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WESTERN SUDAN AGRICULTURAL RESEARCH PROJECT

THE GOVERNMENT OF SUDAN
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THE WORLD BANK
CONSORTIUM FOR INTERNATIONAL DEVELOPMENT
WASHINGTON STATE UNIVERSITY

RECOMMENDED WATER CONSERVATION/UTILIZATION INTERVENTIONS AND RESEARCH DIRECTIONS IN KORDOFAN REGION OF WESTERN SUDAN

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THE WESTERN SUDAN AGRICULTURAL RESEARCH PROJECT

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J.J. Riley

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Terms of Reference

On April 1, 1985, the Director of the USAID Mission to Sudan, Dr. William R. Brown, suggested to the Director of the Western Sudan Agricultural Research Project, Dr. Dafalla Ahmed Dafalla that Dr. James J. Riley look into whether the scope of WSARP research in water resources should be expanded and to evaluate proposed water-related interventions from the technical agricultural perspective. Dr. Dafalla replied on April 4, 1985, indicating his concurrence and approval of the suggested water resources study. (8)

At that time it appeared that it was the intention of the USAID Mission to field a team to conduct the proposed study of which Dr. Riley would be a member. Consequently, Dr. Dafalla suggested that the team address the following points:

> "There have been successful soil and water management programs other countries, but farmers seem rather reluctant to continue them. The team should therefore try to address the questions of how to train adequate staff with sufficient basic knowledge to translate the principles of water management into workable practical programs and how to motivate the Central and Regional Governments to support such programs." (8)

Later it was learned that USAID did not plan to form a formal water resources study team. Therefore, many of the points suggested by Dr. Dafalla were not addressed by Dr. Riley since they fall outside his discipline. However, the CRUX Report prepared by Ahmed, Hexner and Patten does suggest a means by which projects can be planned from the bottom up and ways in which villagers can be involved in the preparation and implementation of projects.

A meeting was convened by Dr. Brown on May 13, 1985, for the purpose of clarifying Dr. Riley's Terms of Reference. Based on this meeting, the following items were included in Dr. Riley's Terms of Reference:

1. Suggest some ideas on water projects that could be started soon on the village level.
2. Projects suggested should be capable of being implemented by private voluntary organizations (PVOs) in an area that would impact on about 100,000 people.
3. The importance of bringing gardud (non-cracking clay) soils into production should be considered in selecting a target area.
4. Attempt to identify projects that have the potential of being developed into larger commercial operations by private individuals.
5. Recommend ideas that have promise but require WSARP research to develop into feasible interventions.

After an initial reconnaissance survey, it was decided to focus the attention of this study on Kordofan Region, where the WSARP program is capable of implementing suggested research topics and providing technical support to recommended interventions.

EVALUATION OF CURRENT WATER RESOURCES DEVELOPMENT IN KORDOFAN

"The geographical distribution of agriculture is very largely determined by the availability of water to drink."
Doxiadis Associates, 1966 (Report DOX-SUD-A57)

The Government of Sudan launched a Freedom from Thirst campaign in 1967 to provide water by drilling wells (boreholes) in areas where it was not readily available and by opening water yards to manage them. An average of 178 water yards per year were installed between 1967 and 1976. (38) (49) Many people are of the opinion that the indiscriminate placement of boreholes and water yards accelerated environmental degradation by enabling people to reside in and cultivate fragile environments that they would otherwise not have been able to inhabit. (39) (19)

The construction of hafirs (man-made depressions excavated in clay soils into which runoff water is channelled during the wet season) was one of the first activities undertaken to increase the year-round availability of water in Sudan. Between 1917 and 1975 over 300 hafirs were constructed throughout the country. (49)

The Nubian sandstone, an excellent aquifer, underlies a large portion of northern Kordofan. Southern Kordofan is underlain principally by the Basement Complex, a poor source of groundwater. However, heavy clay soils in the south are well suited to the construction of hafirs. Therefore 75% of the 700 water yards are in northern Kordofan, and 80% of the 300 hafirs are in southern Kordofan.

Many of the current and proposed water-related activities involve rectification of hafirs (UNICEF) and rehabilitation of water yards (CARE). The EEC has drafted proposals to do more of both in Kordofan and Darfur. (37)

Rehabilitated water yards normally break down in two years while rectified hafirs should continue to operate much longer.

In southern Kordofan UNICEF is carrying out a program to install 1200 domestic wells with handpumps "to provide sufficient quantities of potable water and education about its safe use for drinking, personal hygiene and other domestic needs, for the rural people...and thereby to improve their general health and socio-economic conditions." (UNICEF Masterplan) (26)

The drought has stimulated the drilling of wells in the vicinity of El Obeid by UNICEF, CARE and others to provide the city with additional water since the city's series of supply reservoirs have run dry. Thus, the drought may have started a new cycle of activity that will once again increase water sources in fragile environments which may lead to a further degradation of these areas. Many of the proposed EEC projects and some of the water projects now underway in Kordofan are well conceived but suffer from one or more of the following drawbacks:

(a) They are capital intensive and require large amounts of foreign exchange, and therefore, they are not sustainable;

(b) They are implemented by Government departments with little involvement of the target population and as a consequence may not meet their needs;

(c) They are carried out in isolation from other activities without reference to desirable land/water use policy or plans, which may result in promoting conflicts between pastoralists and cultivators; and

(d) They give little emphasis to conservation and efficient use of water.

Sudan does not have an effective land and water use plan or policy (IES Environmental Monograph 4). (18) Therefore, at present, the

responsibility for prevention of environmental degradation falls on the people, donors and their implementing agencies. Interventions must be selected with care and implemented cautiously lest proposed solutions become problems themselves. Dr. D.L. Johnson of Clark University offered the following guidelines on the application of scientific knowledge for development at an Arid Lands Management Workshop held in Khartoum in 1982:

"(a) the human aspects of the development process need to be the point of departure, not the final consideration, when all other elements are in place;
(b) institutional arrangements must be adequate at the local scale if success is to be achieved; and
(c) management strategies must be built from the ground up (within the context of a comprehensive plan) making adequate allowances for the diversity of local experience and resources.

This implies that modestly scaled development projects that take their initial inspiration, although not necessarily their ultimate form, from indigenous understandings and perspectives have the greatest likelihood of success." (32)

According to Dr. Tom Eighmy, EPP, the Sudan USAID Mission is emphasizing low technology projects that can be carried out largely with local currency with village participation. Foreign commodities and machinery may be included in support of the primary activity if fully justified. This approach appears to be compatible with the precepts set forth by Dr. Johnson and in harmony with the project implementation methodology proposed in the CRUX Report.

Selection of Target Area

Criteria and Considerations

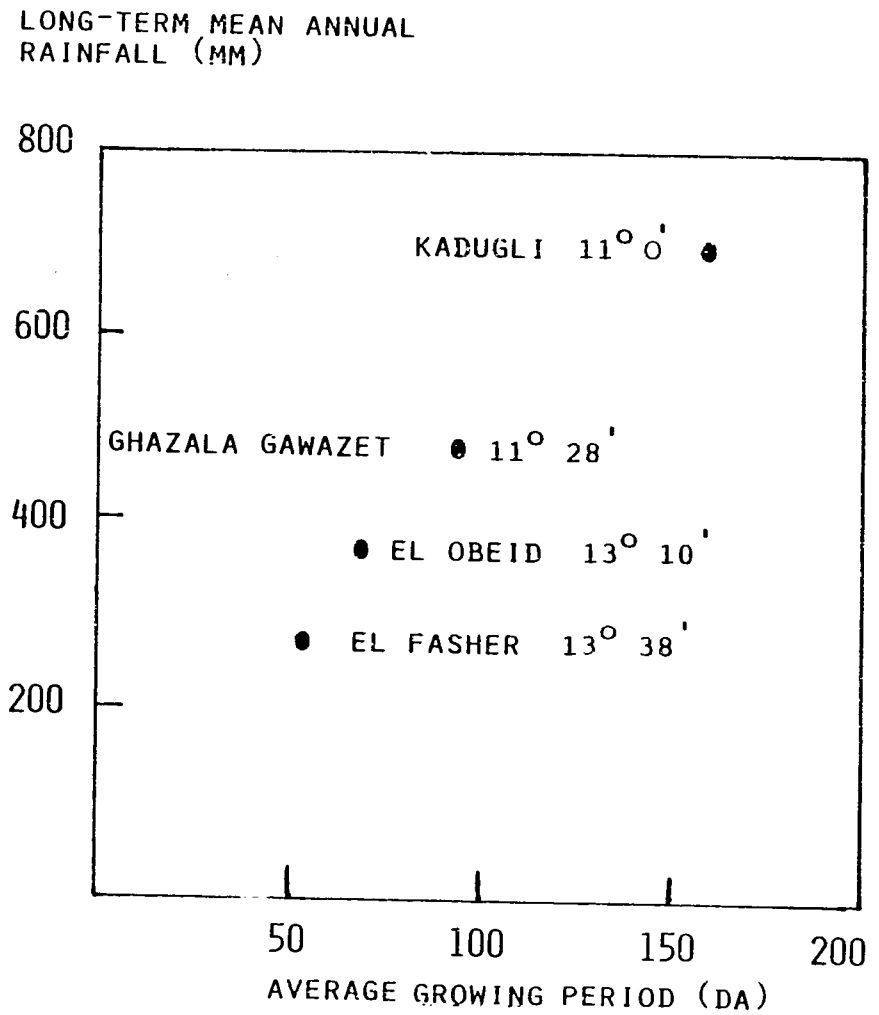
The basic unit of planning for water resource interventions should be a watershed in order that the full impact of introduced modifications can be assessed and incorporated into the planning process. For the purpose of this study the target area (watershed) should be agriculturally productive with the potential of becoming even more productive.

According to the Terms of Reference, the suggested interventions should have the potential of benefitting approximately 100,000 people.

It is generally considered that a minimum of 400mm of rainfall per year is required for stable rainfed crop production. In western Sudan, the length of the growing season and the annual rainfall decrease northward (Figure 1). The 400mm isohyet falls just south of El Obeid in Kordofan and represents the northern limit of the area where early maturing millet (75-day growing period) can be grown without a high risk of failure. Thus, the target area should be south of El Obeid, if more stable agricultural production is to be promoted. Although rainfall has been below average for the last 20 years, the variation in rainfall appears to be cyclical, thus use of long-term means for planning purposes is valid (Figure 2).

Ideally there should be sufficient baseline information available about the target area that projects can be implemented with a minimum of costly resource surveys.

