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BARRIERS TO EXPANDING IRRIGATED AGRICULTURE IN SUBSAHARA AFRICA IMPOSED BY PUMPING COSTS

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1.0 BACKGROUND AND INTRODUCTION

1.1 Project Background

This report is the result of a study undertaken as part of a series of programs initiated in 1983 undertaken by the Office of Energy within U.S.A.I.D to assess critical policy issues functioning to the energy sector and its relationship to other critical economic activities and, in particular, agriculture.

During early 1983 a team from Arthur D. Little, Inc. completed a project in Pakistan dealing with the relationship between rural electrification, irrigation pumping, and agricultural output.(1)* This project exhibited in quantitative terms the important links between rural electrification, national energy planning, and the expansion of agricultural outputs. It dealt with many practical issues which impact near term decisions such as the cost to benefit ratios of increasing agricultural output via pumped irrigation, the impacts of electrified pumping on electric system capacity requirements, and the trade offs between diesel pumps, electrified pumps, and, in the future, photovoltaic pumps. Similar critical policy and project oriented issues are arising with increasing frequency.

In order to obtain additional insights into the connection between agricultural expansion using irrigation and energy sector planning, a member of the project team participated in an assessment of irrigation options at specific sites along the Senegal River(2) and made preliminary assessments of the potential impact of irrigation expansion plans on the energy sector (and vice versa). This work reinforced the conclusion of the vital role of energy related costs on agricultural economics where irrigation pumping is an important input.

*Numbers in parentheses refer to references at the end of the report.

The experience referred to above indicated that it is critical that energy related issues be formally addressed when considering large expansions in agriculture based on pumped irrigation. Otherwise, irrigation projects might be implemented which cannot be economically sustained over the long term once the recurrent costs associated with energy delivery to the pumping systems become transparent.

1.2 Importance of Irrigation Pumping

The expansion of agricultural output in many LDC depends increasingly on pumped irrigation systems. This is true for countries as diverse as Bangladesh, where irrigation pumping is essential for multiple cropping, to Egypt, where further expansion of agriculture is planned in arid new land areas and Senegal where development of the Senegal River Valley depends almost entirely on pumping. The expansion of irrigation pumping is now or could be accomplished via rural electrification programs. These programs are extremely important elements in energy sector planning and policy development. For example, in Pakistan, electric sector expansion consumes over 80 percent of the total energy sector budget. The major donors are also heavily involved in electric sector expansion programs amounting to well over $3 billion in 1982. Roughly 16 percent of World Bank financing and 25 percent of Asian Development Bank financing is devoted to electric sector infrastructure development - much of which is either directly of indirectly associated with rural electrification.

Irrigation pumping is a highly energy intensive process. As a result, the operation of the irrigation pumping systems is often the predominant load within the rural sector. For example, in Pakistan over 20 percent of all power generated is used for operation of pumping systems. Along the middle and upper sections of the Senegal River Valley over 90% of power generated is to operate irrigation pumps*. The large impact of pumping on electric loads is readily understandable given the typically low use in individual homes in LDC (.5-1 kWh per day) as compared to even a modest sized irrigation pump (50-200 kWh/day for a 10 kW pump)

*All power in these regions is produced by Diesel generators or Diesel pumps.

The role of pumped irrigation in increasing agricultural productivity and the well being of rural populations is becoming very important in some countries. For example, Pakistan is now marginally self-sufficient in food largely as a result of pumped irrigation, which is now used in over 15 percent of the arable land. Similarly, increasing agricultural production along the Senegal River Valley depends almost exclusively on the more than 300 pumping units most of which have been installed in the last five years.

In these and other countries, the continued operation of diesel and electrified pumps is becoming increasingly critical to the overall productivity and predictability of the agricultural sector. These pumping operations are, in turn, totally dependent on a predictable supply of energy at economically justifiable costs.

The issues associated with the cost of pumping water may already be influencing thinking on the role of the types of irrigation systems in Africa. For example, one World Bank official indicated that the extensive development of over 1,000,000 acres in Sudan based primarily on irrigation pumping might need to be reconsidered in light of increasing energy cost and lack of electric generating capacity. The higher capital cost options of gravity feed via use of dams and dikes would be an alternative in some areas.

This report deals primarily with the full range of costs associated with irrigation pumping and associated ramifications for agricultural economics and irrigation project planning. It is, however, recognized that many of the problems associated with irrigation projects in general and within Africa, in particular, are associated with institutional, social, and management issues. This view is described , in detail, in Reference 2.0 and was reinforced by a field worker on an irrigation project in Senegal who stated that "90% of my time is spent on managerial and institutional problems and only a small portion at technical and system design issues". It should be noted, however, that irrigation pumping often exacerbates these related managerial and social problems. For example, in Senegal a major portion of the managerial effort associated with operating the small (20 - 40 hectares) perimeters is associated with keeping the diesel driven pumps running. This is one reason that the mission reviewing pumping options in this region leaned toward electrifying the pumps where this was a reasonable option and, thereby, relieving the local irrigation perimeter management of much of the burden of maintaining and operating engine driven systems. In short, the effective management of the water distribution system, cropping schedules, and finances is a difficult enough task without the added complexities of the pumps. The evaluation of irrigation pumping options, therefore, should take into account the persistent problems in running and maintaining complex mechanical equipment as well as the conventional economic comparisons between pumping options.

There is, therefore, a vital link between agricultural production and energy sector capabilities which must be addressed if irrigation projects depending on pumped water are to have long term viability and, in particular, have recurrent cost structures (fuel, O&M, and capital) which are sustainable based on the increased value of agricultural outputs.

2.0 APPLICATION TO SUBSAHARA AFRICA

2.1 Irrigation Expansion Plans

Much of subsahara Africa has been experiencing drought or near drought conditions for over 10 years. This, combined with rapid population increases, has resulted in persistent food production shortfalls in almost all countries affected with associated periodic famine which have gotten renewed public attention as a result of the situation in Ethiopia. As a result of this persistent flirting with agricultural disaster, all the donors in this region are now or are considering placing major emphasis on the agricultural sector.

