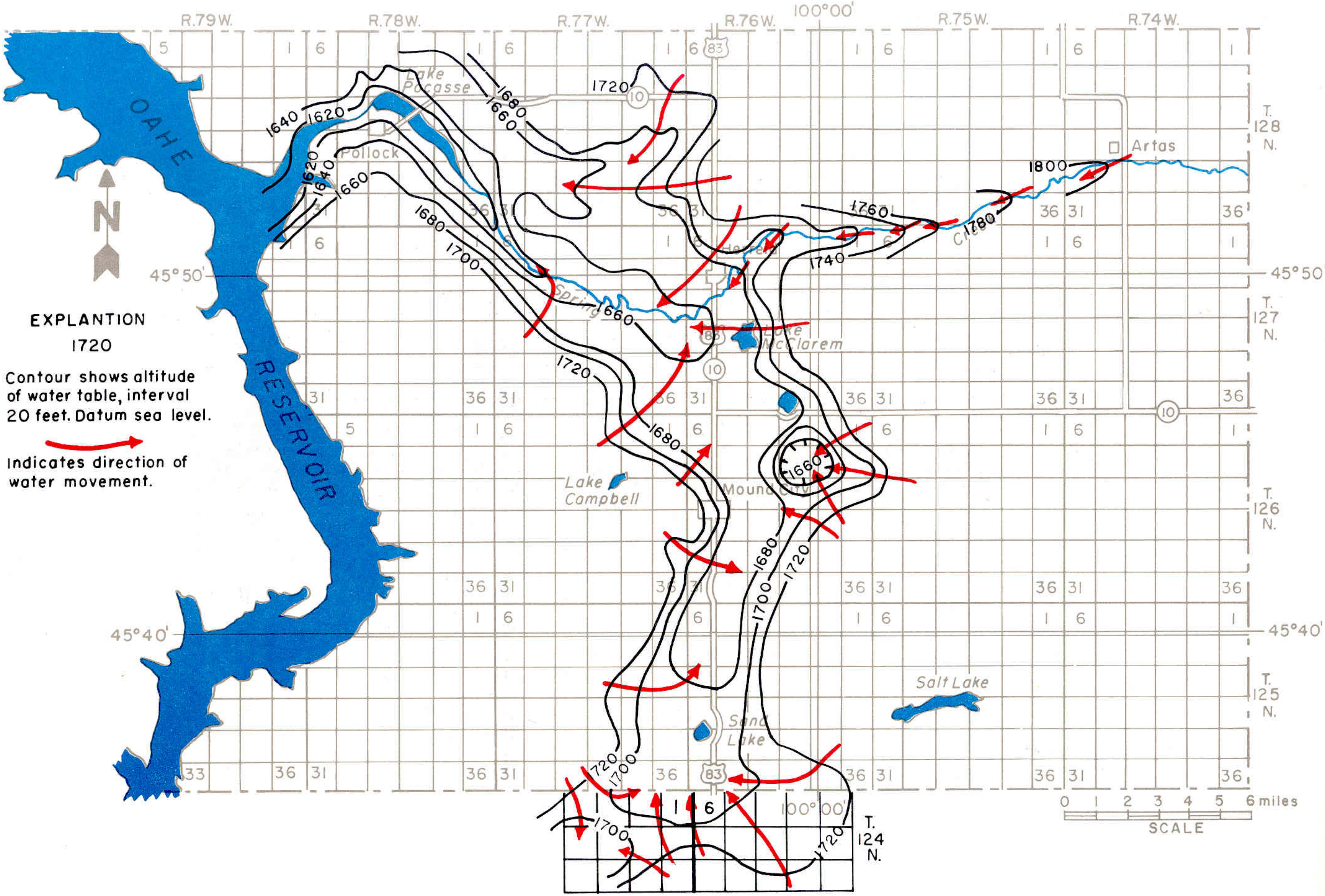

Figure 7. Altitude of water table and direction of ground-water movement, fall 1964.

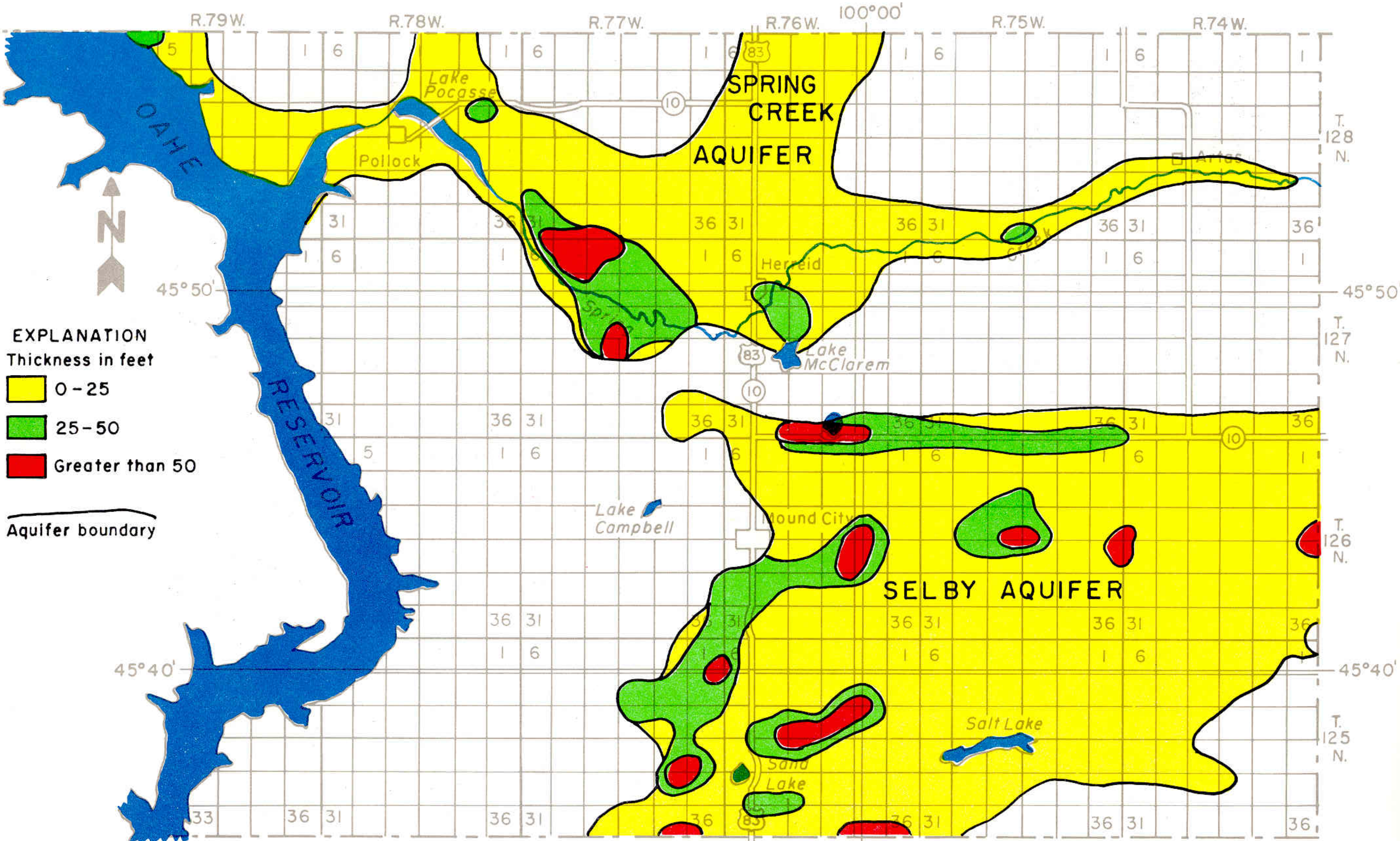

Figure 8. Areal extent and approximate saturated thickness of medium to coarse grained sand and gravel in Spring Creek and Selby aquifers.

Whenever possible, the well screen should be placed next to the coarser sand or gravel.

Much of the aquifer material consists of very fine to fine-grained sand (fig. 5). The coarser material usually overlies the finer material. Only about 12 square miles of the aquifer has a thickness of 25 feet or more of sand with a texture coarser than fine grained (fig. 8).

The thickness and grain size of the sand and gravel vary from place to place. Therefore, before a well is constructed, test wells should be drilled and an aquifer test should be made to determine local characteristics of the aquifer.

Water in Spring Creek may provide an irrigation supply where the creek is connected to the aquifer. When water is obtained directly from the creek where it is connected to the aquifer ground-water will provide large quantities of water. An example of this is the gravel quarry east of Herreid which obtains large quantities of water from the creek. An aquifer test at locations adjacent to Spring Creek would indicate where the creek is connected to the aquifer.

Selby aquifer

The Selby aquifer underlies most of southeastern Campbell County. It occurs at or near land surface, is composed mainly of outwash sand and gravel, and underlies about 26 percent (200 sq. mi.) of the county. The thickness and distribution of sand and gravel in the aquifer are shown on figure 4 and on cross sections K-K′ to S-S′ on figure 5. The water level is at land surface in Sand and Salt Lakes and is within 10 feet of the land surface in areas where the aquifer is not buried. Where the aquifer is buried, the water level is usually more than 10 feet below land surface. Ground water in the aquifer occurs under water-table conditions in some areas and artesian conditions in other area.

Using an average saturated thickness of 25 feet, and a porosity of 20 percent, it was calculated that the aquifer contained about 640,000 acre-feet of water in transient storage in 1966.

Recharge.—The Selby aquifer in Campbell County receives recharge from precipitation and subsurface inflow from adjacent areas. The greatest subsurface inflow occurs at the Walworth County line near U. S. Highway 83 (fig. 7) (Wong, 1960, p. 6). Most of the aquifer is in an area of poorly developed drainage; therefore, very little surface runoff occurs. Recharge is by snow melt and by spring and early summer rains (fig. 6). During the summer months most of the rainfall does not reach the water table because it is held as soil moisture until it is removed by evapotranspiration. To recharge the aquifer, rainfall must be sufficient to bring the soil to its moisture-holding capacity. When this point is reached, any additional infiltrating rainfall will percolate downward and recharge the underlying aquifer.

The infiltration of precipitation or snow melt is the greatest in areas where sand and gravel occur at the land surface (fig. 9). These areas have a water surface that is at or within 10 feet of land surface. The shallow water surface provides a condition where much discharge takes place (fig. 7) by evapotranspiration. Over a period of years the discharge is nearly equal to recharge (fig. 10). When precipitation is above normal, the water surface rises closer to the land surface causing an increase in evapotranspiration which quickly lowers the water surface. When a period of dry weather occurs, the water level declines because discharge exceeds recharge.

Discharge.—In areas where the Selby aquifer is exposed at land surface the discharge is greater than recharge, except during spring and early summer when rain and snow melt are abundant. In the spring and early summer recharge is less in the areas where the aquifer is overlain by till than in areas where it is exposed at the surface. There is very little discharge by evapotranspiration from the areas where the aquifer is buried; thus, ground water moves from the areas where the aquifer is overlain by till to areas where it is exposed at the land surface.

