HYDROLOGY OF A PART OF THE BIG SIOUX DRAINAGE BASIN, EASTERN SOUTH DAKOTA

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INTRODUCTION

In 1960 the U.S. Geological Survey, in cooperation with the South Dakota State Water Resources Commission and the South Dakota State Geological Survey, started a program for the hydrogeologic investigation of glacial drift in selected drainage basins in eastern South Dakota. This program was designed to delineate water-bearing deposits of glacial-outwash sand and gravel, and to determine their water-yielding characteristics, particularly with regard to irrigation and industrial use. Investigations of this type will aid in planning the use and conservation of ground water for future agricultural and industrial growth in South Dakota.

This report describes the part of the Big Sioux River drainage basin from Sioux Falls north to a U.S. Geological Survey gaging station 9½ miles southeast of Brookings (see fig. 1).

The drainage area, about 675 square miles, is in the southwestern part of the Coteau des Prairies section of the Central Lowland physiographic province, as defined by Flint (1955, p. 5). It includes the Big Sioux River valley in Moody and north-central Minnehaha Counties, and the uplands that drain into the valley, from Brookings, Lake, Moody, and Minnehaha Counties, South Dakota, and Pipestone and Lincoln Counties, Minnesota.

This report is based on data from field and laboratory studies and from published and unpublished records of State and Federal agencies. The investigations included: (1) Delineating area of water-bearing glacial outwash deposits; (2) inventorying wells to locate areas of greatest ground-water potential; (3) examining samples from auger holes to define thickness, extent, and character of water-bearing deposits; (4) determining the altitudes of selected test holes and wells for use in preparing cross sections and water-table maps; (5) collecting and analyzing water samples to determine the chemical character of water; and (6) testing aquifers to determine the hydrologic properties of the water-bearing deposits.

Data consisting of logs of wells and test holes, water-level measurements, chemical analyses of water, stream-runoff measurements, and determinations of the hydrologic properties of aquifers are contained in a separate report by Ellis and Adolphson (1968).

Previous Investigations

Several reports that contain information on the geology or water resources of the area or parts of the area have been published. The geohydrologic and water quality maps are, with minor revisions, based upon geologic maps by Leverett (1932), Flint (1955), Tipton (1959a and 1959b), Steece (1959a and 1959b), and Lee (1960a and 1960b). The age relationships of the glacial deposits shown on the geohydrologic map are as proposed by Lemke and others (1965, p. 15-25). Reports by Hall and others (1911), Rothrock and Otton (1947), Lee (1957), Lee and Powell (1961), and Ellis and Adolphson (1965) describe ground-water investigations that include parts of the report area or adjoining areas.

Surficial Geology

The geohydrologic map shows the distribution of surficial deposits in the report area and locations of selected test holes, wells, and other data-collection points. The locations are numbered consecutively, from right to left starting in the lower (southern) part of the map. The surficial deposits are predominantly of glacial origin, and consist of end-moraine, ground-moraine, and outwash deposits. Loess and alluvial deposits, though present, are closely associated with the glacial deposits and, by themselves, are not significant as sources of water. Therefore loess and alluvial deposits are not shown on the geohydrologic map nor discussed in this report. The surficial deposits overlie Cretaceous shale and Precambrian quartzite, which are not commonly used as sources of ground water in the report area and, therefore are also not discussed. Outcrops and quarry exposures of the Precambrian quartzite are shown on the geohydrologic map, however, because the quartzite is a barrier to the movement of ground water.

HYDROLOGY

Ground Water

Most ground water in the report area is obtained from outwash deposits and from sand and gravel lenses in moraine deposits. Moderate to large amounts of water may be obtained from the outwash deposits where they consist of 20 or more feet of saturated sand and gravel. (See geohydrologic map.)

Outwash deposits consisting of less than 20 feet of saturated sand and gravel usually yield small to moderate amounts of water. Sand and gravel lenses in moraine deposits commonly yield small amounts of water, adequate for domestic and stock use, but with no potential for large yields.

Three outwash deposits have a potential for further development as aquifers. The outwash deposits along the Big Sioux River valley are not continuous and function as two separate aquifers connected only by surface flow. A ground-water barrier of quartzite near

Dell Rapids separates the outwash deposits into what are called, in this report, the southern and northern aquifers. The southern aquifer also is bounded on the south by a ground-water barrier of quartzite near Sioux Falls. Less than half of the northern aquifer is within the report area. The northern aquifer extends more than 50 miles north of the report area, to the vicinity of Watertown. The third outwash deposit that has potential for further development as an aquifer is the outwash plain deposit in the northeastern part of the drainage area. A summary of the hydrogeology of the outwash deposits is shown in table 1.

