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SUDAN GOVERNMENT

BULLETIN

No. 1

THE HAFIR

WHAT - WHY - WHERE - HOW

by

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THE HAFIR
WHAT—WHY—WHERE—HOW

BY A. C. ROBERTSON.

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(1) Introduction.

There is an old saying that there is nothing new under the sun, and 'Hafirs' are no exception. They exist all over the Sudan and the Middle and Far East generally. The method of excavation has changed, however, and the observations made in this note are an attempt to put on record the problems now involved as they appear to the writer.

We have yet much to learn, and there have been many suggestions and ideas put forward, some workable and some otherwise, since the Ministry commenced its intensive programme of mechanical Hafir excavation in November 1947. This note is therefore an attempt to give the general picture of Hafir excavation in the Sudan as it exists at present, and views expressed are personal and not necessarily authoritative, but if they only lead to discussion, they will have achieved at least one object.

(2) What is an Hafir.

"Hafir" is an Arabic work derived from "Hafir," — "to dig" — and has now come to mean an excavation made either by hand or machinery and used for the conservation and storage of surface water. Storage is usually below ground level, but in suitable areas the spoil banks are utilized to increase the storage above ground level.

(3) How is it filled.

Filling is at present obtained from either a Khor (seasonal watercourse) or by hill catchment. When filled from a Khor a short connecting canal is sometimes required, and when from hill catchment, contour terracing leading in to the Hafir is necessary. There is no absolute guarantee of the filling of any Hafir in the Sudan; rains are capricious and erratic and may entirely miss a large area one year and cause destructive erosion to earthworks in other years. The most reliable site for an Hafir is therefore on a large, slow flowing Khor, known to run at least several days every year and draining wide area. "Mayas" or natural depressions which normally fill every year are also very reliable sites.

This necessity of having to depend on Khors or hill catchment for filling, very often means that the Hafir has to be sited some considerable distance from where it is required, and water has to be carried to the cultivation or the villages as the case may be. In an endeavour to rectify this disadvantage, an experimental Hafir is to be excavated this year with direct precipitation and run—off from a localized catchment as the object. Final

SKETCH OF AN HAFIR (PARA 2)

FIG ① PLAN

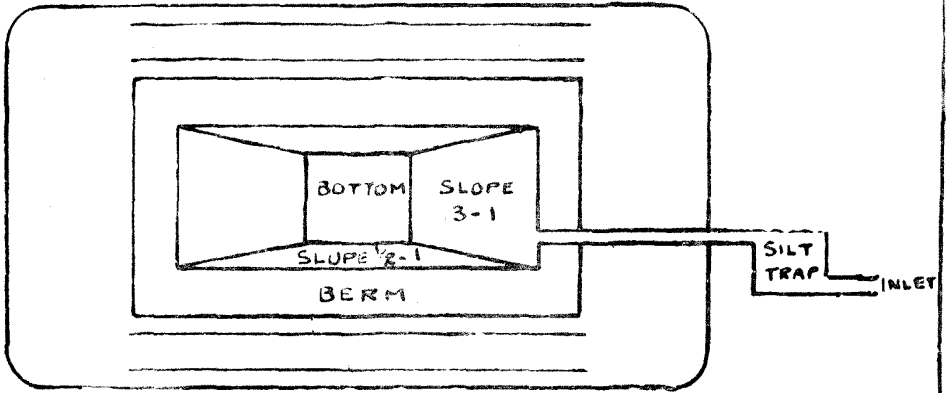


FIG ② SIDE ELEVATION



FIG ③ END ELEVATION



details of design, siting etc. are now being worked out, but it is considered that in a locality of not less than 600 mm per year precipitation, and always providing that precipitation is intensive, an Hafir can be filled to at least two thirds capacity by direct catchment.

(4) How much Water is available for Storage.

Omitting the River Nile and its tributaries, the only water available in the Sudan for the use of man, is that obtained from the rain, impounded on the surface naturally or by excavation, or from wells. Only a portion of the total rainfall is available for use however as the rain on reaching the ground can be regarded as being disposed in three separate fractions—evaporation, percolation and run-off. All these are intimately related to the actual amount of water delivered into any Hafir, and as they will be referred to later, an elementary explanation of each is given.

