Ground-Water Geology of Kordofan Province, Sudan

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1757-J

Prepared in cooperation with the Geological Survey Department of Sudan under the auspices of the U.S. Agency for International Development

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By HARRY G. RODIS, ABDULLA HASSAN *and* LUTFI WAHADAN

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By Harry G. Rodis, Abdulla Hassan, and Lutfi Wahadan

ABSTRACT

For much of Kordofan Province, surface-water supplies collected and stored in hafirs, fulas, and tebeldi trees are almost completely appropriated for present needs, and water from wells must serve as the base for future economic and cultural development. This report describes the results of a reconnaissance hydrogeologic investigation of the Province and the nature and distribution of the ground-water resources with respect to their availability for development.

Kordofan Province, in central Sudan, lies within the White Nile–Nile River drainage basin. The land surface is largely a plain of low relief; jebels (hills) occur sporadically, and sandy soils are common in most areas except in the south where clayey soils predominate. Seasonal rainfall, ranging from less than 100 millimeters in the north to about 800 millimeters in the south, occurs almost entirely during the summer months, but little runoff ever reaches the Nile or White Nile Rivers.

The rocks beneath the surficial deposits (Pleistocene to Recent) in the Province comprise the basement complex (Precambrian), Nawa Series (upper Paleozoic), Nubian Series (Mesozoic), laterite (lower to middle Tertiary), and the Umm Ruwaba Series (Pliocene to Pleistocene).

Perennial ground-water supplies in the Province are found chiefly in five hydrologic units, each having distinct geologic or hydrologic characteristics. These units occur in Nubian or Umm Ruwaba strata or both, and the sandstone and conglomerate beds form the principal aquifers. The water is generally under slight artesian head, and the upper surface of the zone of saturation ranges from about 50 meters to 160 meters below land surface. The surficial deposits and basement rocks are generally poor sources of ground water in most of the Province. Supplies from such sources are commonly temporary and may dissipate entirely during the dry season. Locally, however, perennial supplies are obtained from the surficial deposits and from the basement rocks.

Generally, water from Nubian aquifers is satisfactory for most uses and is of better quality than that obtained from Umm Ruwaba aquifers. The relatively high mineralization of water from the Umm Ruwaba, especially in the eastern part of the Province, makes the water unsuitable for many municipal and industrial uses. The water is generally usable, however, for domestic and livestock purposes.

Some 175 drilled wells located at 75 water yards yield an average of about 1,000 imperial gallons per hour per well from Nubian or Umm Ruwaba aquifers. Generally the water yards provide sufficient water for minimum domestic and livestock requirements throughout the year. Commonly, however, the water yards are widely separated and, hence, not always properly spaced for good range management or for serving the needs of the dispersed rural population.

In 1962, withdrawals from Nubian and Umm Ruwaba aquifers in the Province were approximately 600 million gallons annually. This rate of draft could probably be continued almost indefinitely without significant depletion of the water supply. Nubian and Umm Ruwaba aquifers in the southwestern part of Kordofan offer excellent potential for future development. Nubian aquifers in northern Kordofan need extensive exploration by test drilling before their economic potential can be properly evaluated.

INTRODUCTION

The economic and institutional development of Kordofan Province and the settlement of migrant peoples depend very largely upon the availability of adequate ground-water supplies. Except in the extreme southern part of the Province, surface-water supplies collected and stored during and shortly after the rainy season are not generally adequate to meet the perennial needs of a growing population. As available surface-water supplies are now almost completely appropriated, a knowledge of the availability of ground-water resources must serve as a base for planning the future development of the Province.

This report describes the results of an investigation to determine the occurrence, availability, and quality of ground water in Kordofan Province and is based on analyses of antecedent hydrologic and geologic data and on new data collected during field reconnaissance from October 1961 to March 1962 and in January 1963. This is the final and most comprehensive of three progress reports that describe ground-water conditions in the Province (Rodis and Iskander, 1963; Rodis and others, 1963). The purposes of the report are to provide the basic information needed for planning proper development and management of the ground-water resources and to present this information for the general interest of the scientific and technical community.

The investigation in Kordofan Province was part of an expanded program of the Geological Survey Department of Sudan to evaluate and explore the ground-water resources of the country. The program was under the general supervision of Sayed Ahmed Rida Fareed and Sayed Ahmed Khir, successive Ministers of Mineral Resources, and under the immediate direction of Sayed Mahmoud Ahmed Abdulla, Director, Geological Survey Department of Sudan. Technical assistance to the program was provided by Harry G. Rodis, U.S. Geological Survey, who was deputed to the Geological Survey Department under the auspices of the U.S. Agency for International Development.

Although ground-water studies of local problems have been carried out in Kordofan Province since 1905, it was not until the 1930's that the first reports describing the regional occurrence of ground water in the Province were published. As part of a report on the water resources of Sudan, Grabham (1934) described the general occurrence of ground water. Sandford (1935) described ground-water conditions in the desert and semidesert areas of northwestern Sudan that included part of northern Kordofan Province. A more detailed report of the geology of Sudan by Andrew (1948) includes a description of the water-bearing characteristics of various rock units in the Province. Open-file geologic reports, some containing hydrologic data, have also been prepared by Andrew (1950), Auden (1954), Delaney (1950, 1951), Karkanis (1950, 1952), and Kleinsorge and Zscheked (1958). Generally, these reports contain information on local ground-water problems. Special phases of the geology and occurrence of ground water are discussed by Barbour (1961). The first report that was devoted exclusively to the relationship of geology to the occurrence of ground water in Kordofan Province was written by Mansour (1961).

A plan for a provincewide ground-water investigation was first submitted by Waite (1955). Most of his recommendations have been carried out in the form of this investigation.

The authors wish to thank the many persons who contributed information and assistance during the field investigation and preparation of this report. Appreciation is expressed to the many Rural Council executive officers and officials, town and water-yard clerks, sheikhs, umdas, and well diggers who helped the work by providing geologic and hydrologic data on wells. The willing cooperation of A. Mansour, W. Iskander, O. Mohamed, A. Samuel, and M. Ibrahim in contributing information from unpublished 90- by 60-minute geologic maps is greatly appreciated. We also wish to thank Mutasim Hussein, a surveyor from the Survey Department, who assisted throughout the investigation in the collection and tabulation of various field data. Special mention is made of the late George Yanni Karkanis, who, through his long acquaintance with the geologic and hydrologic problems of Sudan, offered many helpful suggestions to the authors and gave specific data on wells that greatly facilitated the work.

Conversion of metric and English units.—The Geological Survey Department as well as other governmental, scientific, and technical agencies in Sudan were in the process of converting from the English system of measurement to the metric system during 1962. Until such time as this change is fully effected, the Geological Survey Department will use, where possible, both units side by side: the metric measurement first, followed by the English equivalent in parenthesis. For illustrations accompanying this report, the horizontal and vertical scales are given in both units. Numerical equivalents or factors for converting from one unit to the other are given in the headnotes of tables 2 and 3 of this report and also in the Sudan Almanac (Republic of the Sudan, 1963).

GEOGRAPHIC AND CULTURAL FEATURES

LOCATION AND EXTENT

Kordofan Province is in central Sudan, about 900 kilometers or 560 miles west of the Red Sea, between lat. 16°40′ and 9°20′ N. and long. 26°50′ and 32°20′ W. (fig. 1). The Province comprises an area of ap-

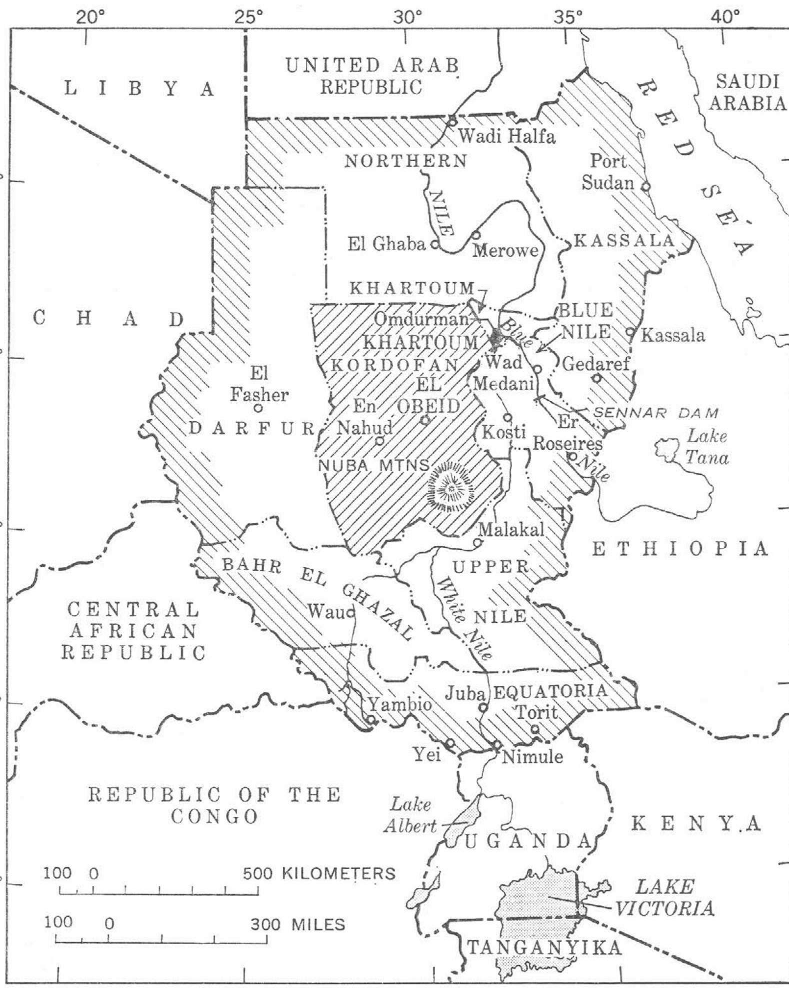

FIGURE 1.—Location of Kordofan Province.

proximately 380,546 square kilometers (146,890 square miles), and its boundaries adjoin all the provinces in Sudan except Equatoria and Kassala. Its maximum extent from north to south is about 800 kilometers (497 miles) and about 580 kilometers (361 miles) from east to west. El Obeid, which is 380 kilometers (236 miles) southwest of Khartoum near the center of the Province, is the principal city and provincial capital.

ECONOMIC DEVELOPMENT

Kordofan Province has a population of 1,762,000 (1960 estimate), or about 4.5 people per square kilometer (11.5 per square mile). Less than 10 percent are permanently settled in towns and villages, but the rest are nomads who migrate seasonally in search of water and pasture for their herds.

The economy of the Province is predominantly pastoral, but dry-farming also provides a significant portion of the provincial income. The grasslands in the central region support extensive herds of camels, cattle, sheep, and goats, many of which are exported. Durra, peanuts, sesame, cotton, and gum arabic are the principal agricultural products, also grown or collected chiefly for export. A variety of other grains, vegetables, and fruits are grown for local consumption. Also, the Province is rapidly becoming the main source of vegetable oil in Sudan. Virtually all crops are grown by dryfarming methods, and irrigation is practiced only locally, primarily for the cultivation of fruits and garden vegetables.

TOPOGRAPHY AND DRAINAGE

The land surface of Kordofan Province is largely a plain of low relief, broken occasionally by a lone protruding jebel (isolated hill or inselberg) or by small clusters of jebels. The only extensive area of marked relief is the Nuba Mountains, where numerous jebels rise high above the surrounding plains (fig. 1). The altitude of the surface over most of the Province ranges between 350 meters (1,150 ft) and 595 meters (1,950 ft) above mean sea level. Jebel Temading in the Nuba Mountains has an altitude of more than 1,400 meters (4,593 ft) above mean sea level and is the highest point in the Province.

Most of the Province lies within the drainage basin of the White Nile River, but the northernmost part of the Province drains to the main stem of the Nile River (fig. 2*A*), generally between the third and fourth cataracts. Except for several small spring-fed streams in the Nuba Mountains, all watercourses (wadis and khors) are ephemeral and carry runoff only during the rainy season. Comparatively little runoff, however, reaches the Nile, the White Nile, or their

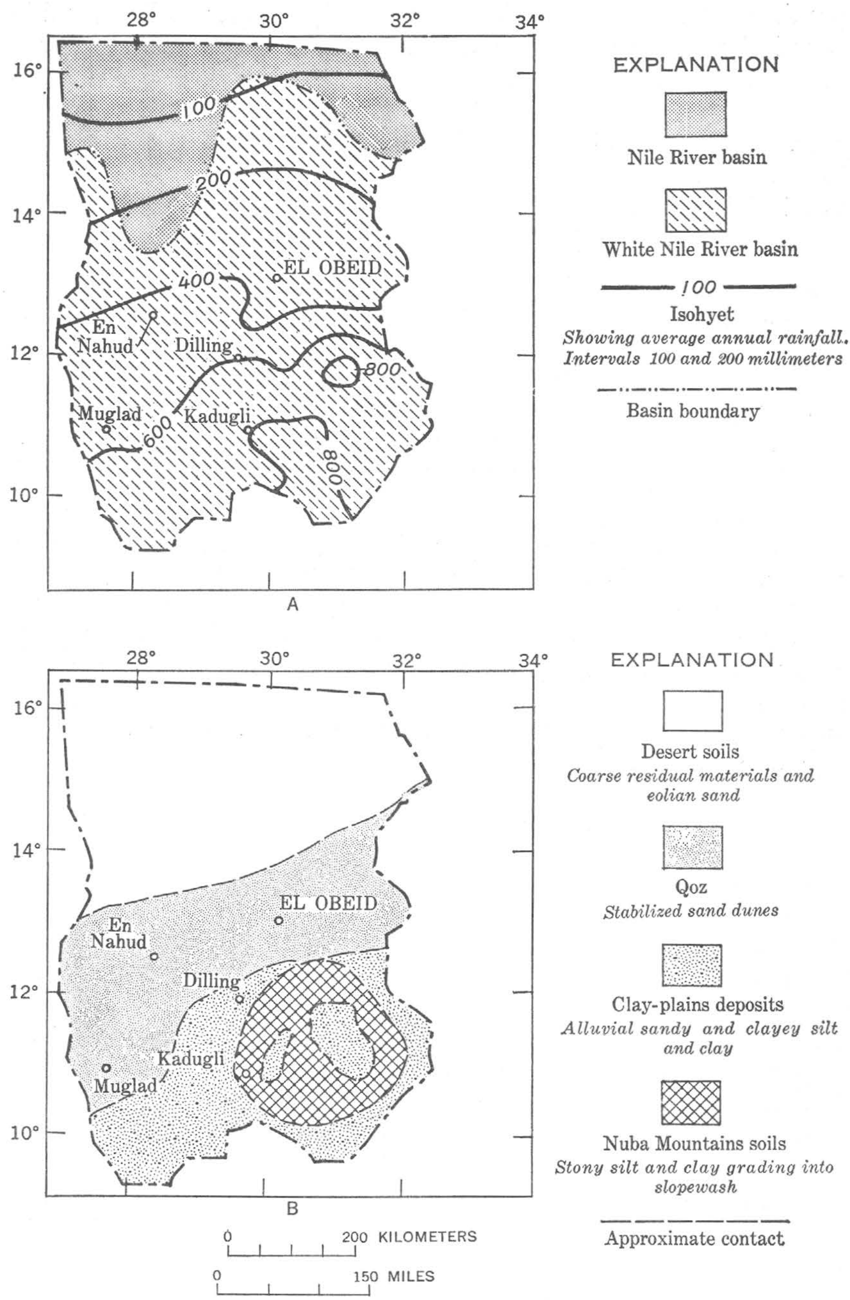

FIGURE 2.—*A*, Mean annual rainfall (1921–60). *B*, General distribution of surficial deposits.

perennial tributaries, as surface flow is largely dissipated by evaporation or by infiltration to the ground. Locally, and more commonly in the southern part of the Province, some runoff is stored in hafirs (excavated ponds) for dry season use. These structures are usually located in topographic lows where, through systems of interconnected shallow ditches, runoff can be easily diverted from natural wadis or khors.

