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ESTIMATE OF UNDERFLOW IN THE NIOBRARA RIVER BASIN ACROSS THE WYOMING-NEBRASKA STATE LINE

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ESTIMATE OF UNDERFLOW IN THE NIOBRARA RIVER BASIN ACROSS THE WYOMING-NEBRASKA STATE LINE[1/]

By H. M. Babcock and C. F. Keech[2/]

Introduction

The purpose of this report is to estimate the amount of ground water flowing across the Wyoming-Nebraska State line within the Niobrara River basin and to evaluate the accuracy of that estimate. The approximate effort involved in obtaining additional data to determine the underflow more accurately also is discussed.

This report was prepared by the U.S. Geological Survey in cooperation with the Wyoming State Engineer and the Director of the Conservation and Survey Division of the University of Nebraska, at the request of the Niobrara River Compact Commission. The following paragraph requesting the work is quoted from the report of the Engineering Subcommittee to the Niobrara River Compact Commission, Ainsworth, Nebr., October 29, 1956:

> Need for additional data under this item is confined to ground-water data since surface-water data discussions are covered under item 1. It is recommended that the Commission request the Geological Survey in cooperation with each of the three states to develop estimates of ground-water flows across state lines, together with ground-water contour maps extending adequate distances into each state, such estimates and maps to be based on existing data and qualified by their evaluation of resultant percentage degree of accuracy. In addition they should be requested to furnish an estimate of cost to obtain additional data necessary to bring the estimate to within a more acceptable degree of accuracy as may be desired by the Commission.

1/Open-file report. Not reviewed for conformance with editorial standards of the Geological Survey.

2/Hydrologists, Water Resources Division, U.S. Geological Survey.

Geologic setting

The Niobrara River basin in the vicinity of the Wyoming-Nebraska State line is underlain by a thick section of Tertiary rocks, which overlie the Pierre Shale of Cretaceous age. The lower Tertiary unit, the White River Group (Chadron and Brule Formations), and the Pierre Shale can transmit only very small quantities of water. The Arikaree Group is the uppermost Tertiary unit and is the only stratigraphic unit underlying the basin that can transmit appreciable quantities of water. The position, thickness, and character of the rocks are shown on plate 1.

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 Wyoming-Nebraska State line. The water-table contour lines on plate 1 are based upon the altitude of the water level in selected wells throughout the area. The altitude of the measuring point at each well was determined by instrumental leveling in the part of the area that lies within Goshen County, Wyo. The altitudes in the remainder of the area were determined by means of surveying aneroid barometers.

The ground water in massive, uniform sands, such as those of the Arikaree Group, may be presumed to move uniformly at right angles to the contour lines from higher to lower elevations. The amount of ground 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. This quantity can be determined by applying Darcy's law, expressed in the equation

$$Q = P\ I\ A$$

in which Q = the quantity of underflow, in gallons per day

P = the field coefficient of permeability; that is, the number of gallons of water per day, at the prevailing water temperature, that is conducted laterally through each mile of the water-bearing bed (measured at right angles to the direction of flow), for each foot of saturated thickness of the bed, and for each foot per mile of hydraulic gradient

I = the hydraulic gradient of the water table, in feet per mile

A = the cross-sectional area of the saturated part of the bed, in mile-feet

Tests to determine the coefficients of permeability of the Tertiary rocks were made on core samples of the rocks collected along the escarpment on the northern margin of the Niobrara drainage basin near the Wyoming-Nebraska State line. The core samples were obtained in an essentially undisturbed condition by cutting blocks from the formation outcrops in the field, and later cutting properly oriented cores from the blocks in the laboratory.

A geologic section was measured near Whitman, Wyo. (sec. 30, T. 34 N., R. 60 W.), and samples were collected from representative beds throughout the section; the samples are believed to be typical of the Tertiary rocks that underlie the Niobrara River drainage basin in the vicinity of the Wyoming-Nebraska State line through which the ground water percolates. The coefficients of permeability obtained from the laboratory tests were averaged and weighted in accordance with the relative thickness of the beds sampled; the results are as follows:

Formation	Number of samples tested	Weighted average coefficient of permeability (gallons per day per square foot)	
		Standard coefficient at 60° F.	Field coefficient at the temperature of water in formation (52° F.)
Arikaree Group	5	45	40
Brule Formation	3	.02	.02
Chadron Formation	2	.002	.002