Only about 46 million gallons of water or 14 percent of the ground water in transient

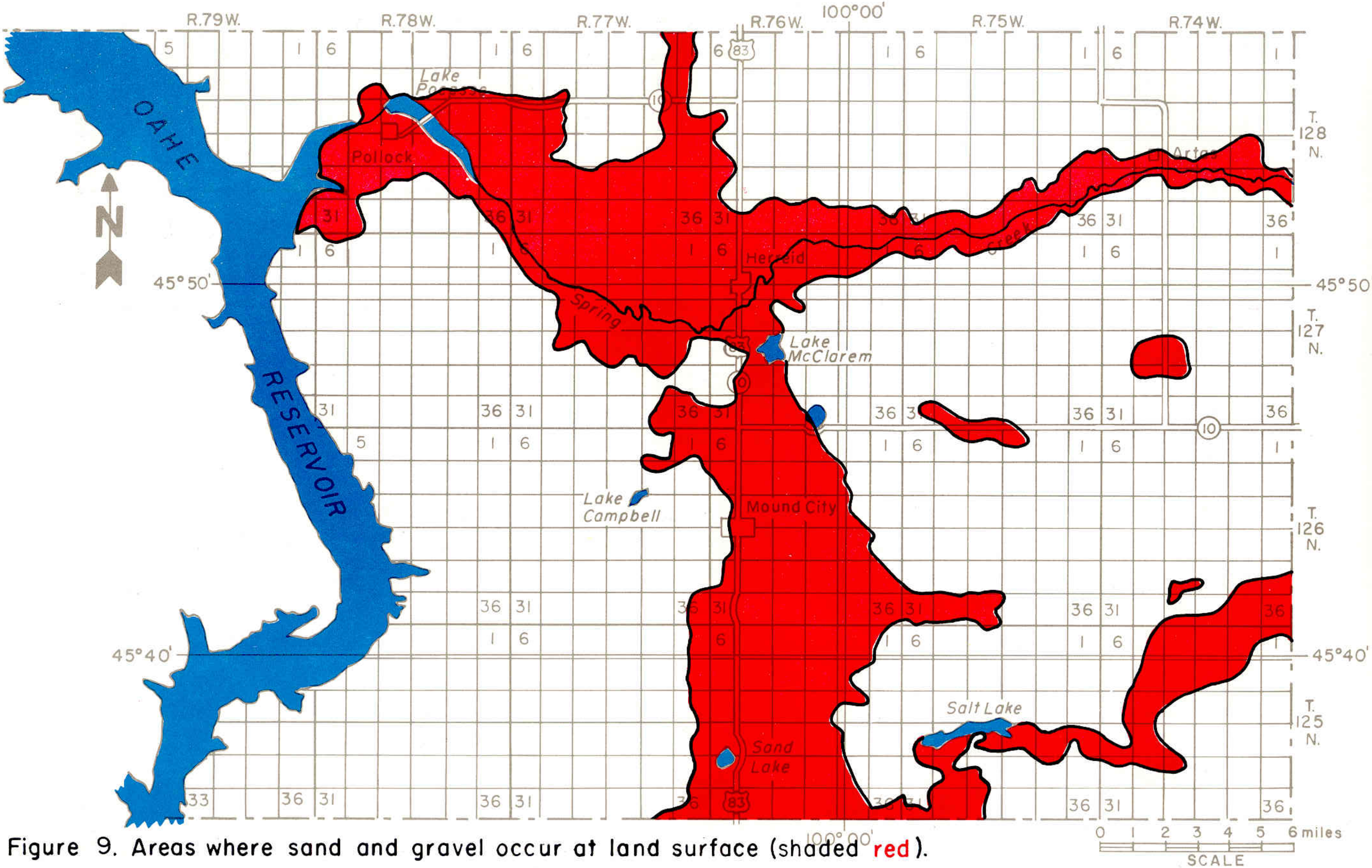

Figure 9. Areas where sand and gravel occur at land surface (shaded red).

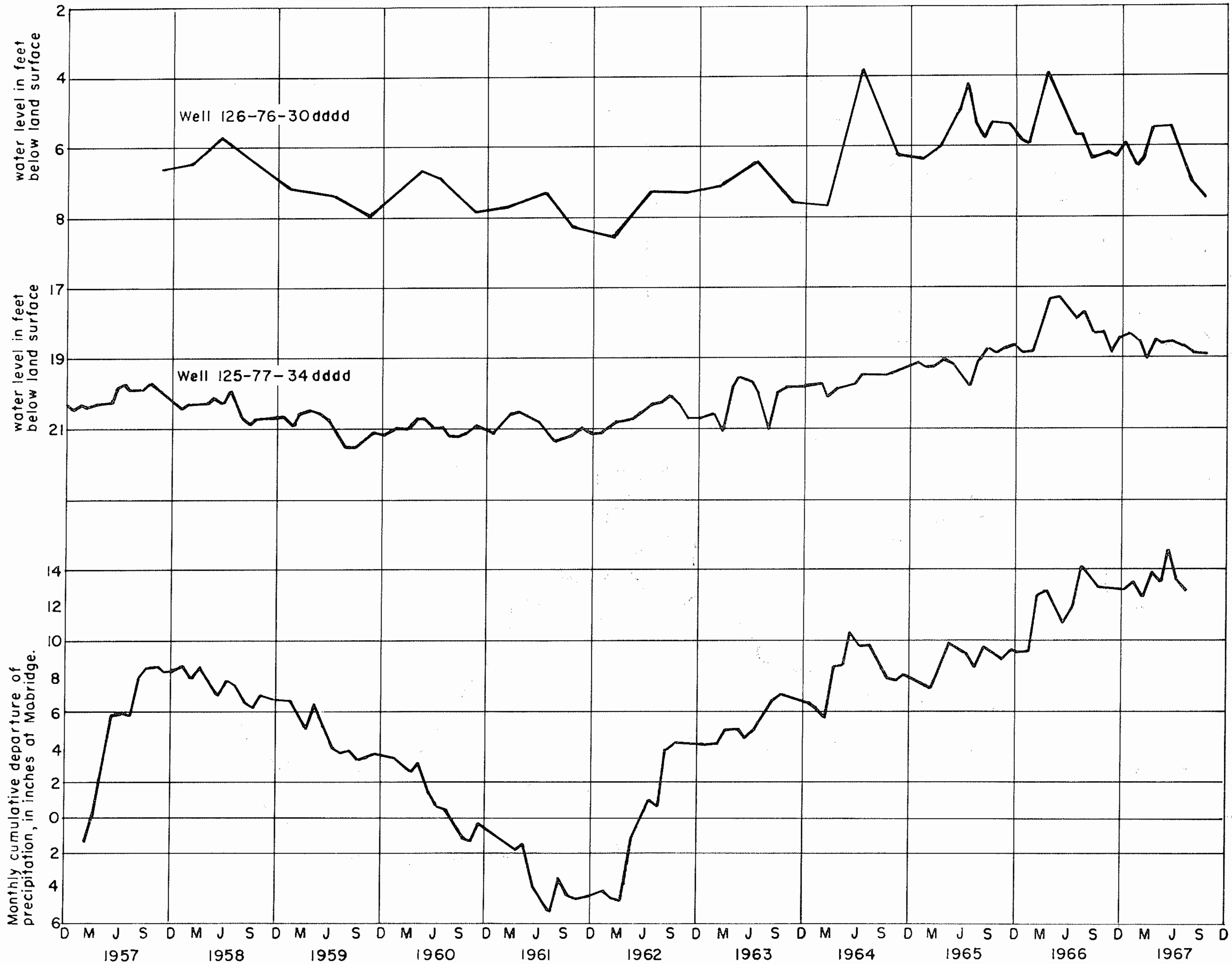

Figure 10. Water levels in selected wells and precipitation at Mobridge, Walworth County.

storage was withdrawn from the Campbell County portion of the Selby aquifer in 1966.

Aquifer test.—The town of Selby, Walworth County, obtains its water from the Selby aquifer. In 1961, a 24-hour aquifer test was conducted at the site of the present Selby wells about 1½ miles southeast of U. S. Highway 83 and the Campbell-Walworth County line. The pumped well penetrated 60 feet of sand and gravel of which 26 feet ranged in size from coarse-grained sand to gravel. The average pumping rate was 333 gpm with a drawdown of 14.30 feet. The transmissivity was about 60,000 gpd per ft and the storage coefficient was 0.18.

The results of the aquifer test and other data indicate areas where medium or coarse grained sand occurs in sufficient thickness (fig. 8) so that wells could be developed for irrigation, particularly in Rs. 76 and 77. Wells should not be drilled near open-water areas (Sand Lake) where the quality of water is not suitable for irrigation (see p. 33). If large quantities of water are removed from the aquifer during periods of prolonged drought, poor-quality water from open-water areas could move to nearby wells.

To the east of R. 76 W., the Selby aquifer contains many clay layers (fig. 5) and it is difficult to determine if all of the sand and gravel deposits are hydraulically connected. Therefore, test holes should be drilled and a careful examination of the aquifer should be made before large capacity wells are constructed.

Deep Aquifer

Deep-glacial aquifer

The deep-glacial aquifer underlies about 20 percent of Campbell County (fig. 11), has an average thickness of 100 feet, and contains an estimated 2½ million acre-feet of water in transient storage. It is composed mainly of outwash and alluvium from the ancient Grand River consisting of sorted and stratified gravel, sand, and silt. In T. 125 N., Rs. 74, 75, 76, and 77 W., the sand and gravel were deposited in the channel of the preglacial Grand River which was connected to a glacial tributary in Campbell County from the northwest. The depth to the aquifer ranges from 150 feet below land surface at Pollock to 300 feet below land surface in the southeastern part of the county. Overlying deposits consist mostly of impermeable silt or till.

Ground water in the deep-glacial aquifer occurs under artesian conditions in Campbell County. The water levels in wells tapping the aquifer range from about 20 to 50 feet below land surface.

Recharge.—The deep-glacial aquifer in Campbell County receives recharge by infiltration of water through the overlying sediments and from subsurface inflow from adjacent areas. The test-drilling program was inconclusive in defining a definite recharge area within Campbell County. The sediments overlying the aquifer in T. 125 N., Rs. 75 and 76 W. contain more permeable layers than in other areas of the county (fig. 5, cross section Q-Q′). These permeable layers may permit ground water from the Selby aquifer to percolate downward to the deep-glacial aquifer. Another source of recharge to the aquifer in Campbell County, as shown in figure 11 by the direction of water movement, is from subsurface inflow from McPherson County at T. 125 N. and 126 N.