SOIL COVER AND VEGETATION

The soil cover in Kordofan shown in figure 2*B* corresponds closely to the distribution of the surficial deposits and consists mainly of four contrasting soil types. Desert soils consist chiefly of coarse detritus derived from prolonged weathering of the underlying bedrock as well as some active sand dunes that cover most of the northern third of the Province. Qoz sand soils, mostly in stabilized sand dunes and locally veneered by silt or clay, extend in a broad belt across most of the central region. Clayey and silty soils, commonly referred to in Sudan as clay-plains or cotton soils cover most of the southern part of the Province. In the Nuba Mountains area the soil mantle consists of clay and silt in the low tracts and grades into coarse slope wash on the flanks of the jebels.

The natural vegetation ranges from a sparse growth of drought-resistant grasses and dwarf scrub in the arid north through a belt of open woods and grassland in the semiarid central region to open forest in the well-watered south. Trees most common in the Province belong to numerous species of the genus *Acacia;* also the tebeldi (baobob) tree is common in the central and southern parts.

CLIMATE

According to Koppen's (1931) classification of climates, Kordofan contains three climatic belts which correspond to three major east-west zones in the sub-Saharan region of Africa where the amount of rainfall and the duration of the rainy season increase toward the equator. The northern part of the Province is a low-latitude desert which merges southward into a belt of tropical steppe. Still farther south is a belt of tropical savanna. The mean annual rainfall, as shown in figure 2*A*, generally ranges from 100 mm (millimeters), or 4 inches (in.), in the north to about 800 mm (31 in.) in the south. Rain generally falls in high intensity storms of short duration between July and September in the north and between April and October in the south. Figure 3 shows graphically the average monthly rainfall of En Nahud and El Obeid in the central steppe belt compared with that of Muglad, Kadugli, and Dilling in the savanna belt, where the average monthly

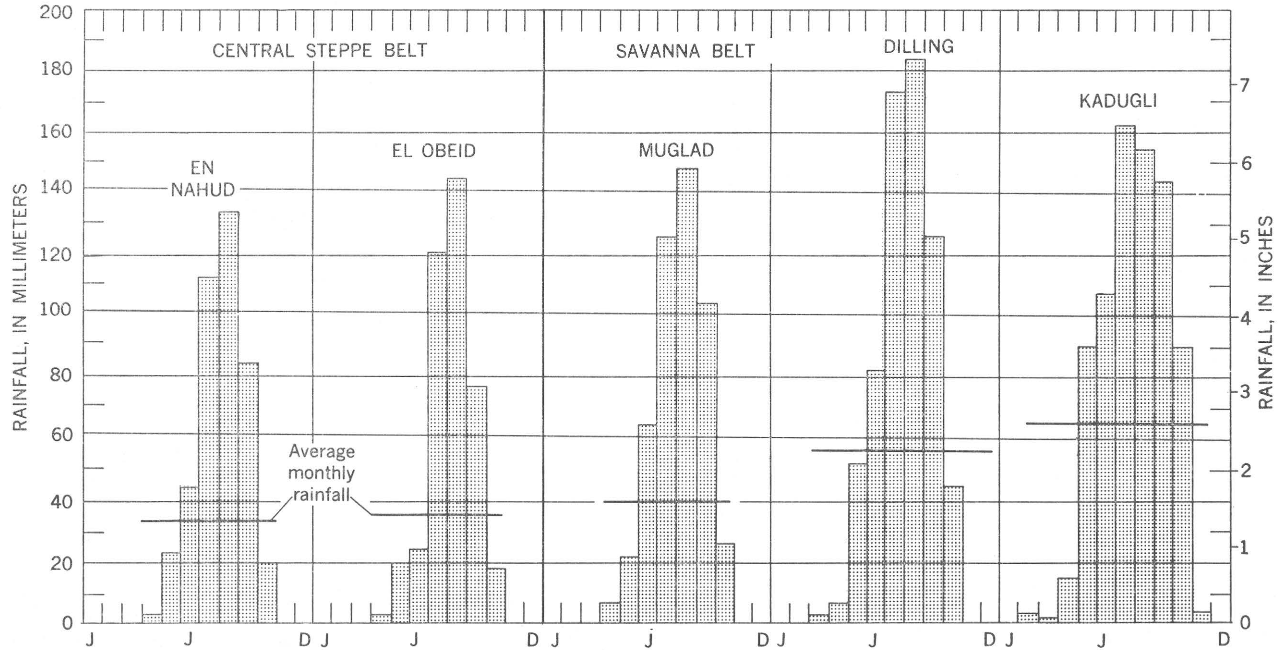

FIGURE 3.—Average monthly rainfall (1930–60) in principal towns.

rainfall is higher and the rainy season longer than in the desert to the north.

The mean annual air temperature for the province is 27°C (80°F), and temperature extremes of 10°C (50°F) and 46°C (115°F) are common to most areas. The mean relative humidity averages about 21 percent in the dry season and 75 percent during the rainy season.

The prevailing winds in the winter are from the north, but during the rainy season they are from the southwest. Wind velocities are usually less than 8 kilometers per hour (5 miles per hr) and frequent calms are not uncommon.

DEFINITIONS OF HYDROLOGIC TERMS

The definitions that follow are of terms used in ground-water reports; a few of the terms are redefined later in the report to clarify the context in which they are used.

Aquifer.—Permeable water-bearing bed, stratum, or group of strata capable of yielding water to wells.

Artesian pressure.—Essentially the same as hydrostatic pressure. (See "Head.")

Confined ground water.—Ground water that is under sufficient pressure to rise above the level at which it is first found in drilling a well, but which does not necessarily rise above the surface of the ground.

Fula.—Most commonly a natural lake or pond located in a topographic low.

Hafir.—Excavated pond used for storing runoff.

Head (pressure head).—"Hydrostatic pressure expressed as the height of a column of water that can be supported by the pressure" (Meinzer, 1923) and generally expressed in meters or feet above or below mean sea level.

Hydraulic gradient.—As applied to an aquifer it is the rate of change of pressure head per unit of distance of flow at a given point and in a given direction (Meinzer, 1923).

Hydrostatic pressure. (See "Head.")

Impermeable.—Not permeable. (See "Permeability.")

Isochlor.—An imaginary line along which the concentration of chloride in water is equal.

Permeability.—The rate per unit cross section at which a water-bearing material can transmit water under pressure.

Piezometric surface.—" * * * an imaginary surface that everywhere coincides with the static level of the water in the aquifer. It is the surface to which the water from a given aquifer will rise under its full head." (Meinzer, 1923, p. 38.)

Porosity.—" * * * the ratio of the aggregate volume of interstices in a rock or soil to its total volume." Usually stated as a percentage (Meinzer, 1923, p. 19).

Salinity.—The concentration of dissolved solids in parts per million. Sometimes used to express qualitatively the relative concentration of dissolved salts in water.

Specific capacity.—The rate of yield of a well per unit of drawdown, generally in liters per second per meter of drawdown or gallons per minute per foot of drawdown.

Water table.—" * * * upper surface of a zone of saturation except where that surface is formed by an impermeable body." (Meinzer, 1923, p. 22.)

Zone of saturation.—Zone in which the functional rock interstices are filled with water under hydrostatic pressure (Meinzer, 1923).

GEOLOGY

SUMMARY OF STRATIGRAPHY AND GEOLOGIC HISTORY

The rock formations that unlerlie Kordofan Province include the basement complex of Precambrian age, the Nawa Series of late Paleozoic age, the Nubian Series of Mesozoic age, laterite of early to middle Tertiary age, the Umm Ruwaba Series of Pliocene to Pleistocene age, and surficial deposits of Quaternary age. These rocks are described sedimentary rock units are shown in the geologic map on plate 1, and the distribution of surficial deposits is shown in figure 2*B*.

The oldest rocks in the region that now constitute the basement complex were formed in Precambrian time. Following the emplacement of these rocks the region was subjected to a period of prolonged erosion that apparently lasted through most of Paleozoic time. Shallow seas invaded parts of the region in the late Paleozoic and deposited the sediments of the Nawa Series. Before the close of Paleozoic time, however, the region was uplifted and most of the Nawa sediments were removed by erosion. Only a few isolated remnants of the Nawa Series are now left in Kordofan as evidence of this once-extensive geologic unit.

Deposition of rock-forming materials in the area did not again take place until Mesozoic time when shallow continental seas covered much if not all the Province. During this time the clastic sediments of the Nubian Series were laid in continental or near-shore marine environments and over a basement rock surface of considerable relief. Near the close of Mesozoic time, the seas receded as the region was again uplifted and then subjected to prolonged subaerial erosion that apparently lasted until Pliocene time. During this interval of erosion most of the Nubian rocks were stripped away and only those occupying the deeper basins in the basement rock surface were left intact. Extensive laterization of Nubian and possibly older rocks occurred during early or middle Tertiary time when climatic conditions favorable to laterite formation prevailed in much of the Province. Tectonic movements in eastern Africa, probably during late Tertiary time, resulted in the formation of several structural basins in the Nubian and basement rocks of Kordofan Province. During Pliocene and early Pleistocene time these basins were filled with fluvial and lacustrine deposits that now make up the Umm Ruwaba Series.

Following deposition of the Umm Ruwaba Series several types of surficial deposits were laid down that now form a virtually continuous mantle over the Umm Ruwaba and older rocks of Kordofan. In late Pleistocene time, the southern part of the Province was subjected to widespread and recurrent flooding. The floods, probably emanating from the Nile headwaters to the south, brought in clay and silt and deposited these over most of the southern part of the Province. Concurrent with flooding in the south, strong northerly winds prevailed in the northern part of the Province and denuded the land surface of much of its residual soil cover. A considerable part of the eroded material was deposited as sand dunes over the central part of the Province. The residual soils in the north, stabilized sand dunes (qoz) in the central part of the Province, and clay-plains deposits in the south remain today as evidence of the climatic conditions since late Pleistocene time.

GEOLOGIC UNITS AND THEIR WATER-BEARING PROPERTIES

BASEMENT COMPLEX (PRECAMBRIAN)

The basement complex, the oldest and most extensive rock unit in Kordofan, consists of granite, gneiss, schist, quartzite, basalt, crystalline limestone, and other igneous and metamorphic rocks. Since they were formed these rocks have been subjected to structural deformation and to various climatic vicissitudes. As a result the rocks are locally weathered to depths as great as 50 meters (164 ft) and may contain joints or other tabular partings to depths of as much as 150 meters (492 ft) below the land surface. In areas of Kordofan where the basement rocks are best exposed and mapped in greatest detail, observed fault lines commonly trend in a northerly direction. Joint systems, however, appear to be randomly oriented.

The basement rock surface, whose configuration is shown in figure 4, contains five rather broad but shallow basins. As shown areally in figure 4 and by geologic section *A–A′* on plate 1, sedimentary rocks of the Nubian and Umm Ruwaba Series fill the basins. Because of the sparsity of well data, the configuration of the basement-rock surface can not be shown in detail greater than by a contour interval of 100 meters (328 ft). In places, however, especially in the east-central part of the Province, logs of closely spaced wells show the basement to have a surface of considerable local relief. Also, data from a gravity survey

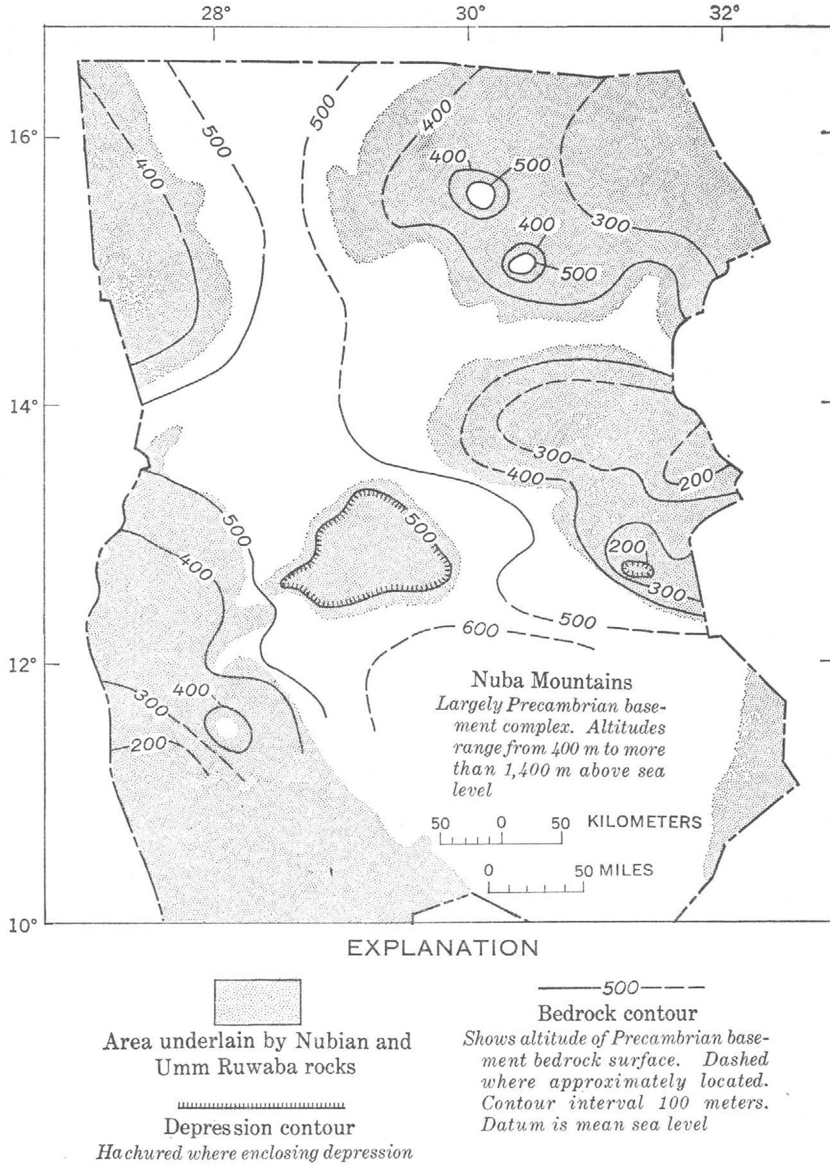

FIGURE 4.—Configuration of Precambrian bedrock surface and extent of Nubian and Umm Ruwaba rocks.