A significant portion of these resources will be directed toward projects involving the improvement or expansion of irrigation systems. For example, the CDSS for the Sahel(4) states "Our investigations have convinced us that the most likely evolution of rain-fed agricultural production will not yield the output goals and schedule we have set for the program. This production will inevitably be hostage to periodic severe drought. It is, therefore, advisable and necessary to undertake a major effort in irrigation development to exploit the considerable volumes of rive water which now pass through the Sahel unused. While much irrigation is currently practiced, only about ten percent of the potential is being exploited. A.I.D. and others have hesitated to undertake major efforts in irrigation because of the expensive infrastructure required, the technical sophistication involved in the operation, and the dismal experiences with many initiatives to date. Yet, irrigation development is required to realize the region's production potential and assure food security and we are convinced that these problems can be overcome. We propose to proceed deliberately, to acquire the necessary knowledge in selected pilot investments, to rehabilitate infrastructure in place and to gradually expand the activity as our competence improves."

On a similar note the Annual Budget Submission for U.S.A.I.D., MALI[5], indicates "From a national and regional planning framework, it is likely that only improved utilization of the Niger River for irrigation will close the gap between food production and population growth." As suggested above, the expansion of irrigation in the Sahel and other drought prone regions of Africa is an almost unavoidable result of a policy to expand agricultural output. As a practical matter, irrigation will be carried out wherever possible using gravity fed systems where the basic water supply is a river. However, in many (if not most) areas the topography is not conducive to gravity fed systems. For example, the Senegal River experiences changes of level of up to 30 feet between the dry season and flood stage and, as a result, almost all irrigation in MALI, Senegal, and Mauritania along this river would (and does) require pumping with significant vertical lifts.

In most countries of Subsahara Africa, long range plans for expanding irrigated areas are still in the development stage or are just beginning to be formulated. As a result it is difficult to project with much certainty the growth in irrigation and the nature (pumped, gravity, etc.) of the irrigation systems themselves.

A recent report on irrigation prospects in the Sahel[6] does, however, provide some figures in the gross potential for irrigation and possible rates of development. Table 2.1 provides an overview of current irrigated areas, potential to the year 2000 based on current trends or government plans, and ultimate potential of all or most lands suitable for irrigation are brought into cultivation. This table deals only with the 8 Sahelian countries. Other countries in a similar subsahara arid zone subject to recurrent drought conditions include Ethiopia, Sudan, Somalia, and sections of Nigeria and the Central African Republic. For the Sahelian region alone the FAO estimates that there is an estimated 12 million acres (4.85 million hectares) of land with potential for irrigation. By comparison, roughly 2 to 3 million hectares of land are now under some form of controlled irrigation in the countries indicated. The figures for the year 2000 are very uncertain for all of the countries which do not have long range plans. However, it appears that something on the order of 4 to 6 million hectors of land might be brought under irrigated cultivation as a minimum requirement to approach food self sufficiency.

2.2 Energy Implications of Irrigation Expansion

Table 2.1 indicates projections for total irrigated areas in the Sahel. A significant portion of this area will, however, be gravity fed in total or in part. For example, in the Niger River delta area most irrigation can be gravity fed by use of barrages and dikes. However, even in areas which use gravity fed irrigation during high water period, pumping may be required during the dry season to ensure a double cropping capability. This appears, for example, to be the case in parts of Niger.

Based on discussions with USAID staff and World Bank officials, it appears that the percentage of area requiring pumping will range between roughly 90% (Senegal) to about 50% (MALI). It is expected other drought prone countries of the subsahara will be equally dependent on active pumping to increase irrigated areas from present levels and allow for reliable multiple cropping.

The energy implications of pumped irrigation depend on several factors including:

- The volume of pumped water (cubic meters/hectare per crop) requirements of the crop as determined by rainfall, climatic conditions, soil conditions, irrigation system design, and crop selection.
- The depth from which water must be pumped.
- The efficiency of the pumping system (engines, motors, pumps, etc.)

The impacts of these factors on pumping energy and infrastructure requirements are discussed in section based on recent field experience in Senegal and

TABLE 2.1

Overview Of Irrigated Areas In Selected African Countries (in thousands of hectors)[1]

COUNTRY	1978	1985	2000	POTENTIAL
Cape Verde	1.9			5
Chad	4.5			280
Gambia	2.2	2.8		70
Mali	111.0	150		1000
Mauritania	1.9			200
Niger	5.8	6	200	220
Senegal	91.0	160[3]	170[4]	250[2]
Upper Volta	9.0	-	-	130
Sudan[5]		1610	2020	3000

1.0 Most figures from reference 10-3

2.0 Along Senegal River Basin alone

3.0 Introducing 25 along the Senegal River

4.0 Assuming 80 along the Senegal River

5.0 Based on discussions with World Bank

Mauritania. As indicated in Section 3.0, if diesel pumps are used, the fuel use can range from 100 liters/HA per crop for rainy season rice and modest lifts (5m) to almost 400 liters/HA per crop for dry season rice with low river levels. Even larger volumes of fuel (over 1000 litres per hector) are required to pump groundwater from depths quite common in the Sahel (30-60 m). This in itself could limit the use of groundwater resources in many areas - particularly for irrigating low value crops such as rice.

If the pumps are electrified, the corresponding electric sector capacity requirements range from 0.3 to 1 kW of generating - transmission capacity per hectare of land.

Of course, the above are just general "rules of thumb" based on water use and equipment characteristics in one regions. It is likely, however, that these figures are indicative of energy use and infrastructure requirements in other regions of subsahara Africa with similarly arid conditions and low rainfall to supplement pumped water.

Using the above general guidelines, that the Sahelian countries alone might have to import over__ barrels of oil annually and/or install up to ___ MW of generating capacity to serve irrigation growth to the year 2000. By comparison, total generating capacity in these countries is now only about __ MW. The energy use and infrastructure remifications of achieving a significant portion of ultimate potential in this region are large compared to present capabilities.

The above strongly suggests that plans to significantly increase irrigated agriculture in subsahara Africa must be closely integrated with energy system and fuel availability planning.

