PREPARED FOR
INTERNATIONAL COOPERATION ADMINISTRATION

Report On

Potable Water Supply In The Republic Of The Sudan

TUDOR ENGINEERING COMPANY, WASHINGTON, D. C.
APRIL 1959

52

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RALPH A. TUDOR
L. A. HELGESSON
CARL A. TREXEL

TUDOR ENGINEERING COMPANY

595 MISSION STREET, SAN FRANCISCO 5 · YUKON 2-9010

Address reply to 1413 K St., N.W., Washington 5, D. C. • STerling 3-5313

International Cooperation Administration
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Washington 25, D. C.

April 15, 1959
Reference: TEC-247, 247-A1

SUBJECT: POTABLE WATER SUPPLY IN THE REPUBLIC OF THE SUDAN

Gentlemen:

Pursuant to Task Order 247 and its revision 247-A1, issued on September 10, 1958, Tudor Engineering Company submits herewith a report on the Potable Water Supply in The Republic of the Sudan. A brief description of the requirements of the task order is included in the introduction to this report.

The Tudor Engineering Company engaged the services of E. C. Marliave and Cole R. McClure, Jr., consulting geologists and ground water specialists. The consultants left Washington, D. C. on January 8 and returned on March 25, 1959. En route to the Sudan they stopped off in Rome, Italy, to investigate the United Nations reports on Water Supply in the Sudan. While in the Sudan they made trips into Kordofan, Darfur, Kassala, and Equatoria Provinces to investigate the field conditions. While in Khartoum, Sudan, they reviewed much of the work being carried on by the various agencies of the Sudanese Government, conferred with the officials, and summarized data available in published and unpublished reports.

The accompanying report was prepared by the consultants after their return to Washington and is based on a review of the materials available in Washington, Rome and Khartoum, and on their own field observations.

A summary of the principal conclusions and recommendations immediately follows the table of contents. The subsequent chapters of the report are devoted to a discussion of the data developed, their analyses, and the proposals which are offered for immediate action, and those which would be extended over a period of time.

If these recommendations are approved and implemented, ICA could make a material contribution towards an increase in the supply of potable water in the Sudan.

Very truly yours,

TUDOR ENGINEERING COMPANY

John G. Marr

John G. Marr
Project Manager

JGM:rbm

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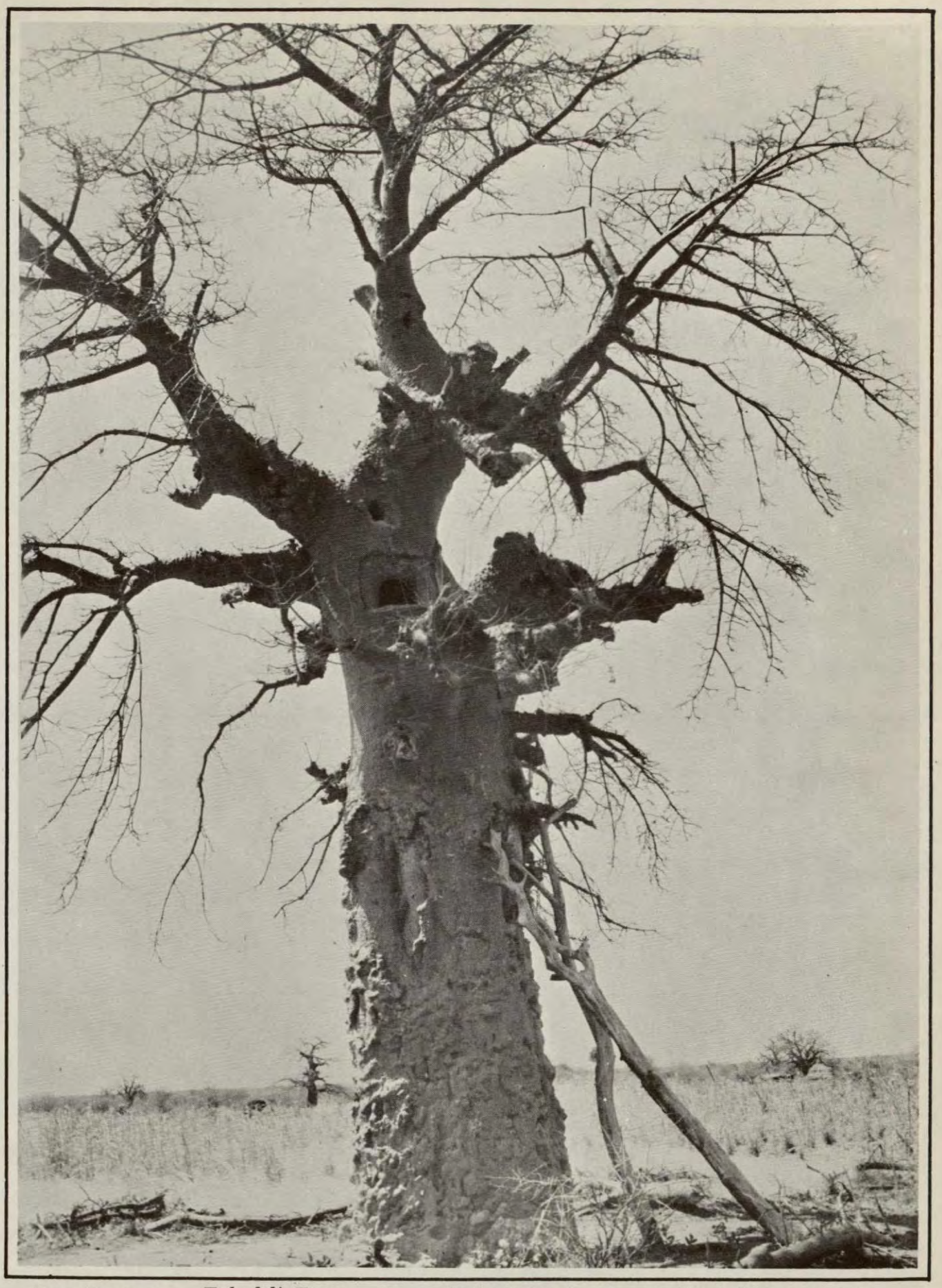

Frontispiece. Tebeldi Tree. A symbol of the shortage of potable water in the Sudan. These trees are hollowed out, filled with water scooped from depressions in the ground or collected in containers during rains, and the water is stored for use during the dry season.

POTABLE WATER SUPPLY
IN
THE REPUBLIC OF THE SUDAN

Summary of Conclusions

As a result of this survey a summary of the principal conclusions is presented below. These are based on the conclusions in Chapter V of the text of this report.

1. There is a great shortage of potable water over much of the Sudan and the relief of any appreciable portion of this shortage in the next few years will require: (a) immediate action, (b) a program of rapid exploitation of the available water resources of the country by means of wells and hafirs (storage ponds) and (c) a long range study to determine more accurately the available ground water supply and the areas where this water may be economically obtained.

2. The areas of crystalline rock bordering the Sudan along the west, south and east sides are not suitable for deep wells. Along the southern boundary, hafirs and small check dams offer the best approach to a partial solution of the water supply problem.

3. The Nubian formation underlying much of the northerly portion of the Sudan, and to a lesser extent the Umm Ruwaba formation in the south central portion offer the best sources of ground water for deep wells, though occasionally saline waters may be encountered in the Umm Ruwaba.

4. A combination of geologic mapping, surface study, drilling data and geophysical exploration offer the best means of attacking the well location problem.

5. A need exists for the following items with respect to training of personnel concerned with potable water supply in the Sudan.

a. A study and training program of advanced methods of well drilling and particularly the use of thin wall casings and knife perforations.

b. An accelerated program for training Sudanese drillers.

c. A training program for Sudanese geologists and geophysicists in the United States in the latest methods of ground water inventory and study and geophysical surveying methods, respectively.

d. A program of assistance to the Sudanese government by United States technicians for a period of about one year in ground water inventory and long range ground water study methods.

e. A program of assistance and training with regard to low cost hafir lining.

6. There is also presently a need for a moderate increase of technical Sudanese personnel on the staffs of both the Geologic Survey and the Land Use and Rural Water Development Department to more effectively cope with any new program of water development adopted. Depending on the nature and requirements of any new program, a plan and appropriate budget for an orderly additional increase of such technical personnel as may be deemed necessary in the future should be provided for over a period of years.

7. Drilling equipment is operated by several government agencies in the Sudan. It would be desirable to have all drilling equipment grouped under one agency for more efficient operation and maintenance.

8. At least two Sudanese government agencies are now operating shops for the repair and maintenance of water well pumps of the same make and type. A single agency should be able to do all the work in a more efficient manner.

9. It would be prudent to have a limited amount of high level technical consultant assistance to, and in cooperation with, the Sudanese government to insure that any program adopted will be prosecuted as effectively and beneficially as possible.

Summary of Recommendations

Based on the conclusions arrived at in this report, the following summary of the principal recommendations is presented. These are in accord with the more detailed recommendations contained in Chapter VI.

A plan of action must be set up at an early date to incorporate the following items:

1. Send the drilling engineer of the Land Use and Rural Water Development Department to the western United States for a period of six weeks to study well drilling procedures and particularly the use of various types of casing and knife perforation of casings in water wells. This recommendation is one of the least expensive and yet one of the most important proposed.

2. Send two Sudanese geologists to a United States agency for 4 or 5 months training in the latest methods of ground water study and inventory, and one Sudanese geophysicist to an approved school in the United States for two years advanced training in methods of geolphysical surveying and practical field work. This suggested training program should be repeated for several years, or as often as desirable to train the required number of Sudanese personnel.

3. Provide three rotary drills of heavy duty type, complete with transport, water tanks, spare parts and fishing

tools. Have the equipment supplier send to the Sudan one drilling engineer, four drilling instructors and a mechanic. The drilling personnel would instruct the drilling crews in the use and maintenance of rotary drilling equipment and the use of mud. The time and cost for a training program is outlined in Appendix A.

4. Contract with a qualified agency for a reconnaissance geophysical survey of the problem areas indicated in western Sudan and, if necessary and desirable, be prepared to implement the reconnaissance survey with more detailed surveys at a later date.

5. Commence at once a ground water inventory and long range study of the ground water situation in the Sudan, utilizing the available ground water geologists of the Geological Survey, assisted by two additional Sudanese survey members to be added to the Ground Water Section, and two United States ground water technicians familiar with ground water techniques.

6. Provide equipment and one United States technician with experience on low cost canal and reservoir lining, research and construction to conduct the proposed experimental work on hafir lining in the Sudan.

7. Provide by proper planning and budgeting for an orderly increase in Sudanese personnel for the Geological Survey and Land Use and Rural Water Development Departments to implement the water supply study and the exploitation of ground water in the Sudan.

8. Place all Sudanese drilling equipment under the supervision of the present Drilling Division and make this agency responsible for its operation and maintenance.

9. Place responsibility for repair and maintenance of all water yard or water well pumps used by the government in the hands of a single appropriate agency.

10. Provide for a limited amount of high level United States technical supervision and consulting service to be available to the Sudanese government for the purpose of implementing the program and providing advice and guidance for future programming when and if needed. This could be in the form of an advisory committee on potable water problems or on an individual consultant basis.

ACKNOWLEDGMENTS

Geographically the Sudan is a very large country and the problems of transport and communications are tremendous. To see and even attempt to study any appreciable portion of the area and the attendant water supply problems in the short time available for this survey would have been very difficult without a great deal of local assistance.

Fortunately, the survey team was given every possible assistance from the highest governmental level to that of the local Sudanese people encountered in the field. Without this generous assistance furnished the team at all times, the gathering of, and reporting on data, would have been almost impossible. Much of the information used in this report has been gleaned from previous publications and particularly from reports and maps made available by the Sudanese Geological Survey. The publications and maps referred to in Appendix G were the references used most frequently.

The many people who assisted the team in its endeavor are too numerous to list in full, although their services are gratefully acknowledged. Particular thanks are due the following persons who were especially helpful:

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Survey Department

Mr. G. Y. Karkanis, Assistant Director, Geological
Survey Department

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Development Department

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Land Use and Rural Water Development
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Mr. Robert W. Kitchen, Jr., Director, USOM, Sudan,
and his staff.

CHAPTER I

INTRODUCTION

Purpose

Potable water supplies are deemed insufficient to meet the requirements of the people in much of the Republic of the Sudan. Especially critical areas are portions of Kordofan, Darfur, Kassala and Equatoria Provinces.

Following discussions with members of the ICA staff in Washington, the USOM staff in Khartoum and members of various interested units of the Government of the Sudan, the team began its evaluation of the development program of the potable water resources. The purpose of the study was to determine what could be accomplished to best meet the potable water requirements of the country. Included in this study was an examination of portions of the current five-year water development plan and a critical appraisal of the ground water program. The team was instructed to make recommendations concerning the most appropriate methods of exploration and exploitation, equipment requirements, capability of existing organizations, and, in general, the most feasible means of obtaining necessary potable water to rapidly solve the critical water shortage problem.

Location

The Republic of the Sudan is located in the northeastern portion

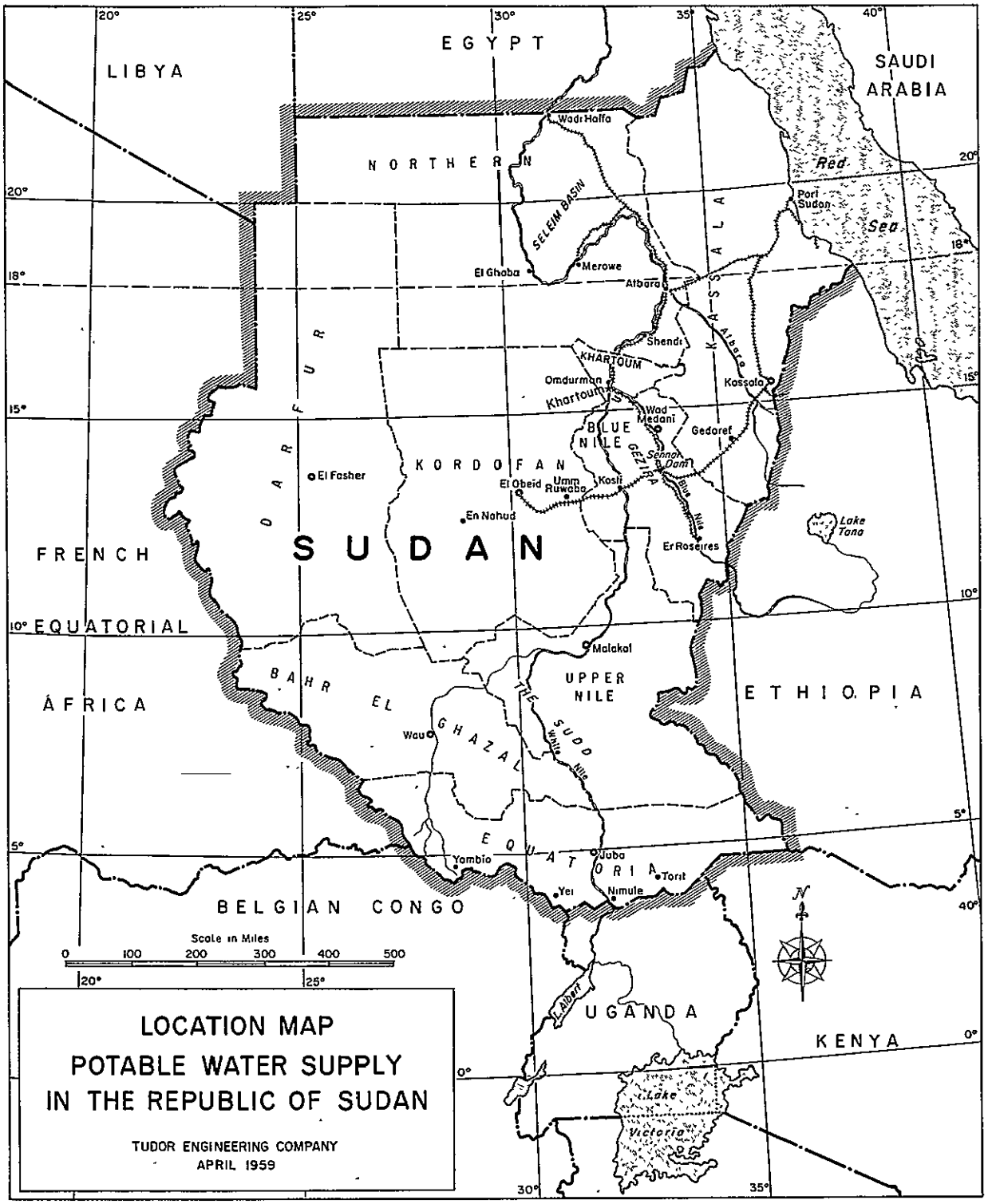
of Africa. It extends from the southern boundary of Egypt and Libya on the north to the northern boundaries of the Belgian Congo, Uganda and Kenya on the south. It is bounded by French Equatorial Africa on the west and the Red Sea and Ethiopia on the east. The Sudan, which is larger than the portion of the United States east of the Mississippi River, has approximately 967,500 sq mi of area, and is about 1300 miles long and almost as wide (see Plate I). This country is characterized by extremes of climate and vegetation. The population of the Sudan, some eleven million people, is composed of various groups, having widely different faiths and cultures.

Climate

The climate is predominately continental in character. The climate of the area bordering the Red Sea is unlike that of most of the country, being greatly influenced by marine characteristics.

The northern portion of the country lying north of 18°N latitude, is essentially a desert area. The rainfall is generally less than 50 mm, (2 in.) and the temperature may range from 50°C to about 5°C.

Central Sudan, an area lying roughly between 10°N and 18°N latitude, is predominately semi-arid and has a rainfall range of from 50 to 900 mm (2 to 36 in.). Precipitation is generally confined to the period from May to October. Temperature in this area may range from over 40°C in the summer to a low of about 10°C in the winter.



LOCATION MAP
POTABLE WATER SUPPLY
IN THE REPUBLIC OF SUDAN

TUDOR ENGINEERING COMPANY
APRIL 1959

PLATE I

The mean annual temperature is about 28°C. The main area of critical shortage of potable water is found within this climatic zone.