(Texas Instruments Corp., 1962) completed in parts of western Kordofan and eastern Darfur Provinces indicates that grabens or channels 1–10 kilometers (0.6–6 miles) long and as much as 500 meters (1,640 ft) deep occur locally in the basement-rock surface. Figure 4, in conjunction with known land-surface altitudes, can be used to estimate the gross thickness of the sedimentary strata and surficial deposits overlying the basement-rock surface.

Of the numerous wells in Kordofan that penetrate basement rocks, relatively few provide water in sufficient quantity for the minimum requirements of domestic and stock use. Many wells are either dry part of the year or provide so little water that they are eventually abandoned. Although the basement rocks are virtually impermeable, water occurs locally in the weathered and creviced zones. The water moves downward into these zones from ponded runoff in fulas and hafirs or from saturated surficial deposits and sedimentary rocks. Where the weathered and creviced rocks underlie areas having low average annual precipitation, such as in the vicinity or Sodiri or El Obeid, the seasonal replenishment is not always sufficient to sustain wells yielding perennial supplies. For example, well 23 (table 3) in Sodiri goes dry shortly after the rainy season in years of below average precipitation. Near El Obeid, drilled wells 43 and 90 (table 2) have been productive only part of the year since withdrawals from them were increased in the 1940's. Conversely, in topographic lows such as those at the northern Kheiran, 80 kilometers (50 miles) east of Sodiri, and Bunjedid, 16 kilometers (10 miles) south of El Obeid, where withdrawals have remained moderate, dug wells continue to yield amply from weathered basement rocks. In areas having a comparatively high average annual rainfall, as in the vicinity of Dilling and Kadugli in the Nuba Mountains (figs. 2*A*, and 3), the weathered basement rocks yield moderate supplies of water to wells throughout the year. Information on several of these wells is given in the section "Present Utilization" and in table 2. In the central part of the Province, small perennial supplies of ground water from creviced basement rocks also are obtained locally where these rocks are interconnected with Nubian and Umm Ruwaba ground-water bodies; a typical example is well 515 at Umm Kreidm (table 2). However, in many of these wells, such as wells 420, 529 and 1017 (table 2; fig. 4), the yields are so low and static water levels so deep that the wells are virtually uneconomical to use.

NAWA SERIES (UPPER PALEOZOIC)

The Nawa Series is the least extensive of the sedimentary rock units and has been identified only in the east-central part of Kordofan south of El Obeid and northeast of Dilling (pl. 1). As only a few wells penetrate these strata, their subsurface contacts with the basement rocks shown in plate 1 (section *A–A′*) are largely inferred. The subsurface distribution of the Nawa rocks suggests that they lie in narrow down-faulted blocks or grabens in the basement rocks. Outcrops of Nawa rocks are rare because the rocks are commonly manteled by a thin but almost continuous cover of surficial deposits.

Information from several unsuccessful drilled wells, including well 821 at Semeih railway station, and observations at surface outcrops show the Nawa strata to be as much as 135 meters (443 ft) thick, to dip moderately, and to be composed of several sedimentary rock types. The series includes well-consolidated micaceous and nonmicaceous sandstone, arkose, shale, mudstone, and thin-bedded limestone.

Except for information provided by well 821 at Semeih, an exploratory well at Nebbaka, and several dozen shallow hand dug wells, the ground-water potentialities of the Nawa rocks remain largely unknown. Because many of the Nawa strata are inherently more permeable than the surrounding basement rocks, additional test drilling will probably reveal that moderately productive water-bearing beds are present in the Nawa Series.

NUBIAN SERIES (MESOZOIC)

Sedimentary rock of the Nubian Series of continental or nearshore marine origin underline large parts of Kordofan but are not extensively exposed at the land surface. The areal distribution of the Nubian beneath surficial deposits and laterite shown on plate 1 and in figure 4 indicates that rocks of the Nubian Series occur principally in four broad depressions in the basement-rock surface. Small outliers, however, partly exposed in jebels and too small to be shown on plate 1, occur sporadically in the higher areas between the depressions. The geologic section *B–B′* and *C–C′* on plate 1 show that the Nubian extends westward beneath the Umm Ruwaba rocks in southwestern Kordofan. Mohamed (1968) reports that they also locally underlie the Umm Ruwaba in the east-central part of the Province.

The Nubian strata are generally flat lying or dip very slightly north. The strata are composed mostly of friable to well-consolidated sandstone, mudstone, and conglomerate. Commonly, the standstone and conglomerate beds are silty and the mudstone is sandy. Hard ferruginous and siliceous layers are also common. Although in a gross sense the Nubian strata can be correlated over long distances, abrupt local changes in lithologic facies can be detected in wells drilled less than 500 meters (1,640 ft) apart. Generally, however, the Nubian strata display similar structural and lithologic characteristics. Information from wells also indicates that most of the Nubian Series is made up of sandstone. For example, geologic section *D–D′* on plate 1 shows that a thick section of sandstone extends for more than 75 kilometers (48 miles) east-west across the outlier east of Nahud. Also, as indicated in section *E–E′* on plate 1, "clean" sandstone as much as 75 meters (246 ft) thick extends for more than 50 kilometers (31 miles) north-south across the same outlier. Many of the sandstone beds are composed largely of subangular to subrounded quartz grains. Generally, however, the sandstone is silty or clayey, and occasionally it is conglomeratic. Crossbedding or current bedding, evidence of a marginal marine or continental origin, is a characteristic of many of the sandstone beds exposed at the land surface. In places, mudstone may be prominent in the Nubian section—for example, geologic section *D–D′* on plate 1, shows the mudstone beds to be as much as 50 meters (164 ft) thick and to extend across the entire width of the outlier. The Nubian Series attains a gross thickness of more than 152 meters (500 ft) in the Nahud outlier of central Kordofan and more than 170 meters (558 ft) in the southwestern part of the Province.

Water in the Nubian rocks is contained largely in the more permeable sandstone and conglomerate beds and is under low artesian pressure. Some water, however, is found in crevices and bedding planes of consolidated mudstones where these rocks lie in the zone of saturation. Ground-water bodies that are virtually continuous extend through most of the areas underlain by Nubian strata but generally terminate against basement rocks where the strata are less than 60 meters (197 ft) thick. A typical example of this termination is the ring of unsaturated Nubian strata that surrounds the ground-water body in the central part of the Nahud outlier (fig. 5). The depth to the zone of saturation in the Nubian aquifers is about 60 meters (197 ft) in some localities but as much as 160 meters (525 ft) in other localities. Because of the many facies changes in the Nubian, the aquifers are commonly of limited areal and stratigraphic extent. Contiguous water-bearing zones, however, may occasionally be more than 30 meters (100 ft) thick and may extend laterally for more than 50 kilometers (31 miles). Most existing single wells in Nubian aquifers yield between 700 and 1,200 gallons per hour (gph), or 3,150 and 5,400 liters per hour (lph); however, yields of 13,500 lph (3,000 gph) or more are not uncommon. Typical examples of higher capacity wells tapping Nubian aquifers are wells 555, 969, 1001 and 1024 at the Jebel Hadub water yard, 4 miles east of Nahud (table 2; pl. 1). The individual yields of these wells in 1962 ranged from 12,600 lph to 17,100 lph (2,800 gph to 3,800 gph). Although aquifers of the Nubian Series have not been adequately tested, available data suggest that in many places the aquifers are capable of sustaining considerably greater withdrawals.

LATERITE (LOWER TO MIDDLE TERTIARY)

Laterite or ironstone was apparently developed extensively on Nubian rocks over much of Kordofan Province during early and middle Tertiary time and corresponds to a prolonged period of deep in-place weathering of the host rock under tropical climatic conditions of alternating wet and dry seasons. Erosional remnants of this once extensive laterite deposit occur east and southeast of Nahud and between El Odaiya and El Fula but are too small to be shown on the map on plate 1. Where exposed at or near the surface, such as shown in sections *D–D′* and *E–E′* on plate 1, the laterite consists of a highly ferruginous layer of hematitic and limonitic ironstone that locally has an oölitic or vermicular texture. In places the laterite is hardly distinguishable from underlying ferruginous Nubian mudstone. The laterite generally ranges from a few meters to 15 meters (50 ft) in thickness. The laterite is unimportant as a source of water to wells as it occurs above the zone of saturation.

UMM RUWABA SERIES (PLIOCENE TO PLEISTOCENE)

The Umm Ruwaba Series consists of lacustrine and fluviatile deposits that, in east-central Kordofan rest largely on the irregular surface of the basement rocks (sec. *F–F′*, pl. 1). In the southwestern part of the Province, however, the deposits are underlain largely by Nubian rocks from which in places they are hardly distinguishable (sec. *B–B′*, pl. 1). Outcrops of Umm Ruwaba strata are rare because these strata are covered in most places by a thin but almost continuous veneer of surficial deposits.

The Umm Ruwaba strata are generally less consolidated than the Nubian, are flat lying, and are composed mostly of mudstone, sandstone, and conglomerate. Facies and bedding changes within relatively short distances are very common. Thin- to thick-bedded or lenticular sandstone, which is interbedded with thin mudstone in places, makes up much of the Umm Ruwaba strata in the Province. Like the Nubian sediments, the Umm Ruwaba sandstone and conglomerate are often silty and the mudstone sandy; however, unlike the Nubian, the mudstone is the dominate rock type in many areas. The Umm Ruwaba attains a thickness of more than 335 meters (1,100 ft) in the eastern part of the Province.

Water in the Umm Ruwaba series is obtained chiefly from the more permeable sandstone and conglomerate beds where they lie within the zone of saturation. The depth to the zone of saturation in Umm Ruwaba aquifers, which are generally confined, generally ranges from 46 meters (151 ft) to 153 meters (502 ft) below the land surface. As abrupt lateral changes in lithologic facies are common, individual

Umm Ruwaba aquifers are generally of limited areal extent and stratigraphic thickness. Except at several localities in the east-central part of the Province, the Umm Ruwaba series contains productive aquifers. The absence of aquifers in some areas underlain by the Umm Ruwaba strata, as is shown in figure 5, can be attributed to buried basement highs that rise above the zone of saturation, to feathering out of the strata along contacts with the basement, or to absence of permeable strata in the zone of saturation. Individual wells in aquifers of the Umm Ruwaba generally yield from 2,700 to 6,750 lph (600 to 1,500 gph), but yields of 12,000 lph or more are not uncommon. Well 59 at Umm Ruwaba and well 1177, 40 miles northwest of Muglad (table 2; pl. 1), are typical examples of wells that obtain moderate yields from aquifers of the Umm Ruwaba.

Where Umm Ruwaba and Nubian rocks are associated, the contained ground-water bodies are essentially continuous hydraulically. For this reason, the interconnected Umm Ruwaba and Nubian ground-water bodies are considered as single hydrologic units. (See discussion of "Hydrologic units".)

SURFICIAL DEPOSITS (PLEISTOCENE TO RECENT)

Kordofan Province is covered by a mantle of unconsolidated surficial deposits (fig. 2*B*). In the northern two-fifths of the Province, the mantle consists of coarse residual desert soils and active sand dunes. Adjoining these deposits to the south and extending over most of the central part of the Province is the qoz sand (largely stabilized sand dunes), sometimes also called the Kordofan sands. Covering the southern part of Kordofan and in places interfingered with the qoz sand are the clay-plains deposits. Alluvium in the channels of wadis and khors and slope-wash deposits around the footslopes of the jebels occur locally throughout the Province. Because of their limited areal extent, alluvium and slope-wash deposits are not indicated in figure 2*B*.

Residual desert soils derived from the weathering of the parent rock are the most extensive of the surficial deposits in the northern part of Kordofan. These materials are unconsolidated, are generally less than 20 feet thick, and consist largely of unsorted angular and subangular rock materials ranging in size from sand to boulders. Most of the finer rock materials in this area were apparently removed by strong northerly winds and deposited as sand in the central part of the Province.

The qoz sand deposits are characteristically red, and their gently undulating surface reflects their eolian origin. The deposits mantle the basement, Umm Ruwaba, and Nubian rocks over a large part of central Kordofan (fig. 2*B*) and consist mostly of unconsolidated quartz sand derived largely from the denudation of residual soils on

Nubian strata to the north. In swales or interdunal areas the qoz sand is locally covered by thin-bedded clay and silt, usually less than 3 feet thick. Well logs indicate that the qoz deposits are as much as 45 meters (148 ft) thick and may contain thin intercalated beds of clay or silt at depth.