2.3 Energy Related Barriers to Agricultural Expansion

The previous section indicating that the costs of fuel importation and energy sector infrastructure development will be formidable if the role of irrigated agriculture is expanded significantly in Subsahara Africa. Clearly, much of the costs associated with infrastructure development will have to be assumed by donor organizations given the marginal financial condition of all the countries involved. However, a necessary condition for long term viability of expanding irrigated agriculture is that the projects at least support the recurrent fuel, O&M, and capital costs associated with servicing debt, fuel purchases, and O&M. If this condition is not met either the government (usually with donor support) will have to subsidize the systems indefinitely or the systems will fall into a state of disrepair as the farmers find themselves unable to provide their share of costs.

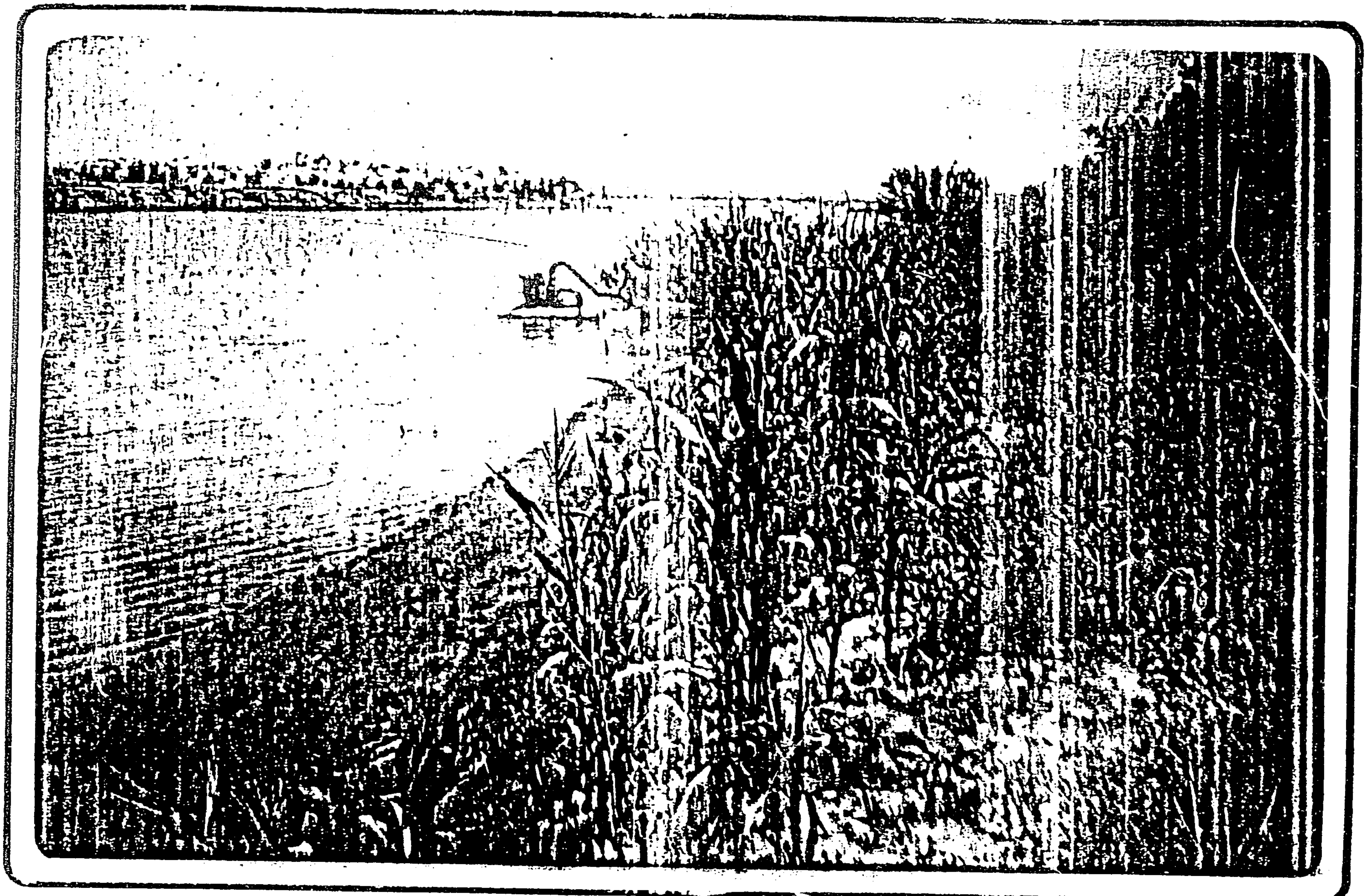
As indicated in Section 3.0, energy related costs impose several practical restrictions on pumped irrigation in the Sahel. These include:

Depth of Pumping:

Pumping energy requirements are directly related to the vertical lift through which water must be pumped. Particularly in regions where rainfall is minimal this can impose severe restrictions on the depth of wells or the height of irrigated areas above rivers. For example, in Senegal it was determined that pumping water through vertical lifts in excess of 10 meters had to be examined very closely based on energy related costs alone. This factor could often cast doubts on the use of groundwater resources even in regions where such resources are widespread.

