PREPARED IN COOPERATION WITH THE
COLORADO DEPARTMENT OF NATURAL RESOURCES, DIVISION OF WATER RESOURCES,
OFFICE OF THE STATE ENGINEER; THE DENVER BOARD OF WATER COMMISSIONERS;
AND ADAMS AND ARAPAHOE COUNTIES

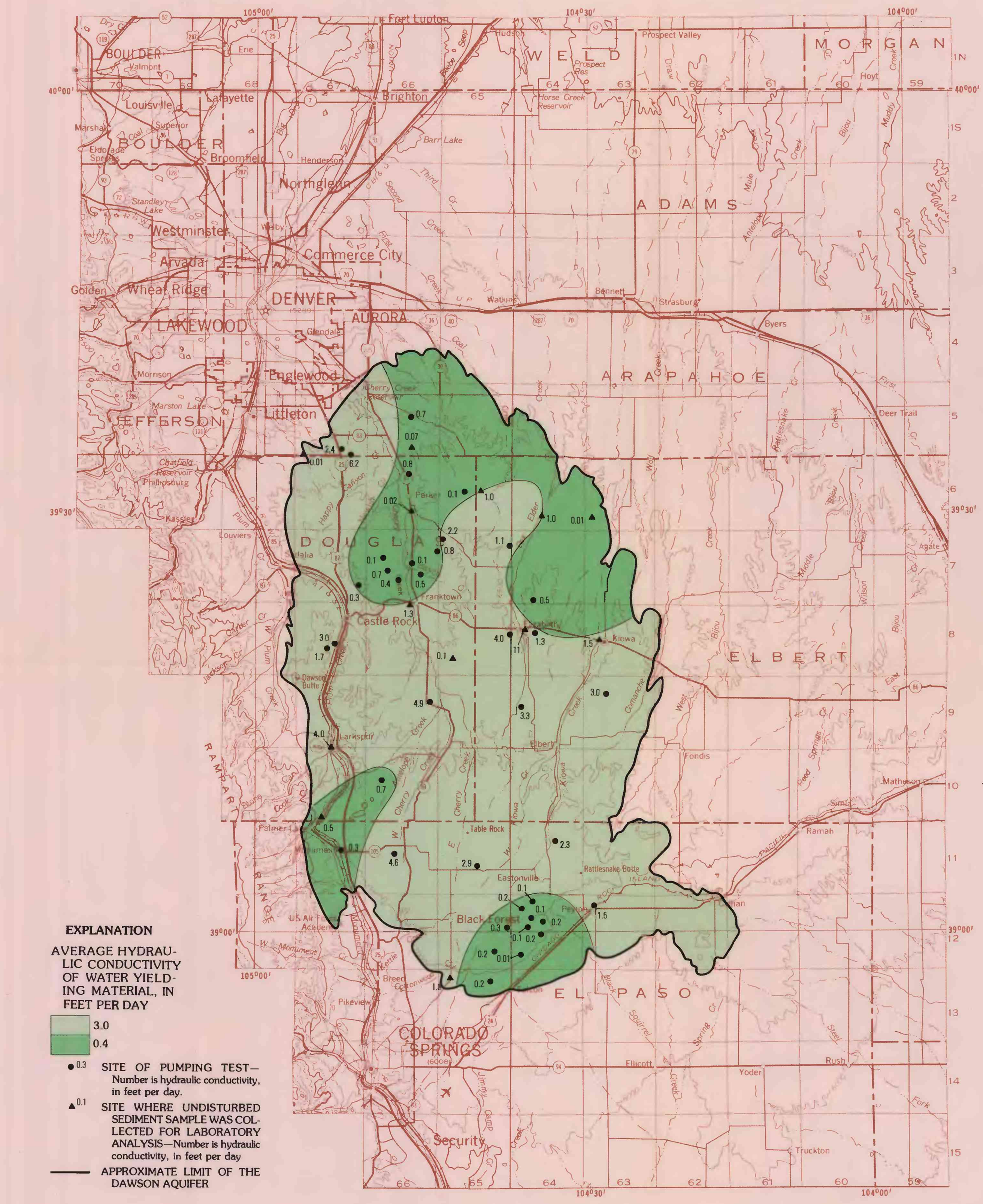

FIGURE 4.—MAP SHOWING HYDRAULIC CONDUCTIVITY OF THE DAWSON AQUIFER

INTRODUCTION

The Denver ground-water basin underlies a 6,700-square-mile area in east-central Colorado, extending from Greely in the north to Colorado Springs in the south and from the Front Range in the west to near Limon in the east (fig. 1). The four principal bedrock aquifers occurring in the basin are the Laramie-Fox Hills aquifer (the deepest aquifer), the Arapahoe aquifer, the Denver aquifer, and the Dawson aquifer. These aquifer are the primary source of water for residents in most of the Denver suburban area and in rural communities and the surrounding farms and ranches.

