DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

POTENTIOMETRIC-SURFACE MAP OF WATER IN THE JUDITH RIVER FORMATION IN THE NORTHERN GREAT PLAINS AREA OF MONTANA

By Gary W. Levings, 1982

OPEN-FILE REPORT 82-562

INTRODUCTION

In 1978 the U.S. Geological Survey began a 4-year study of aquifers of Cenozoic and Mesozoic age in the northern Great Plains to define the hydrologic system, to determine the availability and chemical quality of ground water, and to predict the effects of various water-use management plans on the system. The purpose of this map is to show the generalized potentiometric surface of water in the Judith River Formation.

Data used in compiling the map were collected from water wells and oil or gas test wells (Levings, 1981a, 1981b). The altitude of the potentiometric surface in the water wells was determined from measured or reported depths to water level or was calculated from pressure-gage readings on flowing wells. The water-well data range in age from 1945 to 1980. The altitude of the potentiometric surface of oil and gas test wells was determined by drill-stem tests. The drill-stem-test data range in age from 1959 to 1979.

GEOLOGIC SETTING

The Judith River Formation (Upper Cretaceous) is a sandstone interbedded with siltstone and shale that contains lignite and coal seams. The thickness of the formation ranges from 0 to 900 feet (R. D. Feltis, U.S. Geological Survey, written commun., 1982). In general the unit thins from west to east, with the thickness in the eastern one-half of the area being less than 200 feet. In the Hogeland basin the thickness is 400 to 600 feet, in the area south of the Bearpaw Mountains it is 500 to 700 feet, in the area southeast of the Little Rocky Mountains it is 300 to 500 feet, and in the area west of the Bull Mountains basin it is 500 to 900 feet.

The regional dip of the Judith River Formation is toward the east; however, the structural complexity accounts for many localized exceptions. The continuity of the Judith River Formation is affected by large-scale gravity slides away from the Bearpaw Mountains and by extensive thrust faulting and rifting, tilting, and collapse of the rocks in the slide sheets. These geologic features are described by Reeves (1925) and Hearn (1976). The Judith River Formation has not been recognized in the Black Hills uplift, although an interval of rocks shown on geophysical logs indicates its presence (R. D. Feltis, written commun., 1982).

Rocks underlying the Judith River Formation crop out in areas of structural highs such as the Bearpaw, Little Rocky, Pryor, and Bighorn Mountains; Sweetgrass arch; Bowdoin and Porcupine domes; and Black Hills uplift. The Claggett Shale (Upper Cretaceous), which may be as much as 400 feet thick, is a gray silty marine shale that directly underlies the Judith River Formation in most of the study area.

Overlying the Judith River Formation is the Bearpaw Shale (Upper Cretaceous), a dark-gray marine shale that may be as much as 700 feet thick. In the Crazy Mountains basin, the Judith River Formation interfingers with continental sediments of the Cokedale Formation of the Upper Cretaceous Livingston Group (Roberts, 1972).

POTENTIOMETRIC SURFACE

During 1980, production from 11 gas fields in Montana (see map) was obtained solely or partly from the Judith River Formation (Oil and Gas Conservation Division, 1981). Although the Judith River Formation does not produce oil, many drill-stem tests were conducted on oil or gas test wells. These tests were used to calculate an altitude of the potentiometric surface at each test well using the following equation:

$$h = (FSIP \times C) - PRD + LSD \qquad (1)$$

where

h is hydraulic head, in feet above NGVD of 1929;

$FSIP$ is final shut-in pressure, in pounds per square inch, measured by a pressure-recording device;

C is a factor to convert $FSIP$ to equivalent feet of water;

PRD is depth of the pressure-recording device, in feet below the measuring point; and

LSD is altitude of the measuring point, in feet above NGVD of 1929.

The factor C equals 2.307 feet of water per pressure increment of 1 pound per square inch. It assumes pure water at a temperature of 4°C having a density of 1.00 gram per cubic centimeter. Thus, the hydraulic-head values calculated from drill-stem tests reflect the potentiometric surface of water in the Judith River Formation if it contained a homogeneous fluid having a density of 1.00 gram per cubic centimeter. The density of water in the Judith River Formation at many of the oil and gas test wells is unknown.

In some areas, such as around the Bearpaw Mountains, closely spaced data points indicate more than one hydraulic-head value in the aquifer. Thrust faulting has resulted in the Judith River Formation being repeated two or three times in the subsurface. Thus, a well may penetrate the aquifer more than once, resulting in variations in the altitude of water levels in the same formation. In other areas, the inconsistencies in water levels may be the result of procedures used in conducting drill-stem tests. In some early tests the depth of the pressure-recording device, PRD of equation 1, was not always recorded. If the depth had to be estimated, it could have been in error by several tens of feet. The length of time for recording the final shut-in pressure, $FSIP$ of equation 1, was variable and commonly was not sufficient to allow stabilization of hydrostatic pressure. If the test chart or record of increments of pressure recovery with time was not available, the estimated $FSIP$ probably was too small.