The water level in well 127-76-5add2 one mile north of Herreid (fig. 11) is about 10 feet higher than that in wells to the south and west. This indicates that recharge is probably taking place to the east or north of the well. The quality of water from this well is similar to that from other wells in the deep-glacial aquifer; however, the aquifer tapped by this well is about 5 to 10 feet higher than the top of the deep-glacial aquifer to the south and west. Possibly the deep-glacial aquifer slopes up along the margin. This would enhance the possibility of recharge along the margin of the aquifer.

Discharge.—Natural discharge from the deep-glacial aquifer in Campbell County is by subsurface outflow westward toward the Missouri River near the city of Pollock and south

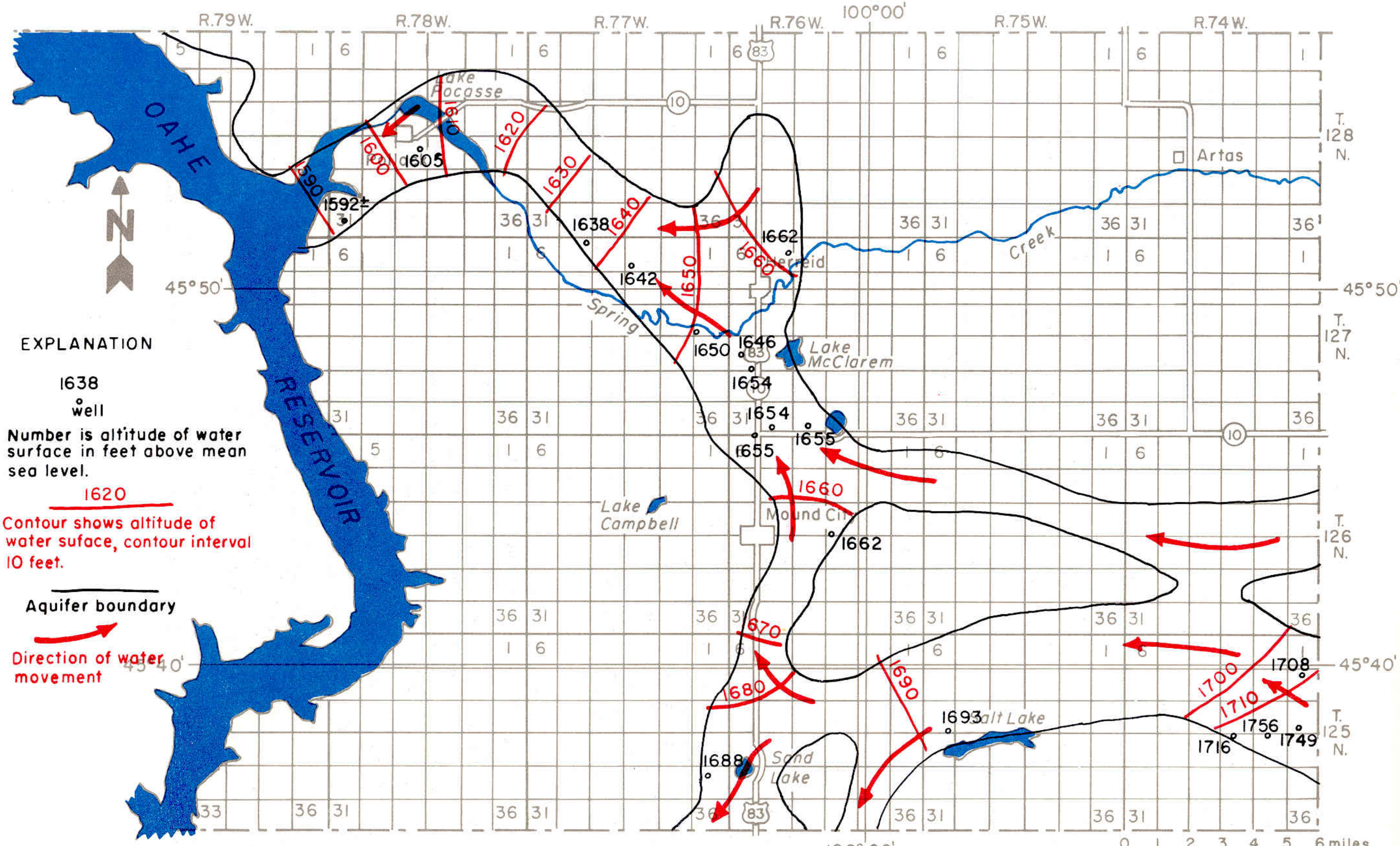

Figure 11. Altitude of water surface and direction of ground-water movement in the deep-glacial aquifer, August 1966.

into Walworth County (Koch, 1969). The water-surface map (fig. 11) shows that ground-water movement is up-gradient of the ancient Grand River valley and its tributary. This apparent reverse flow is due to the location of the recharge and discharge areas. The ground-water movement is opposite to the aquifer slope because recharge occurs in Campbell County and to the east in McPherson County, while discharge is to the Missouri River. The water-surface map also shows subsurface inflow from McPherson County and subsurface outflow into Walworth County and into the Missouri River west of Pollock (fig. 11).

The quantity of water leaving the county by subsurface outflow can be estimated by the equation

$$Q = TIL$$

where Q = the quantity of water in gpd,
T = the transmissivity in gpd per ft,
I = the hydraulic gradient in feet per mile, and
L = the cross-sectional area perpendicular to the direction of flow, in miles.

An approximate T of 100,000 gpd per ft was obtained from an aquifer test at well 128-78-21acaa. (See section on aquifer tests.) The hydraulic gradient, I, and the cross-sectional area, L, can be obtained from the water-surface map (fig. 11).

Substituting the necessary values in the equation, it was calculated that the approximate quantity of subsurface outflow west of Pollock in 1966 was 1 million gpd. A similar calculation for the subsurface outflow at the Walworth County line indicated a quantity of about 3½ million gpd during 1966.

To maintain a constant water level in an aquifer, recharge must equal discharge. Therefore, 4½ million gpd must enter the aquifer in Campbell County either by recharge within the county or by subsurface inflow.

Water-level data obtained in Campbell County since 1965 (fig. 12) show a marked rise in water level from 1965 to 1967. Precipitation in the area is the primary contributing factor to recharge. Figure 10 shows that precipitation was above normal from 1962 through 1967. Even so, water-levels in similar aquifers in South Dakota did not show a marked change during this period, indicating that the large rise in the water surface was the result of a decrease in discharge. The aquifer is essentially undeveloped and no pumpage changes have taken place. Therefore, the decrease in discharge is caused by a change at the place of discharge.

Discharge occurs where the deep-glacial aquifer underlies the Missouri River west of Pollock and at Mobridge, about 3 miles south of the Campbell-Walworth County line. Test-well data at Mobridge indicate that permeable silt and fine-sand lenses extend downward from the bed of the Missouri River to the top of the deep-glacial aquifer. This permeable material permits movement of water between the river and the aquifer. Because the water surface (hydrostatic level) in the aquifer is higher than the Missouri River (Oahe Reservoir), movement is from the aquifer to the river. In January 1965, the water surface in the Oahe Reservoir rose above the pre-reservoir river level. (See fig. 12.) By April 1966, the reservoir surface was 40 feet above the pre-reservoir level. The amount of water being discharged to the reservoir and the elevation of the water surface in the aquifer, are controlled in part by the elevation of the reservoir surface (Koch, 1969). After April 1965, the Oahe Reservoir remained between 20 and 40 feet above the pre-reservoir level and caused a comparable rise in the water level of the aquifer. Thus, a decrease in discharge and a rise in the water surface in the aquifer have resulted. Figure 13 shows the water surface of the aquifer prior to the change in elevation of the reservoir surface. Using the equation, Q = TIL, and data from figure 13, the subsurface outflow for the period 1959-1965 was calculated to be 1½ million gpd from the aquifer west of Pollock. This is ½ million gpd more than occurred in 1966.

If the water surface in the aquifer was lowered, by pumping, below the surface of the Oahe Reservoir, the flow pattern would be reversed and water would move from the

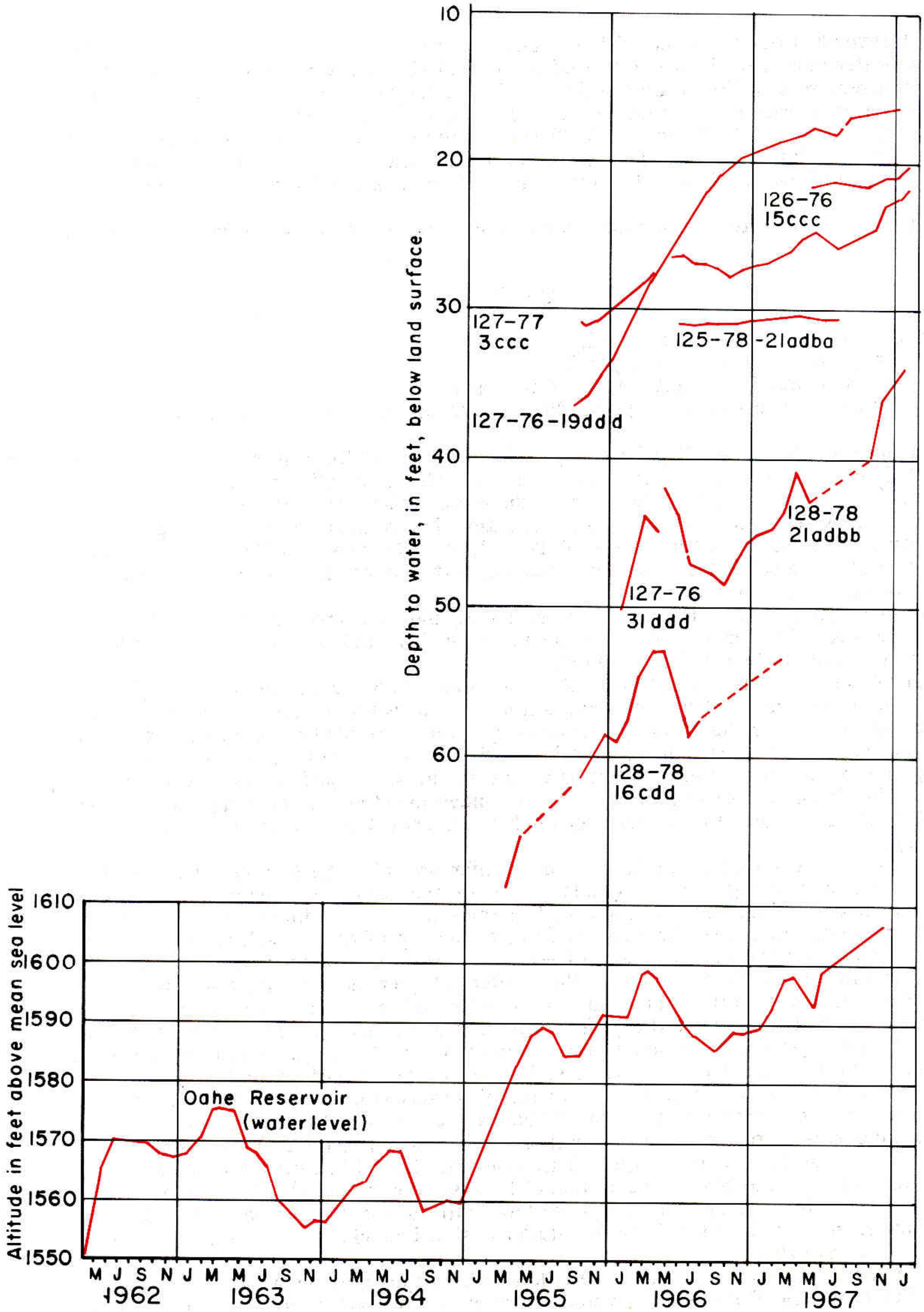

Figure 12. Water levels in wells in the deep-glacial aquifer and of the Oahe Reservoir.

