BULLETIN No. 2.

WATER SUPPLIES

IN THE

ANGLO-EGYPTIAN SUDAN

BY

G. W. GRABHAM

GOVERNMENT GEOLOGIST.

GEOLOGICAL SURVEY OF THE ANGLO EGYPTIAN SUDAN

KHARTOUM
PUBLISHED BY THE SUDAN GOVERNMENT
1934

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INTRODUCTORY.

Rain is the source of practically all the water in the Anglo Egyptian Sudan. In fact it is probable that the country does not contain any supplies from terrestial sources that cannot eventually be traced to rain. The most remote from the direct influence of local rainfall are hot springs such as occur in Halfa and Mongalla Provinces.

Apart from the direct dependence of the water on the rainfall its local value is also principally dependent on the same factor. The supplies are of value in proportion as the country is fertile. In the desert, the water may support oases with limited areas of vegetation. It is where the rainfall is enough to ensure crops and grazing that water may be most needed to enable man and animals to fully enjoy the fruits of the earth. For these reasons, attention is first directed to the rainfall and the observations which supply the statistics.

Chapter I.

METEOROLOGY.

Meteorological Observations.

As soon as the Sudan was re-opened, a system of meteorological and river gauging stations was organised by the Egyptian Government and this service is maintained principally by the Physical Department of the Ministry of Public Works in Cairo. The stations are of various grades according to the numbers and kinds of observations recorded. They are often associated with hospitals and the observer, perhaps the Medical Officer, is paid to see that the observations are properly carried out. There should also be an assistant observer who often does most of the readings. He may be a tamargi and a good observer too. At the principal stations, the observations include the barometer and attached thermometer, wet bulb, dry bulb, maximum and minimum thermometers; evaporimeter, wind direction and force, clouds and rain. Many stations are remote and can only rarely be inspected. It may be helpful if those understanding the observations can occasionally inspect the instruments, taking particular note of their condition and the manner in which they are read. The minimum thermometer and the directions of the wind vane are two matters most likely to call for attention. The observer should possess a copy of the " Handbook of Instructions for Meteorological Observers in Egypt the Sudan and Palestine " issued by the Physical Department, Cairo. This contains descriptions of all the instruments and the methods of use. There should be no interference with the station but, if necessary, a report may be sent to the Controller, Physical Department, Dawawin, Cairo.

The observations are communicated, some daily by telegram, and the rest by post to Cairo, and digests of them are published in various forms ranging from daily weather reports, monthly Bulletins to Annual Reports, with occasional special reports dealing with particular features or localities. " The Nile Basin " Vol. I, by H. E. Hurst and Philips, Cairo, 1931, contains a most valuable general account of the Meteorology and Topography. Volumes II, III and IV pts. 1 and 2 contain statistics of the flow of the Nile. "Climatological Normals", Cairo 1922 gives useful digests of several types of observation. There is also " The Climate of Khartoum " by Sutton, 1923 and " The Climate of the Continent of Africa " by Knox, 1911. Only a small proportion of observations can be published in detail, but the Controller of the Physical Department, Cairo, is always ready to supply full copies of the data to those needing them.

Rainfall.

The first of the following tables gives the mean rainfall, month by month, at the principal stations in the Sudan. It also shews the periods of years covered.

TABLE I.

MEAN MONTHLY RAINFALL IN MILLEMETRES.

—	Periods of Years.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Wadi Halfa	19	—	—	—	—	—	—	—	—	—	—	—	—	—
Port Sudan	16	11	6	2	1	1	0	10	1	0	8	42	17	99
Merowe	16	—	—	—	—	—	—	—	—	—	—	—	—	—
Atbara	19	0	0	0	2	2	4	20	31	9	1	0	0	69
Khartoum	21	0	0	0	0	3	8	40	56	19	5	0	0	131
Kassala	20	0	0	0	2	12	32	102	111	60	12	0	0	331
Wad Medani	19	0	0	0	2	13	42	113	148	67	14	1	0	400
Dueim	19	0	0	2	0	8	21	85	109	52	13	0	0	290
El Obeid	20	0	0	2	1	11	30	92	115	87	18	0	0	356
Fasher	11	0	0	0	0	8	15	103	142	26	8	0	0	302
Singa	9	0	0	0	4	37	82	150	178	86	25	3	0	563
Malakal	6	0	0	9	16	108	168	153	208	154	78	13	0	907
Wau	19	1	6	22	53	139	169	185	207	162	127	17	0	1088
Mongalla	18	2	19	39	106	137	117	132	148	124	109	46	8	987

The quantity of rain differs considerably from year to year and this is shown in Table II which gives the totals, at the same stations, for each of the fourteen years from 1916 to 1930.

TABLE II.

RAINFALL: ANNUAL TOTALS IN MILLEMETRES.

	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930
Port Sudan	168	25	134	98	36	92	41	228	129	422	53	96	73	32	28
Atbara	52	29	5	74	67	141	127	195	76	33	12	73	17	84	42
Khartoum	147	76	94	74	341	248	365	339	158	103	92	216	121	254	223
Kassala	488	314	236	274	388	254	315	462	330	325	134	453	253	(349)	220
Wad Medani....	507	373	303	330	612	344	603	388	299	267	240	389	274	664	403
Dueim	272	298	168	420	368	244	409	350	363	243	233	256	206	449	329
El Obeid	314	370	245	204	452	286	379	360	475	253	206	234	354	423	442
Fasher	—	—	267	301	407	234	547	302	482	179	105	301	360	555	478
Singa	778	411	443	393	1059	538	594	592	652	524	445	534	569	690	527
Malakal	918	1127	749	283	919	799	1010	887	535	1051	995	720	1044	1084	629
Wau	1447	1107	912	1067	1399	915	1208	1581	1381	1080	977	980	977	1191	1046
Mongalla	1465	952	852	1008	1159	896	(989)	1225	993	807	724	703	1042	931	(729)

Figures in brackets are incomplete records. Mongalla Station was closed in October, 1930, and the record is for only 10 months of the year.

The map at the end of the bulletin based on information from the Physical Department of the Egyptian Ministry of Public Works, shows the general distribution of rain in the Sudan. The quantity increases towards the S. and S.E. and is greatest on the high mountains of Abyssinia. It may be seen from the table that the rainfall of the Red Sea Coast as represented by Port Sudan differs from that of other parts of the Sudan. In the coastal district the rain falls during the Winter months from November to January and there is hardly any in the Summer.

The value of the rainfall depends not only on the total quantity but also on its distribution. For the growth of crops in the Central Sudan, 10° to 15° N. Latitude, the ideal is probably to begin with showers in June, increasing to heavy rain in July continuing with falls at intervals to support continuous growth of vegetation until the end of September. If the rains begin late or cease early, the crops do not mature properly and the grazing is affected in a similar way.

Heavy showers late in the season are very favourable for feeding the subsoil water and maintaining supplies to wells and springs until late in the succeeding season. A large total rainfall made up of numerous light showers which evaporate directly from the surface of the ground may be of little assistance to the supply of ground water.

The Nile Floods.

The flow of the Nile represents the result of the rainfall over a considerable part of the basin. The annual flood arises principally from the Eastern tributaries, the Blue Nile and the Atbara, which bring the water quickly into the main stream. The height of the Nile is recorded at numerous places along its course and probably the flow of no other river, from its source to its mouth is so carefully watched and measured. At Aswan the channel is bound by hard granitic rock and is little subject to change. The records of the gauge there extend back to 1869 and form a most important series. A study of the heights attained by the series of floods during this time shows that the period from 1869 to 1899 includes a number of high ones and very few low ones while the following period of thirty years includes some very low floods and almost no high ones. The highest floods of the whole period are those of 1874 and 1878 and these were approached in several years before 1899. The highest flood since 1899 occurred in 1916 and the level was 93.20 m. During the previous 30 years, 1869—1898, this figure was exceeded in seventeen seasons; in 1878 by nearly a whole metre and on seven others by more than half a metre. There has been nothing approaching these floods since 1899, and it can be said that none, among the present generation of officials, has seen a really high flood. Records of the Nile gauge at Roda, Cairo, extend from 641 to 1451 and from 1737 with one break to the present time. "If these maxima are plotted, no regular periodicity appears but it is seen that high or low years tend to occur in groups" (1). We can conclude that the flow of the Nile throughout

(1) Nile Control, Cairo, 1921. p. 36.

history, since the earliest dynasty in about 3200 B.C., has not been subject to any great change and consequently that the rainfall in the Nile basin has also been similar to that of recent times. There have been periods with more rain and others with less but the average has remained fairly constant. We have lately been experiencing one of the dry periods.

Much research has been carried out with the object of ascertaining the factor on which the rain depends and perhaps enabling the height of the Nile flood to be predicted. It seems to be agreed that the rainfall over the Sudan depends on evaporation in the South Atlantic and on the temperature and atmospheric pressure over the Nile basin.

A monthly chart is issued with diagrams of the principal Nile gauge readings and also tables recording the volumes of flow.

Evaporation.

This meteorological factor, though hardly considered in Northern European countries, is of very great importance in the Sudan especially in considering the losses from the surfaces of reservoirs and tanks. The measurements are usually made by means of a Piché tube exposed in an ordinary meteorological screen and the readings of these instruments are given in tables. It has been found that the results of the Piché tube observations have to be multiplied by the factor 0.58 to give figures representing evaporation from open water surfaces such as rivers or large reservoirs in the neighbourhood. The evaporation from a small area of water, such as a hafir or a fula must be relatively greater but we have not yet any direct measurements. The following are results obtained at Khartoum and are the means of observations extending over a period of 16 years. (1) The figures represent the depth of water, in millimetres, lost daily by evaporation :–

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A	12.9	15.6	18.4	19.6	18.6	16.1	13.2	10.2	11.3	14.4	14.4	12.7
B	7.5	9.1	10.7	11.4	10.8	9.4	7.6	5.9	6.5	8.4	8.4	7.7

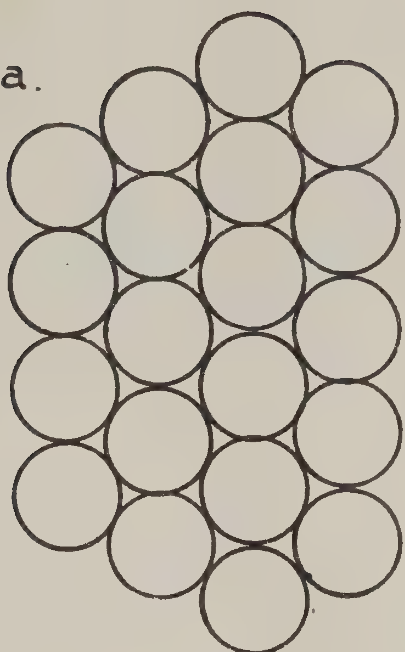
The first line gives the mean Piché readings.

The second line shows the estimated evaporation from large sheets of water on the basis of the reduction factor 0.58. In estimating the loss likely to occur in a hafir, it can be assumed that about 1 cm. depth is evaporated daily. Therefore that a depth of 1 m. of water would last about 3 months if it is not subject to any other losses. This rate of evaporation decreases towards the more humid regions in the South but can be regarded as applying over the Central Sudan.

(1) Climate of Khartoum, p. 60.

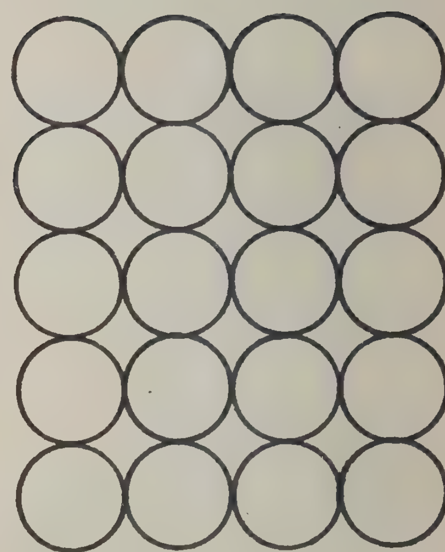
PLATE I

a.



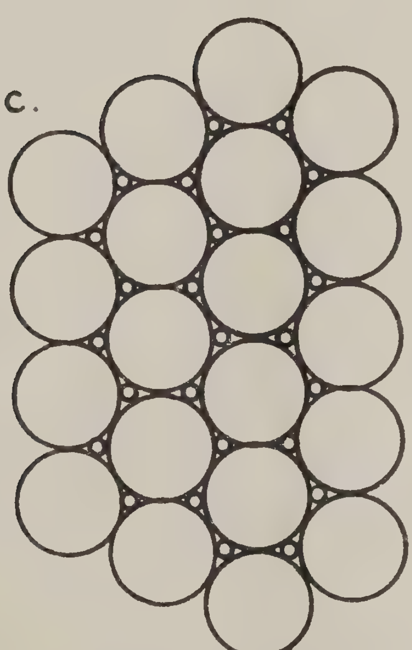
1 cm. Spheres
PORE SPACE 26·0%

b.