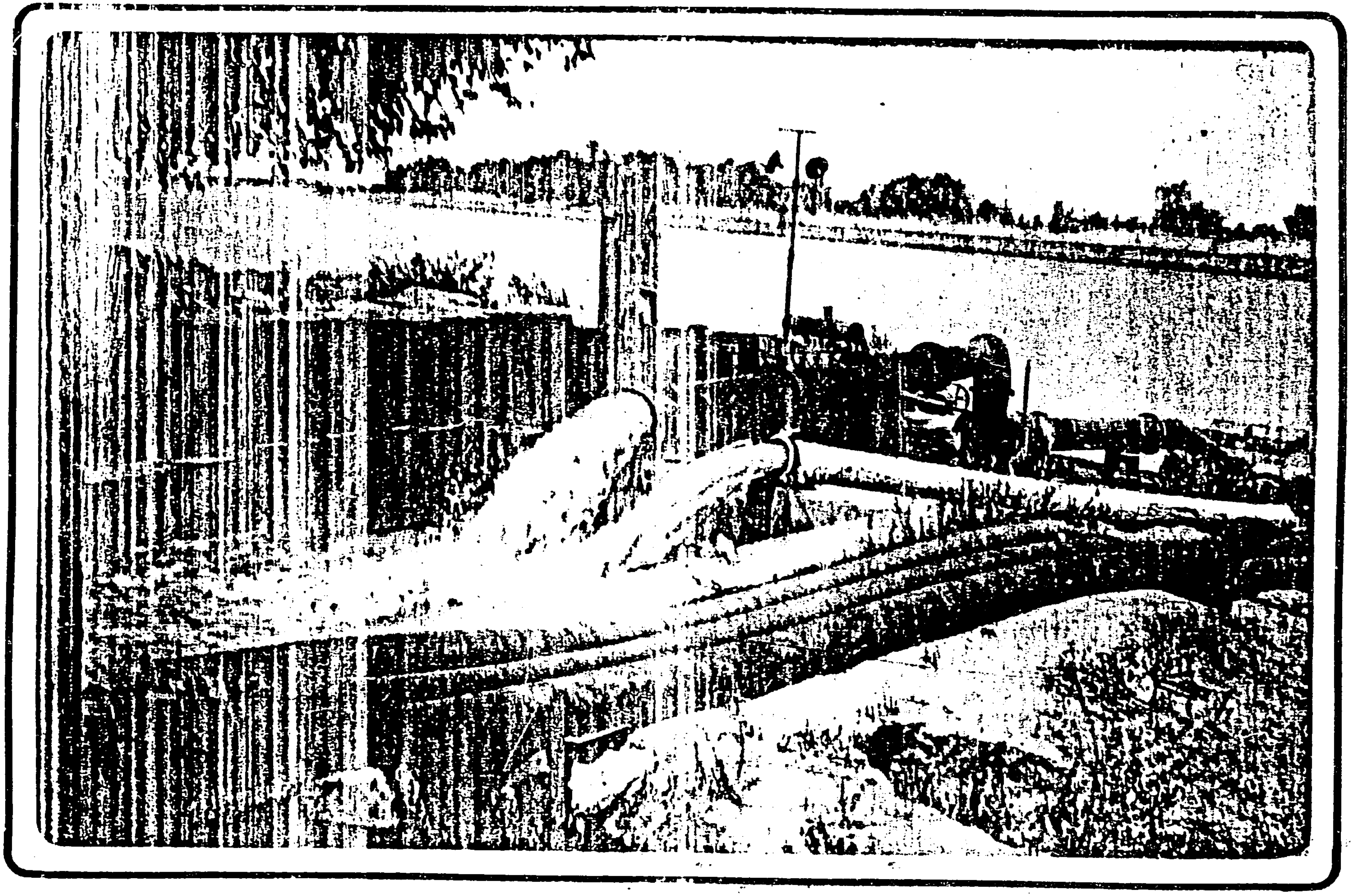
Double Cropping Potential:

A major incentive for pumped irrigation is to allow for reliable multiple cropping. However, "off season" crops are likely to be during dry periods (typically September through June in much of the Sahel) when rainfall is minimal and tran-evaporational rates very high. The result of these factors is that pumped water needs might be twice those of the "rainy season" crops. The economic viability of such hot weather crops should be examined closely in regions with significant pumping heads based on energy considerations alone.



3.4b FLOATING DIESEL PUMP SYSTEM (GNP) ALONG THE SENEGAL RIVER

(Note: Flood recession Maize crop in the foreground)



3.5a VIEW OF THE SUBMERSIBLE PUMP SYSTEM FLOATING PLATFORM, DISCHARGE
(Note: Pumps are suspended beneath the floating platform and are not visible)

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Crop Selection:

For historical reasons, rice is now a staple in many regions of the Sahel. This is unfortunately an example of a crop with very high water requirements even in zones with proper (high clay) soil conditions. In addition it is a crop with ample supplies at low cost in world markets. The combination of high water requirements and low value make rice an example of a marginal crop for pumped irrigation in many areas. The relationship between pumping needs, crop value, and alternative crop selections needs to be examined closely in all situations with significant pumping heads (over 5 meters). For example, in the upper regions of the Senegal River valley the pumping related costs alone are over 60% of the rice crop value. The above suggests the increasing importance of crop related research for the Sahel in order to identify crops with lower water needs than those traditionally grown in this region.

Irrigation System Design and Management:

Currently most pumped irrigation systems in the Sahel use open canals and unlined ditches to distribute water to the crops. These systems are relatively easily implemented in the field and use mostly local labor and materials. They also tend to have rather high losses - usually 30-50% of the water entering the system. In addition, there is a strong tendency to over irrigate, in part, a reaction by individual farmers to ensure that they get "their share" of the water. The net result of these factors is for the amounts of water being pumped to easily be twice that necessary if a low loss, carefully managed, irrigation system were utilized. With natural gravity irrigation the above factors are usually not very important and the open canal, furrow systems, represent an optimal choice for irrigation system design. However, with pumped irrigation the cost of water can be quite high (1-2¢/m^3) and the use of high loss irrigation networks increasingly unacceptable.

The question of balancing costs of irrigation networks (possibly involving canal lining, piping, etc.) in order to lower losses against lower pumping costs requires increasing attention as the role of pumped irrigation expands.

The above indicates several of the issues where pumping energy costs can restrict the options for pumped irrigation or significantly impact on the conditions under which pumped irrigation projects proceed. The situation is seen to involve a complex mix of energy systems, crop selection, and irrigation technology, issues which will be resolved differently in each area. However, the above suggests that it is important that the right questions be asked in the early stages of pumped irrigation project design so that projects are not implemented where energy costs alone call into question longer term economic viability.

3.0 ENERGY IMPLICATIONS OF PUMPING OPTIONS (Senegal Example)

3.1 Pumping Options Considered

As a practical matter, most systems for irrigation pumping in the near term will rely either on diesel driven pumps or on electricity supplied by a grid. The "grid" power will often, in turn, be supplied by a thermal power plant burning fuel oil, diesel fuel, or natural gas. In both cases, petroleum products may have to be imported to support the operation of the irrigation pumping system. The following discusses the fuel use by the two primary modes of energizing irrigation pumping so that their potential impacts on energy balances can be estimated.

a. Direct Diesel Drive

Figure 3.1a is a schematic of a direct diesel drive pumping system typical of those widely used where suction lifts are low. These systems usually consist of a Diesel engine directly driving a centrifugal pump.