(a) *Evaporation.* Much of the rain falls on trees, scrub, grass and vegetation generally, and is thus subject to evaporation by both wind and sunshine before it can run away or be absorbed into the ground, while evaporation goes on continuously from the surface of streams, reservoirs and any area of standing water. If the rainfall is gentle and spread over long periods, then evaporation will be greater than when rain is heavy and concentrated. It is difficult to make an actual measurement of *total* evaporation, but the average *surface* evaporation for the central Sudan is estimated at 10 mm per day or 30 cm per month.

(b) *Percolation.* This is the fraction of the rainfall that soaks into the ground and that may, in some instances, be tapped later in wells or boreholes. Percolation depends on several factors — the nature of the soil, an open, granular, sandy or heavily cracked soil helping percolation, while a hard baked or impervious clay prevents it — the nature of the cover — whether there is a thick scrub or grass that will reduce evaporation and slow down the run—off and so allow more time for percolation — the slope of the ground — steep slopes allowing rapid run-off with no time for percolation, while very gentle slopes or level ground will help it.

(c) *Run-off.* This is a measurable fraction, and consists of the total water discharged into the Hafir from the catchment area or Khor under consideration. The difference between total rainfall and run-off is the amount shared between evaporation and percolation.

METHOD OF FILLING

(PARA 3)

FIG (a) FROM A KHOR

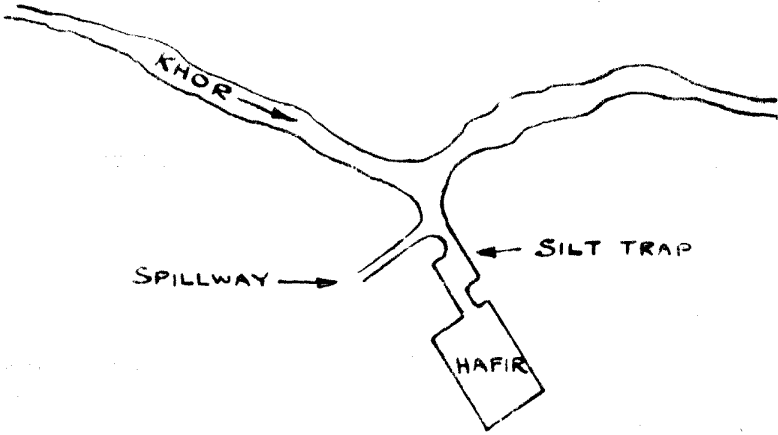
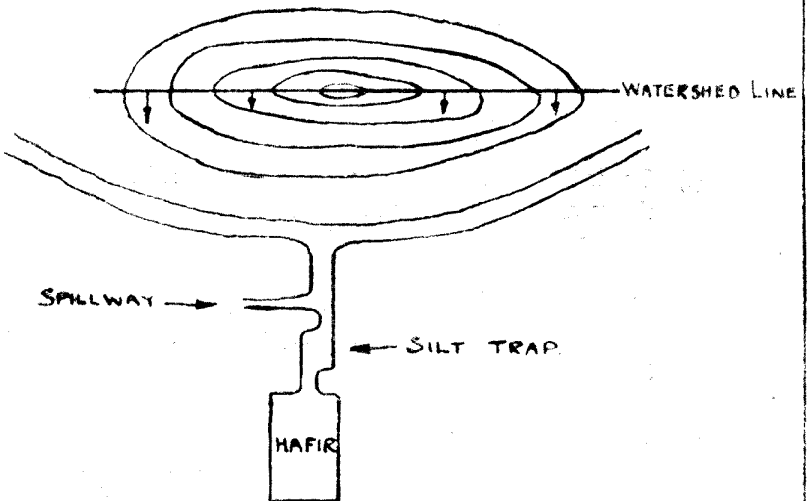


FIG (b) FROM HILL CATCHMENT



(5) What losses occur in Storage.

