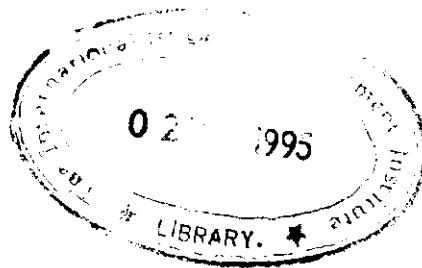


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**LIFT IRRIGATION IN WEST AFRICA:
CHALLENGES FOR
SUSTAINABLE LOCAL MANAGEMENT**



David R. Purkey
and
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INTERNATIONAL IRRIGATION MANAGEMENT INSTITUTE

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Preface

Lift irrigation in West Africa has indigenous roots with traditional technologies and management arrangements. Farmers in the region often invest in modern, pump lift technologies through indigenous credit arrangements. Lift irrigation, either traditional or modern, is generally cheaper to develop than surface irrigation (estimates are that it is often between 10 and 30 percent of the cost), its benefits can be derived more quickly and farmers have much more control over the timing and efficiency of the service. Furthermore, it does not generally require as much government bureaucracy to support its development or management.

While most agriculture in West Africa is rain-fed, the fragility of the agricultural and economic environment motivates farmers to seek to diversify their production and marketing opportunities. Lift irrigation provides such an opportunity. Nevertheless the relatively high development costs and extreme poverty in the region require a careful mix of government subsidies and support services and local financial and organizational investments if lift irrigation is to be both worthwhile and sustainable in the region.

This working paper provides an overview of the status, context and types of lift irrigation technologies and uses in West Africa. Brief case study descriptions provide insights into local interactions between physio-technical, environmental and agro-economic aspects of managing lift irrigation in the region. Research and development priorities are suggested.

Information on Niger and general comments from Kurt Lonsway of IIMI's Niger office have been incorporated into this working paper.

Lift Irrigation in West Africa: Challenges for Sustainable Local Management

David R. Purkey and Douglas Vermillion¹

1. Introduction

Irrigation development in Africa has progressed at a slower pace than in other parts of the developing world. Food security, in most parts of the continent, has traditionally been pursued through rain-fed farming systems. In West Africa, these systems are generally extensive in nature with large expanses of land planted to cereals, such as millet and sorghum, using very few inputs. In recent years, two factors have put increasing pressure on these cropping systems. First, rapid population growth of 3.2 percent per annum (FAO 1986a) increasingly limits the amount of arable land available per family for extensive subsistence agriculture. Second, recent patterns of subpar rainfall have led to repeated crop failures. These two factors alone have led to an increased interest in irrigated agriculture in the region.

Irrigated agricultural systems have existed in West Africa for generations, although they have been viewed primarily as income generating activities which supplement rain-fed agriculture. Now they are increasingly viewed, by farmers and policymakers alike, as a crucial element of a diversified rural economic survival strategy. This change in perception has prompted several recent efforts to improve the efficiency of irrigation systems and to expand the surface area under irrigation. Lift irrigation, exploiting both surface water and groundwater, has been a major focus of these efforts. In fact, lift irrigation, which includes many farmer-managed irrigation systems and systems where farmers participate in management, is increasingly preferred over the development of large-scale, strictly agency-managed, water impoundment and diversion systems.

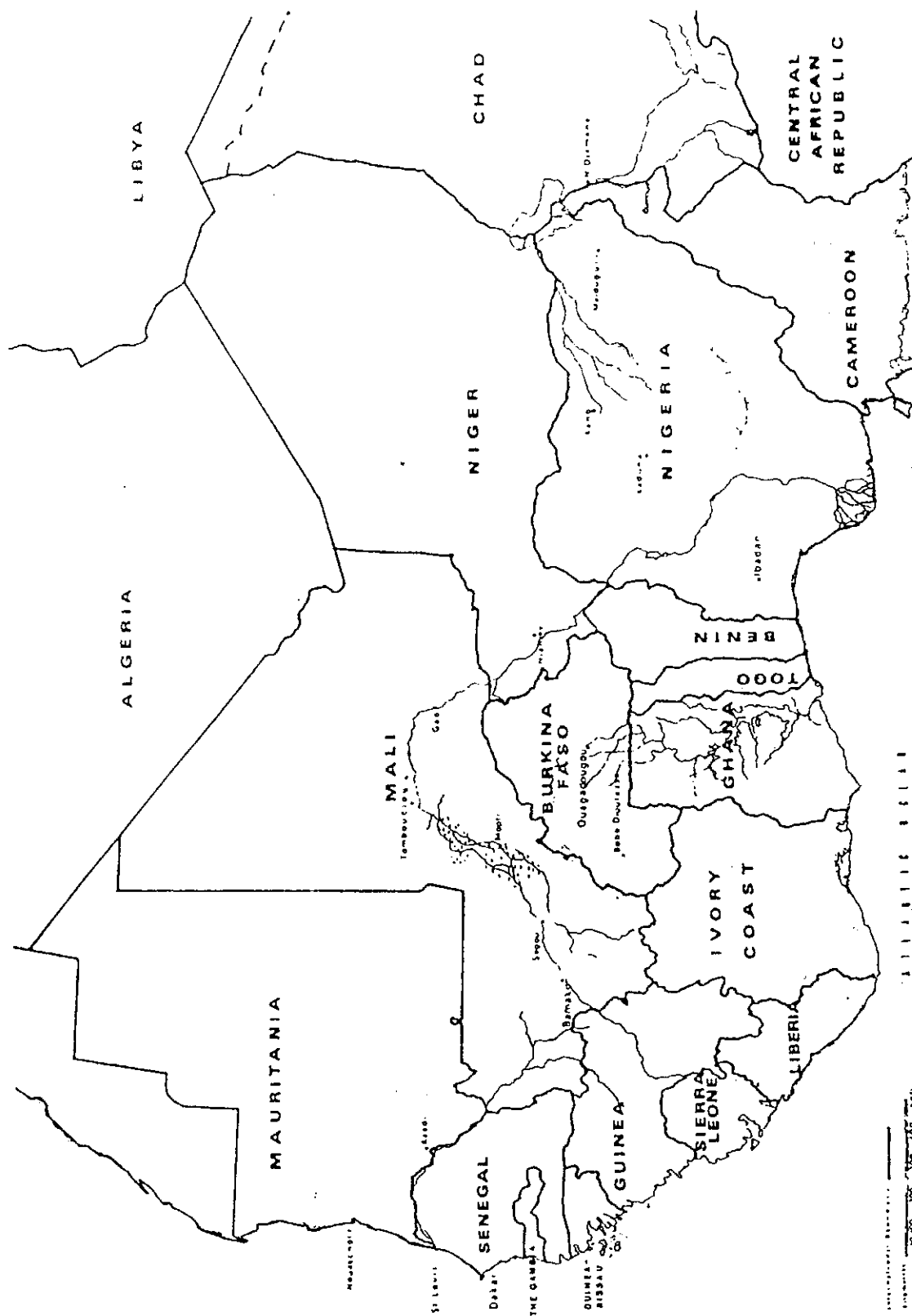
This report examines some of the salient features of lift irrigation in West Africa. It is based on the experience of the authors and on evidence available in the development literature. The document is by no means an exhaustive treatment of the subject. Hopefully, however, it will offer some insight into an emerging development strategy which offers potential to improve the quality of life of rural Africans. Both the successes and shortcomings of lift irrigation system development will be considered in the hope of providing useful recommendations for future initiatives. A special emphasis will be placed on strategies to strengthen the role of local farmers in lift irrigation management.

2. Objectives

The chief objectives of this report are (1) to characterize the current status of lift irrigation management and performance in West Africa, (2) to identify key stresses or constraints upon the sustainability and expansion of lift irrigation in West Africa, and (3) to suggest priorities for research and development action to ensure the viability of locally managed lift irrigation in West Africa. This will be accomplished by examining the technical and institutional arrangements which exist in the region. A set of case descriptions of various lift irrigation sites in the region, which reveal the variety of institutional and social arrangements in place to manage lift irrigation, will guide the examination.

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Figure 1. West Africa.



3. The Context

3.1. *Geophysical and Climatic Context*

In the broadest sense, West Africa can be defined as the great lobe of the continent formed by the westward turn of the Atlantic coastline in Cameroon (Figure 1). Extrapolating the north-south oriented Atlantic coastline below Cameroon, north to the Mediterranean Sea, yields a strictly Cartesian demarcation of the region. In point of fact, this is a good first estimate.

Nonetheless, several geographical features of the region are helpful in refining this demarcation. The most significant of these is the Sahara Desert in the north. Cutting across the western lobe from Mauritania in the west to Chad in the east, the desert forms a formidable boundary between the nations to the south, and the Mahgreb countries along the Mediterranean Sea in the north. Even today, desert crossings are the domain of nomads and adventurers. As such, it is difficult to lump the Mahgreb and West Africa south of the Sahara together for any study, including one of lift irrigation.

The second geographic feature of importance in defining West Africa for this study is the coastal Guinean ecological zone. This zone, which follows the coastline from Cameroon to Guinea, extends inland for several hundred kilometers in places. It is characterized by heavy rainfall and tropical vegetation. Irrigation, even at the smallest scale, is not common.

Positioned between the Sahara Desert and the coastal tropical belt lie the Sahel and the Sudanese zones which extend across the continent from east to west. In this zone rain-fed agricultural systems are predominant. Nonetheless, a significant amount of irrigation is practiced, though largely to supplement farmer livelihood strategies. These systems are either traditional, having been in place often for generations or modern, having been introduced in the past several decades. The majority of them can be classified as lift irrigation systems. It is in this region that the greatest variety of irrigation systems exist and where there is the most potential for irrigated agriculture to make a positive contribution to rural development.

Following these broad boundaries, and selecting countries with the significant amounts of irrigated land or systems, we have included the countries of Burkina Faso, Cameroon, Chad, the Gambia, Mali, Mauritania, Niger, Nigeria and Senegal in this regional study (Figure 1). Several small, tropical, high rainfall countries, such as the Ivory Coast, Ghana, Togo, Benin, Sierra Leone and Guinea Bissau are not considered herein because of the limited extent of irrigation found in these countries.

In this sub-Saharan, Sudano-Sahelian zone, day-time temperatures can reach 30° C and 40° C and night-time temperature 20° C and below. A single rainy season generally spans about four months, with the rain-fed growing season in the area ranging from 60 to 140 days. The mean annual rainfall varies dramatically, often significantly less than 100 mm in places bordering the Sahara to above 1,700 mm in parts of Cameroon and Nigeria. Perhaps more difficult for farmers to cope with than consistently low rainfall is the erratic and uncertain temporal patterns of rainfall both between years and throughout the year. Often, a large percentage of the annual rainfall occurs during a few sporadic days of heavy rains and can result in serious erosion and siltation. These events can be followed by weeks, even months, of drought.

Table 1 presents some typical values of climatic extremes for the countries in West Africa. The data reveal the large variability in climatic extremes both within individual countries and across the region of interest. These extremes certainly influence the practice of irrigated agriculture. In addition, however, they also influence the inclination of farmers to undertake such an enterprise. It is not a gross oversimplification to claim that in areas of higher rainfall, where rain-fed agriculture is increasingly viable, farmers are less inclined to invest in irrigation. Irrigated agriculture becomes an increasingly important element of the rural economic strategy where rain-fed agriculture is marginal.

Table 1. Typical climatic data for countries in the study area.

Country	Maximum temperature (°C)	Minimum temperature (°C)	Maximum precipitation (mm/yr)	Minimum precipitation (mm/yr)	ETP (mm/yr)
Burkina Faso	45	7	-	-	1,750
Cameroon	45	11	4,000	500	-
Chad	40	13	1,400	200	2,100
Gambia	-	-	1,200	900	2,250
Mali	-	-	1,300	<200	-
Mauritania	-	-	600	<200	-
Niger	-	-	100	400	-
Nigeria	-	-	-	-	-
Senegal	37	15	1,500	350	1,200

Source: UN 1988.

This trend is explained by data on the relative magnitude of annual precipitation and potential evapotranspiration. Table 2 compares these values for three sites in the arid Sahelian portion of the region. Here, precipitation can satisfy only a small percentage of the potential evapotranspiration. Under these conditions non-livestock related agricultural endeavors will require irrigation. As these are annual data, they lump the precipitation/ETP ratios from the wet and dry months. In some parts of West Africa, such as Ngouri, Chad, however, it has been found that during dry years the precipitation/ETP ratio can be less than unity every month of the year (ORT 1989). This includes the "rainy" months of July and August.

3.2. Water Resources and Irrigation

Table 3 displays country-averaged data on amount of water resources available from rainfall, groundwater, surface water and the total, by country in West Africa. The data reveal how climatic variations influence hydrologic conditions across the region. Nigeria and Cameroon dominate the region

Table 2. Comparison of annual precipitation and potential evaporation for selected Sahelian sites.

Site	Precipitation (mm/year)	ETP (mm/year)	Precipitation/ETP
Moudjeria, Mauritania	170	1,870	0.03
Nouadhibou, Mauritania	40	1,160	0.03
Kayes, Mali	740	1,870	0.30

Source: UN 1988.

in water availability and average rainfall, lying partially in the humid tropics. Considerable variation exists in average rainfall in West Africa since the region lies in a transition zone between the Sahara to the north and the humid tropics to the south.

Table 4 presents data on area irrigated relative to the potential area for selected West African countries. This indicates that most countries in the region have achieved less than 30 percent of their estimated potential irrigable area. The highest, Chad, has achieved 30 percent of its potential and the lowest, Burkina Faso, has achieved only 13 percent of its potential. Data for Nigeria were not included, as the country is not part of the organization which published these data. Table 4 also shows the annual rates of development of agency-directed irrigated areas for the period 1979 to 1989. Most countries show an increase in agency-directed irrigated area at an average rate of several hundred hectares per year. Senegal had the highest rate of increase, which was 1,250 ha per year while Gambia showed a decrease during the period.

Many of the agency-directed systems fall under the rubric of "modern" irrigation, which tend to rely on full water control in order to provide water to crops. This is in contrast to "traditional" irrigation which functions with less physical control of water (FAO 1986a). Based on these loose definitions, the relative importance of modern and traditional irrigation in the countries of interest has been tabulated in Table 5. The data reveal how important the less-than-full water control systems, many of which are lift irrigation systems, are to irrigation in the region.

These data can be further analyzed to approximate the importance of traditional irrigation in human terms. Assuming that one family of six individuals can farm approximately one hectare under traditional irrigation, approximately 6.5 million people in the region depend on these systems for some portion of their livelihoods. In contrast, modern irrigation, with its higher level of water control would allow the same family to farm approximately 2 hectares (ha). This translates to approximately 700,000 people in West Africa who secure a portion of their livelihood through modern irrigation. These figures offer very striking evidence of the importance of traditional, generally farmer-managed, irrigation in the 9 countries of interest.

Given the scarcity of published data for the region, it is difficult to state the exact amount of lift irrigation which exists in West Africa. A cursory inventory of irrigation in the region (FAO 1986a), however, offers a glimpse of how important lift irrigation is. The amounts of inventoried land under irrigation via water diversion and pumping in selected countries are:

- * Burkina Faso, 2,000 ha diversion, 6,700 ha pumping;
- * Mali, 107,000 ha diversion, 24,460 ha pumping;
- * Mauritania, 6,900 ha pumping;
- * Niger, 2,719 ha diversion, 11,802 pumping;
- * Nigeria, 17,300 ha diversion, 805,000 pumping; and
- * Senegal, 3,200 ha diversion, 16,800 pumping.

Table 3. Water resources and irrigation potential in sample West African countries.

Country	Area km ²	Average rainfall mm	Ground- water resources km ³	Surface water resource km ³	Total water resources km ³
Burkina Faso	274,201	898	4,324	22,829	27,153
Cameroon	475,380	1,717	15,403	117,327	132,730
Chad	1,283,942	381	46,696	36,362	83,058
Gambia	11,303	938	1,285	1,062	2,347
Mali	1,240,115	365	8,931	31,106	40,036
Mauritania	1,030,741	119	2,040	0	2,040
Niger	1,266,995	187	10,878	2,163	13,042
Nigeria	923,744	1,265	49,354	145,358	194,712
Senegal	196,200	777	14,016	11,450	25,466
Total	5,778,877		103,573	222,299	325,872

Source: FAO 1987.

Table 4. Irrigated area, area developed and cropping intensity in selected West African countries.

Country	Total irrigated area (1,000 ha)	Potential irrigable area (1,000 ha)	Potential achieved (%)	Increase in agency-directed area developed (ha)			Cropping intensity*
				1979 to 1980 period	Annual average	Annual rate	
Burkina Faso	21,250	160	13%	4,850	700	5%	75%
Chad	1,020,000	335	30%	700	70	1.5%	69%
Gambia	23,700	95	24%	Decrease		-	47%
Mali	215,000	1,000	21%	Rehabil.		-	59%
Mauritania	75,100	260	29%	9,700	970	20%	40%
Niger	77,000	270	29%	5,200	750	7%	80%
Senegal	140,000	540	26%	12,550	1,250	3%	52%
Total	1,572,050	2,660	24.5%	33,000	3,740	36.5%	60%

* Cropping intensity compared to maximum potential.
Source: Violet et al. 1991 (Data for mid-1980s).