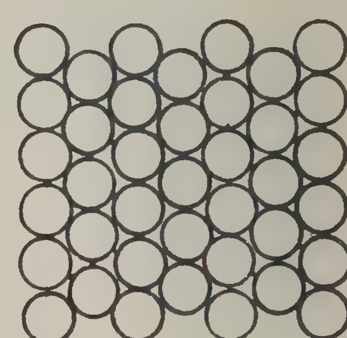
1 cm. Spheres
PORE SPACE 47·6%

c.



Two Sizes Mixed
PORE SPACE 9·4%

d.



½ cm. Spheres.
PORE SPACE 26·0%

Chapter II.

GENERAL PRINCIPLES GOVERNING GROUND WATER AND ITS MOVEMENTS.

Disposal of Rainfall.

Rainfall on land is disposed of by evaporation, by absorption into the ground and by run-off. That which evaporates, concerns us no further. It is lost. Some rain soaks directly into the ground. A great proportion of this may be subsequently drawn back to the surface and evaporate but a part may reach and increase the store of ground water. The third part collects into streams and runs away but in its course, some of it may be absorbed by the stream bed and thus adds materially to the ground water which supplies the wells. This is illustrated by the large number of wells that are situated near stream beds. In estimating the supply of water available from a catchment basin it is important to know the proportion of run-off. In England about 25 % of the rainfall percolates into the ground. About 30% runs away in streams and the rest, about 45%, is lost by evaporation. In the Sudan the loss due to evaporation is much larger. The run-off of the Blue Nile has been estimated to be 18% of the rainfall. The Rahad River represents a run-off of about 13% and in the Northern Sudan there are large areas which contribute nothing to the streams and can be said to have no run-off at all.

Permeable and Porous Rocks.

Wells and springs are fed as a result of the deposit or rock in which they occur, becoming partly saturated, and the nature of the materials and the manner in which they contain water will now be considered. To be favourable for water, the material of the geological formation must be porous and the pores must be large enough to allow the water to drain out under the influence of gravity. The water may occupy cracks and joints in solid, and otherwise impermeable, rock but commonly the materials are granular such as sand, sandstone, or rotten, crystalline rock, and the water fills the spaces between the grains. Sand may be regarded as a typical example of porous material and we shall consider its properties for the purpose of illustrating the features of a water bearing formation. Ordinary sand, deposited either by wind or in water, occurs in layers each consisting of grains of fairly uniform size. This is a consequence of the transporting power of the stream which carried the sand being proportional to its velocity. It is simplest first to consider an ideal sand made up of spherical grains, all of similar size. The diagram Pl. I. shows that the grains of such deposits may be packed in either of two ways. In one of these packings, a. of the diagram, the centres of the grains are at the corners of triangles and each grain would be in contact with twelve neighbours. This is the closest method of packing. In the other, b, the centres of the grains are at the corners of squares and each grain is in contact with six neighbours. With our spherical grains, this method is unstable and they naturally arrange themselves in the 'a' method. There is 26% of voids in the case of the triangular packing and 47.6% with the square packing. These proportions are constant. They depend only on the arrangement and do not alter with the size. The mass of smaller spheres shown in Pl. 1, 'd', obviously has the same amount of pore space as that of the larger spheres in Pl. 1, 'a'. Where the grains are of different sizes, the proportion of voids becomes less since the smaller grains tend to occupy the spaces between the larger. This is shown in Pl. 1, 'c'. The spaces between the closely packed spheres are large enough to hold others between ¼ and 1/5th the size, actually 0.225. The interstices between the spheres will hold back particles about 1/6 their size.

The same principles apply to ordinary silts, sands, grits and gravels. The grains are not round but the packing tends to stability especially in the coarser sands and gravels. In the finer grained silts and clays, the individual particles are very light and there is less tendency to pack in the most stable manner. The consequence is that the pore space is larger, 40% or more while in sands and gravels it is about 30% or a little more.

MOVEMENT OF WATER.

The rate of movement of the water through sands and other deposits depends on the slope or pressure and on the sizes of the pores. Water moves freely through the pores of a gravel or coarse grit. Comparing two materials, one with grains half the size of the other, Pl. 1 'a' and 'd', a unit volume of the smaller material contains eight times as many particles. There are eight times as many passages between but being only half the size, there is much more friction and the water moves more slowly. If the sizes of the particles are reduced below a certain limit, there is so much resistance to the passage of water that the material becomes practically impermeable. This is the case with clays. They are composed of grains less than 0.002 mm. in diameter and water moves through them so slowly that the material can be regarded as impermeable. In these fine grained materials, other forces come into play. The water is held by capillarity and by molecular attraction. The grains are forced apart so that the clay swells on being wetted and shrinks again on drying. The water contents of clays range from 40 to over 50% but none of the water is available for wells. It is held so firmly in the clay that it cannot drain out. Though a coarse sand holds much less water than a fine silt or a clay, a well in the saturated coarse sand will yield water freely owing to the ease with which it can move through the relatively large pores. Such is the distinction between a permeable deposit and one that is porous. Successful wells are in permeable deposits and the yield is in proportion to the permeability. So far, consideration of the movement of ground water has been limited to materials such as gravel, sand and clay. The same general principles also govern the movement of water in consolidated deposits such as sandstone and decomposed crystalline rock as well as through the joints of harder and less decomposed igneous and crystalline rocks.

The movement of water through the pores of rocks is influenced by its viscosity and this decreases considerably as the temperature rises. The flow at 70° F. is about double what it is at 32° F. However, ground temperatures beyond a little depth below the surface remain fairly constant throughout the seasons and the yield of a well would hardly alter owing to this factor. Under similar conditions of materials, a well in the Sudan should yield considerably more water than one in the colder climate of England.

Water in traversing porous materials obeys the ordinary laws of hydraulics. It is subject to gravity, a fact summed up in the statement that water finds its own level. Gravity is the essential cause of all ordinary movement of bodies of water except capillarity which can raise water against gravity. The capillary water, though it may appear as moisture and dampness, is not available for springs and wells and interests us only so far as it indicates the proximity of water and also results in losses.

Water at rest in a permeable deposit assumes a surface of saturation which is level. This is the level at which water stands naturally in wells. It is an important datum and is often referred to as the "water table." However, in nature, the ground water is usually not at rest but is flowing from one place towards another. The water table therefore is not level but slopes down in the direction of the flow.

Where a flood passes over a porous deposit forming the bed of a stream, as may happen in many parts of the Sudan, the water enters the ground and passes down through the pores until it reaches this water table. The zone of saturation is raised by the fresh supply of water and stands at a higher level below the stream than under the surrounding country. The water then proceeds to find its own level by moving outwards from the higher level region into the surrounding rock. The movement is slow and unless the material is extremely porous, the water never finds its true level but always remains higher near the stream bed. This is a reason for making wells near stream beds. Not only is the ground lower, but the saturation level is higher and consequently the well is much shallower than if it were situated at a distance from the stream bed. This feature is a peculiarity of arid regions such as the Northern and Central Sudan.

Ground water in the Sudan is subject to continual loss by capillary action which draws up the water to the surface whence it evaporates. The water from the saturated region beneath or alongside a stream bed is continually flowing outwards to supply these losses. This is in direct contrast to conditions in Northern Europe where rainfall is greater and more evenly distributed through the seasons. The quantity that soaks in not only meets evaporation losses from the ground but there is a surplus which sinks down to augment the ground water at saturation level. The consequence is that in such countries as Britain, the water table commonly follows the contour of the land and is higher below the hills and slopes than in the valleys.

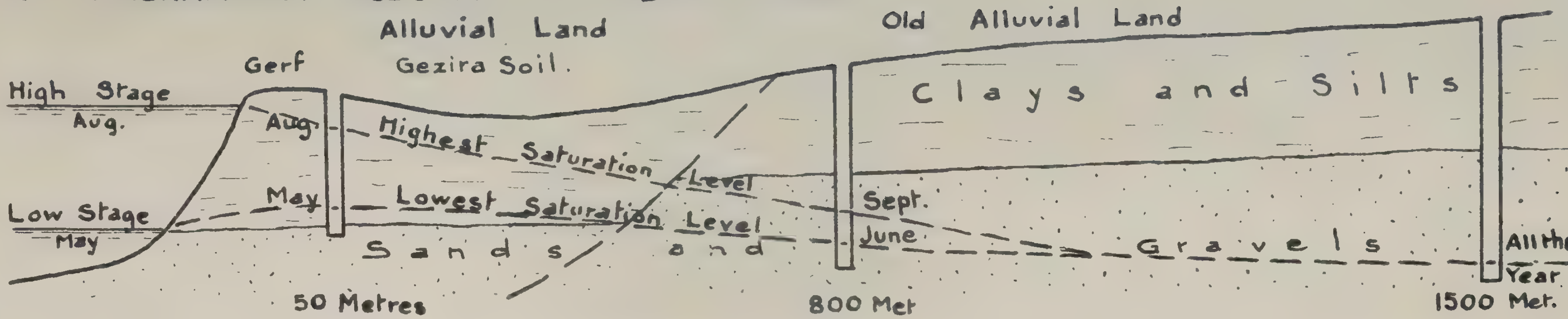
If the surface of the ground is uneven the ground water may travel to some place at lower level where the land surface cuts the water table. It is in such a way that a spring is formed.

Conditions alongside the Blue Nile near Khartoum are illustrated in the section Pl. II e. There is a difference in the river level of about 6 m. between the flood and the low stage level. The consequence is that water passes in to the land from a much higher level during flood and this has been found in Khartoum to affect well water levels back to a distance of about 900 m. from the river's edge. At about 800 m. the subsoil water reaches its highest level about a month later than the highest levels in the river. When the river falls below the level of the water in the subsoil near the river bank there is a reversal of the flow of the subsoil water and some of it runs back into the river. This continues until about May when the river is at its lowest stage and is decidedly below the neighbouring subsoil water. It ceases after the river begins to rise. The more distant subsoil water, however does not return but continues to flow away from the river. In fact, beyond a point about 300 or 400 m. from the river there is a perpetual flow outwards into the land. This flow of water goes to supply what is lost by being drawn up by capillary action and evaporated at the surface. At Khartoum the Blue Nile is flanked by permeable alluvial deposits. At Omdurman, the river banks are formed of Nubian Sandstone which is less permeable and the effect of the Nile flood on the subsoil water levels is limited to a zone not more than 200 or 300 m. wide. The White Nile has a very small slope and consequently a feeble current. Its channel is to a large extent lined with a deposit of clay that is almost impermeable with the result that in many places wells near the river are not successful or only obtain water at depths considerably below the river level. These are examples of the different conditions occurring in association with various stretches of the Nile. Their features can only be arrived at by patient study and geological observation.