Other factors affecting the hydrologic data produced during a drill-stem test include the thickness and permeability of the tested zone, the makeup of the test tools including length of perforations, and the interference of fluid production by heavy drilling muds and mud cake on the formation wall of the drill hole. The object of the drill-stem test is oil or gas production, not water. Therefore, the best water-producing zones commonly are bypassed, with the result that the hydrologic data are from less permeable zones; however, the data may be all that are available.

At some data sites the altitude of the potentiometric surface may be anomalously high or low. These altitudes may represent reported water levels or may reflect problems in compilation of the drill-stem-test data and application of the data to the hydrology of the aquifer system. The anomalous data are retained to show the location of the data site and to indicate that a different interpretation is possible. In some instances the differences in altitude may indicate a decline in potentiometric surface during a number of years as a result of gas or water production. Isolated data points were not contoured.

GROUND-WATER MOVEMENT AND DISCHARGE

Water in the Judith River Formation occurs under water-table and artesian conditions. The areal distribution of wells is shown on the map. Recharge to the aquifer is mainly from infiltration of precipitation on the outcrops. Smaller amounts of recharge may occur from infiltration of streamflow across the outcrops and from leakage across confining beds. Recharge in the Bearpaw Mountains generally moves north toward the Milk River and recharge in the Little Rocky Mountains area generally moves south toward the Missouri River. As indicated on the map, the general direction of regional water movement in the aquifer is from west to east, the same as the regional dip of the formation. Two areas appear on the map as discharge points for ground water: the reaches of the Milk River from near Havre to Malta and the Missouri River south of the Bearpaw and Little Rocky Mountains. A short reach of the Milk River upstream from Glasgow, where the Judith River Formation crops out, also may be a discharge point.

Vertical leakage from or into the Judith River Formation probably is minimal throughout most of the study area because of the relatively thick sections of shale above and below it. One area that may have a significant vertical-leakage component is around the Bearpaw Mountains, where thrust faulting has resulted in extensive vertical fracturing.

The Judith River Formation yields water to wells in a large part of the study area. The average reported or measured discharge from 236 wells is about 10 gal/min. The discharge ranges from 1 to 100 gal/min, with 16 wells having discharges greater than 20 gal/min. The specific capacity of 186 wells ranges from 0.003 to 21.4 (gal/min)/ft and averages 0.66 (gal/min)/ft.

REFERENCES CITED

Hearn, B. C., Jr., 1976, Geologic and tectonic maps of the Bearpaw Mountains area, north-central Montana: U.S. Geological Survey Miscellaneous Investigations Map I-919, scale 1:125,000.

Levings, G. W., 1981a, Selected drill-stem-test data from the northern Great Plains area of Montana: U.S. Geological Survey Water-Resources Investigations Open-File Report 81-326, 20 p.

———1981b, Selected hydrogeologic data from the northern Great Plains area of Montana: U.S. Geological Survey Open-File Report 81-534, 241 p.

Oil and Gas Conservation Division, 1981, Annual review for the year 1980 relating to oil and gas: Helena, Montana, Montana Department of Natural Resources and Conservation, v. 24, 44 p.

Reeves, Frank, 1925, Geology and possible oil and gas resources of the faulted area south of the Bearpaw Mountains, Montana, Part 2 of Contributions to economic geology: U.S. Geological Survey Bulletin 751-C, p. 71-114.

Roberts, A. E., 1972, Cretaceous and early Tertiary depositional and tectonic history of the Livingston area, southwestern Montana: U.S. Geological Survey Professional Paper 526-C, 120 p.

Ross, C. P., Andrews, D. A., and Witkind, I. J., 1955, Geologic map of Montana: U.S. Geological Survey, scale 1:500,000.

METRIC CONVERSION TABLE

The following factors can be used to convert inch-pound units in this report to the International System (SI) of metric units:

Multiply inch-pound unit	By	To obtain SI unit
foot	0.3048	meter
gallon per minute (gal/min)	0.06309	liter per second
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter
mile	1.609	kilometer
pound per square inch	6.895	kilopascal

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by the following formula:

°F = 1.8°C + 32

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "mean sea level."