Table 5. Relative importance of modern and traditional irrigation in the nine countries of interest.

Country	Modern (1,000 ha)	Traditional (1,000 ha)	Modern/ Traditional
Burkina Faso	9	20	0.45
Cameroon	11	9	1.22
Chad	10	40	0.25
Gambia	6	20	0.30
Mali	100	60	1.67
Mauritania	3	20	0.15
Niger	10	20	0.50
Nigeria	50	800	0.06
Senegal	30	70	0.43
Total	229	1,059	0.22

Source: FAO 1986a.

These data are not exhaustive. In addition, they do not include flood irrigation which takes advantage of the natural rise and fall of the regions' surface water bodies. Nonetheless, they serve to reinforce the conclusion that lift irrigation is a major component of the total amount of irrigation in the region. These systems certainly merit closer inspection, particularly regarding the role that the local management can play in their sustainable development and operation.

In contrast to Asia, in West Africa there has been relatively little development of large-scale, agency-managed water impoundment and diversion structures. Those that have been developed are generally perceived to have been less than successful. In fact, many believe that it is difficult to point to any large agricultural project which has made a dent in the current food crisis (ENR News 1985). As a result, a shift in approach is underway towards small-scale schemes which fit appropriate elements of modern irrigation development with traditional agricultural practices, including the integration of farmers into irrigation management arrangements.

A wide variety of irrigation systems found in the region can be classified under the general heading of lift irrigation. These range in sophistication from a farmer using a bucket to draw water from a shallow,

hand-dug well to pump stations of several hundred horsepower pumping water from a major river for several hundred farmers. There is much diversity among lift irrigation systems in the region.

The two primary types of lift irrigation in West Africa are: 1) groundwater lift irrigation and 2) surface lift irrigation systems. Further sub-divisions of these two broad categories are found, respectively, in Section 5 and 6 below. Groundwater irrigation is defined as irrigation which relies on some mechanical system or device to lift water from an aquifer developed using a physical structure. Surface lift irrigation, on the other hand, is defined as irrigation which relies on some mechanical system or device to lift water from a surface water body.

This shift has led to increased interest in small-scale irrigation projects, many of which propose development of lift irrigation systems. Small-scale irrigation is defined as irrigation of small plots of land which calls upon technologies whose operation and maintenance can be carried out by the farmers themselves (CTA 1991). This definition does not apply to all lift irrigation systems in West Africa and it is not applicable to any of the large-scale water impoundment and diversion systems.

In order to properly assess the current and potential importance of lift irrigation in West Africa, it is first necessary to characterize groundwater and river basin resources. Figure 2 presents the basic configuration of the principal watersheds in the region as well as the distribution of the major hydrogeologic units.

In terms of using surface water for lift irrigation, 3 watersheds are of particular importance to West Africa. These are: the Senegal River Basin in the west which is of particular interest to Senegal and Mauritania; the massive Niger River Basin which covers large parts of Mali, Burkina Faso, Niger and Nigeria; and the Lake Chad Basin in the east which contains surface water of importance to Chad and Cameroon. Each watershed contains several rivers with year-round flow. Lift irrigation along these rivers occurs in a myriad of forms. One of the most striking is the small market gardening which has sprung up in the vicinity of riverfront urban centers. Near Bamako and Niamey on the Niger, and N'Djamena on the Chari, farmers lift water from the rivers using any number of methods. These neatly tended farms have, almost exclusively, sprung up through individual farmer initiative. Other lift irrigation systems, such as the Office National des Aménagements Hydro-Agricoles (ONAHA) systems in Niger, rely on large pumping plants to provide water to multiple farm units.

One element of the hydrology of most West African rivers favors the more flexible farmer-managed approach. These rivers are characterized by temporarily varying hydrographs with high flow in the wet season and low flow during the dry months. This feature, combined with the minimal relief typical of much of West Africa, leads to extensive flooding. In the Senegal River Valley, some 5,000 km² of floodplain are inundated at high flow, while at low flow the figure drops to 500 km². Approximately 6,000 km² of fringe floodplain is flooded when the Niger River is at peak flow, the figure dropping by half in the dry season. Most dramatic, in the Logone-Chari floodplain south of Lake Chad, peak flooding covers some 90,000 km², of which only 7 percent remains inundated at low water (Adams 1992). In the absence of major investments in flood control structures, these fluctuations make it difficult to find sites where the large pumping stations required by agency-managed surface lift irrigation systems will be simultaneously above and adjacent to water.

As seen in Figure 1, vast areas of West Africa lie far removed from the perennial streams of the major watersheds. In these areas, lift irrigation relies on the development of groundwater for irrigation. The characteristics of the region's aquifers strongly influence the development of locally managed, groundwater lift irrigation. There are 4 principle types of aquifers in West Africa:

- * Consolidated sediments such as sandstone, schist, and shale which underlie the vast majority of the desert and savanna zones of Niger, Burkina Faso, Mali, and northern Ghana.

- * Weathered and fractured crystalline basement rock which covers portions of Burkina Faso, Ivory Coast, Ghana, Togo, Benin, and Nigeria.
- * Unconsolidated cretaceous sediments and tertiary sands and gravels of the continental shield.
- * Alluvial deposits associated with the principal river basins, coastal plains, and the Lake Chad Basin (des Bouvrie 1973).

These aquifers are by no means uniform in their hydraulic properties when considered on a regional scale. Nonetheless some general statements regarding their potential to support the development of groundwater irrigation can be made.

The second type of aquifer, weathered and fractured crystalline rock, has a fair potential to yield sufficient groundwater for irrigation development. This is due largely to the presence of a decomposed upper margin with high secondary porosities. Very often these margins are found close enough to the surface to justify their development, particularly when they lie below valleys where ephemeral surface flow concentrates and infiltrates. The typical profile in these regions has lateritic soils overlying clayey sand which grade into coarse sands. The zone of alteration lies between these sediments and the unaltered crystalline rock below and is located between 2 and 100 m below the ground surface. The decomposition of the crystalline rock is associated with paleohumidity, and thus, even in dry areas, these aquifers exist.

A large part of water contained in sediment associated with the continental shield (aquifer types 1 and 3) is probably fossil or semifossil in origin. These waters likely found their way to these formation during earlier periods of high precipitation (Quaternary). Significant development of these aquifers would likely exceed the recharge capacity and lead to aquifer dewatering. These aquifers are generally found at great depth, which also limits their usefulness for irrigation. In Niger, for example, geophysical surveys have found that they lie from several hundred to 800 m below the ground surface.

The final aquifer type, alluvial deposits, is extremely variable in West Africa. Some general comments can be made, however, regarding those associated with major West African watercourses. In many parts of the world, alluvial deposits include productive deposits of coarse sands and gravels. In general, coarse sediments are deposited by watercourses which drain zones where the material available for transport includes a large percentage of sand and gravel, and where flow velocities are high enough, as a result of steep topographic gradients, to entrain them (Freeze and Cherry 1979). Neither criteria is commonly met by West African rivers. Watercourse slopes are generally gentle, 0.25-0.5 m/km, and only rarely are extensive deposits of coarse sand and gravel common. River sediments are often fine or very fine which inhibits their ability to recharge and yield water under pumping. Yet, in places, these sediments do offer potential for irrigation development.

A second type of alluvial deposit is associated with zones of flash flooding common in Chad, Cameroon, southern Niger and northern Nigeria. These zones experience sudden heavy rainfall and concentrated runoff. Large quantities of coarse material are entrained by these floods and thus the zones are called "sand" rivers. As most of these rivers do not discharge into permanent water courses, the coarse materials are deposited in concentrated areas and the totality of runoff eventually infiltrates or evaporates. The aquifers in these zones, which are not deep, often contain significant quantities of water. The Bahr al-Gazal in central Chad and the Maradi Goulbi in southern Niger are good examples of this type of aquifer.

It must be kept in mind that aquifer properties are extremely variable, even for materials of similar origin. Local variabilities, such as the degree of weathering in igneous rocks or the clay content in sedimentary formations, can influence yields by orders of magnitude. To demonstrate this variability for

the aquifer types described above, aquifer yields have been compiled in Table 6 for several water-bearing units in West Africa. To put these figures in context one can assume a potential evapotranspiration rate of 10 mm/day. This is not unreasonable for the arid Sahelian regions of the region. If a farmer lifts water for 8 hours at a rate of 1.0 m³/hr, 8 m³ of water would be available for irrigation. If the farmer's irrigation system operates at 60 percent efficiency, this volume would permit the irrigation of approximately 500 m² of land.

Clearly, most of the water-bearing units in the region have yields in excess of 1.0 m³/hr. Thus, it seems that in much of the region irrigation is limited by a farmer's ability to lift water and not by attainable aquifer yields. If such irrigation is to be sustainable, however, care must be taken to assure that the amount of water withdrawn from the aquifer does not exceed the aquifer's rate of recharge. This is a function both of the rate at which farmers are extracting water and the number of farmers who are using the resource.

Making regional generalizations about groundwater quality is even more tenuous than speculating about aquifer hydraulic properties. Any groundwater irrigation development should include a detailed water quality investigation. This being said, two general comments can be made regarding groundwater quality in West Africa.

Table 6. Aquifer yields for selected hydrogeologic formations in West Africa.

Material	Location	Yield (m ³ /hr)
Sandstone	Cameroon Senegal	10-20 15-120
Limestone	Mauritania Senegal	0.1- 1 4
Schist	Mali Mauritania	0.5 20
Gneiss	Mauritania Burkina Faso	1 1-4
Granite	Chad Burkina Faso	2 1-4
Continental shield	Mauritania Mali	1-4 50-100
Aluvium	Mauritania Cameroon	10 10-80

Source: UN 1988.

- * The fossil and semifossil waters contained in the sediments of the continental shield, are often of marginal water quality. In fact, wells tapping these aquifers are preferred by pastoralists for the salt they provide their livestock.
- * Groundwater associated with "sand" rivers is generally of very high quality and can be assumed appropriate for irrigation development.

Due to the small amount of industrial activity in West Africa, it is generally safe to assume that groundwater quality has not been degraded by industrial pollutants. Agricultural chemicals are also used sparingly in the region and as such pose no real threat to irrigated agriculture. Only in the vicinity of urban centers might fecal contamination be a problem.

3.3. **Agriculture**

The most important irrigated crop in West Africa is rice followed by other cereal crops. Other commonly irrigated crops are maize and vegetables. Wheat is sometimes irrigated in northern Nigeria. Millet and sorghum are important rain-fed crops. Table 7 shows the irrigated areas planted in different crop categories. Together, rice and other cereal crops accounted for 87 percent of the total irrigated land use in selected West African countries during the mid-1980s. Table 8 displays data on yields of selected crops in the region. It shows a consistent improvement in yield for rice from flood-recession or bottom land irrigation to irrigation under partial control (supply) and finally to irrigation under full control (supply and distribution). The yields for rice are reported to exceed an impressive 4 tons/ha for full control irrigation in most of the countries. The last column in Table 4 indicates average cropping intensity data for selected countries in West Africa. The cropping intensity figures are relative to estimated maximum potential, which in some cases is one crop and in others two crops per year. The overall average for the region is about 60 percent achievement of cropping intensity potential. Niger has the highest performance, with 80 percent achievement and Mauritania has the lowest achievement of potential, with 40 percent.

Another data set which provides insight into the relative importance of various irrigated crops in the region was developed by the FAO (1986a). As part of an inventory of existing irrigation systems, surface areas planted to various crops were tabulated. These data were not inclusive for any country but they reinforce the emerging picture of a cropping pattern revealed in Table 7. The inventoried surface areas are:

- * Burkina Faso, sugar 3,900 ha, vegetable 2,925 ha, rice 1,875 ha;
- * Mali, rice 117,450 ha, sugar 20,500, wheat 9,000 ha, vegetables 8,860 ha, cotton 2,350 ha;
- * Mauritania, rice 21,650 ha, coarse grains 1,250 ha;
- * Niger, vegetables 4,850 ha, coarse grains 3,739 ha, rice 3,620 ha, cotton 985 ha;
- * Nigeria, vegetables 490,000 ha, coarse grains 415,000 ha, rice 5,300 ha; and
- * Senegal, rice 93,450 ha, sugar 5,000 ha, vegetables 1,550 ha.

Table 7. Crop areas as percent of total irrigated agricultural land and agricultural use of irrigated lands in selected West African countries.

Country	Rice	Other cereals	Market garden crops	Fruit crops	Sugar-cane	Industrial crops	Total (100%)
Burkina Faso	65	3	13	1	18	-	100
Chad	16	78	2	-	3	1	100
Gambia	97	-	3	-	-	-	100
Mali	82	16	0.5	-	1.5	n.s.	100
Mauritania	24	72	4	-	-	-	100
Niger	30	33	31	-	-	2	100
Senegal	41	46	6	-	5	2	100

Source: Violet et.al. (Data for 1986-89).

The diversity of irrigated crops reflects the diverse notch which irrigation fills across the region. The production of coarse grains is generally intended either as a hedge against future rain-fed crop failures or as an attempt to fill familiar nutritional requirements following a poor rain-fed harvest. Vegetables are almost exclusively grown for fresh marketing. With the notable exception of a Nigerian tomato paste industry, very little processing of these products takes place. They are generally viewed as a cash crop and are produced and marketed privately. Most rice, and almost all cotton and sugarcane are grown as part of government-sponsored agro-industrial initiatives. Production of these cash crops is often stimulated through government-sponsored subsidies and credit arrangements. Farmers often view them as a way to supplement income when they lack capital, although they often resent the stipulations placed on production by the agro-industrial enterprises.

Table 8. Yields of main irrigated crops (t/ha) in selected West African countries.

Country	Rice			Wheat	Maize	Onion	Potato	Tomato	Sugar-cane
	Total control	Partial control	Bottom land						
Burkina Faso	4	2	0.6	4.5	-	10-30	10-20	-	80
Chad	2.5-4.8	1.5-2.6	-	-	-	-	-	-	-
Gambia	4.5	-	0.8-1	-	-	-	-	-	-
Mali	5*	1.4							
Mauritania	4.3	-	-	-	1.4**	10	10	10	-
Niger	4.2	-	-	2.1	1.5-3	25-35	7-10	-	13
Senegal	4.5	-	1.1	-	-	-	-	18-27	106

* Yield falls to less than 3t/ha where two crops a year are grown.

** Yield of improved flood recession sorghum (R'Kiz) reached 2.8 t/ha.

Source: Violet et al. 1991 (Data for mid-1980s).

3.4. Social Context

The people of the Sahara are largely nomadic. Those who are sedentary live in communities built around oases which thrive mainly on commerce. At some of these oases, such as Faya Largeau in Chad or Bilma in Niger, the volume of water coming from springs permits the development of irrigated agriculture, primarily for dates. These systems are, however, limited in their current extent and their potential for expansion. In addition, they are largely gravity systems and as such as are outside of the purview of this report.

The inhabitants of the coastal regions are mainly sedentary farmers, but their production systems are primarily rain-fed. The principle culture is cassava which is not necessarily an irrigated crop. In addition, food gathering is practiced. What irrigation does exist, is oriented towards the production of market vegetables. Although these irrigation systems are commonly lift systems, the scale of the activity and its importance relative to other agricultural activities are minor.

The French were the main colonial power in the Sahel between the inlet of the Senegal River and the Lake Chad Basin. As a result, Chad has much in common with its francophone Sahelian neighbors to the west and is a member (along with Niger, Burkina Faso, Mali, Mauritania, Senegal, The Gambia, Guinea Bissau, and Cape Verde) of the Permanent Inter-State Committee for Drought Control in the Sahel (CILSS). Although it lies to the east of the line defining West Africa, Chad will be included in this study, partly because of the importance of the Lake Chad Basin in the region.

The per capita GNP in the region is about the lowest in the world. In 1987, it was at or below FCFA 70,000 (US\$200) per year in Burkina Faso, Chad, Mali and Gambiar while Niger had a 1987 annual per capita GNP of about FCFA 91,000 (nearly US\$300) and the corresponding figure for Mauritania was about FCFA 151,000 (US\$400), partly because of mineral resources. In 1987, 87 percent of the population of these Sahelian countries depended almost entirely on agriculture for their livelihood.