The losses encountered during storage in the Hafir are evaporation and percolation or seepage. The evaporation rate has already been stated and as this is effective on the *surface area* it becomes obvious that the deeper the Hafir the less the evaporation losses will be for the same stored volume. Seepage losses which could theoretically be appreciable, are estimated to be negligible providing the Hafir site has been carefully selected and the full excavated depth is through a heavy, clay soil. In the poorer clays percolation may be appreciable in the first year, but it is anticipated that the walls and bed will seal up with the clay silt and seepage losses rapidly diminish. Theoretically seepage also increases with the depth (pressure) but again, a good clay with its effective sealing properties should discount any appreciable loss.

(6) What are the objects of an Hafir.

These may be generally summarized under four headings.

- (a) To provide a reliable and cheap domestic water supply in an area of good agricultural soil, which hitherto has not been utilized, due to lack of domestic water.
- (b) To allow permanent village settlements to be established. At present many cultivators live in very unsettled conditions due to lack of domestic water supplies. Their cultivation villages are only temporary and are vacated as soon as the crop is harvested — in poor rains crops are often left unharvested — and the cultivators then move to areas where permanent water supplies are available, to return again to the cultivation areas when the next rains begin.
- (c) To induce cultivators to move from the infertile and eroded hill slopes and from over-cultivated lands concentrated around existing water supplies, to the fertile clay plains. This new land will enable each cultivator to produce a bigger and better grain crop, and also allow other suitable cash crops to be grown. With permanency of tenure established rotational cropping can be practised and land fertility maintained.
- (d) To provide an adequate and reliable water supply for animals in good grazing grass, and so segregate as much as possible the cattle-owner from the cultivator, and eliminate overlapping in cases where the two interests cannot be reconciled.

(7) How is Size & Shape determined.

Size. It is difficult to assess accurately the essential water requirements, human or animal, in the Sudan, as it is found that proximity to supply is the main deciding factor, and that while approximately 4 gallons per individual are used when the water is easily obtained, 2 gallons or less will suffice when the water is difficult of access or has to be brought from a distance. For purposes of estimation the following water rations per day have been taken as a basis on which to work and should prove adequate.

Man	20 Litres.
Goat or Sheep	10 Litres.
Donkey	20 Litres.
Cow	30 litres.

NOTE : 1 Litre—220 gallons.
1000 Litres—1 m3.

(a) *For Domestic use.* A perennial supply is required for this purpose, and assuming each family unit to be five heads, and allowing for some domestic animals, say two goats and one donkey per family, then an allowance of 140 litres per day per family should prove ample to cover all requirements. It is also assumed that water is required for approximately 300 days each year, the remaining days being covered by the general availability of water during the rains, coupled with some seasonal movement of the population.

Taking 100 families as a unit, it therefore means that 4200 Cubic Metres of water is required to cover their requirements for 300 days. During this period, however, evaporation is taking place at the rate of 10 mm per day and a total of approximately 3000 m³ Surface area × 10 mm × 100 days is also lost through evaporation. This means that an Hafir of approximately 7000 M³ capacity is required to sustain 100 families over one year (300 days).

(b) *For Cattle Watering.* A slightly different approach is necessary for this purpose, as the water is theoretically only required to last for as long as the grazing. The grazing area has therefore to be assessed, and from that, the number of cattle it will support and for how many days, has to be estimated. Assuming that an area is estimated to graze 3000 head of cattle and that the grazing will last for 60 days, then the water storage required can be estimated as follows — for consumption, 5400 m³, for evaporation, 600 m³, i.e., an Hafir of approximately 6000 M³ is required to sustain 3000 head of cattle for a period of 60 days.

Shape. The shape of the Hafir and side slopes are more or less determined by the operational performance given by the machines in use. The Carryall Scraper unit requires a travel of 30/35 metres to fill the bucket, and a ramp of 3-1 at each end to pull out of the pit. The side slopes are determined by reasons of stability, and a slope of 1/2 — 1 would appear to be sufficient from experience so far gained. Based on the foregoing criteria a 7000 m³ Hafir, 8 metres deep would have the following dimensions :—

Top Length	68m.	Top width	24m.
Bottom „	20m.	Bottom Width	16m.

(8) Where are Hafirs desirable.