The southern area, that portion lying south of 10°N latitude, is characterized by a sub-tropical to tropical climate. The rainfall exceeds 900 mm (36 in.) per year and occurs generally throughout the year, the higher rainfall period being from April through October. Temperatures range from 20°C to about 40°C. Portions of this area are also faced with a shortage of potable water. As will be explained later, this area is treated separately from those in the northern portions of the Sudan primarily due to its climatic differences.

Previous Investigations

Most of the ground water data concerning the Sudan appears in short, unpublished reports prepared by members of the Geological Survey over a period of about 50 years. One of the first published reports on a proposed program of ground water studies was prepared by H. A. Waite in 1955 and is entitled "Program of Ground Water Investigations for the Anglo-Egyptian Sudan." A subsequent report entitled "Geologic-Hydrologic Research in the Arid and Semi-Arid Zones of the Western Sudan" was prepared by H. Kleinsorge and J. Zscheked of the German Federal Republic. This report is dated July 1958, and is concerned with the ground water geology of a portion of western Kordofan Province.

Another report, also prepared in 1958, entitled "A Program of Ground Water Investigation," was published by the Food and Agriculture Organization of the United Nations. This report is critical of the Geological Survey and contains recommendations for ground water development of areas comprised of rocks normally considered to be non-water bearing.

Probably one of the most valuable reports on ground water in the Sudan will be the report now being prepared by G. Y. Karkanis, Assistant Director of the Geological Survey. This report is to present a history and compilation of ground water data obtained during the last 50 years.

There are large amounts of data, both published and unpublished, available from the Geological Survey, concerned primarily with geology other than that of ground water geology and hydrology. A bibliography is contained in Appendix G of this report.

CHAPTER II

GROUND WATER GEOLOGY

Areal Geology

The vastness of the Sudan, the problem of transportation and the limited time available to the survey team prevented a general study of the ground water geology of the country. Nor is such a study necessary in light of the immediate task to be accomplished. Accordingly, emphasis was placed on certain specific aspects of ground water development and the features appurtenant thereto. The following brief description of the general geology of the Sudan is merely to provide a background for the discussion which follows. The information is taken largely from Sudanese publications, supplemented by information obtained from the Sudan Geological Survey, coupled with the limited observations made during various field trips.

The Sudan is essentially a large plain developed on an old crystalline rock erosion surface, probably a peneplane or series of peneplaned areas. Crystalline masses are exposed as mountains and hills along the western boundary and along the southern and southeastern boundaries, while sedimentary hills along the Red Sea are uplifted to the northeast, with the Libyan desert to the north and northwest. These highlands surround a large crystalline mass of low relief

which occupies the central portion of the country (see Plate II). Tertiary volcanics, principally basaltic lavas, cap large areas of the surrounding crystalline mass and to a limited extent occur as smaller cappings in the central plains area.

The present plains area is one of aggradation with sediments being carried down from the surrounding highlands and deposited in the more central area, burying the underlying formations to greater and greater depths and gradually covering the protruding rock masses or inselbergs. This approximates the pan-fan stage of the desert cycle. The Nubian formation, largely sandstone, extends over considerable areas of the northern portion of the Sudan while the south central portion contains large areas of the continental Umm Ruwaba formation overlying the Nubian formation. A dissected plateau surface has been developed on the Nubian suggesting an advanced stage of stream erosion to the point where stream erosion has become a limited factor due to lack of rainfall, and where insolation and gravity are the principal agents in developing the rather stable hamada type surface.

The principal deposition occurring in the central plains area was the Nubian formation, which once covered much more extensive areas and to greater depths and is now being gradually eroded away.

The Umm Ruwaba formation is a continental fluviatile deposit of several hundred feet in maximum thickness and is quite extensive

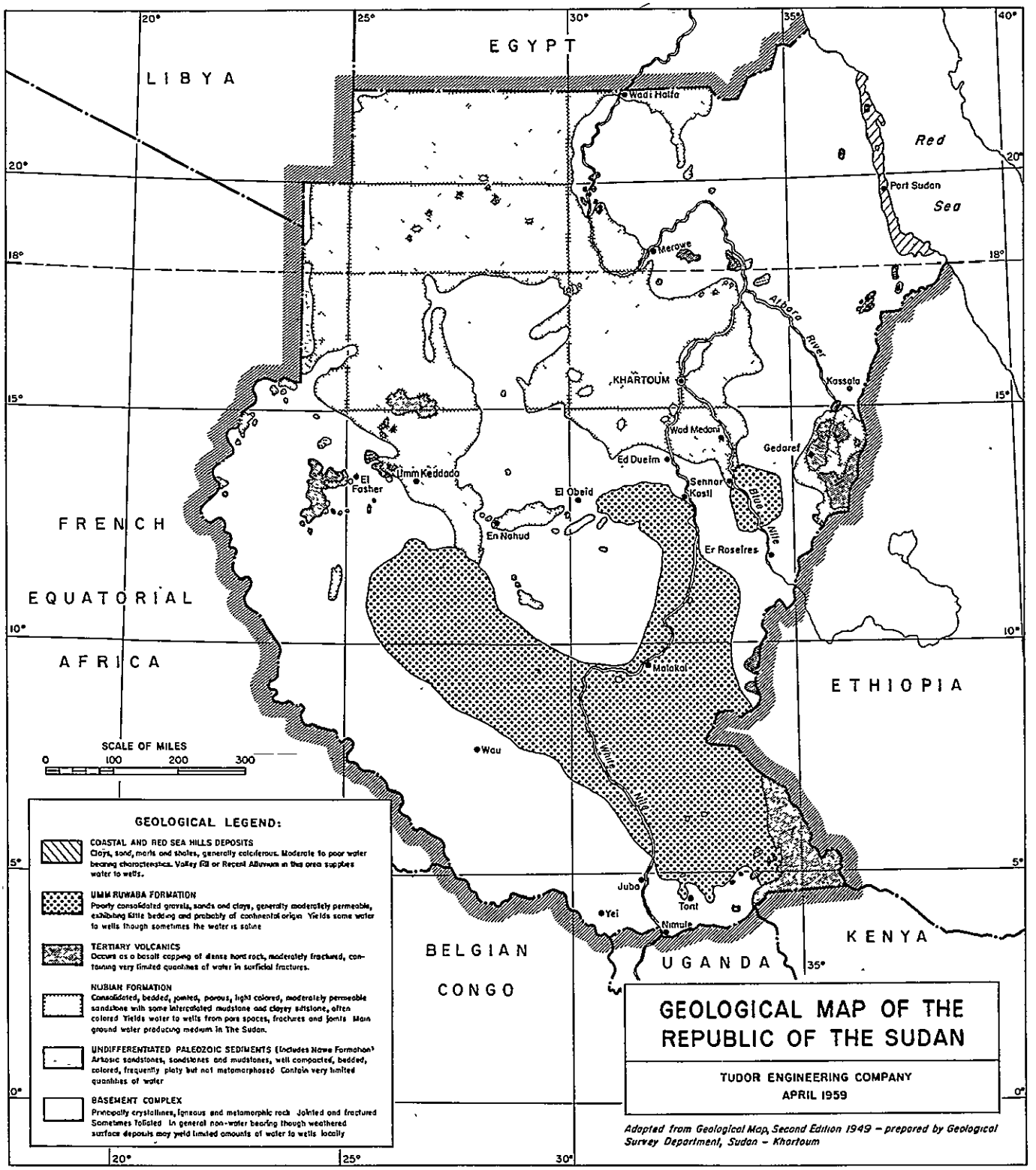

EGYPT
LIBYA
Red Sea
Wadi Halfa
Port Sudan
Merowe
Atbara River
KHARTOUM
Kassala
Wad Medani
Gedaref
Ed Dueim
Sennar
Kosti
Blue Hills
El Fasher
Umm Keddada
El Obeid
En Nahud
Er Roseires
FRENCH EQUATORIAL AFRICA
Malakal
ETHIOPIA
SCALE OF MILES
0 100 200 300
Wau
White Nile
Juba
Tonj
Yei
Nimule
BELGIAN CONGO
UGANDA
KENYA
GEOLOGICAL LEGEND:
COASTAL AND RED SEA HILLS DEPOSITS
Clays, sand, marls and shales, generally calciferous. Moderate to poor water bearing characteristics. Valley fill or Recent Alluvium in this area supplies water to wells.
UMM RUWABA FORMATION
Poorly consolidated gravels, sands and clays, generally moderately permeable, exhibiting little bedding and probably of continental origin. Yields some water to wells though sometimes the water is saline.
TERTIARY VOLCANICS
Occurs as a basalt capping of dense hard rock, moderately fractured, containing very limited quantities of water in surficial fractures.
NUBIAN FORMATION
Consolidated, bedded, jointed, porous, light colored, moderately permeable sandstone with some intercalated mudstone and clayey siltstone, often colored. Yields water to wells from pore spaces, fractures and joints. Main ground water producing medium in The Sudan.
UNDIFFERENTIATED PALEOZOIC SEDIMENTS (Includes Nawa Formation)
Arkosic sandstones, sandstones and mudstones, well compacted, bedded, colored, frequently platy but not metamorphosed. Contain very limited quantities of water.
BASEMENT COMPLEX
Principally crystalline, igneous and metamorphic rock. Jointed and fractured. Sometimes foliated. In general non-water bearing though weathered surface deposits may yield limited amounts of water to wells locally.
GEOLOGICAL MAP OF THE REPUBLIC OF THE SUDAN
TUDOR ENGINEERING COMPANY
APRIL 1959
Adapted from Geological Map, Second Edition 1949 – prepared by Geological Survey Department, Sudan – Khartoum

PLATE II

laterally. These materials are much younger than the Nubian in age and probably represent a wetter climatic cycle than that of the present day. These sediments were deposited in a topographic low in the Nubian possibly created by erosion and by local down warping. The materials are principally poorly consolidated sands and clay sands with some gravelly phases. Above the Umm Ruwaba in geologic succession are the Kordofan sands and Qoz sands of the western desert area and the clay plain deposits of the south central area. Most of the area is centrally drained by the Nile River and its tributaries, though most of the tributaries do not have flow reaching the Nile at the present time.

Apparently little structure has been developed in any of the rocks of Paleozoic or later age other than that resulting from gentle up or down warping. In middle Tertiary times the only significant movement was the rising of the Red Sea Hills block and the Abyssinian Plateau and the development of the Red Sea Basin to the east, probably along a line of major faulting (Rift Valley of Africa) just off the westerly margin of the Red Sea.

For practical purposes the rocks of the Sudan may be divided into two series: the water-bearing and non-water bearing. The water-bearing rocks are those which absorb, transmit and yield water in sufficient quantities to be of economic value, while the non-water bearing rocks are those which do not absorb, transmit or yield water in sufficient

quantities to be of economic importance.

In various parts of the world, the use of the terms water-bearing and non-water bearing may have different meanings since they are relative to the potentialities of the various existing rocks. While the Nubian formation in the Sudan is classed as water-bearing rock, it would generally be considered to be essentially non-water bearing in the western United States because of its low permeability and yield. The crystalline rocks, on the other hand, would generally be classed as non-water bearing the world over, although there are always specific local exceptions.

The non-water bearing rocks are important in that they form the container or basin in which the water-bearing series are deposited and prevent the migration and loss of appreciable quantities of water in a downward or lateral direction.

The water-bearing series absorb, transmit and store water in the pore spaces, joint planes and fractures, and retain or build up a ground water body to a level dependent on inflow and outflow. As water development and exploitation occurs, the water table and the quantity of water in storage may fluctuate depending on the balance between recharge and extraction.

Water-Bearing Series

The three water-bearing rock units noted during this survey of the Sudan are as follows:

(1) The Recent Alluvium of the stream channels and flood plain deposits along the Nile, portions of the Red Sea Hills deposits along the northwest edge of the Red Sea, and the Qoz and Kordofan sands of the western desert area.

(2) The Umm Ruwaba formation.

(3) The Nubian formation.

Recent Alluvium. These deposits are ill sorted, unconsolidated, unweathered gravels, sands, silts and clays of fluviatile origin and are primarily found in the recently active stream channels. Available maps are of such small scale that delineation of the areal extent of these deposits would not be feasible and for this reason they are not shown on the geologic map (Plate II). These materials are important in that, with their inherent high degree of permeability, they allow for rapid absorption of surface water and can store and transmit water to the underlying less permeable formations such as the Umm Ruwaba and Nubian. In the vicinity of the Nile, the Recent flood plain sediments are potential sources of large quantities of ground water though, along most of the ephemeral streams, the deposits are so limited that they do not represent an appreciable source of water.

The Red Sea Hills deposits of clays, sands, marls and shales are included in the water-bearing portions of the Recent Alluvium, as the detrital material from these deposits provide a very limited but permeable valley fill. The Red Sea Hills deposits in themselves are not considered to be permeable to any appreciable extent.

Where the permeable valley fill deposits have access to the waters of the Red Sea, care should be exercised in extraction of the fresh water, as a reversal of a seaward hydraulic gradient would allow the intrusion of saline water into the fresh water body.

The Qoz and Kordofan sands, though generally surface deposits well above the water table, occasionally contain small amounts of perched water.

Umm Ruwaba Formation. This unit consists of a series of gravel, sands and silts and clays, poorly consolidated, slightly bedded, of fluviatile origin primarily, though some of the beds are believed to be lacustrine. Areally it is distributed in the south central portion of the southern half of the Sudan, resting upon the eroded surface of the Nubian sandstone or the crystalline complex.

The Umm Ruwaba formation is capable of absorbing, transmitting, storing and yielding moderate quantities of water. Its absorptive capacity is moderate except where the finer constituents are present at or near the surface. Because of the fine grained nature of much of this formation, water production is frequently low and fines may be pumped with the water unless proper screening or packing measures are employed. Since some of the Umm Ruwaba may have its origin in desert climates and playas probably existed, it is not surprising that saline waters are frequently encountered in this series. When more data are available from various

types of exploration and study, it may be found that the saline areas were located in topographic lows at the time of deposition and that the salines result from evaporation of playa lakes.

Nubian Formation. This formation is comprised primarily of lithified sandstones, moderately well bedded, frequently exhibiting cross bedding, nearly flat lying and moderately jointed. The sands are medium grained and quite uniform in size and indicate rather uniform conditions as well as extensive areas of deposition. Frequent interbeds of mudstone, siltstones, claystones and conglomerates may be found and these are often reddish to purple in color and quite impermeable. The formation as a whole is moderately water-bearing and represents the best source of ground water in the entire Sudan. Water is transmitted and contained in the intergranular pore spaces and along the bedding, joint, and fracture planes. The average permeability is low, hence water is yielded to wells at a low rate.

The Nubian was deposited over an irregular surface, developed on a peneplaned igneous and metamorphic rock mass. The topographic lows were filled first and subsequent deposition, in nearly horizontal fashion, continued over more and more of the eroded surface. Thus the developed thickness of Nubian is not constant. It feathers out along and around the crystalline rock masses and is deepest where original topographic lows existed. Over much of the plains area, isolated hills or ridges of crystalline rock (inselbergs) protrude

through the sandstone thereby indicating peripheral areas where the Nubian is very thin.

In the deeper basins are the lows in which storage of most of the ground water should be expected. These areas are not easy to find by surface geologic mapping, even with the well data available from drilling, since few of the wells have penetrated the entire Nubian section. Hence, geophysical surveying is recommended to determine the location of lows and greatest depths of the Nubian formation.

Non-Water Bearing Series

The non-water bearing series as previously pointed out do not normally yield economic quantities of water. Four non-water bearing units are currently recognized in the Sudan as follows:

(1) Basement Complex

(2) Undifferentiated Paleozoic Sediments

(3) Hudi Formation

(4) Tertiary Volcanics

Basement Complex. The Basement Complex rocks consist primarily of crystalline meta-igneous, meta-sedimentary and granitic types. They are dense and hard and the joints are relatively tight where the rock is fresh and contain no pore spaces for storing or transmitting water. Very limited quantities of water may be obtained near the surface in the more open fractures and joint planes and in the severely weathered surficial portions of such rocks. In general,

they must be considered non-water bearing although, as indicated, locally the weathered mantle and surficial joints and fractures may contain small quantities of water. These rocks should not be regarded as sources of water and, in general, requests for wells in such areas should be denied.

Areas underlain by these rocks, however, may provide excellent locations for surface storage reservoirs, as the rocks act as a confining medium. These rocks are sufficiently impervious to prevent loss of ponded water, except along fractures or joints.

Undifferentiated Paleozoic Sediment. The undifferentiated Paleozoic sediments (including the Nawa Series) are unmetamorphosed arkosic sands, siltstones, sandstones and claystones moderately bedded and lithified. These sediments are generally well cemented and relatively impermeable and therefore they are generally not considered to be water-bearing. Because these formations are of limited extent and of limited importance to a ground water study they have been grouped together.

Hudi Formation. The Hudi formation is composed of chert and sandstone deposits of lower Tertiary age. As the distribution of these rocks is limited to small isolated deposits of low permeability, they are considered to be non-water bearing rocks.

Tertiary Volcanics. The Tertiary volcanics that cap ridges are also considered to be in the non-water bearing series, although near

the surface the fractures and joints may locally contain limited quantities of water. In most instances the volcanics are well above the saturated zones of the water-bearing materials.

None of the aforementioned non-water bearing rocks should be considered as potential sources of ground water in the Sudan. The areas occupied by these rocks as indicated by geologic mapping should be eliminated from any well drilling consideration, except where the basalt cap may be penetrated and the underlying water-bearing materials tapped.

CHAPTER III

GROUND WATER DEVELOPMENT

Exploration

Exploration for ground water may be divided into three parts, namely, geologic mapping, geophysical surveying, and drilling. All three methods have been utilized in the Sudan for a considerable period of time. Currently, the need for water has created a demand for greatly accelerated programs in all of these methods of exploration.