A continuing increase in population in rural communities and suburban areas near Denver has led to a 73- to 220-percent increase in the number of housing units in suburban counties between 1970 and 1980 (Denver Regional Council of Governments, written communication, 1981) and has produced increasing demands for ground-water supplies. The resulting increase in pumpage has caused water-level declines ranging from 100 to 200 feet in 20 years to occur in parts of the four aquifers near the areas of large demand (Robson and Romero, 1981a, 1981b; Robson, Romero, and Zawistowski, 1981; and Robson, Wacinski, Zawistowski, and Romero, 1981). In an effort to better understand and manage this vital water supply, the Colorado Department of Natural Resources, Division of Water Resources, Office of the State Engineer; the Denver Board of Water Commissioners; and Adams and Arapahoe Counties requested that the U.S. Geological Survey conduct a hydrologic investigation of the bedrock aquifers. Four reports describing the geologic structure, hydrology, and water quality of these aquifer are available (Robson and Romero, 1981a, 1981b; Robson, Romero, and Zawistowski, 1981; and Robson, Wacinski, Zawistowski, and Romero, 1981). This is the fifth report in the series.

The investigation of the hydraulic characteristics of the aquifers involved the compilation and analysis of hundreds of aquifer tests conducted on wells in the basin. This work would not have been possible without the cooperation and assistance of the many knowledgeable hydrologists and engineers employed in private industry who allowed U.S. Geological Survey personnel access to some proprietary aquifer-test records in their files. Those individuals or companies making significant contributions include: Blatchley Associates; Henry A. Baski; Layne-Western Company, Inc.; Leonard Rice Consulting Water Engineers; Water Resources Consultants, Inc.; Willard Owens Assoc., Inc.; William Curtis Wells, Inc.; Willows Water District; Wright-McLaughlin Engineers; W. W. Wheeler and Associates; and Zorich-Erker Engineering, Inc.

In this report the term "aquifer test" is applied to a well-pumping test designed to provide a direct estimate of the hydraulic characteristics of the aquifer. The aquifer tests used in this work commonly were single-well tests conducted for periods of 8 to 24 hours and were analyzed using the Jacob modified nonequilibrium method (Ferris, and others, 1962). The term "specific capacity test" is herein used to refer to a well-pumping test designed to provide an estimate of the specific capacity of the well. These tests were conducted for 1 hour and provide a basis for estimating hydraulic characteristics of the aquifer.