The hydrologic properties of the outwash deposits were determined by tests conducted as part of this study and from data given by Rothrock and Otton (1947). Results of aquifer tests are summarized in table 2. Data on the laboratory tests, size analysis and permeability determinations, are given in Ellis and Adolphson (1968).

Recharge and Discharge

Most recharge to aquifers in the outwash deposits is by direct infiltration of precipitation and of surface runoff. The amount of recharge that infiltrates into the zone of saturation depends on vegetation, topography, soil type and structure, rate of evaporation, and the duration, type, and intensity of precipitation.

Ground water is discharged from the aquifers by ground-water outflow, by discharge from wells and springs, by seepage into surface-water bodies, by transpiration by plants, and by evaporation from the soil where the ground-water level is at or near the land surface.

In the report area, the total amount of water that enters the aquifer as recharge and the total amount that leaves as discharge could not be determined. Because long-term water-level measurements reflect no significant change in the average amount of ground water stored, recharge must approximately equal discharge.

Ground-Water Levels

The water table fluctuates in response to changes in storage within an aquifer in much the same manner as the water level in a surface reservoir varies with storage. When recharge exceeds discharge, ground-water storage is increased, and water levels rise. Conversely, when discharge exceeds recharge, ground-water storage decreases, and water levels decline. The water table, however, does not rise or decline uniformly over the area with a change of storage, and changes of water level in one well do not necessarily reflect changes throughout an aquifer. Periodic water-level measurements in a network of observation wells are, therefore, necessary to make quantitative estimates of the amount of ground water in storage at any given time.

As part of this investigation, monthly water-level measurements were made in 33 observation wells. Hydrographs of 4 representative observation wells are shown in figure 2. In the Big Sioux River drainage basin, ground-water levels are generally lowest during the winter months, when the ground is frozen and the aquifers cannot receive any significant amount of recharge. In late March and early April, when the ground thaws, the water level starts to rise, as some recharge is received from snowmelt runoff. During the rest of April and in May the water levels continue to rise in response to early spring rains. In June, the water levels usually decline slightly, although the largest percentage of annual precipitation occurs in June. (See fig. 3.) The decline in water levels that starts in June and continues into September is probably due to large water losses by evapotranspiration during this period when temperatures are high and most plant growth occurs. After the first killing frost, usually in early October, the ground-water level often rises slightly until the ground freezes.

Ground water moves in the direction of the hydraulic gradient, that is, at a right angle to the water-table contour lines. The rate of movement is proportional to the slope (hydraulic gradient) and to the permeability of the aquifer.

Relationship Between Ground Water and Surface Water

Where a stream is in contact with an aquifer, as the Big Sioux River is with the outwash deposits along the Big Sioux valley, water may move into or out of the stream, depending upon the relative water levels. An influent stream supplies water to an aquifer; an effluent stream receives water from an aquifer. A stream may be influent at one location and effluent at another; also, changes can occur with time as stream stages change relative to nearby ground-water levels.

Ground-water discharge from aquifers into the Big Sioux River forms the base flow of the river. This base flow comprises the total flow during much of the year when there is no significant amount of surface runoff but is only a negligible fraction of the total flow during periods of high surface runoff.

The interrelation of ground water and surface water is readily demonstrated by the sustained flow of the Big Sioux River during periods between rains and by the presence of seeps and springs along the Big Sioux valley and along the tributary valleys. Data on ground-water levels and stream stage also show the interrelationship between ground water and surface water. The close correlation between stream stage and ground-water levels is shown in figure 4.

Surface Water

The principal surface water features in the area are the Big Sioux River, its tributaries, and the numerous small lakes and ponds in the area north and west of Colman.

The drainage (topographic) divide, which delineates both the area of this report and the potential limit of surface runoff, generally coincides with the ground-water divide. Small deviations between the drainage divide and the ground-water divide may occur in the northwestern part of the report area where there is an area of internal drainage. (See streamflow map.)

Some other minor deviations between the two divides may also occur in the northeastern part of the area where the outwash deposits along the upper reaches of Spring Creek extend north of the drainage divide.

Streamflow

The channel of the Big Sioux River is generally well defined, but follows a very meandering course through the valley. For the 110-mile reach of the river in the report area the average gradient is about 1.4 feet per mile. The average gradient of the stream valley through which the river meanders, however, is about 2.6 feet per mile.

North of the area (above stream gage 308 on streamflow map) the Big Sioux River drains approximately 4,420 square miles. The average inflow to the report area during the years 1948-65 was 136 cfs (cubic feet per second) and the average outflow was about 310 cfs. Flow of the river is variable; a few periods of no flow have been recorded at stream gage 308. In contrast, the floodplain was inundated six times between 1949 and 1963 (Patterson, 1966). Figure 5 illustrates the seasonal variability of streamflow and shows the probability of obtaining dependable surface-water supplies from the river.