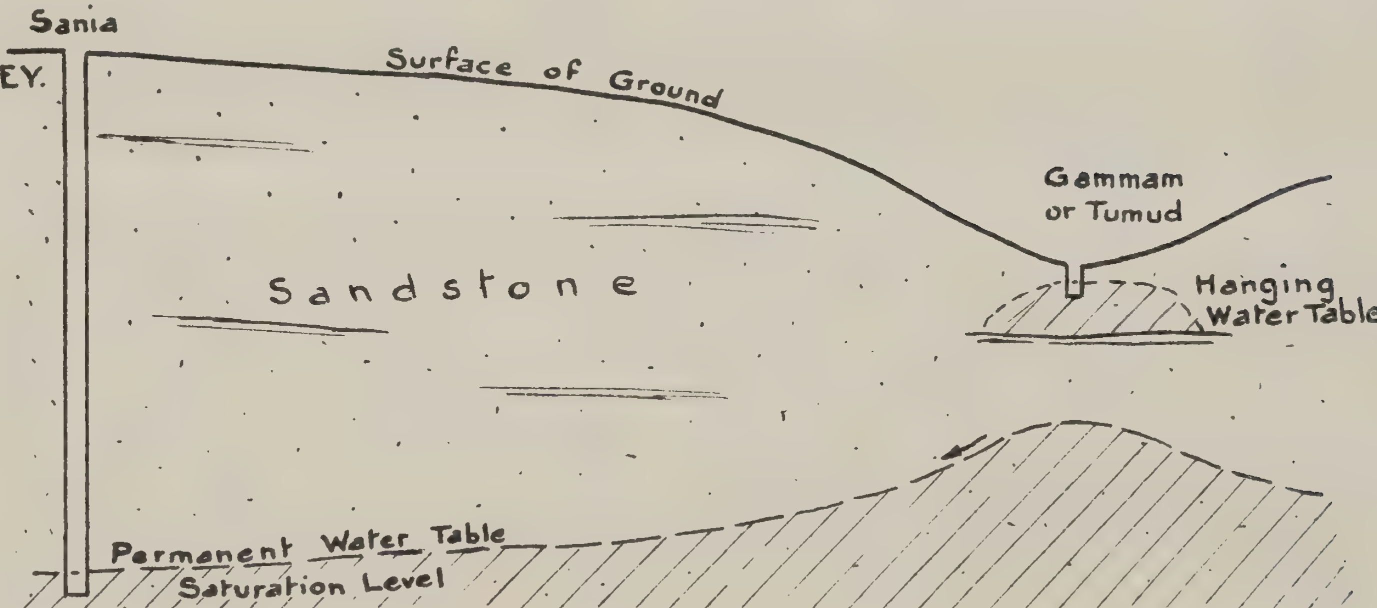
Another example of the slow movement of water through the ground is found in the central Sudan in some streams with sandy beds. After a flood has passed, water is obtainable in shallow wells in the stream bed. Later on, the water disappears and supplies can only be obtained by means of deep wells, reaching the zone of permanent saturation which may be a hundred feet or more below the surface. The explanation of this is that the flood saturates the Khor bed and a "hanging water-table" is formed temporarily. The position of this is shown in Pl. II f. This upper water is gradually dispersed as

PLATE II

e. DIAGRAMMATIC SECTION OF THE NILE BANK



f. SECTION OF VALLEY.



it finds its way downwards in a capillary manner to join the zone of permanent saturation. This phenomenon is not to be confused with temporary supplies in shallow wells known as "tummud" or gamams, due to water being held up by an impermeable layer. Deep wells, drawing from the permanent ground water, are known as sania (plur. sowani) to distinguish them from the shallower and often temporary supplies.

The movement of ground water is slow and large masses are to be considered as moving gradually forwards through joints or minute passages between the grains of the geological formation. Except in limestone country through which tunnels have been formed as a result of the solution of the rock, there are no such things as underground streams or rivers. Water diviners or dowsers usually pretend to discover the positions of underground streams and thus display their ignorance of the principles governing the movement of ground water. On the contrary, water in permeable rocks, after it has found its level may remain practically stagnant. In the search for good wells we require to find permeable formations, saturated with water and capable of yielding it freely when tapped and the less subject it is to movement the more reliable the supply is likely to be.

In order to be of value for water supplies, a permeable formation must be saturated. There are conditions such that no water reaches the permeable rock which consequently remains dry. This may occur as a result of an impermeable covering, closing all inlets and preventing the ingress of water. It might happen in a desert where there is no rain. However dry they are, there is no desert in the Nile valley that is so devoid of rain but that water may be found stored in deep lying and suitably permeable rock. The wells at No. 4 and No. 6 Stations are instances.

So far as is known, there are no conditions in the Sudan favourable for the existence of artesian water. This occurs where stratified geological formations include a permeable bed exposed at the surface on relatively high ground where the rain water is absorbed and dipping beneath a cover of impermeable material. At a low lying place wells may be dug through the impermeable bed until they enter the water bearing bed when water is released and rises, perhaps even flowing out at the surface.

There is a very considerable literature about the occurrence of water but the text books deal with conditions as found in more humid climates. Some occurrences in the Sudan are very similar to those found in the arid parts of the United States and some papers issued by the U.S. Geological Survey have proved most valuable. Among the most instructive in applying the practical and theoretical researches of F. H. King and S. C. Schichter is W. T. Lee's "Underground Water of the Salt River Valley, Arizona" 1905. Among general books there are the following, " A Practical Handbook of Water Supply " by F. Dixey, London 1931 also " Hydrology and Ground Water " by J. M. Lacey, London, 1926. Parker's " Control of Water " is another useful book.

The efforts of dowsers or water diviners are generally discredited among engineering and scientific circles that have had much concern with underground waters. Experiments made some years ago by Prof. Wertheimer at Bristol showed the unreliability of the indications of several water diviners. A summary of the evidence against this form of magic is contained in " The Divining Rod " by A. J. Ellis, 1917, Water Supply Paper 416 of the United States Geological Survey. However, there is evidently a considerable public, mostly ignorant, which is inclined to believe in the dowser, and a recent book "The Modern Dowser " by Vicomte Henry de France, 1930, displays the lengths to which credulity may go. He is careful however, to remark (p. 52) that "the dowser must have a thorough knowledge of geology especially that of the country in which he is working " and one is inclined to speculate to what extent, in his case, the divinations are tempered by shrewd deductions from close geological observation.

Chapter III.

GEOLOGICAL FORMATIONS IN RELATION TO WATER SUPPLIES.

General.

The geological formations hitherto recognised in the Anglo-Egyptian Sudan are as follows :—

- Alluvium.
- Dune Sands.
- Wind Deposited Clay (Loess).
- Volcanic Formations.
- Nubian Sandstone.
- Crystalline Rocks including gneiss, schists, granites and diorites.

The different formations each present essential features in regard to water-supplies and it is only by understanding the geological conditions in seeking water that full measures of success can be obtained and failure reduced to a minimum. The characters of the various formations are dealt with in geological text books (1) and attention here will be limited to the characters of the rocks in regard to the movement and storage of water and as materials from which to obtain supplies.

The Crystalline Rocks.

Although most of these are hard, impermeable and unfavourable for water supplies in their fresh conditions, perfectly fresh rock is rare near the surface and, in decomposed and weathered conditions, some types of these rocks form important reservoirs for ground water and yield valuable supplies. Even in the freshest condition in which they are found at the surface of the ground, crystalline rocks are never completely free from joints and fairly deep wells may yield some water though the amount may be small and the quality sometimes poor.

The following are examples in the Sudan of supplies drawn from jointed and decomposed crystalline rocks :—

Granites	Reira, Sofeiyat el Derishab, Segadi.
Syenite	J. Geili, El Fau.
Acid Gneiss	El Obeid, Melbis.
Felsite	Rueishid.
Schist	Semeiha Station.

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(1) An excellent introduction in "Geology for Beginners" by Watts, publ. Macmillan.

In some places deep wells or mines in fresh crystalline rock yield water and show that even at considerable depths the rock is jointed. Examples in the Sudan are the deep boring in granite made by Sir Henry Wellcome at Jebel Moya and the mine in felsite and schists at Um Nabari. It must be borne in mind that, on the other hand in other parts of the world, deep mines in such rocks are often dry.

THE NUBIAN SANDSTONE SERIES.

Though mainly composed of porous sandstones, the series also includes mudstones, clays, ironstones and some very small limestone beds. It is the most important water bearing formation in the Sudan and the quality of the water is usually good. The sandstone may vary in texture from a conglomerate with gravel to a fine sandstone passing into mudstone. It is usually rather loosely consolidated, is soft and wears easily when used as a paving stone. For a building stone it has a very low specific gravity, about 1.9 or 2.0. It can absorb about 20% of its volume of water. Locally, especially, near the surface, the sandstone may be cemented with either iron or silica forming hard, non-porous rocks : ironstone and silcrete sandstone.

Interbedded with the sandstone are beds of mudstone. This material varies in colour from white or grey to mauve or purple. In texture it is usually chalky and not plastic but some varieties are plastic and clayey. Though the texture has been compared with chalk and people may refer to it as " gir " on account of its value as a whitewash, it is not calcareous and presumably the whitewash has none of the disinfecting and deodorising properties associated with true lime whitewash. The mudstone is siliceous and aluminous. It is essentially impermeable and does not yield water except from joints. It is associated with the sandstone and when met with in wells, work should be continued as the sandstone may occur below.

Ironstone has been mentioned, and both it and the little limestones are of no importance as regards water supply.

Regarding the thickness of the Nubian Sandstone Series, its top is not known in the Sudan but has been observed in Egypt where it is overlain by beds of Upper Cretaceous age, which succeeded it. In the Sudan the sandstone rests on the crystalline rocks and can be regarded as filling hollows in their surface. Borings have penetrated it to depths of nearly 800 feet without reaching the base. We have no means of estimating what its greatest thickness may be but it probably attains thicknesses of well over 1,000 ft.

We have spoken of the Nubian Sandstone formation as a single unit. There is evidence that different parts of it are not of the same geological age and probably when these can be distinguished they will be proved to belong to different formations perhaps ranging in age from Paleozoic to Cretaceous.

Examples of wells in sandstone occur in Omdurman, Monagil, Sáata, Jebel el Hilla.

Volcanic Formations.

At several places in the Northern Sudan there are sheets of basalt or masses of similar rock embedded in the Nubian Sandstone Series. There is also the series of basalt lava sheets forming a great part of the Abyssinian Plateau and stretching into the Sudan in the southern part of Kassala Province. There are volcanic formations in Darfur.

Basalts, are usually in the form of sheets and roughly jointed across so that when the edge of a sheet is seen it appears as a mass of closely packed columns. The upper and lower parts of the sheets may be spongy and porous. When the rock is fresh it is hard but it is sometimes deeply weathered into soft clayey material.

Depending on the rainfall of the region, good supplies of water may be drawn from wells in basalt. The decomposed surface and the joint planes permit the absorption and passage of water through the rock. Between the sheets, there may be impermeable beds preventing the direct passage of water from one sheet to another. In such circumstances good supplies of water may be found in the basalt above the impermeable layer. It can be said that as a rule wells can be made in basalt with excellent prospects of success. The quality of the water is usually good.

In decomposed basalt good supplies of water may occur but the quality is not as reliable as in the fresher rock.

Examples of wells in basalt are to be seen at Gedaref and in its neighbourhood and also at Gallabat.

The Wind Deposited Clay (Loess).

This is a clayey material deposited by the wind and covering large areas in the Central Sudan. The soil derived from it is typically dark, and deeply cracked during the dry season. During the rains it absorbs water, the soil swells, the cracks close up and when thoroughly wet it forms a heavy tenaceous clay. This is the aspect of the clay soil presented on the surface. It passes down into a brown clay usually with lime nodules and this may attain a thickness of 30 or 40 ft. The clay occurs in flat country where there are no slopes to promote erosion. The people call it 'badob', a term applied to any deeply cracked soil of whatever origin.

An important character of the clay soil is that the surface layer may absorb the entire local rainfall. This is held in the surface layers until it evaporates and the soil cracks once more. In this way, the clay soil usually prevents the rain water reaching the underlying rocks and they can only become saturated if water reaches them in some indirect manner. There are exceptions to this, especially where the clay is thin or is cut by a stream bed, so that water is able to reach the underlying rock.

The fact that the whole rainfall is absorbed and held by the surface layers of the soil is shown by complete absence or insignificance of streams over large areas of the clay soil.

In clay regions, water supplies may be obtained from porous rocks where these break through such as groups of granite hills and the water is held in debris or weathered rock. Sandstone covered with clay in one area may be permeated with water from rain or streams elsewhere, where it is exposed at the surface. The ground water penetrates tne sandstone and travels underneath the clay and may be reached by wells sunk through the clay to the requisite depth. Similar considerations apply to other porous rocks such as basalts which may be covered by clay.

The impermeability of the clay however, gives it very great value in connexion with the storage of water in open tanks. From very ancient times the inhabitants of the central and northern parts of the Sudan have been accustomed to dig storage tanks in places favourably situated for filling and where the soil could be relied on to conserve the water. These " hafirs " are often in clay country. The canals of the Gezira Irrigation Scheme owe their efficiency to the clay soil traversed. In fact it is doubtful whether the scheme would have been possible in anything like its present form, had the ground been of a permeable nature.

At Abu Gelfa there are some shallow wells where the clay soil is traversed by a stream bed.

Dune Sands.

These are typically loose porous sands into which rain water readily sinks without collecting into any stream on the surface. In some cases where there is a sufficient depth of such sands, and, presumably, some suitable floor of compact or impermeable material, abundant supplies of water may be obtained by means of wells occasionally quite shallow.