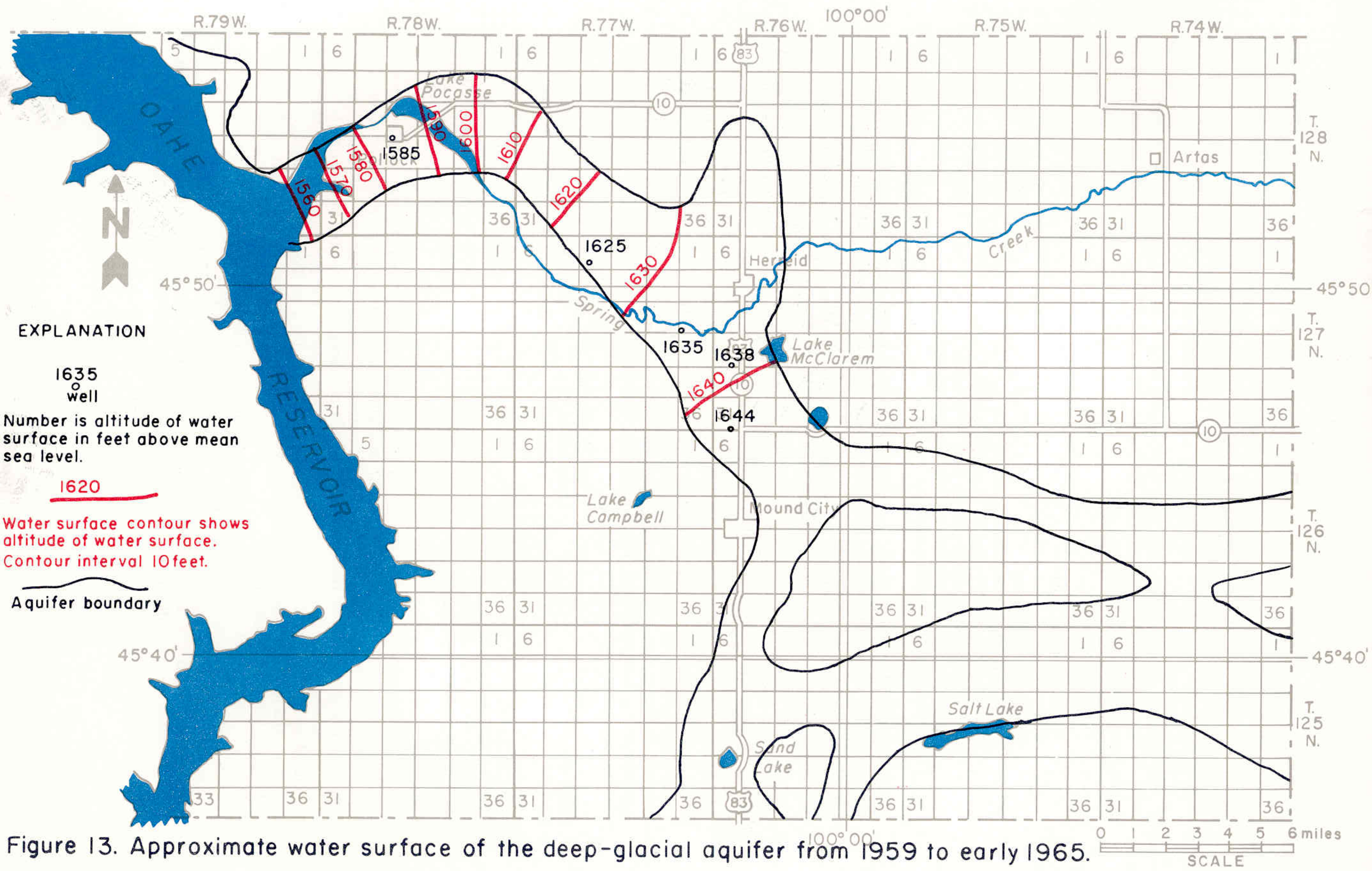

Figure 13. Approximate water surface of the deep-glacial aquifer from 1959 to early 1965.

reservoir into the aquifer. Assuming that the aquifer is relatively permeable where it occurs beneath the reservoir there would certainly be sufficient water available for extensive development.

Aquifer test.—An aquifer test was made using well 128-78-21acaa and 3 observation wells. The test-hole log of well 128-78-21acaa shows 68 feet of sand and gravel in the deep-glacial aquifer as follows:

Material	Depth (feet)
Sand, medium, brown	0- 13
Clay, gray	13-157
Sand, very fine, gray	157-175
Sand, medium to coarse, some coal, gray	175-180
Sand, coarse to very coarse, some coal, gray	180-200
Sand, very coarse, some gravel, coal layers, gray	200-225
Large boulder (other test wells in the area indicate shale below large boulders)	225

In August 1966 the test well was pumped for 22 hours at 400 gpm. Three observation wells spaced at 106, 185, and 345 feet from the pumped well were used to obtain the necessary additional data. At the end of the aquifer test, a drawdown of 14.5 feet was recorded in the pumped well and 4.39, 3.39, and 2.55 feet in each of the three observation wells. By using the Theis (1935) nonequilibrium formula, an average transmissivity of 100,000 gpd per ft and a storage coefficient of 0.003 were calculated. During the following year the test well was used for irrigation and the water-level changes during this time were in agreement with those predicted on the basis of results of the pump test.

Because of the good agreement of actual and predicted water-level changes in the test well, it was felt that the transmissivity value obtained by the aquifer test could be used as a guide in assigning reasonable permeability values to the material supplying water to the well. Permeability values in close agreement with those reported by Wenzel (1942, p. 13) were assigned to grain-size units of the test well (128-78-21acaa) to obtain a transmissivity approximating that computed from the aquifer test, as follows:

Grain-size unit	Total thickness penetrated by well (feet)	X	Assigned permeability	=	Transmis-sivity
Sand, very fine	18		100		1,800
Sand, medium to coarse	5		1,000		5,000
Sand, coarse to very coarse	20		1,500		30,000
Sand, very coarse, some gravel	25		2,500		62,500
Total	68				99,300

The close agreement of this transmissivity value (99,300 gpd per ft) with that computed from the aquifer test (100,000 gpd per ft) indicates that the assigned permeability values are valid and may be used as a guide in estimating transmissivity when test-hole logs are available. Figure 14 shows the transmissivity of the deep-glacial aquifer in Campbell County based on estimated transmissivities at the wells shown, using the technique described above.

The deep-glacial aquifer that extends from Mound City to Pollock usually consists of aquifer material containing few clay layers, whereas south and east of Mound City the aquifer contains many clay layers.

There is more than 150 feet of aquifer material with a transmissivity of about 300,000 gpd per ft in the northern tier of sections of T. 125 N., R. 74 W.

Test well 125-73-7cccc in McPherson County penetrated 157 feet of aquifer material with a transmissivity of about 300,000 gpd per ft. About 42 feet of aquifer material occurs in lenses separated by till (see cross section Q-Q′, fig. 5), but is considered to be part of the

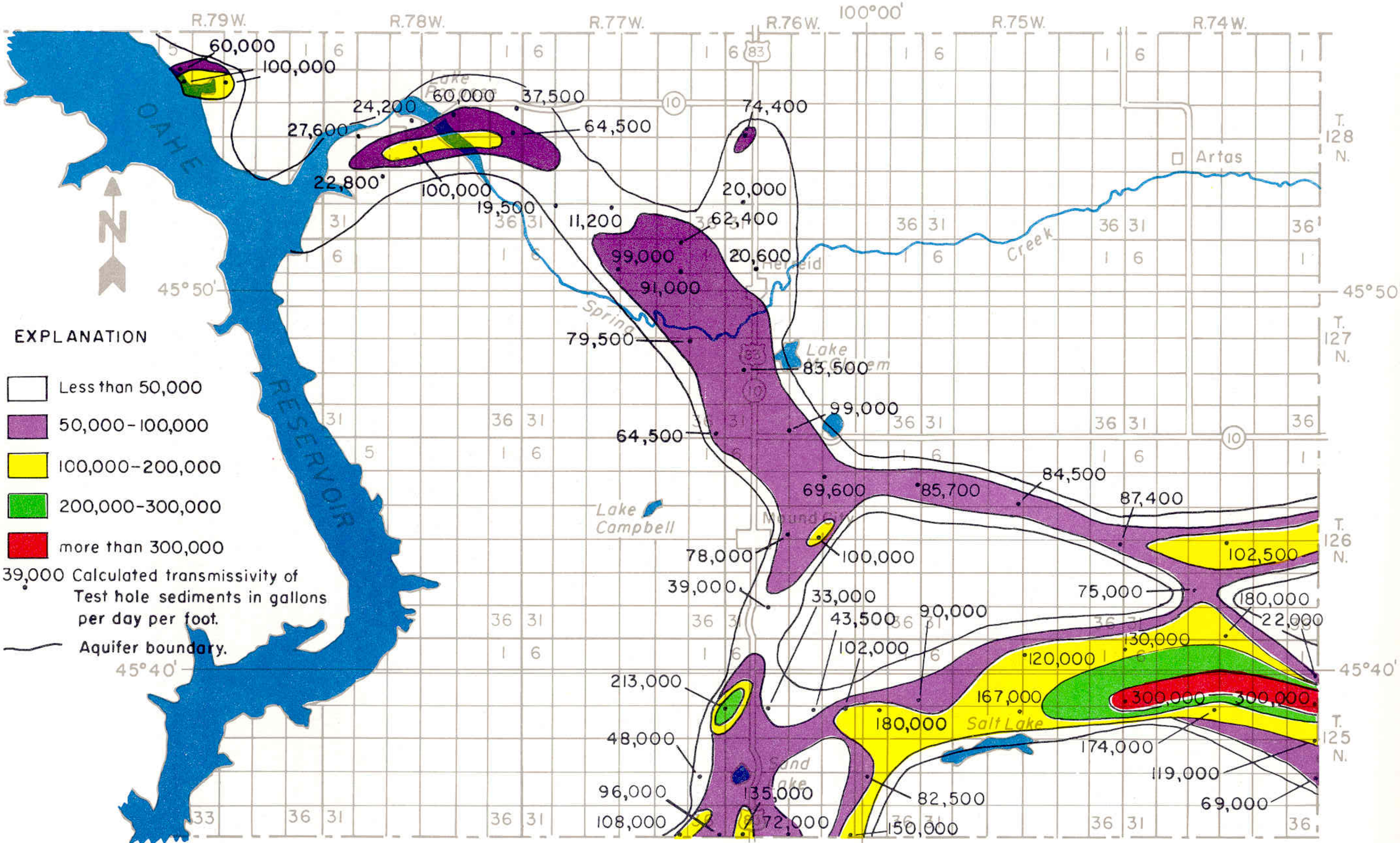

Figure 14. Transmissivity map of the deep-glacial aquifer based on permeability values assigned to test hole data.

aquifer. If additional data were to show that the 42 feet of aquifer was not connected and occurred as isolated sand lenses, then the aquifer thickness would be 115 feet with a transmissivity of about 230,000 gpd per ft. This would still be sufficient for irrigation development.