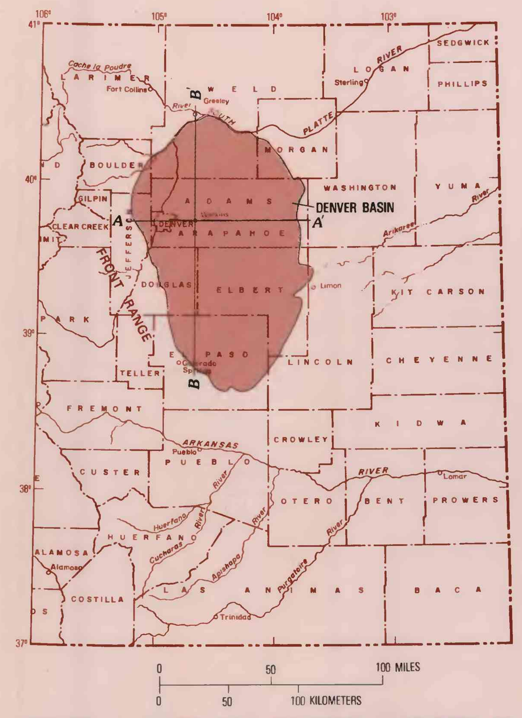

FIGURE 1.—INDEX MAP SHOWING LOCATION OF DENVER BASIN, AND, TRACES OF GENERALIZED GEOLOGIC SECTIONS

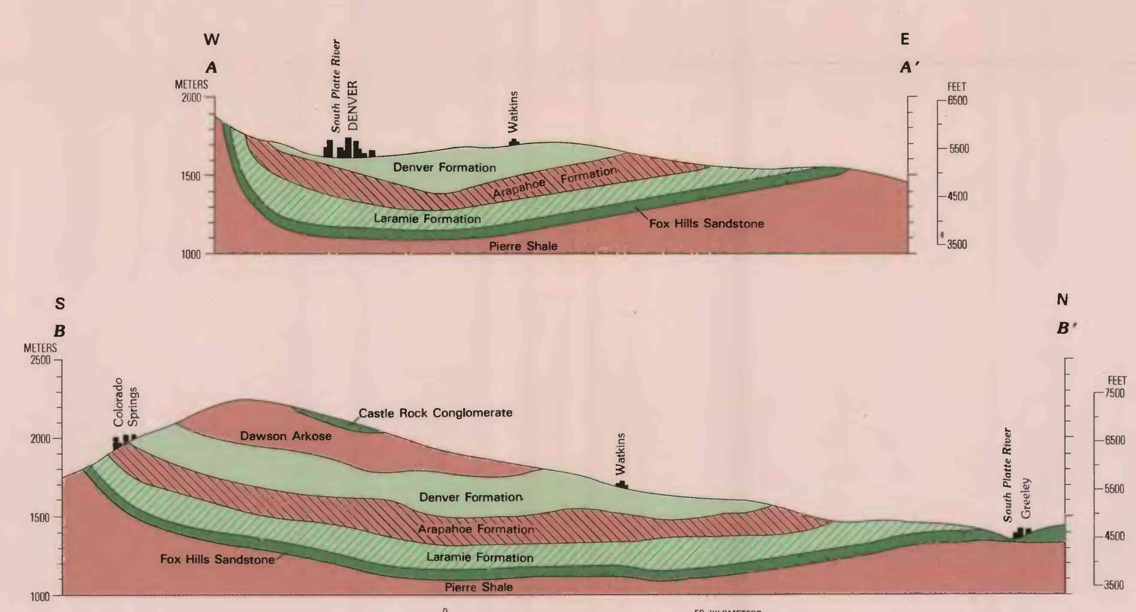

FIGURE 2—GENERALIZED GEOLOGIC SECTIONS THROUGH THE DENVER BASIN
(Trace of sections located on figure 1)