There are also old dune accumulations. There are sands which have moved when the climate was drier and have since become fixed owing to the growth of grass and trees. The undulating surface is preserved and is no longer subject to movement. Under present conditions fine dust certainly tends to accummulate among the vegetation and to mix with the sand which becomes less porous especially in the hollows where pools with muddy floors form during the rains. The sand becomes clogged with clay, less water sinks in and more evaporates from the surface so that the conditions for wells may not be as favourable as in regions of less rainfall where the sand is more porous.

Wells in dune sands occur at Bara and in the Kheiran.

ALLUVIUM.

This term covers deposits by streams and rivers and may comprise grades extending from fine clays, through silts and fine sands to coarse sands, grits gravels shingle and boulders. The clays are impermeable but the sands gravels etc., are capable of holding and transmitting water freely and under favourable circumstances, such alluvial deposits yield very important supplies of water.

In the Sudan, the alluvial deposits flanking the Blue Nile and the Main Nile North of Khartoum are saturated with water from the river. The level of the zone of saturation near the river channel, is affected by the level of the flood. The movement of the water and sequence of levels in the wells has already been referred to. Besides the Nile alluvium, the delta of the Gash and deltaic formations in Kordofan yield important water supplies. The deposits of "Valley Fill" forming the floors of the more important valleys in the Red Sea Hills absorb some proportion of the scanty rainfall and supply many good wells.

Chapter IV.

WATER SUPPLY REQUIREMENTS.

Wells.

The value of a water supply depends on the nature of the surrounding country. In the desert the only need for water is to supply the traveller and enable him to water his steeds. In the absence of either grazing or cultivation, there can be no permanent population. Consequently there is no need for supplies beyond the wants of travellers. Passing from the desert into regions of scanty rainfall, enough only to support a few bushes and a little grass near the stream beds, the nomad with his flocks and herds is found and these require adequate supplies of drinking water. Where there is little grazing, little water is necessary. Continuing to regions where the rainfall is enough to enable crops to be raised during the rainy season, drinking water is essential at other times of the year to enable the cultivators to sojourn on the ground, prepare it for cultivation and harvest the crops. If local supplies of water are not enough, the people must vacate the ground perhaps during nearly the whole of the dry season. The value of water supplies is therefore directly dependent on the nature of the country. A large supply of drinking water in the desert may have little value while on the other hand extensive areas of cultivable land may also be valueless unless there is water to enable cultivators to live on them.

It is only under special conditions, usually close to a river or stream bed, that wells in the Sudan are used to supply water for irrigation. The water must stand at a shallow depth, permitting a copious supply to be drawn to the surface. Its quality must be so good as not to involve danger of the irrigated ground becoming impregnated with salts.

A good well with an ample supply available throughout the year in suitable surroundings allows the maintenance of a permanent village whence the people may sow, reap and harvest crops and graze flocks and herds to the limits allowed by the rainfall. Often, cattle are not watered from deep wells owing to the labour involved in drawing water. During the rainy season they may be watered from temporary supplies and later, driven to other localities where there are rivers, lakes or shallower wells. Well water may contain a notable proportion of salts in solution so long as it is drinkable. If the quantity is less than 1000 parts per million of water, such water in the Sudan is regarded as good. Where the proportion rises to above 2000 parts per million, the water is not desirable in ordinary circumstances, but at Tokar water with 4000 parts is regularly drawn from wells for human consumption. It is difficult to state what is the greatest quantity of salts in solution that water may contain and yet be consumed safely. Usually these salts comprise mainly chlorides, sulphates and carbonates of sodium magnesium and calcium and probably the extreme limit for human consumption is in the neighbourhood of 6000 parts per million. More saline water would only be consumed under the direst necessity. Definitely poisonous water, due to salts is rare. The water of all open wells can be regarded as contaminated. Dust, insects and small animals fall in and buckets, after lying on the ground, are let down and bring in more extraneous matter.

Temporary Supplies.

Passing to water supplies lasting only part of the year, these depend on the rainfall, become available during the rainy season and last for some time afterwards. Their value depends on their situation and duration. Those existing beyond reach of more permanent supplies and lasting for two or three months after the rains where rainfall supports bush, grazing and cultivation, enable animals to be grazed and crops to be harvested. After the supplies are exhausted, the herds must resort to permanent water supplies but the longer they can be grazed around the temporary supplies, the more the fodder is conserved around the permanent sources and the greater are the herds that the region can support. It often happens that there are crops near the permanent water supplies and the advent of the cattle before the harvest leads to trouble between the cultivators and the herdsmen. There are no large permanent supplies of water in the Southern Gezira, the country west and south-west of Singa. Flocks and herds depending on temporary supplies during and for a short time after the rains, are obliged later to resort to the Blue Nile, along the banks of which all sorts of crops are cultivated. It is easy to picture the friction which may arise between the two parties of people and it has happened that the cultivators set fire to the grazing near by so as to render their localities less attractive to the herdsmen. The friction between Cain and Abel is repeated.

Another factor affecting the value of remote temporary supplies is the line of communication. The temporary supplies in the midst of plains may be compared with islands in a sea. An abundant supply of water and grazing at one of these places is useless beyond the stage when neighbouring water supplies fail and stop the line of communication to the permanent water supplies. If the herds remain later, they can perhaps only escape with difficulty. The temporary supplies, especially, are of value in relation to their surroundings and there are certain limits beyond which it is useless to extend them. It is to be borne in mind too, that when rains fail to feed temporary water supplies, the grazing and crops around are likely to be correspondingly poor and there is less demand for water.

The foregoing remarks are based on the idea that water supplies have to be situated in proximity to the grazing. Probably such conditions will hold for a long time. It must, however, be remembered that the problem may also be solved by cutting the grass and carrying hay to regions of good water supplies. This is understood to offer the great advantage that the hay is far more nutritious than grass which has been left standing through the dry season.

Water Consumption.

The Sudan Almanac states that the minimum daily requirement for a man is $1\frac{1}{2}$ gallons a day. This is probably based on military experience and a group of nomad Arabs in the Sudan, including men, women and children could certainly carry on well with such an allowance. It is, however, safer to base estimates on a daily consumption of 2 gallons a head daily.

In Kordofan where water is sold, the quantities consumed by various animals have been carefully observed. The following figures have been supplied by Mr. F. A. Waugh who has obtained them by actual trial with numbers of animals watering at the pumps :—

Animal.	Drink at one time gallons.	Interval between Drinks days.	Average Daily Consumption gallons.
Camel	22.7	4	5.7
Bull	16	2	8
Cattle	10	1	10
Horse ...	5.3	1	5.3
Donkey ...	4	1	4
Sheep ...	2	1	2
Goat	2	1	2

These are hot weather figures. In cold weather, animals only drink about half these quantities.

If the population of people and animals that the cultivation and fodder in an area can support is known, it should be possible to calculate approximately with the aid of the figures given above, the amount of water required for their needs. Any such calculation relating to the central and northern Sudan would be uncertain owing to variations in the rainfall affecting both the vegetation and the water supplies. However, the figures are useful as indications.

Chapter V.

CONSTRUCTION OF WELLS AND DRILLING.

Yield of Wells.

The yield depends on the porosity of the material and the depth that the well penetrates below the water table. A well that just reaches the saturation level is likely to give only a small yield and be very quickly exhausted. During the final stages of sinking, the water should be drawn to the utmost limit of the means available and sinking should continue until it is no longer possible to exhaust the supply of water. So long as the saturation level remains stationary, the quantity of water yielded during sinking will be the maximum output of the well. It is often difficult to cope with the water by hand and in such cases a portable, power driven pump may be applied with advantage during the final stages of sinking. Neglect of these elementary principles has been seen on numbers of occasion. A fine large well is sunk to water level, the lining is completed and then a power driven pump is installed. The well is exhausted immediately the pump is started. If a well is expected to yield enough water to supply a power driven pump, the same pump or preferably a larger one should be applied during the last stages of sinking.

In many places the saturation level fluctuates either on account of the changing height of the neighbouring stream or owing to gradual dissipation of the water during the progress of the dry season. In such places wells should be dug when the water table is lowest. If they are dug at other seasons, they will almost certainly have to be deepened when the water falls. This applies particularly to wells near the Nile. These should always be completed in either May or June so as to take advantage of the lowest ground water levels.

Sinking Wells in Soft Material.

The technical aspects of well sinking and also drilling are very fully dealt with in various text books (1) and remarks will be limited to special methods adopted in the Sudan.

The inhabitants of the Anglo-Egyptian Sudan have always been accustomed to dig wells but the older efforts in search of water, in the absence of explosives, were only in softer materials through which they could dig.

The simplest cases are wells in alluvial deposits either near rivers or in the beds of Wadis or Khors. Near the Nile there is usually clayey soil on the surface, silt lower down resting, in its turn, on sands.

(1) Wells and Bore-holes for Water Supply, by J. E. Dumbleton, London, 1926.

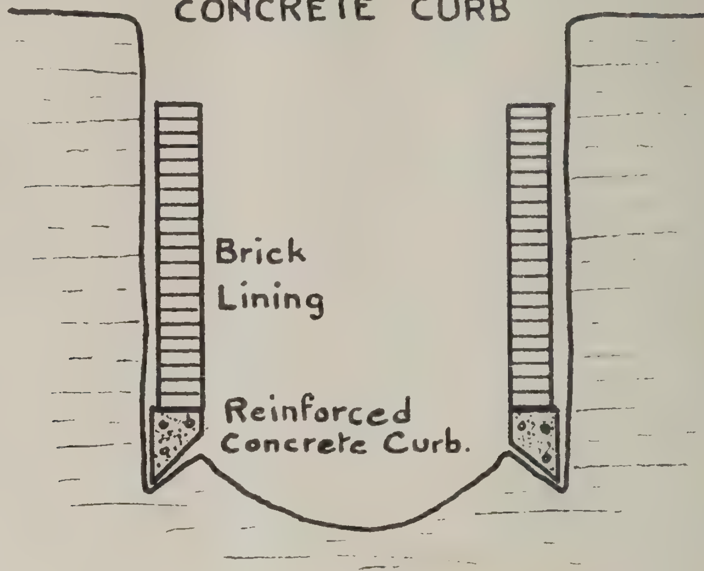
The clayey soil, especially in older parts of the alluvium is hard enough to stand without caving. Trouble arises with the sand especially near water level. This caves and tends to run in, consequently some form of lining is essential. This may be achieved by means of logs of wood built up to form a square lining throughout the part that is liable to cave. Where the trouble is local, the sides of the well may be supported by a lining of thin branches and saplings held into the sides by their own springiness. Some wells in dune sands in Kordofan are made narrow and are lined with long, thin rope-like bundles of grass bound with the bark of 'laot' acacia. The bundle is wound into the sides and the completed well, which may be 150 ft. deep, has the appearance of the inside of the old fashioned British straw beehive. All such linings rot sooner or later, become dangerous and then collapse. In loose sand, unless the sides of the well are supported adequately the sand is liable to run through holes in the lining leaving an empty space behind. The material around caves against the unsupported well lining and may lead to the collapse of the well if not more serious consequences including loss of life.

Various forms of corrugated iron linings have been used in wells dug under Government supervision in soft materials. None of them seems to be quite satisfactory. Owing to cost, the tendency is to use diameters of about 3 ft. or 3 ft. 6 in. which are narrow and restrict the number of buckets that may be worked simultaneously. There seems difficulty in building them into the sides so as to support just the place where it is needed. Some kinds are assembled and lowered from the top and consequently give no support to the sides of the well which may continue caving behind the corrugated iron. The well may subsequently collapse but at any rate the corrugated iron sections, if they extend to the bottom afford protection to the workers and they are not likely to be buried. An instance of this sort of caving was seen at Nahud. The linings, about 3 ft. diameter had been lowered from a derrick and extended almost to the bottom of the well which was in the process of being dug. A soft bed in the upper part gradually caved and the sand running down between the lining and the sides was dug out by the workmen without comment. Finally the cavity became so large that the upper part of the well collapsed. This occurred at night and when the workmen arrived in the morning, they found the linings sticking up out of the centre of a wide crater. Another objection to some of these corrugated iron linings is that the ends of the bolts or edges of the sections stick out and damage the leather buckets used for drawing water. Doubtless under skilled supervision, the use of such linings might be more satisfactory but then the cost is increased.