4. Evolution of Lift Irrigation in West Africa

4.1. Importance of Lift Irrigation

It is difficult to know exactly how lift irrigation in West Africa is developing relative to large-scale gravity systems, except that there are indications that it is developing faster than surface diversion systems. Most available data on irrigated surface areas do not distinguish between the two types of systems, nor do they offer a great deal of insight on how these surface areas have changed over time. Nonetheless, Table 2 contains some evidence to document this evolution in selected Sahelian countries (Violet et al. 1991). The data, particularly on the private systems side, must be viewed cautiously. Still, the increases are large enough to confidently assume that private systems, most of which are lift systems, are becoming increasingly important.

Circumstantial evidence to support this conclusion is readily available. The World Bank is expected to soon fund a Private Irrigation Development Project in Niger, which is designed to stimulate the development and use of tubewell/motor pump lift irrigation systems. In Chad, USAID is financing several small-scale groundwater irrigation projects and has phased out financing of the one gravity-fed system it had been supporting. Even in Nigeria, a country where significant investment continues in large-scale systems, it is recognized that quicker results (compared with large-scale systems), in terms of increased production, are obtained through promoting the small pumpset technology that produce fewer social problems (FAO 1991).

This evolution is undoubtedly accelerated by the relative cost of developing small-scale lift irrigation versus large-scale schemes. A significant cost difference has been recognized for some time. Twenty years ago, des Bouvrie (1973) noted that the development of groundwater for irrigation is financially competitive with irrigation relying on full control of surface water. At that time, he quoted per hectare development costs of US\$55-US\$230 for groundwater irrigation and from US\$400 to US\$2,500 for surface diversion irrigation. He pleaded that groundwater irrigation should thus receive more attention for development.

More recent analysis reconfirms these earlier findings. Violet et al. (1991) produced the following cost estimates for various types of irrigation in the Sahel.

- * Agency directed large-scale pump systems (US\$20,000-US\$32,000/ha);
- * Agency directed large-scale gravity systems (US\$6,667-US\$10,667/ha);
- * Village-based pump irrigation systems (US\$4,000-US\$8,000/ha);
- * Private groundwater irrigation systems (US\$800-US\$1,600/ha); and
- * Improved traditional irrigation systems (<US\$800/ha).

Given the increasing demands on shrinking, or at best nonexpanding, development funds, and the historically poor performance of large-scale irrigation systems in West Africa, it is easy to see the rationale for the shift in priorities towards life irrigation.

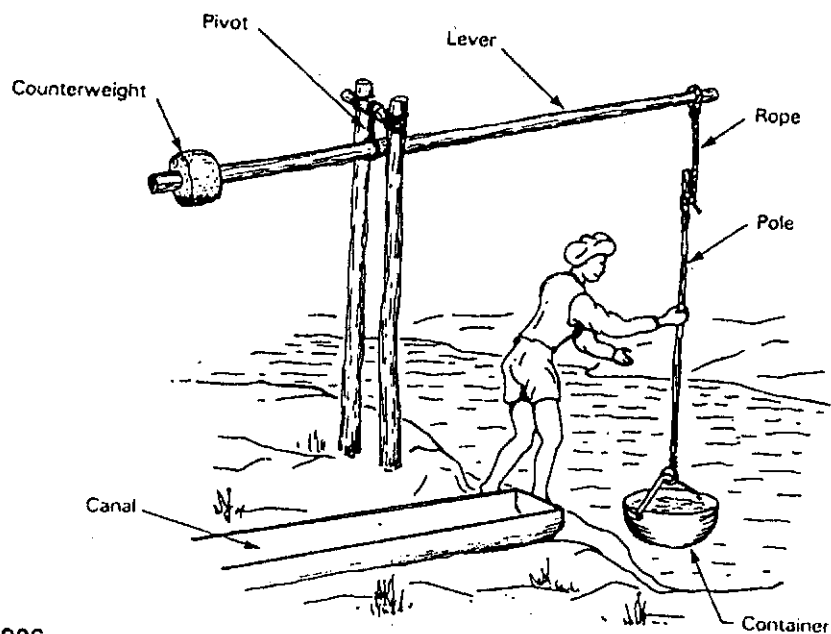
4.2. *Traditional and Modern Lift Irrigation Technologies*

Both groundwater and surface lift irrigation systems in West Africa rely on the same battery of technologies to lift irrigation water from source to field. This section presents the most common of these technologies in a general context. Their specific application to pumping either groundwater or surface water will be discussed in Sections 5 and 6.

Water lifting technologies employed in West Africa cover a wide range of technical sophistication. The degree of sophistication influences the cost of the technology as well as the volume of water available for irrigation. The following discussion presents the salient features of water lifting technologies used for lift irrigation in West Africa, beginning with the least sophisticated. Figures 2-5 are drawings of some of these technologies. Other, less common, pumps are not discussed. Work by the Institut Technologique DELLO (1991a and 1991b) was used in developing this section of the report.

Rope and bucket arrangements. Rope-and-bucket or rope-and-bag techniques are the simplest, and most common water-lifting systems in West Africa. The most simple are receptacles, tied on the ends of ropes, raised and lowered by hand to draw water from wells (Figure 4). In some systems, pulleys and other simple machines are employed to increase the efficiency of water lifting. Receptacles used in rope-and-bucket arrangements include hollowed out half gourds, leather and rubber bladders and plastic and steel buckets. Discharges provided by rope-and-bucket arrangements vary as a function of the volume of the receptacle and the distance over which it must be lifted. The cost of the technology is minimal, generally not exceeding US\$10 for the recipient and some locally manufactured rope.

Figure 2. The "shaduf" counterpoise lift, West Africa.



Source: FAO 1986.

Figure 3. Shaduf lifting water out of stream, Northern Nigeria.



Source: Samaru 1981.

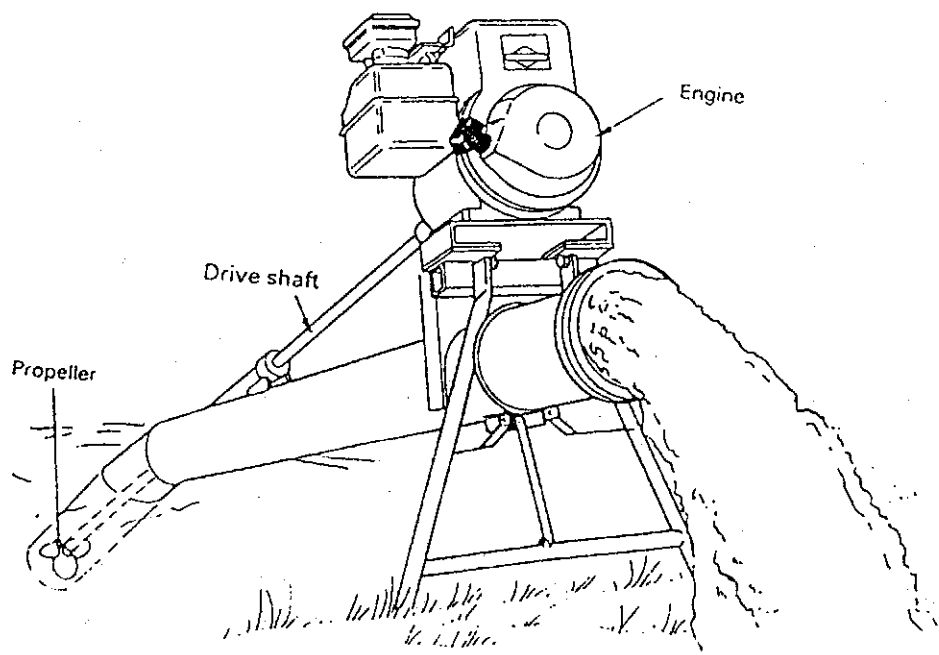
Figure 4. Using rope-and-bag to lift water from a dug-well, West Africa.



Source: FAO 1986.

In some parts of southern Niger, a half-gourd tied to the end of a rope is the chief traditional water-lifting device for irrigation. In the Tarka Valley, where the water table lies only 2-3 meters below the ground surface, the rope-and-bucket provides a discharge of approximately 0.5 a/s and permits irrigation of up to 0.2 ha. Another common rope-and-bucket arrangement is the *shaduf* (Figures 2 and 3). The *shaduf*, common in northern Nigeria, Southern Niger, and Chad, is a counter-weighted lever which assists a farmer in lifting water from deeper wells. The discharge of the *shaduf*, at a depth to water of 2.0 m, is approximately 1.5 l/s, allowing for irrigation of 0.37 ha. In Chad, the cost of the *shaduf*, assembled at the well site is approximately US\$40.

Figure 5. Portable axial flow pump, example of one type of surface lift irrigation technology.



Source: FAO 1986.

Manual devices. Manual water-lifting devices, commonly used for domestic water supply, are occasionally used for irrigation. In fact, many attempts have been made in West Africa to introduce manual water-lifting devices as an appropriate technology for irrigation. Unfortunately, recent experience reveals that they are generally more expensive than rope-and-bucket arrangements without providing significantly greater discharges. This limits their usefulness for irrigation. The most common manual device used for irrigation is the Burkinabe pump. This suction piston pump, which uses a locally crafted leather suction cup, can be installed either on a hand-dug well, a tubewell, or an open water source, although in most cases the water source does not generally effect the yield. At a depth to water of 2.0 m, the pump had an approximate yield of 1.2 l/s and allowed for irrigation of 0.3 ha.

The rower pump and treadle pump are modifications on the Burkinabe pump which allow for the use of different major muscle groups during water lifting. Although they do provide greater discharges, approximately 1.5 and 2.0 l/s respectively, they are more costly to purchase and complicated to install and maintain. Mechanical problems, and the cost of resolving them, are thus of greater concern. In Chad, little interest in these pumps was expressed after a period of field testing.

The rope-and-washer pump is a positive displacement pump which offers a higher instantaneous discharge than either the rope-and-bucket arrangement or the Burkinabe style pumps. At 2.0 m depth the pump yields approximately 1.8 l/s and can irrigate up to 0.43 ha. The technology is very simple for farmers to understand and thus repairs are not problematic. Operation of the rope-and-washer pump is very tiring, however, and thus in the long-term, the time average discharge is not significantly greater than to devices previously mentioned. Farmers usually have a very good initial reaction to the pump, followed by a period of disillusionment.

The diaphragm pump is another pump which is impressive to farmers early on but which soon loses its luster. The attraction in the case of a diaphragm pump is the ease of operation resulting from its design. There is very little friction in the system and thus it is not tiring to operate. Unfortunately, the discharge yielded by the pump, approximately 1.5 l/s at a lift of 2.0 m, is not significantly better than rope-and-bucket arrangements and thus the higher cost becomes a serious drawback.

Animal traction devices. Using the power provided by draft animals for water lifting is an attractive alternative in areas where there is a tradition of using animal traction. The nuances of using an animal for power, particularly related to the harnesses employed and the care and maintenance of the animal, make it somewhat difficult for the inexperienced to profit from animal traction. Those who have used animal traction for land preparation and transport, however, have been able to adapt their experience to water lifting.

The *delou* is a traditional animal traction water lifting device which has been perfected in Niger. This device employs a self-emptying leather bladder which is pulled from the well by an animal walking back and forth along a path leading away from the well. The technology yields approximately 2.0 l/s at 2.0 m of lift, although the technology is particularly well suited for conditions where the depth to water limits the usefulness of manual pumps. The *delou* has been updated using more modern materials and is called the *bidon verseur* (pouring bucket). This device costs significantly more than the simple *delou* but it also yields a greater discharge. The flow pump, a rope-and-washer pump adapted for animal traction overcomes the tiring nature of operating this pump manually and offers a discharge of approximately 2.5 l/s at a 2.0 m lift. In shallow water-table conditions, the Persian wheel or *naria* yields impressive discharges, 1.5 l/s, and has proven very reliable. A secondary advantage of an animal traction water-lifting device is that the animal can be trained to be led by a child. This frees the farmer from the task of water lifting and allows him to concentrate on other agricultural practices or activities.

Internal combustion pumps. There are two main power sources for internal combustion engines; gasoline and diesel fuel. Generally, gasoline-powered pumps are cheaper to purchase but are more expensive to operate (due to higher fuel costs and more frequent repairs) than diesel pumps. A brief description of gasoline and diesel-powered pumps used for lift irrigation in West Africa is presented below.

In recent years, gasoline-powered motor pumps have driven irrigation development in West Africa. Following the discovery of oil in Nigeria the gasoline-powered motor pump became increasingly common. These pumps, generally imported from the Far East, could be purchased for a reasonable price. In addition, the fuel costs were low due to government subsidies, spare parts were commonly available, and repair services initially set up for mopeds and motorcycles could easily branch into motor pump repair. Since the discovery of oil, roughly 300,000-500,000 ha have come under irrigation from small motor pumps in Nigeria (Figure 5).

In countries neighboring Nigeria, the impact of the technology has also been strongly felt. In southern Niger, and northern Chad and Cameroon, small gasoline-powered motor pumps are becoming increasingly common. A favorable exchange rate between the CFA franc and the Nigerian Naira has led to a thriving black market in pumps, parts and fuel, making the technology very affordable. In these countries, a 3.5 horsepower (hp) motor pump can be purchased for the equivalent of US\$300-US\$800. A pump of this size can provide a maximum discharge of approximately 7.0 l/s although the optimal discharge is closer to 4-5 l/s. This discharge should, in theory, permit the irrigation of up to 1 ha, although in practice other constraints (i.e., land preparation) usually prevent the achievement of this target.

In countries which do not directly border Nigeria, small gasoline-powered motor pumps become less affordable. In Burkina Faso, the average purchase price for a motor pump is US\$160/hp while in Niger the cost is only US\$80/hp (Gay 1992). Fuel costs also rise in countries which do not border Nigeria, rising from US\$0.30/l in Niger to US\$0.90/l in Burkina Faso. These higher costs make small motor pumps less attractive as a water-lifting technology for irrigation.

Diesel pumps are generally larger than those powered by gasoline. The initial investment cost is, quite logically, higher as well. A 9 hp diesel pump will cost upwards of the equivalent of US\$4000.00 if purchased in the region. A pump of this size can yield up to 41.7 l/s at shallow depths. This discharge far exceeds the yield capacity of most groundwater development technologies as well as the water required for the typical single landholding in West Africa. As such, diesel pumps are more suited to the development of irrigated areas containing multiple landholdings which rely on a surface body as a water source.

A summary of important parameters for some of the water-lifting devices described above are presented in Table 9.

The performance of manual water-lifting devices will depend on the physical constitution of the operator and may therefore be quite variable.

Alternative pumps. Two alternative energy sources have been applied to water lifting for irrigation in West Africa: solar power and wind power. The use of both these energy sources remains in a trial phase, neither currently being an important resource for lift irrigation in the region. The water-lifting technologies developed to harness these alternative energy sources do have, however, potential under specific conditions. In general, however, they require high levels of institutional development and a long-term planning horizon by farmers.

Table 9. Physical characteristics of selected water-lifting devices.

Device	Head range (m)	Input power (kw)	Flow rate (m ³ /hr)
Watering can	3-5	0.02	0.5
Shadouf	1-3	0.02-0.08	2-4
Dalou	5-10	0.5-0.6	5-15
Rope and washer	5-20	0.02-1.0	5-30
Diaphragm	1-2	0.03-5.0	2-20
Piston	5	0.03	2
Rower	-	-	1.75
Centrifugal	5-60	0.1-500	1-50

Source: FAO 1986b.

Electric pumps driven by solar energy using photovoltaic cells require a large initial investment of up to US\$26,000. This far exceeds the capital available to individual farmers, and most rural communities in West Africa. This requires the creation of credit arrangements. Once the system has been installed, however, the cost of operation is minimal. A typical solar pump has a discharge of 50 m³/day (a time averaged discharge of 0.61/s). In order to take full advantage of this volume of water, either storage capacity is required to collect the water pumped at night, or irrigation must take place 24 hours per day. The first option requires additional investment to develop a storage capacity, the second, institutional arrangements to organize the irrigation rotation. The cost of the technology requires that the farmers possess a long-term commitment to irrigated agriculture and are willing to irrigate year-round.

Windmills have also been tested for irrigation in West Africa. This technology can only be employed in regions with adequate wind resources. In general, 6-8 hours/day of wind, with an average velocity of at least 4 m/s, are required. These conditions are generally found from the Atlantic coast of Senegal across the Sahel to Chad. Two types of windmills have been employed, the first linking the windmill mechanically to a piston pump such as the Burkinabe. These can cost upwards of US\$1,000 to install and their discharge is limited by the potential discharge of the pump. The second type employs a windmill to generate electricity which drives a submersible pump. This type of windmill yields a significantly higher discharge, up to 15 l/s, but is also more costly, running around US\$20,000 installed,

and can only be justified if 24 hour irrigation or night water collection and storage are practiced. The discharge provided by windmill pumps is highly dependent on the depth to water and the wind resource.

5. Groundwater Lift Irrigation in West Africa

5.1. Local Technologies for Groundwater Development

Groundwater development technologies in West Africa range in sophistication from technologies which have been locally mastered for generations to those which have been introduced more recently. The depth at which groundwater can be developed, the types of formations which can be traversed, and the potential well yield are all related to the type of groundwater development technology employed. The degree of sophistication also influences the cost of the technology. The following description of groundwater development technologies begins with the least sophisticated.