Geologic Mapping. Surface geologic mapping is one of the first items to be considered in any regional ground water study. The Sudanese Geological Survey, recognizing this fact, has completed the first stage of this study by compiling a generalized geologic map of the entire country. A second stage of the study is to refine this mapping, giving priority to the water problem areas. The Geological Survey is aware of the importance of this information, and has completed portions of this work.

For the benefit of the non-geologist, geologic mapping may be defined as the delineation of the different rock types and rock units on a map. Such mapping, as it relates to ground water geology, would place emphasis on the water-bearing characteristics of the rocks. This involves the differentiating of the crystalline rocks from the sedimentary rocks, and also the division of the sedimentary rocks

into units based on their permeability and stratigraphic sequence. In the Sudan, for example, the geologist would separate the Nubian formation from the Umm Ruwaba formation, and, of course, separate these two units from the previously defined non-water bearing units, the granitics and metamorphic rocks.

It is obvious that geologic mapping requires that the geologist actually cover the area in the field on a rather closely-spaced grid system. In addition to the geologic mapping, but as a part of this mapping program, the geologist would prepare a report on his findings containing descriptions of the physical properties of the rocks. A ground water study should emphasize the characteristics of the permeable zones and indicate where the water producing zones might be expected. Also, of great significance are the areas of possible recharge or replenishment of the ground water supplies, and the possibility of movement of water from the recharge areas to the producing horizons. Special consideration should be given to any possible barriers to ground water movement, either vertical or horizontal.

Sufficient field personnel should be made available to continue these mapping programs.

Geophysical Surveying. Geophysical surveying is very useful in obtaining preliminary subsurface data over large areas at a relatively low cost and has been utilized by the Geological Survey of

the Sudan for many years with moderate success.

The two geophysical methods most often used in ground water geology are the seismic and resistivity methods, which may provide data on the areal extent and depth of various rock units, as well as data on the permeability of the rocks beneath the surface. In addition, gravity and magnetic surveys may reveal data on the configuration of bedrock and may also be useful in tracing certain rock units. Combined with the use of a geologic map, which indicates the relative water producing potential of an area as far as the surface is concerned, geophysical surveys can be utilized to provide information on the subsurface geology and possible water producing zones prior to the drilling of wells. The utilization of these methods should be of great value in reducing the number of unsuccessful or dry holes. In addition to the saving of the money which would be wasted on the drilling of wells in non-producing areas, there would also be a saving of the critical time of both men and equipment.

In the problem areas of Kordofan and Darfur Provinces, in the general vicinity of En Nahud, there are several locations at which moderately large scale geophysical investigations are recommended. These locations are in areas in which the geologic mapping has recently been completed but where there is insufficient subsurface geologic information upon which drilling might be recommended. These locations, shown on Plate III, are rectangular strips varying

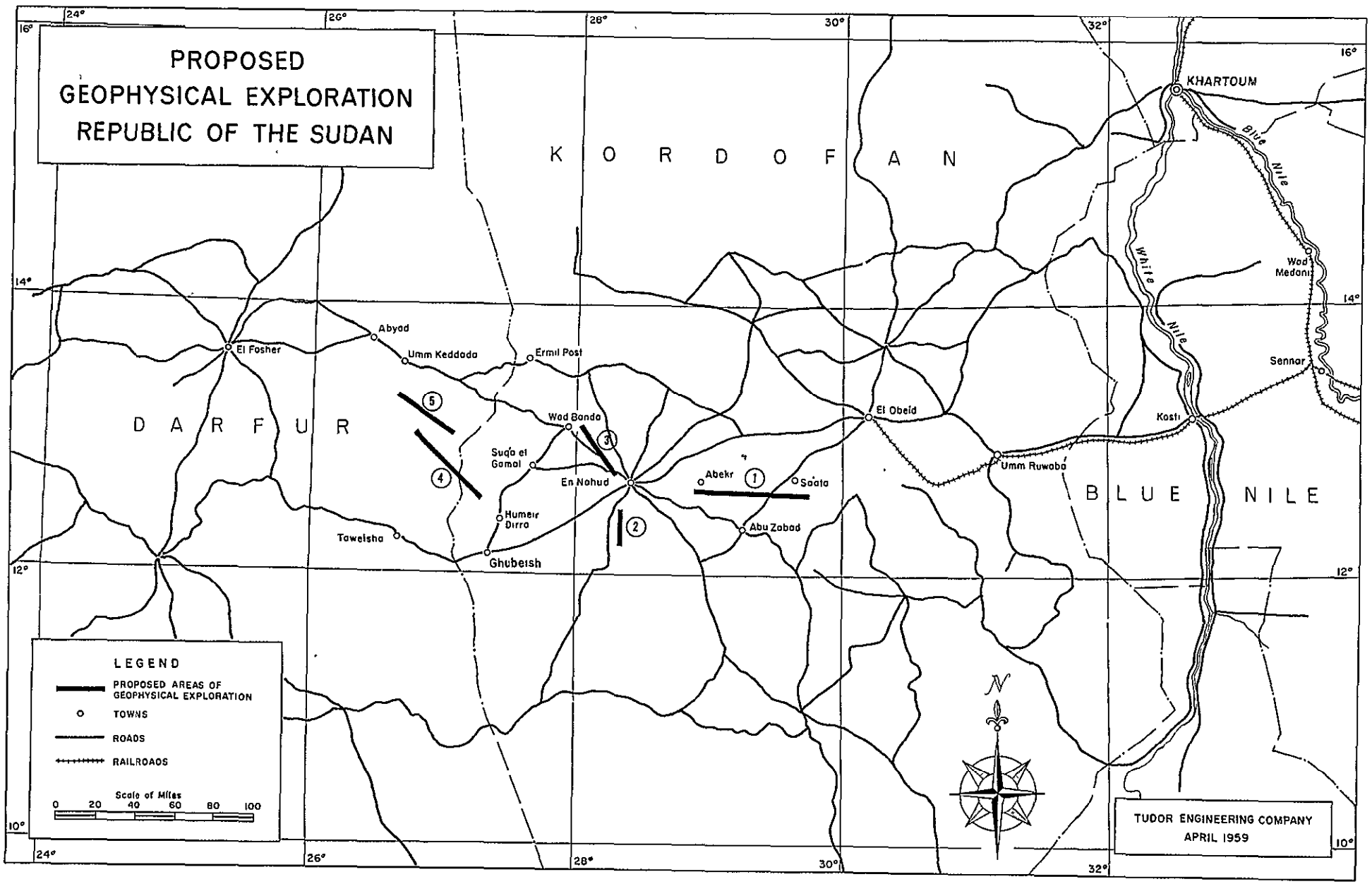

PROPOSED
GEOPHYSICAL EXPLORATION
REPUBLIC OF THE SUDAN
K O R D O F A N
D A R F U R
B L U E N I L E
KHARTOUM
Blue Nile
White Nile
Wad Medani
Sennar
Kosti
Umm Ruwaba
El Obeid
Abyad
Umm Keddada
Ermil Post
El Fasher
Wad Banda
Suqa el Gamal
En Nahud
Humeir Dirra
Ghubeish
Tawelsha
Abekr
Sodata
Abu Zabad
1
2
3
4
5
16°
14°
12°
10°
24°
26°
28°
30°
32°
N
LEGEND
PROPOSED AREAS OF GEOPHYSICAL EXPLORATION
TOWNS
ROADS
RAILROADS
Scale of Miles
0 20 40 60 80 100
TUDOR ENGINEERING COMPANY
APRIL 1959

PLATE III

in length from about 40 to over 100 kilometers, and would be approximately 10 to 15 kilometers in width.

A seismic method of exploration of these areas would undoubtedly provide the most accurate data on the subsurface geology. However, it is believed that this method would cost over one-quarter of a million dollars and, considering the accuracy of the data required at this time and the practicality of spending such a large sum, it is believed that this method is not desirable as a first step.

The resistivity method would be much more economical, but would provide less accurate data, and, more importantly, would be limited to the shallower depths. The accuracy of such data would be questioned at depths greater than 500 feet.

The next two methods considered, gravity and magnetic surveys, if combined should give a moderate accuracy. This type of survey would be well suited to determining the configuration of the bed rock and, therefore, giving some estimate of the water-bearing formations. The accuracy of the results of a gravity survey in the Sudan are dependent upon the relative density contrast between the sediments and the basement complex. As the Nubian sandstone at times contains relatively high iron concentrations and would probably be quite dense, it is possible that the density contrast between the iron cemented sandstone and the bed rock might become quite small, thereby reducing the accuracy of the gravity survey.

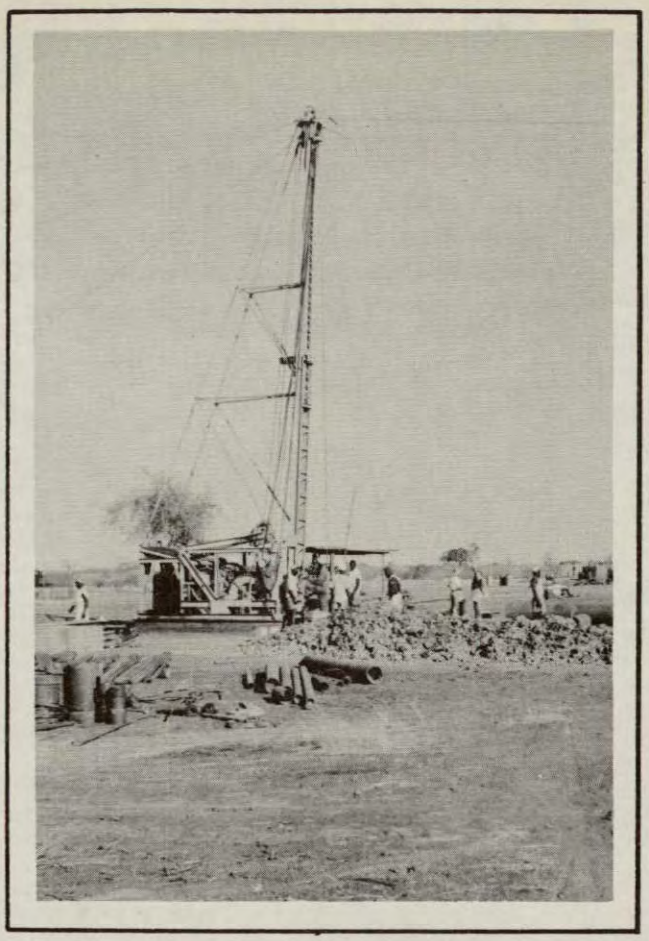
It is, therefore, suggested that gravity and magnetic surveys be run concurrently. The additional cost of running the magnetic survey is relatively insignificant, as most of the personnel and equipment could be used for both surveys. The only addition would be the cost of a magnetometer and operator, as the topographic surveys would be the same for both the magnetic and the gravity surveys. The magnetic survey then would provide an independent appraisal of the subsurface geology, which could be correlated with the gravity survey. It is believed that such a survey would provide the data necessary at this time for the ground water development program and, further, that the survey of the areas indicated on Plate III could be completed in less thanfive months and would cost about $60, 000. Such a program should provide suitable accuracy as there are some scattered points where subsurface data are available from drill hole information to provide control.

Drilling. Much of the drilling of wells in the past has been essentially exploratory drilling. With this in mind, it is easy to understand why the percentage of completion of successful water wells has not been very high in the past few years. As mentioned previously, some information on subsurface geology can be obtained from surface mapping and other information can be obtained from geophysical surveys. However, some reliable form of subsurface control is needed when using the more approximate methods of surveying. One of the best methods

of obtaining such control is the logging of materials penetrated during drilling operations. A geologist available to do this logging at the time of drilling and to provide geologic direction of the drilling of the well could collect extremely valuable subsurface data that could be used for the entire ground water program.

Under present conditions, the Geological Survey is not able to actually log the materials penetrated by the drilling of water wells in the field. Instead, samples are collected by the Drilling Division, one from each five feet of material penetrated, and these are sent to Geological Survey headquarters in Khartoum. Obviously, this leaves much to be desired, both in the technical control of the drilling and in the collection of information obtainable while the drilling is in progress. For example, if a well that is scheduled to go to 500 feet in depth actually reaches the bottom of the entire water bearing section at a depth of, say, 350 feet, the driller, in the absence of geologic advice, would probably drill on through 150 feet of non-water bearing materials, thereby wasting valuable drilling time.

Subsurface controls for geophysical surveying can be obtained by the drilling of test holes or core holes, whichever is deemed suitable in a specific location. This drilling would be primarily for the purpose of obtaining subsurface data rather than that of producing water. Such drilling should be used in areas where very limited data on water-bearing materials are available. This type of exploratory drilling



1. Percussion drilling near Umm Ruwaba. Sudanese drillers operating equipment. Note Woodfield skid mounted percussion drilling equipment.

2. Close up view of the interior of a water yard. Note water being transported by donkey in 5-gallon tins and goat skin bags. Spigots for filling small containers are above the table.

may be used where geophysical data are either lacking or inconclusive. The drilling of such holes would not be considered as a part of the standard water well drilling program, but rather as special exploratory drilling during which testing and analyzing of well data would be required. The success of these wells should not depend on their being able to produce water, but rather on the value of the ground water and geologic data obtained.

Ground Water Resources

The primary source of ground water is precipitation but only a fraction of the total precipitation that falls in a given area infiltrates to become part of the ground water body. A part of the remainder of the precipitation returns to the atmosphere by evaporation and by transpiration through the growing vegetation, that is, by the process called evapo-transpiration. The water that is neither absorbed into the soil and underlying formations nor evaporated at the point of precipitation becomes surface runoff. This runoff continues to move down slope on the surface until it either evaporates, percolates downward to become ground water, collects in basins, or flows to the ocean. The term hydrologic cycle is used to describe this movement of water from the atmosphere to the surface of the land or water body and back again into the atmosphere.

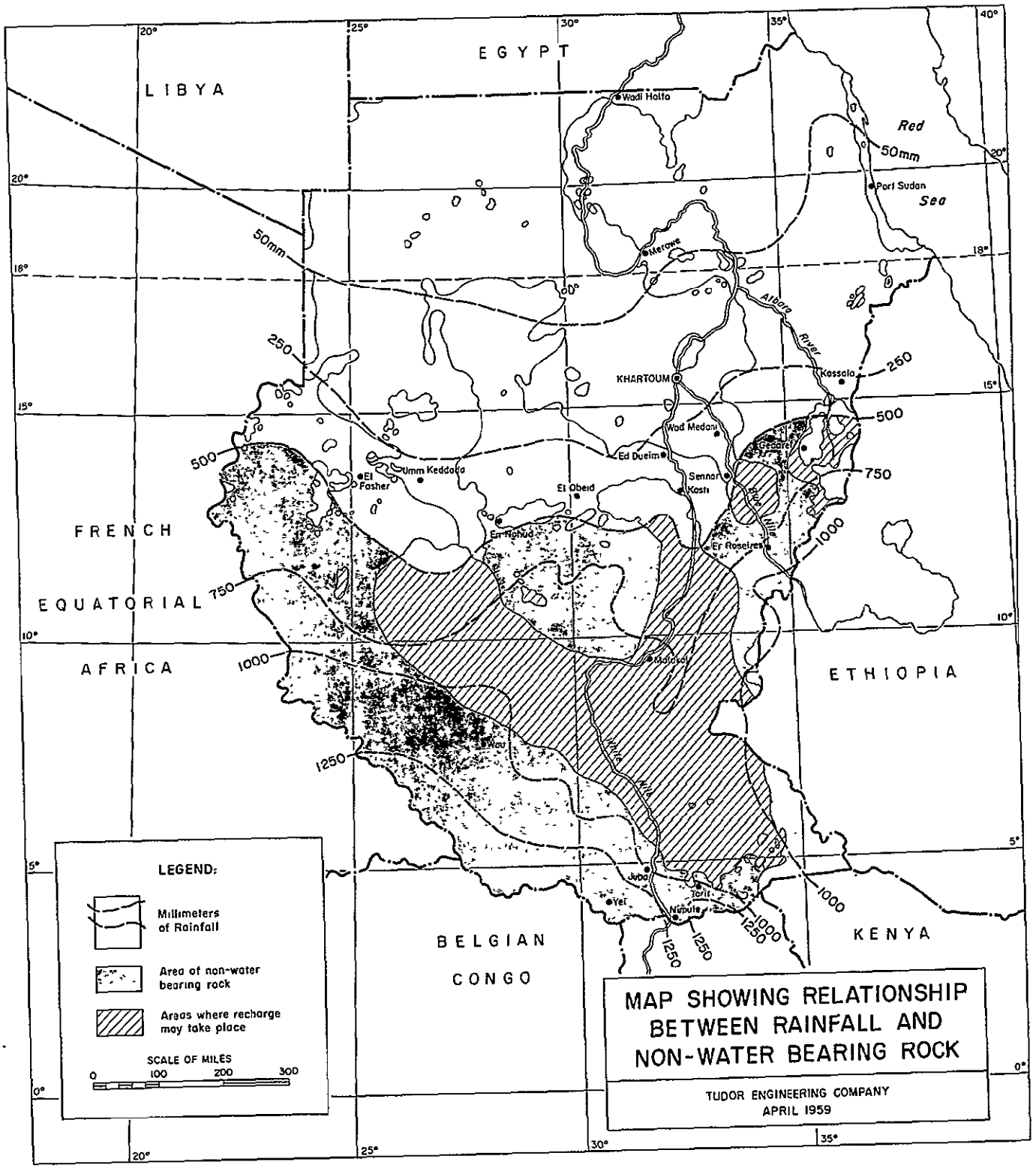
An evaluation of the ground water resources of the Sudan is definitely desirable at this time. To make a reasonable evaluation,

some type of inventory of the component items, such as recharge, movement, occurrence, water quality, storage capacity and ground water extractions is necessary. Without an inventory and evaluation of this important resource, the safe yield cannot be determined and orderly development and utilization cannot proceed.

Recharge. Recharge to ground water supplies occurs as (1) direct percolation of precipitation, (2) percolation of applied surface water, (3) percolation from streams, or (4) underflow.