The general locality — omitting for the present that water may not be there available — can be resolved into the following areas.

- (a) Where suitable agricultural soil is available.
- (b) Where a good grazing area is available.
- (c) Where afforestation is existent or possible.
- (d) Where resettlement is desirable for tribal or other reasons.

(9) How are actual Hafir Sites selected.

If contoured maps existed or if Khor beds were even moderately accurately plotted, the siting of Hafirs would be a comparatively simple operation, but the lack of these facilities makes reconnaissance on the spot a first essential. By intelligent interrogation of the local (or seasonal) inhabitants of the area a general picture of the possibilities can be obtained, such as - number of days on which the Khor usually flows, the height the water rises in the Khor, the direction of flow. (The maps are not always reliable on this point), the areas where water lies after rains and for how long.

The general site area having been selected the next step is to choose the actual site and this is done by contour levelling and pinpointing a site which will meet the necessary requirements such as level, (ground level should not be above level of Khor bed)—adjacency to Khor, to obviate a long lead-in canal,— and, in instances when above ground storage is feasible, where suitable wing banks can be built, using the spoil from the Hafir.

The actual site having been chosen from its above ground suitability there still remains to be proved that the sub-soil is suitable for water storage. To check on this point, examination pits are dug to a depth of approximately 10

metres in points straddling the suggested Hafir site. If the soil thus exposed is considered suitable then the Hafir is proceeded with. In the instances where unsuitable conditions are exposed by the examination pits it then becomes necessary either to choose a new site, or, where the unsuitable soil is at a low level, to restrict the depth of the Hafir.

(10) How are Excavation programmes arranged.

The capital cost of a mechanized excavation team is high — approximately LE.60,000 and for excavation costs to be kept to a reasonable level it is essential that the machines are kept excavating, and time not lost in walking long distances between Hafirs. Large Hafirs are also cheaper to excavate, volume for volume, than small Hafirs, as with the latter, time is lost in moving camp and clearing the ground, while the added expense of extra roads has also to be remembered. Long canals cut by Carryall can also reduce output by as much as 50 per cent. This postulates, that to obtain highest — and cheapest— output, the programme has to be arranged so that the maximum number of Hafirs — preferably large — are excavated with the minimum of travelling distance.

The 1947/48 and 1948/49 programmes were laid out in such a way as to serve two purposes, — to obtain information regarding the varying conditions of rainfall, catchment and soil that might be encountered, and “to show the flag” and prove to the local inhabitants over a wide area that rain can be caught and stored in sufficient quantities to last through the dry season. These objectives were both achieved, and mechanically excavated Hafirs instead of being a doubtful quantity have assumed a very definite role in the economic life of the Sudan. In carrying out these programmes the distances walked by the team were necessarily high — 800 and 1600 miles respectively, and therefore the cost per m³ excavated was higher than would normally be the case.

With the knowledge thus obtained programmes are now plotted so that the minimum of walking distance is involved and that wherever possible Hafirs are excavated on a circuit which commences and ends at railhead.

(11) When can Hafirs be Excavated.

The period available is that between the rains and can be said to be between 1st. October and 1st May, with variation as necessitated by different latitudes. Practice has shown that 15th. October is the target date on which digging should commence; before that date the soil has not dried out and wire rope breakage is heavy, due to the soil being wet and difficult to eject from the excavator. The completion date of 1st. May is taken as the safe date

by which the Team should be back at railhead, and although in some areas this date can be postponed it is essential to remember rain vagaries and to ensure that the team is not caught in the rain belt while still remote from railhead.

(12) What comprises an Hafir Team.

The composition of a Ministry of Agriculture Team is as under :—

<i>Excavating Machinery.</i>	<i>Ancillaries.</i>
(6—Caterpillar D-7 Tractors	2—Wheeled Tractors.
(6—Le Tourneau Carryall. 8 Cubic Yard Scrapers	1—Trailer, Platform.
(1—Caterpillar D—7 Tractor	1— „ Fuel Oil Large.
(1—Le Tourneau 3 Tined Rooter	2— „ „ „ Small.
1—Caterpillar D—7 Bulldozer	2— „ Water Large.
	1— „ „ „ Small.
	1— „ Caravan.
	2—Lorries 3 ton.
	1—Truck 1 ton.