Hand-dug wells. Hand-dug wells, as their name implies, are wells constructed using hand tools. Generally, traditional well-diggers develop the well by physically descending into the well and sending cuttings to the surface via rope-and-bucket arrangements. The diameter of hand-dug wells is generally greater than 1 meter to allow enough work space for the well-digger. These groundwater development structures are the most common in the region, being used for water supply as well as for irrigation. They are most appropriate for aquifers contained in weathered and fractured crystalline basement rock and alluvial deposits where digging with hand tools is possible. Depending on the depth to the water table, hand-dug wells can be as shallow as a couple of meters and as deep as 20 or 25 meters.

Traditional hand-dug wells are either unlined or lined with some locally available material. Branches are generally used to line hand-dug wells in cases where the sides of the well are not stable. Unfortunately, this puts added pressure on dwindling forest resources in many parts of West Africa, putting in doubt the long-term sustainability of this traditional well-lining technique. For hand-dug wells, the rate of advance is dependent on geologic formations being traversed and the depth from which cuttings must be lifted. In compacted clay, however, a skilled well-digger can dig an unlined 6 m well in a couple of days. Lining with branches adds about one day to the process. Traditional hand-dug wells have the major disadvantage that they generally tap only 0.5-1.0 m of aquifer, limiting the well-storage volume and well-recharge rate to the point that the well cannot support certain water extraction technologies. The cost of a 6 m deep unlined hand-dug well is approximately US\$40.00. If the well is lined with branches, the cost can be as high as US\$120.

In cases where the well walls are not stable enough to support themselves during digging, an improved well lining method is often employed. This is particularly important when the aquifer being tapped is fluid and has a tendency to fill the space created by digging. Three well-lining methods commonly employed in West Africa are: lining with steel barrels, lining with cement bricks, and lining with steel-reinforced concrete.

Barrel linings are easily crafted from old 55-gallon drums at a cost of approximately US\$8 per linear meter over and above the cost of digging an unlined well. The barrel well-lining cylinders can be introduced at the surface and lowered during well digging, permitting the use of hand-dug wells in unstable formations. Barrel linings have no structural continuity, however, and they can corrode and deform quite easily in mobile water bearing units. Cement brick well columns are stronger, their shape discouraging deformation. It is also possible to structurally link one course of bricks to the next. At US\$25 per linear meter the method is attractive for individual irrigation development. Unless the bricks are perfectly shaped, however, gaps in the well lining are common and can lead to the silting up of the

capturing column. Steel-reinforced wells are the most structurally robust. They allow for significant capturing depths which increase the well storage capacity and recharge rate. At US\$300 per linear meter, their cost can be considered prohibitive to irrigation development by individuals.

Tubewells. In many cases hand-dug wells are not appropriate for local conditions because they are either difficult to install or unable to provide the water required for irrigation. In these cases, tubewells are a more appropriate technology for groundwater development. Tubewells, small-diameter pipe columns linking the ground surface with underlying aquifers, tap the water resource via either a terminal opening or a slotted well screen. Several methods exist for installing tubewells, the appropriate method being a function of the target tubewell depth, the formations which must be traversed, and the required well yield. Four tubewell installation methods, common in West Africa, are described below. The first three are appropriate for aquifers contained in weathered basement rock and alluvium. The last method is applicable to nearly any aquifer type.

The simplest tubewell installation methodology is the use of a hand-auger. The method, perfected by Luthern World Relief in Niger, relies on a simple auger which can be fabricated by local blacksmiths. The auger is operated by two individuals who advance it by alternatively turning the auger and pulling it back to withdraw the cuttings. Once the desired depth has been achieved, a PVC plastic well, with a locally crafted slotted screen, is installed in the hole. The well is protected from the intrusion of fine sand by a nylon mesh and is outfitted with a simple bailer. The cost of materials alone is US\$15 per linear meter and the well yield is between 0.5 and 1.0 l/s.

A second tubewell installation method is the washbore approach commonly used in northern Nigeria (Carter 1992). This method requires the availability of a motor pump and a separate source of water and results in the direct installation of the permanent well into the aquifer. A PVC pipe column is generally installed by pumping water through the pipe string. The jet of water emerging from the end of the string serves as a cutting tool which loosens the earth and allows for the lowering of the well. Tubewells installed by the washbore method usually have a single terminal opening although a few have well screens. These wells can generally be installed to an approximate depth of 10 m at a subsidized cost of US\$2 per linear meter in Nigeria and can yield up to 3 or 4 l/s.

The "sludger" method is another manual tubewell installation technique. It relies on a recirculating drilling fluid, commonly water laden with clay. A hollow galvanized pipe string, equipped with a sharpened cutting tool on the end, is manipulated in short vertical motions with the help of a lever. A hand placed over the top of the pipe string serves as a valve. On the down stroke, the hand is open and drilling fluid is expelled from the string. Cuttings are entrained in the drilling fluid when the drill string hits the bottom of the borehole. These cuttings are lifted from the well as the pipe string is pulled back with the hand closed. In this way the drill string is advanced to the desired depth. Once this point has been reached, the drill string is retracted and a PVC tubewell with a locally crafted slotted well screen is introduced. A developed gravel pack is installed to prevent the intrusion of fines. Flow rates of over 7 l/s have been obtained in West Africa using this method, at a cost of US\$30.00 per linear meter.

The final method of tubewell installation involves the use of drill rigs. Drill rigs employ a variety of drilling methods depending on the local conditions. Driscoll (1986) describes in detail various well-drilling techniques. In West Africa, the two most common methods are percussion and rotary methods, although it must be pointed out that in rural areas drill rigs are rare. In general, drill rigs are used in regions where the installation of water-supply tubewells is necessary due to the types of aquifer present. The cost of drilling can exceed US\$200 per linear meter, well beyond the means of a farmer hoping to develop a personal water source for irrigation.

5.2. Case Descriptions of Groundwater Irrigation

The case descriptions below represent examples of groundwater lift irrigation in West Africa. They are intended to provide some insight into the technological, financial and institutional aspects of locally managed lift irrigation in the region.

Transition from Shadouf to Gasoline Pump in Ngouri, Chad

Ngouri is located in an arid region northeast of Lake Chad. The landscape is characterized by sand dunes interrupted by an occasional inter-dunal depression. It is the depressions, or wadis, which are the primary physical irrigation capital in the region. The floors of the wadis are covered by clay loam soils of lacustrine origin, deposited when Lake Chad was in a more expansive phase. The regional water table is located 2-5 m below the ground surface. According to local accounts, irrigation, using the shadouf to draw water from large diameter, unlined, hand-dug wells, has been practiced in the area for several generations. Local accounts also say that prior to the arrival of irrigation, the wadis regularly flooded, allowing for flood/recession agriculture. This irrigation system is viewed primarily as an income-generating activity to supplement the more important rain-fed millet subsistence cropping system.

The traditional irrigation system seriously constraints the ability of farmers to develop irrigated agriculture to its full potential. Although the average wadi landholding is approximately one hectare, irrigation with the shadouf allows for irrigation of only 0.15-0.3 ha, depending on the depth to water and the physical ability of the farmer. Farmers complain of the difficulty of operating the shadouf, and of the fact that the restricted irrigated surface areas makes wadi irrigation a difficult undertaking.

Traditional irrigation management arrangements are based primarily on the family, each farmer with his dependents being responsible for arranging for the construction of his own well and shadouf, planting and maintaining his own crop, and irrigating his own plants. There is a Wadi Chief, although his authority is limited to resolving infrequent land disputes (the discrepancy between holding size and the area one can irrigate with the shadouf reduces the pressure on the land). The only task farmers carry out in common is the construction of a thicker fence around the wadi to protect it from wandering animals.

In order to make wadi irrigation more profitable and attractive, an alternative irrigation strategy, based on a small gasoline-powered motor pump, was proposed by a USAID-funded project which started in 1987. These 3.5 hp pumps had already become quite common in neighboring Nigeria. Due to the strong ethnic and commercial links between the Ngouri region and northeastern Nigeria, the pumps had also started to appear in the Ngouri region and had piqued the interest of many individual farmers. However, the lack of a capital structure to finance the acquisition of the pumps and the infrastructure to assure their long-term operation limited the expanded use of the technology. The establishment of institutional arrangements to satisfy these requirements was the initial challenge facing the project.

A regional credit institution was established via a seed grant to an association of farmers interested in acquiring motor pumps. The members of the association, who came from many wadis in the Ngouri area, elected an executive committee to manage the grant. Although regional associations did not previously exist in the area, traditional leaders from the various wadis made up the bulk of the membership. The committee was responsible for approving loans to farmers for the purchase of a motor pump and assuring that payments were made towards reimbursing the loans. A limit of one loan per wadi was set as a quasi-collateral arrangement, additional loans being granted to the wadi only if earlier loans were in good standing (the thinking being that farmers would pressure their neighbors to make loan payments so that the others could receive pumps). In theory, loan approval was based on the applicant's reputation and the satisfaction of several initial conditions. In fact, the first round of loans

generally went to the most influential farmer in each wadi, many whom were also members of the executive committee.

The establishment of institutions to provide infrastructure support was fairly straightforward. Local farmers from around the project zone were selected by their neighbors to manage warehouses of spare parts. These individuals were provided with an initial stock of parts and given instructions in maintaining stock inventory, in ordering replacement parts following sales, and in financial accounting. At the end of nearly two years of continuous operation, the initial stock of these warehouses was completely accounted for and an additional stock had been added through mark-ups on the sale price of spare parts. Pump repairmen were also trained by the project. Each wadi was asked to propose one individual to complete a rigorous training program on pump repair. Those who successfully completed the course were provided with the tools necessary to set up a small workshop. Five individuals set up private shops to service pumps and successfully kept all of the pumps in the project zone functioning for the last nine months of the project. These individuals were compensated for their services by the farmers requesting repairs.

The motor pumps, as expected, provided a larger discharge than the shaduf, and in many cases the unlined, hand-dug wells which provided adequate water under traditional conditions, quickly dried up when pumped using a motor pump. The need for a groundwater development technology which provided a higher water yield led to the addition of the "sludger" tubewell to the technical and credit packages. Together, these new technologies allowed for a discharge of approximately 3.5 l/s and an irrigation of between 0.5-0.7 ha of land. The total cost of the package was approximately US\$1,000 depending on the depth of the tubewell, with both the pump and the well being furnished through private commercial structures created over the course of the project.

Viewed from a purely technical perspective, the motor pump/tubewell technical package performed very well. The acquisition sub-system was dramatically altered, increasing the volume of water pumped and allowing for marked increases in the amount of land under irrigation. In addition, the package freed the farmer from the arduous task of water-lifting and allowed him to improve his cultural practices. This led to yield increases per unit area. The most successful farmer in the Ngouri area (who was neither powerful nor influential) was able to generate a net profit of US\$800 per growing season (two growing season per year) using the package. Others, who received less-spectacular results, were still able to increase the profitability of irrigated agriculture relative to the traditional system.

Nonetheless, not all farmers who purchased the technical package were able to perform up to this level. Two factors limited the performance of the system: (1) time and effort saved by using the motor pump/tubewell system relative to the shaduf were not reinvested in irrigated agricultural production; and (2) labor and energy constraints prevented a significant increase in the land under irrigation. In effect, the use of the new system necessitated a new approach to wadi irrigation, one which was both more intensive and more extensive. Farmers who failed to realize this change had a difficult time profiting from the improved system. Out of a total of 49 farmers who received loans for motor pump/tubewell systems, only 3 failed to earn enough money to make repayments.

Given the poor and risk-prone circumstances of the farmers, this is a surprisingly low rate of default. There was, however, a weakness of the institutional arrangement established to provide credit. Two pumps of the delinquent farmers were promptly seized by the committee as per the credit agreements. However, one farmer, who failed to make payments, was a committee member and a very influential individual in his wadi (he likely had the money to make payments but apparently he was convinced he could intimidate the committee into not seizing his pump). The crisis which resulted nearly broke up the organization. Seeing that the association was either unwilling or unable to impose sanctions, other farmers began to follow the lead of the renegade farmer. The organization's failure to implement

appropriate sanctions was likely a result of not integrating traditional arrangements for credit management and repayment into the institution.

Return to Traditional Irrigation in Abeche, Chad

Another area where traditional irrigation has long been practiced is Abeche, in the vicinity of Abaca in the Ouaddai region of eastern Chad. Here alluvial deposits associated with ephemeral streams draining volcanic uplifts, contain aquifers within 4-6 m of the ground surface. Irrigation is developed by constructing large-diameter, hand-dug wells and lining them with traditional materials to support unstable soil. The traditional wells are difficult to construct, have unreliable yields, and frequently cave in. The loss of irrigable land due to the collapse of a well is a serious problem. Water lifting is accomplished via the shaduf or simple rope-and-bucket arrangements, with individual farmers being responsible for their own water lifting and irrigation. Individual wells are generally located within the limits of individual fields, restricting the distribution and application sub-systems. In Abaca, even fencing was done on an individual basis. The traditional irrigation system serves for the production of large quantities of onions which are sold throughout Chad and Sudan or exported to the coastal countries.

A USAID-funded project started in 1986 hoped to improve the profitability of the onion trade by focusing on the production system. The project attempted to provide farmers with a stable source of irrigation water which would minimize land losses due to well failures and encourage an increase in the irrigated area available to produce onions. The proposed technical solution was to construct one centrally located, steel-reinforced concrete well to a group of farmers. The distribution and application sub-system were separated, with the distribution system coming under common management. Water lifting was carried out by each farmer using improved hand pumps, animal traction devices, or small motor pumps, depending on the financial resources of the individual. No credit arrangements were developed for financing water-lifting technologies.

The new system necessitated the creation of a new irrigation institution: one which allowed for group financing to develop the water source, the installation of a common water-distribution network and the control of access to the water source. Finding a formula for the creation of such an institution proved problematic on all three counts.

Large-diameter, hand-dug wells are expensive, certainly beyond the means of a group of small farmers. The project decided to offer credit directly to the new farmer organizations by financing and constructing the wells. Arrangements for reimbursement of the credit were left unclear, based on the assumption that farmers would be so impressed with the new wells that they would be compelled to repay. Not surprisingly, in the end the rate of default was 100 percent. The beneficiaries had no incentive to pay back a project which would inevitably leave the area. This pattern has been repeated in many lift irrigation projects in West Africa.

Motivation to repay the credit was further weakened by a generally unfavorable impression of the technical arrangements themselves. Farmers in the region were used to drawing water from a well located directly adjacent to their fields. As a result, they had little traditional expertise in constructing distribution canals. In addition, farmers near to the well, who in many cases were the most influential members of the group, were not keen to allow canals to cut across their land. Delivery canals were poorly constructed and followed convoluted paths, reducing the performance of the distribution sub-system.

The failure of the proposed water-lifting devices to perform up to expectations also created problems. The hand pumps did not provide any more water than the shaduf, less at the field boundary, considering the distribution sub-system losses. The animal traction delou performed well but the space required to manipulate the animal limited the number of operators who could work at one time. The motor pump

was favorably viewed by operators as it increased discharge while requiring only a small space near the well. Its cost, however, proved prohibitive to the majority of farmers. In addition, water lifting was made more difficult for non-pump operators due to the drawdown. Finally, farmers restricted to rope-and-bucket arrangements were prevented from using the shaduf because the manipulation required free space not available on a common well. These individuals were forced to use simple buckets which required much effort and thus provided reduced discharge.

One farmer organization did emerge successfully from this technical arrangement. The farmers, who were also closely related, received funding from a wealthy family member to purchase a diesel motor pump. In this case, the single water-lifting device installed on the well provided sufficient water for all the farmers. Due to their established social relationships, the individuals were able to construct a distribution sub-system of reasonable quality and implement a set of rules for water distribution which included procedures for compliance monitoring, the imposition of sanctions and conflict resolution. In this case, the technical arrangement allowed for an increase in the area of irrigated onions. Other organizations eventually broke up, and this left the well-positioned farmer organization with a very reliable and expensive well in the farmers' own field. The others returned to using the shaduf on a traditional well.

In the end, USAID abandoned this approach to increasing the income-generating capacity through expansion of onion production, focusing instead on improving the control which farmers had over the price they received for their product. They hope to accomplish this by introducing improved storage techniques and helping farmers to influence the market. The irrigated production system will likely return to a more traditional approach.

Reluctance to Accept the Tubewell in Cheddra, Chad

A third lift irrigation system in Chad evolved in the Bahr-al-Ghazal sand river region. A traditional irrigation system exists in the area based upon large-diameter, hand-dug wells for aquifer development and the shaduf for water lifting. Well construction in the sand river bottom was particularly difficult due to the loose alluvial formation and the frequent flooding during the rainy season which can result in well collapse. Traditional wells are lined with branches in an attempt to shore up the sides of the well. But the average life of a well does not exceed 2-3 years. Well construction and the loss of irrigated area to well collapses are two of the most important costs associated with the traditional system.