Masonry linings of either brick or stone are very satisfactory but except in favoured places, the necessary materials are difficult to obtain and the cost is prohibitive. Only in exceptional circumstances can masonry be built in to support dangerous parts of the sides in the course of digging a well shaft. Usually recourse must be had either to timber

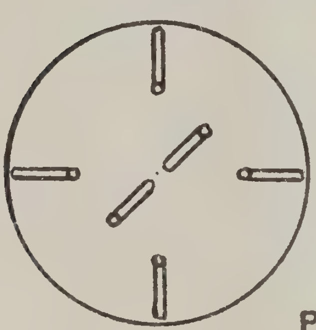
PLATE III.

g. WELL SINKING WITH A MASONRY LINING ON A CONCRETE CURB



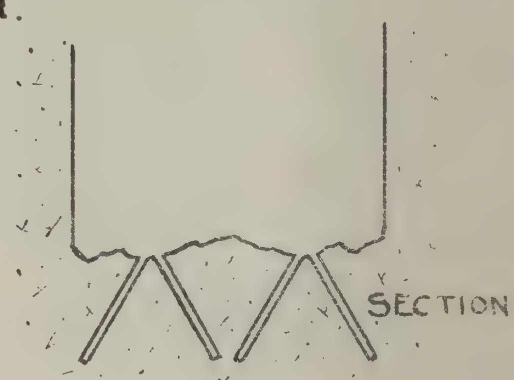
WELL SINKING IN HARD ROCK.
ARRANGEMENT OF SHOT HOLES.

h.

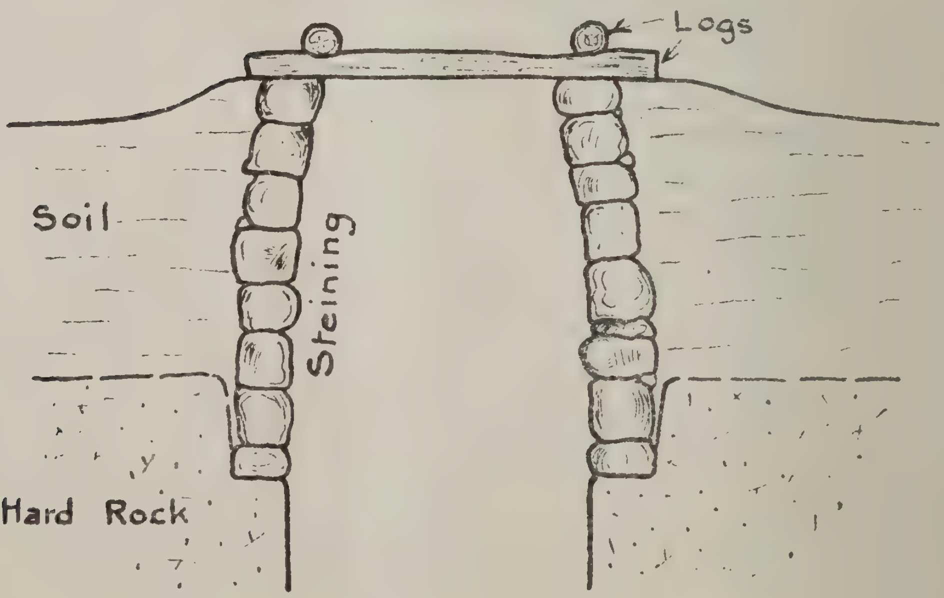


PLAN

i.



j. STEINED WELL MOUTH.



or iron. Sometimes after the well has been dug, a masonry lining may be built up from the bottom but this can only occur in places where the well can be safely dug to water level and the sides stand up long enough. This is, however, the local craftsman's idea of making a masonry lining and many wells near the Nile, lined with brick, have been made in this way. There are some pre-Dervish wells with brick linings in the Gezira South of Khartoum.

Wells up to 40 or 50 ft. deep may be made by building the lining on a curb which may be of wood or iron armed with a cutting edge so that as the material is removed from inside the well, the increasing weight of the masonry drives the curb down into the ground. The masonry, usually of brick, continues to be built up as the excavation progresses and the curb sinks down. The ordinary methods of building on curbs are well known and are described in books. The Engineering Department of the Sudan Railways has been very successful in use of curbs made of reinforced concrete. The well, which may be of any size up to about 20 ft. in diameter, is dug to a depth of 10 ft. or so. A mud mould is made for the curb, the reinforcing iron bars are put in position and the concrete is filled in to the mould, enveloping the metal strands. The section of the curb is chisel shaped and the general procedure may be gathered from Pl. III g. Excavation continues within the lining and as this sinks down, the masonry is built up. The curb should be about 4 inches larger in diameter than the lining so as to reduce the friction of the lining against the material in which the well is being dug. Friction of the strata eventually grips the masonry and prevents it going down further. Greater depths can be attained by making another curb within the first but this involves a reduction in diameter. The method of sinking on a curb offers the great advantage that the well is lined right down to its greatest depth. It might be possible by means of some form of grab to sink the curb below water level but usually the water level must be lowered by pumping during sinking. The curb is convenient for this purpose as a pump fixed to the lining sinks with the curb.

Sinking Wells in hard Material.

Sandstone cannot be described as a hard rock but it is usually sufficiently consolidated to ensure the sides of wells standing when they are sunk through it. The rock is soft enough to be excavated by means of simple tools and in several places there are wells that have been dug to obtain water at depths exceeding 200 ft.

Sinking wells in hard materials such as granite, gneiss, basalt etc. usually involves blasting and this has only become possible in recent times. In a few places, by taking advantage of joints and belts of shattered or decomposed rock, the people have been able to reach water level in these hard rocks. Such shafts may be tortuous and at Um Rueishid, for instance, a man has to remain down the well to carry the buckets along a level part. The existence of such wells shows how strenuously the search for water has been prosecuted in former times. We are almost justified in concluding that, apart from abandoned sites, new supplies are only to be found in places where the water could not be reached owing either to the hardness of the rock, it being too hard to be penetrated without modern means, or where the materials are so soft that the people were unable to prevent it falling in as fast as they dug.

With the aid of explosives and expert workers, good shafts may be readily sunk through granite, gneiss or basalt. The gang should include a blacksmith to sharpen and temper the drills. The blacksmith is a fairly highly paid individual and the work of the gang largely depends on his skill. The drills are usually sharpened by hammering and shaping on an anvil when the metal is at red heat. The tempering is done by taking the sharpened tool at a certain state of heat judged by its colour, and plunging it into cold water. Drilling holes for blasting requires a man to hold and turn the drill and one or two to strike with hammers. Such a party of men should be able to drill about 3 m. length of hole daily in sound granite. The holes are started with short drills and continued with longer ones. In a quarry where this drilling is done by men working in pairs, a hole 7/8 inch diameter is paid for as piece work at the rate of P.T. 10 a metre. This indicates that the pair of men can average about 3 metres of drilling daily. The ideal well is probably a circular shaft about 6 ft. in diameter. A smaller shaft does not allow enough room for the men to work. The blasting holes are arranged in the manner shown in Pl. III, h and i so as to break and lift up the rock. A gang should comprise a reis capable of siting the holes and charging them with explosive, a blacksmith and six labourers who can both drill and haul out the debris. There are many men, especially those from Abu Hamed district, who have been employed in mines and quarries and who understand blasting, from among whom well sinking gangs might be drawn. With men who are moderately skilled, the shaft should be sunk in hard granite at a rate of about 2 ft. a day for the first 100 ft. and rather less below. We have no figures for such work in the Sudan but the cost of the gang with blasting materials may be estimated at about £E. 30 a month or about P.T. 50 a foot of the well.

It is possible to obtain jacks of all the trades who can attend to all aspects of shaft sinking but perhaps enough has been said to show that the work should be in the hands of a gang of skilled men with occasional expert supervision. Some good shafts were formerly sunk in hard rock with organised gangs under the Public Works Department but none have been made since the dissolution of the Roads and Communications Section. Very often wells are sunk by villagers and are stopped by hard rock before water is reached. It would be a boon in such cases if the help of skilled gangs could be enlisted. Otherwise the attempt is abandoned, the shaft falls in and the money spent is wasted.

Samples of rock representing the material traversed by wells should be collected from time to time and sent to the Geological Survey.

STEINING.

The soil and soft material near the surface of the ground has been supported in many old wells by means of dry-stone steining. This is the case especially in wells entering hard rock deeper down. The steining is then usually based on the harder material. Good examples are seen at some places in the Red Sea Hills as at Derudeb and Delai. These wells are situated in stream beds and are filled with sand during floods. The sand is dug out subsequently. Steining is shown in the diagram Pl. III. j, but the art of making such walls to support the loose soil near the surface, seems to have died out in the Sudan. Either iron or masonry has been used in wells of recent date. The metal will eventually corrode and fail. The masonry may only be held together with mud mortar and this, too, cannot last long where it may be subject to the splash from buckets. It is hoped that the art of steining may be reintroduced.

DRAWING WATER.

The commonest method of drawing water is simply by means of a rope with a leather bucket, 'delu,' attached. In the country east of Khartoum wells attain depths of nearly 300 ft. and the labour of drawing water is very great. Often some draught animal, a camel or a donkey, is attached to the end of the rope and walks a distance of nearly 100 yards, drawing the bucket to the surface. The rope is lifted into forked sticks to prevent it trailing on the ground as the bucket is drawn up. Formerly, the rope passed over the logs of wood or a stone of the well mouth wearing both the rope and the log. The use of pulleys for this purposes was introduced about 20 years ago under Mr. J. D. Craig and as a result a frame work carrying the pulleys is erected over the well mouth. The people have found that these pulleys run much better on wooden spindles which they themselves make. Either the simple well rope or the pulley offer the advantage that a number of people can draw at the same time. There may be as many as 20 buckets working simultaneously. The frames may carry 8 or 10 pulleys. The yield of wells may be three or four buckets a minute each of four gallons approaching a total of a 1000 gallons an hour.

In Kordofan the windlass, either with handles or hand over hand type, is often used over wells. There are two buckets, one at each end of the rope so that one goes down as the other is raised. It seems that these windlasses restrict the output of the wells. Only one bucket can be drawn at a time and this often occupies two men. A point in their favour is that the barrel of the windlass may be made hollow with a few stones inside. These rattle when the windlass is in use and inform the owner of any clandestine attempt to draw water.

The open well offers the great advantage that any one with a bucket and a sufficiently long rope can draw water. The water supply is not dependent on mechanical appliances.

BORE-HOLES.

The term bore-hole or drilled well is usually applied to the results of drilling to distinguish them from wells which are usually accepted as implying open shafts excavated by hand.

There are various methods of drilling but most of the work must be left to experts and consequently little need be said about it here. It is very fully dealt with in books. (1) It suffices to enumerate some of the commoner methods.

Augers. Sets of tools are obtainable, including rods in sections, by means of which it is said that holes up to 12″ diameter can be drilled to depths of 100 ft. I am not aware that these tools have been tried in the Sudan. Obviously they could only be used in soft but stable materials. They could not penetrate loose sands that cave. It is very doubtful whether such tools can be of any general use in the Sudan.

Drive Tube Wells. These consist simply of a pipe about 2 inches diameter, with a point at the bottom and a perforated section about 2 or 3 ft. long just above the point. This pointed pipe can be driven down with a simple form of striker, in soft materials such as sands, and when the saturation level is reached, the water enters through the perforations. If the water level is at less than about 25 ft. down, the water can be drawn by means of a pump attached to the pipe. Such wells may be driven to greater depths but where the water stands below about 25 ft. depth, a special pump must be provided to draw the water. Owing to higher prevailing temperatures in the Sudan a pump cannot draw water from as great depths as in Britain where the theoretical limit is about 33 ft. The drive tube wells are very convenient for obtaining supplies of water from shallow depths, but conditions in the Sudan are rarely favourable for their use.

Drilling. This may be accomplished either by means of hand rigs or power driven rigs. The hand rig is capable of making a hole 4 inches in diameter to a depth of about 100 ft. in soil, sand or soft rock. The power driven machine such as the " Star " rig which has worked well in the Sudan will drill a hole up to 12 inches in diameter to a depth of 800 ft. or more depending on the length of rope available. The hand rig may use an auger in soft material but the percussion method is that followed by the other rigs above referred to. A heavy steel bit or chisel is repeatedly lifted and dropped onto the bottom of the hole and gradually pounds its way through the rock. A fair supply of water is required for the purpose of the drilling so that the debris may be held in suspension and not impede the action of the drill. The method is satisfactory in soft or loosely consolidated deposits where depths of 20 ft. or more can be penetrated daily. In soft materials the hole must be lined with steel casing. Progress is slow in hard materials. In granite, for instance progress may not be more than about 2 ft. a day. In such rocks it is an advantage to adopt the rotary

(1) Emergency Water Supplies , by A. Beeby Thompson , 1924.

method of drilling. This is always carried out by a power driven rig. There is a cylindrical crown which is armed with hard substances either black diamonds (bort) or chilled steel shot. The rotation of the crown cuts through the rock and a core rises through the crown into the core barrel above. At intervals the core is broken off and brought to the surface. Besides penetrating the hardest types of rock, rotary drilling has the merit of producing cores of the materials passed through. The samples yielded by the percussion method are crushed and broken but their examination generally enables the nature of the rock to be identified.