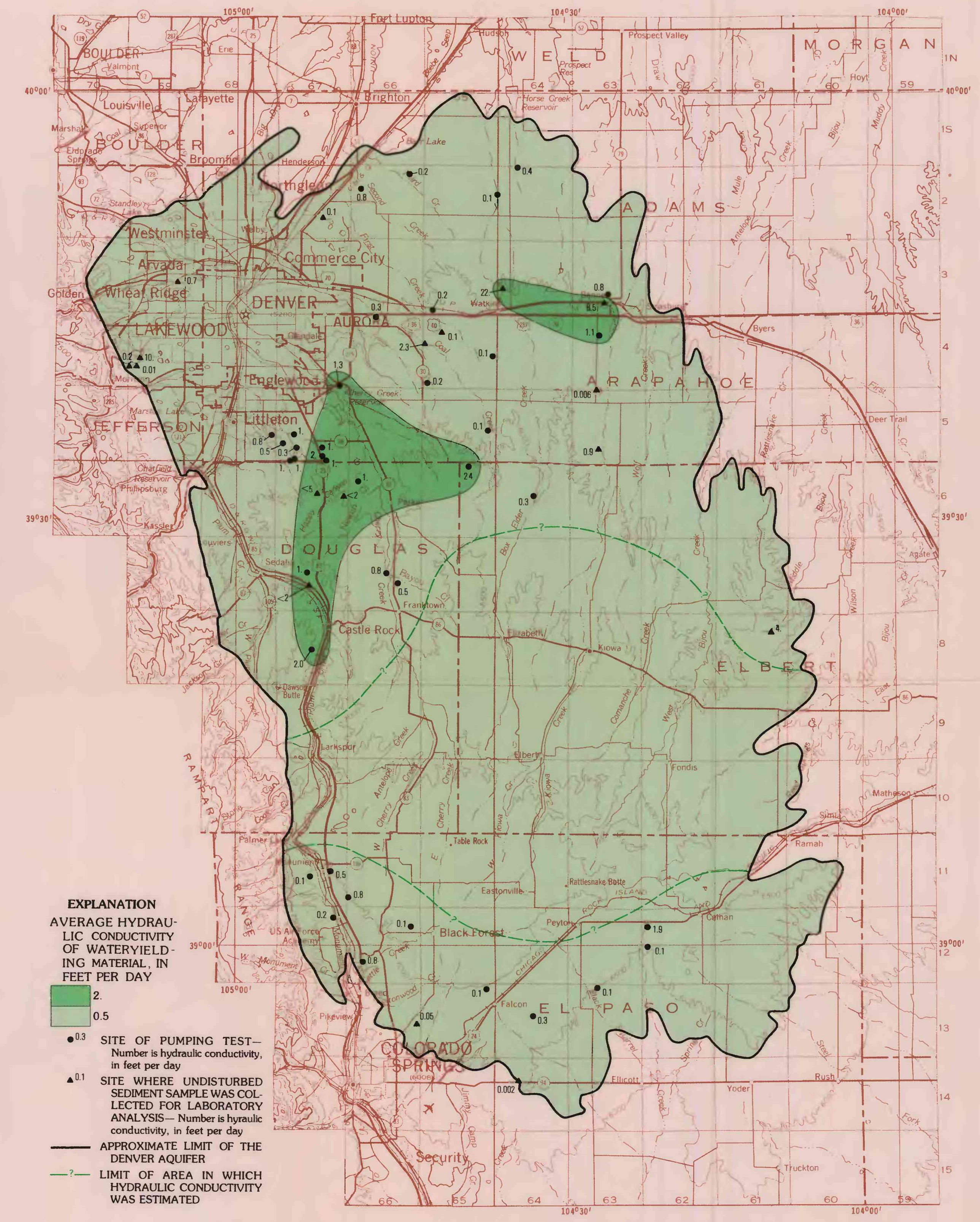

FIGURE 5.—MAP SHOWING HYDRAULIC CONDUCTIVITY OF THE DENVER AQUIFER

GEOLOGIC SETTING

The four principal aquifers occur in the Fox Hills Sandstone, the Laramie Formation, and the Arapahoe Formation of Late Cretaceous age, and in the Denver Formation and Dawson Arkose of Late Cretaceous and early Tertiary age (Romero, 1976). The formations occur in a sequence of layers that form a bowl-shaped basin with low-angle dips along the north, east, and south margins and high-angle dips along the faulted and tectonically altered west margin (fig. 2). The aquifers consist of fine to medium grained, poorly to moderately consolidated, sandstone and conglomerate interbedded with siltstone, claystone, and shale. The sandstone, conglomerate, and siltstone form the principal water-yielding strata and comprise 30 to 60 percent of the material in the aquifers (table 1). The claystone and shale, being relatively impermeable, form confining layers that impede vertical, and in some instances lateral, movement of ground water.

Table 1.—Average distribution of permeable and relatively impermeable strata within the aquifers

Aquifer	Percent sandstone, conglomerate, and silstone strata	Percent claystone and shale strata
Dawson	45	55
Denver	30	70
Arapahoe	40	60
Laramie-Fox Hills	60	40

The sediments that form the Dawson aquifer primarily consist of conglomerate, sandstone, and shale varying from light gray to yellow-brown or pale green in some areas. The conglomerates and sandstones generally are coarse grained, poorly to moderately well consolidated, and occur as lenticular beds ranging in thickness from a few inches to as much as 200 feet. A layer of shale 100 to 250 feet thick commonly separates an upper and lower sequence of conglomerate and sandstone in Arapahoe, Douglas, and Elbert Counties. In the southern part of the aquifer this intervening shale is absent and the conglomerate and sandstone, with minor amounts of shale, form a continuous sequence 400 feet or more thick. Saturated thickness of the Dawson aquifer ranges from zero at the aquifer boundary to as much as 1,100 feet in the area between Castle Rock and Franktown. Total conglomerate and sandstone thickness ranges from zero at the aquifer boundary to more than 400 feet in southeastern Douglas County.