FIGURE 1 RELATIONSHIP BETWEEN MEAN ANNUAL RAINFALL AND LENGTH OF AVERAGE GROWING PERIOD IN WESTERN SUDAN



DATA SOURCES: SUDAN METEOROLOGICAL DEPARTMENT
FAO REGIONAL STUDY ON RAINFED AGRICULTURE

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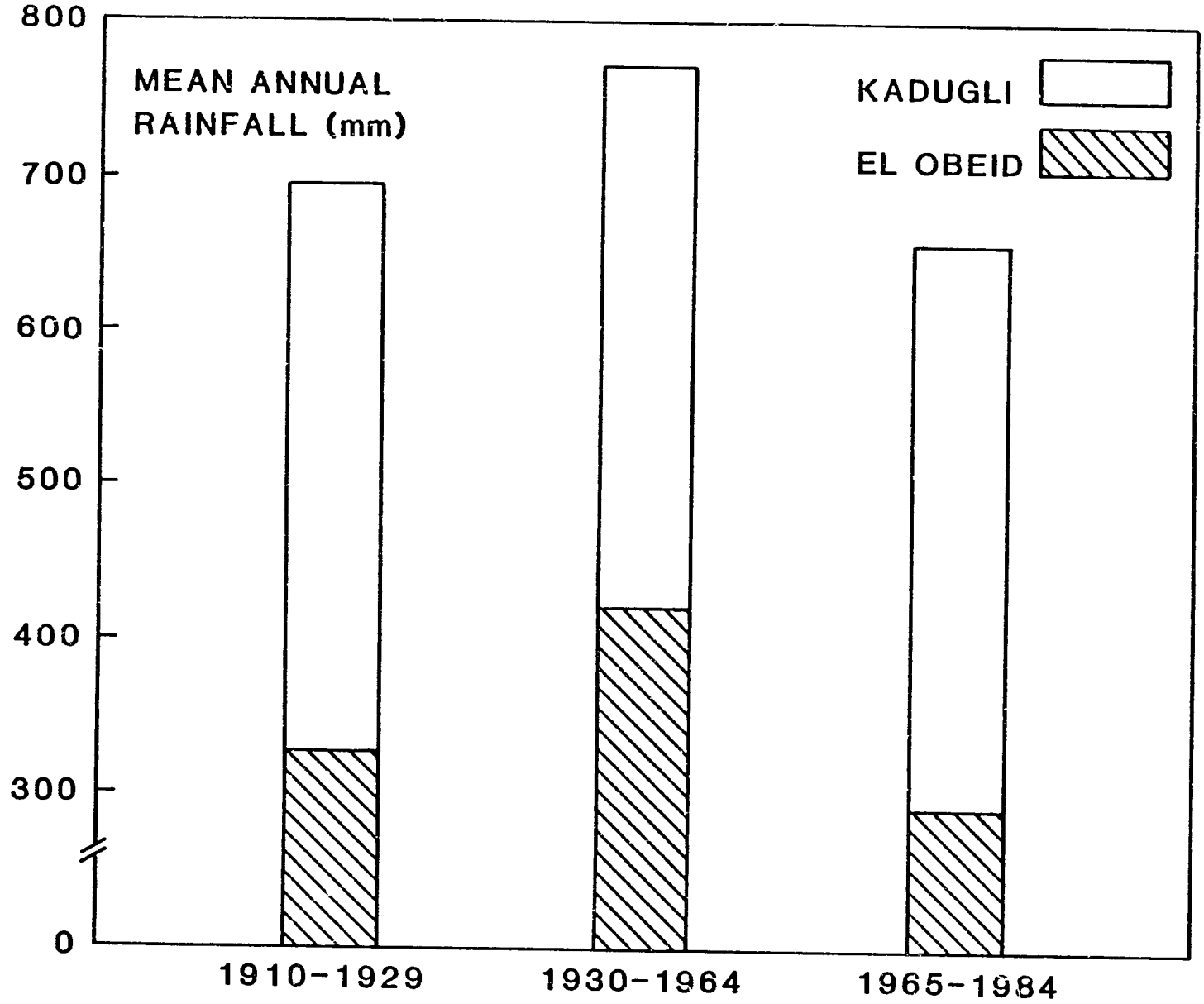

FIGURE 2 MEAN ANNUAL RAINFALL FOR SELECTED PERIODS AT KADUGLI AND EL OBEID, KORDOFAN, SUDAN

DATA SOURCE: SUDAN METEOROLOGICAL DEPARTMENT

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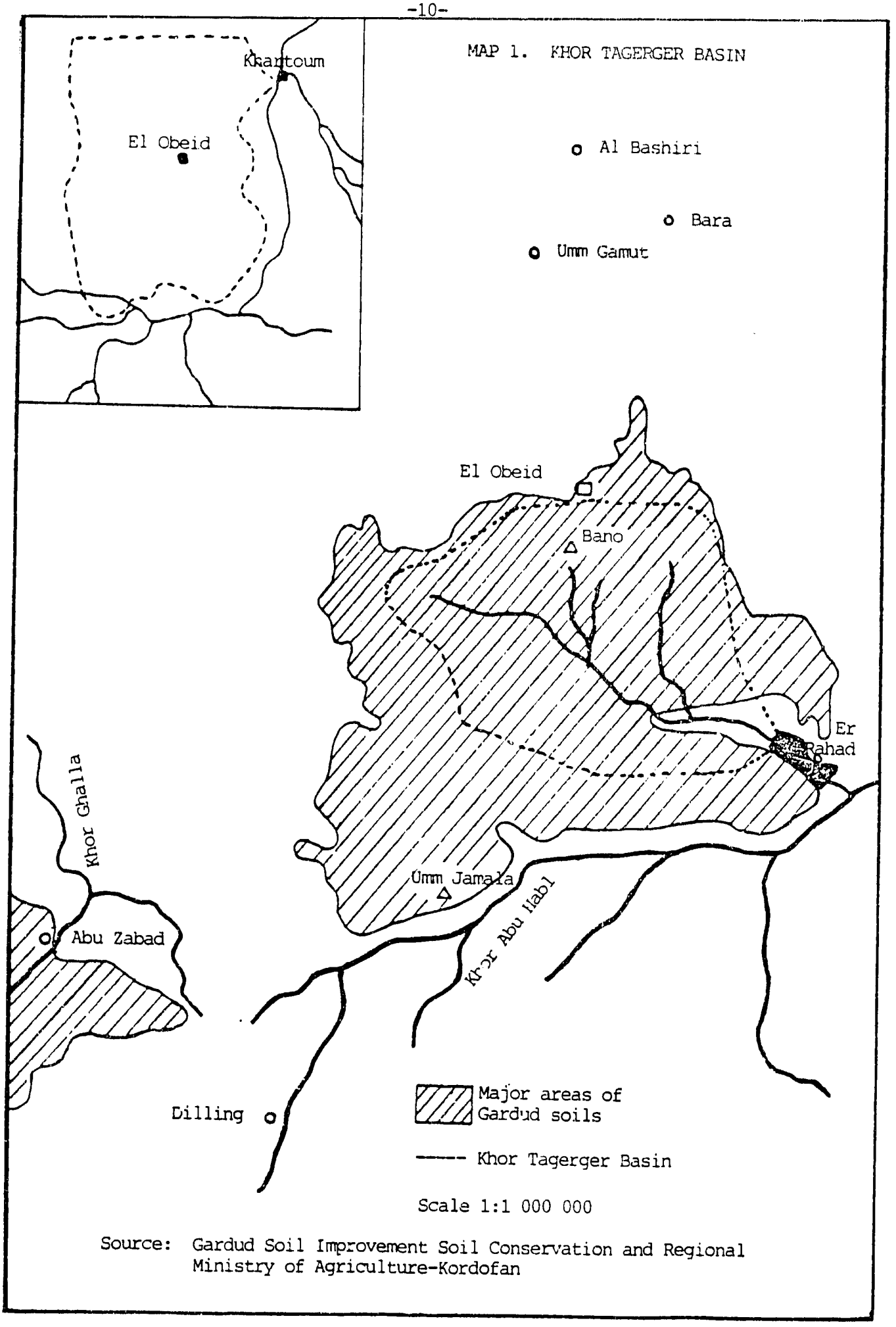
Characteristics

The most comprehensive and extensive study of natural resources in Kordofan Region was the Land and Water Use Survey, carried out by Doxiadis Associates in the early 1960's for the FAO and the UN Special Fund. In reading the reports that were issued from this study, my attention was drawn in general to the agricultural potential of the clay pediplain (gardud) soils South of El Obeid and, specifically, to the Khor Tagerger Basin. The basin is adjacent to Khor Abu Habl, the main drainage system for central Kordofan, but is a separate closed watershed (Map 1). A network of khors and wadis in the Khor Tagerger Basin drains the 4100 km squared watershed into Rahad Lake which, when full, contains 40 million cubic meters of water and extends over 16 square kilometers. The lake waters are under-utilized. Currently it provides water to Er Rahad City, to nearby horticultural gardens and to migrating pastoralists and their herds in the dry season (Doxiadis reports DOX-SUD-A41 and A52). (12) (15)

Khor Tagerger Basin is bounded on the north by El Obeid and on the south by Er Rahad, where the long-term average annual rainfall ranges from 374mm to 435mm, respectively (Table 1). The annual potential evapotranspiration is about 2400mm, which means that soil surfaces dry rapidly and open bodies of water lose more than two meters of water per year via evaporation. (35)

The Khor Tagerger is underlain primarily by undifferentiated Basement complex covered with superficial sandy-clay deposits. Several iselbergs and pediments occur near Banjadeed and Abu Haraz. A small portion of the basin between and Er Rahad and Banjadeed is underlain by the Nawa series. (12)



MAP 1. KHOR TAGERGER BASIN

Source: Gardud Soil Improvement Soil Conservation and Regional Ministry of Agriculture-Kordofan

Table 1 Comparison of Er Rahad and El Obeid Rainfall Data, Kordofan, Sudan

	El Obeid	Er Rahad
North latitude	13° 10'	12° 43'
Beginning of station records	1911	1931
	Mean Annual Rainfall (in mm)	
1930 - 1964 (above average rainfall period)	421	473
1965 - 1984 (below average rainfall period)	293	369
Long-term mean	374	435

Data source: Sudan Meteorological Department (36)

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According to Yagoub A. Mohamed: "The Basement complex is the oldest (Precambrian) formation of igneous origin, therefore has poor water bearing capacity. The rocks generally bear water in deep weathered materials, fractures and joints." (38)

Clayey pediplain (gardud) soils cover approximately 80% of the basin, with about 15% sandy pediplain (goz) soils and the remaining 5% alluvial flood plain soils. These are general soil classifications and do not convey the full diversity of soils found in the area. They are included here to give an overview of the basin's soil characteristics. Gardud soils have low infiltration and high runoff rates. Doxiadis estimated that approximately 5% of the basin's total rainfall eventually flows into Rahad Lake (Doxiadis 1966 report DOX-SUD-A57). (12)

South of the main khor, vegetation is mainly composed of the Acacia mellifera Association and to the North principally the Acacia mellifera - Commiphora Association. Near Kazgeil and an area just North of it there is an occurence of the Acacia seyal - Balanites Association. Riparian vegetation occurs along the khors. Approximately 5% of the basin is covered by a forestry reserve; 10% is densely cultivated; 10% is lightly cultivated; and about 8% is an Acacia seyal production belt. (12)

Khor Tagerger Basin is used by a large, but unrecorded, number of transhumanants and nomads for grazing and browsing throughout the year. Wet season grazing is extensive and due to the large number of natural pools (rahads, fulas and turdas) forming on the pediplain. Intensive dry season grazing occurs near permanent water sources along the khors and Rahad Lake. (Doxiadis report A48 and Institute of Environmental Studies study of the Environmental Impact of the Agricultural Marketing Road). (48) (30)

Millet, sesame and groundnuts are the most frequently cultivated rainfed crops in the area. Individual crop plots range from 1-3 ha, although occasional large plots (10 or more ha) of groundnuts occur. Three-quarters of family farms range between 4-10 ha. Most farm families have donkeys and goats. Approximately 50% have cattle, 40% sheep and 15% camels. Farming is the principal occupation of nearly 85% of the heads of household in the area. Secondary occupations are animal owner (30%), gum collector (13%) and producer of charcoal/firewood (13%) (IES N. Kordofan Rural Water Supply Baseline Study). (31)

Reeves and Frankenberger note in their second report:

"The scarcity of drinking water is an important constraint on crop production since farmers are reluctant to cultivate areas where there is not a reliable water supply...