Direct percolation of precipitation occurs in parts of the Sudan where rainfall is heavy. However, as may be noted on Plate IV, the areas susceptible to this type of recharge are limited due to lack of sufficient rainfall. The only area in which such recharge could take place is the area south of the 500 mm isohyet. This is on the assumption that the amount of water percolating to the water table would be negligible if less than 500 mm of rainfall per year occurs. The dark area on Plate IV indicating the location of the non-water bearing rocks should not be considered capable of either absorbing or transmitting any appreciable quantity of water. Therefore, direct recharge to the ground water would have to occur essentially in the areas indicated by the cross-hatched symbol.

Recharge by percolation from influent streams also occurs in the Sudan. At the present time, sufficient hydrologic data are not available to determine the precise locations or quantities. Undoubtedly,


EGYPT
LIBYA
Red
Sea
Wadi Halfa
Port Sudan
Metowe
Atbara River
KHARTOUM
Kassala
Wad Medani
Gedaref
Ed Dueim
Sennar
Kosti
El Obeid
Umm Keddada
El Fasher
Er Roseires
Malakal
Wau
Juba
Yei
Nimule
Torit
White Nile
Blue Nile
FRENCH
EQUATORIAL
AFRICA
ETHIOPIA
BELGIAN
CONGO
KENYA
50mm
250
500
750
1000
1250
LEGEND:
Millimeters of Rainfall
Area of non-water bearing rock
Areas where recharge may take place
SCALE OF MILES
0 100 200 300
MAP SHOWING RELATIONSHIP BETWEEN RAINFALL AND NON-WATER BEARING ROCK
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APRIL 1959

PLATE IV

there are reaches of both the White and Blue Nile, as well as many of the smaller intermittent streams, that contain losing reaches.

Percolation of applied surface water would only occur in irrigated areas. Underflow, the last method of recharge discussed, is always difficult to determine due to the lack of sufficient data. In the Sudan, at the present time, there is such a great lack of hydrologic data that no evaluations are attempted.

Movement. The direction of movement of ground water is generally determined by constructing maps which indicate the contours of the ground water surface. The water then may be assumed to move from the higher elevation to the lower, in a direction normal to the contours. In the Sudan, information on the ground water surface is very meager, due to the limited number of wells. Therefore, only general assumptions can be made but the general movement of ground water is probably in a northerly direction from the southern upland areas, with some contribution from the western portion of the country. The distribution of the non-water bearing rocks as shown on the geologic map (Plate II) indicates that there is little subsurface area through which underflow from the southern area can move to the northern.

As the sediments, especially the Nubian formation, are composed of rather extensive deposits of sandstone, siltstone and claystone, or fine grained material, movement would be quite restricted, especially in the vertical direction, across the bedding. These fine grained

materials are relatively impermeable and function as a confining medium.

Occurrence. Ground water occurs as either free or confined water. If the water moves through permeable media without restriction caused by an impermeable confining material, it would be termed free ground water. Such waters would move under the control of the slope of the water table.

Confined water is water which moves in strata or conduits under the control of hydrostatic head. If a well is drilled into a permeable confined stratum, water will rise in the well to some point above this stratum, but not necessarily to or above the ground surface. This confined water is often referred to as artesian water.

Data obtained on water levels in existing wells indicates that much of the ground water in the Nubian formation is confined. This water is generally under moderate pressure. The water surface in a well may often rise on the order of 100 feet after the water-producing stratum is tapped. The slightly tilted claystones and siltstones in the Nubian formation may overlie a relatively permeable and saturated sandstone stratum, thereby forming the confining body.

A diagrammatic cross-section in an east and west direction across the Sudan is shown on Plate V. This plate indicates the possible typical relationships between the basement and overlying formations and the ground water tables.

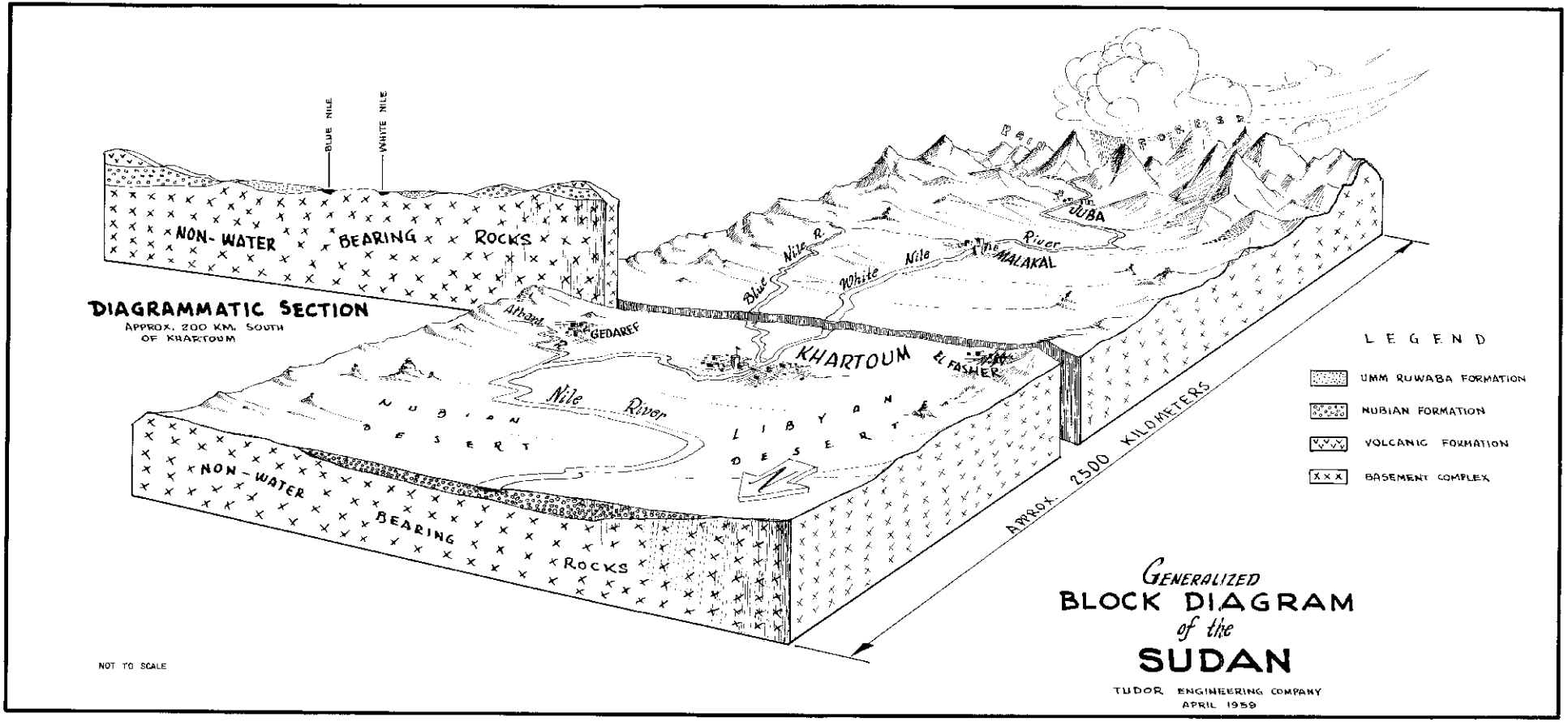

BLUE NILE
WHITE NILE
NON-WATER BEARING ROCKS
DIAGRAMMATIC SECTION
APPROX. 200 KM. SOUTH OF KHARTOUM
Blue Nile R.
White Nile
River
MALAKAL
JUBA
Atbara R.
GEDAREF
KHARTOUM
EL FASHER
Nile River
NUBIAN DESERT
LIBYAN DESERT
NON-WATER BEARING ROCKS
APPROX. 2500 KILOMETERS
LEGEND
UMM RUWABA FORMATION
NUBIAN FORMATION
VOLCANIC FORMATION
BASEMENT COMPLEX
NOT TO SCALE
GENERALIZED
BLOCK DIAGRAM
of the
SUDAN
TUDOR ENGINEERING COMPANY
APRIL 1959

PLATE V

Limited data available on the Umm Ruwaba formation indicates that water occurs in discontinuous and often relatively isolated permeable bodies or lenses in a relatively impermeable deposit. Hydrologic continuity between these permeable zones is often quite poor. Therefore, the location of the better producing horizons, the possibility of pressure water and also the quality of the water are difficult to predict.

Water occurs in fractures and joints in the non-water bearing or crystalline rocks but the quantity and pressure present are entirely dependent upon the interconnection of these fractures and joints. The ability of this type of rock to yield water depends upon the characteristics of the fracturing or upon the weathering of the rock surface which may cause the material to become permeable. Major fractures and fracture zones are usually widely spaced. Crushing and shearing are usually limited to definite zones and separated by unfractured or moderately fractured material. Therefore, it is very difficult to predict or to determine the locations of such sheared zones that might contain very limited quantities of water.

Weathering diminishes with depth and small cracks and fractures usually tighten very rapidly at lower levels. Therefore, only limited quantities of ground water can be expected in the crystalline rock and these at relatively shallow depths.

Quality of Ground Water. Water occurring in nature is never pure or entirely free from mineral constituents. Precipitation from

the atmosphere contains only very small amounts of minerals, principally dissolved gases, and, therefore, has the effect of diluting the concentrations of mineral constituents in surface or ground waters. Consequently, water from perennial streams, particularly in regions of higher rainfall, generally contains less dissolved solids than ground water does. Also, the greater the distance water moves underground, the longer it remains as ground water, and the slower it moves through the sediments, the greater is the opportunity to dissolve mineral constituents from the rock. The quality of ground water in any area is largely determined by the climate and the geology. The kind and relative proportion of each of the mineral constituents are controlled by the type of minerals forming the rocks and soils through which the water passes.

The mineral analyses of waters are generally reported in parts per million or equivalents per million. One part per million equals one part by weight of the mineral constituent to one million parts by weight of the water. One equivalent per million may be defined as one equivalent weight of an ion in one million weights of solution. The equivalent weight of an element is the quantity that will exactly react with another element. The total number of anions (acetic ions) in equivalents per million, that is, the bicarbonates, sulfates, chlorides, nitrates, and the total cations (basic ions) in equivalents per million, that is, calcium, magnesium, sodium and

potassium, should be equal or balanced in an accurate analysis of the ground water. This is a fact that permits utilization of many short-cuts in the field determinations and approximations of water quality data with a limited amount of laboratory work.

A method of great value in the laboratory, and still more valuable in the field, is the use of the electrical conductivity of the water. The specific electrical conductance of the water furnishes an approximation of the total mineral content or total dissolved solids. It does not, however, give any indication of the relative quantities of the different constituents in solutions. The relation of specific conductance to the total dissolved solids when used in specific areas and with partial field analyses of the water can provide sufficient data on the quality of the water to determine its suitability. This method, although approximate, is extremely practical and very important to an effective ground water development program.

Presently, water samples, obtained from each well at the completion of the drilling, are sent to a chemical laboratory in Khartoum. A considerable amount of time is consumed in transporting the samples to the laboratory and in making the analyses and reporting the results to the appropriate departments. The well-drilling of the second well in a water yard, that is, the companion well, must either be deferred pending information on the quality of the first well, or else the driller must gamble on the quality of the

well and proceed with the second well, thereby risking a loss of valuable drilling time. It is believed that, if field chemical analysis kits are provided geologists in the field, the drilling operations would be accelerated and there would be less chance of wasting time in starting a well where the water quality is unsuitable. Furthermore, the geologist in the field who would perform these analyses would derive a great deal of subsurface information from the analyses, and would be immediately aware of what mineral constituents might be reaching, or be expected to reach, the critical concentrations in the specific area. Obviously, this program would supplement, but not replace, the existing program of obtaining relatively complete mineral analyses in the laboratories in Khartoum. The field determinations would provide data to expedite field operations.

The percentage of wells sampled for complete water analysis is currently quite high in the Sudan, and this is one phase of ground water development in which the Sudanese are advanced over most of the rest of the world. This geochemical data will soon be sufficient to aid the Geological Survey in making ground water studies, especially in evaluating useable storage capacities and predicting with high accuracy the quality of water to be encountered in future drilling programs. The data will also provide important information on ground water movement when recorded over a period of years.

Presently, predicting the quality of ground water occurring in the Umm Ruwaba formation is quite difficult. It is probable that at least portions of the Umm Ruwaba formation were deposited under lacustrine or playa conditions. Under this theory the poor quality water would then be due to concentration by evaporation of the water during or prior to deposition of the sediments. Although paleontological evidence does not confirm the theory, it remains the best explanation of the occurrence of these bodies of saline water found in the Umm Ruwaba formation.

Ground water in the Nubian formation is generally of suitable quality for domestic or municipal use. There are analyses of waters from the Nubian formation that show definite evidence of degradation. At the present time, there is still insufficient geochemical data available to determine the exact source of this degradation. However, with the accumulation of more analyses from new wells being drilled, and with the historical records of quality of the older wells, the Geological Survey will probably soon be able to determine much about the characteristics and sources of degradation of this ground water.

Ground water in the so-called non-water bearing rocks, the basalts, granitics and the metamorphic rocks, occurs primarily in fractures, cracks and joints. This water tends to be more isolated than water occurring in granular media and therefore there is less chance of dilution by waters containing lower concentrations of various

salts. Therefore, if a well is drilled into these crystalline rocks and happens to intersect a sufficient number of these fissures to produce water, it is quite possible that the water would be of poor quality. In addition to the doubtful chemical quality of the water in these fractures, contamination from surface sources may easily occur.

Storage Capacity. In order to estimate the ground water storage capacity of any basin, it is necessary to know the areal extent and the thicknesses of the saturated deposits and the specific yield of the materials composing them. The specific yield of a material saturated with water may be defined as the ratio of the volume of water it will yield by gravity to the volume of the saturated material, the ratios generally being expressed as percentages. The different materials, gravels, sands, silts and clays may be assigned specific yield value based on tests. Then, by examination of the well logs, and by calculating the thickness of each type of material, an average specific yield for the materials near the well can be determined. As numbers of the wells are analyzed, and the average specific yield values by depth intervals computed, estimates of storage capacity for various intervals and larger areas may be obtained. Estimates of areas and depths can be based on existing subsurface data, and these estimates can be refined by the proposed geophysical explorations and future drilling operations (see Plate III).

The quality of the water must be considered in any ground water inventory, and that portion or those zones that are unsuitable should be deleted from the estimates. Such zones may be sealed off during well construction. Then, considering the economic limitations, as determined by the cost of extracting water from excessive depths, and taking into account the quality, a basis is created for estimating the useable storage capacity.

The Sudan Geological Survey should give special consideration immediately to estimating storage capacities and making annual inventories in a number of ground water basins of limited size. Examples of such basins are to be found in the vicinity of En Nahud, El Fasher and Gedaref. In order to make these inventories of real value, records of the depth to water in the wells must be maintained regularly. Such records should be taken often enough to show at least the approximate annual highs and lows of the water surface elevations. One method is to measure the depth to water in wells at convenient intervals. Another method is to install automatic water level recording instruments on suitable open wells. Such wells would then become key wells and a continuous record of the water level in these wells would be obtained. These records, coupled with those obtained from the wells measured at intervals, should provide sufficient data for the ground water inventory. This information would be absolutely

necessary in predicting the capability of a ground water basin to furnish the future water requirements of any area.

Exploitation

The drilling of wells began in the Sudan about a half a century ago with percussion type drilling equipment. Presently, the Drilling Division of The Republic of the Sudan has 18 drilling units. Most of the drills are rather light units designed to drill small wells to depths of about 500 feet. Recently, the Drilling Division acquired about three relatively heavy duty percussion drills and one rotary drill.

Drilling Operations. The well drilling equipment of the Drilling Division is widely dispersed over the country, causing severe problems of transport and supply. Widely scattered equipment which requires continual servicing in the form of fuel, parts, casing, pipe, and other miscellaneous equipment is a problem in any country. In the Sudan, it becomes an extremely difficult problem due to the great distances involved, lack of communications, and the poor condition of the roads. Furthermore, these problems of accessibility cause the Drilling Division engineer great difficulty in exercising supervision and control.

Another problem that is created by the great distances between the drilling units is that of providing geological assistance and advice at the various drilling sites. It is probable that if the entire Geological Survey staff were directed to stop all other activities they would still

be unable to furnish constant geologic assistance at the drilling locations.

In order to reduce the above stated problems to the very minimum, it is recommended that an effective grouping of the drilling equipment be accomplished as soon as possible. This grouping should be reasonably free of political pressures from local government officials and should be concerned only with the most practical deployment of the drilling equipment. Effective grouping of the equipment would be such that the drills would be contained within the smallest practical areas, as selected from the scheduled list of wells to be drilled. It would be desirable to have all the equipment within not more than three major groups. Effective supervision and service could be expected if group supervisors could move from one drill to another within a period of time not to exceed one day.

In addition to the regrouping of drilling equipment for purposes of repair, maintenance and control, it is equally essential that schedules for drilling be designed to keep operations in any group within relatively close distances. These schedules are one of the keys to reduction of lost time. If prepared and approved during the off-drilling season, and adhered to during the drilling season, a greater number of wells can be produced. In certain cases, requests for some isolated wells could better be scheduled for hand digging, using the additional crews subsequently recommended herein.

3. Well field in fula at En Nahud. Contamination can occur from both human and animal sources. Replenishment of water supply occurs during rains when water flows down the khor.

4. Watering stock by bailing from a dug well 130 kilometers west of En Nahud. Dug wells are an important part of local water supplies in the western area.

If this plan of grouping the equipment is put into effect, the forty per cent lost time reported in the Drilling Division's evaluation of its operations could be reduced sharply by the reduction of transportation, supply and supervision problems. The Geological Survey would then be able to provide permanent full time geological assistance to the most critical of the field units.

The Drilling Division has a stock of approximately two million dollars' worth of extremely heavy, odd-sized, and various types of water well casing stored at Khartoum and El Obeid. The use of these types of heavy casings in many cases probably doubles the drilling time that would be required to drill a well in the same material with a different type of casing. This very heavy casing imposes loads that exceed the designed capacity of the drilling equipment while extracting temporarily installed casing. It is the opinion of the survey team that, if the proper types of casing were used for the various materials being drilled and under the varying drilling conditions, the rate of completion of drilled wells could be appreciably accelerated.