The Denver aquifer consists of a 600- to 1,000-foot thick series of interbedded shale, claystone, siltstone, and sandstone. The siltstone and sandstone occur in poorly defined irregular beds that are dispersed within relatively thick sequences of claystone and shale. Individual siltstone and sandstone beds commonly are lenticular and range in thickness from a few inches to as much as 50 feet. Total siltstone and sandstone thickness ranges from zero at the aquifer boundary to as much as 350 feet near Larkspur. Distinguishing characteristics of the aquifer are its olive, green-gray, brown, and tan colors; the presence of coal; and a preponderance of shale and claystone with respect to other rock types.

The Arapahoe aquifer consists of a 400- to 700-foot thick series of interbedded conglomerate, sandstone, siltstone, and shale. Conglomerate and sandstone beds commonly are lenticular, moderately consolidated, and range in thickness from a few inches to 40 feet. These beds may be so closely spaced that they from a single hydrologic unit that is 200 to 300 feet thick in some areas. Total conglomerate and sandstone thickness ranges from zero at the aquifer boundary to more than 400 feet in an area southeast of Castle Rock. In some areas the aquifer can be divided into an upper and lower part. The upper part consists of 200 to 300 feet of shale containing some conglomerate and sandstone beds. The lower part consists of 200 to 300 feet of sandstone and conglomerate and contains less prevalent beds of shale. The sediments normally are light to medium gray with local very light-gray and grayish-green beds grading to darker colors in the upper 100 to 200 feet of the aquifer near the overlying Denver Formation.

The Laramie-Fox Hills aquifer occurs in the lower sandstone and shale units of the Laramie Formation and the upper sandstone and siltstone units of the underlying Fox Hills Sandstone. The thickness of the aquifer ranges from zero at the aquifer boundary to between 200 and 300 feet in the central part of the basin. Total sandstone and siltstone thickness of 150 feet is common, with thickness of as much as 250 feet occurring in a few isolated areas. The part of the Laramie-Fox Hills aquifer within the Fox Hills Sandstone generally is 150 to 200 feet thick and is composed of an overlying bed of very fine-grained silty sandstone 40 to 50 feet thick underlain by 100 to 150 feet of shaley siltstone and interbedded shale. The part of the Laramie-Fox Hills aquifer within the Laramie Formation generally is 50 to 100 feet thick and is composed of fine- to medium-grained sandstone separated into an upper and lower member by shale beds 10 to 20 feet thick. A shale bed 5 to 20 feet thick commonly separates the Laramie part of the aquifer from the Fox Hills part.

The 400 to 500 feet of Laramie Formation overlying the Laramie-Fox Hills aquifer consists of gray through black shale, coal seams, and minor gray siltstone and sandstone beds. The subbituminous to lignitic coal seams range in thickness from a few inches to 10 feet and are present in several stratigraphic horizons. The Pierre Shale underlies the Laramie-Fox Hills aquifer and consists of 5,000 to 8,000 feet of shale and minor siltstone and sandstone beds. The upper part of the Laramie Formation and the Pierre Shale form relatively impermeable boundaries above and below the Laramie-Fox Hills aquifer.

HYDRAULIC CONDUCTIVITY AND TRANSMISSIVITY

Results of aquifer tests on about 200 wells were compiled from the files of the U.S. Geological Survey and private consultants in the area. Some of the aquifer tests were conducted using less than optimum techniques and the results are less accurate than results of the more carefully controlled tests. Because the accuracy of the tests could not always be determined, the transmissivity, hydraulic conductivity, and specific capacity data derived from these tests represent reasonable estimates of these characteristics rather than exact measurements.

Some of the wells used for aquifer testing were not perforated through the full saturated thickness of the aquifer or were perforated in more than one aquifer. In order to make maximum use of these data, the transmissivity values determined from the aquifer test were converted to hydraulic conductivity and these values were assumed to be representative of the average hydraulic conductivity of the water-yielding materials in the aquifer. For some wells completed in two aquifers, the average hydraulic conductivity in the well was proportionally divided into components attributable to each aquifer, on the basis of the thickness of each aquifer open to the well and available hydraulic-conductivity data for one of the aquifers.

