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E. C. Reed

C. F. Keech

UNITED STATES DEPARTMENT OF THE INTERIOR

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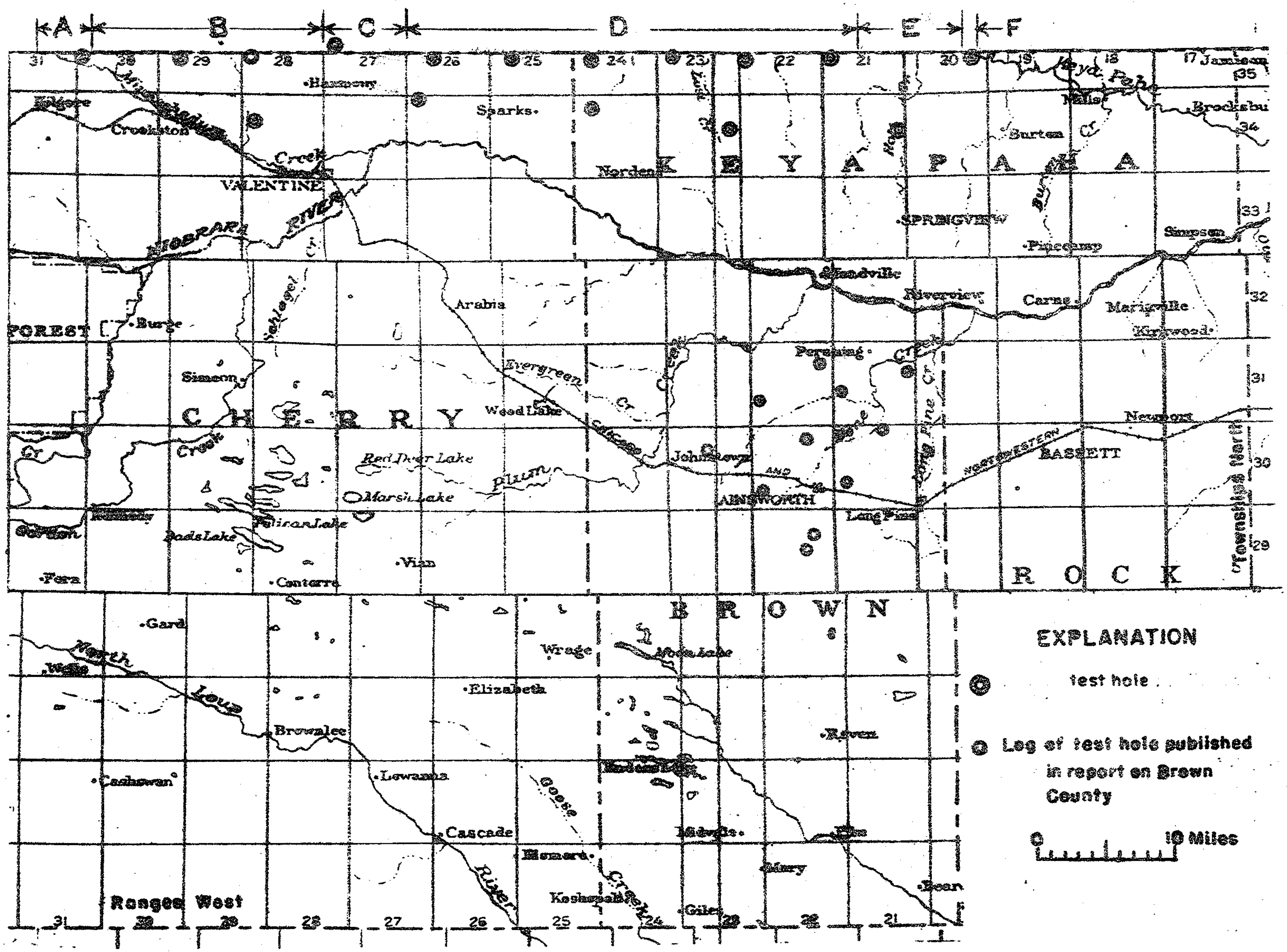


MAP OF NORTHEASTERN CHERRY, KEYA PAHA, BROWN, AND ROCK COUNTIES SHOWING LOCATION OF TEST HOLES.