It is proposed that the drilling engineer of The Republic of the Sudan's Drilling Division be sent to the United States to observe methods used there in the drilling of water wells with percussion and rotary drilling equipment and using various types of casings. Special emphasis should be directed to methods which do not require the extraction of casing. It is recommended that the drilling engineer visit

drilling operations in areas geologically similar to those in the Sudan. Such areas are found in the western part of the United States. More specifically, the drilling engineer should visit approximately five different locations of percussion and rotary drilling operations in California, Arizona and Utah. In addition to visiting these operations, it is suggested that he have conferences with several drilling and casing engineers in various parts of the country, and observe the various types of casings and muds used in rotary drilling.

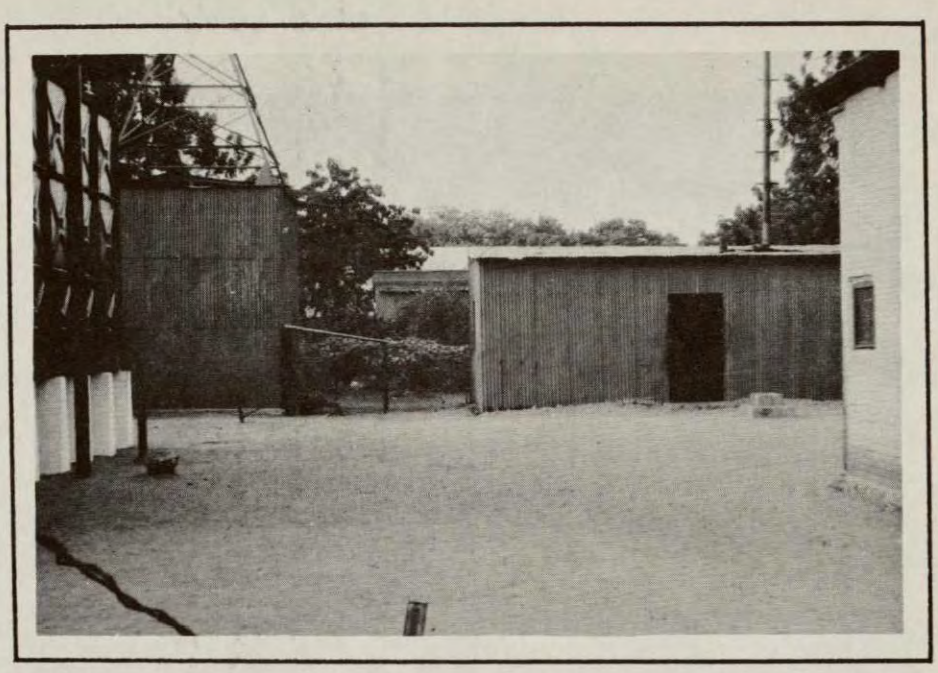
It is further recommended that he examine the United States excess stock that might be available for the Drilling Division's future equipment needs. It is estimated that it would probably take approximately six weeks time, including travel time to and from the Republic of the Sudan. It is believed that, if the visit can take place during the first part of July 1959, the drilling operations in the Sudan will not suffer from his absence, as this is normally a period when drilling operations have stopped due to the extremely high temperatures and heavy rainfall.

In the water yards, constructed for the production, storage and distribution of water, two wells are provided, usually spaced about one hundred meters apart, although some wells are only twelve meters apart. As these wells are operated simultaneously, a very inefficient operation results. Pumping of wells located this close together causes mutual interference, excessive pumping costs and

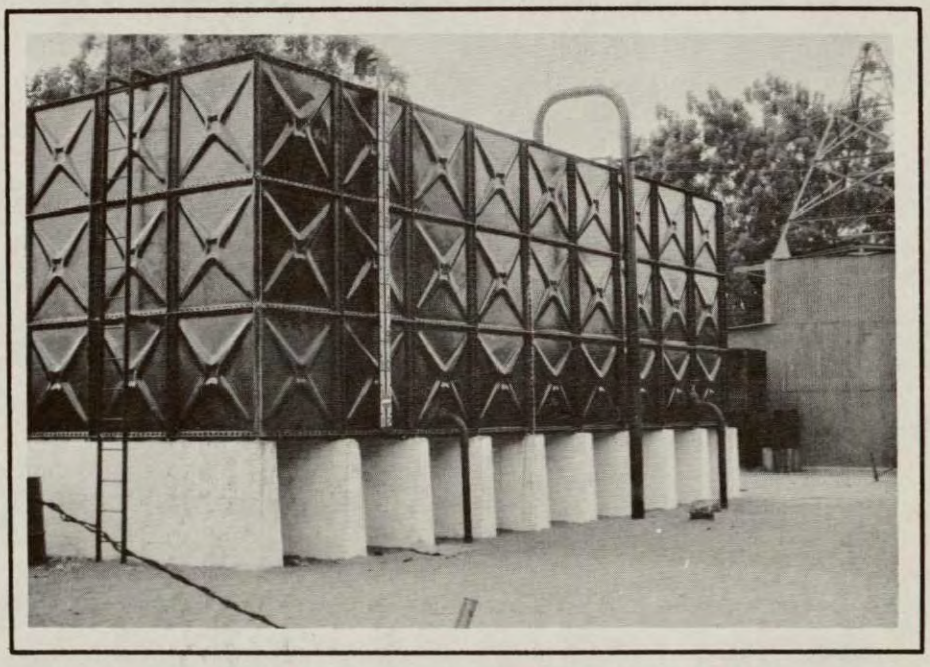
lower yields per hour, especially as the water table is lowered. Furthermore, if one well were to become contaminated, the opportunity for contamination of both wells under such conditions of spacing is very greatly increased.

It is recommended that the well spacing be standardized at, at least, 300 meters. Such a spacing is only approximate, but one which is generally accepted throughout the world. In specific areas, detailed permeability and water level drawdown tests may provide a basis on which this distance might be altered.

The cost of providing dual wells at each water yard as a safeguard against failure or contamination is a costly insurance procedure. Since both wells are generally pumped about 20 hours a day, there is actually no standby well. One slightly larger well and pump could produce the desired quantity of water more efficiently. It is true that there is a certain safety factor with the dual well system, in that, if one well fails, the other can go on producing. However, since the two wells are of approximately the same age and have had the same use experience, it might be expected that both would fail at about the same time. Should one well become contaminated, the twin well might be expected to become contaminated shortly afterwards, thereby destroying in either case the value of the twin wells at the yard.



5. First water yard constructed in the Sudan, at Umm Ruwaba. This yard was constructed about 1913. The two wells are only 12 meters apart - an undesirable situation.



6. Water storage tank in water yard at Umm Ruwaba

As previously suggested, a minimum spacing of 300 meters between wells would be considered good well spacing practice. To carry this idea one step farther, consideration should be given to single wells in water yards spaced possibly on the order of three to five miles apart. This would offer several advantages as follows:

a. Less congestion and overgrazing, and less waiting time for watering stock.

b. Less average travel and water haul distance for the local population.

c. Elimination of the danger of mutual contamination.

d. In the event of failure of one water yard, the other is only a few miles away.

e. More detailed geologic and drilling information would become available to the Geological Survey.

The disadvantages would be:

a. More yards and storage tanks, although sizes might be reduced.

b. Additional operators would be required.

It might be well to review the past record of well failures, particularly the mechanical type, to see if the dual well system as presently being used is worth its cost and if another approach similar to that suggested above would be more efficient or satisfactory.

As the population grows and villages are built near the water yards, more wells are usually drilled. During the same period, the yields of the existing wells may be reduced by sanding or incrustation

in the perforations of the casing, often requiring replacement with new wells. It is believed that slightly larger wells and possibly gravel-packed wells would have the additional capacity needed to provide a margin of safety if yield is reduced over a period of time, or if greater demands for water occur. Production could be controlled by installing small capacity pumps, if desired from a land use standpoint, but the well would still have the capacity to produce in time of need. These proposed changes in the design of the wells should greatly reduce the number of wells that would have to be redrilled or replaced and, of course, permit the drilling equipment to be utilized to provide new water supplies in other areas. It is realized that the suggested well capacities are probably in excess of those now recommended by the Department of Land Use and Rural Water Development. It is not intended to propose any modification of the maximum production recommended by this department, but rather to produce water more efficiently, to reduce the frequency of the cleaning and redrilling of wells, and to provide for additional capacity if the need arises.

Hand-Dug Wells. A number of open hand-dug wells constructed by personnel of the Land Use and Rural Water Development Department were visited by the survey team. These wells may be constructed with a minimum of equipment, maintenance and supervision. Usually only one truck, a windlass, cables and a few hand tools are required. Approximately half of the required personnel are employed continuously

in the construction of these wells, and the other half are obtained locally from the villages as needed. One problem noted was that digging presently is not possible below approximately three feet below the water table. The use of some type of dewatering equipment, perhaps something like a moderately small hand pump, would greatly help in the construction of these wells by allowing greater depth to be penetrated below the water table.

It is not suggested that the construction of these wells will solve the water problems of the Sudan. However, it is believed that, during the present critical shortage, more hand-dug wells will serve a very useful purpose. It is recommended that the number of well digging teams, now about seven, be increased to at least ten. It is estimated that with the increased personnel and with the aid of some type of dewatering equipment, approximately 25 to 30 satisfactory low-yield wells could be constructed per year.

Organization. Drilling equipment in the Sudan is now being operated by several governmental agencies. In addition to the Drilling Division, the Department of Public Works, the Sudan Railway, and the Gezira Board all have drilling equipment. Since each unit must have its own facilities for maintenance, operations, supply and supervision, this situation creates unnecessary duplication. It is suggested that serious consideration be given to the idea of placing all the drilling operations under the Drilling Division, which would

then operate and supervise all drilling for the Government of the Sudan.

The operation and maintenance of pump engines and supplementary equipment utilized in providing water for villages and larger cities in the Sudan is a large scale operation. Presently, the Department of Public Works is operating and maintaining such equipment for more than 70 water yards, requiring repair facilities, spare parts, supplies, and the procuring and training of personnel. The Land Use and Rural Water Development Department has duplicate facilities to provide similar operation and maintenance service to the water yards under its control. At El Obeid, for example, two completely separate service units, one for each department, located only a few hundred meters apart, are both rebuilding Lister pump engines for water yards. It is recommended that this duplication of service be eliminated and that a single agency be responsible for all operation.

The personnel who have become skilled in the operation and maintenance of pumping equipment are heavily concentrated in the vicinity of El Obeid. It is suggested that a portion of the trained personnel and repair facilities be transferred from El Obeid into the eastern area, perhaps around Gedaref, and establish a small facility there. This would then become a service center for the eastern area. It is also probable that additional personnel and

equipment will soon be required in Khartoum.

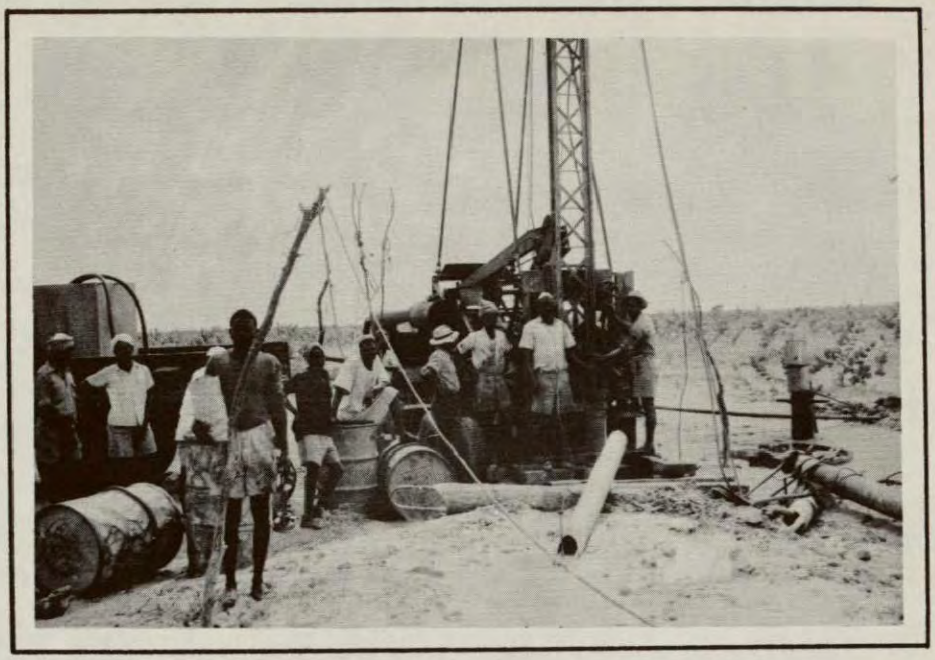
In summary, then, it is recommended that the facilities of the two departments now be combined under one administrative head and that a portion of the personnel and equipment be transferred to other parts of the Sudan to meet the service and maintenance requirements that are rapidly developing in these areas.

Originally, the Drilling Division was administered through the Geological Survey Department. Then the Division was transferred to the Public Works Department, and then, more recently, to the Department of Land Use and Rural Water Development. Both the Geological Survey and the Land Use and Rural Water Development departments are concerned with the planning stages of the well drilling program. However, it is the Geological Survey that has the responsibility for the final location of the wells to be drilled. Furthermore, the Geological Survey must be concerned with : (1) the obtaining and interpreting of samples of materials penetrated during the actual drilling of the wells; (2) the field water quality determinations; and (3) the responsibility of determining the depth to which each well should be drilled and the location of the water producing horizons encountered. Obviously, the program must be carried out with the maximum possible amount of cooperation between the geologists and the drilling personnel.

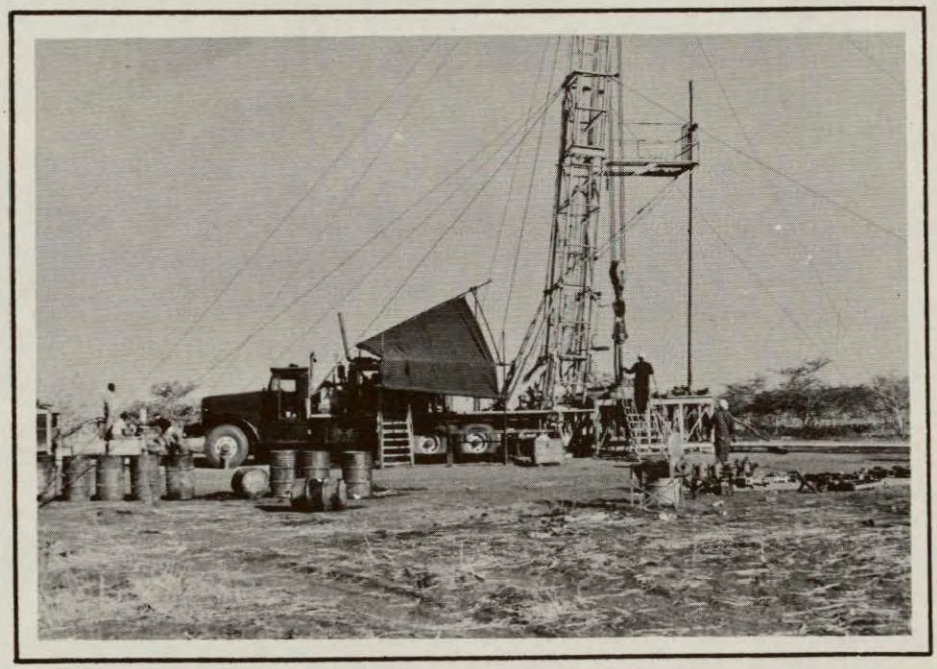
It is recommended that the organizational status of these agencies be altered to provide that the Geological Survey Department and the Drilling Division be at least in the same Ministry. It becomes immediately apparent to anyone visiting the country that water is the most precious mineral resource, and it seems quite logical that the exploration and the evaluation of this mineral resource be administered through the Ministry of Mineral Resources.

It is suggested that the Drilling Division be reestablished within the Geological Survey Department. Furthermore, it is suggested that, after the Drilling Division has completed the drilling and pump testing of a well, another agency should then assume responsibility for the installation of the water pump, storage tanks and buildings, and the production and sale of the water. The Drilling Division then would be able to concentrate its entire efforts on drilling operations.

Equipment. The above comments, recommendations and suggestions do not reflect discredit on the Department of Land Use and Rural Water Development, nor on the present drilling engineer. On the contrary, the survey team has the utmost confidence in the abilities of both. The present year's well production will about triple the average number of wells drilled three and four years ago. The Drilling Division has completed efficiency studies of its own operations and found a forty per cent lost time , which was due largely



7. Percussion drilling with all Sudanese crew near Tindelti, about 85 kilometers west of Kosti.



8. Ballerini "75" - a rotary drill working near Gedaref. This rig completed a 1,000 foot well in about one month. The percussion rigs in general use in the Sudan require about eight months to do the same job.

to the lack of satisfactory transportation and repair facilities. After making this determination, the Drilling Division requested ICA assistance and the USOM/Sudan requisitioned trucks, mobile repair shops and other supplies from United States excess stocks. Delivery of this supplementary equipment as soon as possible would greatly help the water development program of the Sudan.

The Drilling Division recently obtained a rotary drill somewhat larger than an American-built Failing 2500 and has been operating it in the eastern area of the country, near the city of Gedaref. Its operation requires greater skills than the operation of percussion drills usually in use. However, using expatriate and Sudanese crews, wells were drilled much faster with the new rotary drilling equipment. Furthermore, as the water table drops due to the increased demand on the ground water supplies, wells of greater depth will be required, and the use of the rotary type equipment will be required from a practical standpoint. Therefore, it is recommended that three new rotary type drills, complete with water trucks, pumps, electric welding equipment and power plants, as well as the necessary drill bits, drill collars, drill pipe, fishing equipment and all necessary miscellaneous tools, be provided the Drilling Division. Serious consideration has been given to the size of drills required. It is strongly recommended that these rotary drills be capable of drilling 11-5/8 inch diameter holes to

approximately 2000 ft. It is believed that drills capable of drilling wells of this diameter to the proposed depths are necessary if the water development program is to be efficiently conducted during the next five years.