"Farmers do not have adequate water supplies in many of these villages throughout the year. Water shortages adversely affect farmers' animal husbandry patterns and force many farmers to migrate during the dry season. In addition, high water costs during the dry season seriously deplete the earnings farmers gain from crop output." (44)

The largest settlements are located near reliable year-round water sources (Table 2). However, nearly 60% of the farm households surveyed in Physiographic Zone VI (includes Khor Tagerger Basin) (Map 2) by the Institute of Environmental Studies had to walk 1.6km or more for water. Only 3% of households were located within one-half kilometer of a water point. Sixty-five percent of the interviewed households in the area spent more than an hour daily getting water, making an average of 1-2 trips. Shallow wells (near khors) and hafirs are the primary source of household water. (31)

Table 2 Distances to water in wet and dry seasons for selected villages in Khor Tagerger Basin

Villages surveyed by Reeves and Frankenberger in Khor Tagerger Basin	Distance from El Obeid	Estimated population	Distance to water point in wet season	Distance to water point in dry season
	(km)		(in minutes)	
Geifil	33	600	10-15	near village
El-Filia	40	500	10	420
Burbur	40	500	15	15
Banjadeed	23	8000	nearby	nearby
Kazgeil	43	5000	nearby	30
Umm Arada	25	1000	10	10
Umm Ramad	30	3700	nearby	nearby
Abu Hazaz	47	5000-10,000	nearby	nearby
Wardas	37	400	5-30	45
Umm Subagha	23	140	nearby	300

Source: Initial Village Survey, Reeves and Frankenberger Report No. 1, 1981. (43)

M A P 2. PHYSIOGRAPHIC ZONES USED IN NORTH KORDOFAN RURAL WATER SUPPLY BASELINE SURVEY

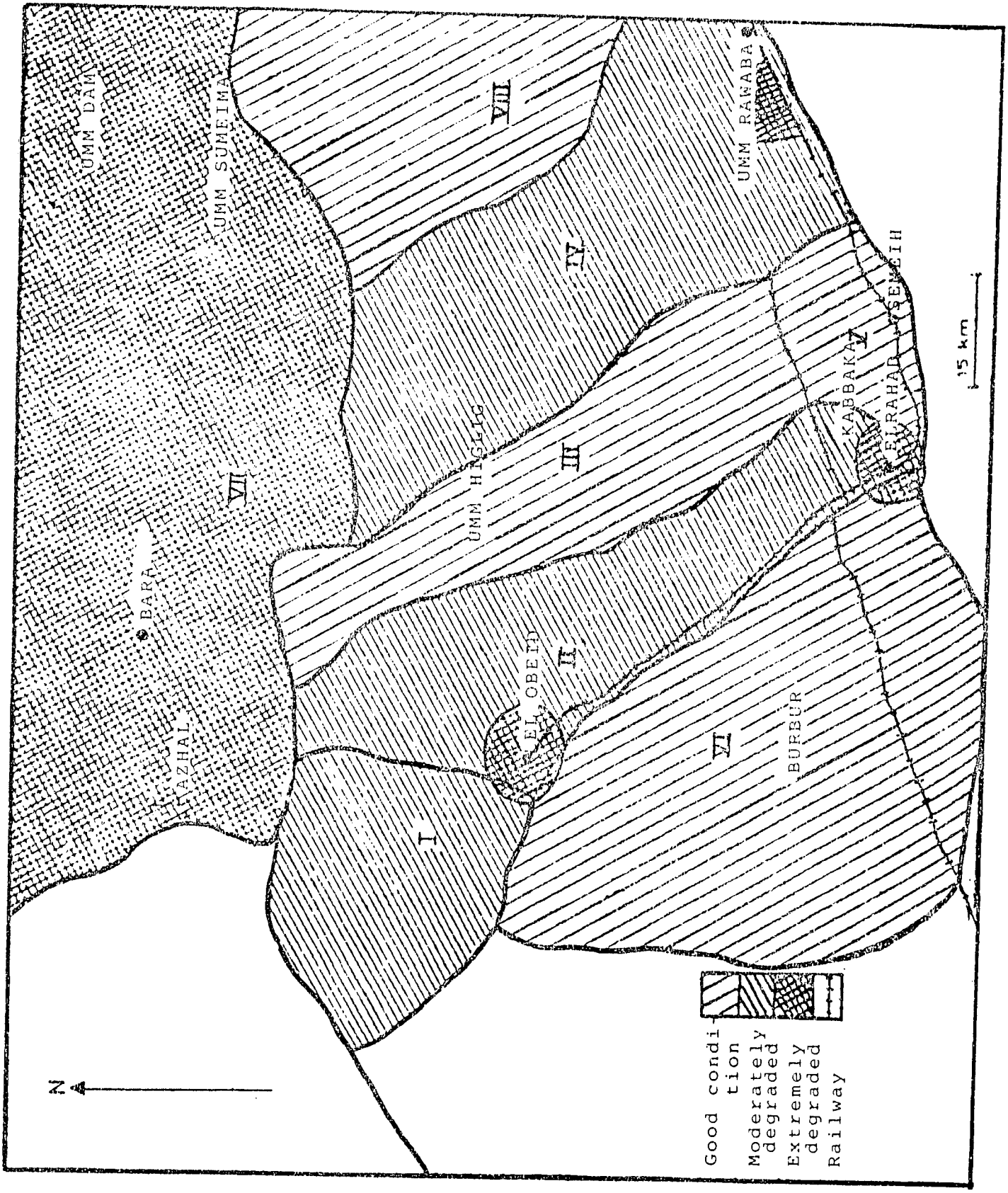


Fig. 14 Environmental Map

Source: North Kordofan Rural Water Supply Baseline Survey. Institute of Environmental Studies

Horticultural crops are grown in privately owned gardens along the khors. They are usually irrigated with water pumped from shallow wells. Extensive garden farms are found in the basin at Banjadeed (600 ha), Khor Al-Abiyad (300 ha), Er Rahad (250 ha) and Abu Haraz (125 ha). They are the main sources of vegetables, citrus, mangos and guavas in the local markets. During peak periods some of the produce is trucked to Khartoum (WSARP Reports 6 and 27). (57) (41)

The water supply reservoirs for the city of El Obeid are located in Khor Tagerger Basin. There are seven reservoirs and four impoundments with a total capacity of 9.5 million cubic meters (Table 3). (46) (3) A pipeline connects all of the reservoirs to the city's distribution system. (All were observed to be bone dry on a field trip in mid-June 1985.)

Khor Tagerger Basin encompasses all of the Kazgeil and portions of the Rahad and Abu Haraz rural councils. The latest census figures estimate a sedentary population of approximately 56,000 (H. Scott-Villiers). (It is interesting to note that this is almost exactly equal to the 1963 Doxiadis estimate of 14 persons/square km.) (11) Umm Ramad, Kazgeil, Er Rahad and El Obeid are the main marketing centers. The Western Agricultural Marketing Road is scheduled to run along the eastern border of the target area (parallel to the rail line) and when completed should greatly improve the access of villages and farms to markets inside and outside Kordofan region. (Map 3)

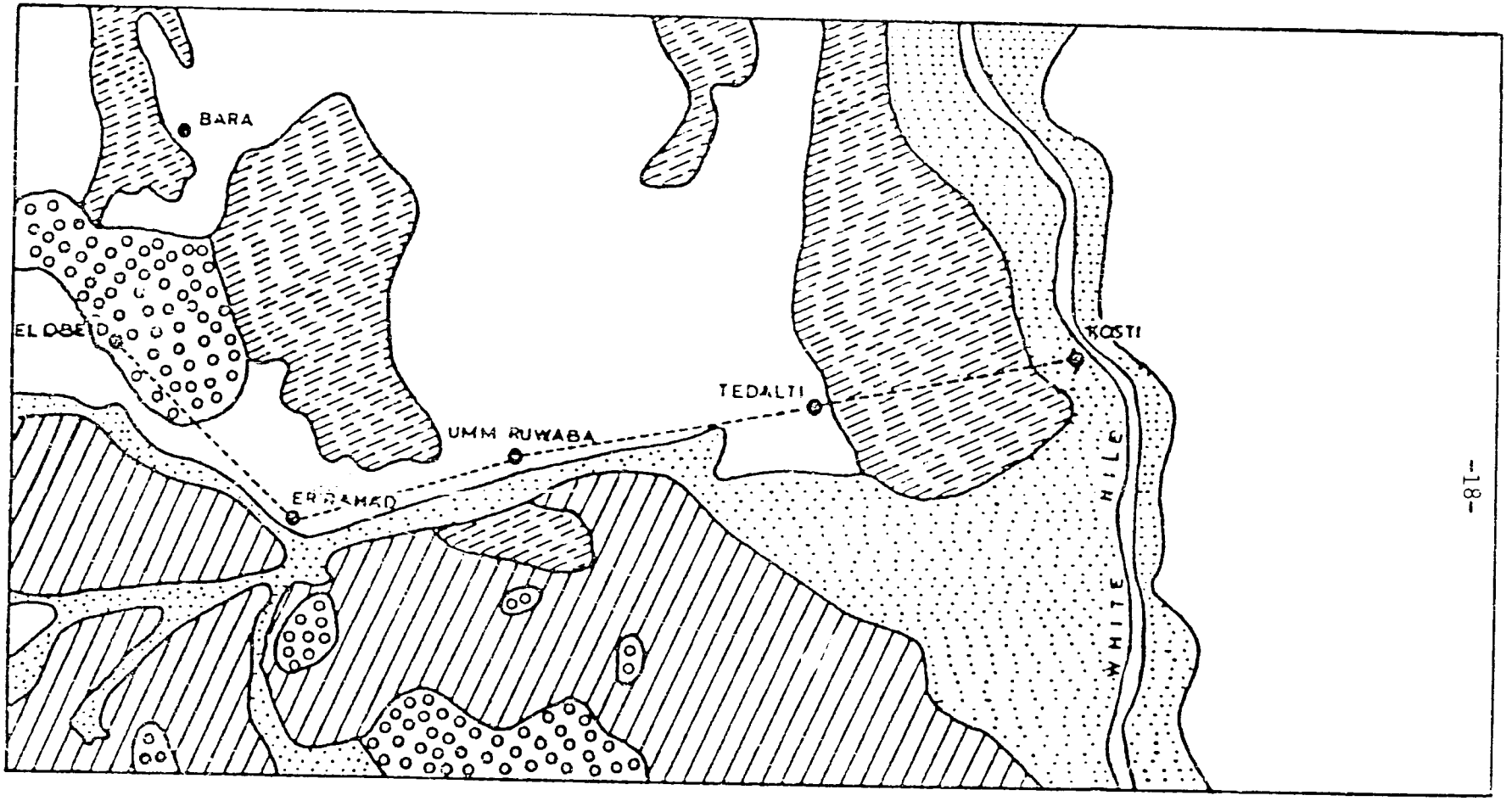
There are considerable baseline data for Khor Tagerger Basin. Doxiadis Associates issued approximately 50 reports on the water resources and agronomic potential of the area as a result of their studies from 1963-1966. (Doxiadis reports are available in the Sudan collection of the University of Khartoum Library, Shambat. Geologic soil and vegetation maps

Table 3 Current Capacity, Area and Depth of El Obeid City Impoundments and Reservoirs (Hafirs), Kordofan, Sudan

Location	Depth Max	Depth Vol/area	Area	Volume
	(in m)		(10,000 x m²)	(millions of m³)
Baggara				
Impoundment	3.0	1.9	237.8	4.54
Hafir No. 1	6.5	3.1	7.0	.22
Hafir No. 2	6.0	3.2	6.6	.21
Hafir No. 3	7.0	3.8	13.2	.50
			264.6	5.47
El Ain				
Impoundment	3.0	1.3	179.8	2.27
Hafir No. 1	7.5	5.2	8.7	.45
Hafir No. 2	7.5	4.8	8.9	.43
			197.4	3.15
Banou				
Impoundment	3.4	1.4	31.3	.44
El Obeid				
Airport impoundment	-	1.3	11.5	.15
Fula No. 1	-	6.8	1.6	.11
Fula No. 2	-	4.7	3.4	.16
			16.5	.42
	AVE 1.9		TOTAL 509.8	TOTAL 9.48

Sources: Sir Alexander Gibb & Partners (Africa), 1979, Working Paper Prior to Interim Report, Existing Sources, Management, Yield, Development and Improvement; Feasibility Study for Water Supply to El Obeid. (46)

Associated Consultants & Partners, 1985, Existing Water Supply Facilities - Rehabilitation Report, El Obeid Water Supply System. (3)



MAP 3. Proposed Alignment of Kosti-El Obeid Road

Source: Environmental Review for the Western Agricultural Marketing Road. Institute of Environmental Studies

Sand sheet

Alluvial wadi fill swamp deposits

Sand ridges and fixed dunes

Rock out crops gravels and non cracking clays

Residual clays sandy clays and graduad

------ proposed road

scale 0 20 km

of the Doxiadis study area are available from the Soil conservation and Desertification Control Unit, Kordofan Regional Govt, in El Obeid). Stajo-Export, a Czech firm, made a detailed survev of the geology and groundwater resources in a portion of Kordofan and Darfur regions in 1969-1976. Khor Tagerger Basin was included in some of their surveys. (A set of the Stajo-Export reports and maps can be found at the Khartoum Headquarters of the National Water Corporation.) The Soil Conservation, Land Use and Water Programming Administration conducted cultivation studies on the gardud soils near Banou beginning in 1967. (The results are contained in reports in the Administration's Khartoum office.)