The slope of the water table and the width of the aquifer through which the ground water moves were measured along the 4,700-foot water-table contour line (see pl. 1); the saturated thickness of the Arikaree Group was estimated from cross section A-A' shown on plate 1. Section A-A' was placed to pass through the three wells for which logs were available, the measured section of the Arikaree Group at Whitman, Wyo., and other points at which the elevation of the land surface was known. The general direction of ground-water movement is southeastward and the cross-sectional area through which the flow was computed is at right angles to the direction of flow. Applying the preceding formula (Q = P I A), the ground-water underflow across the 4,700-foot line is summarized in the following table:

Aquifer	Field coefficient of permeability (gallons per day per square foot)	Saturated thickness (feet)	Coefficient of transmissibility (field coefficient of permeability times the saturated thickness)	Slope (feet per mile)	Width (miles)	Flow	
						Gallons per day	Cubic feet per second
Arikaree Group	40	500	20,000	16.8	21.3	7,160,000	11.0
Brule Formation	.02	359	7	16.8	21.3	2,500	.004
Chadron Formation	.002	200	.4	16.8	21.3	140	.0002

The 4,700-foot contour is not coincident with the State line; therefore, in order to obtain the ground-water flow across the State line correction must be made for the recharge from precipitation on the areas between the contour line and the State line. The area between the 4,700-foot contour line and the State line, on the Nebraska side, is about 35 square miles; that on the Wyoming side is about 55 square miles. Thus, the recharge from precipitation on about 20 square miles must be added to the flow across the 4,700-foot contour line. Recharge from precipitation, estimated in the next section of this report, is about 0.33 inch per year, or about 314,000 gpd (0.5 cfs) on 20 square miles. Thus, the estimated flow across the State line is about 0.5 cfs more than the flow across the 4,700-foot contour line, or about 7,470,000 gpd (11.5 cfs).

The foregoing computations show that essentially all the underflow across the Wyoming-Nebraska State line is through the Arikaree Group and amounts to about 7,470,000 gallons per day (gpd) or 11.5 cubic feet per second (cfs). The amount of ground water moving through the underlying White River Group (Chadron and Brule Formations) is negligible, amounting to approximately 2,600 gpd or about 0.004 cfs.

Determination of underflow by the ground-water-discharge method

A separate and independent determination of the underflow across the State line was made by considering the amount of ground water being discharged into the Niobrara River downstream from the State line. This determination was made to serve as a check on the results obtained by the computations given in the preceding paragraphs.

Inspection of the water-table contour lines on plate 1 shows rather conclusively that the ground water moving across the Wyoming-Nebraska State line is moving toward and finally is discharged into the Niobrara River. Therefore, if the amount of water flowing in that stream which originates as underflow across the State line is known, the amount of the underflow likewise will be known. This underflow can be estimated as described in the following paragraphs.

The configuration of the water table is shown on figure 1 by contour lines constructed at 50-foot intervals; the ground-water flow lines are drawn at right angles to the contours. The flow line on the south side of