The clay-plains deposits consist of laminated, loosely compacted clay, silt, sandy clay, and sandy silt formed during successive floods of extensive areas, chiefly in southern Kordofan (fig. 2*B*), in late Pleis-

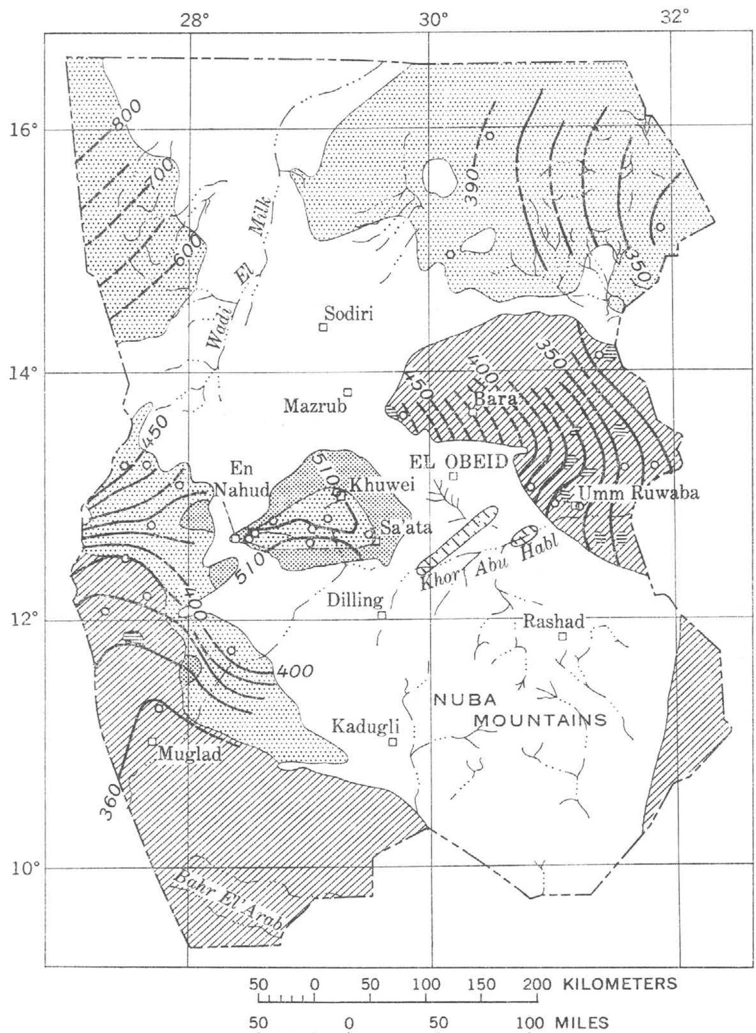

FIGURE 5.—Piezometric surface of zone of saturation in Nubian and Umm Ruwaba aquifers. Explanation on facing page.

tocene and Recent time. The deposits rest largely on the undulating basement or Umm Ruwaba rocks. Near their northern limits of the deposits they are covered by qoz sand, locally as much as 100 feet thick. Because of the relative sparsity of subsurface data, the thickness and lithologic characteristics of the clay-plains deposits are not well known; as these deposits are covered by qoz sand in places, they probably are in part older than the qoz.

Alluvium in wadis and khors and slope-wash deposits around the jebels, although important as sources of ground water, are the least extensive of the surficial deposits. The alluvium is found in wadi or khor channels chiefly in areas underlain by the impermeable basement rocks or clay-plains deposits. Wadis and khors and their alluvium are conspicuously rare in the central part of the Province because of the permeable absorptive nature of the qoz sand. The alluvium usually consists of unconsolidated sand, silty sand, and gravel and of loosely compacted silt, sandy silt, clay, and sandy clay. The alluvium is generally less than 15 meters (50 ft) thick and is in bands not more than 500 meters (1,625 ft) wide that may extend continuously along the entire length and width of a wadi channel. Slope-wash deposits are composed largely of unsorted coarse angular clastic material, ranging in size from sand to boulders, that has been transported only a short distance from the source. The deposits occur in aureoles around the

EXPLANATION

Regional zone of saturation and areas not yet explored

Area where little or no ground water is found

Umm Ruwaba Series
Pleistocene and Pliocene

Regional zone of saturation and areas not yet explored

Area where little or no ground water is found

Nubian Series
Mesozoic

Nawa Series
Upper Paleozoic

Basement complex
Precambrian

Approximate contact

——350———
Piezometric contour
Shows altitude of piezometric surface as determined by barometric reading. Dashed where approximately located. Contour interval 10 meters except where indicated. Datum is mean sea level

o
Drilled well

footslopes of jebels. In places they attain a thickness of more than 30 meters (100 ft) and a breadth of several kilometers. Buried slope wash as well as wadi alluvium having no apparent surface expression are believed to occur sporadically in parts of the Province where basement rocks lie near the surface.

The wadi alluvium and slope-wash deposits are the most important sources of water among the various categories of surficial deposits. Water also occurs locally in the qoz sand, where underlain by impermeable clay-plains deposits, and in the more permeable strata of the clay-plains deposits.

Water bodies in the alluvium of the wadis are generally perched with respect to the regional zone of saturation. Moreover, in the northern and central parts of the Province, such bodies are ephemeral and are directly dependent for replenishment on seasonal infiltration from runoff during and shortly after the rainy season. A typical example is the wadi alluvium of Khor Abu Habl that drains the northern part of the Nuba Mountains. Many agricultural schemes along this watercourse were abandoned because of the unreliability of the seasonal runoff needed to replenish the alluvial aquifer from year to year. The alluvium is a dependable source of water only in the southern two-thirds of the Province, where the average annual precipitation exceeds 150 mm (6 in.). Perennial ground-water bodies in the alluvium are found in the extreme south and southeast, as in the flood plain of the Bahr el Arab, where the average annual precipitation exceeds 500 mm (20 in.). The water in the alluvium is generally unconfined, except where lenses of silt and clay retard the movement of water through permeable sand and gravel and create small bodies of confined water.

Most wells in slope-wash deposits tap water that is derived directly from runoff from jebels and from local precipitation; the unlined wells on the south side of Jebel Kagmar (80 km north of Bara), most of which yield about 2,250 lpd (500 gpd) through most of the year, are of this type. The water in the slope-wash deposits occurs under unconfined conditions, and, as they are underlain largely by impermeable basement rocks, the water bodies in the slope-wash deposits in other localities as well, are perennial.

Shallow ground water, generally perched with respect to the regional zone of saturation, occurs locally in the qoz sand deposits, particularly where these overlie the clay-plains deposits near the qoz-sand–clay-plains contact shown in figure 2*B*. Typical are the ground-water bodies near Muglad, El Fula, El Odaiya, and Abu Zabad that yield as much as 3,150 lpd 700 gpd to individual wells during much of the year. The water-bearing sand generally lies directly above the virtually impermeable clay-plains deposits.

GROUND WATER

GENERAL FEATURES

The ultimate source of ground water in Kordofan Province is precipitation. Most of the rain that falls either becomes surface runoff or is retained by the soil and later lost to the atmosphere by evaporation or plant transpiration. The remainder percolates downward through the soil to the zone of saturation and becomes ground water (water which occurs in the zone of saturation and fills interstices in the rocks under hydrostatic pressure).

A rock unit within the zone of saturation capable of transmitting water and of yielding it to wells is called an aquifer; the unit may be one bed or a series of beds in one geologic unit but may include strata from more than one geologic unit. The rate at which an aquifer can transmit water under hydrostratic pressure is its permeability, and this is dependent on the degree of interconnection of pore spaces. Sedimentary rocks such as mudstone, clay, or silt have a high porosity, but because of their lack of interconnection between pore spaces, they have low permeability. In other porous rocks, such as sandstone, conglomerate, or alluvial sand and gravel, the pore spaces are interconnected to some degree. If the interconnected pore spaces are large, then the bed has a high permeability; if the interconnected pore spaces are so small that substantial pressure is necessary to transmit water, the bed has low permeability. Unweathered basement rocks such as granite or quartzite, which have almost no interconnected pore spaces, are considered to be virtually impermeable. Where they are weathered or contain interconnected fractures or crevices, however, they possess a characteristic known as secondary permeability.

The piezometric surface of a water-bearing formation or aquifer is the level at which water stands in a well penetrating the aquifer. If the aquifer is not confined by an overlying impermeable bed, this level corresponds to the water table. If the aquifer is confined above and below by less permeable beds, the water is under artesian conditions and the piezometric surface is above the base of the upper confining bed. Water in an aquifer that is separated from the regional zone of saturation by an unsaturated zone is perched ground water.

280-249—68——4

HYDROLOGIC UNITS

The Nubian and Umm Ruwaba strata contain five discrete ground-water bodies that are defined by piezometric contours (fig. 5) and that constitute independent hydologic units. The two ground-water bodies on the western side of Kordofan, although seemingly unconnected, are actually the eastern extensions of a much larger hydrologic unit that extends over much of Darfur and Bahr El Ghazal Provinces (fig. 1). In these two units the piezometric surface slopes southeast to south from a high of 800 meters (2,635 ft) in the north to 360 meters (1,170 ft) in the south (fig. 5). The hydrologic units in the east-central and northeastern parts of Kordofan have no evident hydraulic connection. The piezometric surface of the east-central unit (largely in rocks of the Umm Ruwaba Series) slopes eastward from a high of about 470 meters (1,527 ft) to a low of about 330 meters (1,072 ft) on the eastern side of the Province. The piezometric surface of the northeastern unit also slopes eastward from a high of more than 390 meters (1,267 ft) to a low of less than 340 meters (1,105 ft). As is apparent from the spacing of the piezometric contours in figure 5, the hydraulic gradient in the east-central unit is almost twice as steep as that in the northeastern unit. The outlier in rocks of the Nubian Series in central Kordofan also constitutes an independent hydrologic unit (Rodis and Iskander, 1963) whose piezometric surface at about 510 meters (1,667 ft) stands 50–100 meters above that of the hydrologic units to the east and west (fig. 5).

RECHARGE

The regional zone of saturation in sedimentary and crystalline rocks of Kordofan Province is recharged by underground inflow from adjoining Darfur Province to the west and by infiltration through the mantle of surficial deposits, either directly from local precipitation or from the runoff in wadis and khors. Some recharge to the regional zone of saturation probably occurs in most years in the central and southern parts of the Province, where the annual rainfall exceeds 150 mm (6 in.), and the amount of recharge probably increases southward with increasing rainfall. In the arid, northern part of the Province, however, recharge probably occurs only sporadically by infiltration from ephemeral wadis and khors while in flood and may be negligible in most years.

Sufficient observational data were not available to evaluate quantitatively the amount of recharge by infiltration of rain. As the rains are generally of high intensity and short duration and commonly fall on warm or hot sandy surfaces, most of the rain probably evaporates soon after it falls, and most of the water entering the soil is probably transpired by vegetation. The residual quantity of water available for recharging the zone of saturation is, thus, relatively small and in many areas negligible. As each of the hydrologic units in the Province has a large surface area, a very low average annual rate of recharge from rainfall would result in a significant increment to ground-water storage. For example, recharge at a rate of as little as 0.002 inch per year over the areas underlain by the principal hydrologic units would more than balance the 1962 rate of withdrawal. Recharge from runoff in wadis and khors occurs only locally in the qoz sand region of central Kordofan but occurs more commonly in the clay-plains and Nuba Mountains regions of southern Kordofan, particularly after prolonged storms. If conditions in other regions of the world having similar climatic environments are analogous, recharge may range from almost nothing in arid northern Kordofan through about 5 percent of the annual rainfall in the semiarid central part of the Province to as much as 20 percent in the subhumid south, where annual rainfall is 800 mm (32 in.).

MOVEMENT

Although some lateral movement of ground water takes place through all the rocks of the Province where ground water is present in the regional zone of saturation, the bulk of the flow is probably concentrated in the more permeable hydrologic units constituted by sediments of the Nubian and Umm Ruwaba Series. Lateral ground-water flow through rocks of the basement complex is, at best, very slow and may be negligible where weathered and creviced zones are lacking. As indicated by the piezometric contours in figure 5, ground-water flow through the Nubian and Umm Ruwaba strata, which constitute the two hydrologic units on the western side of Kordofan, is generally southeast to southwest toward the Bahr El Arab. Ground water in the Nubian outlier of central Kordofan moves laterally outward into surrounding basement rocks. In the east-central and northeastern hydrologic units, ground-water flow is toward the White Nile and Nile Rivers, respectively.

DISCHARGE

Discharge from the regional zone of saturation in Kordofan takes place naturally by evapotranspiration and lateral outflow from the Province and artificially by withdrawals from wells. Among these discharge factors, evapotranspiration from the regional zone of saturation does not seem to be quantitatively important because the depth to this zone in most of the Province is commonly more than 46 meters (151 ft) below land surface. Conversely, there may be significant evapotranspiration from perched ground-water bodies that occur in the alluvial deposits of the wadis and khors, in the slope-wash deposits associated with jebels, and the qoz sand deposits of central Kordofan. In some areas, as near the Kheiran, Bara and Bunjedid, the water tables of shallow ground-water bodies lie within several meters of the land surface and hence, within limits of direct evaporation or transpiration by long-rooted plants, such as members of the *Acacia* family.

Some natural discharge from aquifers in Nubian and Umm Ruwaba strata probably takes place from the hydrologic unit on the western side of Kordofan near the Bahr El Ghazal and the White Nile. Also, as the piezometric contours in figure 5 indicate, natural discharge from the east-central and northeastern hydrologic units probably takes place in or near the White Nile and Nile Rivers. The amount of natural discharge by lateral outflow could not be estimated during the present investigation owing to the lack of essential hydrologic data; however, the amount would depend chiefly on the regional hydraulic gradients (as indicated by the piezometric contours) and on the permeability and thickness of the aquifers.

Ground water is also discharged artificially from aquifers of the Province by withdrawals from drilled and dug wells. Withdrawals by pumping from drilled wells in central Kordofan were conservatively estimated to be about 550 million gallons in 1961. Of this, about 23 percent, or 125 million gallons, was pumped from the Nubian aquifers in the hydrologic unit of central Kordofan; about 48 percent, or 265 million gallons, from Nubian–Umm Ruwaba aquifers in the hydrologic unit of western Kordofan; and about 29 percent, or 160 million gallons, from Umm Ruwaba aquifers in the east-central hydrologic unit. Withdrawals from both drilled and dug wells in the central part of the Province, although increasing in the past few years, have not measurably decreased ground-water storage. Assuming that the specific yield is 5 percent and the storage capacity is about 320,000 acre-feet per foot of saturated rock, the general water levels in the hydrologic unit of central Kordofan would decline only 1 foot in 165 years at the 1962 rate of withdrawal. This estimate of water-level decline is conservative because most of the ground-water bodies undoubtedly receive some recharge from precipitation. Also, measurements of water levels in wells, many of which have been observed since 1930, indicate that during the period 1930–62 no appreciable increase or decrease occurred in ground-water storage (fig. 6). The amount of ground water in storage has remained virtually unchanged at the heavily pumped localities of Jebel Hadub water yard and the municipality of Umm Ruwaba, where the wells tap the Nubian and Umm Ruwaba aquifers, respectively.