The typical landholding size in the Cheddra is approximately 0.25-0.30 ha. As the depth of water is quite shallow, most farmers can irrigate their entire landholding using the shaduf. The production of onions in the area is quite well-developed with middlemen from the capital coming right to the farm-gate at harvest time. Although the shaduf is tiring to operate, an increase in the volume of water lifted would not necessarily permit a production increase. Groundwater development is definitely the most important constraint.

Another USAID-funded project initiated in 1986 was designed to eliminate this constraint. Several improvements were tested, including lining hand-dug wells with empty barrels. The fluid nature of the sediments in the sand river resulted in elevated pressures which crushed the barrels. Thought was given to introducing steel-reinforced concrete wells, although the lack of desire on the part of farmers to congregate around a common water source and the high cost of the technology discouraged the use of this technology. In the end, the sludger tubewell was perfected for use with the Burkinabe hand pump. The technology was attractive to farmers as it provided adequate water to irrigate the typical landholding and the well was able to withstand the frequent flooding characteristic of the region.

The introduction of a new technology certainly necessitated the development of new irrigation institutions. The traditional system was based almost exclusively on individual initiative. The only

support structure was the private well diggers who have perfected the traditional well-lining method. All other work (shaduf construction, fencing, land preparation, irrigation, etc.) was carried out by the farmer and his family. New structures were required to drill the sludger wells, install the Burkinabe pump, provide spare parts and carry out repairs. Financing of the technology was also a concern. None of these tasks could be accomplished using the existing institutional arrangements.

Unfortunately, those implementing the project decided to provide the services themselves rather than taking the slower, more sustainable track of developing local institutions. A team of technicians trained and paid by the project installed wells at cost (materials only) for farmers who were required to make a down payment of approximately US\$4.00 (4% of material costs of approximately US\$100.00). Arrangements for repayment were not formalized in a binding loan agreement. Pump parts were manufactured in the project workshop and repairs were carried out by project technicians. None of these arrangements encouraged a sustainable technology management approach.

These arrangements were maintained for nearly two years when funding ended. Receiving further donor funding was conditional on the transfer of organizational management to local organizations. Tubewell drilling and hand-pump installation were transferred to a private enterprise. Spare part manufacture and pump repair were also transferred to individual technicians. Finally, an attempt was made to develop sustainable credit arrangements to assure long-term financing availability for technology purchase. These changes created problems. In order for a private enterprise to install the tubewell/hand pump, cost recovery for materials, labor, and transport as well as a profit margin had to be included in the price. This increased the price to approximately US\$300. In setting up local arrangements for credit, a down payment of 10 percent of the value of the technology (US\$30) was required. These changes represented a tripling of the total cost of the technology and a 7.5-fold increase in the down-payment requirement.

Farmers were reluctant to accept these conditions given that their neighbors had earlier received the technology for less money under more favorable terms (as in Abaca, loans made directly from the project to the farmer were seldom repaid as no arrangements had been made to impose sanctions). The earlier experience engendered a dependent, speculative attitude amongst the farmers. Although the tubewell/hand-pump system had clear technical advantages over the traditional system, interest in the technology declined drastically because of expectations which had developed among farmers that they could obtain better subsidized terms with other projects. The perception that the technology would have improved their profitability from irrigated onion production was not in question. The problem was a failure to motivate farmers to collectively sponsor investment in a technology which was thought to contain a higher potential for external subsidy. The joint-investment strategy failed when farmers thought they had more subsidized options available.

Profitability of Motor Pumps and Tubewells in the Tarka Valley and Maradi Goulbi, Niger

Irrigation using groundwater is very well developed in southern Niger. Farmers, in both the Tarka Valley near Madaoua and to the east in the Maradi Goulbi near Maradi, practice traditional irrigation. In both areas, aquifers contained in alluvial deposits are easily exploited using unlined, hand-dug wells and rope-and-bucket arrangements. In the Tarka Valley, the water table is close enough to the surface (2-3 m below ground level) to allow for use of a simple traditional bucket attached to the end of a rope. In the Maradi Goulbi, where the water table is typically 5-6 m below ground level, the shaduf is more commonly employed.

The most detailed evaluation of the traditional irrigation systems in southern Niger has been conducted by Norman and his colleagues (1990a and 1990b). Measurements made in both locations found that rope-and-bucket arrangements yielded a discharge of 0.6 l/s (although the shaduf is usually

operated under greater depth-to-water conditions). Irrigated surface areas are quite restricted in both locations, generally being less than 0.2 ha. This surface area corresponds more closely to the typical field size than to the maximum yield of the rope-and-bucket arrangements. Groundwater development is accomplished via unlined hand-dug wells.

As in Chad, onions are the principal crop, grown within the traditional irrigation system in southern Niger. The onion production system is viewed as an income generating activity with farmers willing to put up with the physically difficult traditional water-lifting technology and the small surface areas in order to profit from the lucrative market in neighboring Nigeria. Most individuals participate in the system, even if they must lease land from a local landowner. Even though the land resource is limited, under the traditional system all those who want to participate can generally find a field, dig a well and plant a crop. The only important institutional arrangements in the traditional system are those for leasing land. Large landowners either (1) lease land for a fixed fee to a farmer who finances and installs his own production system or (2) finance an onion production system for a tenant farmer to whom they pay a fixed percentage of the profits.

The traditional system has come under increasing pressure recently due to the growing number of small gasoline powered motor pumps appearing in the area. These pumps are purchased in neighboring Nigeria at a price made attractive by the favorable black-market rate for the CFA Franc used in Niger. Taking advantage of this black market, a small gasoline-powered 3.5 hp motor pump can be purchased for approximately US\$300. Gasoline and spare parts are also readily available and reasonably priced in southern Niger thanks to the favorable black-market exchange rates. It is important to note that this technology arrived quite spontaneously, outside of the purview of any formal project. The development of an appropriate groundwater-development technology has not been as easy.

Well yields from hand-dug wells do not permit the sustained operation of the motor pump. This is despite the fact that the pumps are generally operated at a discharge of approximately 2.5 l/s, well below its potential maximum discharge. In addition, the increased drawdown associated with the use of the motor pump exposes the unstable side of the well, leading to more frequent well collapse. These conditions prompted development organizations in the area to launch a search for a more suitable groundwater-development technology. This effort focused first on the construction of steel-reinforced concrete wells. This technology eliminated the problem of well collapse and increased the amount of water available for pumping. Efforts were made to establish local arrangements for the construction of these wells by training and equipping well construction teams. As previously mentioned, however, these wells are expensive and financing became a serious constraint.

It was hoped that the cost of wells constructed during the training of the installation teams would be paid back to the teams, allowing them to finance additional wells. Once again, however, no capacity to impose sanctions for nonpayment was put in place and sustainable local rules and institutions failed to develop. As a result, loans were not paid back and the well teams, lacking capital for new projects, became inactive. The fact that cement-lined wells are immobile also created problems as many landholdings are scattered. Construction of an expensive cement well does nothing to improve the groundwater development situation in distant fields. Hand-dug wells require lower investment and can be quickly constructed elsewhere as the need arises.

In order to overcome this drawback, efforts were made to perfect a less-expensive tubewell technology. The method chosen relied on a hand auger which could be simply assembled in a workshop equipped with an arc welder. The auger is operated by two individuals who dig a hole down to 10-12 m below ground level. A PVC tubewell is inserted in a borehole, wrapped in fine nylon mesh to prevent the invasion of sand into the tubewell. These tubewells are less expensive than cement-lined wells, allowing for construction in several disjointed fields, but well yields have been largely unsatisfactory, rarely permitting operation of a motor pump at a discharge of more than 2-2.5 l/s.

Nonetheless, farmers are requesting tubewells and are able to make a significant profit using the motor pump as part of the onion production system. Harzebrouck (1991), who studied a series of small farms (0.06-0.25 ha) in the Tarka Valley, found that a per season profit of approximately US\$650 (based solely on seasonal costs and receipts) could be made on farms of greater than 0.2 ha (approximately US\$2,600/ha). Even if the cost of financing a motor pump and tubewell is deducted from this figure, it is clear that after only a few seasons the technology can be paid for, allowing for significant long-term profits. Not surprisingly, a performance assessment of the new system is very positive. The acquisition sub-system has been drastically improved. Local structures are in place to assure both the procurement and the maintenance of the required groundwater development and water-lifting technologies.

In fact, it is the performance of the system and the promise of long-term profits which have made the tubewell/motor-pump system so attractive. Landholders who once leased land to others are now capable of producing onions on the entirety of their land, making it difficult for the poor to profit from the new technology. Indeed it is difficult for them to find land on which to practice the traditional methods. This may create social problems in the future. An additional issue which must be addressed in southern Niger is improved water management. Norman (1990a and 1990b) found that farmers who own motor pumps tend to overirrigate and operate their pumps at less than optimal operating speed. Nonetheless, the development of a new irrigation system using groundwater in southern Niger demonstrates that potential exists for successful future efforts. Additional effort is required both to match existing technologies to the actual size conditions and to introduce other more appropriate technologies at acceptable investment costs.

Fadama Groundwater Irrigation, Northern Nigeria

In northern Nigeria, an impressive expansion of groundwater lift irrigation has occurred in the "fadama" alluvial bottom lands. This expansion has been driven by the inexpensive availability of fuel in Nigeria and the arrival of the small gasoline-powered motor pump. Remarkably, the expansion has been nearly spontaneous in character, arising from the interest and financial resources of the local population, not from a formalized project funded by an external donor. Only this type of spontaneous movement could result in the situation witnessed in northern Nigeria today, that is, small motor pumps irrigating private holdings in nearly every alluvial depression.

Since the arrival of the small water pumps, the technology has slowly displaced the shaduf as the traditional water-lifting technology for irrigation. This process has been accelerated by government subsidies which reduced the cost of the pumps themselves and the fuel used to run them. During the Nigerian oil boom of the early 1980s, pumps could be purchased for as little as US\$75 and the fuel to operate them cost as little as US\$0.15 per liter. Early on, most of the pumps were operated on hand-dug wells. As in other parts of West Africa, these wells often lacked the capacity to supply the water required for efficient operation of the motor pump. To overcome this limitation, the government also launched a program to subsidize the installation of washbores and tubewells.

The agencies charged with the installation of these tubewells were the Area Regional Development Authorities (ARDAs) for each state. In the vicinity of Kano, the KNARDA offered washbores at US\$21 per well and tubewells at US\$57 per well. The difference in cost was due to the fact that the washbore had no well screen nor gravel pack, simply a terminal opening in direct contact with the water bearing formation. Tubewells were equipped with well screens and a developed gravel pack. Not surprisingly, the tubewells had a much higher rate of success. Reportedly, farmers in the area were generally unhappy with the performance of their washbores while tubewell owners were generally satisfied with their wells. In fact, it is apparent that many farmers desired additional wells to permit the expansion of irrigation into areas which, due to topography, are inaccessible from their current water source point.

Unfortunately, Nigeria's oil boom has since receded. Although the subsidy programs are still officially on the books, the ARDAs are no longer provided with materials to install washbores and tubewells. Vouchers which were once given for the purchase of a motor pump by farmers who intended to grow wheat, have not been distributed for several years. The use of small motor pumps for groundwater irrigation has, of late, moved towards the truer costs of the technical package. Nonetheless, interest in the technology continues to grow with farmers who still operate the shaduf, fully intending to purchase a motor pump in the near future. This differs from the situation in Chad and Niger where the poorest farmers doubt that the motor pump/tubewell technical package will ever benefit them personally.

To respond to the continued interest in small motor pumps in northern Nigeria, a variety of support services has emerged in the private sector as a direct result of the decrease in government subsidies. Mechanics capable of repairing motor pumps are found in even the smallest villages. Commonly required spare parts are found in the same shops which sell matches and lamp wicks. New motor pumps are available in even the smallest provincial capitals and, more interestingly, dealers in second-hand and reconditioned motor pumps have set up shop across northern Nigeria. Finally, private enterprises have emerged to fill the ARDA's role in installing wells, although they offer them at the real market value rather than at subsidized rates. A typical farmer who obtains a net income of nearly US\$400 per season growing wheat on approximately 0.5 ha is generally willing to pay the higher costs associated with the private sector. His neighbors, witnessing his success, are usually inspired to abandon the shaduf and invest in the new technical package.

This universal interest has led to two problems associated with using the motor pump/tubewell technical package. Washbores and tubewells are being installed in bottom lands whose sub-surface characteristics are very heterogeneous. Those who install tubewells are not always successful in placing the well in a water bearing stratum which can provide sufficient water for irrigation. These well failures drain both the resources and ambition of farmers who are willing to invest in the technical package. The other negative result of the rapid expansion of motor pump/tubewell irrigation has been the overexploitation of some aquifers leading to increased drawdowns, higher pumping costs, and in some cases the drying up of wells. Both these problems could be addressed through an increased understanding of the hydrogeology of the fadama lands and their potential to support irrigation development.

6. Surface Lift Irrigation in West Africa

6.1. Overview

The second type of lift irrigation practiced in West Africa, surface-lift irrigation, relies on the development of surface water bodies. As the region is quite arid, conditions required for surface-lift irrigation are less common than for groundwater irrigation. Most water courses are characterized by highly variable flow rates, both seasonally and annually, and protracted periods of dryness. Lakes, ponds, and swamps advance and recede according to local rainfall and runoff conditions, often drying up completely during the dry season. These conditions make it very difficult to rely on the presence of water for irrigation. This is not to say, however, that these resources are never developed for irrigation. They often can be exploited at a small-scale irrigation level with minimal investment in technology.

If a significant investment is to be made in land improvement and technology, the water source must be more reliable than the ephemeral resources described above. Only the few major rivers in the region offer this kind of reliability. The major river systems in the region include: the Senegal, the Niger, the Volta, the Ja'mana, and the Chari-Logone. Many private and public surface lift irrigation systems line

these rivers and their tributaries. The private systems generally rely on locally available water-lifting technologies which can be purchased and managed without external support. Systems which permit more extensive development of irrigated agriculture usually rely on new technologies and necessitate the development of new institutional arrangements.

The earliest technical developments in irrigation in the region have been for lifting surface water. Historically, the major West African rivers have experienced relatively little high dam development. Although recent years have seen the construction of large capacity dam/reservoir systems, such as the Manantali Dam in the Senegal River Valley, in many areas river levels noticeably fluctuate according to annual precipitation and runoff patterns. These fluctuations result in the advance and recession of the river edge, by as much as 1,000 m in some areas. As the land suitable for irrigation development usually lies adjacent to the high-water river edge, it is often necessary to dig and maintain trenches from the low-water river edge to the irrigated fields. This type of effort requires a communal effort of the beneficiaries of surface lift irrigation. In areas where the high- and low-water river edge closely coincide, a floating pump platform is often a communal resource.

Some surface lift irrigation systems require no communal arrangements to develop. These cases occur where landholdings are held on the exposed river bed and individual water-lifting devices are displaced in response to water level fluctuations. Systems where individual water-lifting devices draw water from non-receding rivers also do not generally have communal water development systems.

6.2. Case Descriptions of Surface Lift Irrigation

The following cases represent some of the combinations of surface water development and water-lifting technologies employed for surface-lift irrigation. The cases are intended to provide insight into the interaction between technological, economic and institutional issues pertaining to the sustainable local management of lift irrigation in West Africa.

Basing Motor Pump Units on Traditional Social Groupings in Richard-Toll, Senegal

The Ndombo-Thiago lift irrigation scheme, southeast of Richard-Toll, was selected in 1979-80 as the site of an experiment in farmer management of a surface lift irrigation system. The system had been under the direct management of Societe Nationale d'Amenagement et d'Exploitation des Terres du Delta du Fleuve Sénégal et de la Falémé (SAED) which carried out multiple administrative, technical, commercial and industrial functions in the area. This all-encompassing role had the effect of severely limiting the initiative of local farmers. The experiment at Ndombo-Thiago was designed to investigate ways to empower farmers to eventually take control of surface lift irrigation systems in the Senegal River Valley. This description of the experiment is based on the work of Diop (1990).

The system in Ndombo-Thiago, with a total surface area of 720 ha, was divided into 12 independent sub-units of approximately 60 ha each, with its own hydraulic infrastructure and motor pump. These sub-units were further divided into blocks of 15 to 20 farmers responsible for 12 to 15 ha. The initial grouping of farmers into sub-groups and blocks was done with the assistance of a sociologist who helped assure that these groups were based on an affinity between members.