WSARP, ICRISAT and INTSORMIL have continued agronomy trials on gardud soils at the Kaba Farm used by Doxiadis. In 1981-82 Reeves and Frankenberger, INTSORMIL anthropologists, studied the farming systems in the vicinity of El Obeid. Many of their studies took place in and around villages in the Khor Tagerger Basin (see Table 2). Berhe, INTSORMIL agronomist, has conducted on-farm research trials at several locations in the basin in 1983 and 1984. WSARP initiated on-farm horticultural trials in Banjadeed in 1983 and in Khor-Al-Abiyad in 1984. WSARP carried out several studies on gardud soils near Banou in 1984-85. (The results of INTSORMIL, ICRISAT, and WSARP studies can be found in the ARC Library at the Gezira Research Station, the WSARP Headquarters and USAID's library in Khartoum.)

The Institute of Environmental Studies of the University of Khartoum conducted and published the "North Kordofan Rural Water Supply Baseline Survey", which included the Khor Tagerger Basin. IES has conducted other studies in the region, all of which are available in their excellent library in Khartoum. Thus, the Khor Tagerger meets the criteria established for selection of a target area in which water resource interventions can be focussed.

Potential Interventions

> "It is time to stop drilling in sites simply because underground water may be available. Techniques must be found to solve the water problems of areas not having easily accessible groundwater supplies..."
>
> Institute for Environmental Studies, 1982, "North Kordofan Rural Water Baseline Survey" (31)

Approximately 49% of Sudan is underlain by basement complex and therefore does not have a good source of groundwater. The Khor Tagerger Basin presents an excellent opportunity to meet the challenge put forth above by the Institute of Environmental Studies.

> "The Regional Government would like to see, as a part of a long term planning policy, the movement of people from the highly utilized and exhausted Qoz (goz) soils in the low rainfall area to less intensively used soils further south. However this requires improvements in a wide range of conditions...(including)...improvement in water supply and in the properties of the 'gardud' soils..." (Gardud Soil Improvement Proposal, 1982) (1)

The latter may present a greater challenge than the former when one considers the properties of the gardud soils:

> "Gardud soils have finer texture (than goz soils). The clay content varies from...10...to 30 percent... Thus, they are thought to have a better potential for water and nutrient retention and, therefore, a higher potential productivity. In their present condition, however, the gardud soils are very hard and difficult to cultivate with traditional hand tools... The infiltration rate is very low. As a result, much of the rainwater is lost as runoff. The surface appears to be highly eroded and stoney in many instances. Because of lack of moisture and high mechanical impedance, vegetative growth is sparse and consists mainly of scrub type vegetation. The lack of moisture and organic matter is reflected by its hard massive structure. Available reports suggest that most of the soil profile is slightly alkaline to alkaline and that nitrogen and phosphorus contents are low." (Results of 1984/1985 WSARP Soil and Water Management/Conservation Research) (56)

The introduction of tractors is an obvious intervention and has been suggested by several consultants including Doxiadis:

> "The clayey pediplain soils of this area are variable but in general suitable for mechanized dry land farming and fodder and pasture production, and the rainfall is sufficient to sustain a good harvest. The whole setting is thus attractive for a capitalized development considering the good communication and the market proximity." (Doxiadis, 1966, Report DOX-SUD-A57) (17)

However, mechanized farming, as it has been practiced in the Sudan, is a highly capital intensive venture, beyond the resource capacity of traditional farmers. It is usually practiced on a large scale. Great swaths of natural vegetation are destroyed in preparing fields for cultivation. Introduction of vast mechanized farms on the gardud soils of the Khor Tagerger Basin would accelerate soil erosion and heighten the conflict between migrating pastoralists grazing their livestock in the basin and sedentary farmers. Recalling that there is no enforceable land/water use plan or policy in the region, interventions must be selected carefully and applied incrementally, if development in harmony with the environment is to result.

Improving the water supplies in the area also requires considerable forethought and planning to avoid the problems encountered in introducing water sources into other locations in Sudan. (42)

> In Eastern Sudan, "over-exploitation of parts of the area is becoming a major problem. It is, perversely, often a consequence of ample rather than meager water supplies. The capacity of the water points in question is the critical factor. Large water points attract dense populations and this leads ultimately to over-cultivation. Because water supplies are good, the accumulation of livestock usually proceeds unchecked and over-grazing results. In extreme cases dereliction of the land removes the means of earning a living and this, rather than scarcity of water, limits the size of settlements and may even cause decline. In contrast, where water supplies restrict the size of the settlement, the soil and vegetation resources of the surrounding area tend to be preserved through less intensive utilization." (A. Graham, Man-Water Relations in East Central Sudan) (27)

In Eastern Kordofan El Tayeb found that water production, from boreholes, was positively correlated with the number of new households established. The age of a borehole was negatively related to the carrying capacity of the range, the number of grass species and the number of trees per hectare (El Tayeb, 1981, The Impact of Water Points on Environmental Degradation, IES). (24)

Dr. El Tag Fadlalla A/Rahim, former Minister of Agriculture, Kordofan Region, said that while it was important for water-use efficiency to be raised in the basin, there should be neither an expansion of horticultural gardens (requiring irrigation with shallow well water) nor an increase in the dry season water points for livestock. He considers it acceptable to increase water availability for rainy season crop production through water spreading on alluvial soils or augmenting infiltration on gardud soils, but the growing season should not be extended. Furthermore, he stressed that sites for intervention should be chosen so that they do not interfere with water catchment areas of reservoirs, horticultural gardens, shallow wells, or hafirs.

With these considerations in mind, the following interventions are recommended:

1. Village Drinking Water Catchments and Storage Tanks

Many villages in the area require a supplemental source of drinking water. Harvesting and storage runoff from the gardud soils appears to be an excellent way of providing it. (7) (25) The catchment/storage tanks designed by Doxiadis Associates for the goz soils would not be suitable for the hard gardud soils, since they are too difficult to excavate by hand. However, their design considerations would be appropriate for both soil types. They were:

"a. The solutions should give the fullest possible stimulus to the indigenous skills and aptitudes of the people.

b. They should make the smallest possible call on the services of professional or craft-trained people.

c. They should make the maximum possible use of materials found on the spot.

d. They should make the minimum use of materials requiring to be transported to the site or bought for cash; especially imported materials requiring foreign exchange.

e. There should be a minimum of mechanical plant, especially plant which has to be bought from abroad with foreign exchange."

(DOXIADIS ASSOCIATES 1965 Document DOX-SUD-A42) (13)

Therefore, it is proposed that a commercial service company be established (or utilized) that villagers could hire to dig storage tanks with small-scale excavating equipment. The tanks would be similar to mini-hafirs. They could be lined with mud, if seepage was excessive. Appropriate local materials could be used to cover the tanks to reduce evaporation and contamination. Priority should be given, in selecting storage sites, to locations where naturally occurring pools could be deepened to increase their holding capacity. Storage tanks should be limited to the needs of the community and not made so large that they promote increased habitation or environmental degradation. (19) Provisions should be made to provide separate outlets for human and animal usage.

2. Cultivation of Gardud Soils

Gardud soils must be cultivated more extensively if there is to be any hope of reducing the pressure on fragile goz soils. Gardud soils are not homogeneous. A wide range of soil types are grouped under this general

classification. Those more amenable to cultivation should receive priority attention. Doxiadis Associates, the Soil and Conservation and Land Use Department, Western Sudan Agricultural Research Project, amongst others, have shown that gardud soils can produce good crops. However, we are a long way from understanding gardud soils, especially what makes them hard and what is the best way of making them more productive, agriculturally. Therefore, a combined development and research program is recommended. The suggested development program is described in the following paragraphs while the accompanying research program is included in the following section.

The most difficult question to be addressed is what is the best way of opening gardud soils for planting. WSARP has been evaluating the use of "seed cradles", shallow depressions in the soil approximately 10cm in diameter. The "cradles" act as microcatchments trapping water and fine soil and fostering crop establishment. The most attractive feature of "seed cradles" is that they can be made easily with hand tools. (WSARP Report No. 35 by L.M. Arya) (53) WSARP's evaluation of "seed cradles" has only just begun, so it is too early to say whether they will prove agronomically and economically successful.

Doxiadis Associates demonstrated that plowing effectively increases water intake. Ridges and furrows trap runoff and may keep the soil from reverting to its original state. The Internation Crops Research Institute for the Semi-Arid Tropics, ICRISAT, has developed a crop production system for Indian vertisols that makes efficient use of limited rainfall. (48) Alternating wide beds and narrow furrows are made across the land slightly inclined to the slope in the shape of a wide "V". The center of the "V" is open to permit runoff to flow along a grassed channel into a pond at the

bottom of the slope. Plants receive water directly from rain falling on the beds and also from runoff infiltrating into the beds from the narrow furrows. Excess runoff, estimated to be 10% of rainfall, collects in the pond and is available for "life saving" irrigation during periods when the rains are interrupted or when they cease early. The general layout of the beds in the ICRISAT system is similar to the Australian "roaded catchment" (Figure 3).

A variation of the ICRISAT scheme for vertisols is proposed for evaluation on gardud soils. Ridges and furrows across the slope at a slight angle are to be made in a similar pattern as described above. Cereal and oil seed crops are to be planted in alleys between several rows of trees, or tree-like crops such as pigeon-peas (Figure 4). Trees are to be planted along the borders of the cultivated areas and in the central drainage channel leading to the collection pond to further shelter crops from the wind and to reduce soil erosion (Figure 5). Interplanting crops between naturally occurring shrubs or trees, also, is to be encouraged, for the same reasons. A word of caution - crops produced near trees may suffer increased damage by predatory birds.

Village wood lots were once common in Sudan. The proposed scheme may be one way of re-introducing them and of helping villagers to recapture their manifold benefits. I found the staff of the Sudan Renewable Energy Project and the Soil Conservation, Land-Use and Water Programming Administration to be enthusiastic about the proposal and willing to provide technical support. The latter organization had conducted numerous studies on gardud soils and has a wealth of relevant information on gardud soil reclamation.

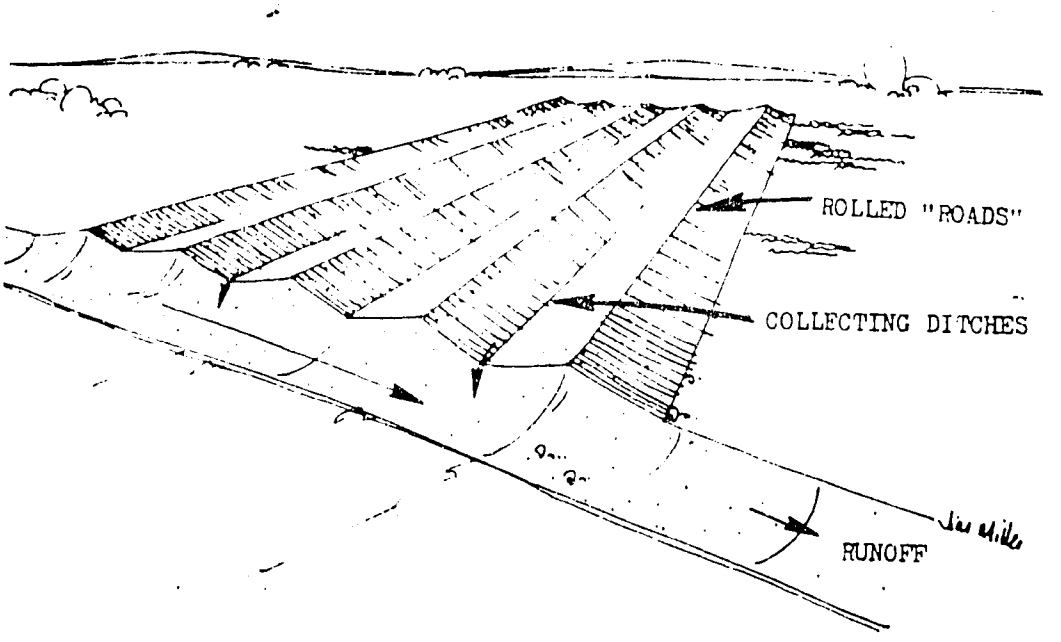


FIGURE 3 AUSTRALIAN "ROADED CATCHMENT"