Staff

Engineer in charge.

1—Clerk/Storekeeper.

1—Medical Orderly

4—Labourers

2—Watchmen.

12—Carryall Operators

2—Diesel Fitters.

2—Rooter „

4—Greasers.

1—Bulldozer „

2—Wheeled Tractor Drivers

2—D—7 Driver Operators (Reserve) 3—M.T. Drivers.

This means that including servants, camp followers etc. a total of approximately 50 personnel have to be catered for.

With the exception of the British Engineer in charge, each team is 100% staffed by Sudanese. Two shifts of 10 1/2 hours each are worked per day of 24 hours — 10 hours excavating, 1/2 hour refuelling and servicing — and during a normal tour a volume of approximately 2000 m³ is excavated per elapsed day, with up to 4500 m³ per excavating day on a straight forward large Hafir. Hours are long and the work tiring so off-duty hours are spent in rest and the radio set which accompanies each team provides the relaxation desired and is tuned in to "Radio Omdurman" every evening.

(13) **What are the problems so far encountered.**

(A) CONSTRUCTIONAL

These can be summed up under three headings, — mechanical, domestic and supply, and although each tour presents a new problem, experience already gained now usually provides a quick solution.

(a) *Mechanical.* Eliminating replacements necessitated by normal wear and tear or accident, mechanical failures have not been abnormal, with track trouble perhaps the most common, possible due to long walks and — at the start of a tour — inexperienced drivers. Wire rope consumption is also high and here again inexperienced drivers and digging in damp soil are the main reasons.

(b) *Domestic.* The main problem on this side has been water, both for human, and mechanical consumption, and on past tours a round trip of 200 miles by Tractor and Tank Trailer has often been necessary. This problem is already considerably eased by utilization of the water stored in Hafirs excavated on previous tours, and on future tours the problem will be solved until such times as completely new waterless areas are tapped. Health can also produce difficulties, as hard and continuous work, in areas sometimes malarious, reduces the vitality of the staff and productive efficiency is lessened. A medical orderly with a full supply of first aid and prophylactic medicines accompanies each Team, and unless the illness or accident is serious, treatment can be given on the spot. Foodstuffs and personal requirements present no difficulty and arrangements are made for these to be drawn monthly as necessary from the nearest market, while in most areas fresh meat etc. can be obtained from nearby villages.

(c) *Supply.* The fact that the daily fuel oil, benzine and lubricant consumption of a Team is high, and that supplies have to come from rail-head or river port — always a considerable distance from the scene of operations — makes this one of the points which requires careful attention. Provided bulk storage accommodation for fuel oil can be made available at rail/river head, the problem is eased, but this is not always possible, and with delays occurring between order and supply, it is essential

that wherever possible requirements are accurately anticipated on the line of route, and an intimate check kept on demand and supply. Delivery to the Team is made either by Tractor and Tank Trailer, or Tank Lorry, and, as in the case of water supply, considerable mileages have to be covered. In the 1948/49 tour round trips of up to 400 miles were made.

(B) OPERATIONAL.

(a) *Inlets and Spillways.* These are required to be as simple as possible and automatic in action as it must be remembered that the majority of Hafirs are situated "in the blue" with supervision, if any, an unknown quantity, therefore the inlet and spillway should be so designed that whatever else happens all the available water will get into the Hafir on the first flush.

Inlets. Three types of inlet have been tried, leading from an earth bank or masonry weir, — the pipe, the stone pitched flume and the wire bound grass mattress flume. Of these the pipe can be considered as most satisfactory and also easiest to install, but essentially it must be of large diameter (and when necessary, duplicated) and carried down to the Hafir bed to prevent wall scouring; control by a pipe gate is also easily obtained, and back flow can be checked immediately the water level in the Khor or feeder channel drops below the Hafir level. The stone pitched flume is also satisfactory providing it is well constructed, but the transport and costs of materials and the extra excavation and skilled labour required make this type expensive to install and maintain. The grass mattress flume has generally proved a failure, as anchorages scour away and considerable wall damage results.