In addition to a motor pump, each sub-unit received a fleet of motorized equipment including a tractor, a trailer, an atomizer (sprayer) for the application of ag-chemicals, and a thresher. Finally, each sub-unit was endowed with a revolving fund of US\$7,200 to cover the annual operating expenses associated with irrigated agriculture. In return for these initial investments, the sub-units were expected to collect fees to refinance the revolving fund and to fund a depreciation fund for the eventual replacement of mechanized equipment.

The results of the experiment have been mixed. In terms of rice yields, rice being the principal irrigated crop, the farmers in Ndombo-Thiago have exceeded the production levels achieved by other farmers in the Senegal River Valley. Between 1982 and 1989, the farmers in Ndombo-Thiago achieved an average yield of 5.7 t/ha with a maximum of 6.26 t/ha in 1983/84 and a minimum of 5.28 t/ha. These impressive yields, together with improvements in local management, have contributed to increasing net revenues generated by the sub-units. In the best case, net revenues (after expenses) rose from US\$527.68/ha in 1981/82 to US\$1,784.95/ha in 1986/87. The least spectacular increase was from US\$959.79/ha to US\$1,381.52/ha over the same period.

These results compare favorably with those reported in the vicinity of Matam further upstream where SAED maintained more restrictive control over the surface-lift-irrigation systems (Réseau Recherche Développement 1989). In this region, the yields averaged around 4.5 t/ha. Considering the real costs of production of US\$735/ha, and assuming a market price of US\$350/t, this translates to average net revenues of US\$840/ha. These levels of performance are markedly less than at Ndombo-Thiago.

Despite these impressive levels of production and net profit, the maintenance of the initial funds required to assure the long-term viability of the sub-units has been less spectacular. The equipment depreciation funds have not been maintained as expected. Between 1986 and 1988, the rate of coverage of equipment depreciation ranged from a low of 24 percent to a high of 103 percent, the average rate being 56 percent. The condition of the revolving funds, a more immediate concern for farmers, has also deteriorated. In sub-units, the capital available no longer permits the complete financing of operational expenses. Farmers are thus obliged to search for capital on the competitive local credit market.

The variable degree of success with which the sub-units have maintained their financial resources has affected the first renewal of equipment. Many groups have had to take out loans with the Caisse Nationale de Credit Agricole in order to finance the purchase of new equipment. In general, they have used what depreciation fund they had built up as a down payment. The remainder of the required sum was borrowed at an interest rate of 13.5 percent. Only one sub-unit, which had covered equipment depreciation at a rate of 103 percent, was able to replace its equipment using its own financial resources. The sub-units which were forced to borrow money are now faced with meeting their debt requirements, maintaining a fund to finance operating expenses, and building up a depreciation account to cover future equipment purchases. These obligations will tax the impressive yields which are achieved by the sub-units.

The experiment in Ndombo-Thiago is entering its second phase. The results of the first phase show that direct farmer operation of lift irrigation systems is possible. By basing the creation of sub-units and blocks on cultural affinities, the farmer organizations were put on the road to eventual success. The second phase of the project will have to place more emphasis on the management of finances and equipment. This will require added emphasis on monitoring compliance and imposing sanctions to assure the financial stability of the institutional arrangements. Nonetheless, the experiment at Ndombo-Thiago bodes well for the eventual management transfer to farmers of lift irrigation schemes in the Senegal River Valley.

Technical and Financial Constraints on Pump Irrigation in Bakel, Senegal

The experiences in two village irrigation perimeters along the south bank of the Senegal River near Bakel is a tale of contrast. They demonstrate the different outcomes which can occur when a single pump operated by a parastatal agency is used to provide water to a group of individual plots. The following discussion is largely based on a paper by Snaterse and Slabbers (1990).

The Gande and Gallade village irrigation schemes are located several kilometers apart downstream of Bakel, Senegal. The villages have similar populations, 600 and 500 inhabitants, respectively, and the systems themselves are of similar size, 6 ha in Gande and 5 ha in Gallade. The pump works in both systems are managed by SAED (Société d'Aménagement et d'Exploitation des Terres du Delta du Fleuves Sénégal et de la Falémé) who also coordinate the construction of the canal infrastructure and the provision of required inputs. The farmers in both systems, who were organized into associations, were responsible for managing on-farm irrigation and production for repaying SAED for the services provided.

Further similarities between Gande and Gallade exist at the purely technical level. Both systems relied on a 2-cylinder Lister diesel engine driving a Godwin centrifugal pump to lift water over 12.5 m of elevation head at the lowest river level. In addition, both systems were laid out on homogeneous *fondé* soil with an average infiltration rate of 75 mm/hr. Hoping to profit from two such similar sets of conditions, research was conducted to assess the performance of the two systems. Performance differences could, in this case, be more confidently attributed to institutional arrangements rather than physical dissimilarities.

Both systems were closely monitored between October 1983 and May 1984, during which time maize was the principal crop under irrigation, although in both schemes some vegetables were also irrigated. In both systems, initial measurements were made of the dimensions of structures, canals, dikes, parcels, and plots. During actual irrigation events, monitoring included the measurement of: the time of pump operation, fuel consumption, discharge, plots irrigated, irrigation times, and infiltration rates. Qualitative records were made of the persons present and their activities, the tools they used, the occurrence of overflow or leakage from canals, and of the communications between the farmers' associations and SAED.

Based on the data collected during this period, the performance of the two systems was evaluated. The conclusion: for all their similarities, the systems performed differently. The system in Gande was wrought with conflict while its counterpart system in Gallade functioned markedly better.

In Gande, a problem of repayment developed between the farmers' association and SAED, a vicious circle from which no exit was found. Because of back debts totaling US\$4,000, SAED refused to repair or replace the system's motor pump when the eight year old unit stopped functioning--unless the farmers settled their accounts and agreed to an expansion of the irrigation system. The association refused, claiming that SAED had not made irrigation profitable and that an earlier effort to expand the system, to which farmers had been required to contribute had failed because of an improper design imposed by SAED. In addition, the association insisted that many farmers had already abandoned irrigation because it was unprofitable and thus no justification existed for system expansion. A protracted period of such "dialogue" preceded the repair of the pump. There were no local rules established which were accepted by both the farmers and SAED, which could be used to resolve the conflict. Farmers were not convinced that their efforts would lead to increases in yield and SAED had no confidence that the farmers would repay costs and enforce sanctions.

In Gallade, the association and SAED maintained much better relations. When the seven year old pump encountered problems, SAED readily replaced it with a new engine. At the end of the research period, the association was in arrears by only US\$52. The farmers were confident their efforts were worthwhile and SAED felt sure that their partners had established capable irrigation institutions.

The situations reported above are outward manifestations of different levels of system technical performance. The root causes of variable performance in two similar systems are enlightening. While the total volume of water pumped in the two systems were similar, 40,972 m³ in Gande and 45,231 m³ in Gallade, the irrigated areas were not, being 2.0 ha and 4.7 ha, respectively. This translated to a uniform applied depth of 2,049 mm in Gande while in Gallade the total discharge applied was only 963 mm. Taking into account the length of the growing season, this translated to 15.4 mm/day and 7.6

mm/day, respectively. Even considering its Sahelian location, far too much water was being pumped in Gande.

Such different water management scenarios have a real impact on the costs associated with irrigation and the resulting profitability. The water/fuel ratio of the pump installed in Gande, 34,615 liters of water per liter of fuel, was similar to that which operated most of the season in Gallade, 36,000 liters of water per liter of fuel. Thus it seems that the difference in fuel cost per acre, US\$450/ha versus US\$192/ha, is due primarily to differing water management practices. When the total value of production ranges between US\$400/ha and US\$800/ha, of which approximately US\$160/ha is for non-water costs (pump parts, seed, fertilizer, and pesticide), the repayment conflict in Gande and the relative calm in Gallade are readily understood.

It seems that two factors contributed to the significant difference in performance between the two systems. First, both systems had some plots which were managed communally. In Gande, these plots were grouped together in the portion of the system the farthest removed from the pump discharge point. For some reason, be they social or technical, these plots received a much higher irrigation supply than the individual plots. An average application (including conveyance losses) of 255 mm was applied on an 8.8 day irrigation interval, or an astonishing 28.0 mm/day. The individual plots received an average application of 10.8 mm/day. In Gallade, on the other hand, the communal plots were evenly dispersed over the system. Here the average application ranged from 6.9 mm/day near the pump discharge point to 8.1 mm/day in those plots farthest removed from the pump. The communal plots in Gande certainly contributed disproportionately to the higher fuel consumption and operating costs in Grande.

A second difference between the systems in Gande and Gallade was the characteristics of the irrigation structures. The top width of the primary canal in Gande was only 0.33 m, as compared with 0.52 m in Gallade. In addition, weeds and debris were much more common in the Gande canal. Finally, the topography of the Gande system was much more uneven than in Gallade. All three factors contributed to a much higher occurrence of canal overflow and leakage in Gande with associated increases in conveyance losses. The scale of the irrigation basin also differed between the two systems. In Gande, the common basin was a 450 m² strip which took from 1 to 4 hours to irrigate. The typical basin in Gallade was a rectangle of approximately 150 m² which could be fully irrigated in 10 to 20 minutes.

The very different performance levels achieved by these two systems, which on the surface seem very similar, highlight some crucial elements of surface lift irrigation of multiple plots irrigated from a common water source. They also shed light on the problems and potential of surface lift irrigation managed by a parastatal agency.

Dependence on Ineffective Support Services in Diré, Mali

Surface lift irrigation development in the vicinity of Diré, Mali (located between Mopti and Timbuktu along the north bank of the Niger River), is a singular example of how even the best laid plans can go awry. It is a case where individual water source control and water lifting were promoted by a bilaterally funded project. The results were less remarkable than were expected. The following information is based extensively on a paper by Moris (1984).

The project Action Blé-Diré, funded by USAID, was implemented by the Malian government starting in 1979. Farmers in this area had, for centuries, traditionally irrigated wheat during the cool dry season (November to February) by lifting water with calabash buckets from the Niger River. Government officials in the region proposed that the irrigation be expanded, and made less vulnerable to the yearly fluctuations in river level, through the introduction of small diesel-powered motor pumps. It was hoped that the irrigated surface area per farming unit could be increased from approximately 0.4 ha to 4-5 ha.

Diré is an isolated location, accessible from Mopti and points south by river during the high water portion of the year (October to March) and by an arduous off-road 311 km journey when the river becomes impassable. Recognizing the difficulty of managing a project in such an isolated location, USAID stipulated that five components be included in the project.

- * First, as pumps were to be purchased at a reduced price from an Indian supplier with no presence in Mali, a stock of spare parts was to be set up in Diré at the time of pump purchase.
- * Second, farmers were to receive a pump, on credit, for individual operation but would be required to select two cosignatories to guarantee their loan.
- * Third, Action Blé-Diré (ABD) was to offer operating loans to farms which required repayment, with 8 percent interest, within 30 days of harvest but which also required ABD to supply sufficient amounts of fuel, oil, fertilizer, spare parts, and mechanical services.
- * Fourth, ABD was to provide eight contract machines, free of charge, for three years until local residents could be recruited and trained to take their place. Prior to receiving a pump, farmers were to be trained in pump operation and preventative maintenance.
- * Fifth, ABD was to strengthen its extension and applied research capacity in order to disseminate improved wheat varieties as well as improved cultural and water management practices.

Farmer input was actively sought and considered in developing these components.

At this point, the project seemed poised for success. Farmers who already knew how to grow wheat under irrigated conditions, in an area largely free of wheat pests and disease, were excited to accept the new pump technology and wheat varieties. The local market for wheat was strong and any surplus production could be processed, stored and subsequently transported to the south when transportation conditions allowed. Unfortunately, all did not go as planned.

The first setback was a one-year delay in the release of project funds, planned for August 1978. In order to preserve the initial 1979-1980 growing season, pumps were purchased and distributed to farmers without training them in pump O&M and without setting up the stipulated spare parts stock and pump repair workshop. In spite of the accelerated efforts, only 34 of the planned 250 pumps were operational during the first year of the project. The following year, the total number of operational pumps rose to 250 in about 50 villages.

A second paradox arose as poor ABD accounting procedures led to USAID freezing project funds. This, in turn, caused ABD to undertake even more dubious financial management procedures making the resolution of the initial problems, and then unfreezing of funds, even more problematic. The impacts of this dispute were profound:

- * The few loan repayments made by farmers were used to pay ABD operating expenses, not to build up a special fund for support services and eventual pump replacement.
- * Investment was not made in setting up the spare parts stock and pump repair workshop, leading to loan waits for pump repairs.
- * Fuel supplies were interrupted at critical stages of crop development.

- * Improved seed varieties were not made available to farmers.
- * Extension services failed to provide pump O&M training to farmers and improved water-management strategies were not conceptualized.

As a result of these shortcomings, most farmers repaid neither their loan instalment (\pm US\$350) nor paid their service levy (@ US\$0.02/kg).

In 1982, the situation had deteriorated to the point where USAID decided to suspend its support of ABD. Rather than completely abandon the project, which had allowed for wheat cultivation in years when historically low river levels prevented traditional irrigation, USAID decided to directly manage the effort in collaboration with village leaders. The name of the project was changed to "Activities Paysannes."

The goal of this effort was to revitalize the effort to the point where it could be successfully transferred to the farmers themselves. This was to be accomplished by finally setting up the spare parts stock and pump repair workshop. In addition, a real effort would be made to train local mechanics. By this time, however, the Indian pump supplier had stopped manufacturing the pumps used by the project and as such few spare parts were available. In desperation, the mechanics began cannibalizing parts from the broken-down pumps to repair those which had some hope of functioning in the future.

Although attempts were made to improve the fuel and oil supply channels, low river levels stranded a crucial fuel shipment upstream of Diré and the wrong oil was provided by a project supplier. Perhaps the critical blow was the continued low river levels (a manifestation of continued drought and a harbinger of the impending 1984-1985 famine) which required that the pumps be used to lift water from the distant river channel to the floodplain depressions which are, in normal years, flooded and the source of irrigation water. The pumps would then be moved to lift water from these depressions to the fields.

The project had become a continual struggle to resolve crises before another set arose. In this environment, little time was left for the one activity which could have improved the chances for long-term sustainability, namely the development of a viable local institution to manage irrigation. Despite all of the failures, farmers were still anxious to participate because irrigation provided security against local food shortages and because secondary crops had emerged as a result of expanded irrigation, which offered real income-generating potential (spice sold downstream in Niamey, Niger fetched approximately US\$8/kg; the market for tobacco was also robust). The tasks of instilling into farmers a notion of the importance of sound pump O&M, developing an indigenous pump-repair capacity, and involving private merchants in the fuel and oil supply channels, were unfortunately put on the back burner. Had proper attention been paid to these tasks, the outcome of the project might have been much different.

Village Cooperation and Support from NGOs in Gao, Mali

Since the protracted Sahelian drought and associated famine of 1984, there has been a rapid increase in the number of lift irrigation systems in the vicinity of Gao, Mali. Like Diré, these systems rely on the Niger River as the primary water source. Unlike Diré, there was no well-developed traditional irrigation sector in the area (although flood-recession agriculture was widely practiced). The following summary of lift irrigation development in the Gao area was derived from the work of Diabate (1990), Demebeley (1991), and Darghouth and Seckler (1989).

The development of lift irrigation systems in the vicinity of Gao has followed a general physical strategy. This includes a protection dike to protect the command area from high water, an earthen water distribution network to distribute water via gravity to individual plots, and a motor pump to lift water from

the river to the canal system. By 1989, the number of village irrigation systems had risen to a total of 50 schemes irrigating 650 ha scattered along 400 km of the Niger River floodplain.

Some of the systems developed near Gao were set up with financing provided by donors and administered by the Malian government. Others were supported by nongovernmental organizations active in the area while still others sprang directly from local initiative and investment. Initial investment costs for these systems ranged from a high of US\$16,033/ha for systems receiving outside financing to a low of US\$1,212/ha for systems financed through local initiative. Despite these different start-up costs, the rice yields were fairly uniform from system to system, ranging from 3-4 t/ha, a 5 to 10 fold increase in yields relative to flood recession production systems.

The costs associated with production in the village lift irrigation systems are low. This is positive in the short-term but risky in the long-term. Little investment is made in fertilizer; in some cases none at all. Money to purchase fuel is often in short supply, leading to failure to replace oil and filters at recommended intervals. A mechanical problem with the pump is often followed by a protracted period without irrigation, while farmers try to pull together the money needed for replacement parts and services. Cumulatively, these shortcomings lead to yields, which though better than traditional systems, fall short of what is being achieved elsewhere in West Africa.

This situation is aggravated by the low price, US\$0.28/kg, which the government is willing to pay for unprocessed rice. In some cases, this fails to meet even the costs of production. Processing the rice before marketing offers some potential to improve the situation but requires additional investment in processing equipment.