The primary parameter determining fuel use in such a system is the system efficiency defined as:

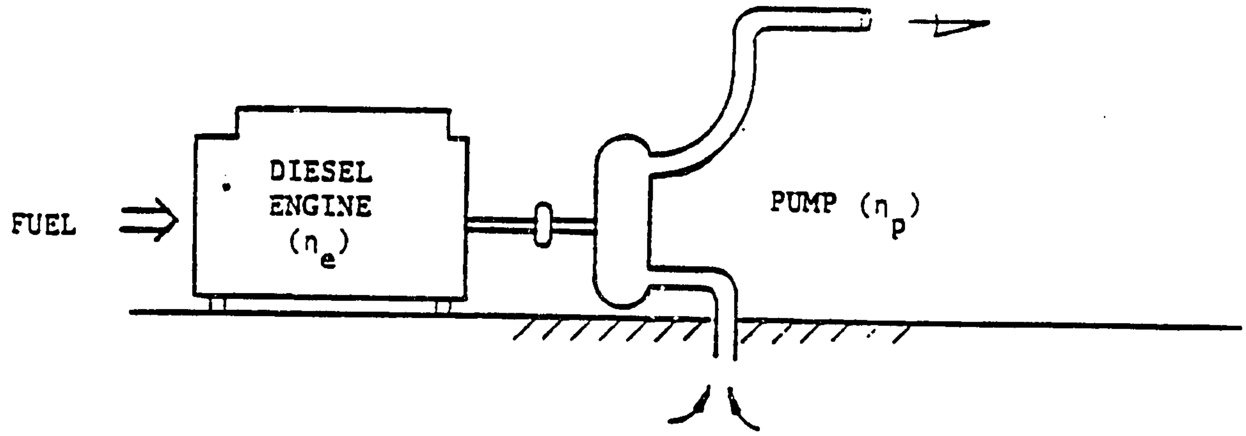
$$\eta_s = \eta_e \times \eta_p$$

where:

η_e - diesel engine efficiency

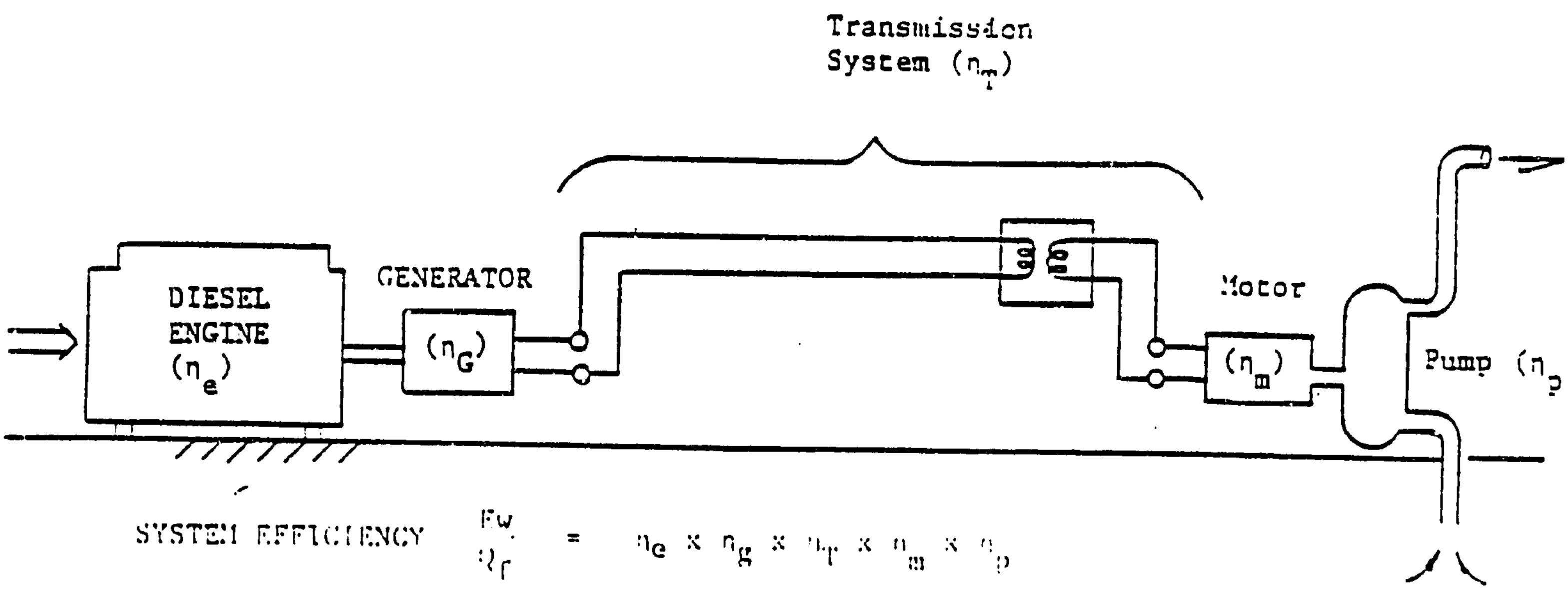
η_p - pump efficiency

As indicated in Reference 2, Diesel engine efficiencies in modest size (3 - 30 kw) typical of use in the Sahel are in the 20-25% range under field conditions. Properly selected pumps can operate with efficiencies of 70-80%. The net system efficiencies of direct drive Diesel systems is, therefore, in the 14-17% range. Achieving this efficiency range is still contingent on properly matching engines and pumps for the applications in question. For example, centrifugal pump



$$\text{SYSTEM EFFICIENCY} = \frac{\text{Energy to Water}}{\text{Fuel Input}} = \eta_e \times \eta_p$$

(a): EFFICIENCY OF DIESEL PUMP UNIT



$$\text{SYSTEM EFFICIENCY} \quad \frac{E_w}{Q_f} = \eta_e \times \eta_g \times \eta_T \times \eta_m \times \eta_p$$