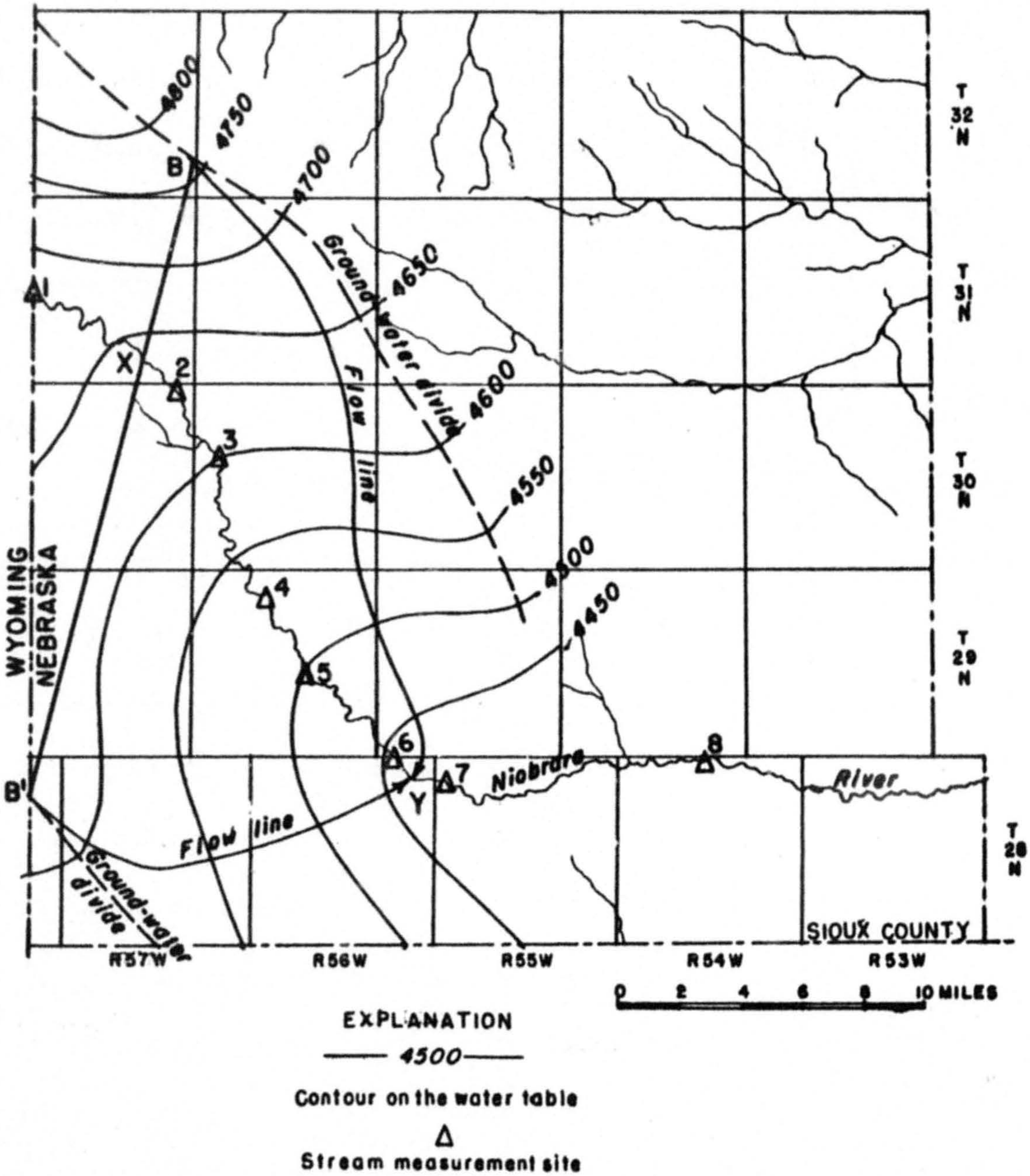

Figure 1.--Map of part of Sioux County, Nebr., showing contours on the water table, ground-water flow lines, and locations of stream-measurement sites.

the river was begun at the junction of the water-table divide with the State line and drawn down the maximum slope until it intersected the Niobrara River at point Y. The flow line constructed on the north side of the river was begun at point Y and drawn up the maximum slope of the water table until it intersected the ground-water divide at point B about 6 miles east of the State line. Therefore, all the ground water moving through section B-B', which connects the points of origin of the flow lines, will be discharged to the river between line B-B' and point Y, or between points X and Y on the river. The amount of ground water contributed to the river between these points can be determined by measuring the increase in streamflow in that reach of the stream during a period when all the water in the stream can be assumed to consist of base flow.

On January 8, 1957, measurements of the discharge of the Niobrara River at eight different points were made by personnel of the Water Resources Division, U.S. Geological Survey. (See fig. 2.) Because the air temperature was below freezing when the measurements were made, runoff from snowmelt was not contributing to the streamflow, essentially no evaporation was taking place, and no diversion to irrigation canals was being made. The stream was open at all stations, although at station 4 some ice was forming along the banks at the time of measurement. The measurements obtained at stations 1 to 7 are believed to be relatively accurate, but as the temperature had dropped to 5° F. by the time the measurement was made at Station 8, the discharge as measured at this station is believed to be less than it would have been if some water had not been going into ice storage.

