POTENTIOMETRIC-SURFACE MAP OF WATER IN THE EAGLE SANDSTONE AND EQUIVALENT UNITS IN THE NORTHERN GREAT PLAINS AREA OF MONTANA

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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 Eagle Sandstone and equivalent units--Virgelle Sandstone and Telegraph Creek Formation. For convenience in this report all three formations are referred to as Eagle Sandstone.

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 measurements of flowing wells. The water-well data range in age from 1936 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 1967 to 1980.

GEOLOGIC SETTING

The Eagle Sandstone (Upper Cretaceous) is composed of alternating beds of gray to buff thin-bedded shale and sandstone that contain two thin coal beds. The thickness of the formation ranges from 0 to 1,200 feet (R. D. Feltis, U.S. Geological Survey, written commun., 1982). In general the unit thickens from west to east, with the thickness in the eastern one-half of the area being more than 600 feet. In the Hogeland basin the thickness is 300 to 500 feet, in the area south of the Bearpaw Mountains it is 400 to 600 feet, in the area southeast of the Little Rocky Mountains it is 300 to 500 feet, in the area west of the Bull Mountains basin it is 600 to 700 feet, in the Crazy Mountains basin it is 500 to 850 feet, and in the Powder River basin-Miles City arch area it is 1,000 to 1,200 feet.

The regional dip of the Eagle Sandstone is toward the east; however, the structural complexity accounts for many localized exceptions. The continuity of the Eagle Sandstone 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 Eagle Sandstone 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 Eagle Sandstone crop out in areas of structural highs such as the Bearpaw, Little Rocky, Pryor, and Bighorn Mountains; Sweetgrass arch; Porcupine dome; and Black Hills uplift. The Colorado Group (Upper Cretaceous), which can be as much as 2,000 feet thick, is a dark-bluish-gray to black marine shale that contains a number of subordinate sandstone beds and underlies the Eagle Sandstone in most of the study area.

Overlying the Eagle Sandstone is the Claggett Shale (Upper Cretaceous), a gray silty marine shale, which may be as much as 400 feet thick. North and south of the Bearpaw Mountains, Tertiary volcanic rocks overlie the Eagle Sandstone and obscure its contact. In the Crazy Mountains basin, the Eagle Sandstone underlies the continental sediments of the Cokedale Formation of the Upper Cretaceous Livingston Group (Roberts, 1972).

POTENTIOMETRIC SURFACE

During 1980, production from 26 gas fields and 1 oil field in Montana (see map) was obtained solely or partly from the Eagle Sandstone (Oil and Gas Conservation Division, 1981). 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 Eagle Sandstone if it contained a homogeneous fluid having a density of 1.00 gram per cubic centimeter. The density of water in the Eagle Sandstone 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 Eagle Sandstone 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 oil or water production. Isolated data points were not contoured.

GROUND-WATER MOVEMENT AND DISCHARGE

Water in the Eagle Sandstone 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 from the Bearpaw Mountains generally moves north toward the Milk River and south toward the Missouri River, and recharge from the Little Rocky Mountains area generally moves south and west 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. In the northwestern corner of the area the movement is from east to west. The principal discharge point for ground water is the Missouri River south of the Bearpaw Mountains.

In the area north of the Bearpaw Mountains, the potentiometric contours appear to indicate aquifer discharge to Big Sandy Creek and the Milk River. However, it is doubtful that vertical leakage is occurring because of the several hundred feet of overlying Claggett Shale. One explanation for the decline in potentiometric surface would be the depressurization of the Eagle Sandstone from gas production.

Vertical leakage from or into the Eagle Sandstone probably is minimal throughout most of the study area because of the relatively thick sections of shale above and below it. One area that has potential for vertical leakage is south of the Bearpaw Mountains, where thrust faulting has resulted in extensive vertical fracturing.

The Eagle Sandstone yields water to wells in a large part of the study area. The average reported or measured discharge from 115 wells is about 23 gal/min. The discharge ranges from 0.5 to 200 gal/min, with 28 wells having discharges greater than 20 gal/min. The specific capacity of 85 wells ranges from 0.006 to 20.3 (gal/min)/ft and averages 1.4 (gal/min)/ft.