One mile south of the above test well, at test well 125-73-18cccc, there is 71 feet of aquifer material with a transmissivity of 119,000 gpd per ft. The aquifer material is separated by till layers as follows: 35 feet of aquifer, 7 feet of clay, 16 feet of aquifer, 37 feet of clay, 15 feet of aquifer, 5 feet of clay, and 5 feet of aquifer. (See basic data report for description of test-well logs.) If more data indicate that none of these aquifer zones are connected, and if only the uppermost aquifer is extensive, then the transmissivity is about 70,000 gpd per ft which would still provide sufficient water for irrigation development.

Figure 15 shows the thickness of the deep-glacial aquifer. Information on figures 14 and 15 are based on data obtained from available test wells and should not be considered conclusive as to whether there is sufficient aquifer material for development of an irrigation well, but only used as a guide to the aquifer capacity. Therefore, a test well should be drilled to determine the thickness and grain size of the aquifer in the desired area before irrigation or other production wells are drilled, and an aquifer test should be run a sufficient length of time to ascertain the effects of sustained pumping at a high rate.

Bedrock Aquifers

Bedrock is any consolidated rock exposed at the surface of the earth or overlain by unconsolidated materials. The Fox Hills Formation is the youngest bedrock formation in Campbell County. L. S. Hedges (written communication, 1968) indicates that the Timber Lake Member (sand and sandstone) caps the high buttes and the Trail City Member (sandy shale) occurs at the surface and subsurface along the Missouri River north of T. 126 N. These members of the Fox Hills Formation are not a source of water in Campbell County. The Pierre Shale, which ranges in thickness from 400 to 700 feet, is the youngest bedrock in most of the county. See table 1 for a listing of bedrock types and a description of each.

Ground water moves downward through the overlying unconsolidated material into the fractures, sand lenses, and other permeable zones in the Pierre Shale, which generally are concentrated in the top 50 to 75 feet of shale. Wells in the shale along the Missouri River can usually obtain sufficient quantities of water for domestic and limited farm needs, but elsewhere yields are usually insufficient.

No data are available in Campbell County to indicate the potential of the Niobrara Marl and Greenhorn Limestone as aquifers, but the formations do yield sufficient quantities of water for domestic and stock needs in some areas of the state. Electric logs obtained from wells in counties adjacent to Campbell County indicate that these formations have permeable zones. It is not known whether these zones are extensive enough or contain sufficient quantities of water for development.

The Dakota and Fall River aquifers are the main bedrock aquifers in the area. Ten Dakota Sandstone artesian wells are known to have been drilled in Campbell County to depths ranging from about 1,500 to 2,000 feet. Most wells yield water from the Fall River aquifer with the exception of two or three of the older wells located in the Missouri River valley which yield water from the Dakota aquifer. The wells are located along or near the Missouri River with the exception of well 126-76-18dba at Mound City.

The geologic section (fig. 16) is constructed along the approximate dip of the bedrock (northwest). It is based on electric, gamma, and driller's logs of wells in adjacent counties and, although very generalized, it can be used to determine the approximate depth to the Dakota or Fall River Sandstone aquifers at a particular location. Using the land-surface elevation at a proposed well site the approximate depth to the aquifer can be determined at the cross section by drawing a line from the well site perpendicular to the cross section line (see index map). The difference between the surface elevation at the site and the projected elevation of the top of the aquifer is the approximate depth to the aquifer at the well site.

Knowledge of the water-bearing characteristics of the Dakota or Fall River Sandstone is limited. The water-yielding capacity of the aquifer is not known although some data

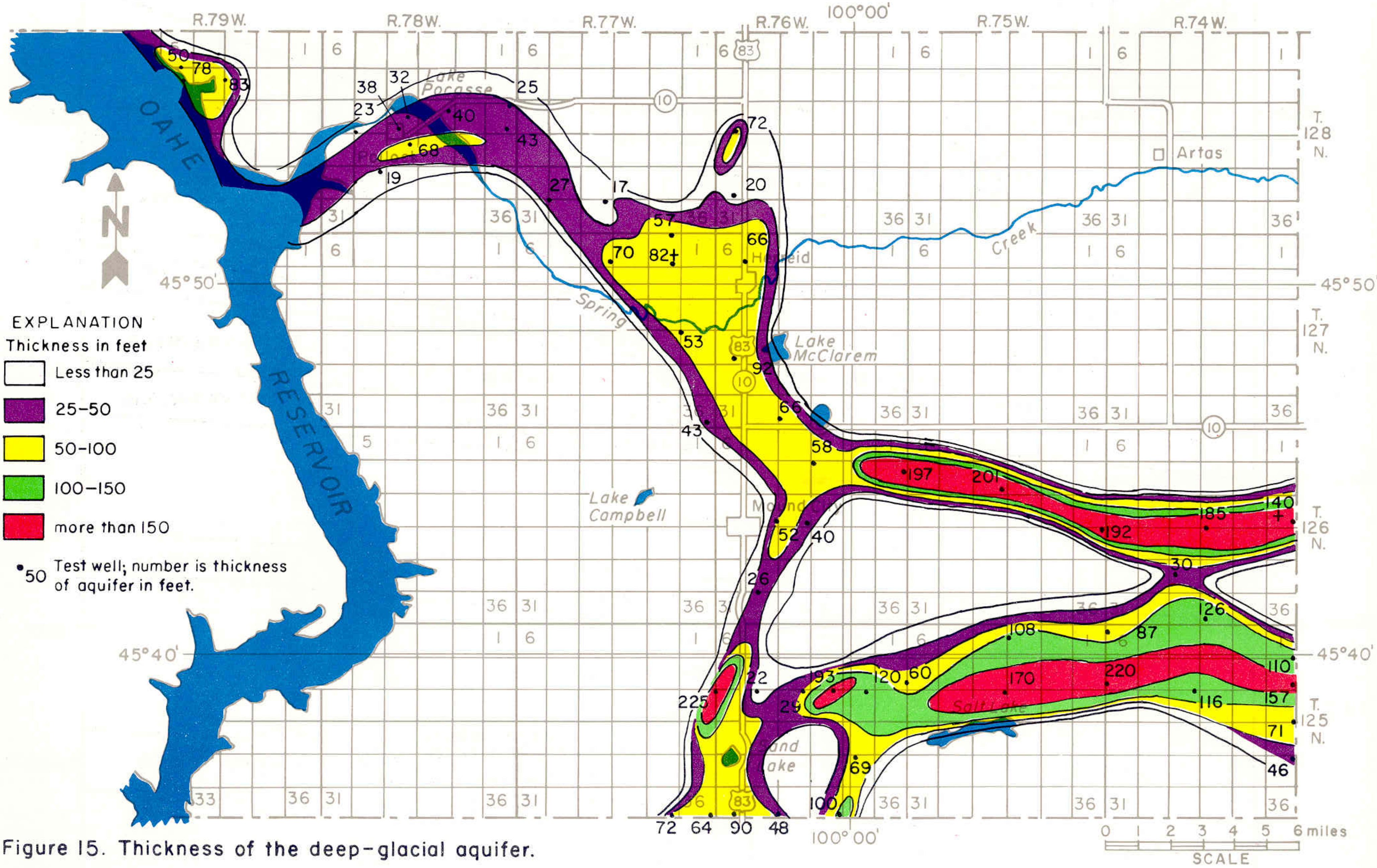

Figure 15. Thickness of the deep-glacial aquifer.

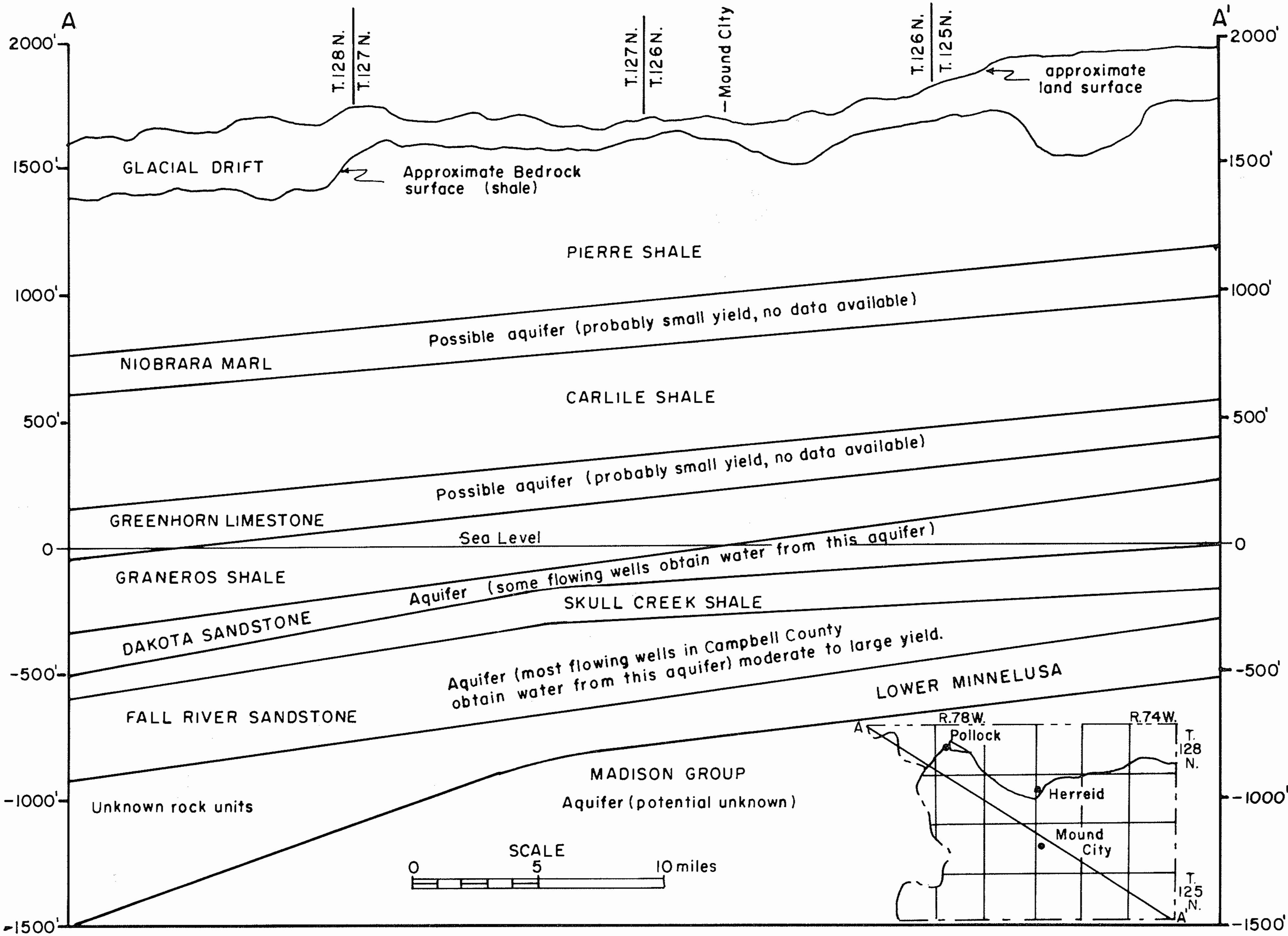

Figure 16. Generalized northwest–southwest geologic section showing possible aquifers in the bedrock.