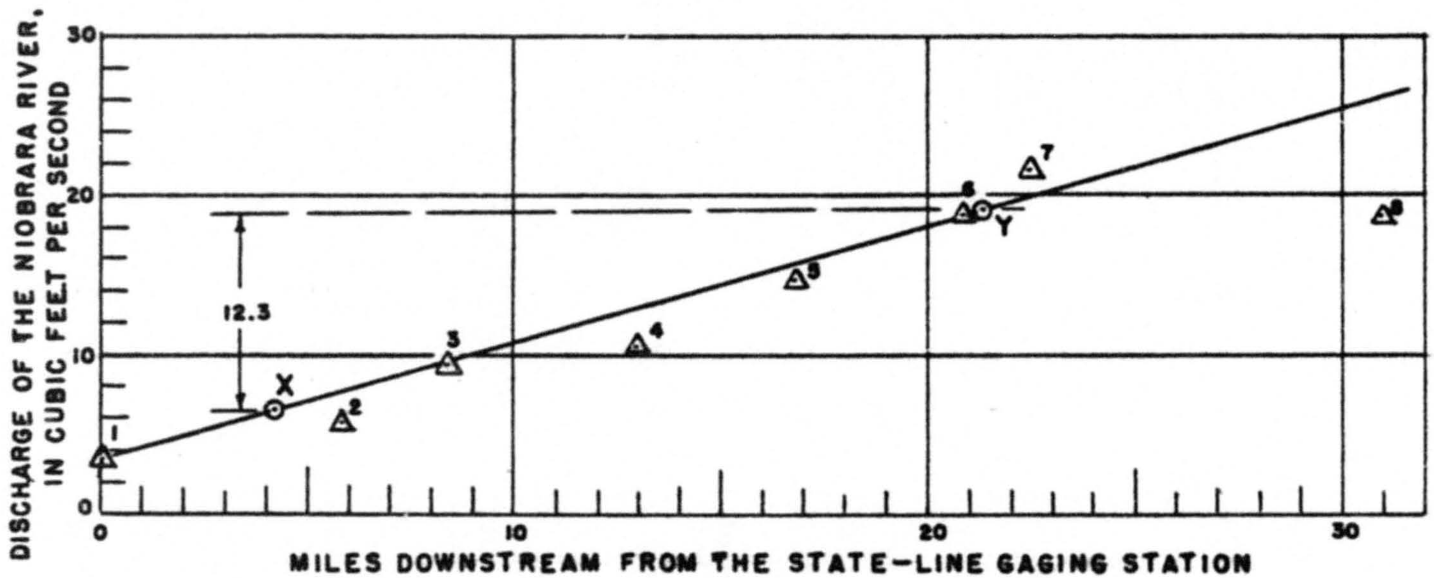

Figure 2.--Graph showing the increase in ground-water flow into the Niobrara River downstream from the Wyoming-Nebraska State line.

The streamflow measurements and the corresponding distances along the stream channel of the points of measurement from the State line are as follows:

	Station							
	1	2	3	4	5	6	7	8
Distance from State line, in miles..............	0	5.8	8.25	12.9	16.7	20.8	20.5	31.1
Discharge, in cubic feet per second............	3.61	5.87	8.94	10.7	14.5	18.8	21.7	18.7

The straight line drawn through the plotted stream discharges on figure 2 (not considering Station 8) is believed to be reasonable and represents the rate of discharge of ground water to the river between the State line and Station 7. The increase in the flow of the river between points X and Y is about 12.3 cfs, or almost 8,000,000 gpd.

The base flow of the Niobrara River at point Y is about 18.7 cubic feet per second or about 12,000,000 gpd. (See fig. 2.) This water has its origin as recharge from precipitation in the Niobrara River basin above point Y, an area of about 770 square miles. Thus, the annual recharge from precipitation on the area is about 0.33 inch per year, which is of a magnitude comparable to that for similar High Plains areas.

The area of the part of the basin between the flow lines and down-gradient from line B-B' is about 22.2 percent of the entire basin above point Y. If it is assumed that the amount of recharge is distributed evenly over the entire area, 22.2 percent of the total recharge, or about 2,700,000 gpd, will originate within the area bounded by the flow lines and line B-B'.

It follows, then, that about 2,700,000 gpd of the 8,000,000-gpd increase in flow in the river between X and Y must have its origin from precipitation east of the line B-B' and the difference between 2,700,000 and 8,000,000 gpd, or 5,300,000 gpd (8.2 cfs), is the magnitude of the underflow through a cross section of the aquifer beneath line B-B'. The rate of movement of ground water beneath line B-B' is estimated to approximately equal the rate of ground-water underflow at the State line.