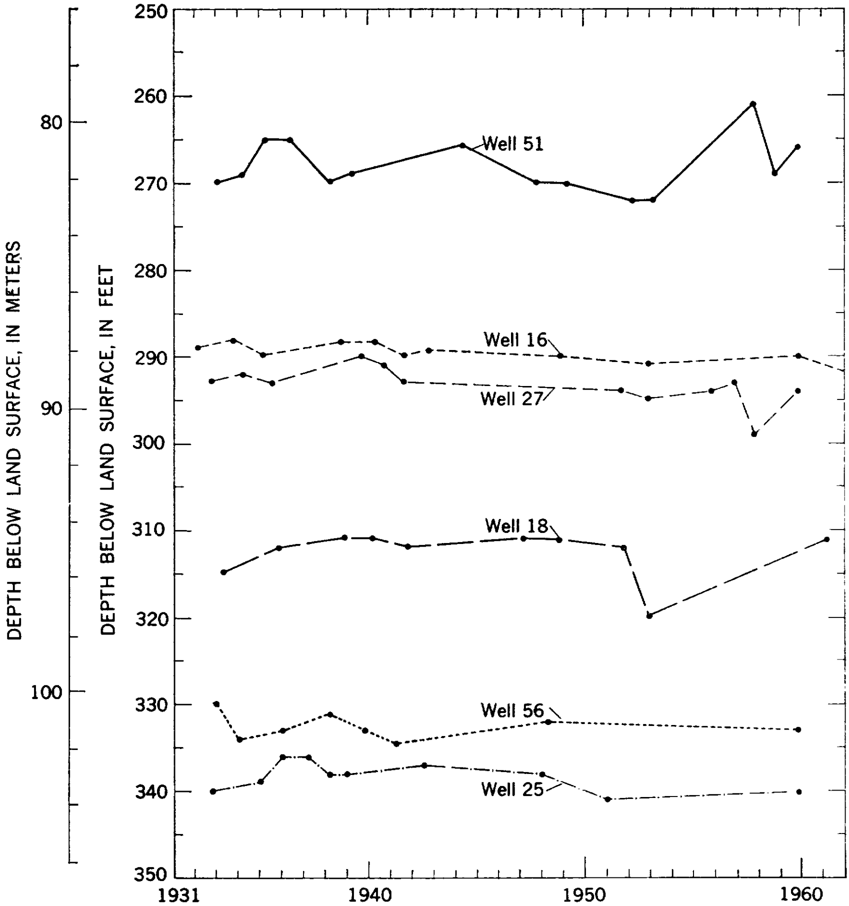

FIGURE 6.—Water-level fluctuations in selected drilled wells.

CHEMICAL QUALITY

The chemical quality of ground water depends on the nature and concentration of mineral constituents dissolved in the water and is not necessarily related to the bacterial or sanitary quality. For descriptive purposes the following empirical terms have been adopted to indicate the general nature of water quality in Kordofan Province with respect to tolerance by plant, man, and beast (Newport and Haddor, 1963).

Rating	*Approximate dissolved solids (ppm)*
Good quality	<1,500
Fair quality	1,500–3,000
Poor quality	>3,000
Fresh water	<3,000
Brackish (moderately mineralized) water	3,000–6,000
Salty (highly mineralized) water	>6,000

Chemical analyses of water from approximately 100 representative wells in the Province show that there is a general relationship between the chemical quality and the geologic source of the water. This relationship is illustrated by 19 selected chemical analyses given in the bar graphs in figure 7 and by the areal distribution of hardness and mineral content of ground water shown in figure 8.

Water from Nubian aquifers, as compared with water from other geologic units, is characterized by nearly consistent low dissolved-solids content (fig. 7) and by low hardness (fig. 8). Chemical analyses of water from 45 selected wells tapping Nubian aquifers show the total dissolved-solids content to range from 100 parts ppm (per million) to 340 ppm and the total hardness from 60 ppm to 264 ppm. The low dissolved-solids content of the water suggests that little soluble material is present in rocks of the Nubian Series. Exceptions to the generally good quality of water from Nubian aquifers occur locally, as the high fluoride content of the water in well 1146 (table 4).

Water from Umm Ruwaba aquifers contains total dissolved solids averaging 1,050 ppm and generally ranging from 420 ppm to 3,000

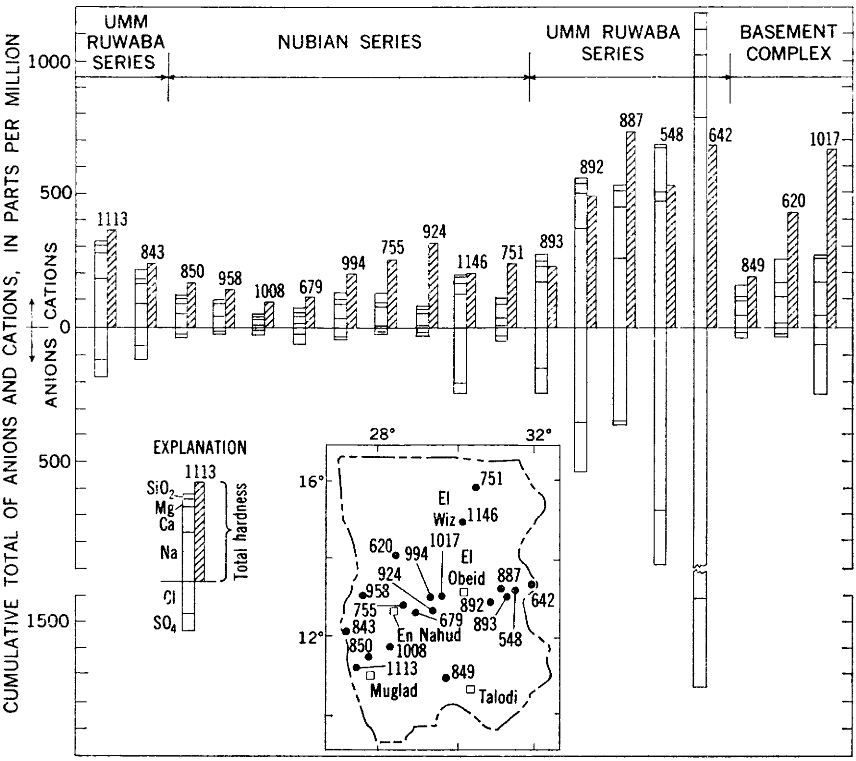

FIGURE 7.—Chemical analyses of ground water.

ppm. Figure 5 shows that the water from Umm Ruwaba aquifers in western Kordofan is generally of better quality than that in the eastern part of the Province, where the total dissolved-solids content ranges from about 1,500 ppm to 3,000 ppm. Water of low hardness is locally found in Umm Ruwaba aquifers in the extreme eastern and western parts of the Province (fig. 7).

Few chemical analyses are available for water from the basement rocks and surficial deposits. The water from weathered basement rocks

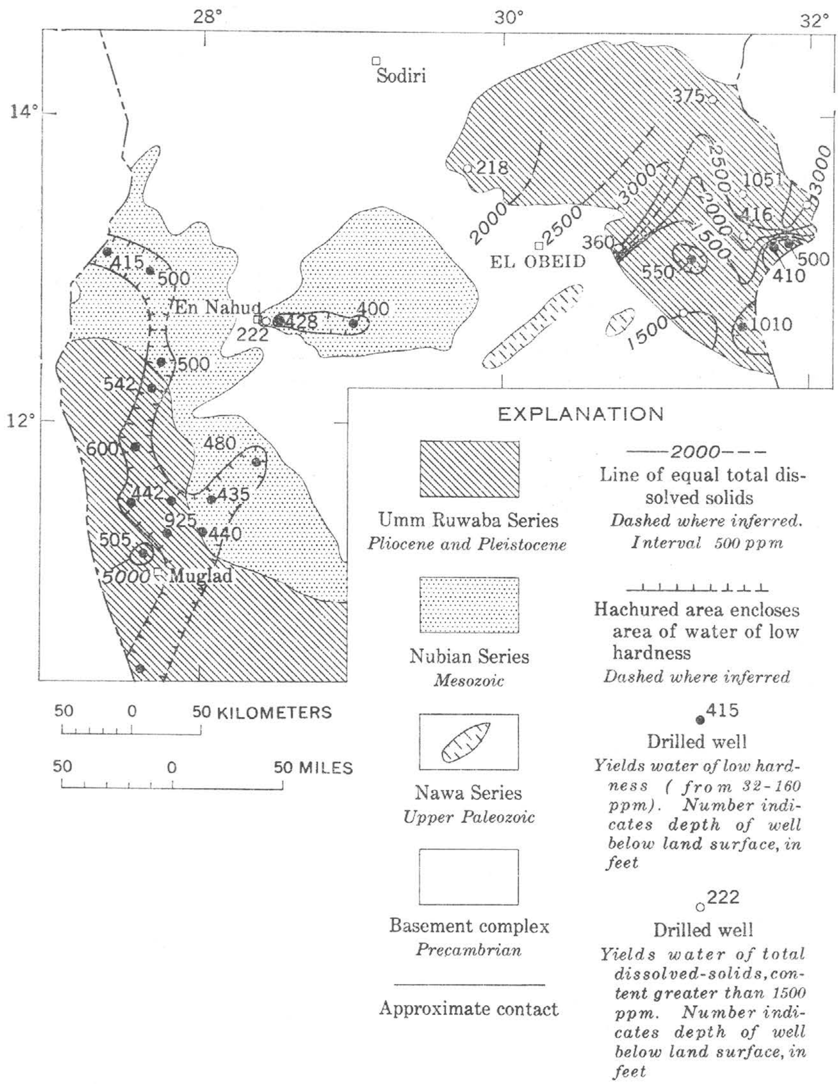

FIGURE 8.—Areal distribution of hardness and dissolved solids in ground water.

in the northern two-thirds of the Province is commonly brackish or salty. For example all the dug wells in the Jebel El Ga'a–shershar–Jebel El Gherait area, some 30 miles northeast of Mazrub (pl. 1), yield salty water. Water of poor quality is also obtained from wells (for example, wells 620 and 1017, fig. 7) in the central and northern parts of the Province, where there is little or no ground-water circulation in basement rocks. In contrast, the analysis for well 849 (fig. 7) suggests that water of better quality is obtained from these rocks in southern Kordofan, where seasonal replenishment from rainfall is appreciable and there is relatively active ground-water circulation. Also, the water from wadi alluvium and slope-wash deposits is generally reported to be of good to fair chemical quality.

AVAILABILITY

The availability of ground water is shown areally in figure 9. Also, a summary of the availability of ground water in Kordofan Province was given by Rodis, Hassan, and Wahadan (1963) in an earlier progress report on the present investigation. Figure 1 of that report has been revised and is superseded by figure 9 of this report.

The Province is divided into map areas of ground-water availability on the basis of (1) the general geological source of the water, (2) the

Map area of ground-water availability	Availability of ground water (Based on data from drilled wells unless otherwise indicated. Depths to water-bearing strata are from land surface.)	Brief description of geologic and ground-water conditions
A_1	Most wells obtain water from Umm Ruwaba aquifers at depths of approximately 150 ft.	Nubian and (or) Umm Ruwaba strata overlain by surficial deposits and underlain by basement rocks; or Nawa strata overlain by surficial deposits and underlain by basement rocks.
A_2	Most wells obtain water from Nubian or Umm Ruwaba aquifers between depths of 150 ft and 300 ft.	
A_3	Most wells obtain water from Nubian or Umm Ruwaba aquifers between depths of 300 ft and 500 ft.	
A_4	Most wells obtain water from Nubian or Umm Ruwaba aquifers from depths greater than 500 ft.	
A_{1D}	Most dug wells obtain water from aquifers in surficial deposits or Umm Ruwaba strata from depths of 30 to 150 ft.	Ground water generally occurs in more permeable Nubian and Umm Ruwaba sandstone and conglomerate; occurrence of ground water in Nawa comparatively unknown. Ground water occurs locally in surficial deposits and in the weathered and creviced zones of basement rock; however, these materials are not dependable sources.
A_{2D}	Most dug wells obtain water from Umm Ruwaba aquifers between depths of 150 ft and 250 ft.	
A_c	Water very high in total dissolved solids; wells either abandoned or limited in use; depth to water not recorded.	
A_{2c}	Water very high in fluoride content, wells abandoned; depth to water from 150 ft to 300 ft.	
A_{0c}	Attempts to find ground water usually failed. Where water has been found it is very high in total dissolved-solids content.	
A_0	Attempts to obtain water usually failed or resulted in a small yield.	
A_x	Ground-water potential unexplored; however, geologically favorable to ground-water exploration and development.	
B	Most dug wells are from 10 to 250 ft in depth and are dry part of the year; few drilled and dug wells obtain perennial supplies.	Basement rocks overlain by surficial deposits. Ground water occurs locally in weathered and creviced zones of basement rocks and in surficial deposits.

depth to or absence of water-bearing strata, (3) the occurrence of water of extremely poor chemical quality, and (4) the areas geologically favorable for ground-water exploration. Because of the sparsity of subsurface information, map areas shown in figure 9 are only approximately located, and subsequent test drilling and ground-water develop-

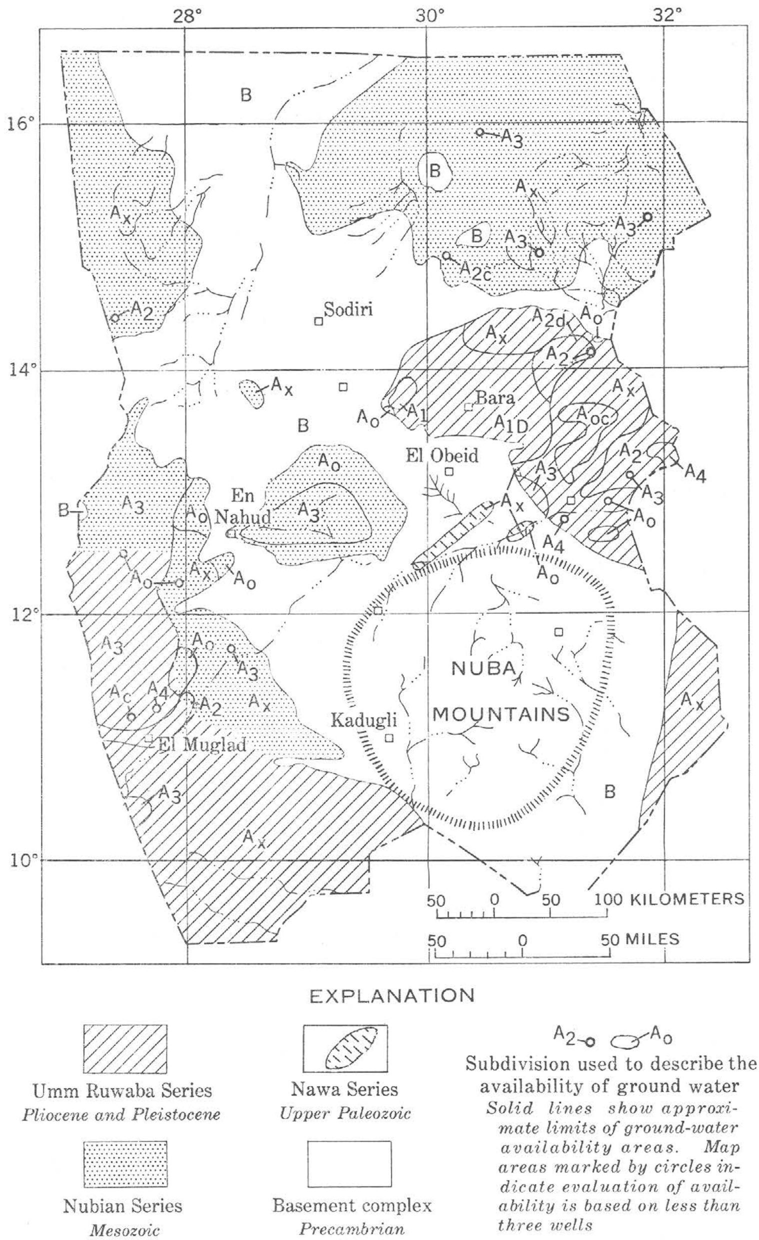

FIGURE 9.—Availability of ground water.

ment will probably necessitate revision of many of the indicated boundaries. The information on map areas thus can serve only as a general guide in exploration for new or additional ground-water supplies.