(b): EFFICIENCY OF ELECTRIC PUMP SYSTEM

FIGURE 3.1 SCHEMATIC OF EFFICIENCY TRAIN IN PUMPING STATIONS

TABLE 3.1

PUMPING SYSTEM OPTIONS

- FLOATING PLATFORM DIESEL PUMPS
- FLOATING PLATFORM ELECTRIC-DRIVEN SUBMERSIBLE PUMPS
  - DEDICATED DIESEL GENERATORS
  - CONNECTION TO LOCAL ELECTRIC GRID (BADEL AND PODOR ONLY)
- PHOTOVOLTAICS
  HAND PUMPS
- STATIONARY PUMPS (USING DEDICATED DIESEL GENERATORS)
  - RIVER WATER
  - GROUND WATER

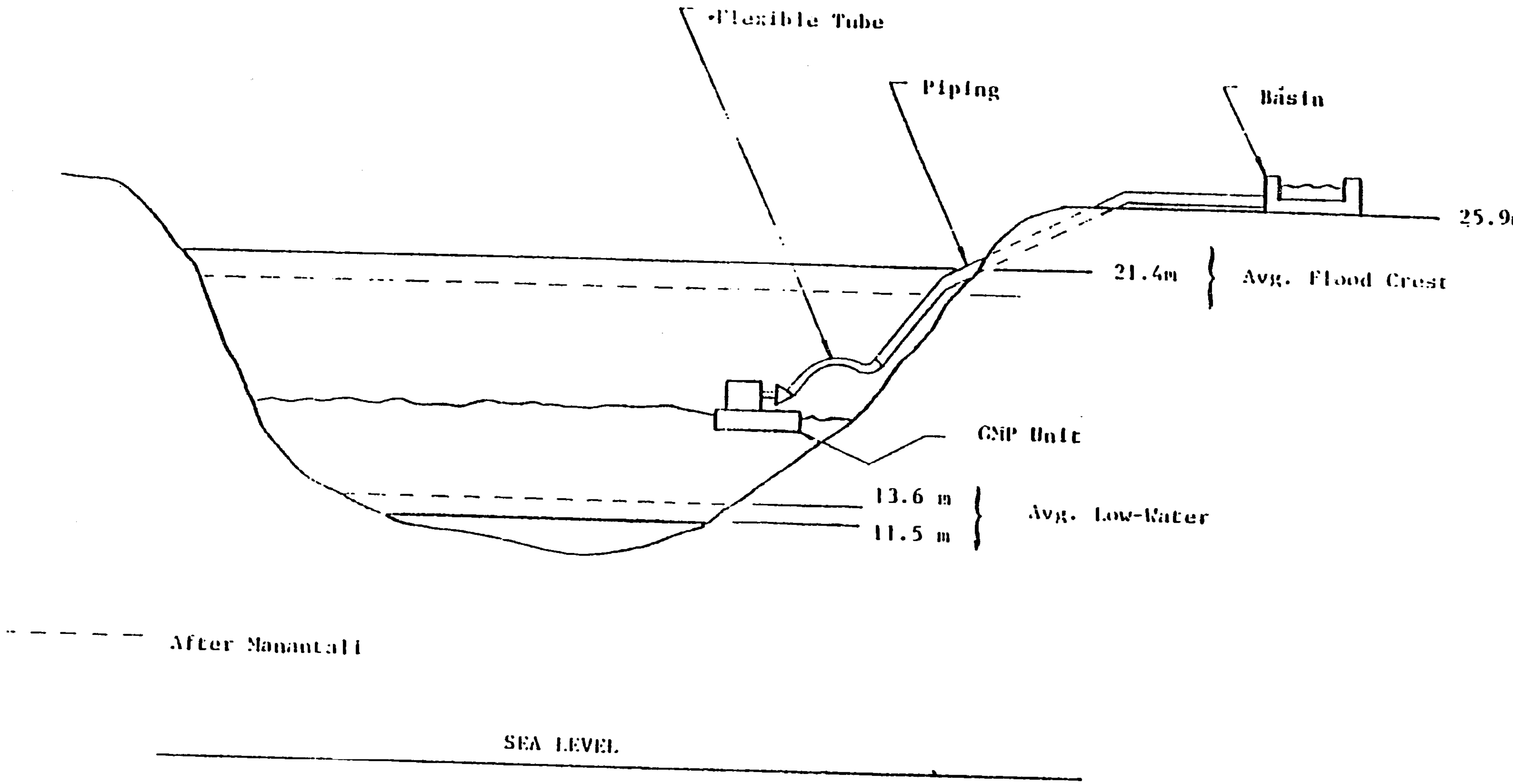


FIGURE 3.3 SCHEMATIC OF FLOATING PUMP SYSTEM (BAKEL REGION)

efficiencies can easily drop to 50-60% if used under inappropriate head conditions and/or poorly maintained inlet suction conditions. Improper pumping system can easily increase pumping fuel requirements by 30-50%.

b. Electric Driven Pumping System

Figure 3.1b is a schematic of an electric driven pumping system assuming the source of electricity is a thermal plant (shown as a diesel generator). As indicated, the efficiency of this arrangement (which includes many rural electrification systems) is given by:

$$n_s = n_e \times (n_g \times n_T \times n_M) \times n_p$$

n_s = electric generator efficiency
n_T = transmission/distribution line efficiency
n_M = electric motor efficiency

There is a common perception that the electric option would be more energy intensive than the direct drive Diesels due to losses in electricity generation transmission, and motors. Indeed, if the engine and pump efficiencies for the two options are the same, then the electric option will require 20-30% more fuel than direct drive Diesel systems even with line losses within accepted ranges. In practice, however, the electric option will often involve larger Diesel generators operated by the utility which, on average, might be more efficient than small, locally maintained, engines. For example, this appears to be the case in Senegal. The small (500 kW) of Diesel capacity at the towns along the Senegal River operate with efficiencies of 25-28% which is higher than would normally be expected from a 20 kW field unit. In properly designed systems (particularly those with low line losses), the higher engine efficiencies will tend to counteract the electric conversion/transmission inefficiencies.
To account for the wide range of possibilities two cases are considered below:

(i) High Efficiency System

This case assumes a well maintained electric generating and transmission system and use of high quality electric driven pumps. The efficiency assumptions are:

η_e - 28 percent (good central diesel generators or small steam power plant)
η_g - 90 percent
η_T - 90 percent
η_M - 90 percent
η_p - 70 percent

System Efficiency = η = 14.3 percent

(ii) Low Efficiency System

This case corresponds to one commonly found in LDC which have a combination of:

- Low efficiency electric generation facilities comprised of some mix of small (poorly maintained) steam plants, gas turbines, or old diesel engines.
- High transmission/distribution losses due to a combination of undersized lines, poor connection practices, and long distances.