Borings in soft materials, clays, sands and gravels must be lined with steel tubes referred to as "casing." A hole may start with a diameter of 12″ so that 12 inch casing must be used. This may continue down to perhaps 100 ft. at this depth the diameter may be reduced to say 10 inches and 10 inch casing used—and so on. The lowest sections of the casing must be perforated in some way to admit the water. This class of casing is referred to as screen, slotted or perforated casing according to the pattern. It is important to arrange that the screens should be situated opposite water yielding beds. There may be a good deal of trouble in clay beds owing to the screens becoming clogged.

The driller must keep a "log" of the boring showing the dates, depths drilled, casing used, nature of material traversed and level of water etc. A set of samples corresponding to the record, must be kept for geological examination.

A boring can penetrate deep below water level. It must reach a considerable depth below saturation level so that there may be enough pressure to bring an adequate supply through the screens into the boring. This must enter fast enough to replace the water as quickly as it is pumped. Yields vary according to conditions but single bore holes may yield from 2000 or 3000 gallons an hour down to 100 gallons or less.

Provided there are no set-backs and no undue expense for transport, a boring 300 ft. deep may cost about £E. 500. It may happen that there are delays owing to a tool being dropped or becoming jammed in the hole. There may be trouble with the screens or casing. If such things occur the hole with casing may have to be abandoned and £E. 2000 or more may be spent before a supply is secured. Having found the water, a pump must be provided to bring it to the surface. For yields of 2000 gallons or more an hour, steam pumps are often employed. Oil or producer-gas engines seem to work satisfactorily for yields of 500 to 1500 gallons an hour from depths up to 300 ft. If yields are small windmills may be employed. A storage tank should be provided so that the mill may work night or day, whenever there is wind enough to turn it. The cost of the surface installation with an oil engine to deliver about 1000 gallons an hour, a tank and a shed may be estimated at about £E. 600.

If the machinery fails, no water can be obtained from the borehole. It is essential therefore in places distant from other supplies that there must be either ample storage or a duplicate bore from which supplies can be drawn to tide over the interval.

SANITATION.

Water from open wells is inevitably contaminated. Dust carried by the wind continually falls down. Insects, frogs, lizards etc. may fall in, drown and decompose. Wood linings rot near water-level. The dark interior of a well is often a resort of bats, resulting in the water continually receiving droppings. The ropes and buckets used for raising water lie about on the ground in the intervals, and carry down more dirt. The ground around wells situated in khor beds or depressions and resorted to for drink by numbers of cattle becomes thickly strewn with droppings. The water that infiltrates from the surface during the rainy season to replenish the ground water, has to pass through this material. When samples of water from open wells are submitted for analysis, it is not surprising that the Chemist almost invariably reports the presence of nitrites. Where examinations have also been made in the Sudan by the bacteriologist, the water with most nitrites has usually proved to contain the most bacteria. In spite of this pollution, the water generally, is freely consumed by both people and animals in the Sudan without obvious harm. Perhaps some pathogenic organisms do not survive but the unseasoned stranger is advised to take precautions.

An elementary precaution usually taken in the Sudan is to raise the mouth of the well a foot or more above the neighbouring ground. This prevents water spilled on the surface, from running back into the well.

The supplies from drive tube wells drawing water from relatively shallow depths are not subject to direct contamination but such sources must be regarded with suspicion. They are often polluted.

The water from bore-holes over 50 ft. in depth is usually safe from contamination especially when it is derived from rock and not from unconsolidated sands and gravel.

Chapter VI.

CONSERVATION OF WATER.

Conditions.

Water storage has been practiced in the Central Sudan from very early times and many rock cisterns and tanks on old sites still remain in use. They seem to have been made originally in connexion with cultivation and their northern limit seems to follow that of the land where crops may be raised under rain conditions. In later times they have proved very useful for watering flocks and herds grazing around them.

Stored water is of value in regions where the rainfall at certain seasons is enough to promote the growth of crops and herbage but where there are no permanent sources of water such as rivers, springs or wells to enable the people to prepare the ground, harvest the crops or graze herds. Storage appears to be practicable in country receiving annually an average of 100 mm. or more of rain. As regards the upper limit, the length of the dry season is the most important factor but where rainfall exceeds 1000 mm. the dry season is shorter and permanent supplies are usually more abundant. In regions of rainfall less than an average of 100 mm. such as in that between the Nile and the Red Sea in the Northern Sudan, the scanty water is often concentrated by hill slopes on to the valley floors where wells yield permanent supplies, consequently there is no need for storage.

Supplies of stored water are useful satellites to permanent sources. With their aid it is possible to extend both cultivation and grazing during the rainy season.

Tanks are often found near villages where there are also wells. Such tanks afford convenient supplies during the rains both for cattle and domestic needs, and the villagers, being saved the labour of drawing from the wells, are set free to tend their crops in the fields. Even near the river, villagers make tanks and here the object is to keep the herds away from the river and so avoid loss due to the ubiquitous crocodile, more dangerous in the turbid and troubled water of the flood than in the clear, placid water of the low-stage. The cattle are also preserved from the treacherous steep banks against which the river rises during flood.

Situations.

The first hafirs were certainly natural and occurred in places where water collected. These are commonly found near hills where the water runs down the rocky and sandy slopes on to clayey plains. The water naturally remains on the surface of the clayey ground. Animals come to drink, wallow in the mud and carry some of it away making a hollow where the ground was perhaps only swampy to begin with. It was a simple step to dig out the earth to increase the capacity. There are slight hollows in the cotton soil plains where water tends to collect. Such places may be almost impossible to recognise during the dry season but they become obvious during the rains and hafirs have been dug in many of them. It is probable that hafirs have been dug in many of the most favourable sites but experience in Kassala has shown that there are many to be found by a combination of surveying and a practised eye for the country. Perhaps the practised eye is the more valuable asset.

The best catchment is rocky, stony or sandy ground with a definite slope. Clayey ground is often flat and deeply cracked so that the rain is absorbed by the cracks and almost none runs off. The neighbourhoods of the isolated groups of hills that rise from the plains of the Central Sudan are very favourable localities for collecting water for storage. The rock hills are surrounded by aureoles of sandy soil and debris the surface of which slopes gently outwards until it meets the plain. The rain water runs off copiously from the hills and slopes and may be either held on the lower part of the slopes or on the plain. In a region where there is a rainfall of 400 mms. a year, concentrated during a rainy season of three months, the conditions for filling a tank of say 5000 cubic metres capacity with a superficial area of 1600 square metres may be outlined as follows:—

Direct rainfall on 1600 sq. m.	640 cubic metres.
Catchment, 43,600 sq. m.	4360 cubic metres.

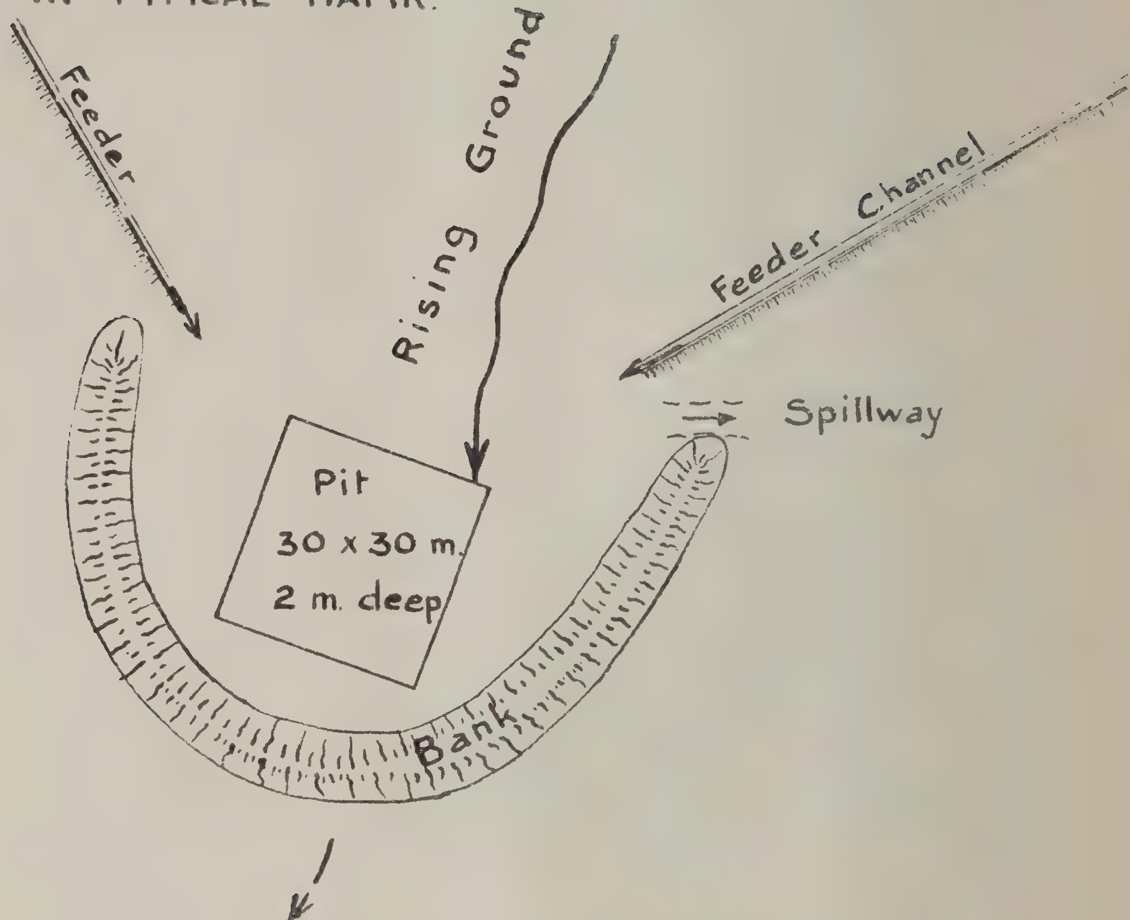
This assumes that the proportion of run-off, the amount of rainfall received by the tank from the catchment, is 25% of the rainfall. In such a case the catchment area must be about 11 acres. The rest of the rain water, 75%, is either absorbed by the soil or evaporated from the ground.

There are many old hafirs in good situations but as a result of neglect, a large proportion are now ineffective and require clearing and repair.

Storage tanks may be designed to fill from khors or streams. The advantage of such situations is that the stream may catch the first shower of rain and fill the tank very early. The difficulty is that unless an adequate spillway or by-pass is provided, a rush of water through the hafir may silt it up very rapidly or the retaining bank may be breached. The provision of stored water early in the rainy season is of great value in places remote from permanent supplies. The people are able to come to prepare the ground for cultivation and they can bring their cattle with them. The great value of the early supply compensates for the additional labour of maintaining the storage tank under rather unfavourable circumstances.

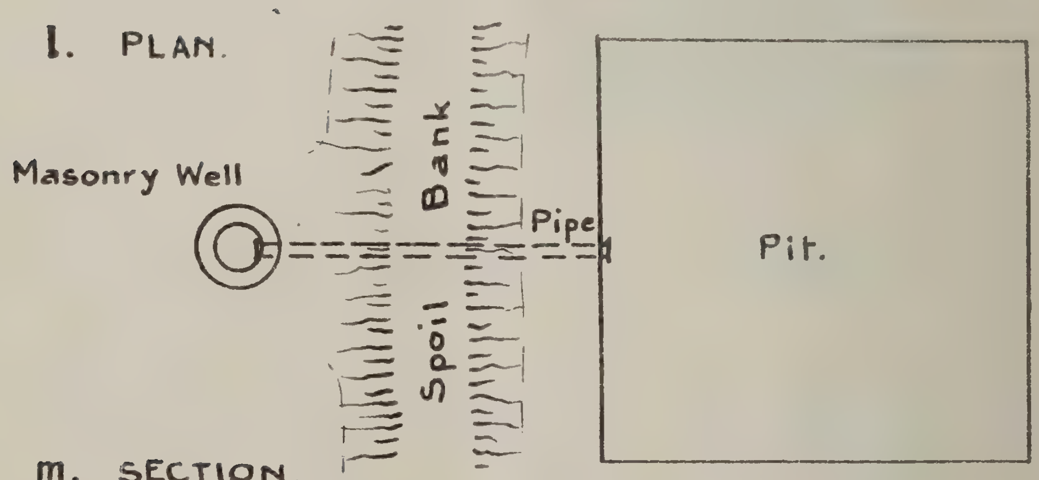
PLATE IV.

k. TYPICAL HAFIR.