Because wells with aquifer tests were located primarily in the more densely populated western part of the basin, it was necessary to obtain additional data from wells in the more rural northern, eastern, and southern parts of the basin. This was done by conducting specific-capacity test on wells in these areas. A statistical analysis of the relation between transmissivity and specific capacity indicated that a high degree of correlation ($r = 0.93$) existed betweeen the transmissivity calculated from an aquifer test and the specific capacity calculated at the end of the first hour of pumping. The correlation was found to be less when specific capacity was calculated at times less than 1 hour and was only slightly greater when specific capacity was calculated at times greater than 1 hour. The empirical relation between the 1-hour specific capacity and transmissivity shown in figure 3 was developed from data from about 150 aquifer tests. This relation was used to convert the specific capacities measured in about 110 wells in the rural areas of the basin to estimates of the transmissivity of the aquifers. The empirical relation departs from the theoretical relation between transmissivity and specific capacity (Lohman, 1972) due to effects of well-bore storage and other factors not considered in the theoretical relation.

In an effort to provide additional data in the rural areas, undisturbed samples of permeable bedrock materials were collected from outcrops and excavations and submitted for laboratory determination of hydraulic conductivity, porosity, specific retention, and grain-size distribution. Results of these analyses (table 2) plus records available from the laboratory analysis of other surface samples and drill cores (McConaghy and others, 1964; Major and others, 1982), provided an additional 100 hydraulic-conductivity determinations.

These data were used to map the distribution of average hydraulic conductivity in each of the bedrock aquifers in the basin as shown in figures 4, 5, 6, and 7. The average hydraulic-conductivity values shown in these figures were computed by delineating areas having data of a similar magnitude and computing a weighted average of the data in each area. The averages were weighted to allow data of greater reliability to more strongly affect the average. Where data from analysis of surface samples were not in good agreement with pumping-test results, as occurred near the eastern margin of the Laramie-Fox Hills aquifer, the weighted-average hydraulic conductivity was more strongly affected by the better quality pumping-test results. The average hydraulic conductivity of water-yielding material was found to range from 0.05 foot per day in the northwestern part of the Laramie-Fox Hills aquifer to as much as 7 feet per day in the Arapahoe aquifer near Littleton. The variations in average hydraulic conductivity are due to differences in grain size, sorting, and degree of induration of the water-yielding materials. The distrubution of data points is adequate to provide definition in all but the central parts of the Denver, Arapahoe, and Laramie-Fox Hills aquifers. In these areas pumping-test data are unavailable, in most instances, because the aquifers occur at depths below those reached by most water wells. Hydraulic conductivity in these areas was estimated to be similar to that in surrounding areas.

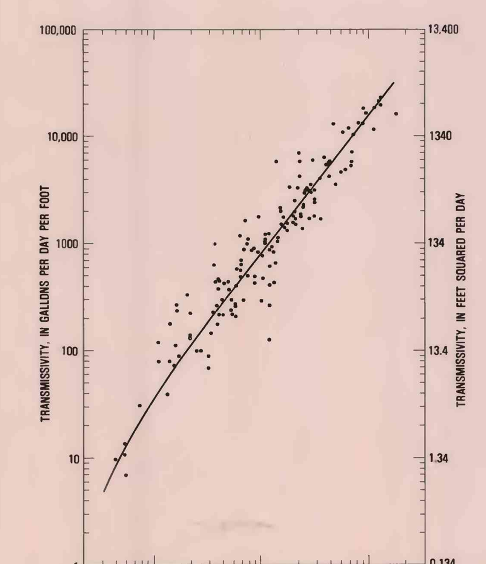

FIGURE 3.—GRAPH SHOWING RELATION OF 1-HOUR SPECIFIC CAPACITY TO TRANS MISSIVITY

METRIC CONVERSION FACTORS

The inch-pound units used in this report may be converted to SI (International System) metric units by the following conversion factors:

Multiply	By	To obtain
inch	25.40	millimeter
foot	0.3048	meter
mile	1.609	kilometer
square mile	2.590	square kilometer
gallon per minute	6.309×10^{-5}	cubic meters per second
gallon per minute per foot	2.07×10^{-4}	cubic meters per second per meter
foot per day	0.3048	meter per day
foot squared per day	0.0929	meter squared per day
$foot^{-1}$	3.281	$per\ meter^{(-1)}$
inch squared per pound	1.45×10^{-4}	meter squared per Newton
pound per cubic inch	2.71×10^{-5}	Newton per cubic meter
gallon per day per foot	0.0124	meter squared per day