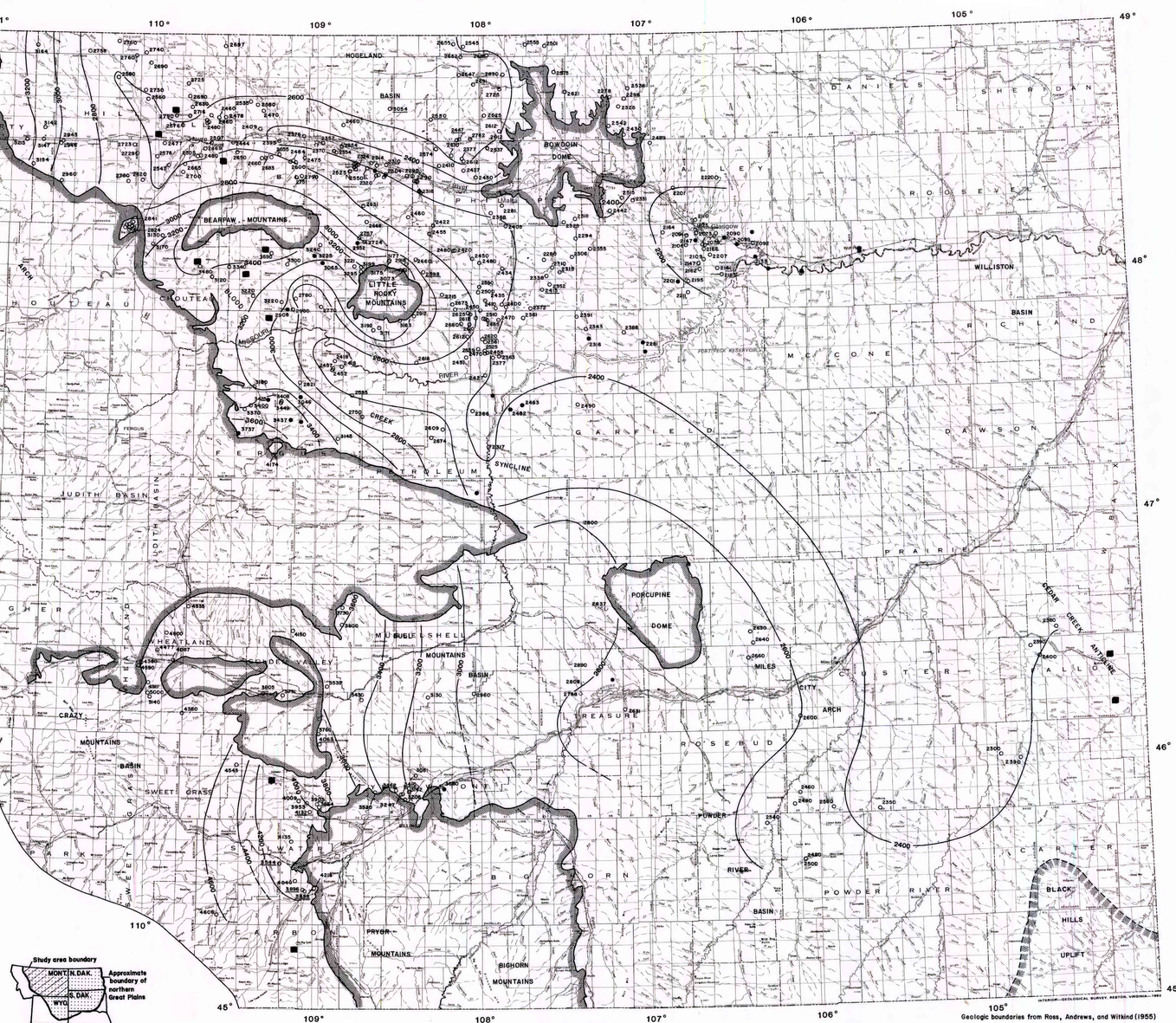
EXPLANATION

CONTACT OF UPPER CRETACEOUS JUDITH RIVER FORMATION AND UNDERLYING UNIT--Dashed where approximately located. Pattern shows underlying unit; pattern width does not indicate true area of outcrop

3000 GENERALIZED POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells completed in the Judith River Formation. Dashed where approximately located. Contour interval 200 feet. National geodetic vertical datum of 1929

O 3370 ● 3737 DATA SITE AND NUMBER--Shows location of water well or oil or gas test well. Number is altitude of water level, in feet above national geodetic vertical datum of 1929. Numbers are omitted in areas where data sites are too closely spaced for clarity or where the altitude of water level is unknown. Solid dot indicates flowing well. Underline indicates anomalous value not used in contouring

GAS FIELD PRODUCING FROM THE JUDITH RIVER FORMATION--Approximately located



POTENTIOMETRIC-SURFACE MAP OF WATER IN THE JUDITH RIVER FORMATION IN THE NORTHERN GREAT PLAINS AREA OF MONTANA

By

Gary W. Levings

1982