indicate the aquifer could yield large quantities of water. In 1966, the water level in well 127-78-20ddc was 129.36 feet above land surface or 2,129 feet above sea level. A well measured at Eureka in 1966 showed the water level to be more than 212 feet above land surface or more than 2,100 feet above sea level. The water level in well 127-78-5cdba is 430 feet above land surface or 2,170 feet above sea level. If these 3 wells are representative, then any well obtaining water from the Dakota or Fall River Sandstone aquifers in Campbell County would flow.

Wells drilled to obtain water from the Dakota or Fall River Sandstone aquifers are usually developed to provide no more than sufficient yields for domestic and farm needs. Therefore, no data are available on maximum yields. Two of the wells are estimated to produce about 100 gpm each.

QUALITY OF WATER

The chemical and bacterial content of water largely determine its acceptability for domestic, agricultural, and industrial use.

The mineral constituents in the water determine its chemical quality. Rain water contains very few mineral constituents but as it percolates into the ground, it dissolves minerals from the soil and rocks. The amounts and kinds of minerals in the water are dependent on the solubility of the rocks encountered and the length of time the water is in contact with them. In Campbell County, mineral concentrations are usually less in water from shallow-glacial aquifers than in water from deep-glacial aquifers. A discussion of some mineral constituents is given in tables 2 and 3.

Water used for irrigation should not have a detrimental affect on the productivity of the soil. The main water properties that effect soil productivity are total dissolved solids and the relative proportion of sodium to calcium and magnesium. Relatively small amounts of boron or other constitutents can be toxic to certain plants.

The amount of dissolved solids in irrigation water and the soil type determine the accumulation of salts in the soil. Salinity hazard is the tendency of water to cause an increase of salts in the soil. The specific conductance of the water is used to calculate the salinity hazard.

The relative proportion of sodium to calcium and magnesium in irrigation water can affect soil structure. Calcium and magnesium flocculate the soil, giving it looseness, providing for penetration of air and water, and good tillage properties. Sodium tends to deflocculate soil which produces packing, thus preventing or reducing the movement of air and water. The effect on soil of high concentrations of sodium in irrigation is called the sodium hazard which is determined by the sodium-adsorption ratio.

The salinity hazard and sodium hazard (U. S. Salinity Laboratory Staff, 1954) of water are shown in figure 17 which is interpreted as follows:

Salinity Hazard

Low-salinity water (C1) can be used for irrigation of most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.

Medium-salinity water (C2) can be used for irrigation if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

High-salinity water (C3) cannot be used for irrigation on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

Very high salinity water (C4) is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt-tolerant crops should be selected.

Table 2.--Principal sources of selected chemical constituents in water and their effects upon water use.

Property or constituent	Source	Effects
Iron (Fe)	Many types of rock and soil. Iron pipes and bacteria	0.3 mg/l or more causes reddish-brown stains on fixtures and fabrics. Gives water a bitter taste.
Manganese (Mn)	Some rocks and soils.	Same as iron in concentrations of 0.2 mg/l or more.
Calcium (Ca) and Magnesium (Mg)	Most rocks and soils, especially limestone, dolomite, and gypsum.	The main cause of hardness, which reduces the ability of soap to lather, causes a white deposit to form on fixtures and the formation of scale when water is heated.
Sodium (Na)	Most rocks and soils.	A high content will cause water to be unsatisfactory for irrigation. (See section on Sodium Hazard).
Potassium (K)	Most rocks and soils.	Most water does not contain sufficient quantities to have any effect for most uses.
Bicarbonate (HCO_3) and Carbonate (CO_3)	Forms when carbon dioxide in water reacts with carbonate rocks.	With calcium and magnesium cause hardness.
Sulfate (SO_4)	From rocks and soils containing gypsum and anhydrite (Pierre Shale in Campbell County).	In water high in calcium and magnesium it causes the formation of scale in boilers. May have a laxative effect and give water a bitter taste in concentrations of more than 250 mg/l when combined with other ions, notably sodium or magnesium.
Chloride (Cl)	From rocks and soils; connate water, salt deposits, sewage.	Gives water a salty taste when combined with sodium in concentrations of more that 400 mg/l. In large quantities increases the corrosiveness of water.
Fluoride (F)	Some rocks and soils.	In proper concentration reduces dental decay; 1.1 mg/l is optimum for dental protection in Campbell County. (U. S. Public Health Service, 1962, p. 8).
Nitrate (NO_3)	Organic matter, sewage, soil, and fertilizer.	Concentrations in excess of the average for the area may suggest pollution. Harmful to infants if 45 mg/l or more.
Dissolved solids (all mineral constituents)	Mineral constituents dissolved from rocks and soils.	Large concentrations unsatisfactory for human consumption or irrigation uses. See Specific Conductance.

Table 3.–Selected properties of water and their description and effects upon water use.

Property and unit of measurement	Description and causes	Effects or significance
Hardness as $CaCO_3$	Caused mostly by compounds of Ca and Mg	Determines the ease with which soap suds formed. Is classified by the U. S. Geological Survey as follows: (classification: grains per gallon / milligrams per liter) Soft: 0-3.4 / 0- 60 Moderately hard: 3.5-7 / 61-120 Hard: 7.1-10.5 / 121-180 Very hard: more than 10.5 / more than 180
Percent sodium	Obtained by dividing the sodium concentration in milliequivalents per liter (meq/l) by total cation concentration and multiplying by 100.	When percent sodium is over 50 it causes some soils to become less permeable.
Residual Na_2CO_3	The amount in epm of HCO_3 and CO_3, in excess of Ca and Mg.	Same as percent sodium. Less than 1.25 epm, safe for irrigation; 1.25 to 2.5 marginal; more than 2.5, not suited (depending on soil conditions).
Sodium-adsorption ratio (SAR)	$SAR = \frac{NA^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$	A means for determining the suitability of water for irrigation. The larger SAR is, the poorer water becomes for irrigation.
Specific conductance (micromhos at 25°C)	Mineral constituents in water measured by the capacity of water to conduct an electric current.	Same as dissolved solids (table 2). Livestock use / Specific conductance Excellent: 0- 999 Good: 1,000-3,999 Satisfactory: 4,000-6,999 Unsatisfactory: 7,000 and over
Hydrogen ion concentration (pH)	pH is balance between acids and alkalis.	pH of 7.0 is neutral; above 7 is alkaline; below 7 is acid. Above pH7 water can be incrusting, below pH7 water can be corrosive.

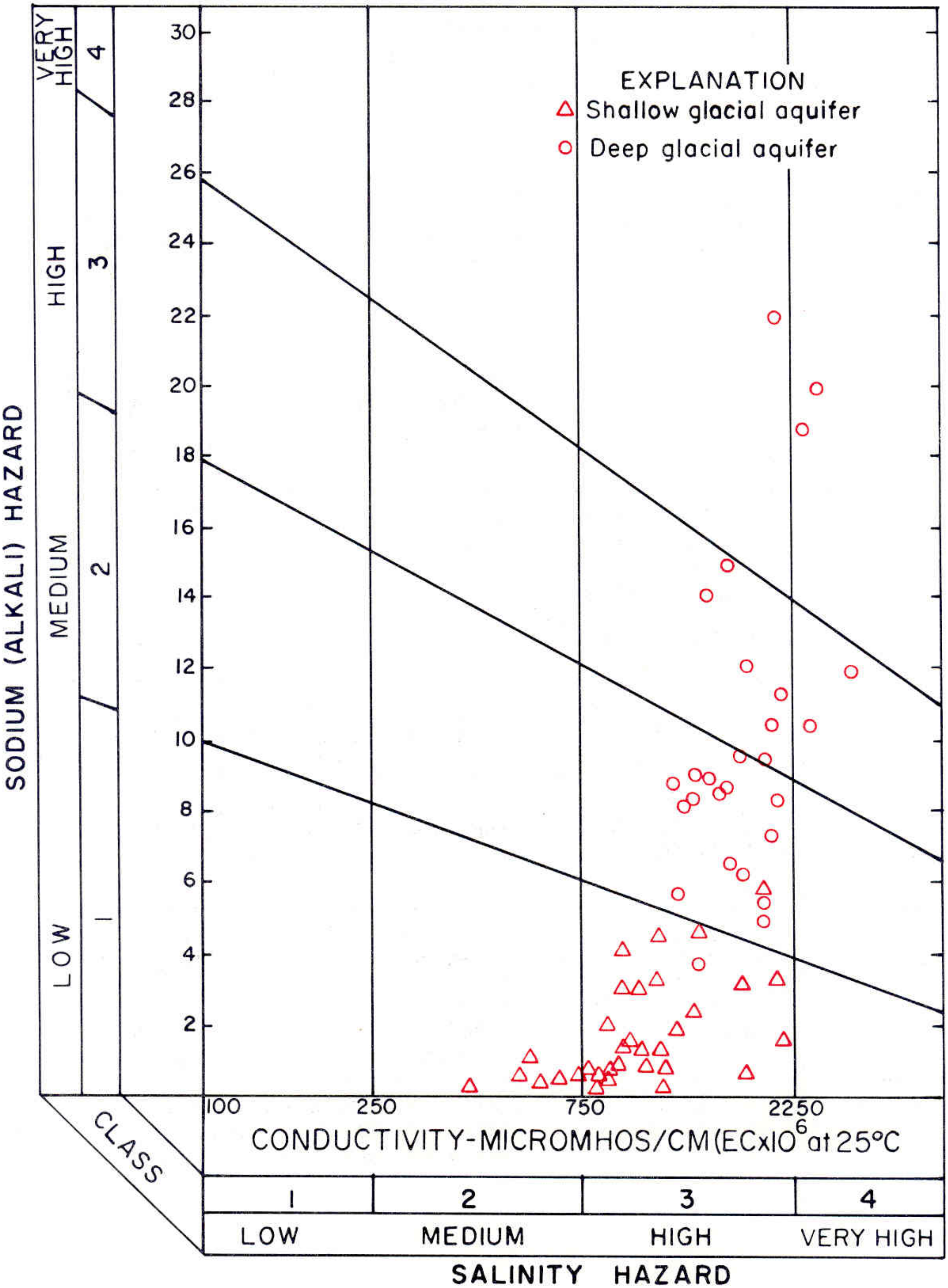

Figure 17. Classification of ground water for irrigation use (classification developed by U.S. Salinity Laboratory Staff, 1954).