SOURCE: FAO CONSERVATION GUIDE 3

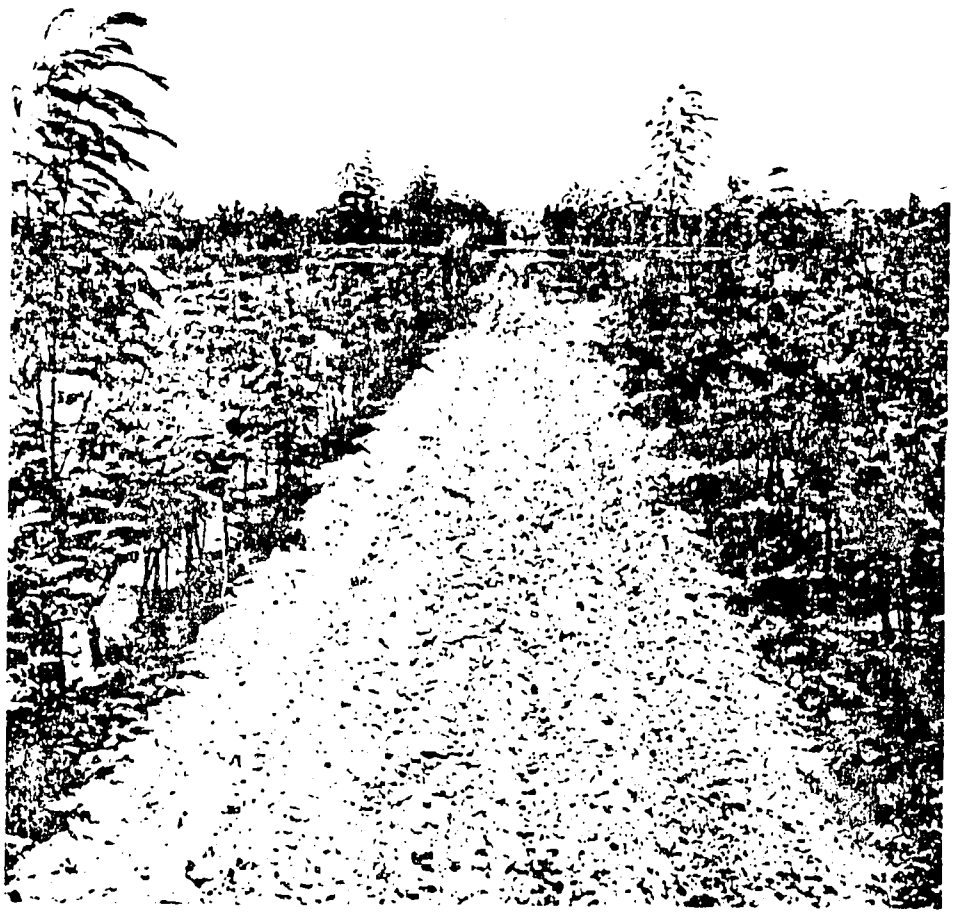
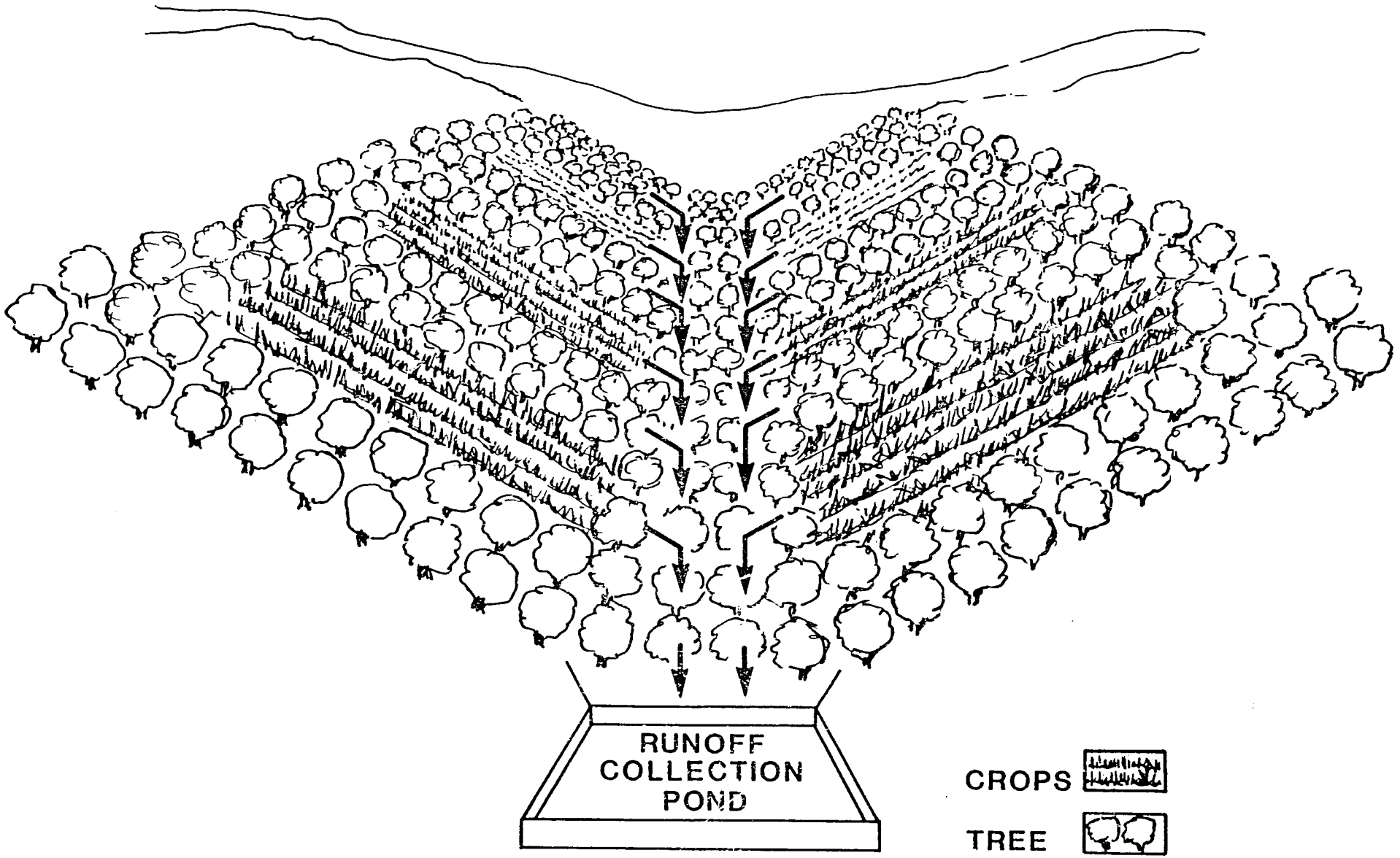


FIGURE 4 ALLEY CROPPING WITH LEUCAENA LEUCOCEPHALA

SOURCE: AT ICRISAT No. 9, JAN-MAR 1985

FIGURE 5 SKETCH OF PROPOSED AGRO-FORESTRY PLOT FOR FARMERS' FIELDS ON GARDUD SOILS. KORDOFAN, SUDAN



JJR 1 JULY 1985

I see no way of avoiding the use of tractor drawn plows to open the hardest gardud soils. Once ridges and furrows are made, farmers should be able to maintain them with hand tools for several years. Then, if necessary, tractors could be used to re-establish the ridges and furrows. It appears that the best way to make tractors available, when needed, while avoiding large scale destruction of the landscape, would be through the use of tractor service firms. *

While the program described above is aimed at bringing more soil under the plow, unless the productivity per unit area is increased, it may be impossible to check the unbridled expansion of cultivated area, which would lead to further environmental degradation and a heightening of the conflicts between pastoralists and farmers. Therefore, there is an urgent need for commercial outlets of seed, fertilizer and other agricultural inputs to be opened throughout western Sudan. Farmers will not become truly productive until they can purchase good quality seed of early maturing varieties, well suited to the harsh environmental conditions and the inputs to enable them to reach their genetic yield potential. In this regard, phosphorous fertilizer may be the single most important input in raising crop yields in western Sudan. (54) A high priority should be assigned to making it available for purchase by traditional and mechanized farms in Kordofan and Darfur in the near future.

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* The Islamic Development Company (IDC) has established the Agricultural Services Company, which in cooperation with the Agricultural Bank loans equipment to farmers. Dr. El-Tag Fadlalla A/Rahim, Managing Director, IDC, should be contacted for details.

3. Drip Irrigation for Commercial Gardens

"Water availability is one of the most limiting factors for agricultural production in North Kordofan. In some localities, however, a limited supply of underground water is available. This water is utilized for irrigating horticultural crops. Farmers pump water from open wells and irrigate by flooding. Most often the wells run dry after a few hours of pumping and a waiting period is usually necessary to get the wells recharged. The present method of conveying water via open channels and irrigating fields by flooding is highly wasteful. A significant amount of water is lost to seepage and direct evaporation. Digging channels and maintaining them and conveying water to all parts of the field is labor intensive. The amount of water that is applied is usually much in excess of what is actually needed. This causes crop diseases, promotes leaching of nutrients, and interferes with farm operations. Weeds are a serious problem, which not only occupy much of the labor force to control them, but also detract nutrients and water which would otherwise be available for plant growth.

There is, thus, a need for an efficient method of irrigation. With the drip system of irrigation, both the water conveyance and application are highly controlled. There is almost 50 percent reduction in water usage. Pumping costs are reduced accordingly. Water is delivered to the plants directly and dissolved fertilizers can be fed to the plants via drip outlets. Between row spaces are always dry so that weed growth is minimal and farm operations such as staking, picking, and pruning continue uninterrupted. Earthwork to move water from one end of the field to another is usually eliminated." (Figure 6)

(WSARP Publication No. 35 on Soil and Water Management and Conservation Program, North Kordofan by L.M. Arya) (53)

There are at least 1200 ha. of commercial gardens in Khor Tagerger Basin that could benefit from the introduction of drip irrigation. The high value of the produce should make installation of drip systems economically attractive. WSARP has installed a small drip irrigation system and found the technology to be well suited to the area. The pipes and most, if not all the parts, could be manufactured locally. However, the probable economic net benefit should be calculated prior to installation at any given location.

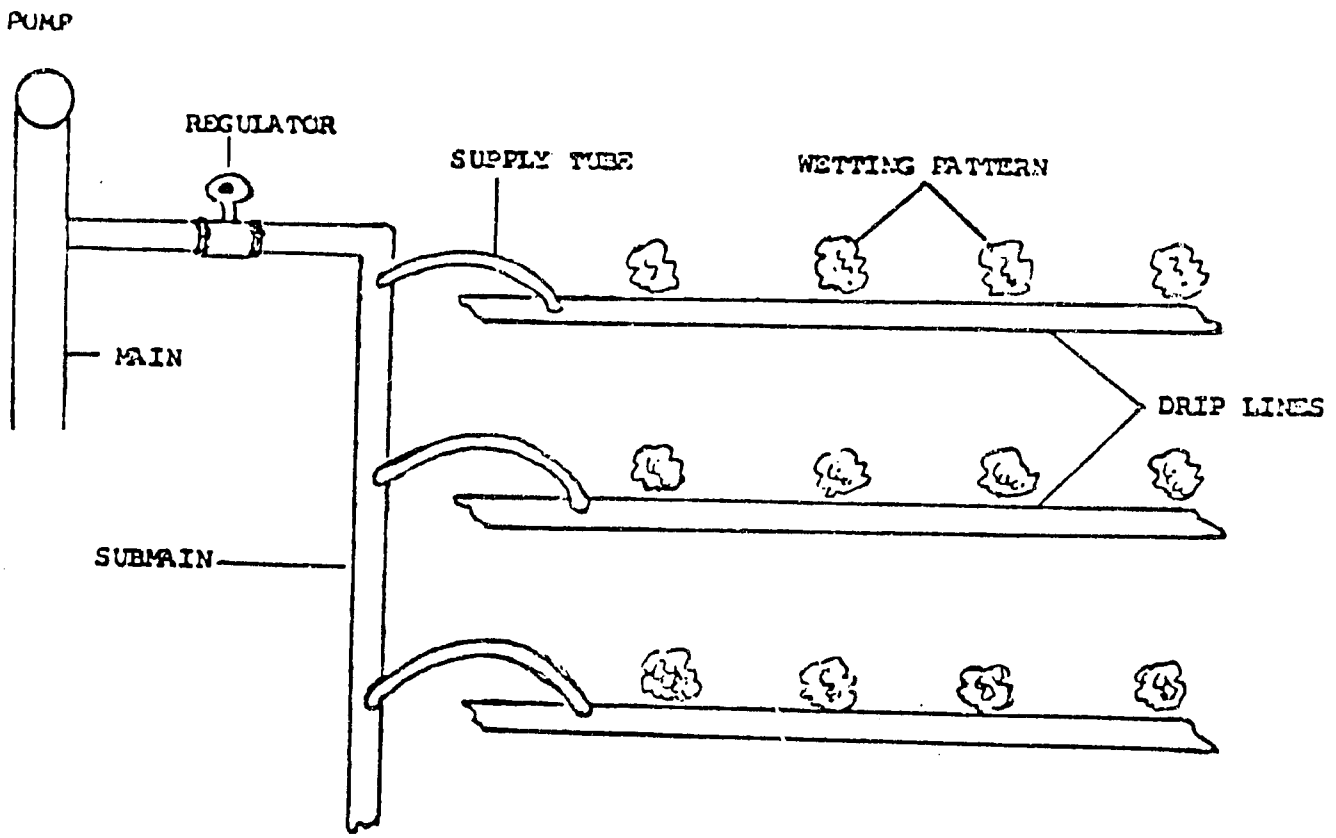

FIGURE 6 A SCHEMATIC LAYOUT OF THE DRIP SYSTEM OF IRRIGATION

SOURCE: WSARP PUBLICATION NO. 35

4. Water Spreading and Sand Dams

Water spreading is a technique in which flood water is diverted from a stream channel and allowed to flood over an adjacent land surface (Figure 7). It is an ancient method of irrigation that can be improved upon by applying hydrologic principles. The water can be used for crop production and/or for recharging shallow aquifers. (23) (10) (40) Opportunities for both uses occur in Khor Tagerger Basin.