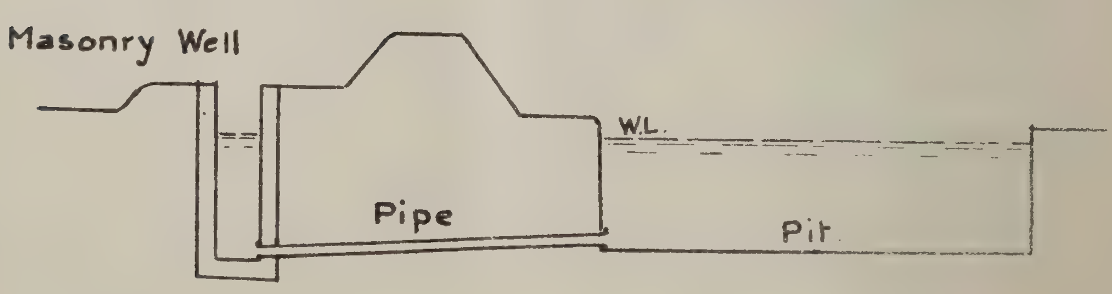


HAFIR WITH DRAWING WELL.

l. PLAN.



m. SECTION.



DESIGN AND VARIETIES OF STORAGE TANKS.

Open reservoirs are usually referred to as tanks while covered reservoirs are called cisterns.

Hafirs. The open storage tank excavated in soil is known as 'hafir' (plur. hafair) in the Eastern Sudan and as 'fula' (plur. fual) in the Western Sudan. The essentials for these are that the ground should be clayey enough to hold the water and that there should be a catchment whence the water runs off and collects to fill the tank. The spoil from the excavation is usually piled to form a horse-shoe shaped bank enveloping the hollow on three sides. The open side is towards the slope so that water flowing down may enter. Under favourable conditions of ground, the bank may hold a considerable amount of water above the surface of the ground and add materially to the storage capacity. The scheme is shown by the diagram Pl. IV. k. where a pit 30 × 30 m. in area and 2 m. deep has been made on sloping ground on the course of a small stream. The pit is made with vertical sides and the toe of the spoil bank should be at least 4 m. distant so as to prevent, as far possible, the material slipping back again. The object of steep sides of the main pit is that owners of cattle must lift the water out into troughs near by for the herds to drink. Otherwise if the beasts go into the water, they are liable not to be able to get out again up the steep sides. Watering cattle outside the hafir makes for cleanliness, as otherwise the beasts walk in and the water soon becomes very foul. A spillway is made by digging a channel at one of the ends of the horse-shoe. Care must be taken that the floor of the spillway channel is at least a couple of feet below the lowest part of the bank. The native often does not realise the importance of this matter with the result that the spillway is at too high a level and the water instead of passing out harmlessly, finds its way through a weak point in the bank which is breached immediately.

A modification of the design is to make one of the sides of the rectangular pit sloping with a slope of about 1 in 4. The sloping side should be towards the opening of the horseshoe-shaped spoil bank. The object of the sloping side is to allow animals to come to the water without risk of falling down the steep sides and perhaps not being able to get out again without considerable assistance.

Feeder channels may be provided so as to augment the amount of water reaching the hafir. These may be about ½ m. wide and deep and the spoil should be piled on the outer side so as to form a bank to retain the water in the channel.

On nearly level ground, the spoil bank around a hafir can hold hardly any additional water and its shape is of less importance provided its toe is well back from the edge of the pit.

Neglect leads to the filling of the hollow and quite often the bank is breached. There is much to be done in many parts of the Central Sudan in cleaning and repairing old hafirs. In most cases, a pit preferably 2 m. or more in depth is dug in a selected position within the hafir and the spoil is used to fill the breach and heighten the original banks. Such work must be controlled by levelled surveys. These demonstrate the best position for the pit and also where the bank most needs strengthening.

Rock Cisterns. ' Galta ' (plur. Gulut or Gilid) ' Kalgaieh ' in S. Gezira. These are pits or clefts in rock such as granite. They usually seem to have been formed naturally and it has only been necessary to find them and clear out the soil and debris to prepare them for storing water. Often these pits are on hills. The water may be guided in by channels and the mouth may be covered with sticks, stones etc., to keep out intruders and incidentally affording a little protection from evaporation. The sides of these rock cisterns are often nearly vertical and they form very effective storage. The principal trouble is due to the water becoming foul as a result of the decomposition of insects, birds and animals that fall in and cannot escape.

In the Butana region, there are several places where hafirs are associated with pitted granite floors. Such places are usually named El Sofeiya or a name with the same root, Um Sifi etc. The original attraction of these sites was certainly the presence of the rock pits and much still remains to be done in clearing them. The sides cannot fall in.

Masonry Cisterns. These are common in many parts of the world for storing rain water. In the Sudan there are remains of ancient ones at sites on the Red Sea Coast. In recent times a few were built and successfully used at points on waterless stretches of the road from El Obeid to Fasher. The cisterns were built of brick, below ground level. The bricks were made and burnt on the spot. They were filled with water by gravity from a neighbouring hafir. The supply of water was left under lock and key and was most valuable to travellers. They are less sought after now that the motor car has superseded camel transport.

Such cisterns are usually cylindrical in form so as better to withstand the earth pressure. The size may be about 4 m. diameter and 3 m. deep giving a capacity of about 35 cubic metres (nearly 8000 gallons). Some form of small settling tank or trap is provided to prevent coarse silt and sand from entering and filling the cistern. It is probable that the expense of this kind of storage can at present only be justified by special reasons such as the supply of drinking water in a town or along a road.

Steel Tanks. Mr. Beeby Thompson proposed the construction of large steel storage tanks with a capacity of several thousand tons like those used in many places for the storage of oil. Hitherto the designs submitted have involved sections of considerable weight which could only be transported by mechanical means. The tank would stand above ground level and a pump with a skilled engine driver would be required to fill it either from a stream or from a depression where rain water accumulates. Such tanks might be useful on the railway on some waterless stretches. There, both the construction and the maintenance would be less difficult, but, otherwise, the cost of construction of such a tank would only be justified in special circumstances to meet the ordinary needs of the people.

Tebeldi Trees. The commonest kind of closed cistern in the Sudan is the " tebeldi " tree or baobab (Adansonia digitata) but these are definitely limited in use to Kordofan. The wood of these bulky trees is soft and readily excavated by the people. The entrance hole is usually situated just above one of the lowest branches at a height of 10 to 15 ft. from the ground. The tank is hollowed out down to about 6 or 7 ft. above ground level. The wood below this level is usually unsound and if excavation were carried deeper, the water would escape. The outer wood towards the bark is rather harder so that the workmen know when to stop. The tree subsequently forms a bark-like skin over the excavated surface and this helps to conserve the water. The average capacity of these trees is about 350 gallons. In order to fill them, a hollow is prepared around the base of the tree. This catches and holds the rain water. The owners of the tree then proceed to fill buckets, haul them up and empty them into the hollow space within the tree. After the reservoir is full, the hole is closed with a pad of plaited grass and sealed with mud to keep out insects and other creeping things. If the water is well sealed up it will remain in good condition for several years. In fact if the seasons are favourable, the people allow the unused water to remain for long periods. It is the custom in Kordofan to sell the water stored in these trees, usually at the rate of 5 m/ms. for a jar containing about 3 gallons. As a consequence, the capacities of the trees are very well known. A large tree may hold as much as 2000 gallons. The provision of borings and pumps supplying water by payment in areas formerly dependent on tebeldi tree reservoirs, such as Wad Banda, has led to the abandonment of the trees in these neighbourhoods. The people do not trouble to fill them.

Small Iron Tanks. The question has arisen of extending the method of storage to which the tebeldi tree has been adapted. The number of trees is limited. All suitable ones in Kordofan have been hollowed and it is not practicable to grow the trees for immediate use as required. As substitutes, iron tanks of about 200 gallons capacity and weighing about 200 lbs. have been tried with a measure of success. They have been made in Khartoum, cylindrical in form, about 125 cm. high and 100 cm. diameter. The cylindrical side is of iron sheet about 1/32nd. inch thick and the top and bottom are of stouter metal about 1/8 inch thick. The top is provided with an opening which can be closed with a hinged door, secured by a hasp with a padlock. These tanks must be well painted so as to resist corrosion. It is to be kept in mind in the design and construction of these tanks that they are intended only for the storage of water and not for transporting water. If tanks are required for transporting water, they must be much stronger and correspondingly heavier than is necessary when the object is only storage at the place of supply. The storage tanks which are being considered here have been referred to as " tin tebeldis." Their weight is such that a camel may easily transport a pair. The cost of such tanks made in Khartoum has varied from about £E. 2½ to about £E. 5. They can be made by any blacksmith and it will always be best to assemble them near to the place where they are to be used, since it is easier to transport the flat sheets than the bulky tanks. If a large demand were to arise, it should be possible to obtain such tanks of good quality at under £E. 3 apiece. In use, they may be placed anywhere where it is convenient to fill them during the rainy season. There are many purposes for which supplies stored in such tanks may be very useful. The pair of tanks would contain 400 gallons, or ample to maintain two men for more than three months. Such a quantity would be very useful for families or small parties of harvestors and gum collectors. It would suffice them for a considerable period on the assumption that they keep the water to themselves and do not also supply sundry visitors and travellers. The entrance to these tanks besides being closed with a padlocked iron door, may be plastered over with mud and in this way the contents can be protected from evaporation losses. It has been proved that the water can be stored almost indefinitely. These tanks would be useful for holding supplies of water for use by cultivators who are preparing ground for rain cultivation at the end of the dry season so as to have it ready to take advantage of the first showers. Another use for these tanks might be the provision of drinking water for labourers excavating hafirs. Hafirs cannot be excavated while water stands in them and often when they have dried, there is no other supply in the district available for the workmen. The ' tin tebeldi ' tanks would be filled before the hafir becomes empty and even one or two pairs would provide enough water to enable a useful amount of work to be done by a party of labourers.

The attempt has been made to use these small tanks to provide supplies for roads but they are too light to be left unattended. The unauthorised traveller easily breaks in and later the tank may be found with the padlock forced, the hinges broken and perhaps a hole in the tank itself. The tanks must be placed where they are protected and they must also be convenient for filling. The best place for those used by the people will probably be in houses or sheds within the villages or near the gum garden, cultivation etc.

It seems possible that the tin tebeldi tanks may be useful to store supplies of water required for drilling. The necessary number of tanks would be brought to the site during the preceding dry season.

They would be filled from a local stream or hollow during the rains. A watchman or two would be needed to guard them but there the water might remain for months, until it is needed.

There can be no doubt that closed storage cisterns offer decided advantages both in regard to the period of storage and sanitation. The water is not lost by evaporation and it can be kept until whatever season of the year it is required.

Losses.

The water stored in open tanks excavated in soil is subject to losses due to evaporation from the exposed surface and also by percolation into the ground.

The largest proportion of water is lost by evaporation. Evaporation depends on dryness of the atmosphere, the temperature and the area exposed. The velocity of the wind is also a factor but it affects equally the means by which evaporation is measured. The figures for evaporation for the neighbourhood of Khartoum have been given in Chapter I. Evaporation occurs at a rather greater rate from a small hafir, because the surface is relatively small and also because the sun heats the shallow muddy water. The amount of water lost by evaporation from a large hafir, with an area of more than 1000 square metres may amount to about an average of 1 cm. depth daily during the Autumn and Winter months. The loss from a smaller hafir is greater. Since the loss depends directly on the area of the exposed surface, it is most important that hafirs should be made as deep as possible. A depth of 1 m. of water, if there is no other loss, will last for about three months. The amount of water that can be used during those three months depends on the depth in excess of the 1 m. If the hafir is to hold water for a longer period, it must be made proportionately deeper. The ideal is a rectangular pit 20 or 30 m. across or more and two or three metres deep according to circumstances.

It has been suggested that the loss due to evaporation might be reduced if the hafir were roofed over or covered. The hafir would then become a closed tank and the loss would be reduced considerably but no successful attempt at roofing has yet been made in the Sudan. The support of the large area of roof required is one of the problems. Masonry pillars might be built on the floors of the hafirs but require costly foundations if they are to be stable. It has been suggested that hafirs should be made long and narrow so as to be spanned by a relatively simple form of roofing. Another essential factor is the maintenance of the roofing in good condition on hafirs in remote places far from villages and where they may be at the mercy of any passing stranger.