The information given in figure 5 of this report and a topographic map of the Province can be used to estimate the depth to water-bearing strata for availability areas shown in figure 9. As the surface of the zone of saturation coincides closely with the piezometric surface shown in figure 11, the minimum depths to aquifers can be calculated by subtracting the altitude of the piezometric surface from the altitude of the land surface.

PRESENT UTILIZATION

The principal present uses of ground water in Kordofan Province are for domestic, stock, and municipal supplies; only a very small quantity is used for irrigation. Except in the southern quarter of the Province, where adequate surface-water supplies are obtained from hafirs and fulas, use of ground water exceeds that of surface water. There are approximately 175 successful drilled wells in the Province and about an equal number of unsuccessful or abandoned drilled wells. Open hand-dug wells number into the thousands, but many of these go dry shortly after the end of the rainy season or yield inadequate supplies during the dry season. Where adequate quantities of water are available in the rocks, drilled wells are gradually replacing dug wells because they yield larger and more dependable supplies and are less subject to pollution.

More than 90 percent of the productive drilled wells in the Province are in water yards where there are two to five companion wells, commonly less than 90 meters (295 ft) apart. The wells range in diameter from 102 mm (4 in.) to 406 mm (16 in.) and in depth generally from 15 meters (50 ft) to more than 366 meters (1,201 ft). Most are equipped with 5 or 6 horsepower diesel- or benzine-driven piston pumps and are finished with standard-width slotted pipe screens. The water from the wells is pumped directly into elevated steel storage tanks where it is then distributed by gravity flow to nearby watering troughs or taps, commonly inside the fenced water yard. A field inventory indicates that about 170 of the drilled wells were pumped in 1962 (table 2). Reportedly, the average rate off pumping from each well was about 1,000 imperial gallons per hour, and the wells were pumped an average of 10 hours per day throughout the year. Withdrawals were largely from Nubian and Umm Ruwaba aquifers in the hydrologic units of the central part of the Province, within an area shown in figure 8, withdrawals in 1962 are estimated to have been approximately 550 million imperial gallons, or 1,530 acre-feet. The estimated withdrawal in 1961 from the hydrologic unit of the Nahud outlier alone was 125 million gallons, or 383 acre-feet (Rodis and Iskander, 1963). Individual well yields could be measurably improved by using either prefabricated well screens or gravel-packed slotted pipe screens having specifications designed for the lithologic texture and water quality of the aquifer. Such measures would lower the unit cost of water production, would extend well life, and would eventually lead to realistic well spacing and optimum well yields.

Dug wells are located chiefly in areas underlain by basement rocks, where low yields and adverse drilling conditions preclude the construction of drilled wells. In most basement-rock areas dug wells are productive only during and shortly after the rainy season, and many fail in the dry season. In some localities, however, such as near Fara and Essirer (wells 8 and 18, table 3), perennial supplies are obtained from dug wells tapping water in saturated sandy zones near the surficial deposits—Umm Ruwaba contact. In other localities, such as at Iddenabog and Zaida (wells 4 and 13, table 3), perennial supplies are obtained from deeper dug wells tapping Umm Ruwaba or possibly Nubian aquifers. At Hamat Esh Sheikh, water for school use is obtained (well 22, table 3) by taping a water-bearing zone which is near the surficial deposits–Nubian Series contact. Productive and abandoned dug wells of both temporary and permanent construction number into the thousands and range in diameter from 0.61 meters (2 ft) to more than 3.0 meters (10 ft) and in depth from 0.9 meters (3 ft) to more than 60 meters (197 ft). Wells of more permanent construction that tap unconsolidated surficial deposits are generally lined with cemented brick or rock, but dug wells of temporary construction have no lining at all. Sections of dug wells penetrating Nubian or basement rocks are sometimes unlined where the rocks are consolidated. The water is commonly brought to the surface manually by means of a rope attached to a leather bag or to a "safiha" (4 gallon benzine tin). At many of the deeper wells, donkeys or camels are used with rope and pulley to raise the water to the surface. Where ample quantities of water are available, benzine- or diesel-driven piston pumps are used to lift water, particularly where fairly large quantities are needed as for irrigation. Hydrologic data for 26 typical dug wells whose locations are shown on plate 1 are given in table 3.

The towns of Dilling, Kadugli, En Nahud, and Umm Ruwaba have public water systems supplied by wells. The municipality of El Obeid at one time obtained most of its water supply from wells but now has a filtered water supply obtained from surface runoff stored in fulas; the wells are now used only for auxiliary supply during prolonged dry seasons. Water for smaller towns and villages in the Province and for livestock is supplied by water yards, dug wells, hafirs, and fulas. The water supply for both Dilling and Kadugli is obtained from wells tapping weathered basement rock. The temperature of the water at both places ranges from 28°C (83°F) to 29°C (84°F). In Dilling, the water is obtained from four wells (954, 197, 198, 955), all of which reportedly are less than 46 meters (151 ft) deep. The water is of good quality and the supply is reported adequate for present needs. Kadugli, like Dilling, is in the Nuba Mountains area and obtains its municipal water supply from three wells (849, 917, 953), which average approximately 90 meters (296 ft) deep. In 1961, the wells provided more than 50,000 cubic meters (1,565,000 cu ft) of good quality water. The water supply for En Nahud is supplied by four wells (555, 969, 1001, 1024) located about 8 kilometers (5 miles) northeast of the town. The water, whose temperature ranges from 32°C (90°F) to 33°C (92°F), is obtained from Nubian sandstone aquifers ranging in depth from 138.9 meters (456 ft) to 150.6 meters (494 ft) below land surface. The 1961 total output of all four wells was 97,000 cubic meters (3,424,100 cu ft). Although the water is of good quality, the present supply meets only the minimum present requirements of the town. The public water supply for Umm Ruwaba is obtained from wells 27, 27A, 286, and 1134, all tapping Umm Ruwaba sandstone. The wells range from 114.3 meters (375 ft) to 137.1 meters (450 ft) deep, and the water temperature ranges from 32°C (89°F) to 34°C (93°F). The average output of the wells in 1961 were 1,600 imperial gallons per hour which satisfied only the minimum needs of the town.

FUTURE DEVELOPMENT

In the central and southern parts of Kordofan Province, the rate of natural replenishment to ground-water storage from precipitation and from subsurface inflow is probably more than adequate to balance the present (1962) rate of withdrawal from wells. Also, the present (1962) quantity withdrawn by wells from the ground-water reservoir in the northern part of the Province is so small that no perceptible change in storage would be detectible in the immediate future, even though natural replenishment may be negligible. Thus, the annual draft of about 600 million gallons prevailing in 1962 from Nubian and Umm Ruwaba aquifers in the Province could be continued indefinitely with no significant decrease in the amount of water in storage.

On the basis of hydrologic and geologic data available for this investigation, the Nubian and Umm Ruwaba aquifers in the hydrologic unit occupying the southwestern part of the Province appear to have excellent potential for future ground-water development. Inasmuch as aquifers yielding adequate quantities of good quality water are found in the nothern part of this unit, they probably occur also in the relatively unexplored area farther south. This hydrologic unit has excellent development potential and longevity prospects because it is part of a larger hydrologic unit that extends west into Darfur Province and receives subsurface inflow from that Province, and because it probably receives more natural replenishment to the zone of saturation by infiltration from rain than any other hydrologic unit in Kordofan Province due to relatively high annual precipitation. Absence of hydrologic data for Nubian strata in the virtually unexplored northern part of the Province precludes any reasonable estimate of the relative ground-water potential of these strata. The Nubian strata in northern Kordofan, however, undoubtedly contain potentially productive aquifers that could be utilized whenever the financial resources are available for water development.

Future development of ground water in Kordofan should generally be accompanied or preceded by appropriate hydrologic studies by well-qualified geologists or engineers. If such development is carried out at the same moderate pace as it has been in the recent past, then the hydrologic studies could be made concurrently with the development. If, however, economic pressures necessitate immediate development of large quantities of ground water in any one area, then detailed hydrologic investigation should precede development. As the final results of hydrologic studies depend largely on the interpretation of all antecedent data, participating governmental agencies should continue to make every effort to contribute and exchange complete and accurate geologic information and well data.

Any significant effort toward development of ground water in Kordofan Province must be based on a thorough understanding of the regional geology and hydrology and should be coordinated with planning for agricultural and industrial development as well as for the settlement of the migrant population. As ground water is a dynamic resource and is subject to change, it must be constantly evaluated as its development and use proceeds. Such a continuing evaluation should include more precise measurements of (1) the rate and amount of replenishment to the principal hydrologic units, (2) the extent and thickness and the permeability and storage coefficients of the aquifers in the hydrologic units, (3) the areal distribution of ground water of various types of chemical quality, and (4) the annual pumpage and the water levels in wells. Thus, local overdevelopment could be prevented, and optimum over-all development of the ground-water resources of the Province could be assured.

BASIC DATA

Hydrologic data selected from more than 250 drilled wells and 100 dug wells are given in tables 2 and 3, respectively. Selected logs of drilled and dug wells in Kordofan Province are shown in tables 5 and 6, respectively, and on the six geologic sections accompanying this report. Data on chemical quality of water that were compiled and interpreted for this investigation are given in tables 1 and 4 and in figures 7 and 8.

TABLE 1.—*Summary of physical and water-bearing characteristics of the geologic units in Kordofan Province*

Geologic age			Series or unit	Thickness		Physical characteristics	Water-bearing characteristics	Selected chemical characteristics where available [1]
				(feet)	(meters)			
Cenozoic	Quaternary	Recent ---?--- Pleistocene	Surficial deposits	0–148+	0–45	Unconsolidated residual soils; fixed and active sand dunes. (qoz sand); massive and thin-bedded silt and clay (clay-plain deposits); alluvial and slope-wash deposits.	Not water bearing in most places. Small bodies of perched water occur locally in permeable alluvial and slope-wash deposits and qoz sand.	
Cenozoic	Quaternary / Tertiary	---?--- Pliocene	Umm Ruwaba Series	0–1100+	0–335+	Loosely consolidated to unconsolidated sandstone, mudstone and conglomerate. Sandstone and conglomerate commonly silty and mudstone sandy.	Water occurs in permeable sandstone and conglomerate in zone of saturation.	Total dissolved solids: 420, 1050, 2360. Hardness as $CaCO_3$: 140, 330, 1000. Chloride content: 45, 258, 1400.
Cenozoic	Tertiary	Early to middle Tertiary	Laterite	0–50+	0–15+	Mostly semiconsolidated ferruginous laterite or ironstone. Residual deposit developed on Nubian.	Generally above the zone of saturation and not water-bearing.	

Mesozoic		Nubian Series	0–558+	0–170+	Consolidated to semiconsolidated, thin- to thick-bedded sandstone, silty sandstone, mudstone, sandy mudstone, silty and sandy conglomerate. Ferruginous strata are common.	Water occurs in permeable sandstone and conglomerate, and in tabular partings in mudstone in zone of saturation.	Total dissolved solids: 100, 200, 340. Hardness as $CaCO_3$: 60, 172, 264. Chloride content: 8, 65, 410.
Paleozoic	Late Paleozoic	Nawa Series	0–443+	0–135+	Indurated sandstone, arkosic sandstone, shale, mudstone and limestone.	Water potential largely unknown.	
Precambrian		Basement complex	?	?	Igneous and metamorphic rocks predominantly granite, granite gneiss, biotite gneiss, schist, quartzite and crystalline limestone.	Largely impermeable, however, water occurs locally in more permeable weathered zones and in joints and other fractures.	(Refer to fig. 7.)

[1] Given in parts per million in the order: low, average, high.

TABLE 2.—*Description of selected drilled wells (boreholes)*

Conversion factors: To convert feet to meters, use 1 foot=0.3048 meter; to convert Fahrenheit to centigrade, subtract 32° and multiply the remainder by 5/9; to convert imperial gallons per hour to liters per hour, use 1 imperial gallon=4.5437 liters; and to convert miles to kilometers use 1 mile=1.609 kilometers.
Lithology: ss, sandstone; ms, mudstone; cg, conglomerate; ag, agglomerate; gr, granite, bgr, biotite granite; bsch, biotite schist; wb, weathered basement rock; qtz, quartz.
Geologic unit: Pc, Precambrian; N, Nubian series; UR, Umm Ruwaba Series; UR/Pc, Umm Ruwaba Series and (or) Precambrian; N/Pc, Nubian Series and (or) Precambrian; UR/N, Umm Ruwaba Series and (or) Nubian Series. Yield: Yield reported at time of completion of well.
Remarks: Abd, abandoned.