Maintenance of the diversion dams and dikes can be time consuming, particularly in areas with frequent large floods. (23) Before implementing a water spreading project, one must make sure that the diversion of water does not interfere with current downstream uses. For example, diversion of water above Banjadeed might cause the wells supporting the horticultural gardens to run dry.

Shallow hand-dug wells along the khors in the Basin are a source of water for domestic settlements and migrating livestock. Slowing the flow of floodwaters over the alluvial beds in which the wells are dug may recharge the shallow aquifers and lengthen the period over which the wells can supply water. This may be desirable or undesirable depending on the area and the principal purpose for which the water is used. For example: A village depending upon shallow wells for drinking water would benefit from having a more dependable water supply. On the other hand, an increase in the dry season availability of water for migratory livestock may accelerate the depletion of grasses and other vegetation.

No interventions are suggested specifically for pastoralists, but in selecting the crop production interventions, consideration has been given to minimizing interference with present use of the Basin for livestock production. (42) Also, in the following section, a means of reducing the grazing pressure on northern ranges is presented for evaluation on a pilot scale.

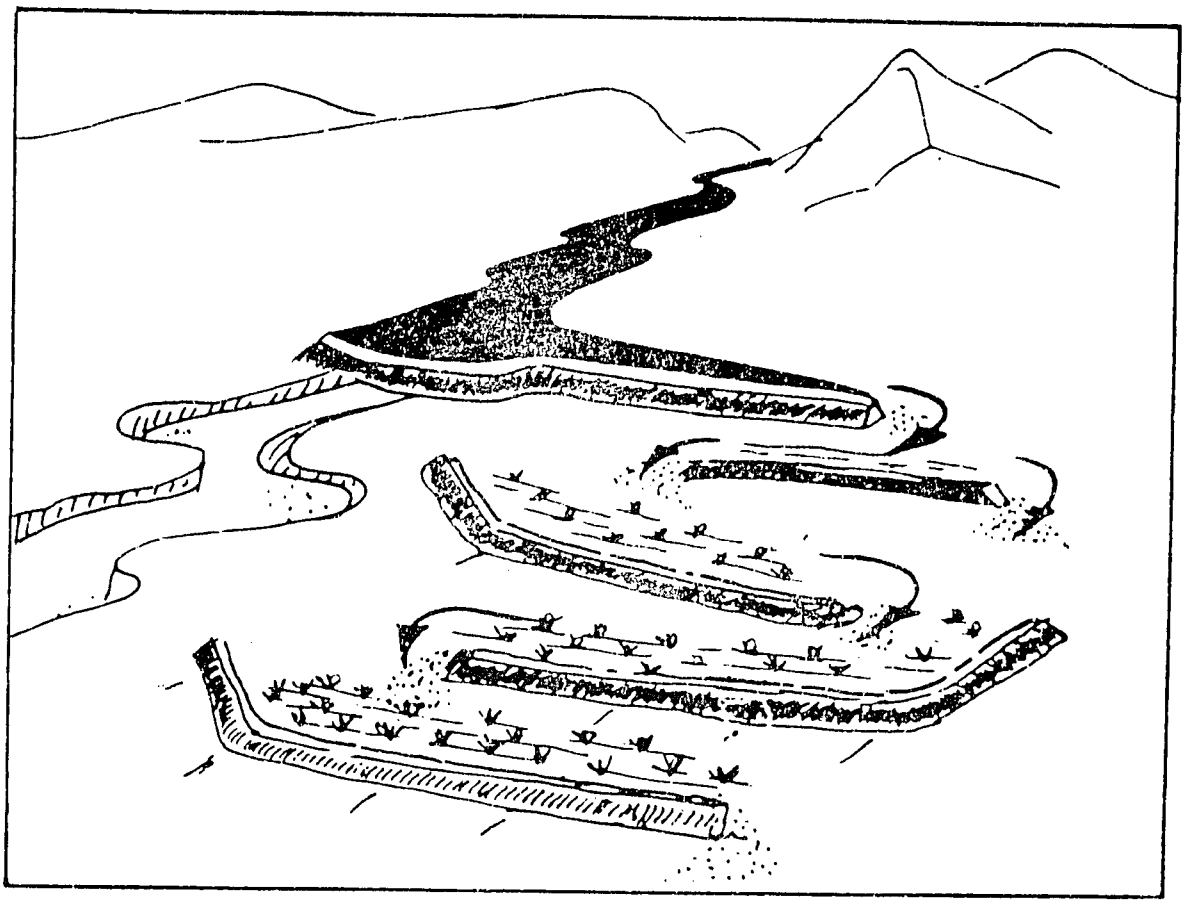

FIGURE 7 SKETCH OF A WATER SPREADING SYSTEM

SOURCE: FAO CONSERVATION GUIDE 3

> "Sand dams are reservoirs filled with coarse sand stones or loose rock. The water is stored in the pores of the accumulated bed of sand. This greatly reduces the evaporation losses of water. Water is drawn from the sand dam by a drain pipe or from a well dug into the sand bed near to the dam (Figure 8)."

(Artificial Recharge - Chapter 9 in Community Water Supplies) (28)

Sand dams are constructed in stages to insure that only coarse sand and gravel are deposited behind them. Depending on the permeability of the underlying formation, sand dams can be effective in recharging shallow aquifers as well as serving as a source of water for villages.

In Khor Tagerger Basin, sand dams may provide additional domestic water sources for communities located on minor khors where natural alluvial deposits are too shallow for hand dug wells. The dams, also, could serve to promote recharge of perched aquifers, along the larger khors, feeding shallow wells.

5. Reduction of Evaporation Losses from Open Water Surfaces

Open bodies of water in Northern Kordofan lose over 2 meters of water annually due to evaporation. The El Obeid city reservoirs and Rahad Lake evaporate as much as 6 and 20 million cubic meters of water per year, respectively. The El Obeid City reservoirs and Rahad Lake have a mean depthof around 2 meters, when full. Thus, saving one half of the evaporated water would nearly double the water available. Hafirs evaporate at the same rate as reservoirs and lakes, and similar savings could be made by reducing the annual evaporation losses.

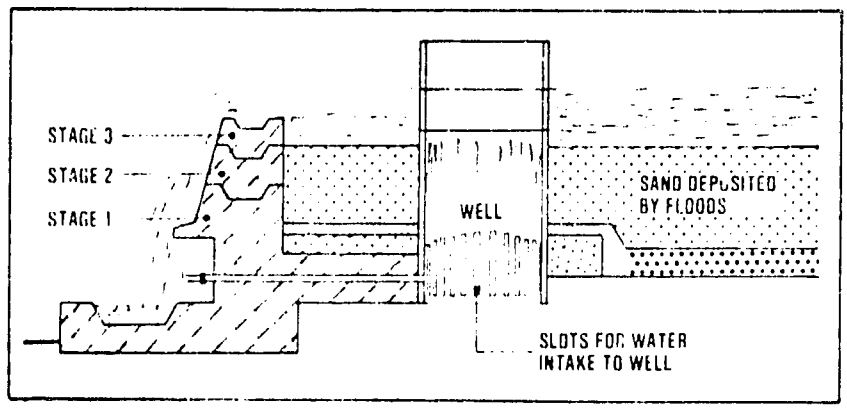

FIGURE 8 CROSS SECTION OF SAND DAM

SOURCE: COMMUNITY WATER SUPPLIES

No immediate intervention is recommended for Rahad Lake, since it appears to be under-utilized and a mechanism for recovering the costs of applying water saving technologies is not apparent. However, if the consumption of water from Rahad lake increases and/or if the inflow into the lake from Khor Tagerger is reduced by natural means or as a result of widescale application of some of the proposed interventions, the reduction of evaporation losses from Rahad Lake should be reconsidered.

In the spring of 1985, all the El Obeid city reservoirs went dry for the first time since their construction. Water was being hauled by rail from Rahad Lake and via truck from the wells in nearby horticultural gardens. Several organizations began drilling boreholes to supplement the supply from the city's existing well fields.

Some consultants have recommended the construction of a pipeline from Rahad Lake to the El Obeid city reservoirs along Khor Baggara. The reservoirs are 40km from Er Rahad and at a 50m higher elevation. The construction and pumping costs of such a venture would be extremely high and it would require several years to complete. In my opinion, alternative means of increasing the dependability of the El Obeid City water supply should be tried first. I recommend, therefore, that the reduction of evaporation from the city's reservoirs receive high priority attention. Available water could be increased significantly through the application of evaporation suppression technology and optimized compartmented reservoir management (Figures 9 and 10). (5) (6) Dr. C. Brent Cluff, Arizona Water Resources Research Center, University of Arizona, is preparing a separate consultancy report on application of these technologies to the El Obeid City Reservoir System and other locations in western Sudan.