All of the streams tributary to the Big Sioux River in the report area are intermittent, most of them flow only as a result of surface runoff from precipitation or snowmelt. Tributary streams which drain areas where there are saturated outwash deposits, such as Spring, Mud, and Flandreau Creeks, however, generally flow from early spring until late summer because they receive ground-water discharge from the outwash deposits. In the area of internal drainage, shown on the streamflow map, streamflow occurs in the rudimentary drainageways only after very heavy rains or rapid melting of thick snow deposits.

Floods

The first known flood in the Big Sioux valley occurred in 1881 (Reeves, 1922, p. 47). Little is known about this flood, but floods since then have generally resulted in a greater monetary loss because of increasing property values in the valley. A schematic illustration showing the frequency of over-bank flow by the Big Sioux River and the average recurrence interval that bank-full may be exceeded by the specified amounts at stream gage 83 is shown on the streamflow map. Over-bank flow usually is caused by snowmelt runoff in late March and early April and occasionally by heavy spring and summer rains.

Because of the relatively small drainage areas involved local heavy rains in the upper reaches of tributary streams in the report area affect the flow of the Big Sioux River only slightly. Flood damage along the tributaries usually consists of washed out roads and culverts and some damage to highway bridges.

The magnitude and frequency of floods are essential elements in studies involving flood-control design or the economics of structures within the reach of flood waters. Flood frequency and relation curves in a report by Patterson (1966) can be used to estimate the magnitude of a flood for a selected frequency at any site in the upper part of the Missouri River basin. Curves applicable to the report area, and an example of their use, are given in figure 6.

Chemical Quality of Water

Water samples from moraine and outwash deposits in the drainage basin were analyzed to determine their chemical quality and to aid in evaluating the suitability of ground water for domestic and irrigation uses. Because ground water from the outwash deposits and water from the streams are closely related, analyses of water from the Big Sioux River and two of its tributaries were also evaluated. The general chemical characteristics of all water samples used in this study are shown on the quality of water map.

A summary of water analyses, grouped by source, and a description of the significance of dissolved mineral constituents and physical properties of water are given in tables 3 and 4.

The quality of water for domestic and irrigation use is evaluated in table 5. The suitability of water for domestic use was evaluated by the suggested criteria of the U.S. Public Health Service (1962, p. 6-8) and the World Health Organization (1963, p. 27-29).

Methods of evaluating water for irrigation are largely experimental and are based on average conditions of soil, crops, drainage, permeability, and climate. A discussion of methods for classifying irrigation water is contained in reports by the U.S. Salinity Laboratory Staff (1954, p. 69-82) and by Wilcox (1955). Four factors commonly are considered: salinity hazard, sodium hazard, residual sodium carbonate, and boron concentration. In the report area, both residual sodium carbonate and boron concentrations of all water samples analyzed were too low to be detrimental to irrigation; therefore, only salinity and sodium hazards will be considered further.

Because salinity hazard and sodium hazard are directly related to the specific conductance and the sodium-adsorption ratio, respectively, water for irrigation may be classified by using a diagram developed by the U.S. Salinity Laboratory Staff (1954, p. 80). The classification of water from the report area, using this method, is shown on figure 7.

The following tabulations shows the distribution of water samples by irrigation class and occurrence.

Irrigation class	Number of wells producing water of a given class		Number of surface-water samples of a given class
	Outwash deposits	Moraine deposits	
C1-S1			1
C2-S1	11		8
C3-S1	14	4	5
C4-S1		3	
C4-S2		1	
Total number of water samples	25	8	14

The interpretation of these irrigation classes by the U.S. Salinity Laboratory Staff is as follows:

"Low-salinity water (C1) can be used for irrigation with most crops on most soils, with little likelihood that a salinity problem 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 if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most instances without special practices for salinity control.

High-salinity water (C3) cannot be used 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.
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 and avocados 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."

WATER RESOURCES

An evaluation of the hydrologic budget of the area and on a comparison with the amount of water currently being used, will aid in estimating the potential for future development of water resources of an area.

Hydrologic Budget

The hydrologic budget of an area is the balance between water gain, change in storage, and water loss over a given period of time. A common method of expressing the budget is:

(Water gain) ± (Change in storage) = (Water loss)

Lack of data precludes giving an exact hydrologic budget of the report area, but by using average values of long-term hydrologic measurements and estimates based on field data, reasonable average annual hydrologic budgets can be made. Table 6 provides for comparison of three such budgets for areas in the Big Sioux River drainage basin. (See fig. 8.)