It is recommended that the supplier of the three new drills provide for the services of one drilling engineer, four drilling instructors, and one mechanic to aid in the training of the drilling personnel of the Drilling Division. It is believed that a year of training will be sufficient, as some of the drilling personnel to be trained will be expatriates. The training of relatively inexperienced Sudanese personnel can take place over a two or three-year period under the supervision of the expatriates. They have had some experience with the use of rotary equipment and, if a highly trained staff provided by the supplier can provide a relatively short, on-the-job, training course, the expatriate personnel can then continue with this training program without further assistance.

It is proposed that as much of the new equipment as practical be obtained from United States excess stocks. For example, it is possible that the trucks on which the drills are to be mounted may be available from excess stocks, as well as the water tanks and water trucks, and the small water supply pumps and, possibly, the power plants.

One very important consideration in supplying this equipment to the Drilling Division is that the equipment be in the Sudan by the first part of October 1959. The reason for this recommendation is that the working or drilling season in the Sudan lasts only about eight months. Therefore, if this equipment is available at the start of the new working or drilling year, which would be in October, a major contribution to the potable water development program of the Sudan can be accomplished during the following eight months.

The survey team carefully considered various proposals and various methods of supplying equipment and personnel to best meet the potable water requirements of the country on both a short term and a long range plan. A plan given a great deal of consideration was a proposal to furnish 40 water yards, or 80 wells, to The Republic of the Sudan by means of a contract to be financed by ICA funds. It was concluded that this plan would be very expensive, would not accomplish the desired training, and would not make a long range contribution to the water development program. Therefore, if the proposed equipment can be made available to the Drilling Division by October of 1959, and, also, if the other proposals are adopted, such as effective scheduling and grouping of the drilling equipment, use of proper casing, and training of personnel, then a greater number of wells will be completed during the first year's operation than by any other means considered.

Water Yards. For many years the Sudanese Government has constructed water yards as a means of supplying drinking water in critical areas where the local supply is failing or has failed. Usually, these areas have been previously supplied by dug wells or small runoff catchments constructed by the local people at province or village level.

A water yard consists of a fenced area possibly 100 meters long by 40 meters wide containing two wells, or twin bores as the Sudanese call them, with pumps, a storage tank, possibly a few crude watering troughs, or else a small watering pond, and occasionally a few faucets to furnish small quantities for domestic use. There is frequently a small booth for a ticket seller, and some of the newer yards have sleeping accommodations or rest houses for the use of traveling government officials. The first water yard of record is the one constructed at Umm Ruwaba, about 1913 (see Photograph 5). This yard is still in operation.

Originally, it was planned to pump only one well at a time and use the other for a standby, but in nearly every instance observed by the survey team both wells were being pumped, reportedly from 16 to 20 hours per day. During the day-time the demand usually equals or exceeds production. No water can be stored

during peak demand periods, which appear to be continuous during the daytime.

Small capacity pumps usually produce about 1000 gph. Water is sold to the populace at various rates, sometimes two milliemes to five milliemes per tin (five gallon petrol tin), or at so many milliemes per animal (goat, sheep, cow, horse, camel), in accordance with their average water requirement. A native brings his flock or herd to the yard and is admitted when his turn arrives. His animals are counted, he pays for the water, receives a ticket, waters his stock and departs. The next herd is then served. While the prices charged are seemingly low in money value, they are a deterrent to wastage of water.

CHAPTER IV

SURFACE WATER DEVELOPMENT EXCLUDING THE NILE RIVER PROJECTS

Southern Area (South of 10°N Latitude)

This area as indicated on the geologic map (Plate III) is occupied largely by crystalline rocks which are units of the non-water bearing series.

The weathered surface deposits of the crystalline rocks may contain small quantities of water. Wells dug by the inhabitants of many villages, like the one shown in Photograph 10, have produced limited supplies. These wells can be dug only to limited depths below the water table without dewatering equipment. They frequently produce water the year around, although in some areas, they become dry during several months of the year. Often the water that accumulates in a well overnight, or in a few hours, is bailed out for use in an hour or less, and it is then necessary to wait for several hours for additional water to seep back into the well. The boring of deep wells in the crystalline rocks does not offer good opportunity for ground water production and generally should be discouraged.

There are many streams in the southern area that flow throughout the year or at least for many months. Presently, these waters are not used, but they provide a good potential source of

supply. A system of small storage dams of the weir or flash-board type on some of the small tributary streams is suggested as the best means of developing or improving water supplies. Sites should be selected where the configuration of the channel is such as to give a reasonable amount of storage (see Photograph 9). Many such locations were noted by the survey team along the Juba-Yei, Juba-Torit and Juba-Nimule roads where such storage might well be feasible.

Central Area (Between 10°N and 18°N Latitude)

One of the principal means of supplying water to the nomadic people in the outlying areas and particularly in the desert problem areas of Kordofan and Darfur provinces is by hafirs.* A hafir is a small catchment area or excavated basin surrounded in some cases by an embankment constructed of excavated material. Ephemeral stream flow or flood water is diverted into the hafir and kept for a period of several months for domestic and stock watering use.

There is less water in the west central area and most of the streams or khors ** are definitely ephemeral. Here, as in the case of El Fasher and El Obeid, hafirs constitute one of the principal sources of water supply (see Photograph 12). Certain locations in

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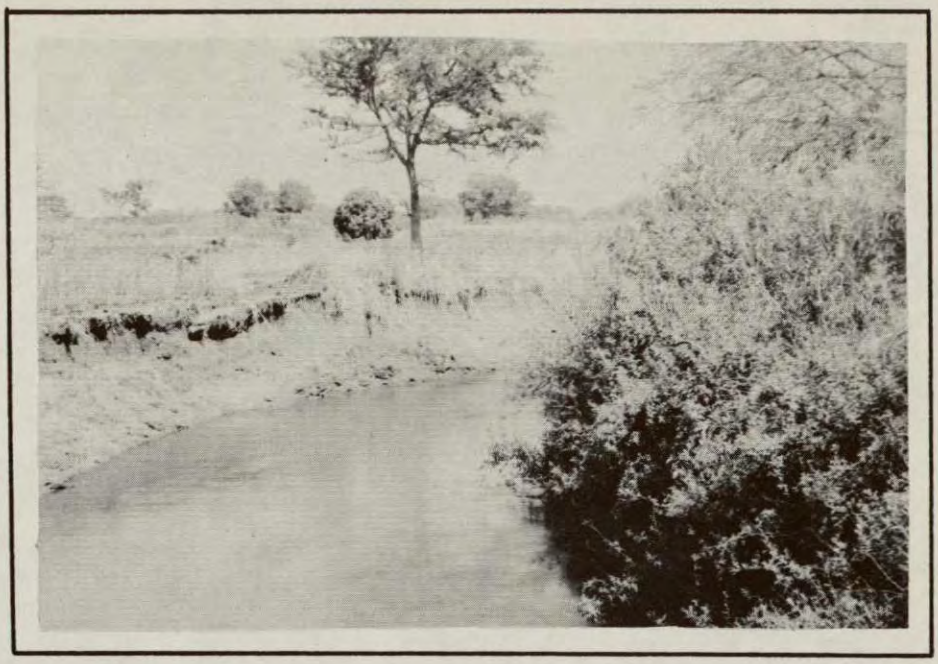
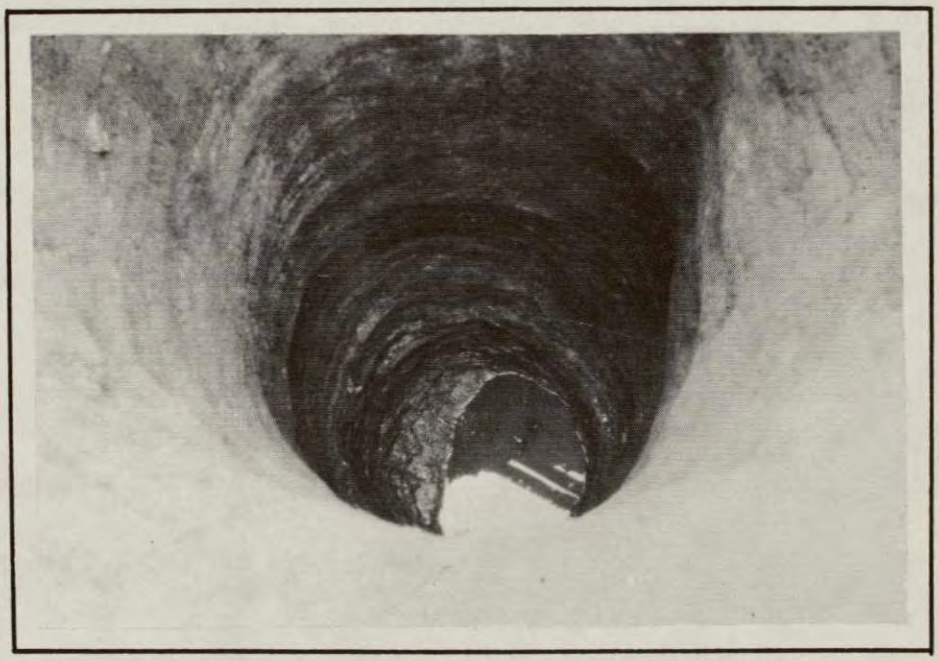
* The terms hafir and fula are used interchangeably in this report. Definitions according to J. D. Tothill are as follows: fula - a large pool; hafir - a pit, locally a pool, usually made by man.

** A khor is a small intermittent stream.



9. Kireyei River near Torit. Perennial streams such as this could be dammed to provide more water to the area. Water could then be diverted by canal to central points of use and long water hauls could be reduced.



10. Hand dug well near village of Loda about 60 miles southwest of Juba. Depth is about 30 feet. Water collects over night and is bailed out in the morning. Rock is a platy weathered metamorphic.

the central area appear suitable for additional hafirs or small dams on the main ephemeral khors between Gedaref and Khartoum.

The main hope of increasing the surface water supply in both the southern and central areas lies in the construction of small check or diversion dams on some of the smaller perennial streams. It is not intended that they would interfere with any plans for major water development on the streams. The structures suggested are small gravity type dams with overpour spillways, or flash-board type structures that would allow for passage of floods, yet retain substantial quantities of water in storage in the upstream channel during periods of low flow. These modified hafirs should have storage capacity great enough to provide water for domestic and stock use, and might even permit limited diversion by ditch to nearby villages, or offstream hafirs, which would reduce water transport problem to some of the villages. In some instances, limited irrigation might be practiced during part of the year near the villages.

Consideration of stocking these hafirs with fish is recommended if they contain water the year round.

Northern Area (North of 18°N Latitude)

That portion of the Sudan lying north of 18°N latitude is essentially a desert area. This is particularly true of the westerly half, which is the southerly extension of the Libyan or Sahara Desert. Here vast stretches of shifting dune sands may be seen for miles with

only occasional breaks where crystalline ridges, dikes or hills protrude through the sands. The Nubian formation underlies this western portion of the northerly half but is apparently thin, thereby reducing the chances of its storing appreciable quantities of water.

Because of the extremely low rainfall in this sector, there is almost no vegetation. The lack of vegetation prevents the dune sands from becoming stabilized, thereby creating very undesirable living and traveling conditions, and making impossible the grazing of animals. Some concern has already been expressed in regard to the encroachment of this desert area into the northerly portion of the west central area as a result of overgrazing. Where overgrazing has occurred, the dune sands become unstable and apparently have migrated in a southerly direction.

In the absence of suitable living and grazing areas, this sector is very sparsely populated and consequently little exploitation of water has been attempted and very little is known about potential water supplies. It is generally agreed that, due to lack of rainfall and the thinness of the Nubian formation, there is little water in this area.

The easterly half of the northern area is occupied almost entirely by crystalline rock with only thin, isolated, small patches of Nubian and occasional small, isolated cappings of Tertiary

volcanics scattered over the area. The crystalline rocks have been previously described as unsuitable for supplying water to drilled wells. Rainfall is so scanty in this area that there is little hope for anything but small hafirs and probably few of these.

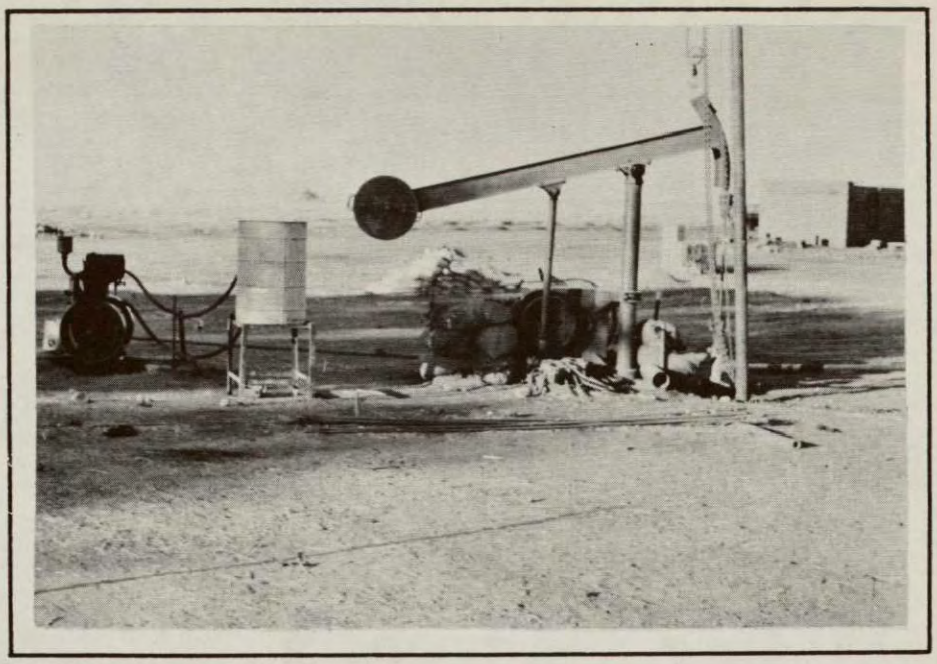
At a later date, when some of the more pressing problems regarding water supply are solved, it may be desirable to extend geological and geophysical surveys into the northern area to determine how far north of the 18° parallel water may be economically exploited.

Hafir Construction

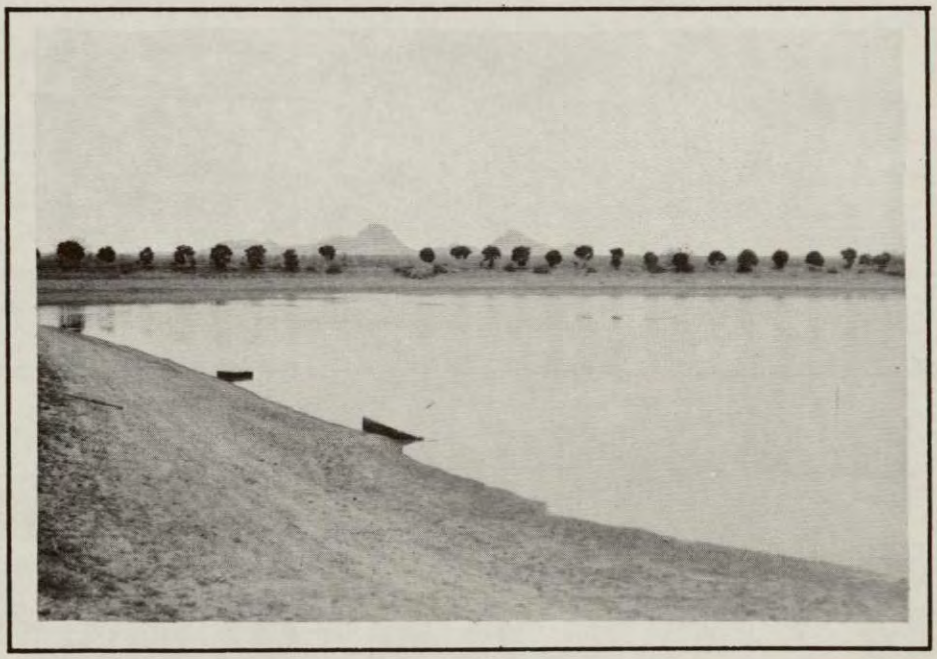
Hafirs, sometimes under different names, have been constructed for many hundreds of years in the Sudan as well as other desert countries. In the Sudan at the present time, there are many locations in the southern and central western desert areas where small ephemeral flows might be collected to provide drinking water for a period of several months for modest sized communities. Unfortunately, the soils of many of the areas in which the hafirs are needed are so sandy that the seepage losses would practically render them valueless.