A specific example of a village lift irrigation scheme in the vicinity of Gao is the Boya system, located 60 km from the regional capital. The system was developed through cooperation between the village and two NGOs, one Malian and one Canadian. A total surface area of 50 ha, divided into individual plots, is irrigated by two motor pumps. The protecting dike and canal works were constructed by the villagers themselves. The protective dike was equipped with a control structure to provide direct access to river water when the river level allowed. New agronomic practices, such as seedling nurseries and the use of fertilizer were also promoted.

The end result of the collaboration between the village of Boya and the two NGOs is a lift irrigation scheme which seems ready to be operated independently of external support. Following four years of financial and technical support, the elected managing committee has taken over operation of the system with promising prospects for long-term success.

The economic performance data from the Forgho lift irrigation scheme reveal that irrigation of rice in the vicinity of Gao is not as profitable as in other parts of West Africa. In 1988, the net benefit in this system was US\$757.80/ha. This was below what was achieved in the Senegal River Valley.

Often, the strategy of the farmer is not at the level of capitalization or income maximization, but of minimizing poverty and ensuring a sense of dignity, as is indicated in the following remarks by a farmer in Mali about his irrigated land:

"It doesn't rain and we have nothing else. Between falling into debt growing your own rice, and falling into debt in idleness in Gao, what would you choose in our place? We've always been in debt since the drought. What's new is that there's hope here. While the irrigation scheme may not be good economics, it does mean dignity. We shall never leave!" (Club du Sahel 1991, 59)

Fadama Surface Lift Irrigation in Northern Nigeria

In the past two decades in northern Nigeria, surface water bodies in shallow depressions or "bottom lands" have rapidly been developed for irrigation using small gasoline-powered motor pumps for water lifting. This has been part of the rapid expansion in *fadama*, (alluvial bottom land), irrigation which has occurred in the past decade. The majority of new *fadama* irrigation relies on the development of groundwater as a water source. Nonetheless, wherever reliable surface-water resources are found, farmers are finding ways to exploit them using the small motor pump. This has led to some very interesting organizational arrangements which have arisen out of spontaneous farmer cooperation, rather than from the initiative of government agencies or external donors.

Along Gari Creek in the Ja'mana River Valley, a communal buried pipeline had been installed by a group of 16 farmers, to carry water from the stream to the top of a ridge which parallels the watercourse, at a distance of approximately 500 m from the water's edge. Financing of the pipeline was done in collaboration by the farmers without external assistance. They also worked together to construct a fence around their approximately 5 ha of land. Each farmer had his own motor pump, however, and was responsible for irrigating his own crop. The members of the farmer group took turns setting up their pumps at water's edge and using the common discharge pipeline to deliver water to the top of the ridge. From there they directed the water towards their own field through a communal water distribution network. During peak irrigation periods, farmers generally had access to the pipeline once every five or six days.

Another organization for the use of surface water arose along the banks of an impoundment reservoir built as part of a larger gravity-fed irrigation system. In this location, a group of farmers had dug a common trench back from the low water mark of the reservoir to their fields, which were located on the high-water banks of the reservoir. The trench was over 300 m long and over three meters deep once it arrived at the irrigated fields. Using this trench, the farmers had access to irrigation water, which they lifted from the trench with individually owned motor pumps, even when the reservoir level was lowered to satisfy the irrigation requirements of farmers in the gravity-fed system downstream. Maintenance of the trench was carried out in common, although all other tasks related to irrigated agriculture were carried out on an individual basis.

A study conducted by the Ahmadu Bello University in Zaria, Nigeria in 1981 compared production costs of tomato production on surface *fadama* land under irrigation using the traditional shaduf versus small motor pump lift technologies. (Nwa 1981) The study, conducted near Zaria, found that the average water-lifting rate for farmers using the shaduf was 75 liters/minute (l/min), with a range varying from 2 to 87 l/min, depending on the age, strength and experience of the operator, as well as time of day. The typical 5 hp motor pump lifted a more steady average of 300 l/min. For the shaduf system the study demonstrated that labor inputs constituted 63 percent of total production cost, with irrigation being the highest labor-consuming activity. For the pump system, irrigation labor constituted only 15 percent of the total production cost, with harvesting being the highest labor-consuming activity. The total cost of tomato production on one hectare of *fadama* land was found to be 2,800 naira (US\$4,900, in 1981 dollars) for the shaduf system and 2,866 naira (US\$5,015, in 1981 dollars) for the pump system.

The advantages of the shaduf system are its low investment costs (about 431 naira per unit; US\$754, in 1981 dollars). Its disadvantages are its very high labor requirements (which is also costly since other studies have shown that even since the 1970s much of the irrigation labor was hired, [Orewa 1978]), its low discharge and water application rates and the small area which can be irrigated. The reduced area is important, since to be obliged to irrigate only land adjacent to the stream or pond area often excludes cultivation potential on unflooded slope land which is more suitable for higher-value cash crops such as tomatoes, onions, potatoes and carrots. The advantages of the pump systems are their

much higher discharge, larger area which can be served through conveyance of water over greater distances (including to nonadjacent slope land) and lower human labor requirements. The main advantages of the pump systems are their higher investment costs (about 1,085 naira per unit; US US\$1,900, in 1981 dollars). Over the last two decades there has been a rapid increase in the use of small motor pumps for fadama irrigation. There is now approximately 800,000 ha of irrigated fadama land in Nigeria.

Farmers in northern Nigeria are clearly willing to both invest in and organize themselves to take advantage of the presence of reliable surface-water bodies, using small motor pumps. There is currently very little space left unirrigated along the rivers and streams in fadama areas. The challenge facing these farmer organizations is to assure that their needs and desires are not ignored as rapidly growing northern Nigeria grapples with how best to allocate surface-water resources between the sometimes competing interests of surface lift irrigation, gravity-fed irrigation, inland fisheries, and industrial development. In addition, close attention will have to be paid to the environment quality of the water and soils in the low-lying fadama lands.

Attempted Management Transfer in Logone River Valley, Cameroon

In northern Cameroon along the west bank of the Logone River, a large-scale lift irrigation scheme was established by Societe d'Expansion et de Modernisation de la Riziculture de Yagoua (SERMY) which supplied water to about 5,300 ha of land. The system involved the installation of four electric pump stations, the construction of a flood control dike to protect the command area from high water, and a drainage network to evacuate water from the command area. Details of the SERMY system are taken primarily from the work of Bikoi (1991).

The total management of the system was assured by the agency itself, leaving very little authority in the hands of the farmers. In fact, their role could be accurately be described as that of laborers in an agro-industrial enterprise. They were required to pay dues to SERMY for the inputs they received and to sell their rice to SERMY for distribution (the objective of irrigation development was to reduce Cameroon's dependence of imported rice). In 1988, the income derived by farmers from rice production was US\$480/ha. However, the typical holding in the SERMY system was only 0.5 ha, resulting in an annual income of US\$420/year.

In spite of the dominant position of SERMY, the final cost of the rice they produced was US\$0.87/kg, well above the US\$0.32/kg paid for imported rice off-loaded at the port of Douala. The difference was due largely to the difficulty of transporting rice from the extreme north of the country to the population centers in the south of the country. In its best years, SERMY was supplying only 20 percent of the national market (although a good deal of SERMY's rice finds its way illegally to Chad and Nigeria where its cost is more competitive). Efforts to subsidize SERMY rice led to further drains on SERMY's finances and in the end it was decided to realign the SERMY production goals into line with the demand in Northern Cameroon and transfer much of the management authority to the farmers.

This transfer process was done quickly, with little attention being paid to institutional development. This was a serious mistake since many of the farmers in the region had moved into the area in search of an income-generating activity. There were no traditional institutions in place between these individuals which could structure the management of the irrigated rice land. Although some farmers did try to organize themselves into an association for the procurement of inputs and the marketing of rice, most were left to their own devices. At the time of Bikoi's research, production levels were down as were irrigation-related revenues. Farmers who had moved into the region were returning home out of frustration with the low profitability of the enterprise. The failure to develop strong institutions, especially

for corporate provision of inputs, marketing and irrigation, had placed the future of the entire system, and the investment which had been made in its construction, in jeopardy.

Successful Agency Support for Self-Managed Lift Irrigation: ONAHA, Niger

A relatively successful example of agency-supported development of lift irrigation transferred to local management by farmers is in the case of Office National des Aménagements Hydro-Agricoles (ONAHA) which was established in 1979 in Niger.

ONAHA is the parastatal agency responsible for irrigation development, oversight for management and guidance and support for farmer-irrigation cooperatives. Farmer cooperatives are organized and frequently consulted during the design and construction of new projects. Where possible, farmers are further organized into Groupement Mutualiste de Production (GMPs) (Mutual Production Groups) along more traditional lines composed of members from the same village for example. ONAHA's primary role is to provide advice, training and other support to the irrigation cooperatives rather than engaging in direct management of the irrigation systems.

ONAHA interacts with cooperatives and enters into contracts with them to provide required training and other services. Contracts between individual farmers and the cooperative should obligate and entitle farmers to responsibilities and rights specified in each cooperative's Agreement. Unfortunately, irrigation cooperatives have not yet received full legal status in Niger to effectively enforce rules and regulations. Cooperatives and farmers currently deal with this unfavorable situation through seeking help from outside local government and administrative authorities.

In theory, irrigation cooperatives agree to make certain investments and repayment for new irrigation projects, plan the crop calendar, provide agricultural inputs, set and collect irrigation fees, perform routine maintenance, manage capital depreciation/replacement and crop input credit funds, and manage diverse sideline enterprises for additional revenue raising. In fact, this varies between cooperatives with many facing serious economic hardships making financial commitments more difficult to achieve.

ONAHA is often contracted by the cooperatives to conduct heavy maintenance or rehabilitation work or to maintain some pumping stations. It also grants loans to the cooperatives for both irrigation and agricultural purposes (Club du Sahel 1991, 55). ONAHA is currently undertaking complete restructuring where it will relinquish prior construction activities and concentrate more on providing essential services. ONAHA will retain a level of maintenance responsibilities (pumping stations, some infrastructure maintenance) under similar contractual arrangements as in the past. Perimeter directors previously paid and supervised by ONAHA will be redesignated as cooperative directors with much more responsibility to the cooperative itself. Eventually, it is hoped that the cooperatives will cover all costs associated with perimeter management and maintenance.

7. Research and Development Priorities for Lift Irrigation in West Africa

7.1. Technical Challenges

The internal combustion engine is the dominant modern technology used for water lifting in West Africa, particularly the small gasoline-powered motor pump. Some would argue that the use of these pumps is not sustainable and thus cannot be considered an appropriate technology. Some point to the eventual decline in the availability of fossil fuels and the more immediate lack of infrastructure to support the pumps (i.e., spare parts, repair services) as justification in support of promoting manual water-lifting

devices and pumps which rely on alternative sources of energy. Evidence from several locations in West Africa refutes this assessment.

The explosive increase in the use of small motor pumps in northern Nigeria was initiated through a program of government subsidies and credit programs. However, now many farmers have secured and operated their pumps outside of the structure of a formal project to provide spare parts and repair engines. Certainly, some of these pumps were poorly maintained and operated, broke down early, and failed to provide an attractive return of the initial investment. The continued interest in the technology, however, proves that this pattern of failure has not been universally felt. In fact, many, if not most, individuals in northern Nigeria have had a positive experience using the motor pump, or witnessed positive results from neighbors. The emergence of private support structures in support of the technology confirms that those with money to invest are optimistic that the technology will remain viable for the foreseeable future.

Experiences such as in Ngouri, Chad show that local motivation and capability exists in marginal and even poorer areas in West Africa to invest in and manage irrigation powered by small motor pumps. In Chad, support arrangements for the motor pumps were created where none had previously existed. Both a spare part distribution network and a pump repair capacity were successfully developed. The pumps are being successfully operated by individuals willing to use them to their potential. In fact, across West Africa, farmers who have access to adequate land resources have been able to profit from the introduction of small motor pumps. As for the long-term availability of fuel in the region, the known reserves in Nigeria and anticipated oil fields in Chad, Cameroon, Niger and elsewhere should assure the availability of fuel in the foreseeable future.

1. For the foreseeable future the motor pump will be a cornerstone of farmer-managed lift irrigation development in West Africa. As such, efforts should be made to make its use as profitable as possible. However, in many purely farmer-managed lift irrigation systems employing motor pumps, the pump is not operated nor the irrigation water managed in the most efficient manner possible. Evidence from southern Niger suggests that the incidence of excess fuel being consumed through improper pump operation and irrigation water being lost through inefficient distribution and application sub-systems reduce the profitability of motor pump use. Fuel prices are expected to continue to rise in Nigeria and will likely increase significantly in other West African countries. This fact, along with motor pump purchase price increases, should provide a strong incentive to maintain profitability through better use.
2. Wherever motor pumps are used for lift irrigation there is a need for local people to learn how to optimize pump operation under local conditions. The key physio-technical factors which users or equipment providers need to understand are depth to water, pumping head and well recharge rates. To improve water-use efficiencies farmers must learn to develop better canal design, reduce canal losses and increase on-farm application efficiency. Governments in the region need to ensure that support services are extended by technology suppliers and by involved government agencies and that the agents are well-trained in technical aspects. Farmers also need to be properly trained in preventive maintenance to extend the life of their motor pump.
3. Efforts are needed to evaluate how optimal pump operation and water management would change for various cropping patterns. These efforts should be planned in such a way to develop general recommendations based on simple parameters, such as soil texture, which can be used for support providers to make useful suggestions regarding pump and irrigation management in particular locations. This will also help ensure that the correct technology package is matched

to the actual site conditions which will make optimization of operation and water management easier to achieve.

4. A reliable water source is crucial for successful motor-pump operation. In most cases, tubewells are better suited for use with the motor pump than hand-dug wells. Several tubewell installation methods have been developed in the region, each having its advantages and disadvantages. Technical initiatives by governments or NGOs should include a rapid inventory of tubewell installation methods and the development of criteria to be used in selecting the most appropriate method for local conditions. These criteria should account for the local hydrogeologic conditions, the capacity of the pump, and the anticipated water demand.
5. Access to adequate land resources is another requirement for profitable use of the motor pump. *If a farmer cannot expand his irrigated surface area to the optimal capacity of the motor pump, he will not be able to fully profit from its use.* In these cases, it may be better to rely on manual or animal-powered water-lifting devices to improve the performance of lift irrigation systems. Past experience with manual pumps has failed to provide a clear-cut alternative to traditional rope-and-bucket arrangements. Any increases in discharge which have been realized have been offset by higher investment costs and more complicated operation and maintenance. Nonetheless, certain conditions, such as in Cheddra, Chad may favor the use of a manual pump, particularly if it is associated with an improved groundwater-development technology. In these cases, a useful technical initiative would be training private enterprises to provide these pumps to the consumer. More work remains to improve the design of animal-traction water-lifting devices. If perfected, they should be promoted in areas where the local population has experience with animal traction and where the depth of water makes rope-and-bucket arrangements infeasible.
6. To date, the introduction of alternative energy sources for lift irrigation has remained fairly undeveloped. Photovoltaic cells have been successfully used to meet domestic water demand in isolated communities, although the lack of local competence to maintain and repair the systems has led to prolonged interruptions in service. Such interruptions would be disastrous if the pumps were being used for irrigation. If the reliability of the technology could be improved then it might merit further attention for irrigation. A more promising technical approach, however, is using windmills to generate electricity which can be used to power pumps. Commercial systems are already developed and being tested in North Africa, which will permit the irrigation of up to 15-20 ha under depth-to-water and wind conditions typical of West Africa. A study of the performance of such systems in West Africa, and the constraints on their introduction and use, would be a valuable technical initiative.

7.2. Agricultural and Economic Challenges

Given the tendency for farmers to associate irrigation with rice and the declining value of rice relative to other crops, there is a need to support experimentation and extension efforts for cultivation and irrigation practices for other crops which have higher economic potential and may be more suitable for local conditions than rice, with its high water requirements. Often, the difference between financial viability or nonviability of irrigated production hinges on the production of a second crop.

A study done by the Club du Sahel (1991) estimates that one new hectare of land brought under irrigation creates additional permanent employment for between 5 and 15 people, depending on the yield

and cropping intensity. A village system growing two crops per year produces near to the 15-person figure. This is based on the assumption that between 80 and 200 person-days of labor are required per crop, which varies largely according to whether seeds are broadcasted or the crop is transplanted and to what extent any necessary threshing is mechanized. It is estimated that only an additional 25,000 ha of irrigated land was developed in the Sahelian countries (not including Nigeria or Cameroon) between 1978 and 1989. Following the above figures, this could have produced between 200,000 and 400,000 jobs, which is very modest in comparison with an increase in population of about 10 million people during the same time period. There are reports that male farmers have benefitted much more from irrigation development in the area than have female farmers, who lack the same access to the new production inputs, credit and income.