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METRIC CONVERSION TABLE

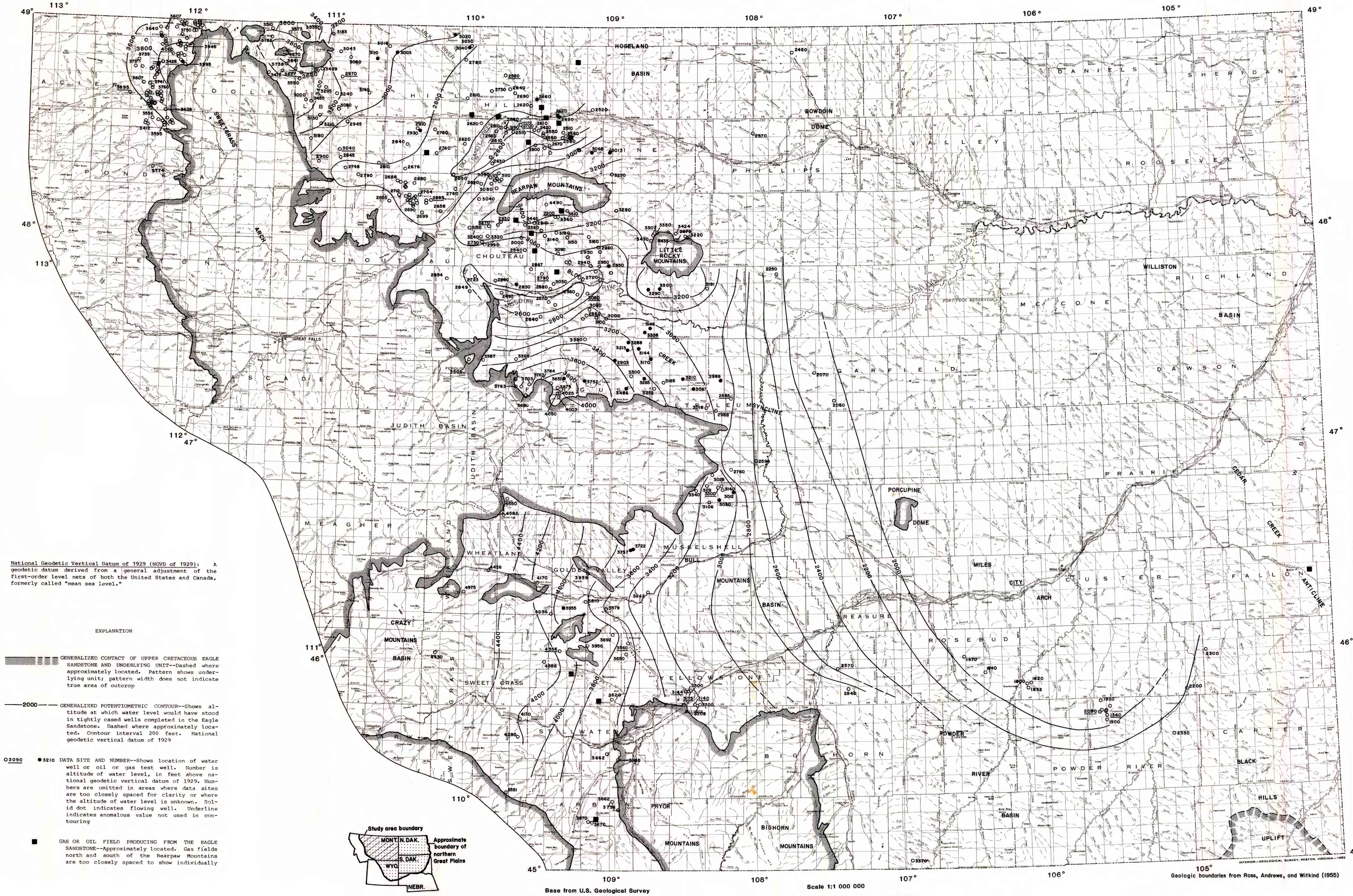
The following factors can be used to convert inch-pound units in this report to the International System (SI) of metric units:

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

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

—2000— — GENERALIZED POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells completed in the Eagle Sandstone. Dashed where approximately located. Contour interval 200 feet. National geodetic vertical datum of 1929

O2090 ●3210 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 OR OIL FIELD PRODUCING FROM THE EAGLE SANDSTONE--Approximately located. Gas fields north and south of the Bearpaw Mountains are too closely spaced to show individually

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