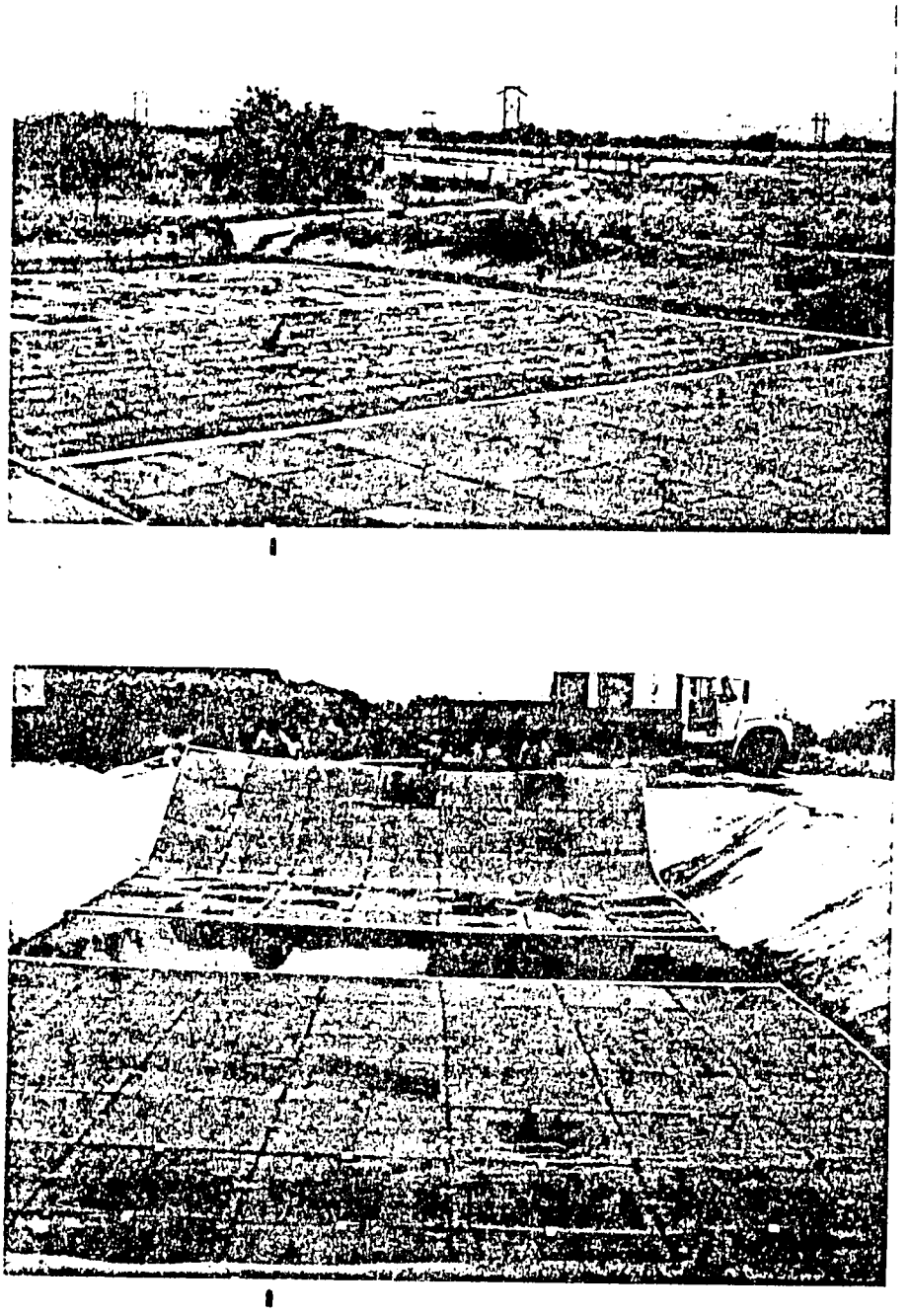

FIGURE 9 POLYSTYRENE RAFTS ON RESERVOIRS TO REDUCE EVAPORATION

SOURCE: EVAPORATION CONTROL FOR INCREASING WATER SUPPLIES BY C.B. CLUFF

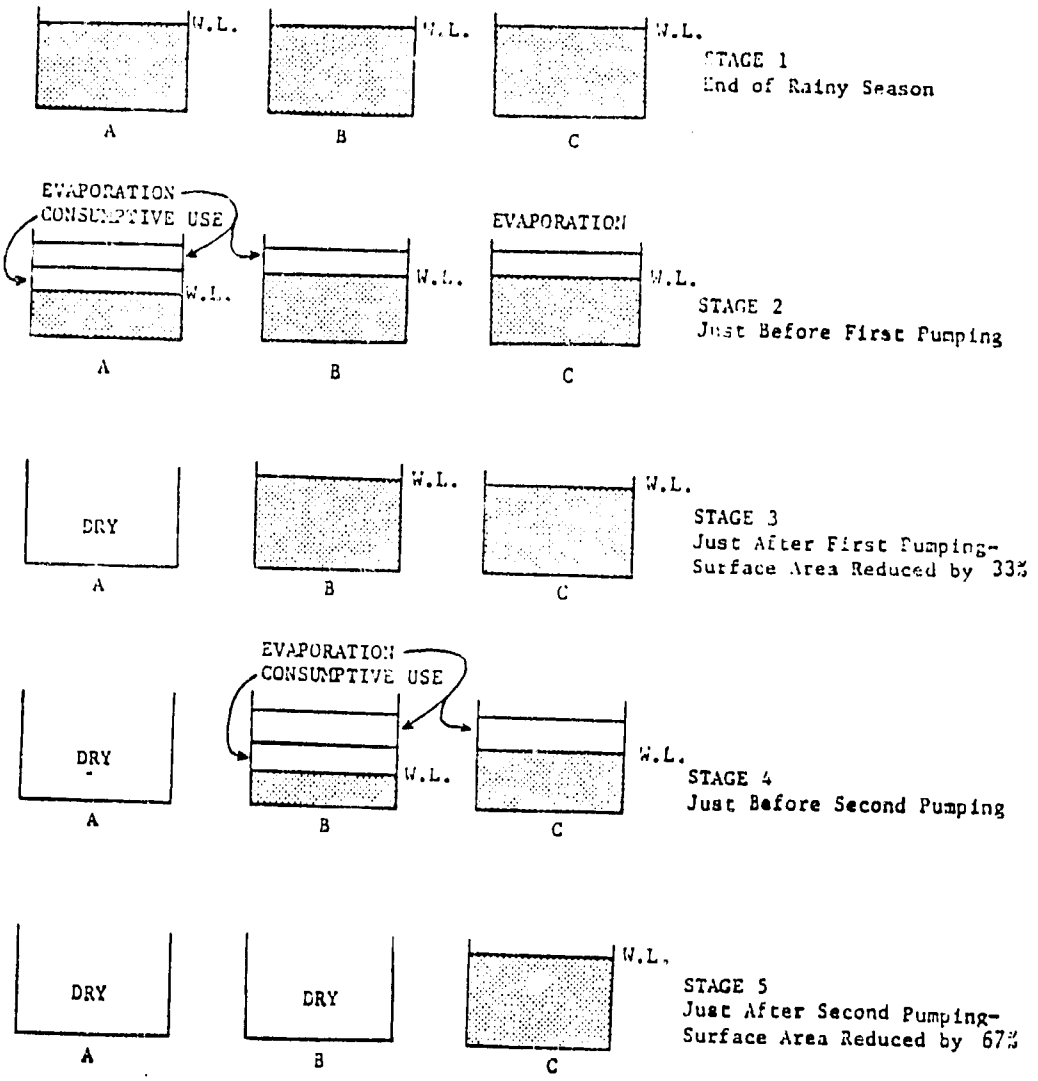

FIGURE 10 SCHEMATIC CROSS-SECTIONAL DIAGRAM OF A THREE COMPARTMENT RESERVOIR.

(W.L. = WATER LEVEL)

SOURCE: THE COMPARTMENTED RESERVOIR BY C.B. CLUFF

6. Irish Bridges for Fording Streams

Thunderstorms, that occur frequently over the Basin during the rainy season, cause "Flash Floods" which block normal transport routes for days at a time. Reeves and Frankenberger (1981) noted:

> "In the rainy season.... roads in the goz areas are usually reliable, but in the gardud areas they can be treacherous because of the many depressions and water courses that cannot be crossed after a heavy rain." (43)

The placement of rocks and cement on stream beds at crossing points, termed "Irish bridges", permit lorries to ford flooded streams with ease. The construction of Irish bridges requires primarily manpower, cement and rocks and one or more lorries to haul them. This is an exercise within the technical capabilities of the area, but, it remains to be determined whether the villagers would contribute their own labor and resources to increase their access to markets during the rainy season.

PRIORITY RESEARCH DIRECTIONS

A. Soil-Water-Plant Relations

The WSARP soil and water conservation/management program, initiated by Dr. L.M. Arya, has produced some significant results in only one complete growing season; namely:

- top layers of the goz soil dry rapidly forming a natural sand mulch which reduces further loss of water by evaporation. Consequently, the soil profile below contains readily available water for deep rooted plants (trees or crops) throughout the year;
- "seed cradles", made with hand tools, enhance crop establishment on gardud soils; and
- application of mulch to sorghum grown on vertisols doubled grain yield. * (56) (55)

The WSARP soil and water conservation/management program should continue to yield useful results, as long as the direction of research remains unchanged. Dr. Mohamed Gamal Ahmed Yonus, Technical Director, Soil Conservation Laboratory, Khartoum, suggested that WSARP should examine what makes the gardud soils hard. Once this is known, it may be possible to ameliorate gardud soil structure, which would enable farmers to cultivate these soils with hand tools. I think this is a good suggestion and should be included in the WSARP research program.

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* Initial trials used range grass, the transport and placement of which made it uneconomic. However, use of crop residues and cut weeds may bring down the cost of mulching and make it a feasible practice for local farmers.

B. Pilot Grazing Program in Southern Kordofan

The 1984-85 WSARP Research Plan for Kordofan recommends the establishment of a pilot project to explore the possibilities for increasing grazing utilization of the southern Kordofan ranges, in cooperation with transhumant pastoralists and the Regional Government. (52) The study has not yet been initiated. The proposal contained in the WSARP work plan, is included here to re-emphasize its potential importance to the management of rangelands throughout Kordofan, including those in the Khor Tagerger Basin:

> "A feasibility study for improving the utilization of dry-season ranges in South Kordofan
>
> Evaluations into rangeland productivity and patterns of resource use by the existing livestock biomass in South Kordofan indicate that only 6-10% of the net primary production is consumed by livestock on an annual basis. Relative to other regions in Africa where this percentage reaches 25-35%, the use of grazing lands in South Kordofan is clearly inefficient. This is attributed to factors related to the availability and quality of forage, such as the timing and distribution of grazing, water availability, plant palatability, and forage losses from fire, natural decomposition, wind and herbivory by small mammals and invertebrates.
>
> With regard to migratory livestock, which amount for 70-80% of the ungulate biomass in the province, grazing in the South is confined to the dry-season, coinciding at the outset with a dramatic reduction in forage abundance and quality immediately after the growing season. Declining conditions at this time are exacerbated by limited water supplies which lead to localized high concentrations of livestock, and intense competition for grazing. The outcome is a steady depletion of available forage in radiating arcs from water points as the dry-season progresses. This forces animals to travel greater distances to water and graze, causing increased energy expenditures and reduced food intake. Fires further aggravate the problem of decreasing forage supplies by annually consuming up to 30-40% of the net primary production, while also inducing undesirable changes in the vegetation. The results are collectively manifested in poor animal growth and productivity, as well as greater susceptibility to disease and mortality.

These conditions, coupled with land-use conflicts posed by expanding cultivation and the increasing inability of pastoralists to control their resource base, limit the options available for improving the productivity of migratory livestock in South Kordofan. A strategy which shows high potential for achieving this objective is the introduction of water in appropriate dry-season ranges which are currently unutilized due to the absence of water. It is estimated that as much as 30% of the rangelands in South Kordofan are unavailable for grazing because of the lack of dry-season water, and the fact that insects, disease, and mud prevent their use during the growing season. Thus, the strategic development of water offers the potential of a sound ecological and socio-economically acceptable approach for (1) improving the productivity of livestock and the efficiency of resource utilization in areas currently uninhabited and receiving little or no agricultural use; (2) providing alternative sources of grazing for migratory livestock under conditions where resource competition and land-use conflicts are minimized; and (3) developing land-use plans, in cooperation with regional and national governments, for the future integration of livestock and crops whereby the productivity and stability of these regions are optimized.

In view of the resource deterioration frequently associated with water developments, the nature of the environment and the use to which it will be subjected are critical to the long-term success of such a program. The types of areas proposed are characterized by extensive plains of cracking clays where annual rainfall averages 750-800mm. These areas are not only capable of supporting high year-round land-use pressure, but the incidence of insects, disease and mud during the rains currently precludes occupancy by both people and livestock at this time. Unless some relief from these problems is provided, which is unlikely in the near future, the use of these areas will be confined almost exclusively to dry-season grazing, when physiological damage to plants is negligible. In the event that habitation by people and animals is made possible during the wet-season, the range communities here are such that moderate to high grazing pressures in the growing season would tend to favor improvements in species composition, with little or no risk of resource deterioration. An important implication of animal-health control measures is the possible indirect effect for alleviating pressures on wet-season ranges in the more fragile North, through the attraction among producers for securing a more stable source of forage in the South.

Based on the potential for substantially improving livestock productivity and resource utilization in South Korodfan, the Kadugli Research Station is proposing a feasibility study with the regional government for introducing water on a limited, pilot-trial basis to increase the availability dry-season grazing. Such a trial would be accompanied by an improved system

of grazing management with strategic measures for animal-disease control. The latter will involve efforts to reduce the incidence of ecto- and endo-parasitic infestations which have been shown to significantly affect the productivity of livestock under both migratory and sedentary conditions.

The initial stage of the feasibility study will require (1) in-depth discussions with regional government for coordination and assistance, (2) extensive, multi-discipline oriented surveys in the evaluation of potential sites, sources of water, and the pastoral group(s) to be involved, (3) an assessment of the resources associated with potential sites in terms of a number of households and livestock which can be supported on a seasonal and year-round basis, and (4) an evaluation of the logistical and technical inputs necessary for the effective implementation and monitoring."