PRELIMINARY ESTIMATE OF THE UNDERFLOW ACROSS THE SOUTH DAKOTA-NEBRASKA STATE LINE IN THE NIOBRARA RIVER AND PONCA CREEK DRAINAGE BASINS

By E. C. Reed[1] and C. F. Keech[2]

Introduction

The purpose of this paper is to estimate the amount of ground water flowing across the South Dakota-Nebraska State line within the Niobrara River basin, including the Ponca Creek basin. The study was made at the request of the Niobrara River Compact Commission. The estimates given in the paper are preliminary and subject to revision.

Geologic Setting

The Niobrara River basin lies across the South Dakota-Nebraska State line and is underlain by deposits whose water-yielding properties extend over a considerable range of values. A longitudinal section of the water-bearing formations is somewhat wedge shaped. The water-bearing formations are about 205 feet thick where the State line crosses the western boundary of the Minnechaduza Creek basin; the formations progressively diminish in thickness eastward for about 60 miles and then essentially disappear. The water-bearing deposits rest upon older formations that are almost impervious.

Surficial deposits of Quaternary age and immediately underlying deposits of the Ogallala formation of Tertiary age are the important water-yielding formations. The White River group (Chadron and Brule formations), also of Tertiary age, underlie the Ogallala formation. The Pierre shale of Cretaceous

1/ Director of the Conservation and Survey Division of the University of Nebraska.

2/ District Engineer, Ground Water Branch, U. S. Geological Survey, Nebraska.

age underlies the Tertiary deposits. The White River group and the Pierre shale have very low permeabilities and can transmit water at only a very slow rate; the water they can yield is relatively unimportant.

In addition to the wedge-shaped section of water-bearing deposits just described, thin sections of permeable alluvial materials overlie the bedrock under the valleys of the Keya Paha River and Ponca Creek. These deposits are of sufficient saturated thickness at most places to ~~yeild~~ yield water to wells of small capacity.

Determination of Underflow by the Application of Darcy's Law

Lateral movement of the ground water is in the direction of the slope of the water table. Plate 1 shows by contour lines the approximate configuration of the water table in the vicinity of the South Dakota-Nebraska State line. The water-table contour lines are based upon the altitude of the water level in selected wells throughout the area. The altitude of the measuring point of each well was determined from topographic maps in areas that had been topographically mapped and by means of aneroid barometers in other areas.

The amount of water that flows through an aquifer is proportional to the slope of the water table, the permeability of the aquifer, and the cross-sectional area through which the water moves. The field coefficient of permeability of an aquifer may be expressed as the rate of flow of water, in gallons per day, through a cross section 1 foot high and 1 mile wide under a hydraulic gradient of 1 foot per mile and at the prevailing ground-water temperature.

Two factors were considered in estimating the amount of ground-water movement across the Nebraska-South Dakota line between Minnechaduza Creek and the Keya Paha River. They are (1) the hydraulic gradients at right angles to the State line as determined from the regional water-table contour map (pl. 1), and (2) the transmissibilities of the permeable materials lying below the water table, which were estimated from the test-hole records. If additional water-table elevations are obtained, especially in South Dakota, the hydraulic gradients may be determined more accurately but the resulting revisions likely will be unimportant. The transmissibilities were determined by estimating the coefficient of permeability of each type of relatively permeable material below the water table, multiplying this figure by the number of feet of the material drilled, and totaling the results for all computations for each test hole. The estimates of permeability are thought to be reasonable but could be substantially in error.

The field coefficients of permeability assigned to various types of material are based on a comprehensive study of test-hole cuttings. Texture, cementation, and other factors were taken into account. Assigned field coefficients of permeability, in gallons per day per square foot, are as shown by the following general scale:

Sand and gravel (medium sand to medium gravel)	1,500
Sand and gravel (fine-medium sand to fine gravel)	1,200
Very coarse sand	900-1,000
Medium to coarse sand	750
Medium sand	500
Fine to medium sand	250- 300
Fine sand	200
Relatively unconsolidated sandstone	175
Fine- to medium-grained sandstone	150
Fine-grained sandstone	125
Siltstone to sandstone	75- 100
Clay, silt, and siltstone	0

The permeability values assigned to the different materials are probably accurate within 20 percent but cannot be guaranteed to be so. The computed range in estimated ground-water movement is shown in table 1; on the basis of experience and general knowledge of the area, however, the lower rather than the higher value is believed to be more nearly correct.