The efficiency assumptions of this case are:

η_e - 23 percent
η_g - 90 percent
η_T - 75 percent
η_M - 90 percent
η_p - 70 percent

System Efficiency = η_s = 9.7 percent

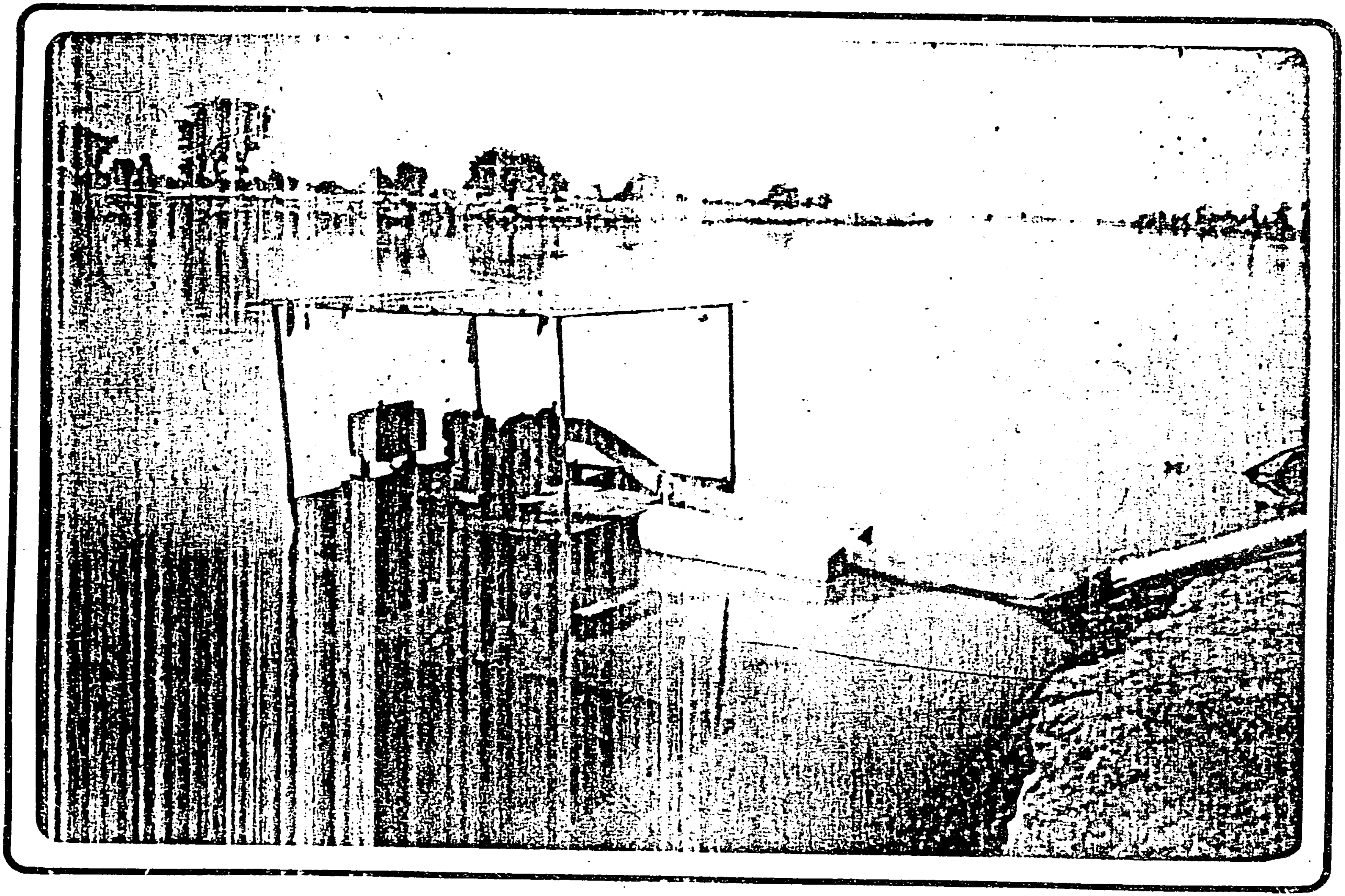
Figure 3.2 indicates the resultant fuel consumption per M^3 of water pumped for these two cases.

3.2 Capital Cost Implications of Pumping Options (Large vs. Small Scale Pumping)

Each situation will have specialized characteristics affecting the selection of pumping system. Table 3.1 indicates a range of pumping system arrangements specifically addressed in a study on pumping options in Senegal and Mauritania. These options are also those in use or which could be considered for use in other areas where irrigation pumping is required. Of the options indicated, the Diesel driven floating pumps (GMP) are most commonly used along the Senegal River. Similar units are also used in Mali and Niger. One incentive for floating units along such rivers is the large variation in river level by season and associated shifting of river channels (per Figure 3.3). Each of these units can irrigate 20-50 hectares of land.

There are also a small number of fixed pumping stations in place or being considered for providing water to large projects (500-1000 hectares). Figure 3.4, 3.5, and 3.6 are views of several of these pumping options as they are used along the Senegal River. Figure 3.4 shows a 22 Hp floating platform GMP unit with its associated flexible piping line to account for large changes in river level. Figure 3.5 shows views of an electric pumping system using four floating submersible pumps. Electricity in this system is provided by a 100 kw generator set placed on shore thereby facilitating maintenance. Figure 3.6 is a view of the pumping house and discharge canals of a 1000 HA irrigation project at PODOR. Electric power for the system is provided by a 500 kw dedicated generating facility. However, a similar installation at KAEDI (Mauritania) is served by the local, (Diesel based) electric utility.