Excerpt From: WSARP RESEARCH PROGRAM
FOR KORDOFAN REGION 1984-85 (52)

C. Hafir Water Conservation and Management

Hafirs are an important source of water on the cracking clay vertisols in southern Kordofan and the gardud soils in northern Kordofan. UNICEF has recitified 50 hafirs in southern Kordofan and proposals have been prepared to restore others. However, no attention has been given to the conservation and management of hafir water. The WSARP research program should include studies on:

- reduction of evaporation losses using locally produced or gathered materials;
- inexpensive means of clarifying the water (hafir water tends to be muddy and unpalatable);
- integrated management of all water resources for rural families, etc.

D. Utilizing Rahad Lake Water More Efficiently

Rahad Lake, the largest body of water in western Sudan, is not being used efficiently (Table 4). A study of the current and potential use of the Lake's water should be undertaken as part of the comprehensive

Table 4. Estimated Losses and Approved Allocation of Water from Rahad Lake. Kordofan, Sudan

ALLOTTED USE	VOLUME
	Millions of M^3
Evaporation and other losses	28
Er-Rahad Town Supply	2
Semeih Irrigation Project	6 1/
Er-Rahad Horticultural Production	10 2/
Reserve	10
TOTAL	56

1/ Canal to Semeih built in 1969 not successful. Currently being used to irrigate vegetable plots near Rahad.

2/ Estimated use for 1000 Feddans (420 ha).

SOURCE: Sir Alexander Gibb & Partners (Africa) 1980 Volume IV, Feasibility Study for Water Supply to El Obeid. (47)

development of the land and water resources of the Khor Tagerger Basin. I recommend that the study team be composed of representatives from the following, plus perhaps other, organizations:

Western Sudan Agricultural Research Project
Institute of Environmental Studies
Fisheries Research Center, ARC
Soil Conservation, Land-Use and Water Programming Administration (National Gov't)
Soil Conservation and Desertification Control Administration (Kordofan Regional Gov't)
Rural Water Corporation

The study should include: preparation of a water balance for the Lake; recommendations on the best means of reducing evaporation and seepage losses; evaluation of the potential for introducing fish and development of a modest fishing industry; examination of the present validity of previous recommendations on utilization of the lake water; and development of a plan for maximizing the economic returns from the available water resources in the region including Khor Abu Habl.

Doxiadis Associates concluded that construction of a gravity pipeline or canal to Tendelti was preferable to the building of a water pipeline to El Obeid. They estimated that, in the 1960's, the Er-Rahad to Tendelti line would benefit 75,000 people along its 150km path. The water would be allocated for irrigation of high value crops. The study team should re-examine this proposal to see if it would be valid today, especially in light of the construction of a road along the proposed pipeline route.

E. Increasing the Bio-Productivity of Hafirs and Reservoirs

Hafirs and natural or man-made reservoirs represent a potential source of aquatic products that could greatly benefit the people of Western Sudan. For example, Krishnamurthy (UNICEF 1985) (33) reviewed the possibility of introducing fish into hafirs in Southern Kordofan. He concluded that hafir fish culture could produce another source of protein and possibly an additional source of income for the indigenous population. Tilapia would be the preferred species considering their ease of production and popularilty with consumers. However, in areas where schistosomiasis is endemic, molluscivorous fish might be introduced, as well, to destroy the snails which vector the disease.

Another idea worth WSARP evaluating is the possibility of introducing the floating fern, Azolla to water bodies in western Sudan. Azolla is grown in Asian paddies as a source of nitrogen for rice.

> "Azolla is one of the few ferns adapted for aquatic living; by itself it is incapable of fixing nitrogen, but in a special pouch in one of its fronds floating on the surface of the water are found colonies of a blue-green alga, generally Anabaena, which fix nitrogen in great quantities. It is not know exactly why Anabaena prefer to live in these pouches of Azolla; the organism can generally be removed from the pouch and cultured separately. What is known, however, is that nitrogen fixation and growth proceed better within the special environment of the pouch than in the world outside."
>
> A.W. Galston in
> Lumpkin & Plucknett's book
> Azolla as a Green Manure (34)

Lumpkin and Plucknett give several examples of Azolla's productivity that are relevant to western Sudan:

> "One hectare of azolla can produce 1 to 2 tons of fresh fodder per hectare per day, equivalent to 10 to 30 kg of protein per day. ... In one month one hectare of azolla can produce 6 to 8 tons of dry matter, with 540-720 kg of crude protein."
>
> "Fodder for cattle ...in Vietnam... (it) is fed at a rate of to 10 kg of fresh azolla per day. To supply this amount would require a field of 50-100 square meters of azolla per head." *
>
> "Forage for Fish Azolla is a preferred forage for many species of herbivorous fish...Grass Carp... and Tilapia mossambica." (34) (35)

Lumpkin, in a personal communication (1985) indicated that there is little chance of Azolla becoming a pest, like water hyacinth. Besides, a species of Azolla (Azolla nilotica) occurs naturally in the White Nile. It has been the attention of some preliminary studies by the Department of Agricultural Botany at the University of Khartoum. Lumpkin also said that the evapotranspiration from a pond covered with Azolla is less than that from an open pond. Thus, Azolla could help suppress evaporation while producing feed for fish or livestock. Azolla could be used, also, as a nitrogen rich organic soil amendment.

I recommend that WSARP, in cooperation with the ARC's Fisheries Research Center (based in Khartoum), look into the above mentioned possibilities, as well as other means of making hafirs and reservoirs more biologically productive.

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* Lumpkin in a personal communication said that cattle generally do not prefer Azolla, but other animals (goats, sheep, etc) find it quite palatable.

A FINAL WORD ON THE SUGGESTED INTERVENTIONS AND RESEARCH PRIORITIES

Each year Khor Tagerger Basin receives 400mm of rain over its 4000 square kilometers. This is a total of 1600 million cubic meters of water, equivalent to 2.5 days of peak flood stage flow of the Nile at Khartoum. Most of the rainfall on Khor Tagerger watershed is lost by evaporation. The challenge is to try to capture and use the water more efficiently to improve the economic welfare of the people.

The recommendations made are intended to draw on the natural and human resources of the region to increase agricultural productivity in a series of small steps in a manner compatible with the physical and social environment. All the suggested and potential interventions presented are intended to be complementary. Also, they are interrelated as they apply to the water and land resources of a single watershed. The introduction of limited small scale mechanization (2)* to supplement hand cultivation is designed to increase productivity per unit are of farms on gardud soils without interfering with pastoralists use of the Basin. Sedentary communities should benefit directly from the re-introduction of village wood lots as part of an agro-forestry system as well as reduce their cutting of native trees.

Additional use of the Khor Tagerger Basin by pastoralists is to be discouraged by not increasing the number or size of current watering points. Use of the area by livestock may decline over time, if the proposed pilot study to increase grazing on southern Kordofan ranges (B)* achieves its intended purpose.

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* Refers to recommended interventions and research priorities.

Drinking water for small communities away from khors is to be supplemented by harvesting water off gardud soils (1). Settlements, near khors which rely on shallow wells for their domestic water supply will benefit from the recharge of alluvial aquifers via water spreading or sand dams (4). In other locales, water spreading will bring new lands into production. Communities depending on hafirs for their primary water source can increase the amount of water available to them by application of known evaporation suppression technology (5). Improved hafir water quality and more efficient use of the water should result from the proposed WSARP research program on hafir management (C). Hafirs, lakes and reservoirs have the potential of becoming a source of additional protein for humans and livestock through the introduction of fish and Azolla (E).

Horticultural growers will benefit from increased water-use efficiency brought about by the installation of drip irrigation systems (3). The reduction in pumping costs, as well as the labor saved for weeding and furrow irrigation, should more than offset the increased capital cost and management requirements of the drip irrigation system.

The WSARP Soil-Water-Plant research program (A) will complement all the above recommended interventions and research thrusts. The program will generate superior means for developing and managing the whole Region's land and water resources.

The installation of Irish bridges at key points along major transport routes (6) will increase market access of farmers and pastoralists. It should enable them to better market crops and livestock during the rainy season; to purchase agricultural inputs and veterinary medicines when needed; and to buy food from urban markets during the "hungry season".

The El Obeid city water supply is to be made more dependable through the application of compartmented reservoir management theory and proven technology for reducing evaporation losses (5). El Obeid is the principal

market center for all Kordofan and much of Darfur. Insuring a stable water supply to El Obeid will benefit, not only the city's 150,000 to 200,000 inhabitants, but also, the rural populace which depend upon it as the hub of regional commerce.

The waters of Rahad Lake could serve to stimulate a wide range of economic activities that would benefit all Kordofan. The proposed study (D) should clarify the optimal use pattern to maximize its impact.

Some of the interventions and research directions suggested in this paper could be applied more widely in western Sudan, others are specific to gardud soils and the Khor Tagerger Basin. Many potential interventions have been considered and discarded as inappropriate for the selected target area. The references appended contain a wide range of technologies which may be applicable in other locations of western Sudan. The resource persons, noted in the following section should be consulted further as the proposed interventions and research programs are being implemented.

Donors should be prepared to make not short, but long term commitments towards the proposed incremental development plans. The approach suggested should yield slow, but sustainable, progress. Dramatic successes should not be expected.

DW2/mew

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WSARP PUBLICATIONS

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1	Henson/Noel	WSARP General Outline of Early Planning and Implementation Requirements	1979
2	Henson/Noel	Scope of Work for Initial WSARP Activities	1980
3	Dwyer	Consultant Report on Range-Livestock	1980
4	Henson/Noel	First Annual Report	1980
5	Henson/Noel	Summary of WSARP Planning Meeting of October-November 1980 Including Consultants Reports	1980
6	Ahmed, Dinar Geneif, Riley, Elhussein	The Horticultural Resources of the Kordofan Region of Sudan	1982
7	Henson/Noel	Second Annual Report	1981
8	Meinhart	Consultant's Report on Research Station Development	1980
9	Wilson	Consultant's Report on Livestock Production	1981
10	Bunderson	Annual Report on Range Research	1981
11	Araujo	WSARP Social Perspectives on Agricultural Research and the Southern Kordofan, Sudan: Systems of Agricultural Production Among the Nuba	1981
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13	Henson/Noel	Work Plan, Volume I: General Research Program and Plans	Oct. 1982
14	Henson/Noel	Work Plan, Volume II: Project History and Functional Structure	Oct. 1982

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15	Henson/Noel	Work Plan, Volume III: Research Plan for the Kadugli	Oct. 1982
16	McGuire	Review of Seed Program in Sudan	Oct. 1983
17	Krezdorn	Report of Visit to Sudan to Review Fruit Tree Research Program and Related Factors	Oct. 1983
18	Riley	Work Plan, Volume IV: Initial Research Proposals -- Kadugli Research Station	Aug. 1983
19	Henson/Noel	Fourth Annual Report	Aug. 1983
20	Riley	A Summary of the Darfur and Kordofan Planning Workshops	Apr. 1983
21	Nunn	Report of Visit to Sudan to Review the Organization and Development of Research Support for the WSARP Experimental Station	Feb. 1983
22	Riley	Research Program for the Kordofan Region 1984-85	May 1984
23	Cook, Runderson Fadlalla, Henson	Application of Farming Systems Research and Development to an Extensive, Sedentary Livestock Production System in Southern Kordofan, Sudan	Nov. 1983
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27	Obeidalla, Riley	Development of the Horticultural Potential of Kordofan Region of Sudan	Sept. 1984
28	Patrick	Adoption of a New Technology and Problems Encountered in a Nuda Mountain Village	Sept. 1984

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29	Cook, Bunderson Fadlalla	Range/Livestock Research Activities 1982-83	Aug. 1984
30	Patrick, Abu Sabah	The Sedentary Production System in the Nuda Mountains Area	Oct. 1984
31	Dwyer	Consulting Report: Range/Livestock Research Review and Recommendations	Oct. 1984
32	Winch	Farming Systems Research: Its Strengths and Weaknesses and the Need to Link Farm Research to Macro-Economic Circumstances	Dec. 1984
33	Henson/Noel	Fifth Annual Report	Feb. 1985
34	McDonald	Hybrid Sorghum Production in the Sudan	Jan. 1985
35	Arya	Soil and Water Management and Conservation Program, North Kordofan	Feb. 1984
36	Riley	Research Program for the Kordofan Region: 1985-1986	May 1985
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