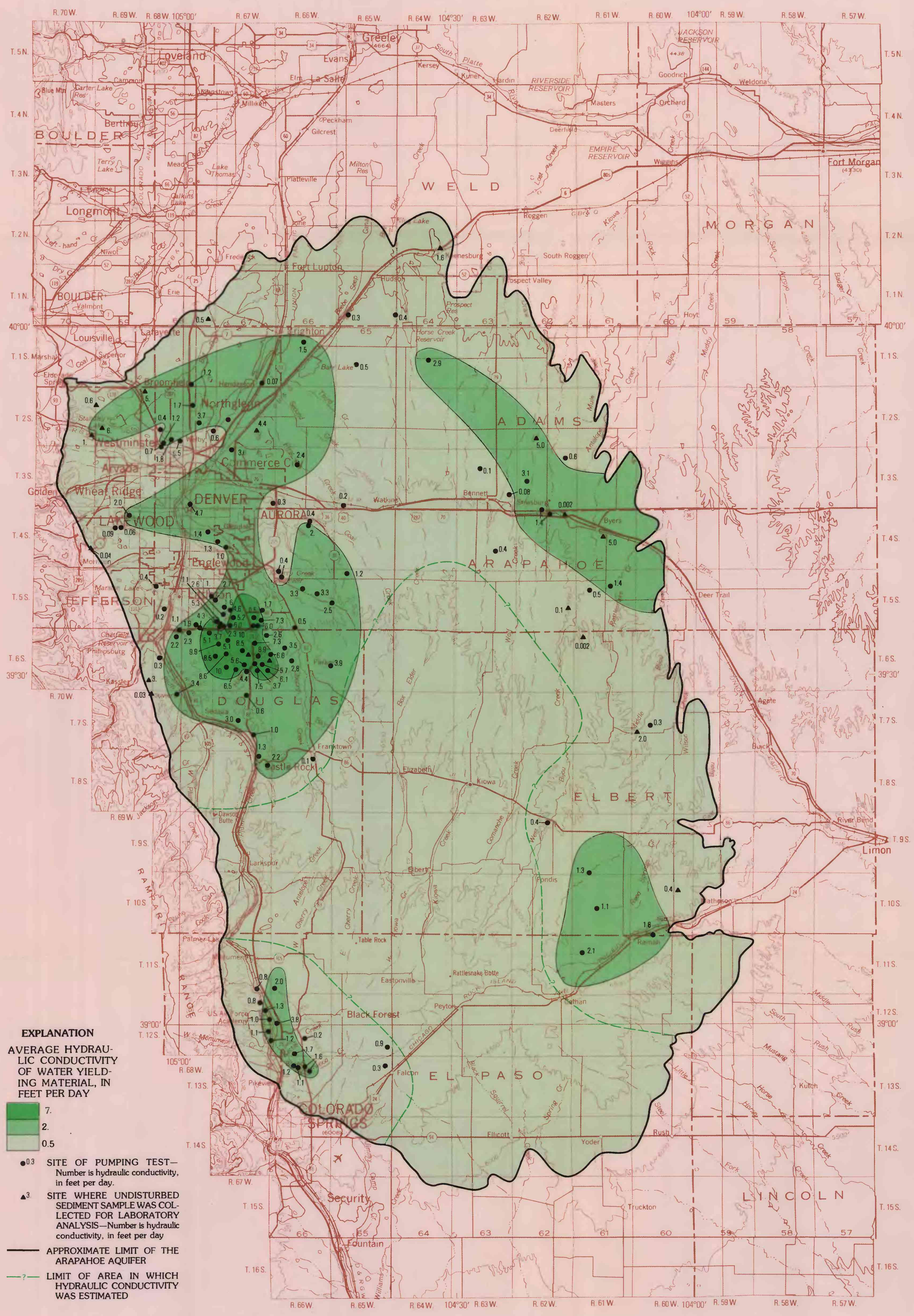

FIGURE 6.—MAP SHOWING HYDRAULIC CONDUCTIVITY OF THE ARAPHAOE AQUIFER

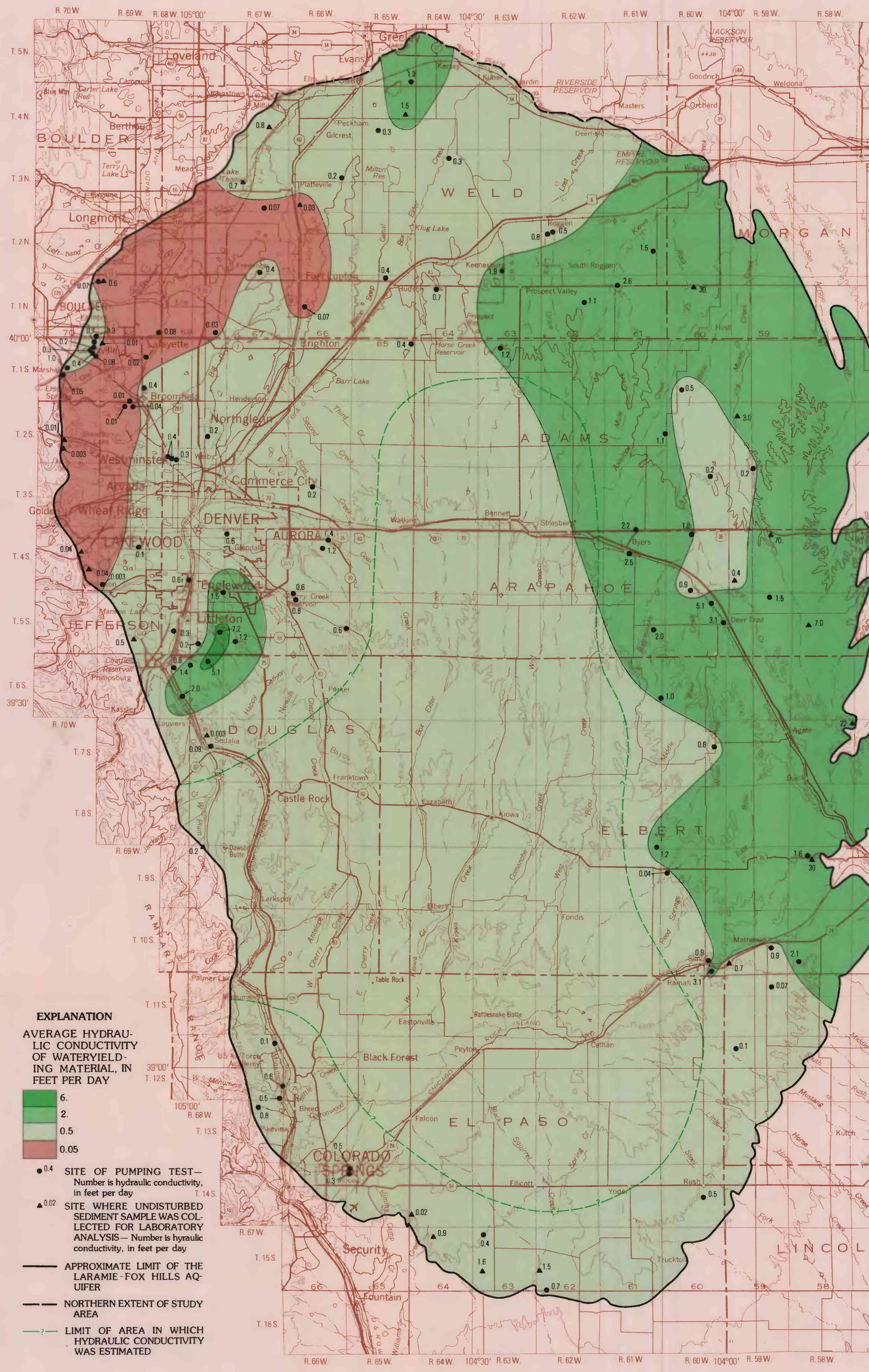

FIGURE 7.—MAP SHOWING HYDRAULIC CONDUCTIVITY OF THE LARAMIE-FOX HILLS AQUIFER

Base from U.S. Geological Survey 1:500 000 State base map

SCALE 1:500 000
10 0 10 20 30 40 50 MILES
10 0 10 20 30 40 50 KILOMETERS
CONTOUR INTERVAL 500 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

HYDRAULIC CHARACTERISTICS OF THE PRINCIPAL BEDROCK AQUIFERS IN THE DENVER BASIN, COLORADO

By
S. G. Robson
1983

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