Regulations for Hafir Construction

The Land Use and Rural Water Development Department has issued certain regulations concerning the locations of these hafirs. One is that they are to be located in an area where the local people (in absence of stream flow data) are able to indicate that definite flows occur at certain times of the year and nearly every year. Secondly,



11. Pump and engine at the water yard under construction about 15 kilometers southwest of Gedaref.



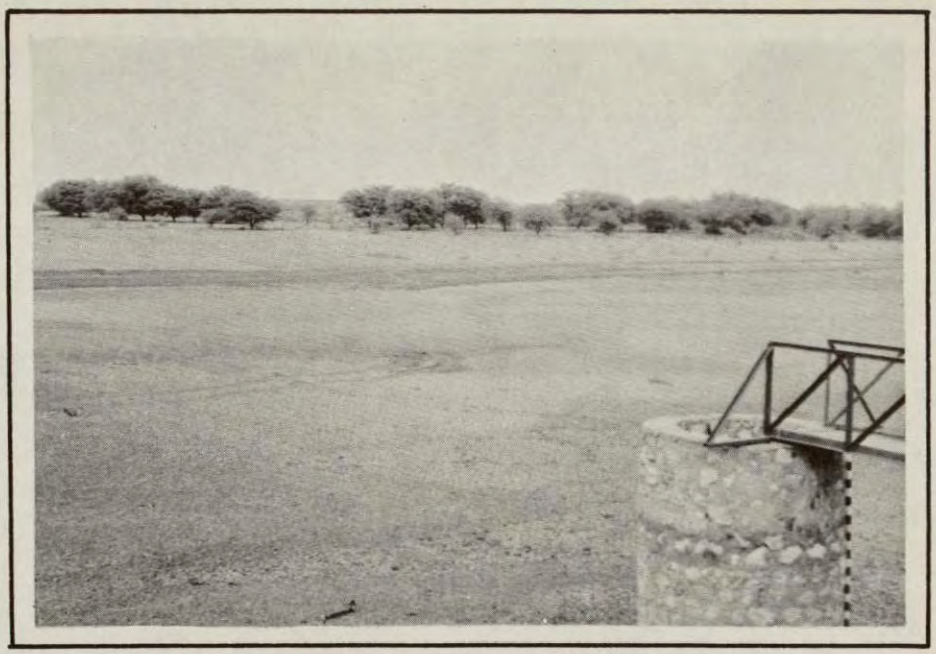
12. Hafir at El Ein. The clear water has been transferred from one catchment area just to the left of this photo and is now ready for pumping to the El Obeid city supply.

it is required that requests for hafirs be confined to areas where the top 10 to 20 feet of soil is reasonably clayey or impermeable. This requirement is mandatory because there are no means at present available for inexpensively reducing seepage loss from these reservoirs.

Size of Hafirs

Lack of hydrologic data makes it difficult to establish the economic size of hafirs to be constructed. The problem of seepage and evaporation is of the utmost importance. While a normal hafir constructed under ideal conditions may contain water for a period of months, or even years, depending on size, available supply and rate of withdrawals, those constructed in the more permeable materials, such as the Qoz sands, will be subject to severe losses due to seepage. In addition, loss by evaporation will vary from about 9 to 12 feet of depth per year. Hence, the most desirable design of a hafir is one with steep sides to minimize the surface area and evaporation loss. The average hafir is about 100 meters in length and 40 meters in width, with a depth of approximately 10 meters, of which 4 or 5 meters may be accounted for by the surrounding embankment. Side slopes are frequently constructed on the order of 1-1/2 to 1.

In some locations, the size of the completed hafir is probably too small. This is evidenced by the fact that water often flows over the spillways or through by-pass structures, even though the hafir may have insufficient capacity to provide water for the community throughout



13. Outlet structure at El Bannu hafir near El Obeid. This hafir is dry early in the dry season yet it had spill during the wet season indicating too limited a storage capacity.

14. Hafir Jebel El Sherif 30 kilometers west of Gedaref. No rain had occurred in this area for over a year at the time of the visit but considerable water remains.

the year. For example, at Fula Bannu, during 1958, the rainfall was only about 30 per cent of that normally expected and the area was facing a serious shortage, yet an appreciable quantity of water passed over the hafir spillway during this dry year.

Seepage from Hafirs

In the sandy, permeable section of the west central provinces, there has been natural reluctance to construct new hafirs because of the excessive seepage losses.

Heavy losses are quite apparent at El Bannu, where two pumps operating out of a pit just downstream from a hafir recover considerable water. Similar recovery could be accomplished around the downstream one-third of the perimeter of this hafir but such a procedure would be very costly. Better ways of reducing seepage losses might be to install a cut-off under the core of the hafir embankment, or to introduce a clay, bentonite or chemical sealant into the interior surface of the hafir, or to blanket a portion of the sides and bottom upstream from the core to reduce seepage by increasing the path of percolation under the dam.

The Land Use and Rural Water Development Department has attempted to find a method of preventing hafir seepage and, in one experiment, tried an interior lining. A hafir was excavated and the embankment placed in the usual way without rolling. The total cost was about five thousand pounds, or roughly $15,000. The Shell Oil

Company then undertook to provide an impervious lining for this hafir on an experimental basis. By using bitumuls and local sand available at the site, they were able to design an impervious mix which was plastered on the sides and floor of the hafir much as plaster is applied to the walls of buildings. This lining cost about five thousand pounds, equivalent to the cost of constructing the hafir. This lining cost was considered prohibitive.

The survey team made a brief investigation of problems of low cost canal and reservoir linings in the United States on return from the Sudan. This was motivated by the fact that the Land Use and Rural Water Development Department had indicated that there were over 100 sites for urgently needed hafirs in locations where water was available to fill them during normal years but where they could not be constructed because of the permeable nature of the soil.

Based on previous studies of the seepage problem, a review of the publications listed in Appendix G, and an examination of soil materials in various areas of the Sudan considered for hafir construction, three possible methods are suggested for consideration, namely the asphaltic membrane, a blanket of sandy clay, and a rolled impervious blanket. Several other methods have been studied and the possibilities examined, but these three appear at this time to offer the best prospects of success.

What about Columbia soil cement?

The asphalt mix would be sprayed over the floor and side walls of a hafir by means of a bar nozzle attachment to a spray machine. This process will require that the mix be heated and delivered at temperatures of 375 to 400°F. The sprayed membrane should be spread over the surface of the hafir to a depth of 1/8 to 1/4 of an inch. It appears that several light applications might be more satisfactory than a single heavy one in many of the areas where the material is fine grained and relatively uniform in size. After application of the asphaltic mix, in a hot state, the surface must be covered with a coating of sand or fine gravel, or other locally available granular material to serve as a protective cover against the trampling effect of men and animals. Once the asphaltic membrane is ruptured, the imperviousness is lost in the immediate area.

It seems possible that asphaltic residues from the petroleum industry might be imported from Saudi Arabia, or nearby oil-producing countries where refineries exist, by sea transportation to Port Sudan. Rail haul from Port Sudan to points within 100 to 300 miles of the areas of use might be expected. Hauls from the rail head to the site of use would have to be by truck.

The application of a hot asphaltic mix seems to offer a relatively inexpensive method. Contract costs in the United States for preparation of surface, spraying the oil mix, and protecting it

with a gravel or sand blanket have varied from about 70 cents to $1.40 per square yard. An average of $1.00 per square yard would not seem unreasonable for contract work in the United States. While it is realized that in a previous experiment in the Sudan, the cost of a similar lining was considered too high, it is believed that with the low cost of labor an application method might be devised whereby the cost could be reduced.

The second method which should be considered is that of using a blanket of fine material, such as a mixture of sand, silt and clay. Such a soil mixture should not require moisture control, compacting equipment or special technicians. It would probably be easier to devise a sand, silt, clay mixture than to discover a clay deposit, and it could be placed or dumped as a blanket without use of water. This material would have the effect of blanketing the permeable hafir surfaces with a less permeable material for use against low hydraulic head, rather than a completely impervious membrane. Side slopes inside the hafir would have to be flatter than would be possible with rolling. This method should be especially applicable to the smaller hafirs. Where suitable fine grained materials are available near the hafir site, the cost of using this type of blanket should be lower than either of the other methods considered.

The third method involves the locating of deposits of finer silty or clayey materials, and hauling them to the hafir area. Using

moisture control, or possibly a soil cement stabilized mixture, an impervious blanket might be placed over the pervious bottom and sides of the hafir using sheepsfoot rollers. This method may be more costly in time, equipment and technical skill required than the other two methods.

It is suggested that a limited experimental program be set up in the vicinity of Khartoum, where sandy soil is available for hafir construction and where any amount of water is available from the Nile River. The cost of transporting small quantities of asphalt to Khartoum should not be prohibitive, and equipment and personnel to operate the tests may be readily available. Several small experimental hafirs could be constructed and treated with the asphalt, sandy clays, rolled fill, plastics and other materials. The cost of the surface treatment work and the loss of water in each case should be studied and evaluated to determine which type of treatment would be most feasible for either general or limited use. This experimental program would be of tremendous value if it resulted in establishing an economically sound method of constructing hafirs in permeable soils.

Prior to undertaking such a program, the services of a technician qualified in the field of canal and reservoir lining and blanketing processes should be obtained to:

(a) Plan a detailed testing program to determine the best methods of constructing the hafirs.

(b) Prepare an estimate of the cost of the program.

(c) Supervise the testing operations.

Assistance to Provinces

The Land Use and Rural Water Development Department has established certain procedures to be followed in making requests for hafir construction. In an excellent memorandum for the Governors' meeting of January 1959, the Director of the Land Use and Rural Water Development Department went into considerable detail on this subject. In addition to the numerous requirements relative to location, need and physical conditions, he proposed that, prior to submission to the Land Use and Rural Water Development Board, any proposal be passed upon by a Provincial Land Use and Water Development Committee comprised of:

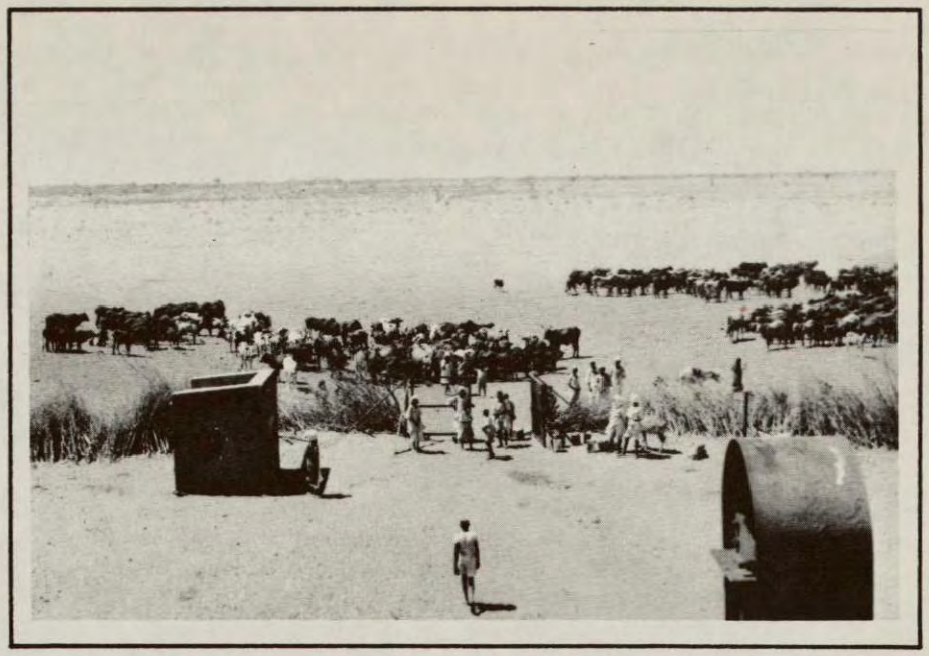
Regional Engineer)	Land Use and Rural Water Development Department
Land Use Officer)	

Senior Inspector of Agriculture

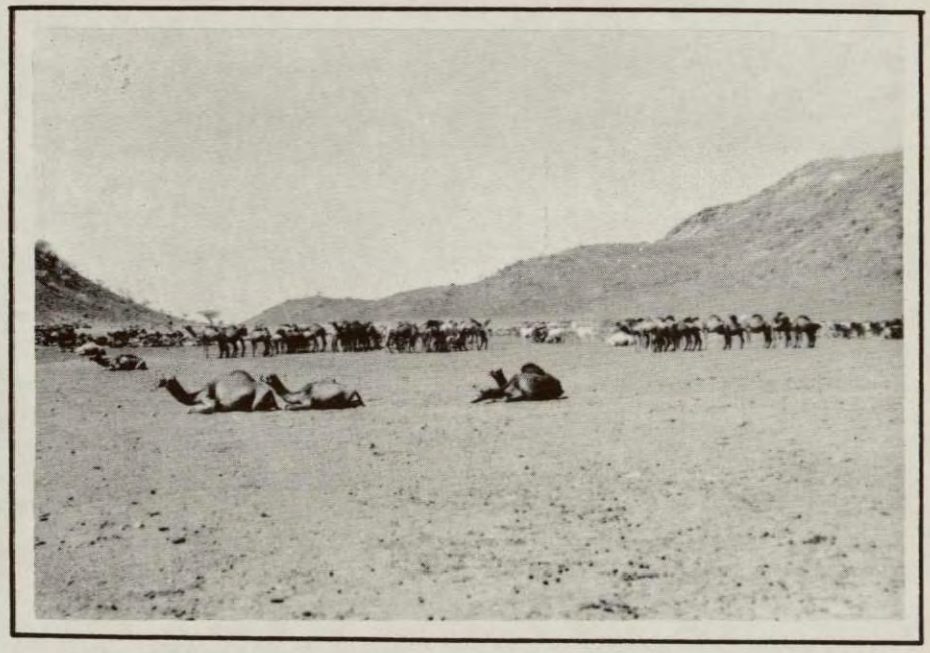
Senior Inspector of Animal Production

Should the proposed hafir be approved by this provincial committee it would then be submitted to the Board. Apparently Board approval would then turn the project over to the Land Use and Rural Water Development Department for implementation.

If the Regional Engineer at provincial level is a technician who understands hafir construction, this procedure should be satisfactory. If not, a technician from the Department skilled in hafir development might well be furnished the provincial committee. It would also be very desirable to have a staff member from the Geological Survey on, or available to, the provincial committee. The geologist would be acquainted with the soils, geological conditions and location of construction materials and could evaluate the proposal in terms of the alternative of well construction and ground water quality. Having all necessary technical personnel on the site at provincial level would greatly reduce the work of the Board and might avoid the need of subsequent investigations. Any additional technicians as proposed could schedule their appearance at the various provinces well in advance, so that each provincial committee in turn could have at its disposal all available data and utilize the advice and assistance of the best technical services in the country.



15. Animals waiting at gate of Moneim water yard. Photo from top of 12,000 gallon elevated water tank.



16. Water from wells in the granitic debris at Jebel El Fau has supplied large herds of animals for many years. The hills surrounding this pass contain some water stored in fractures that is yielded to the pocket of debris which is the main water holding medium.

CHAPTER V

CONCLUSIONS

1. A shortage of potable water exists now in the Sudan and will continue to exist for a considerable length of time.

2. To eliminate this shortage or to make an appreciable reduction in the shortage will require immediate remedial measures.

3. The crystalline rocks that surround the country and occur in the central portion are considered to be non-water bearing and will not provide a satisfactory source of ground water.

4. The Nubian sandstone which occurs in the northern area is the best water producing medium available.

5. The Umm Ruwaba formation overlying the Nubian particularly in the southern and central areas is a fairly good water producing medium. Saline waters may be encountered in this formation.

6. In the critically water deficient areas of Kordofan and Darfur Provinces there are large areas where little hydrologic or geologic information is available. Investigations of subsurface configuration and thickness of water-bearing materials are needed in this area.

7. Additional geophysical work of an exploratory nature is and will be needed in the Kordofan and Darfur Province areas on a

continuing basis. This may be done by contract and by limited use of the Sudanese Geological Survey seismic equipment. Additional training of Sudanese personnel in the latest methods of geophysical surveying is desirable.

8. The percussion drilling equipment being used to drill wells at the present time is too light for the casing being used, the depths to which wells must be drilled, and the nature of the formation penetrated. The drilling rate is slow. There is an immediate need for many additional wells to increase the potable water supply.

9. There is a need for additional well drilling equipment of the rotary type to exploit the potable water supply at greater depths.

10. The Drilling Division is presently using heavy oil field type casing for water wells. The rate of drilling could be appreciably accelerated in many cases by the use of a more suitable type of casing. It would be desirable to send the Drilling Engineer from the Drilling Division to the western United States to study well drilling methods and particularly the use of light weight casings, and the use of a knife perforator.

11. A long range study of geologic and hydrologic conditions should be made to evaluate the quantity, sources, and recharge possibilities of ground water and to determine the approximate safe yield of the various ground water provinces.

12. A need exists for training Sudanese field geologists in methods of ground water study and inventory.

13. With the proposed expanded drilling program, additional personnel will be required to obtain the data for this program and to assist in starting the long range ground water study.

14. It has been noted that out of 16 field geologists in the Sudanese Geological Survey only one is presently budgeted for ground water work. While others have been budgeted for future years, it is believed that, since the ground water need is so pressing at the present time and has been in the past, consideration should be given in high levels to increasing the budgeted positions at once. Other Geological Survey personnel not presently so budgeted are working on ground water at the present time due to the foresight of the Director of the Geological Survey.

15. In the future there will be a need for more exploratory work to be done by the Geological Survey and any drilling done for exploratory purposes should not be charged as dry holes against the Drilling Division.

16. The Geological Survey should have responsibility for the final location of all water wells to be drilled and should obtain and interpret the samples taken from wells being drilled in the field, make field water quality determinations, determine when to stop

drilling and decide at what depths perforations should be made.

17. Certain minor equipment and supplies will be required in connection with the enlarged drilling and hydrologic study program.

18. Particularly in the southern part of the Sudan, there is a need for geological reconnaissance of certain perennial streams to determine foundation conditions for small channel and off-channel storage reservoirs, or hafirs, to increase the potable water supply.

19. A limited testing program is desirable to determine the feasibility and least costly method of lining hafirs in areas having permeable soils at and near the surface.

20. Dug wells are desirable in the small village areas where geologic conditions are favorable for such wells. They can usually be dug locally at low cost. The production of such wells can be enhanced by the use of small sump pumps and limited amounts of minor equipment to enable the diggers to work below static water table.

21. Certain technical assistance will be required on some of the programs suggested in the report and Appendices. This assistance should be of highest caliber.

22. A limited amount of high level consulting services may be desirable to insure the effectiveness and correctness of any program followed.

CHAPTER VI

RECOMMENDATIONS

1. The drilling engineer for the Drilling Division should be sent to the western United States for a period of about six weeks to study various types of thin wall and lighter types of casing and its installation with both percussion and rotary drilling and also the use of knife perforations.

2. Three rotary drills capable of drilling 11-5/8" holes to depths of 2000 feet, including necessary accessory equipment and specialized training personnel should be made available to the Sudanese government by October 1959.

3. A reconnaissance type geophysical survey to be accomplished by contract using magnetometric and gravimetric equipment should be made for the Sudan in the areas indicated on Plate III. At a later time when this reconnaissance survey is completed the needs for further geophysical surveys may be more intelligently determined.