Spillways. In designing a spillway it must always be remembered that in the Sudan the first flush of water may also be the last for the season, and that whatever else happens, all that water must get into the Hafir. The spillway, which has found most favour so far, has been located on the feeder channel to the inlet pipe or chute, the theory being that the water flow is only by-passed when the Hafir is full, or in the event of a very heavy run-off which the inlet could not accommodate; in practice, however, this type has been found unsuitable for Sudan conditions and in some instances Hafirs have failed to fill due to inlets being too small and spillways too low.

Wing banks straddling the Khor to impound all the water possible, would seem to be the best method of ensuring a full Hafir, and a simple spillway on this wing bank remote from the Hafir, or on the downstream spoil bank of the Hafir itself, may possibly be the best solution. A breached Hafir spoil bank can easily be rebuilt, and any way the Hafir is still full to ground level capacity.

(b) *Silting*. It will be readily understood that the first heavy precipitation of rain causes a considerable amount of grass, vegetation and silt to be carried into the collecting channel to the Hafir. If this is allowed to enter the Hafir then a heavy silt deposit will be formed and the Hafir gradually deteriorate in capacity. If a long enough rainfall could be depended on, then the first trash and silt laden flush could be by-passed, but unfortunately this is too risky under Sudan conditions and other means of elimination have to be found.

Generally, the quantity of silt carried in suspension in a stream increases with the velocity, and decreases as the velocity of the water falls, and the lower films of water carry a larger percentage of solid matter in suspension than the higher. With this knowledge, the method used to reduce the amount of silt carried into the Hafir is (a) the provision of a silt trap which while reducing the velocity of the water allows the silt to be deposited *outside* the Hafir in an easily cleaned excavation, and (b) so arranging the inlet that the water is drawn from as high a level as possible. Detailed variations of these practices are now under test, but until experience over some years is obtained the best method of silt control has yet to be established.

(c) *Scouring of Spoil Banks*. Experience has shown that this can be excessive especially from the end spoil banks ; not only are the banks damaged but the soil is carried into the Hafir accelerating the silting up process. Contour terracing of the spoil bank, leading into a trench at berm level is a method being adopted to cut down scouring of the spoil bank, while draining this trench into the bed of the Hafir proper, should minimise scouring of the Hafir and walls. Establishment of suitable grasses on the spoil banks would also serve as a binding medium, but the fact of the end spoil banks being built of the deep soils makes this difficult in the first years although in the earlier dug Hafirs a certain amount of grass growth is now becoming evident. The discovery and establishment of a suitable grass is the next step in counteracting scour damage.

(d) *Sudds or Barrages*. In cases where an Hafir has to be sited close to, and fed by, a deep flowing Khor, a sudd across the Khor becomes necessary to ensure the Hafir's being filled to capacity. It has been found in practice that a sudd made from the top clay soil, excavated from the Hafir, is not satisfactory and washes away easily. In future the deep soil will be used as it should allow better compaction, while if necessary, the sudd can be reinforced with locally hewn timber to give added security, but a stone weir is obviously the correct answer when this practice is necessary.

(14) What problems can be anticipated in the future.

This can be visualized as maintenance and prevention of pollution, and while the first can be fairly accurately assessed the second poses some queries the answers to which are still unknown.

(a) *Maintenance.* Providing Hafirs are properly fenced and guarded, the only maintenance visualized as necessary, is the repair of any scour damage to spoil banks and Hafir walls, and the extraction of the silt accumulation from the Hafir bed, and it can be assumed that the former can be effected manually, but that mechanical equipment will be required for the latter. The extraction of the silt would seem to depend upon whether the Hafir was completely dry, or if it still contained some water; if dry, then excavation to the original depth presents no difficulties, and can be done by Carryall scraper; if however, the Hafir still contains some water, two approaches are offered. — the extraction by Dragline excavator or the excavation of a *second small* Hafir adjacent. The size of this second Hafir would be assessed to receive the amount of water still remaining in the silted up Hafir as on say 1st. March, and this water would then be transferred by pump to the new Hafir. This method would not only permit the large Hafir to dry out and allow silt extraction by Carryall Scraper, but also considerably cut evaporation losses on the water still remaining. This principle of transfer of water could also be resorted to in any year of poor rains to reduce the evaporation losses to the minimum.