Summary and evaluation of the estimates

The authors believe that the best estimate that can be made from the available information is: (1) the coefficient of transmissibility of the Arikaree Group along the Wyoming-Nebraska State line is between 15,000 and 30,000 gpd per foot; and (2) the underflow is between about 5,000,000 and 8,000,000 gpd.

Additional refinement of the water-table contour map probably would not appreciably change the slope values or the length of section. Test drilling probably would not change materially the estimated saturated thickness of 500 feet, which probably is not more than 10 percent in error.

The accuracy of the computation of underflow by using the saturated thickness of the aquifer, the slope of the water table, and the coefficient of permeability (Darcy's law) is directly proportional to the accuracy of the data used in the computation. Of the three factors used in determining the amount of underflow, the largest probable error lies in the determination of the coefficient of permeability.

Even though the Arikaree Group is relatively uniform in character, the particle size of the materials that constitute the various beds differs appreciably. Although the core samples from the stratigraphic units that were tested were carefully collected to obtain samples representative of the major beds comprising the Arikaree, considerable error may be present in the values of permeability, especially because those values were obtained from materials at only a few points in the section but are applied to the entire section. However, a comparison of the coefficient of transmissibility (coefficient of permeability times the saturated thickness) as determined by laboratory tests with that determined by an aquifer test on a well in the vicinity of Wheatland, Wyo., indicates that the laboratory tests give a reasonably accurate value.

The well tested in Wheatland Flats penetrated approximately 500 feet of the Arikaree Group, which appears to be very similar to the Arikaree in the vicinity of the Wyoming-Nebraska State line. Computations based on the aquifer test of this well gave a coefficient of transmissibility of 9,400 gallons per day per foot and a specific capacity of 7.3 gallons per minute per foot of drawdown.

The average reported specific capacities of several irrigation wells in the vicinity of the Wyoming-Nebraska State line is about 10. However, these wells penetrate only about the top two-fifths of the aquifer, and the specific capacities would be considerably greater if the wells penetrated the entire aquifer. Assuming that the average specific capacity of wells penetrating the entire aquifer is about 20, a comparison of this specific capacity with the specific capacity and transmissibility of the well near Wheatland indicates that the coefficient of transmissibility of the Arikaree Group near the Wyoming-Nebraska State line should be about 25,000 gpd per foot. Although this determination of transmissibility is subject to considerable error, it compares favorably with the value of 20,000 determined by the laboratory tests.

Estimate of work required to determine the underflow more accurately

The accuracy of the computations of the ground-water movement across the State line made by the ground-water-discharge method is dependent upon the accuracy of the data obtained for use in the computations. Refinement of the water-table contour map and the ground-water flow lines of figure 1 probably would increase the accuracy of the computations to some degree.

Special care was used in making the streamflow measurements, which were made at a time when no water was being diverted from the stream and when the evapotranspiration losses were at a minimum. Therefore, refinement of these data probably would increase but little the accuracy of the results obtained by the ground-water-discharge method.

In attempting to compute the amount of water that moves through a water-bearing formation, the computations must be recognized to be subject to certain errors that are inherent in the methods used in making them. The configuration of the water table could be determined more accurately by including more wells in the inventory and by determining measuring-point altitudes by instrumental leveling. However, the authors believe that this additional work would not materially change the results obtained by using the existing data.

The total and saturated thickness of the Arikaree Group could be determined more accurately by drilling four or more test holes.

Of the three factors involved in computing the underflow, the coefficient of permeability is the most difficult to determine and affords the greatest opportunity for error. The most practical way to determine this factor more accurately would be to make aquifer tests by pumping the test holes. The making of aquifer tests would require casing the test holes for at least part of their depth, and the installation of pumping equipment. Applying the values of the coefficient of permeability obtained from the aquifer tests to the entire section of underflow would still afford opportunity for error. This error could be reduced somewhat by drilling and testing more than the minimum of four test wells, but whether the coefficient of permeability could be computed within an accuracy of 10 percent or less is questionable.

The amount of water that flows through the underlying White River Group (Chadron and Brule Formations) is so small that no useful purpose would be accomplished by additional testing of these materials.