For purposes of computation, the State line was divided into six segments in each of which the general conditions of gradient, transmissibility, and direction of movement are similar. Starting from Minnechaduza Creek, the first segment (A) is 2 miles long and has comparatively low gradients but comparatively high transmissibility; the second segment (B) is 17 miles long, with low transmissibilities and high gradients; the third segment (C) is 6 miles long and is essentially along the ground-water divide; the fourth segment (D) is 32.5 miles long, with high gradients and generally low transmissibilities; the fifth segment (E) is 8.5 miles long and is an area where shale is at or near the surface and where there is little or no ground-water movement; and the sixth segment (F) is the Keya Paha Valley bottom land, about 1,100 feet in width, with high transmissibilities and low gradients. The ground-water movement across segments A, B, and F is toward Nebraska and the ground-water movement across Segment D is toward South Dakota. The ground-water movement across segments C and E is believed to be insignificant. The computation and summation of the ground-water movement across these segments is summarized in table 1.

Table 1.--Estimated ground-water movement across the Nebraska-South Dakota State line in the Niobrara River basin

Segment	Length, in feet	Average transmissibility, in gallons per mile per day		Hydraulic gradient, in feet per mile	Flow across segment					
					In gallons per day		In acre-feet per day		In second-feet	
		Maximum	Minimum		Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
A	10,500	62,500	50,000	12	1,500,000	1,200,000	4.60	3.7	2.3	1.85
B	89,750	21,000	17,000	20	7,200,000	5,800,000	22.1	17.7	11.10	8.9
C	31,700	--	--	--	--	--	--	---	--	--
D	171,600	9,000	7,000	26	7,600,000	6,100,000	23.3	18.6	11.7	9.4
E	44,900	--	--	--	--	--	--	--	--	--
F	1,100	10,500	8,500	4	8,900	7,100	.03	.02	.01+	.01
Total movement toward Nebraska					8,700,000	7,000,000	26.7	21.4	13.4	10.75
Total movement toward South Dakota					7,600,000	6,100,000	23.3	18.6	11.7	9.4
Net movement toward Nebraska					1,100,000	900,000	3.4	2.8	1.7	1.35

Determination of Underflow by the Ground-Water-Discharge Method, Minnechaduza Creek Basin

The Minnechaduza Creek basin includes about 303 square miles, of which 42 percent or about 127 square miles is in South Dakota and 58 percent or 176 square miles is in Nebraska.

Measurements of the flow of Minnechaduza Creek are made at a gaging station at Valentine, Nebr., near the mouth of the creek. The flow in Minnechaduza Creek during periods of little or no precipitation is ground-water discharge. During dry periods in winter months the flow in the creek represents the total ground-water discharge from the basin because essentially no ground water is being discharged by evapotranspiration. The discharge of ground water received from precipitation, the only source of recharge in the basin, is believed to be at a generally uniform rate because, owing to the relatively slow rate of ground-water movement, the irregularities in the rate and amount of recharge are smoothed out and averaged before the discharge points or areas are reached.

Records of the U. S. Weather Bureau show that November 1955 was very dry; only 0.06 inch of precipitation fell at Valentine during the month. Therefore, it can be assumed that no water was contributed to the flow in the creek by direct runoff. The average flow in Minnechaduza Creek at the Valentine gaging station during November 1955 was 28.1 second-feet, or about 55.5 acre-feet per day; this flow is believed to be a measure of the total ground water discharged from the entire Minnechaduza Creek basin and to represent the average rate of ground-water discharge from the basin. As but little ground water is discharged from the basin by other than natural means, this average rate of ground-water discharge, therefore, essentially equals the average rate of ground-water recharge. Then, if the recharge from precipitation is assumed to be uniform over the entire basin, 42 percent of the recharge or about 23.3 acre-feet per day occurs in South Dakota. As the ground-water discharge is essentially all in Nebraska, it follows that about 23.3 acre-feet (11.7 second-feet) of water per day is moving across the State line from South Dakota and into Nebraska in the Minnechaduza Creek basin.

Recharge from Precipitation

If the recharge to the Minnechaduza Creek basin is 55.5 acre-feet per day as computed above, the recharge to the basin in 1 year is about 0.105 feet on 303 square miles; that is, about 1.25 inches of the average yearly precipitation recharges the ground-water reservoir. According to the Weather Bureau, the average annual precipitation at Valentine is 18.26 inches; thus, the recharge to ground water is about 7 percent of the precipitation. This value for recharge from precipitation, considering similar data from other areas and considering the topography, soil, and geology of the basin, is believed to be reasonably accurate.