Well	Latitude (N.) Longitude (E.)	Locality	Year drilled	Depth of well below land surface (ft)	Approximate water level: Below land surface (ft)	Approximate water level: Date measured	Water-bearing material: Depth to top below land surface (ft)	Water-bearing material: Lithology	Water-bearing material: Thickness (ft)	Water-bearing material: Geologic unit	Yield (imperial gallons per hour)	Temperature (°F)	Remarks
4	13°10′ 30°12′	El Obeid	1919	--------	116	1919	266	--------	--------	Pc	188	--------	
7	13°01′ 30°23′	El 'Ein	1926	128	--------	--------	--------	--------	--------	Pc	--------	--------	abd
11	13°04′ 30°06′	Jikka	--------	260	--------	--------	--------	--------	--------	Pc	--------	--------	
12	12°58′ 29°59′	Abu Haraz	1919	215	--------	--------	117	--------	--------	Pc	90	--------	abd
15	12°28′ 29°20′	Abu Galb	--------	105	--------	--------	--------	--------	--------	Pc	750	--------	abd
16	12°41′ 29°32′	Sa'ata	1920	390	300	1920	300 350	ss cg	30± 20±	N N	1,500	--------	
20	12°41′ 28°25′	En Nahud (Tama Fula)	1921	222	76	1961	140	--------	--------	N	900	--------	abd
28	12°43′ 30°51′	Semeih	1925	409	220	--------	340 400	ms ms	--------	Nawa series	150	--------	abd
43	13°10′ 30°12′	El Obeid	1927	280	38	--------	280	--------	--------	Pc	960	--------	
46	12°47′ 27°41′	Suaa El Ghmal	1927	387	327	--------	340	--------	--------	N	1,320	91.0	
47	13°11′ 30°05′	Werri	1927	157	--------	--------	157	--------	--------	Pc	--------	--------	abd
54	13°17′ 27°28′	Dar Gamad	1929	390	331	--------	390	--------	10+	N	800	--------	
59	12°54′ 31°13′	Umm Ruwaba	1929	390	295	--------	295	--------	--------	UR	1,000	--------	
62	13°03′ 31°37′	Umm Ushara	1932	335	255	--------	335	--------	--------	UR	1,000	--------	
65	13°24′ 28°41′	Iyal Bakhit	1930	202	--------	--------	--------	--------	--------	Pc	--------	--------	abd

69	13°18′ 28°50′	Umm Zuman	1932	94	--------	--------	74	--------	--------	Pc	--------	--------	abd
72	13°15′ 28°32′	Abu Mangim	1932	339	211	--------	--------	--------	--------	Pc	10	--------	
75	12°08′ 27°21′	Ghabeish	--------	450	--------	--------	358	--------	--------	UR	80	--------	
77	13°09′ 30°31′	Gofil	1939	300	--------	--------	--------	--------	--------	Pc	--------	--------	abd
81	13°14′ 29°43′	Boteh	1937	146	--------	--------	--------	--------	--------	Pc	--------	--------	abd
82	13°20′ 29°55′	Abu Sunun	1937	267	--------	--------	266	gr	--------	Pc	100	--------	
83	13°16′ 29°57′	Hawashat	1937	200	--------	--------	--------	--------	--------	Pc	--------	--------	abd
86	13°05′ 29°13′	Khuwei	1938	465	386	1961	390	ss	50±	N/Pc	800	91.0	
90	13°10′ 30°12′	El Obeid (Water works area)	1939	365 370	90	1939	370	bsch	--------	Pc	260	--------	
118	12°05′ 27°19′	Umm Geleima	1942	458	348	1942	358	cg	32+	UR	1,320	--------	
132	13°10′ 30°00′	Ayyara	1944	400	305	1944	400	qtz	--------	Pc	200	--------	abd
133	13°12′ 30°18′	Khor Taggat	--------	220	133	--------	--------	--------	--------	Pc	1,450	--------	
137	13°52′ 29°19′	Mazrub	1944	239	--------	--------	--------	--------	--------	Pc	--------	--------	abd
139	13°12′ 30°47′	Taiyara	1945	360	240	1945	360	ss	1+	UR	200	--------	
156	12°41′ 29°14′	Umm Defeis	1946	316	210	1960	211	ss	20±	N	1,565	--------	
158	13°06′ 29°23′	Dudiya	1947	216	--------	--------	--------	--------	--------	N	--------	--------	abd
164	11°42′ 27°28′	Magru	1947	450	330	6–47	337	ss, cg	30±	UR	1,200	--------	
193	11°58′ 29°30′	Salara Dam	1949	1,262	--------	--------	--------	--------	--------	Pc	--------	--------	
213	13°03′ 30°50′	Kedada	1948	420	285	8–48	420	ss	1+	UR	1,200	--------	
215	13°07′ 28°53′	Humeir Gabir	1948	315	--------	--------	--------	--------	--------	N/Pc	--------	--------	
216	12°55′ 28°55′	Markib	1949	450	375	--------	--------	--------	--------	N	1,080	--------	
244	11°34′ 27°58′	Rahad Es Sidr	1950	483	--------	--------	--------	--------	--------	UR/Pc	--------	--------	abd
252	12°59′ 30°22′	El Ein	1950	125	--------	--------	--------	--------	--------	Pc	--------	--------	abd
253	13°10′ 29°14′	Umm Mgeisein	1950	337	--------	--------	--------	--------	--------	N/Pc	--------	--------	abd
257	12°52′ 29°08′	Lubana	1950	450	354	1953	--------	--------	--------	N	1,000	86.0	
262	11°45′ 28°23′	Rigl El Fula	1950	431	340	4–50	--------	ss	13	N	1,360	91.5	

TABLE 2.—*Description of selected drilled wells (boreholes)*—Continued

Well	Latitude (N.) Longitude (E.)	Locality	Year drilled	Depth of well below land surface (ft)	Approximate water level		Water-bearing material				Yield (imperial gallons per hour)	Temperature (°F)	Remarks
					Below land surface (ft)	Date measured	Depth to top below land surface (ft)	Lithology	Thickness (ft)	Geologic unit			
280	12°13′ 27°42′	Umm Debeiba	1951	542	360	3–51	--------	--------	--------	N	1,500	--------	
281	12°29′ 27°29′	Humeir Dirra	1951	485	355	4–51	--------	--------	--------	N	1,200	--------	
287	12°54′ 31°13′	Umm Ruwaba	1951	398	--------	--------	240	--------	--------	UR	1,600	--------	
313	12°54′ 31°27′	El Ghabsha	1951	445	256	12–51	--------	cg	--------	UR	1,000	--------	
362	12°41′ 29°36′	Saata	1952	408	266	7–52	--------	--------	--------	N	1,220	--------	
408	15°12′ 31°53′	Umm Inderaba	1953	332	260	--------	--------	--------	--------	N	1,100	--------	
411	12°56′ 31°02′	Umm Gezira	1953	457	314	--------	--------	--------	--------	UR	920	--------	
413	12°56′ 30°56′	Samandia	1953	436	321	--------	382	ms	--------	UR	340	--------	
416	14°54′ 30°58′	Adat El Sungur	1953	366	230	--------	--------	--------	--------	--------	1,100	--------	
419	13°15′ 31°46′	Umm Bundug	1954	472	250	--------	472	bgr	--------	N/Pc	800	--------	
420	13°06′ 27°57′	Wad Banda	1953	450	347	--------	450	ss	--------	N	1,100	--------	
422	12°49′ 31°02′	Abu Hamra	1953	690	285	--------	306	cg	--------	UR	700	--------	
464	11°17′ 27°18′	Tibbun	1954	526	316	2–54	475	--------	--------	N	1,050	--------	
508	12°43′ 28°34′	Muniem	1955	508	400	--------	405	--------	--------	N	--------	--------	
509	12°59′ 31°09′	Umm Eennas	--------	377	270	--------	230/377	ss	15	UR	400	--------	
512	13°09′ 31°46′	Fuweila	1955	410	196	--------	250/410	cg	100+	UR	500	--------	
515	13°40′ 29°44′	Umm Kriedm	1954	238	178	--------	--------	--------	--------	UR/Pc	720	91.5	
520	13°40′ 29°47′	Umm Kriedm	1954	218	162	--------	176	--------	--------	UR/Pc	--------	91.5	

524	13°16′ 27°39′	Surfan	1955	402	325	--------	325	ss	--------	N	940	--------	
525	12°40′ 31°35′	Takual Musa	1955	1010	385	--------	455/512	ss	--------	UR/Pc	--------	--------	
529	13°39′ 29°43′	Umm Keidium	1955	261	--------	--------	--------	--------	--------	UR/Pc	--------	--------	abd
537	13°14′ 31°11′	Yasin	1955	435	--------	--------	435	--------	--------	UR/Pc	--------	--------	abd
543	14°08′ 31°25′	Idd Nabaq	1955	335	195	1955	223/335	ms, ss	12	UR	208	--------	abd
548	13°14′ 31°34′	Abu Awa	1956	416	260	1–56	290/416	ss	20+	UR	--------	--------	
553	14°06′ 31°22′	--------	1955	375	235	6–55	261 375	ss ss	9+ 1+	UR	1, 520	--------	
555	12°42′ 28°32′	Nahud	1955	478	360	10–55	380	ss	40±	N	1, 016	92. 0	
558	11°44′ 27°50′	Rahad	1956	467	352	4–56	405	ms, ss	50±	UR	1, 000	--------	
560	13°11′ 31°20′	Yassin	1955	361	--------	--------	--------	--------	--------	UR/Pc	--------	--------	abd
563	13°17′ 28°51′	--------	1955	155	--------	--------	--------	--------	--------	Pc	--------	--------	abd
563A	13°10′ 29°06′	Umm Bum	1956	70	--------	--------	--------	--------	--------	N/Pc	--------	--------	
567A	13°05′ 29°05′	Umm Bum	1956	460	--------	--------	--------	--------	--------	N/Pc	--------	--------	abd
589	13°04′ 31°18′	Sinnein (Umm Riswa)	1956	550	288	--------	360	--------	--------	UR	1, 030	--------	
607	12°49′ 29°02′	Zaleta	1956	512	400	6–56	425	ss, cg	30±	N	1, 200	85. 0	
608A	11°44′ 27°50′	Rahad Aradeib	1956	475	360	12–56	405 475	ss ag	55±	UR	--------	--------	
614	11°30′ 28°03′	Sumuaa	--------	435	300	--------	--------	--------	--------	UR/N	--------	--------	abd
620	14°07′ 28°29′	Suwgar	1956	230	--------	--------	--------	--------	--------	Pc	--------	--------	abd
625	13°32′ 31°35′	Wad Radalla	--------	1, 051	--------	--------	--------	--------	--------	UR	--------	--------	
641	11°01′ 29°43′	Kadugli	1957	85	45	1–57	58	wb	22±	Pc	800	--------	
642	13°26′ 31°59′	Between Umm Sagaum and Fashakhti.	1957	585	232	1–57	298 585	ss ms	10±	UR	1, 000	--------	
679	12°40′ 29°00′	Khommas	1957	406	320	1957	--------	--------	--------	--------	1, 200	--------	
751	15°55′ 30°30′	Abu Urguq	--------	530	400	--------	440	--------	--------	N	960	--------	
755	12°48′ 28°43′	Near Markib	1957	475	345	10–57	350	ss	85+	N	1, 200	--------	
765	13°15′ 32°00′	Umm Damir	--------	550	--------	--------	440	--------	100	UR	--------	--------	

TABLE 2.—*Description of selected drilled wells (boreholes)*—Continued

Well	Latitude (N.) Longitude (E.)	Locality	Year drilled	Depth of well below land surface (ft)	Approximate water level: Below land surface (ft)	Approximate water level: Date measured	Water-bearing material: Depth to top below land surface (ft)	Water-bearing material: Lithology	Water-bearing material: Thickness (ft)	Water-bearing material: Geologic unit	Yield (imperial gallon ptr hour	Temperature (°F)	Remarks
766	12°27′ 28°24′	El Tehib	1957	274	--------	--------	--------	--------	--------	N	--------	--------	abd
775	11°32′ 27°22′	Iral El Dash	--------	416	335	--------	365	--------	--------	UR	1,200	--------	
820	14°25′ 29°05′	Sodiri	1958	130	--------	--------	108	--------	--------	Pc	--------	--------	abd
843	12°04′ 27°07′	Sharafa	1958	500	345	--------	365	ss	30+	UR	1,080	--------	
849	11°01′ 29°43′	Kadugli	--------	120	33	--------	35	--------	--------	Pc	1,200	84.0	
850	11°29′ 27°50′	Sidr El Arad	--------	445	300	--------	320	cg	5+	UR	800	--------	
868	14°31′ 27°24′	Adat Es Sunta	1958	325	80	5–58	145	ss	15+	N	1,100	--------	
881	13°12′ 31°52′	Umm Kheizina	1958	500	--------	--------	250	--------	--------	UR	--------	--------	abd
884	12°55′ 31°07′	Umm Gannas	--------	555	--------	--------	--------	--------	--------	UR	--------	--------	
885	13°32′ 31°13′	Tibna	1959	500	--------	--------	--------	--------	--------	UR	--------	--------	
891	13°34′ 31°23′	Shurri	1959	580	--------	--------	--------	--------	--------	UR	--------	--------	
892	12°37′ 30°58′	Samandiya	1959	440	321	--------	--------	--------	--------	Pc	--------	--------	
893	13°06′ 31°18′	Wad Abu Sayed	--------	452	290	--------	--------	--------	--------	UR	--------	--------	
898	12°43′ 30°39′	Rahad	1959	400	80	--------	--------	--------	--------	Pc	1,250	--------	
909	11°29′ 27°35′	Geber El Dar	--------	442	315	--------	315	ss	--------	UR	900	--------	
920	11°52′ 27°35′	Humeidan	1959	600	--------	--------	390	ss	15	UR	--------	--------	abd
924	12°49′ 29°29′	Doma El Salam	--------	480	358	--------	435	--------	--------	N	960	--------	
925	11°18′ 27°46′	Babnusa	1959	925	305	3–59	330	ss	85+	UR/N	--------	105.0	

958	12°59′ 27°40′	Bardan El Nur	--------	450	332	--------	350	--------	--------	N	1,000	--------	
964	13°02′ 29°22′	Geber	--------	372	--------	--------	--------	--------	--------	N	--------	--------	
965	12°45′ 31°12′	Habubiya	1959	1,224	380	1959	1,155	ss	10	UR	320	--------	
969	12°42′ 28°30′	Nahud	1959	480	360	--------	365	--------	--------	N	2,800	91.5	
973	11°02′ 27°44′	Muglad	--------	490	280	--------	290	--------	--------	UR	--------	88.5	
994	13°01′ 29°19′	Between Wad El Shagh and Wad Qassin.	1959	450	355	--------	362	ss	--------	N/Pc	960	--------	
998	12°25′ 27°45′	Abu Rait	--------	500	370	--------	395	--------	30+	N	1,200	--------	
1008	11°45′ 28°23′	Rigil El Fula	--------	480	355	--------	370	--------	--------	N	960	--------	
1009	12°42′ 28°30′	Nahud	--------	482	363	--------	363	--------	--------	N	3,430	--------	
1017	13°07″ 29°38′	Umm Semema	--------	233	225	--------	233	bsch	--------	N/Pc	--------	--------	abd
1024	12°42′ 28°30′	Nahud	1960	490	365	--------	386	--------	--------	N	2,400	90.5	
1038	12°39′ 27°29′	Dar Doq	1960	425	320	--------	335	--------	--------	N	1,080	--------	
1040	11°18′ 27°38′	Umm Zaraib	1960	505	--------	--------	360	--------	--------	UR	--------	--------	
1092	13°01′ 31°44′	Umm Highligh	1960	507	--------	--------	--------	--------	--------	UR	800	--------	
1112	11°18′ 28°02′	Baggara	1960	440	220	--------	225	--------	--------	N	--------	--------	
1113	11°13′ 27°32′	Umm Deryna	1960	435	--------	--------	360	--------	--------	UR	240	--------	abd
1115	13°01′ 31°44′	--------	1960	505	252	--------	280	--------	--------	UR	1,152	--------	
1118	11°42′ 28°31′	Rigil El Fula	1960	485	--------	--------	--------	--------	--------	N	--------	92.0	
1141	12°43′ 30°39′	El Rahad 55–M	1960	225	--------	--------	95	ms, ss	30	--------	1,000	--------	
1146	14°59′ 30°08′	Hamrat El Wiz 55–A	1960	488	180	--------	272	--------	--------	N	1,920	--------	abd
1172	10°23′ 27°38′	El Fuda 54–G	1960	975	320	--------	395	--------	--------	N	1,900	--------	
1177	11°05′ 27°31′	--------	1961	430	--------	--------	290	--------	--------	UR	1,000	--------	

TABLE 3.—*Data from selected dug wells*

Map well number: Location is shown on plate 1 and parentheses indicate that log is listed in table 6.
Depth and water level: Measuring point top of inside curb on north side of well. Measured well depths and water levels are given in meters and centimeters. Reported measurements are approximate and are given in meters.
Diameter: Measured diameters are given in meters and centimeters: reported diameters are given in meters.
Lithology; ss, sandstone; cg, conglomerate; cm, creviced mudstone.
Yield: Reported or estimated yield at the time water level was measured.
Conversion of units: Meters may be converted to feet by using, 1 meter=3.28 feet; °F may be converted to °C by subtracting 32° and multiplying the remainder by 5/9.