A covering of vegetation has been proposed as a possible means of reducing evaporation losses. Either ordinary duck-weed, Lemna, or the Nile cabbage, Pistia, suggest themselves in this connexion. These weeds are often found covering the surface of water in rock cisterns in places remote from where such weeds are ordinarily found. It is supposed that the covering is due to plants descended from individuals or seeds transported on the feet of migrating birds. The general experience is that the vegetation causes greater losses. More water is transpired and lost by it than would be the case from a free water surface.

Another suggestion is to use a film of oil on the surface of the water. Oil on water often spreads out and forms a film of microscopic thickness covering extensive areas. The surplus oil collects in drops and shallow sheets on the surface of the water. Experiments by Mr. Colchester showed that the thin film was not effective in preventing evaporation. Using locally made sesame oil, nearly three litres (4 or 5 pints) are required to form a continuous layer on the surface of the water on an area of 1 square metre. This layer stopped the evaporation loss. The cost of the protection seems so high as to be prohibitive and even so the layer is not completely effective since it is easily blown to one side by the wind. A thinner film could be made of ordinary parafin oil but this evaporates so that it cannot be regarded as useful. The flavour of the parafin oil would be objectionable. It seems that a protective covering might be made by the use of crude oil or some heavy mineral oil.

The presence of trees near hafirs appears to be beneficial. They act as a screen and protect the water from wind. It may be very difficult to grow trees near hafirs which are resorted to by herds. The saplings would require efficient protection as well as watering. The trees, however, would give welcome shade besides preserving the supply of water.

Evaporation accounts for approximately nine tenths of the water lost from hafirs. The loss due to absorption by the soil and percolation through it must be small. It may be regarded as occurring in two ways. First, water required to moisten the ground in immediate contact with the reservoir and, second, the water which passes away and travels beyond the immediate vicinity of the tank. A fairly definite quantity is absorbed by the first and having been absorbed, the loss does not continue to any extent except to supply the moisture evaporated from the wet ground in the immediate vicinity of the tank. Most hafirs are in heavy clay soil and very little water travels through the ground away from them.

Even when hafirs are excavated in relatively permeable material such as silty soil or compact sandstone there is a tendency for those reservoirs to become watertight. The water brings in clay which forms a water-tight film over the walls and floor. It is well established that the water-retaining powers of a hafir improve with age.

It is clear that the losses by absorption and percolation depend directly on the area of the wetted surface. The loss is greater from a large shallow hafir than from a deep hafir of the same capacity but covering a smaller area.

Rock cisterns with impermeable sides and deep in proportion to their areas are subject to relatively small losses. These are reduced in covered tanks. The closed cistern with impermeable sides such as the iron tank can be said to be free from losses. A masonry cistern is subject to a small loss owing to the porosity of the masonry.

EXCAVATION.

Hafirs are usually dug by hand. The ground is broken and loosened with picks and then carried out in baskets to the place where the spoil has to be deposited. If possible, the work is done on a piece work basis. For this purpose it is convenient that the plan should be rectangular so that measurements are readily made. The cost of excavation in Kassala Province is said to have worked out at about P.T. 6 a cubic metre, using local labour and including cost of transport of drinking water for the men. The great advantage of excavation by hand is that the pits can be perfectly rectangular and the spoil may be disposed of to form banks according to any design. The subsidiary works including feeder channels and spillways are relatively small and must be done by hand.

A cheap and effective method of excavation was developed by Mr. J. Smith in the Gedaref region. Bull teams were used. One pair broke the ground by means of a plough and three other pairs were employed in drawing "gassabias" or shovel shaped scrappers which can pick up and transport the loosened soil. The scrapers are manoeuvred by the team driver, who lifts the handle and turns out the contents when the top of the bank is reached. The method sets limits to the form of the excavation which is usually boat shaped with steep sides and sloping ends up which the teams drag the spoil-laden scrapers. Depths of two or three metres can be attained while the cost of excavation has proved to be between P.T. 3 and P.T. 4 a cubic metre. The teams hitherto employed have been Abyssinian with Abyssinian drivers. Presumably local bulls and men might be trained to do the work and it would be more satisfactory.

Much work is necessary on old sites. For the most part a rectangular pit is made within the old hafir and the spoil is used to repair and strengthen the original banks. This work must be done by hand though the bull teams might be useful in some cases. In the ordinary way, the people should clear hafirs annually, removing the cracked and loosened soil from the floor.

Blasting has been tried with the object of loosening the soil and facilitating excavation. The charges used were found to form hollows about the point of explosion and the soil around the hollow was compressed and hardened. The results were ineffective. It is possible that larger charges might have resulted in actually displacing the soil but possibly the results still might not have justified the cost, especially in view of the low cost of labour.

The use has been proposed of machines after the style of those employed for excavating the canals in the Gezira irrigation area. It is possible that some such machines may be effective for the purpose. The points urged against the employment of machines are, the relatively small amount of work at any particular point, the cost of transport of the machine, fuel and water and the cost of the skilled supervision necessary to work it. However, trials have been made at Ereitil in the Blue Nile Province and conveniently situated for machines normally working on irrigation canals.

Sanitation.

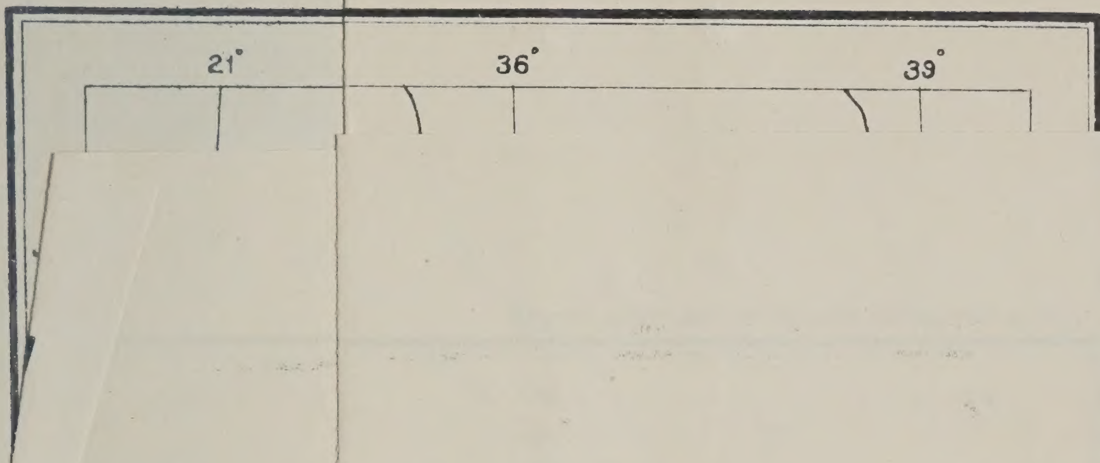
Some samples of water from hafirs that have been submitted for analysis have proved fairly satisfactory as drinking water. The water may contain clay in suspension but it has only a very small quantity of dissolved solids. This has been picked up from the ground with which it is in contact since none of it has percolated through any soil. It is obvious that the water is liable to become very foul as a consequence of animals coming to drink and often wading into it if shallow. In fact the last residues of the water, just prior to the final exhaustion, are usually avoided by both people and animals except in dire necessity.

The desirability of hafirs being rectangular in form with steep sides has been mentioned both as regards reduction of losses and also convenience of excavation. The steep sides have their value in tending to prevent pollution of the water. If cattle are allowed to approach, they are liable to fall in in the attempt to drink the water. The herdsmen then have to haul them out. To avoid this the cattle are kept at a distance and the water is drawn and carried out to them. It gives some work to the herdsmen but it results in the animals being kept away from the hafir. Only the quantity of water needed is actually drawn and the remainder of the supply is not contaminated.

It has been suggested that the water might be drawn by means of a well made near by and connected by a pipe to the bottom of the hafir. The scheme has not yet been tried in the Sudan. It offers the merit of simplicity Pl. IV., l. and m. A joint and a float might be added to the inlet pipe so that the water might be drawn from just below the surface so as to avoid both the accumulations on the bottom and the floating debris at the surface.

Trees are often found growing from the floors of old hafirs. They become ideal refuges for birds which may roost in them without fear of molestation by most enemies. The water below the trees is subject to showers of excreta from the birds and, picturesque as the trees may look, they should not be tolerated within the hafir.

Floating vegetation such as duck weed and Nile cabbages may not be in themselves offensive though they certainly increase the evaporation loss. Their presence entices insects, other small animals and sometimes big animals too, which fall in, drown and then decompose in the water.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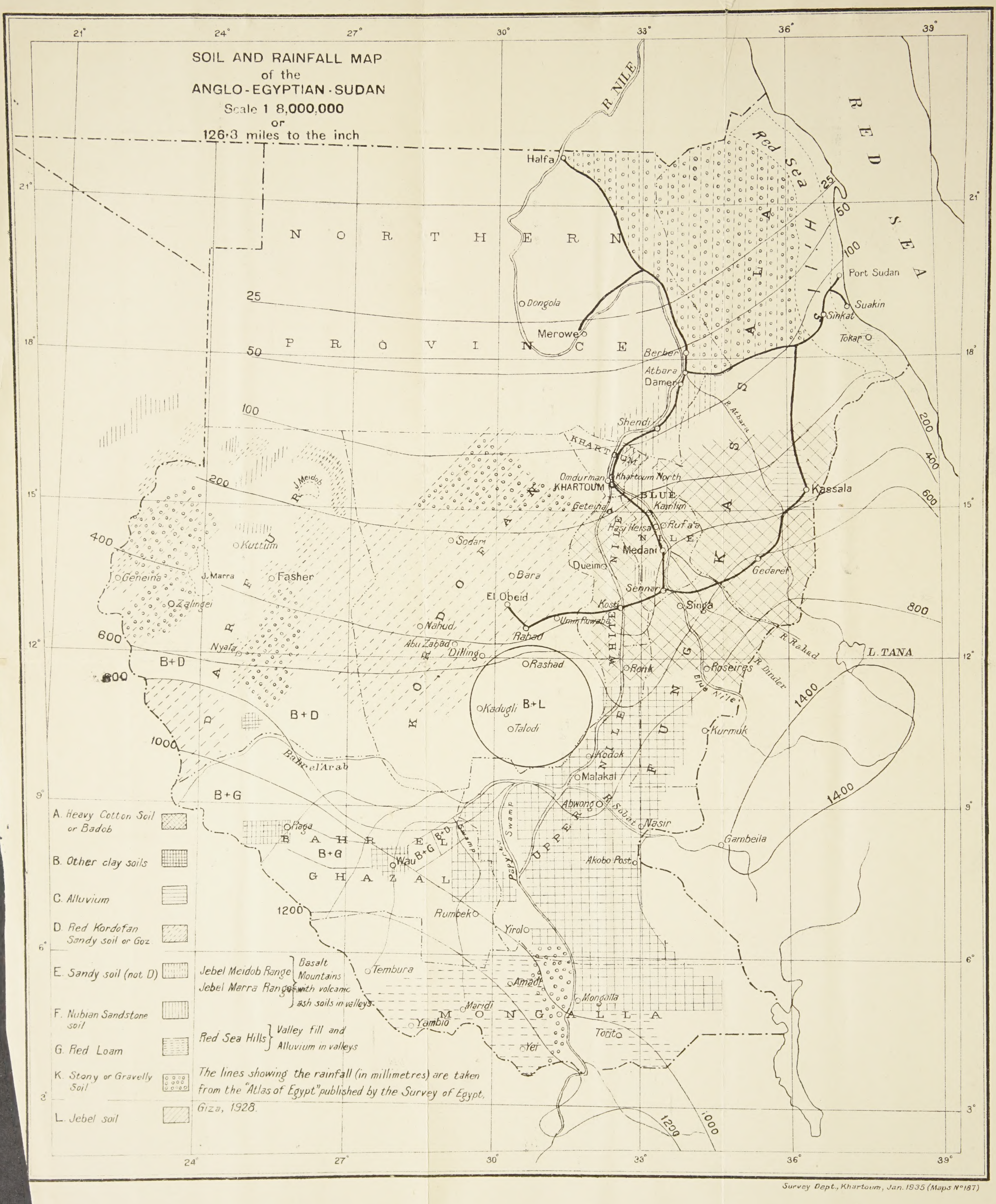

Survey Dept., Khartoum, Jan. 1935 (Maps N°187)