Sodium Hazard

The classification of irrigation waters with respect to SAR is based primarily on the effect of exchangeable sodium on the physical condition of the soil. Sodium-sensitive plants, however, may suffer injury as a result of sodium accumulation in plant tissues even when exchangeable sodium values are lower than those causing deterioration of the physical condition of the soil.

Low-sodium water (S1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stone-fruit trees may accumulate injurious concentrations of sodium.

Medium-sodium water (S2) will present an appreciable sodium hazard in fine-textured soils having high cation-exchange capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse textured or organic soils with good permeability.

High-sodium water (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management—good drainage, high leaching, and organic-matter additions. Gypsiferous soils may not develop harmful levels of exchangeable sodium from such water. Chemical amendments may be required for replacement of exchangeable sodium, except that amendments may not be feasible with waters of very high salinity.

Very high sodium water (S4) is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity, where the solution of calcium from the soil or use of gypsum or other amendments may make the use of such water feasible.

Surface Water

The water in streams, some lakes, and drainage dugouts contains small amounts of dissolved constituents. The amount and type of dissolved solids are dependent on the mineral composition and solubility of the soils and rocks that come in contact with the water. Rain water that flows over the ground surface and reaches the surface-water bodies quickly has only small amounts of dissolved solids, whereas rain water that enters the ground-water system before reaching the surface-water bodies has a higher amount of dissolved solids.

The Oahe Reservoir was sampled twice at Pierre in 1964, in April with a discharge of 14,600 cfs (cubic feet per second) and in September with a discharge of 8,300 cfs. Both samples had a specific conductance of about 784 and a SAR of 2. All of the constituents were less than the recommended maximum limits in the U. S. Public Health Service drinking-water standards (see table 4). The water is predominantly a calcium, sodium, sulfate, and bicarbonate type.

Lake Pocasse water was sampled twice, in July and August 1964. The average specific conductance was 440, percent sodium 26, and SAR 1. The reason for the low specific conductance is that most of the water in Lake Pocasse is the result of large flows during the spring of the year into Spring Creek.

Spring Creek water was not sampled, but analyses of water from shallow wells in sands that are hydraulically connected to the creek, show that water from these wells is very similar to that from Lake Pocasse.

Sand, Salt, and most other lakes in Campbell County have a very high dissolved-solids content. The high dissolved-solids content is the result of evaporation which causes the dissolved-solids content to increase. Total dissolved solids of Sand Lake in 1952 was 9,338 mg/l.

Dugouts are either filled from surface runoff or ground water. The quality of dugout water ranges from excellent to poor depending on the type of soil and length of time it takes rain water to reach the dugout or the quality of the ground water entering the dugout.

Shallow-Glacial Aquifers

The quality of water in Spring Creek and Selby aquifers is quite uniform throughout

Table 4.--Summary of chemical analyses of ground water from the shallow and deep-glacial aquifers.

Constituent or property	Recommended maximum for public supply[1]	Deep-glacial aquifer, average of 30 analyses (mg/l except as indicated)	Shallow-glacial aquifers, average of 34 analyses (mg/l except as indicated)
Calcium (Ca)		77	117
Magnesium (Mg)		22	40
Sodium (Na)		332	72
Potassium (K)		11	10
Bicarbonate (HCO_3)		767	422
Sulfate (SO_4)	250 (500)	279	221
Chloride (Cl)	250	71	36
Fluoride (F)	1.5[2]	.5	.3
Nitrate (NO_3)	45	4.7	47[3]
Iron (Fe)	.3	2.53[4]	.22
Manganese (Mn)	.05	.31	.44
Hardness as $CaCO_3$		282	459
Specific conductance (micromhos per cm at 25°C)	500 (1,000)	1,831	1,141
Percent sodium		70	22
Sodium-adsorption ratio (SAR)		9.6	1.6
Residual Na_2CO_3 in epm		7.2	.36
pH		7.7	7.7

[1] U. S. Public Health Service (1962). Figures in parentheses are recommended maximum concentration of the South Dakota Department of Health (written communication, March 20, 1968).
[2] Recommended upper limit for Campbell County. (U. S. Public Health Service, 1962, p. 8).
[3] Half the analyses had less than 18 mg/l; 9 analyses had more than 45 mg/l.
[4] Half the analyses had less than 1 mg/l.

Campbell County. Local conditions, however, have caused some variation. Evaporation in Sand and Salt Lakes has caused an increased salt content in the adjacent ground water. This is the result of lake water moving into the adjacent ground-water system. An increased salt content is also produced wherever the water table is at or within 2 or 3 feet of the land surface.

Water from the shallow-glacial aquifers is very hard and is a calcium bicarbonate, sulfate type (fig. 18 and table 4).

Pollution of water in the shallow-glacial aquifers is a major concern because of local recharge. Careful selection of a well site in relation to a septic tank or other source of pollution is important. Spring and summer rains can flush fertilizers and "barnyard" wastes downward to the water table causing sudden changes in nitrate content. See table 4 for average nitrate.

The average quality of water from the shallow-glacial aquifers indicates a high salinity hazard and a low sodium hazard. (See fig. 17.) The shallowest wells, in general, have the lowest specific conductance and sodium-adsorption ratio.

Deep-Glacial Aquifer

The quality of water from the deep-glacial aquifer is generally uniform throughout Campbell County. It is predominantly a sodium bicarbonate and sodium sulfate type with specific conductance, iron, and sulfate in excess of U. S. Public Health Service (1962) standards (table 4). At most locations the water has a high salinity hazard and medium sodium hazard (fig. 17). In some areas the water is very high in calcium and sulfate or bicarbonate (fig. 18). These extremes in quality are in water from wells located along the edge of the aquifer, where the well screens are placed in the uppermost sands which are very fine grained, or from the wells in the southeast part of the county that are at least 360 feet deep.

Till and Shale

The quality of water in till and shale varies considerably. In wells 20 feet deep or less, the water quality is similar to water from wells at like depths in the shallow-glacial aquifers. Water from deeper wells in the till and shale varies in type from sodium bicarbonate to calcium bicarbonate, and specific conductance increases with depth. Therefore, advice should be obtained from the County Agent before using water from the deeper till and shale wells for irrigation.

Bedrock Aquifer

The water from the Dakota and Fall River Sandstone aquifers is very hard, saline, and of the sodium calcium sulfate type (fig. 18). It is satisfactory for all livestock uses but is not suitable for irrigation. Generally, the water contains iron, fluoride, sulfate, and total dissolved solids in excess of the recommended maximum drinking-water standards of the U. S. Public Health Service (1962). However, the well at Mound City has a fluoride content within the recommended limit. Specific conductance averages 3,000 micromhos per centimeter which is in the very high salinity hazard classification for irrigation. Sodium hazard is in the medium to high range. Water temperature ranges from 26° to 31° C (78° to 88° F).

Chemical analyses of water from six Dakota and Fall River aquifer wells in Campbell County and one at Eureka, McPherson County, show a quality of water change from a sodium sulfate type to a calcium sulfate type from northwest to southeast.

WATER USE

About 40 percent of the water used in Campbell County in 1966 was from the shallow-glacial aquifers (table 5). The deep-glacial aquifer yielded approximately 11 percent,

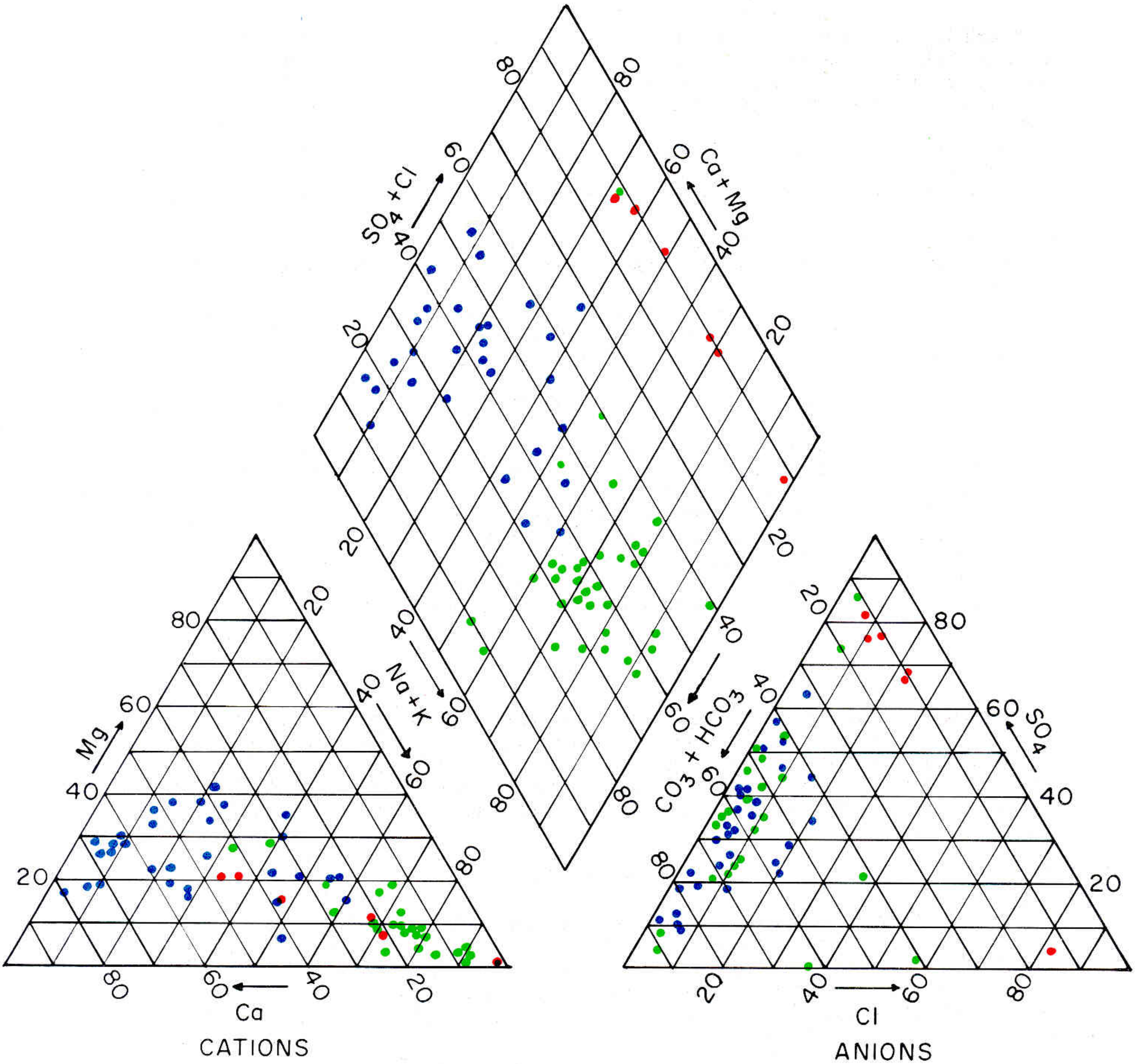

Figure 18. Trilinear diagram of chemical analyses of water from the shallow aquifers, deep-glacial aquifer, and Dakota aquifer.