Water gain.--Precipitation is the only known source of water gain for the Big Sioux River drainage basin above Sioux Falls. For the report area, however, streamflow accounts for about 10 percent, ground water inflow for less than one quarter of 1 percent, and precipitation for almost 90 percent of the water gain. For the drainage area of the southern aquifer, precipitation accounts for only 35 percent of the water gain, while streamflow accounts for 65 percent of the water gain.

Change in storage.--Changes in storage can be significant factors in the calculation of a precise hydrologic budget. In a wet year following several dry years, a considerable amount of the water gain is used in replenishing water stored in surface water bodies, in making up the moisture deficit in the surficial material, and in replenishing water reservoirs in the bedrock. In the preparation of a general budget based on averages, however, the effects of dry and wet years tend to cancel each other.

Water loss.--Evapotranspiration is one of the most significant factors in water loss from eastern South Dakota. Although there is as yet no direct practical method of determining water loss due to evapotranspiration for large areas, the loss can be approximated by restating the hydrologic budget:

(Water loss from evapotranspiration) = (Water gain) ± (Change in storage) - (Sum of all other water losses)

Evapotranspiration accounts for about 94 percent of the water loss from the entire Big Sioux River drainage basin above Sioux Falls, about 75 percent of the water loss from the report area, and only about 20 percent of the water loss from the drainage area of the southern aquifer.

The large differences in water loss from evapotranspiration in the three areas, summarized in table 6, are primarily due to differences in the percent of the total area that has internal drainage. Areas of internal drainage usually have numerous small ponds, lakes, and sloughs from which large amounts of water are lost through evaporation. Evaporation from surface water bodies in the Big Sioux drainage basin averages from 32 to 36 inches per year. Thus the larger the percentage of the area that has internal drainage, the larger the percentage of water loss due to evapotranspiration. Approximately 35 percent of the drainage basin above Sioux Falls has internal drainage, but only about 10 percent of the report area has internal drainage (see streamflow map), and there are no significant areas of internal drainage in the drainage area of the southern aquifer.

Water Use

The average annual amount of water withdrawn for consumptive use in the report area is estimated to be about 14,000 acre-feet. The four main consumptive uses and estimated amounts are as follows: livestock, 1,200 acre-feet; public water supplies, 11,000 acre-feet; rural domestic use, 500 acre-feet; and irrigation, 1,400 acre-feet. These estimates are based on population, amount and kind of livestock, field data, and water consumption rates (MacKichan and Kammerer, 1961). About 70 percent of the water used is ground water from outwash deposits, about 20 percent is ground water from moraine deposits, and about 10 percent is surface water.

Potential Water Development

Within the report area, only slightly more than 1 percent of the water available from precipitation, streamflow and ground-water inflow is used. Under present conditions, it is estimated that there could be almost a 5-fold increase in water use without significantly affecting ground-water conditions. Adequate planning, the construction of surface-water control structures, and ground-water recharge facilities could possibly increase potential water use as much as 10 to 15 times present use.

Ground water.--There is a great potential for ground-water development in the Big Sioux River drainage basin. Outwash deposits offer the greatest potential because only a small amount of the ground water held in transient storage is now being used; and because the hydrologic properties and locations of the aquifers are such that they readily receive recharge. The sand and gravel lenses in the moraine deposits are also potential sources of additional ground water, but only small to moderate yields can be obtained.

As much as 30,000 acre-feet per year of ground water, more than is currently being used, probably could be withdrawn from the outwash deposits. Any large-scale development of ground water, however, should be coordinated and well planned. High capacity wells should not be placed too close to each other or to domestic or stock wells. A network of observation wells should be established to provide data to aid in preventing discharge from exceeding recharge. Water quality should be thoroughly checked to confirm suitability for domestic or for irrigation use.

Surface water.--There is little or no potential, under present conditions, for further development of surface-water resources in the Big Sioux River drainage basin because there are no dams to store water from peak runoff. Although an average of 224,000 acre-feet of water leaves the report area each year, most of this runoff is from snowmelt and precipitation and occurs over very short periods of time. As much as 25 percent of the total annual streamflow may occur in one week. Over 50 percent of the annual streamflow usually occurs in April, and almost 90 percent of the annual streamflow generally occurs between March 25th and July 15th.

The construction of storage and control structures would aid, not only in storing water from peak runoff periods for distribution when it is needed, but also in controlling floods. The engineering and legal aspects of constructing and managing dams are beyond the scope of this report, but if dams are constructed they should complement the present hydrologic system in the drainage basin.

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