Effect of Soils and Geology

The soils of the Minnechaduza Creek basin are sandy and permeable and permit water from precipitation to percolate easily to the water table.

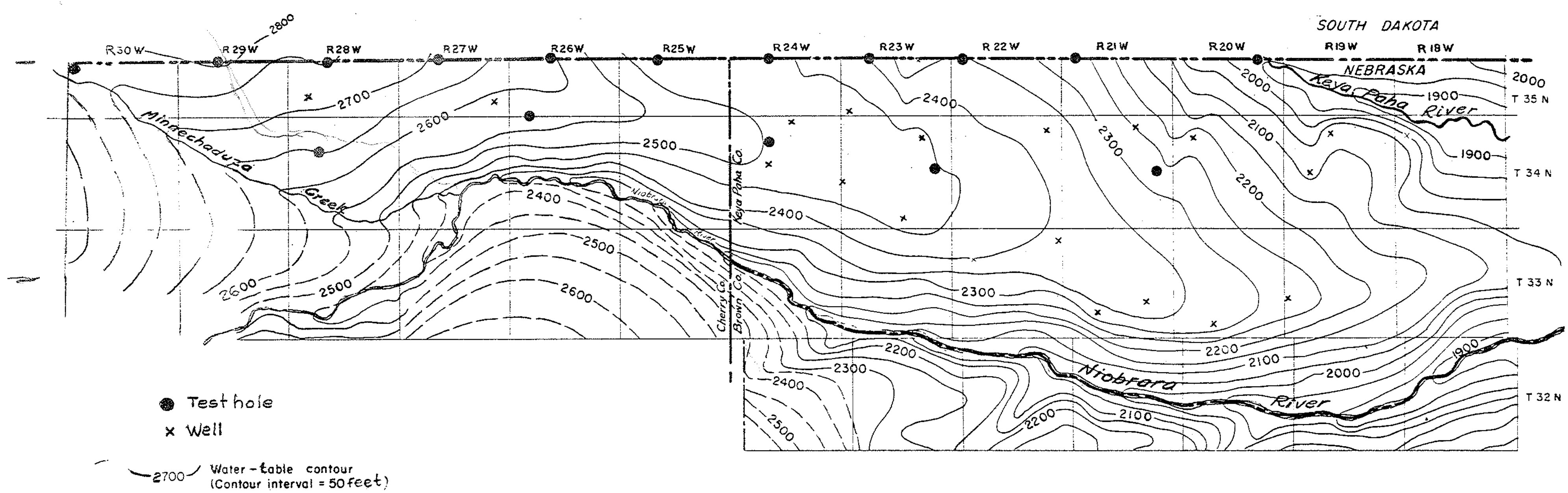
The geologic formations upon which the soils are developed are of sufficient permeability and thickness to provide a large capacity for ground-water storage.

The soils of the Keya Paha River basin and Ponca Creek basin, which are composed largely of dense clay, are almost opposite to those in the Minnechaduza Creek basin. The soils are hard and are low in absorptive qualities, and rainfall is rapidly discharged by direct runoff. Recharge to the ground-water reservoir from precipitation in these basins is small. Furthermore, the soils mantle formations of low permeability which provide but small capacity for ground-water storage. Except in the shallow alluvial fills in the valleys of the Keya Paha River and Ponca Creek, there are no saturated materials of sufficient thickness to yield significant amounts of water to wells. No potential for large ground-water development exists in these basins, and the amount of ground water moving across the State line in them is very small.

Summary

Analysis of the available data indicates that part of the ground water that originates in South Dakota moves as underflow across the State line into Nebraska and, likewise, part of the ground water that originates in Nebraska moves into South Dakota. The amount of ground water moving into Nebraska is estimated to be about 11 second-feet, most of which originates in the Minnechaduza Creek basin. The amount moving into South Dakota is estimated to be about 9.5 second-feet, most of which originates in the Keya Paha River basin. The net movement into Nebraska is between 1.0 and 1.5 second-feet.

Plate 1



MAP OF NORTHEASTERN CHERRY AND WESTERN KEYA PAHA COUNTIES SHOWING CONTOURS ON THE WATER TABLE