Map Well No.	Latitude (N.) Longitude (E.)	Locality	Year constructed	Depth	Diameter	Water level		Water-bearing bed		Temperature (°F.)	Yield (imperial gallons per day)
						Below land surface (meters)	Date measured	Depth to top (meters)	Lithologic character		
(1)	13°51′ 29°51′	Shereia	----------	54	----------	----------	----------	53	Ss	----------	
(2)	14°01′ 31°02′	Shateb	----------	62	----------	60	----------	61	Cg	----------	
(3)	14°04′ 31°07′	Nubala	----------	60	----------	59	----------	59	Cg	----------	
4	14°10′ 31°15′	Iddenabag	----------	60	----------	56	----------	----------	----------	----------	
(5)	14°20′ 30°12′	Shershar (West)	----------	12	----------	----------	----------	----------	Ss	----------	
(6)	13°56′ 31°04′	10 miles south of Abu Shok	----------	58	----------	----------	----------	57	Cg	----------	
(7)	14°12′ 30°02′	Rubshan	----------	60	----------	----------	----------	----------	Cm	----------	
8	13°42′ 30°23′	Bara (East)	1958	17.3	1.7	17.2	11–61	----------	----------	85	
9	13°40′ 30°30′	Rokab	----------	30	2	----------	----------	----------	----------	----------	
10	13°39′ 30°30′	Umm Laham	----------	32	2	----------	----------	----------	----------	----------	
11	13°44′ 30°59′	Umm Bathi	----------	47	2	----------	----------	----------	----------	----------	
12	13°24′ 30°42′	Qoz Es Suweiba	----------	47	2	----------	----------	----------	----------	----------	
13	13°18′ 30°57′	Zaida	----------	49	----------	----------	----------	----------	----------	----------	
14	13°56′ 30°43′	Mireihbida	----------	34	----------	----------	----------	----------	----------	----------	
15	13°32′ 30°55′	Majrur	----------	45	----------	----------	----------	----------	----------	----------	

16	13°44′ 30°26′	Shereim El Omda	1951	20.0	2.3	19.5	11–61	----------	----------	87	4,000±
17	13°32′ 30°21′	Umm Galgi	1957	27.1	1.7	25.7	11–61	----------	----------	85	1,000±
18	13°36′ 30°24′	Essirer	1958	24.3	1.8	24.1	11–61	----------	----------	89	100±
19	14°24′ 30°24′	Kagmar	1951	10.4	1.2	10.0	11–61	----------	----------	81	
20	12°03′ 28°16′	El Odaiya	----------	13.9	----------	13.6	1–62	----------	----------	78	246+
21	12°21′ 29°15′	Abu Zabad	----------	11.5	1.0	4.2	1–62	----------	----------	80	6000±
22	14°26′ 27°58′	Hamrat Esh Sheikh	----------	19.3	1.5	19.1	1–62	----------	----------	----------	500±
23	14°24′ 29°09′	Sodiri	----------	27.4	----------	15.8	12–61	----------	----------	----------	1,000±
24	10°37′ 30°23′	Talodi	----------	21.0	----------	13.0	1–62	----------	----------	83	
25	11°52′ 31°03′	Rashad	----------	4.2	----------	2.0	1–62	----------	----------	----------	
(26)	12°38′ 28°32′	Rahad Es Silik	----------	44	----------	43	----------	----------	----------	----------	320±
27	13°29′ 28°06′	Umm Bel	----------	40	----------	36	----------	----------	----------	----------	

TABLE 4.—*Chemical analyses of water from 18 selected drilled wells (boreholes)*

[Results in parts per million except as indicated. Analyses made by the Ministry of Health, Republic of Sudan]

Well	Depth of well (feet)	Depth of well at time of sampling (feet)	Date of collection	Geologic unit containing principal aquifer	Specific conductance (micromhos per cm at 20° C)	Total hardness as $CaCO_3$	Total dissolved solids	Calcium (Ca)	Magnesium (mg)	Sodium (Na)	Silica (SiO_2)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Fluoride (F)	Ammonical nigrogen	Abbuminoid nitrogen
280	542	72	1951	Nubian	325	156	220	49	8	34	10	10	11	1.3	0.8	0.04	--------
419	425	--------	1954	do	3,500	--------	3,060	328	38	--------	28	624	1,120	--------	.8	.84	--------
463	344	235	1954	do	345	186	236	52	14	--------	28	31	21	.3	.6	.04	0.22
509	378	--------	--------	Umm Ruwaba	650	200	500	56	16	--------	20	76	84	--------	.6	.52	.48
510	330	--------	1955	do	1,000	258	720	69	22	--------	30	128	142	1.0	.8	.24	.10
512	410	--------	1955	do	1,300	140	1,000	90	--------	--------	50	90	240	20.0	.5	--------	1.0
524	325	--------	1955	Nubian	135	--------	130	20	2	--------	20	25	14	--------	.4	.18	.22
548	405	405	1956	Umm Ruwaba	3,000	550	2,360	160	35	4,490	20	290	680	50.0	.4	.68	.2
589	480	--------	1956	do	950	240	790	65	15	200	--------	15	180	28.0	.4	--------	--------
641	80	80	1957	Precambrian	550	302	420	81	24	27	160	10	26	4.0	1.3	--------	--------
820	108	108	1958	do	9,000	6,800	14,300	1,600	680	3,990	20	1,550	7,150	102.0	.2	.50	--------
909	442	442	--------	Umm Ruwaba	210	92	220	20	10	36	15	10	6	11.6	.6	.04	--------
925	925	440	1959	Umm Ruwaba or Nubian	350	78	260	18	8	83	10	10	40	.8	.3	.40	--------
953	335	335	--------	Nubian	310	134	240	40	8	41	10	10	22	.5	.9	--------	--------
973	315	315	--------	Umm Ruwaba	450	170	340	43	15	62	20	14	26	.6	.8	.08	--------
1040	505	--------	1960	do	4,000	37,000	--------	960	316	313	30	816	2,300	26.7	.3	.06	--------
1112	235	235	1960	Nubian	180	90	--------	23	8	19	10	10	4	1.4	.8	.04	--------
1146	450	450	1960	do	750	216	1,920	43	26	136	6	38	200	--------	3.1	.40	--------

TABLE 5.—*Logs of selected drilled wells (boreholes)*

Lithologic character	*Thickness (ft)*	*Depth (ft)*
Well 213:		
Surficial deposits:		
Sand (qoz)	35	35
Umm Ruwaba Series:		
Mudstone, sandy, yellow	26	61
Mudstone, sandy and gravelly	351	420
Well 408:		
Surficial deposits:		
Sand, fine-grained, loose, and reddish	13	13
Nubian Series:		
Mudstone, yellowish-brown	142	155
Mudstone, yellowish-brown	86	241
Mudstone, sandy, ferruginous	91	352
Well 464:		
Surficial deposits:		
Sand (qoz)	65	65
Umm Ruwaba Series:		
Sandstone, clayey, brown	117	182
Mudstone, greenish-brown	98	280
Sandstone, coarse-grained	75	355
Mudstone, sandy	117	472
Nubian series(?):		
Sandstone, pebbly	11	483
Sandstone, clayey	43	566
Well 492:		
Surficial deposits:		
Sand (qoz)	30	30
Nubian series:		
Sandstone, coarse- to medium-grained calcareous, pink	40	70
Sandstone, clayey, pink	50	120
Mudstone, sandy	80	200
Mudstone, sandy, pink	30	230
Sandstone, pebbly	40	270
Sandstone, clayey and pebbly	60	330
Mudstone, sandy and pebbly	70	400
Sandstone, silty and pebbly	90	490
Well 751:		
Surficial deposits:		
Not recorded	10	10
Nubian Series:		
Shale	5	15
Sandstone, medium- to coarse-grained, ferruginous	45	60
Mudstone, sandy, red	35	95
Mudstone, purplish-gray	125	270
Sandstone and mudstone, interbedded	35	255
Shale	120	375
Mudstone, clayey, pink	45	420
Sandstone, medium- to fine-grained	50	470
Sandstone, clayey, pink	40	510
Well 849:		
Surficial deposits:		
Clay, sandy, having decomposed rock fragments	20	20
Basement complex:		
Crystalline rocks, undifferentiated	275	305
Well 868:		
Surficial deposits:		
Sand, clayey, calcareous, buff	30	30
Nubian Series:		
Mudstone, sandy, white and buff	30	60
Sandstone, fine-grained, pebbly; contains some clay	100	160
Mudstone, pebbly	40	200
Sandstone, clayey, calcareous, pink	40	240
Mudstone, pebbly, reddish-brown	85	325

TABLE 5.—*Logs of selected drilled wells (boreholes)*—Continued

Lithologic character	*Thickness (ft)*	*Depth (ft)*
Well 994:		
Surficial deposits:		
Sand, ferruginous, reddish-brown (qoz)	40	40
Nubian Series:		
Sandstone, clayey	20	60
Mudstone, sandy, orange-gray	115	175
Sandstone, coarse-grained, clayey	10	185
Mudstone, sandy	30	215
Sandstone, coarse-grained; contains pebbles	10	225
Sandstone, clayey, and pebbly	40	265
Mudstone, sandy; contains pebbles	30	295
Sandstone, clayey yellowish-brown; contains rounded quartz pebbles	60	355
Sandstone, fine- to medium-grained, pebbly and clayey	15	360
Sandstone, pebbly	30	400
Basement complex:		
Crystalline rocks, undifferentiated	50	450
Well 1038:		
Nubian Series:		
Sandstone, fine-grained, calcareous, pink	80	80
Sandstone, clayey, pink	40	120
Sandstone, coarse-grained, clayey	95	315
Sandstone, clayey and pebbly	15	330
Sandstone, medium-grained, clayey, pink	105	455
Well 1092:		
Surficial deposits:		
Sand, clayey, yellowish	45	45
Umm Ruwaba Series:		
Mudstone, sandy, yellowish-brown; contains calcareous nodules	145	190
Mudstone, conglomeratic, calcareous	75	265
Sandstone, pebbly, yellowish-brown	30	295
Sandstone, clayey, bluish-white	112	507
Well 1146:		
Surficial deposits:		
Clay, sandy, buff	10	10
Sand, loose, pebbly	45	55
Nubian Series:		
Sandstone, fine-grained	70	125
Mudstone, calcareous and nodular	10	135
Sandstone, coarse-grained, clayey, purple	10	145
Mudstone, purple, gray, brown	160	305
Mudstone, gray	153	458
Well 1172:		
Surficial deposits:		
Sand	10	10
Umm Ruwaba Series:		
Sandstone, clayey	230	240
Sandstone, pebbly	60	300
Sandstone, clayey and pebbly	200	500
Sandstone, pebbly	35	535
Sandstone, clayey	30	565
Mudstone, sandy	10	575
Sandy mudstone and clayey sandstone, interbedded	235	710
Nubian Series:		
Sandstone	10	720
Sandy mudstone and clayey sandstone, interbedded	90	810
Sandstone, clayey	55	865
Mudstone, sandy	6	871

TABLE 6.—*Logs of selected dug wells*

Lithologic character	*Thickness (meters)*	*Depth (meters)*
Well 1:		
Surficial deposits:		
Sand, red, grading to white (qoz)	9	9
Umm Ruwaba Series:		
Mudstone, gray, soft	1	10
Sandstone, loosely consolidated	43	53
Sandstone, semiconsolidated, water-bearing	1	54
Well 2:		
Surficial deposits:		
Sand, red, grading to yellow (qoz)	37	37
Umm Ruwaba Series:		
Mudstone	24	60
Conglomerate, clayey	1	61
Conglomerate, loosely consolidated, water-bearing	1	62
Well 3:		
Surficial deposits:		
Sand, red (qoz)	37	37
Umm Ruwaba Series:		
Mudstone	21	58
Conglomerate, clayey	1	59
Conglomerate, unconsolidated, water-bearing	1	60
Well 5:		
Surficial deposits:		
Silt, gray, compact	11	11
Sand, yellow, compact	1	12
Well 6:		
Surficial deposits:		
Sand, red (qoz)	35	35
Umm Ruwaba Series:		
Mudstone	21	56
Conglomerate, clayey	1	57
Conglomerate, unconsolidated, water-bearing	1	58
Well 7:		
Surficial deposits:		
Sand (qoz)	6	6
Umm Ruwaba Series:		
Sandstone, unconsolidated	36	42
Mudstone, gray; contains crevices; water bearing near bottom	18	60
Well 26:		
Nubian Series:		
Mudstone, brown	24	24
Mudstone, sandy, gray	1	25
Mudstone, gravelly	4	29
Basement complex:		
Gneiss, weathered	1	30

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