While on this subject it is essential to remember that if trees are planted in the vicinity of an Hafir, they must be so located as to allow unrestricted working space for any excavating machinery which may be used on future maintenance.

(b) *Pollution.* This can be caused by either or both of two agencies human and animal, but providing that the Hafir is adequately fenced and guarded, and that the method of water extraction used prevents direct access to the waterspread, then the danger of pollution from the domestic agencies can be reduced to a minimum. Birds, however may yet prove to be a major problem, with possibly the waders as the chief offenders, while the planting of trees on Hafir banks may also be a step in the wrong direction in this respect ; as the waterspread is generally of moderate areas adequate patrolling by the resident watchman may prove to be sufficient, possibly augmented by some simple bird scarer.

(c) *Sediment in Suspension.* The wind can be reckoned as the carrier of sand, decayed vegetation etc. which will be deposited on the water-

spread in varying quantities and in relation to the situation and orientation of the Hafir, while birds have also to be remembered in this respect. The precipitation of this sediment may or may not present a minor problem and possibly an algae will have to be found which will help in this respect and if this is satisfactory, a sub-aquatic species is preferable so that evaporation losses are not increased.

(d) *Mosquito Breeding.* Evidence has yet to be produced that Hafirs are potential breeding grounds for mosquitoes and bilharzia. It is felt that the steeply sloping sides with no shallows, high evaporation rate and strong sunlight with no vegetative cover, are all factors against their breeding. In case, however, that this assumption may be proved—in correct, experiments are being carried out with fish stocking, using amongst others the species “gambusia” which is known to feed on mosquito larvae. In this connection it is interesting to note that two unknown species of fish were found in the Megeines Hafir in December 1949 and as this Hafir filled for the first time in August 1949 it would appear that nature, with the assistance of the larger river birds, may prove of help in the matter of fish stocking, even although allowance will have to be made for fish extraction by the same means.

(e) *Reduction of evaporation losses.* With loss through evaporation being so high it follows that any means by which this can be reduced has everything to recommend it. The provision of a roof is the simple answer, but the type of roof, whether supported on the Hafir walls or floating, and the type of roofing material to be used are decisions still to be made, even in this apparently simple problem experience by prototypes offers the only way to arrive at an answer and even then efficacy will have to be weighed against cost of installation and maintenance. There is also the question as to whether the gain by reduction of evaporation might not be offset by increased pollution, if the roof became the roosting, and possibly nesting place for birds.

(15) **Roads.**

It will be readily understood that most Hafir sites are located well off the beaten track and accordingly roads are primarily required not only to get the machines to the site, but also to permit an easy route for the necessary supply lines to water points and railhead. In the plotting of these roads, however, long view is always taken and the routing so selected that coincidentally with new areas of development being opened up, a graded road to railhead also becomes immediately available for the extraction of crops. The roads made are dry season only and make no effort to follow watersheds, the shortest

distance to railhead being generally the main objective. As the majority of these new roads are through unmapped territory it can be understood that a considerable amount of preparatory work is necessary in trace clearing etc., but as this subject is supplementary to the Hafir proper, details of the operational procedure and problems will not be given in this note.

(16) Conclusion.

It is hoped the foregoing will have given the general picture of Hafir excavation as at present practiced by this Ministry, and also serve to show the various interests which have to be reconciled. The plotting, preparation and execution of any Hafir excavation tour can be reckoned as a major operation, and must be approached as such, and with so many interests involved it is most essential that each official concerned always remembers the bigger picture and does not limit himself to his own parochial boundary.

LIST OF BULLETINS

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No. 1. ROBERTSON, A.C. 1950. The Hafir. Price 5 piastres (one shilling).

وزارة الزراعة

حكومة السودان

بالتين نمرة ١

الحفير

ما هو - ولم - واين - وكيف هو

المؤلف

ا. س. ر. ر. ر. ر. ر.

لجنة النشرة الزراعية

الخطوم

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