Table 5.–Water use in Campbell County for 1966.

Source	Area underlain		Number of wells		Amount withdrawn	
	Square miles	Percent of total	City	Farm	Million gallons	Percent of total
Ground Water						
Deep-glacial aquifer	160	20	2	38	35	11
Spring Creek aquifer	100	13	4	118	86	27
Selby aquifer	200	26	0	122	46	14
Till and shale			0	135	50	15
Bedrock aquifers	763	100	1	9	100[1]	4[2]
Surface Water[3]						
Dugouts				600	95	29[2]
Total			7		326[2]	100

[1] Amount removed from aquifer (includes flowing wells). An estimated 15 million gallons was used.
[2] Percent or amount based on used portion.
[3] Does not include small irrigation withdrawals from Oahe Reservoir and Lake Pocasse.

whereas 15 percent of the water used was from farm wells in till or shale. About 29 percent of the water used in Campbell County in 1966 was from dugouts. Water in dugouts located where the shallow-glacial aquifer is at the land surface is from ground-water seepage, whereas water in dugouts located in till or shale is from surface runoff. Ground-water dugouts are a more dependable source of water during dry years than those fed only by surface runoff.

Dakota and Fall River Sandstone aquifers yielded about 4 percent of the water used in Campbell County in 1966. As shown in table 5, this percentage was an estimated 14 million gallons but about 86 million gallons of unused water was discharged by flowing wells.

Water use in Campbell County was estimated to be 215 million gallons in 1950, 270 million gallons in 1960, and 326 million gallons in 1966. In 1966 about 52 percent of the water used in Campbell County was supplied by the shallow and deep-glacial aquifers. The present rate of withdrawal produces no lasting change in the water surface of the aquifers beyond the season during which the water is removed.

The deep-glacial aquifer has the best potential for development in Campbell County. The aquifer contains 2½ million acre-feet of water in transient storage, plus vast recharge potential from Oahe Reservoir, and contains water of satisfactory quality for most uses.

The shallow-glacial aquifers also have good potential for development. Increased use of the aquifers would lower the water surface thus utilizing water that would otherwise be lost by evapotranspiration. Water from Oahe Reservoir will supply the proposed Pollock-Herreid Irrigation Unit which would recharge the Spring Creek aquifer and further increase its potential.

The Dakota and Fall River aquifers can yield water to flowing wells in Campbell County. The water is not suitable for irrigation, but is satisfactory for drinking purposes.

Surface water use in 1966 was primarily for wildlife and recreation. Two irrigation projects were using surface water. Water from the Oahe Reservoir was used to irrigate about 180 acres and water from Lake Pocasse about 100 acres in 1966.

Prospects for development of surface water resources are excellent. A proposed plan (study made by Bureau of Reclamation) to irrigate 15,000 acres and provide water for municipal and industrial use to Pollock and Herreid has been approved. The plan also includes water use for fish and wildlife enhancement in the area.

SUMMARY

Glacial outwash deposits of sorted sand and gravel are the important water-bearing rocks in Campbell County. The deep-glacial aquifer has the greatest potential for development of ground-water resources in Campbell County. Yields of more than 1,000 gpm may be obtainable from properly constructed wells.

The deep-glacial aquifer underlies about 160 square miles (21 percent) of the county. It ranges in depth from 150 feet below land surface at Pollock to 300 feet below land surface in the southeastern part of the county. Water in the aquifer is under arteisan pressure in Campbell County and the water surface ranges from 20 to 50 feet below land surface. The aquifer contains an estimated 2½ million acre-feet of water in transient storage in Campbell County.

Recharge to the deep-glacial aquifer is by infiltration of shallow ground water in T. 125 N., Rs. 75 and 76 W., where more permeable layers overlie the aquifer, and from subsurface inflow from McPherson County at Tps. 125 and 126 N.

Discharge from the deep-glacial aquifer occurs as subsurface outflow toward the Missouri River at Pollock and Walworth County. Ground-water movement is from east to west toward the discharge areas.

Water levels in wells tapping the deep-glacial aquifer in the area north and west of Mound City have risen from 10 to 20 feet from 1965 to 1967. During this same period, the water surface of the Oahe Reservoir rose about 40 feet. Because the aquifer is hydraulically connected to Oahe Reservoir the water level in the aquifer corresponds to the water-level changes in the reservoir. If development of the aquifer is sufficient to lower its water surface below that of the Oahe Reservoir, the reservoir water would recharge the aquifer.

The thickness and transmissivity of the deep-glacial aquifer vary greatly in Campbell County. From Mound City to Pollock, the aquifer averages about 70 feet in thickness with a transmissivity from 50,000 to 100,000 gpd per ft. East and south of Mound City the aquifer averages about 150 feet in thickness with a transmissivity of about 100,000 to 200,000 gpd per ft. Very few clay layers occur in the deep-glacial aquifer from Mound City to Pollock, whereas many clay layers of varying thickness occur east of Mound City.

Yields of as much as 500 gpm can be obtained from the shallow-glacial aquifers which underlie 300 square miles (39 percent) of the land area of Campbell County. In 1966, these aquifers contained about 1 million acre-feet of water in transient storage.

Recharge to the shallow-glacial aquifers is by infiltration of precipitation, seepage from Spring Creek, and ground-water inflow from Walworth County. An increase in pumping could salvage and put to beneficial use some ground water now lost by evapotranspiration in places where the water table is shallow as in Rs. 76 and 77 W.

Where the glacial aquifers do not exist, ground water can be obtained from the bedrock Dakota and Fall River Sandstone aquifers. Wells from about 1,500 and 2,000 feet deep produce flowing water in sufficient quantity for domestic and farm needs. The water is not suitable for irrigation.

Three water-quality groups are apparent in figure 18. The shallow-glacial aquifer is high in bicarbonate and sulfate but ranges from 24 to 80 percent calcium with the low-calcium water being high in sodium. Water from the deep-glacial aquifer is high in bicarbonate and sulfate similar to the shallow-glacial water but is of a high-sodium type. Water from the Dakota aquifer is high in chloride and sulfate and ranges from a sodium to a calcium type.

The classification of ground water for irrigation use is based on the salinity and sodium hazard. Water in the shallow and deep-glacial aquifers has a salinity-hazard classification of C3 with the shallow-glacial water having a lower salinity than the deep-glacial water. Water from the shallow-glacial aquifers generally has a low-sodium hazard and is classified as S1. The average sodium-adsorption ratio from 34 water analyses was 1.6. Water from the deep-glacial aquifer has a medium-sodium hazard and is classified as S2. The average sodium-adsorption ratio from 30 water analyses from the deep-glacial aquifer was 9.6. The deep-glacial water is usable for irrigation under certain soil conditions. In order to improve the quality of water for irrigation, wells drilled where both the shallow and deep-glacial aquifers exist should be screened opposite both aquifers. The mixed water will improve the quality and permit irrigation on less suitable soils.

About half of the water used in Campbell County in 1966 was supplied by the shallow and deep-glacial aquifers. The present withdrawal rate does not produce a change in the water surfaces of the aquifers beyond the season during which the water was removed.

Periodic water-level measurements should be continued to record changes in water storage as withdrawals increase. This will provide a basis for better understanding of the hydraulic characteristics of the aquifers and help to determine when withdrawals from the aquifers exceed recharge.

SELECTED REFERENCES

Flint, R. F., 1955, Pleistocene geology of Eastern South Dakota: U. S. Geol. Survey Prof. Paper 262, 173 p.

Hedges, L. S., unpublished, Geology and water resources of Campbell County, South Dakota, Part I: Geology: S. Dak. Geol. Survey Bull. 20.

Hedges, L. S., and Koch, N. C., 1970, Geology and water resources of Campbell County, South Dakota, Part III: Basic data: S. Dak. Geol. Survey Bull. 20, 172 p., 3 figs., 5 tables.

Hem, J. D., 1959, Study and interpretation of the chemical characteristics of natural water: U. S. Geol. Survey Water-Supply Paper 1473, 263 p.

Koch, N. C., 1969, Effects of reservoir filling on a buried aquifer of glacial origin in Campbell County, South Dakota: U. S. Geol. Survey Prof. Paper 650-B, p. B169-B173.

Lee, K. Y., 1956, The water supply at Mound City, Campbell County, S. Dak.: S. Dak. Geol. Survey, 15 p.

Rothrock, E. P., 1943, A geology of South Dakota, Part I. The surface: S. Dak. Geol. Survey Bull. 13, 88 p.

Theis, C. V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., p. 519-524.

Thwaites, F. T., 1961, Outline of the glacial geology: Edwards Brothers, Inc., Ann Arbor, Michigan, 142 p.

U. S. Geological Survey, 1961-1965, Surface-water records of North Dakota and South Dakota (water years 1961-1964). U. S. Geol. Survey Basic Data Rept.

____, 1964, Compilation of records of surface waters of the United States, October 1950 to September 1960; Pt. 6-A, Missouri River Basin above Sioux City, Iowa: U. S. Geol. Survey Water-Supply Paper 1729, 507 p.

____, 1966, Water resources data for North Dakota and South Dakota, 1965, Part I. Surface Water Records. U. S. Geol. Survey Basic-Data Rept.

____, 1967, Water resources data for South Dakota, 1966, Part I. Surface water records: U. S. Geol. Survey Basic-Data Rept.

U. S. Public Health Service, 1962, Public Health Service drinking water standards 1962: U. S. Dept. Health, Education, and Welfare, Public Health Service Pub. 956, 61 p.

U. S. Salinity Laboratory Staff, 1954, Diagnosis and improvement of saline and alkali soils. U. S. Dept. Agriculture Hand. 60, 160 p.

Wenzel, L. K., 1942, Methods for determining permeability of water-bearing materials with special reference to discharging-well methods, with a special section on direct laboratory methods and bibliography on permeability and laminar flow by V. C. Fishel: U. S. Geol. Survey Water-Supply Paper 887, 192 p., 6 pls.

Wong, Harold D., 1960, Shallow-water supply for the city of Selby: South Dakota Geol. Survey Spec. Rept. 9, 19 p.