1. Research is needed on the suitability of growing various nonrice crops under different regimes of irrigation, from partial to full water control conditions.
2. Extension efforts to promote farmer trials with wheat production in the cold dry season should be supported as another way to increase cropping intensity. Greater interaction between Nigerian and francophone countries regarding wheat research and extension would be useful.
3. Crop diversification should be vigorously supported by governments with the help of NGOs and private enterprise. Crop diversification has the potential to increase the employment-generation capacity of irrigation and would also help to spread out the risks in West Africa's risk-prone environments. However, prior to any crop diversification recommendations, thorough marketing studies need to be undertaken to ensure that markets exist that can absorb increased production at a price profitable to the farmers.

7.3. Financial Challenges

As West Africa is one of the world's poorest regions, the introduction of new irrigation technologies usually encounters financial constraints. This has definitely been true in the case of the motor pump. Even some manual water-lifting devices, such as the one promoted in Cheddra, Chad, require larger investment on the part of farmers relative to traditional arrangements. Farmers evaluate the performance of new technologies in light of their personal financial situation. To develop a market, new technologies must perform well from the start. Prolonged periods of field-testing with frequent design revisions will weaken farmers' confidence that the technology offers potential long-term profitability.

The increasing popularity of internal combustion engines for water lifting has brought on a legitimate concern that the poor will not profit from improvements in lift irrigation performance. The cost of the technology itself, combined with the increasing pressure on the land in some areas, conspires to prevent poor farmers from practicing even traditional lift irrigation.

Development banks, government agencies and other credit-supplying institutions in West Africa have a generally poor record of financial sustainability. Because of low repayment rates and poor financial management, agricultural credit institutions often go bankrupt or move into less risky enterprises than helping poor farmers. Consequently, input providers are now very reluctant to supply inputs on the basis of credit. Farmers find it difficult to obtain credit from formal institutions and hence fall into a pattern of obtaining credit through local informal channels and paying cash to input providers. The risk inexorably falls back to the farmer.

Once a new technology is successfully introduced and in demand on the local market, however, financing the technology will remain a concern. Attempts by donor-funded projects and irrigation

agencies to act as credit providers have generally ended in disaster. The experiences in Abeche, Chad and Gande, Senegal bear witness to this danger. Repayment rates have been so low that either the program itself has collapsed or conflicts between lenders and borrowers have become so extreme that production has suffered. Attempts to create farmer-managed credit schemes to finance lift-irrigation activities have had mixed results. In Richard Toll, Senegal, some of the farmers' organizations have been able to secure loan repayments from their members and maintain the integrity of their credit systems. Others have seen a steady erosion of their financial resources due to noncompliance. Noncompliance and the failure to impose sanctions have also threatened the viability of the farmer-managed credit arrangements in Ngouri, Chad.

In both cases, sociologists played key roles in designing the credit arrangements. Although they made strong contributions to these institutions, they might have relied too heavily on external notions of financial management. These include the use of collateral, the application of fixed repayment schedules, and the reliance upon civil procedures to resolve conflicts.

1. Efforts are needed to identify constraints upon and options for access to the poorer farmers to modern lift irrigation, including group credit or rental arrangement. Governments and NGOs should examine traditional arrangements for credit and design financial arrangements which incorporate traditional notions of credit management. Field-testing and fine-tuning of these designs in various lift irrigation systems could improve the long-term viability of new technologies. Given the capital constraints felt in the region, financial initiatives may be the most important which could be launched. In many locations, it may be possible to help small farmers take greater control of marketing their produce by joining together in marketing cooperatives, especially where greater homogeneity exists within villages.
2. A clear distinction must be made between irrigation-development strategies for subsistence food security and development of irrigated agriculture for commercial purposes. Subsidized pumps and tubewell installation directed toward small-farmer groups may be needed for the benefit of modern lift irrigation technology to reach the poor. Development of commercially oriented irrigated agriculture can be facilitated by saleable land and water use rights, clear laws and regulations concerning investment practices and incentives to companies to invest where market conditions are favorable.
3. Training of farmer organization leaders in basic bookkeeping and financial management skills is needed urgently since the lack of financial control and financial mismanagement is a frequent cause of the failure of lift irrigation projects. Extension workers typically lack this kind of training and they should be given it to be passed on to the farming community. The fact that most farmers are illiterate does not make developing basic book keeping and financial management skills easy. However, a number of NGOs have been successful in developing these skills using simple methods while continuing to place great importance on literary training.
4. Given the difficulties experienced by state- and agency-run credit institutions with repayment, pilot efforts to establish village or supra-village level savings and loans organizations should be supported as an alternative strategy to extend credit to farmers, perhaps with help from the NGOs. It is important from the beginning that farmers understand and accept the necessity to meet their financial obligations. Moreover, state- and agency-run credit institutions need to carefully consider farmer ability to manage and repay credit before it is granted.

7.4. Environmental Challenges

As with irrigation in other arid and semiarid regions of the world, there are legitimate concerns regarding waterlogging and salinization associated with lift irrigation. This is particularly true in areas where irrigation water is characterized by elevated salinity levels, or where soils are saline. In areas such as these, farmers have developed an indigenous competence to manage soil salinity.

1. The use of investment in motor pumps requires that locally needed leaching and drainage practices be integrated into efficient water management practices. This can best be defined by the technology providers which can be supported by government incentives and sanctions. Farmers often understand the need for drainage and leaching but often require financial assistance in order to apply the excess water to make leaching and drainage possible.
2. In other areas of West Africa aquifer overdraft is a real concern. Motor pumps increase the quantity of water withdrawn from groundwater relative to traditional rope-and-bucket arrangements. In places such as northern Nigeria, the number of pumps is increasing so fast that drops in regional water tables are becoming noticeable and discontinuous perched aquifers are drying up. There is a real need to provide expertise to determine the capacity of regional hydrogeologic resources to meet the increased water demands associated with groundwater irrigation. Environmental initiatives should monitor and protect against the emergence of long-term environmental degradation and the more eminent possibility that water supplies will fail to meet demand. There is a need to develop regional geographic information systems, based on hydrologic units such as river basins or aquifers, in order to monitor water and land quality conditions relative to land use practices.
3. The increase in irrigated area associated with motor pump use also puts increasing pressure on land resources. Using traditional water-lifting arrangements, farmers in many parts of the region have been unable to irrigate their entire landholdings. By default, a fallow rotation is often practiced whereby a farmer irrigates a portion of his land, paying little attention to soil fertility management, until he notices yield reductions. He would then move to another section of his land and begin anew. Based on this rotation, fallow periods could last as long as 10 to 15 years. The increased discharge provided by motor pumps allows farmers to irrigate larger areas. This will undoubtedly shorten the duration of the fallow period and, unless increased attention is paid to *soil fertility management*, could reduce long-term productivity of the soil. Environmental initiatives in the region should consider this possibility and develop strategies to monitor and avoid soil fertility depletion through extension and training efforts.

7.5. Institutional and Policy Challenges

As has been indicated by the case descriptions and also by the conclusion in a study by the Club du Sahel (1991), agency-driven lift-irrigation projects in West Africa too often entail conflicts of interest between the agency and farmers as well as lack of farmer participation. High construction and recurrent costs (which farmers are often unable to pay) often lead to a poor collective response by farmers, poor financial and maintenance sustainability and low-cropping intensity. On the positive side, agency-driven projects tend to include land reform or allocation, creation of input and market-support services, credit programs and high potential for productivity and profitability, if managed properly (which however, is often

not the case). Typically, countries in the region have a very low capacity for technical supervision and administration of support services.

Lift irrigation which is developed and traditionally managed tend to have limited potential for expansion or intensification. Credit, marketing and other support services are often restricted or not available. On the positive side, traditional lift irrigation tends to evolve more compatibly within the overall livelihood strategies of villagers. It is low-cost, places importance on low-risk subsistence needs of villagers and is much more locally sustainable than agency-driven projects.

Modern farmer-managed irrigation institutions have only recently begun to emerge in West Africa. These institutions are filling the void between traditional systems which rely on the initiative of individual farmers and the agency-managed systems driven by the rules of irrigation bureaucracies. As a result, nascent groups of irrigators suffer from a lack of experience in establishing new institutions. In the SERMY system in Cameroon, irrigation institutions which were rushed into existence failed to provide for the most basic inputs for irrigated agriculture.

In the environment of structural adjustment programs of the 1980s and 1990s, West African countries are increasingly transferring management of irrigation and irrigated-agricultural functions to farmer organizations, rural development NGOs and private enterprises. This is often being done in an environment where liberalization and development of viable local institutions for managing agricultural resources are still in the very early stages. Irrigation management transfer has gone the farthest so far in Mauritania, with the privatization of Société Nationale de Développement Rural (SONADER) for irrigation development and management and in Senegal with the disengagement of the state SAED (Société d'Amenagement et d'Exploitation des Terres du Delta du Fleuve Sénégal et de la Falémé) for management of irrigated agriculture. That farmer organizations have the potential to manage irrigation systems and jointly manage technical equipment such as pumping stations is partly affirmed in the case of ONAHA in Niger. This is also a case for evolving a clear and well-managed role for an agency as a provider of support services.

Issues of land tenure and related water rights weigh heavily on the viability of locally managed lift irrigation in West Africa. A great variety of traditional and modern systems exist. In Niger, all land legally belongs to the state. Irrigated land is generally found on land- developed by the state, so that farmers settle on land upon which usufruct rights are then allocated. There tend to be fewer conflicts in this setting than in places like Senegal, where state-owned and -developed irrigable land has often been superimposed on village lands with old traditional systems of land and water rights. Traditional systems are often in conflict with state welfare or equity objectives. Given the varied and complex ethnic and traditional legal systems, village authorities often get the upper hand in determining which system is realized locally. Most land in Chad is controlled by village chiefs, although local entrepreneurs can, in theory, purchase land titles through local district government offices.

1. Institutional initiatives to support sustainable lift irrigation in West Africa should include low-cost farmer-to-farmer training for leaders of new farmers' associations. In many cases, new organizations are at a loss as to how to proceed in defining the rules needed to govern their existence. The growth of NGOs in the region is a welcome sign because their role is much needed in addressing the technical and institutional aspects of small-scale lift irrigation projects at the village level.
2. An additional requirement for institution building is policy analysis directed towards the creation of legal structures which protect and promote the rights of these associations. Policy analysis should be launched to determine the feasibility of codifying land tenants' rights and promoting long-term leases. Insecure land tenure creates disincentives to optimize agricultural production.

Stronger land tenure laws and sanctions could give farmers both the confidence and the security needed to locally create and govern institutions necessary for effective lift irrigation.

3. Governments should actively promote the role of the private sector in tubewell installation, including training activities as well as policy analysis leading to institutional reforms which will permit the emergence of private tubewell installation enterprises. Governments need to help promote increasing activity of NGOs and private enterprises and coordinate their activities to ensure compatibility with national equity and welfare objectives.
4. There is a need for more emphasis on "in-house" training of agency staff for agencies reorienting themselves as providers of support services. Emphasis is needed on how to provide various technical, financial and managerial services to farmers in response to requests from farming communities. Technical staff and extension workers could considerably enhance their ability to work effectively with farming communities through training understanding that farmers are partners and knowledgeable resources in development and gaining knowledge of methods as participatory rural appraisal. NGOs are particularly suited to this kind of activity and should be engaged extensively by West African governments as partners, especially in village-level training programs.

8. Conclusion

Farmer-managed lift irrigation is a growing opportunity for rural populations in West Africa to take better advantage of their local resources to increase food security and income generation. If they can do so in an environmentally sustainable manner then lift irrigation will certainly contribute to a better quality of life in West Africa.

References

- Allen, W.M. 1992. Wasting the rain: Rivers people and planning in Africa. Earthscan, London.
- Bikoi, Achille. 1991. Large-scale irrigation schemes in Northern Cameroon: Development and disengagement. ODI Irrigation Management Network (African Edition). no. 8. pp. 1-23.
- Biswas, Asit K. 1987. Irrigation in Africa. ICID Bulletin. vol. 36. no. 2. pp. 1-11.
- Bunting, A.H. 1987. Irrigation in Africa's agricultural future. ICID Bulletin. vol. 36. no. 2. pp. 12-23.
- Chambers, Robert. 1988. Managing canal irrigation: Practical analysis from South Asia. Cambridge University Press, Cambridge, U.K.
- CTA. 1991. Irrigation: Les petits projets ont plus de chance de reussir. Spore. no. 36. pp. 1-4.
- Darghouth, Salah and David Seckler. 1989. Private-sector irrigation in Mali. World Bank Mission Report. Washington. D.C.
- Dembele, Souleymane. 1991. Developing village lift irrigation in Mali. ODI Irrigation Management Network. no. 5. pp. 9-12.
- des Bouvrie, C. 1973. Eaux souterraines facteur important du developpement agricole de l'Afrique Occidentale. L'Agronomie Tropicale. vol. 28. no. 9. pp. 607-626.
- Diabate, Teninko. 1990. Les perimetres irrigues dans la vallee du fleuve Niger-Nord du Mali (Gao). Workshop on African Experiences with Farmer-Managed Irrigation Systems. IIMI/MARA. Rabat, Morocco.
- Diop, Mor. 1990. L'amenagement de Ndombo-Thiago: l'experience du perimetre intermediaire et les bases d'une operation d'autogestion paysanne. Workshop on African Experiences with Farmer Managed Irrigation Systems. IIMI/MARA. Rabat, Morocco.
- Driscoll, Fletcher G. 1986. Groundwater and wells. Johnson Filtration Systems. Inc. St. Paul, Minnesota.
- ENR News. 1985. Big irrigation projects fail at feeding Africa. McGraw-Hill Construction Weekly. vol. 214, no. 3. pp. 10-11.
- FAO (Food and Agriculture Organization of the United Nations). 1986a. Irrigation in Africa south of the Sahara. Investment Center Technical Paper No. 5. Rome.
- FAO (Food and Agriculture Organization of the United Nations). 1986b. Water lifting devices. Irrigation and Drainage Paper No. 43. Rome.

- FAO (Food and Agriculture Organization of the United Nations). 1987. Irrigation and water resources potential for Africa. Rome.
- Fraenkel, P.L. 1986. Water lifting devices. FAO Irrigation and Drainage Paper 43. Rome: FAO.
- Freeze, R. Allen and John A. Cherry. 1979. Groundwater. Prentice Hall. Englewood Cliffs, NJ.
- Gay, Bernard. 1992. Les systemes de pompage. Groupe de Recherche et d'Echange Technologiques (GRET). Paris.
- Harzebrrouck, D.M.C. 1991. Analyse des resultats et des techniques des exploitants des perimetres irrigues. Project Base Vallee de la Tarka. Fond European de Developpement. Naimey, Niger.
- Institut Technologique DELLO. 1991a. L'eau au Burkina Faso. Aubervilliers, France.
- Institut Technologique DELLO. 1991b. Presentation technique et economique de quelques petit systeme de pompage devant etre diffuses au Niger. Aubervilliers, France.
- Moris, Jon R. 1984. Managing irrigation in isolated environments: A case study of Action Ble-Dire, Mali from African Regional Symposium on Small-Holder Irrigation. ed. M.J. Blackie.
- Norman, W. Ray and Mohamadou Gandah. 1990. Characteristics of irrigation water management among small traditional systems of rural Niger. Presented at the Winter Meeting of the American Society of Agricultural Engineers. Chicago, Illinois.
- Norman, W. Ray and Abdou Sami. 1990. Irrigation water cost among different sahelian systems: The case of Niger. Presented at the Winter Meeting of the American Society of Agricultural Engineers. Chicago, Illinois.
- Nwa, E.U. 1981. An evaluation of small pump and shaduf systems of irrigation in Northern Nigeria. Samaru Journal of Agricultural Research Vol. 1 (December): 2.
- Orewa, S.I. 1978. The economics of dry season tomato production under the Cadbury Tomato Scheme in Zaria Area. Unpublished M.Sc. thesis, Ahmadu Bello University, Zaria.
- ORT. 1989. Reports of the Lake Chad Agriculture and Farmer Training Project. ORT, 'Djamena, Chad.
- Réseau Recherche Développement. 1989. Etude de cas: Les perimetres irrigués villageois de Matam (Senegal). Restitution de l'Atelier - Debat du 13 Fevrier. Paris, France.
- Samaru Journal of Agricultural Research. 1981. Vol. 1, No. 2.
- Snaterse, Arjen and Jaques Slabbers. 1990. Farmers, agencies and irrigation systems: A comparison of two village schemes in the Bakel Department in Senegal. Irrigation and Drainage Systems. Vol. 4. pp. 183-194.

UN (United Nations). 1988. Groundwater in North and West Africa. Natural Resources/Water Series No. 18. Department of Technical Cooperation for Development. New York.

Violet, J. Aviron; B.D. Ido A. Soumaila; P.N.G. van Steekelenburg and A. Waldstein. 1991. The development of irrigated farming in the Sahel: Irrigation policy limitations and farmer strategies, Synthesis Report. For OECD, Club de Sahel and CILSS. International Institute for Land Reclamation and Improvement: Wageningen, Netherlands.