The minimum additional studies that would be required to refine significantly the preceding estimates of the amount of ground-water underflow across the State line would require an expenditure of not less than $40,000, of which about $20,000 would be required for test drilling, casing, and pumping four test holes and about $20,000 would be required for salaries of technical personnel. The estimated expenditures are based on 1969 operational costs.

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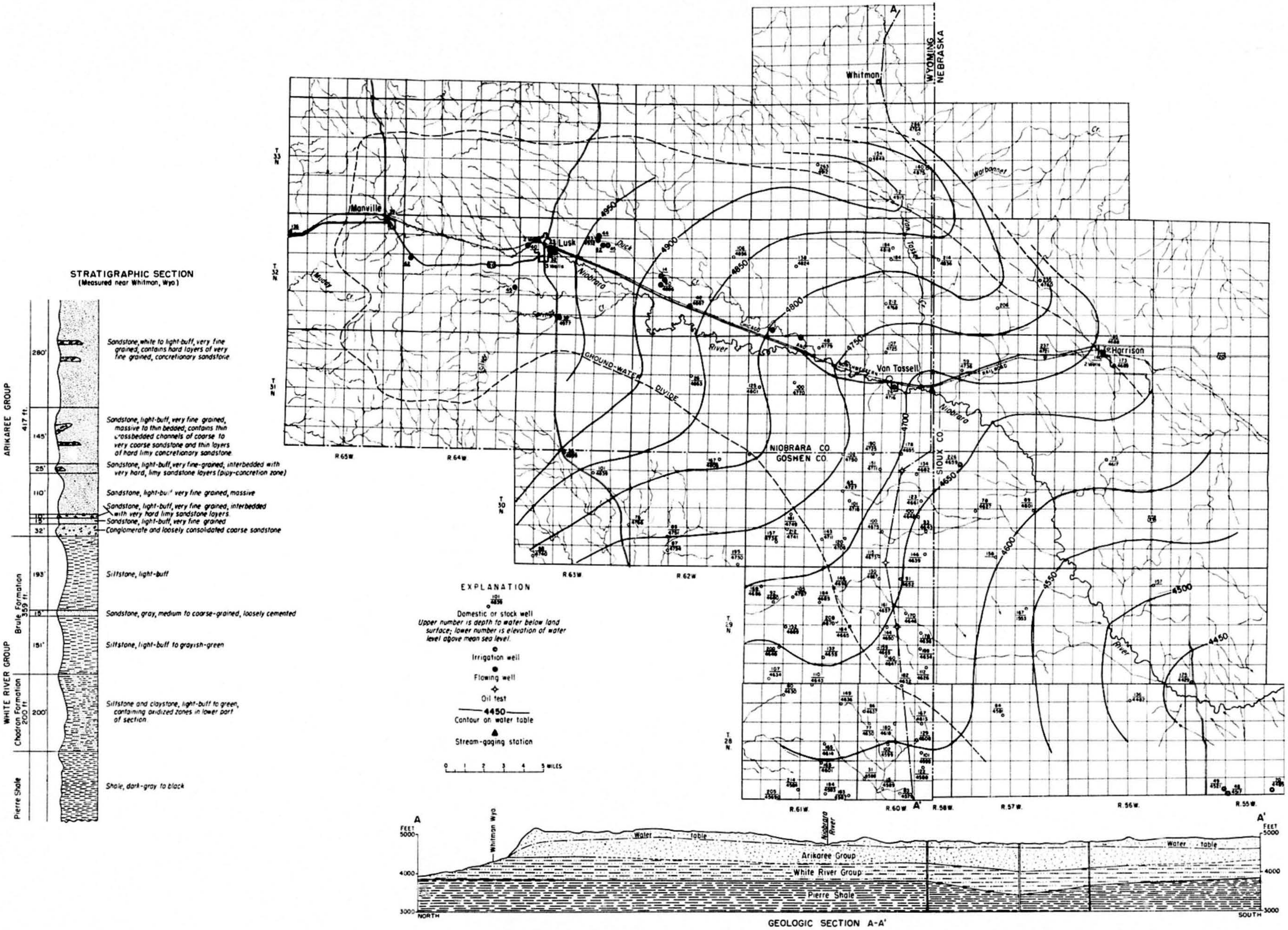

MAP OF THE NIOBRARA RIVER BASIN IN THE VICINITY OF THE WYOMING-NEBRASKA STATE LINE SHOWING CONTOURS ON THE WATER TABLE.