4. Two Sudanese field geologists should be sent to the United States each year for a period of 4 or 5 months training in the practical application of ground water study and inventory methods. This training program should be repeated for several years.

5. Two qualified engineering geologists with ground water experience should be brought to the Sudan and assigned to the

longer?

government for a period of one year to assist the Geological Survey staff with the drilling program, including scheduling of operations and the collection, interpretation and presentation of hydrologic data. These men should be limited strictly to the above hydrologic work and not be used to do general geology, economic geology or mineralogic studies.

6. Additional personnel should be added to the ground water section of the Geological Survey after a re-evaluation of necessary work in light of the items recommended in this report. Two experienced Sudanese geologists should presently be transferred to full time ground water studies, to be trained to assist the Director in organizing and directing the ground water investigations.

7. The Geological Survey and the Drilling Division should be together as a unit. The Drilling Division should be under the Geological Survey or at least in the same Ministry. The purpose of this proposal is to place the drills with the agency responsible for locating wells, interpreting the drilling data and making the preliminary water quality analyses. When a well is completed and determined to be successful, it should be turned over to a separate agency, which would install the water yard, fence, pumps and buildings and produce and sell the water.

8. One Sudanese geophysicist should be sent to an approved United States school for advanced study in geophysical surveying and

also to obtain some practical experience in the field. This would require that the selected geophysicist spend a period of approximately two years in the school.

9. It is recommended that the Geological Survey be provided with the following items of equipment:

a. Additional Technical Books (see Appendix E).

b. Geochemical kits for field water quality analysis (see Appendix D).

c. Three electric logging devices of suitable type capable of logging to depths of 2000 feet (see Appendix D).

d. An appropriate resistivity field apparatus (see Appendix D).

10. The Geological Survey should examine all proposed small dam and hafir sites to determine the suitability of foundations, storage area and materials sources.

11. The drilling of new wells should be confined to those areas underlain at depth with Nubian or Umm Ruwaba formations and particularly to areas of known or probable water production capability.

12. Provision should be made to secure the services of a qualified United States technician in the field of low cost canal and reservoir lining to institute and supervise a testing program on feasibility and cost of hafir lining in the Sudan.

13. The Geological Survey should be provided, in the near future, with a combination drill capable of doing both percussion and

rotary drilling, and possibly air drilling, for exploratory work. The rig would be maintained and operated by the Drilling Division as other rigs are at present, and used by that agency for well drilling when the Geological Survey does not need it for exploratory work.

14. Local dug-well construction should be encouraged and the number of governmental well-digging teams should be increased from 7 to 10. Minor digging equipment and small sump pumps should be supplied to these teams.

15. Since the success or failure of much of the recommended work will depend to a large extent on the quality of United States personnel supplied the Sudanese government, only top quality individuals should be considered for these assignments.

16. A limited amount of high level consultant service to implement any program adopted should be employed.

The proposed equipment and training schedules for items 1, 2, 3, 4, 5, 8, 9, 12, and 13 are shown on page 96.

PROPOSED EQUIPMENT AND TRAINING SCHEDULE

PROGRAM	1959 May	June	July	Aug	Sept	Oct	Nov	Dec	1960 Jan	Feb	Mar	April	May		
Training - Drilling Engineer in U.S.															
Training* - Two Geologists in U.S.															
Provide Drilling Equipment and Training															
Provide Geophysical Survey - with Training*															
Training* - Geophysist Academic and Practical											To continue until Oct. 1961				
Provide Two U.S. Ground Water Geologists								To continue for one year							
Provide Hafir Lining Test Program															
Equipment for Geological Survey	One electric logging device, ten water level recorders, and four field water analyses kits should be provided the Survey as soon as possible. A second electric logging device should be provided with the three additional drills. A combination rotary and percussion drill should be provided in the near future.														

* Provides for training of Sudanese personnel.

APPENDIX A

SPECIALIZED TRAINING FOR SUDANESE PERSONNEL

SPECIALIZED TRAINING FOR SUDANESE PERSONNEL

1. Ground Water Training for Sudanese Geologists. Send two Sudanese geologists to the California Department of Water Resources in the United States for a period of four to five months for specialized training in ground water study and inventory methods.

These men should be given instruction and work on the latest methods of ground water study and inventory, including stream percolation studies, consumptive use studies, specific yield studies, storage capacity studies, safe yield determination of basins and latest methods of data presentation. This program would accentuate the approximate methods so necessary to the Sudan where detailed information for a long period of time is not available.

The trainees would work on present day ground water projects currently being studied and worked upon by the Department of Water Resources and would participate in all phases of the study and report preparation. The trainees would participate in field trips and the actual field collection data, sample taking and field mapping. This phase of the training program should be accomplished from May to December 1959.

As other trainees become available at a later date they may be sent, if desirable, to other agencies in the United States doing

similar types of work.

Approximate cost of this program for two Sudanese geologists for a five month training period in the United States may be tabulated as follows:

Transportation	$3,000
Living expenses	4,000
Miscellaneous travel and transportation expense in the United States	2,000
Total	$9,000

2. Geophysical training for a Sudanese Geophysicist. One Sudanese geophysicist to be sent to an approved University in the United States to study advanced geophysical survey methods with emphasis on field methods and interpretation of data.

The courses to be taken would be based on the trainees previous academic training. Approximately nine months each year would be spent in academic study with a summer training period of three months in the field each year with a recognized agency doing engineering geologic work or ground water studies by geophysical methods in the field and particularly in the western United States.

The estimated cost for a two-year training program is as follows:

Two years of academic and practical training (school costs)	$2,000
Transportation	1,500
Living allowance	6,000
Miscellaneous travel expense and other items	1,500
Total	$11,000

This suggested training program should be repeated for several years, or as often as desirable to train the required number of Sudanese personnel.

3. Training Sudanese Drilling Engineers in the United States for a Six Weeks Period. Drilling engineers sent to the United States would be sent to the western portion of the United States where they might see several types of well drilling operations and the use of various types casings, particularly thin walled and light weight casings, various drilling fluids and also the use of knife perforating machines.

They would also visit the various casing manufacturing plants and discuss with other drilling engineers the problems common to both countries.

The drilling engineers should also inspect excess government stocks with a view of determining what equipment presently available would be of particular use in the Sudan in the near future.

This phase of the program should be accomplished during July and August of 1959.

The estimated cost of sending one drilling engineer to the United states for a six weeks period is as follows:

Transportation	$1,500
Living expenses	500
Local transportation between various areas	1,000
Total	$3,000

Note: If it is deemed desirable to send two drilling engineers from the Sudan in 1959 the above costs should be doubled.

APPENDIX B

PROPOSED GEOPHYSICAL SURVEYS

PROPOSED GEOPHYSICAL SURVEYS

Combined gravity and magnetic surveys are recommended to outline the depth to basement complex over the five areas indicated on Plate III. It is suggested that the Geological Survey provide some personnel to assist in the program and to receive training. Such a program should provide the data necessary at this stage for the water development program. The survey is recommended as the logical first stage of this exploration and it is believed that the program will be completed within five months.

The following are two plans requiring personnel from both the Geological Survey and a contractor. Plan A would permit more Geological Survey participation and training and hence is preferred over Plan B. Both plans are indicated as it may not be possible for the Survey to provide personnel required under Plan A.

PLAN A

Equipment

2 Gravity meters
2 Magnetometers
2 Sets surveying instruments
2 Trucks - four wheel drive
2 Jeeps
Camping equipment
Food and supplies.

Monthly Cost - $6,000

Personnel

1 Party Chief
1 Meter observer
2 Surveyors

Monthly Cost - $4,000

Total Monthly Cost -$10,000

Transportation to and from the Sudan - 10,000

Total for five-month period - $60,000

In addition the Geological Survey would provide:

1 Magnetometer operator*
2 Computers*
4 Chainmen
1 Cook
2 Drivers
4 Laborers

* Personnel to be trained by contractor on the job.

PLAN B

Equipment

2 Gravity meters
2 Magnetometers
2 Sets of surveying instruments
3 Trucks - four wheel drive
2 Jeeps
Camping equipment
Food and supplies

Monthly Cost - $6,000

Personnel

1 Party Chief
2 Meter observers
2 Surveyors
2 Draftsmen and computers
4 Chainmen
3 Drivers
4 Laborers

Monthly Cost	$8,000
Transportation to and from the Sudan	12,000
Total for five-month period	$82,000

APPENDIX C

DESCRIPTION OF PROPOSED TRUCK MOUNTED ROTARY DRILLING MACHINE AND ACCESSORIES

PROPOSED DESCRIPTION OF TRUCK MOUNTED ROTARY DRILLING MACHINE AND ACCESSORIES

Rotary table should be minimum 18" diameter opening, of enclosed oil bath type with spiral, bevel, precision cut lapped gears. Unit should be equipped with diesel type engines of approximately 90 hp each. Hydraulic drives are fitted to each engine with fluid couplings of approximately 17-1/2" size.

The drill unit should have a compound drive, in order that one engine may power the mud pump and the other may power the rotary and draw works or both engines may be compounded to power the mud pump, rotary table and draw works; or either or both engines may be used on the draw works when hoisting heavy strings of drill pipe or casing. Drill transmission should have minimum four speeds forward and one speed reverse and should include a master clutch to the draw works and rotary table.

The draw works assembly shall be made of structural steel frame, and include a main hoisting drum with two air clutches and sand reel with air clutch, and including a special air actuated spinning or breakout cathead, in addition to a standard cathead. Complete draw works to be enclosed with a light weight metal guard.

The air system should be complete with two air compressors, each with ample capacity for operation.

The mast shall be a minimum of 58 feet in height, made in three sections, consisting of seamless steel with folding platform and pipe holder, crown block, safety guard, crows nest, all installed on drill unit. The complete mast should be wired and equipped with electric lights. The mast raising system should include suitable oil pump, two mast raising cylinders with safety check, hydraulic piping guard and controls located on the left hand side of the drill frame.

The drill frame proper shall be all steel, electric welded, with tool box and completely covered with heavy, diamond type floor plate.

The mud pump shall be minimum 7-1/2" by 8" duplex power pump, fitted with surge chamber and fully assembled for slush service. The mud pump drive to be fitted with an air clutch and 2-1/2" piping from standpipe to mud pump. The mud pump to be equipped with a thousand pound mud pump pressure gauge and relief valve. The mud pump gauge shall be in visible sight of the operator. Suitable shale shaker to be furnished with this proposal.

Machine shall be equipped with all necessary hand tools for normal maintenance of the drilling equipment.

All sub-structure, jacks, and supports are to be furnished with the drill. Complete tong hanger and counter balance weight

assembly for supporting drill pipe and casing tongs to be furnished. A suitable rathole table stand and drive assembly shall be made a part of the drill unit.

The following tools, equipment and accessories shall be furnished:

Minimum 2" heavy duty water swivel. Kelly of approximately 34 feet length and 4-5/8" diameter with three drive grooves. Kelly drive bushing and all necessary subs. Swivel hose, suction hose, strainer, traveling block with a minimum of two sheaves, drum line and sand line should be minimum 3/4" and 7/16" diameter, respectively. Tongs suitable for use with both drill pipe and casing. Two thousand feet of range one 3-1/2" API internal flush drill pipe. Drill pipe should be fitted with tool joints and threaded protectors. Drill pipe and casing elevators provided with suitable elevator links. Drill collars should be minimum 20' length and 6-1/2" diameter. Suitable quantity of roller rock bits, sizes from 7-5/8" through 11-5/8" diameter.

The unit shall be capable of drilling 11-5/8" diameter hole to a maximum depth of 2,000 feet using 3-1/2" drill pipe plus two drill collars, 6-1/2" OD.

The mast shall have a capacity of 90 thousand pounds. The

draw works shall be suitable for hoisting 60 thousand pounds of drill pipe or casing loads. All casing and drill pipe slips to be furnished.

A recommended light plant shall be installed on the drill frame.

Seventy tons commercial drilling mud in one hundred pound sacks to be furnished.

The drill unit should be mounted on a suitable 6 x 6 all wheel drive truck, powered with a diesel engine and equipped with sand tires suitable for traversing desert areas. If possible, trucks will be supplied the manufacturer at his plant, from excess United States stocks.

Spares amounting to 10% of the total value of the drilling equipment shall be furnished for all three drills. Adequate spares will be stocked by the manufacturer at the source of supply in the event an emergency whereby parts must be ordered within a few hours notice.

A 6 x 6 all wheel drive water truck consisting of minimum 1,000 gallon tank capacity shall be furnished with each drill rig. This water truck shall have a centrifugal pump, hose, with all fittings, and winch with winch line shall be made a part of the water truck.

Fishing tools for each drill shall consist of one drill pipe tap

and die. Three circulating and releasing overshots with slips to fit both tool joints and tubing of drill pipe.

List dealers who will stock supply parts within a 1,200 mile radius of Khartoum.

List 10 agencies or individuals now using the drilling equipment your company intends supplying.

Three complete units are required.

A drilling engineer, plus mechanic and four drill operators, one acting as relief driller should be furnished with the proposed three drill machines. All drilling personnel are to act as drill instructors and will be available for call any time during the drilling operations.

APPENDIX D

PROPOSED HAFIR LINING TEST PROGRAM

PROPOSED HAFIR LINING TEST PROGRAM

Because of the problem of permeable materials at and near the surface of much of the area of the Sudan, and the attendant expected loss of appreciable quantities of water from seepage in hafirs, the following test program is recommended.

A technical expert with experience on low cost canal and reservoir lining should be obtained from the United States and sent to the Sudan for a period of six months to initiate and supervise a test program of possible hafir lining methods. Asphaltic membranes, various loose and rolled earth materials, plastic linings and bags, soil cement stabilized mixes and chemical sealants should be considered.

Small test hafirs should be constructed in permeable areas, near Khartoum where water is available and the supply of materials and equipment may be facilitated. Various linings should be tried and seepage and evaporation losses determined and the relative values and cost of each type lining should be determined.

Estimated cost as follows:

U. S. Technician (6 months)	-	$10,000
Travel	-	1,500
Living expenses	-	2,500
Materials and equipment	-	26,000
Total	-	$40,000

APPENDIX E

EQUIPMENT PROPOSED FOR THE GEOLOGICAL SURVEY DEPARTMENT

APPENDIX E

EQUIPMENT PROPOSED FOR THE GEOLOGICAL SURVEY DEPARTMENT

In order to conduct the ground water exploration program efficiently and also to assist drilling operations most effectively it is recommended that the Geological Survey be furnished the following equipment:

1. Electric Logging Equipment

One electric logging device is presently needed by the Geological Survey to be used with the rotary drill now being operated in the Sudan. Without this logging device it is quite possible to by-pass water-producing zones. Therefore the following equipment is recommended:

WIDCO Model XMV-Type PR or equal. Equipment should be capable of recording potential and single-electrode resistivity curves, simultaneously to depths of 2000 feet; including 110 volt, 60 cycle, 1500 watt generator, and sufficient spare parts for at least one year's operation.

Estimated Cost (FAS United States Port) $8,000.00

One additional electric logging unit will be required with the purchase of the three rotary drills proposed in the report.

2. Water Level Recorders

The Geological Survey should be provided with ten water level recorders to be used in the ground water inventory program. One recorder has recently been provided the Survey by ICA. The following water level recording equipment is recommended:

10 - water level recorders, Stevens Type FM, gage 1:5, metric system

300 - recorder sheets

3 - spare clock units

10 - spare clock weights

10 - spare weights for float line

5 - spare floats, 4" diameter

5 - spare floats, 5" diameter

5000 feet - recorder line or cable

Estimated Total Cost $3,000.00

3. Water Analysis Kits

Water analysis kits are proposed in order to determine the quality of water in the field rather than delaying drilling operations due to the time involved in sending the water samples to Khartoum.

It is recommended that the following be furnished the Geological Survey Department:

4 - Chemical analyses units, including necessary chemicals and equipment to make approximate quantitative analyses of chlorides, sulfates, bicarbonates, hardness, ph, and electrical conductance of ground water.

Estimated Total Cost $2,000.00

4. Earth Resistivity Equipment

In many small areas resistivity surveys are useful in determining the probable location of permeable and saturated materials. The Geological Survey needs such equipment in determining the best locations for wells in the more unexplored areas.

Earth Resistivity Equipment, Gish-Rooney Type, complete with:

Potentiometer and Milliameter mounted as a single unit, Battery box and distributor panel, auxiliary battery box, all necessary batteries, two pairs of

reels and wire necessary to explore to 500 feet, two sets of electrodes. Box of complete service tools and spare parts for one year's operation.

Estimated Total Cost $1,000.00

5. Proposed Combination Percussion and Rotary Type Well Drilling Equipment

This well-drilling machine shall be of the combination percussion and rotary type. This equipment shall be capable of drilling an eight inch diameter hole to a depth of 1500 feet by either percussion or rotary methods. The well-drilling equipment shall consist essentially of a 4-drum hoist with bull reel, casing reel, sand reel; rotary hoisting reel, wire line spudder, counter shaft with clutches, frame, rotary drive shaft, derrick, and power unit all mounted on I-beam sills, for truck mounting. This unit would include a diesel powered 6 x 6 all-wheel drive, truck equipped with sand tires suitable for traversing desert areas. The machine shall

be capable of storing the rotary unit, including the rotary cable, reel, swivel and block on the machine, both during transit and also when drilling by the percussion method. A 5" x 8" mud pump shall be furnished. In addition, all accessory tools, fishing equipment, and necessary tongs, drill collars, rock bits, spare parts amounting to approximately 10 per cent of the total value of the drilling equipment shall be furnished.

Estimated Total Cost	$80,000.00

It is not essential that this drilling equipment be provided this year but it should be provided in the near future.

APPENDIX F

PROPOSED PUBLICATIONS

TO BE PROVIDED

THE GEOLOGICAL SURVEY

PROPOSED PUBLICATIONS TO BE PROVIDED THE GEOLOGICAL SURVEY

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APPENDIX G

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