There is often a perception that large projects might offer economies of scale and hav- larger developmental impacts. However, experience in the Sahel



3.4a CLOSEUP OF FLOATING DIESEL PUMP SYSTEM

- The electrification of the pumps even at a local level paves the way by establishing local distribution networks for more comprehensive electrification via grid extensions in the future once the loads increase to warrant such extensions.

There are, therefore, a number of practical reasons for considering the use of electrified pumps, particularly if irrigation projects are considered in an overall regional development context. Also, such longer term planning does not necessarily result in higher initial capital costs for those electric pumps installed during the earlier stages of development when dedicated Diesel generators are used for pump energization.

The investment costs indicated by figure 3.7 range from less than 500 to $1,500 per hectare depending on pump type used, location, and size. In general, these costs are often relatively modest compared to the overall costs of implementing irrigation projects in Africa. These costs often run over $10,000 per hectare which is one of the reasons that expansion of irrigation in Africa has proceeded rather slowly. However, some of the smaller perimeter developments with large inputs of local labor (for example, Bahel-Collerga) have reported costs as low as $2,000 per hectare. In general, the capital investments associated with properly selected pumping systems do not appear, in themselves, to represent a major barrier to expanding irrigated areas. The primary issues are the recurrent costs associated with fuel use, maintenance, and rapid depreciation (note: engine driven pumps will usually have useful lives of less than 10 years).

3.3 Crop Selection and Water Use

The crops grown along the Senegal River Valley are typical of those in many regions of the Sahel. They include rice, sorghum, corn, and garden type crops such as onions. Most of the irrigated perimeters are now devoted to rice during the rainy season crop (August through October in Senegal) and to "mixed crops" during other seasons. It should be noted that, with the exception of rice, the crops grown in irrigated areas are also grown using traditional methods of flood recessional and rain fed agriculture.

Crop selections and associated pumped water use requirements are dependent on a complex range of site specific variables including:

- soil conditions
- climatic conditions
- crop strain and fertilizer use
- irrigation system efficiency and type

In general, rice is usually selected for areas with soil having higher clay content and low permeability and grains for lighter soils with higher permeability. Both types of crops are, however, commonly grown in parallel (or in series during different seasons) on the same irrigated perimeters along the Senegal River.

Table 3.2 shows estimates of pumped water requirements for three locations along the Senegal River by crop types. As indicated, there is a significant variation in water use by crop, location, and season. Reasons for this include:

- o Locations, such as Bakel, have higher rainfall than the other two locations resulting in lower rainy season pumping requirements.
- o Kaedi in Mauritainia is very dry and hot resulting in particularly high transevaporational losses.
- o Grain crops (surghum, etc.) require much less water than rice even when grown in areas having soil with higher permeability.

The reason stated above for variations in pumping water requirements (i.e., different rainfall patterns, climate and crops) will result in similar variations throughout the Sahelian region. Pumping water requirements of 3,000 m^3/HA to 25,000 m^3/HA per crop will be common in this region based on present crop selections and irrigation technologies utilized.

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TABLE 3.2

CROP PUMPED WATER REQUIREMENTS - SELECTED SITES ALONG THE SENEGAL RIVER VALLEY
(CUBIC METERS PER HECTARE)

	PODOR	KAEDI[3]	BAKEL
HIVERNAGE[1] RICE	20,000	14,000	8,800
CONTRA SEASON[2] RICE	25,500	23,200	17,800
MIXED CROPS (RAINY SEASON)	9,900	9,900	3,700
MIXED CROPS (CONTRA SEASON)	15,100	15,100	5,400

[1] "HIVERNAGE" REFERS TO MAIN RICE CROP GROWN THROUGH THE RAINY SEASON, JULY - NOVEMBER.

[2] "CONTRA SEASON" REFERS TO AN OFF-SEASON RICE CROP TYPICALLY GROWN FROM JANUARY TO MAY

[3] KAEDI IS IN MAURITANIA, THE OTHER TWO SITES IN SENEGAL.

3.4. Fuel Use Per Crop

The source of water for all the locations considered along the Senegal River was the river itself. The vertical lifts varied significantly by location and by season. In the upper valley, the vertical lifts range from 5m to 10m during the year while in middle valley location (Podor) the lifts are much lower (2-6m). These large differences in lifts are reflected in large variations in pumping energy requirements. As indicated by Table 3.3 the primary fuel consumption in a Diesel engine pumping unit for rainy season crops in Bakel are about 100 liters/HA. This increases to over 350 liters/HA during the dry season for rice when both pumping lifts and water requirements are higher. By contrast pumping energy in Podor for rice ranges from 120 liters/HA to 315 liters/HA. The lower pumping needs as compared to Bakel are due entirely to the lower vertical lifts associated with perimeters near the river.

The fuel use for "mixed crops" is seen to be much lower than for rice in all locations due to the more modest water requirements of these crops. Nevertheless, in areas with large vertical lifts pumping energy for mixed crops can easily exceed 150 liters/HA, even if river water used.

3.5 Observations on Fuel Consumption Trends

Figure 3.2 displays several important trends relative to primary energy use in the operation of irrigation pumping systems. These include:

- The energy required is directly proportional to the lift through which the water is pumped. This requires careful examination of irrigation projects which entail pumping from wells of significant depth (certainly over 20 meters) or in the sizing of pipes which might be used to transfer water over large distances.
- A well designed direct diesel drive is probably the most energy efficient method of pumping water - particularly for larger systems which generally have higher efficient engines.

- The primary fuel consumed by a rural electrification system is critically dependent on the technical characteristics of the system. For a well maintained system, primary fuel consumption is comparable to that of a direct diesel drive. However, for a poorly maintained and operated system, primary fuel consumption of the power plant could be twice that for a good diesel drive.

As a practical matter, therefore, the energizing of irrigation pumps via rural electrification does not have favorable energy use impacts if the electricity is generated by oil fired thermal plants. The energy use related advantages of electrically driving the pumps will depend on a major portion of electricity being generated by some combination of:

- thermal facilities burning low cost fuels such as coal, peat, or residual oil.
- low cost hydropower.
- renewable energy systems such as wind or solar.

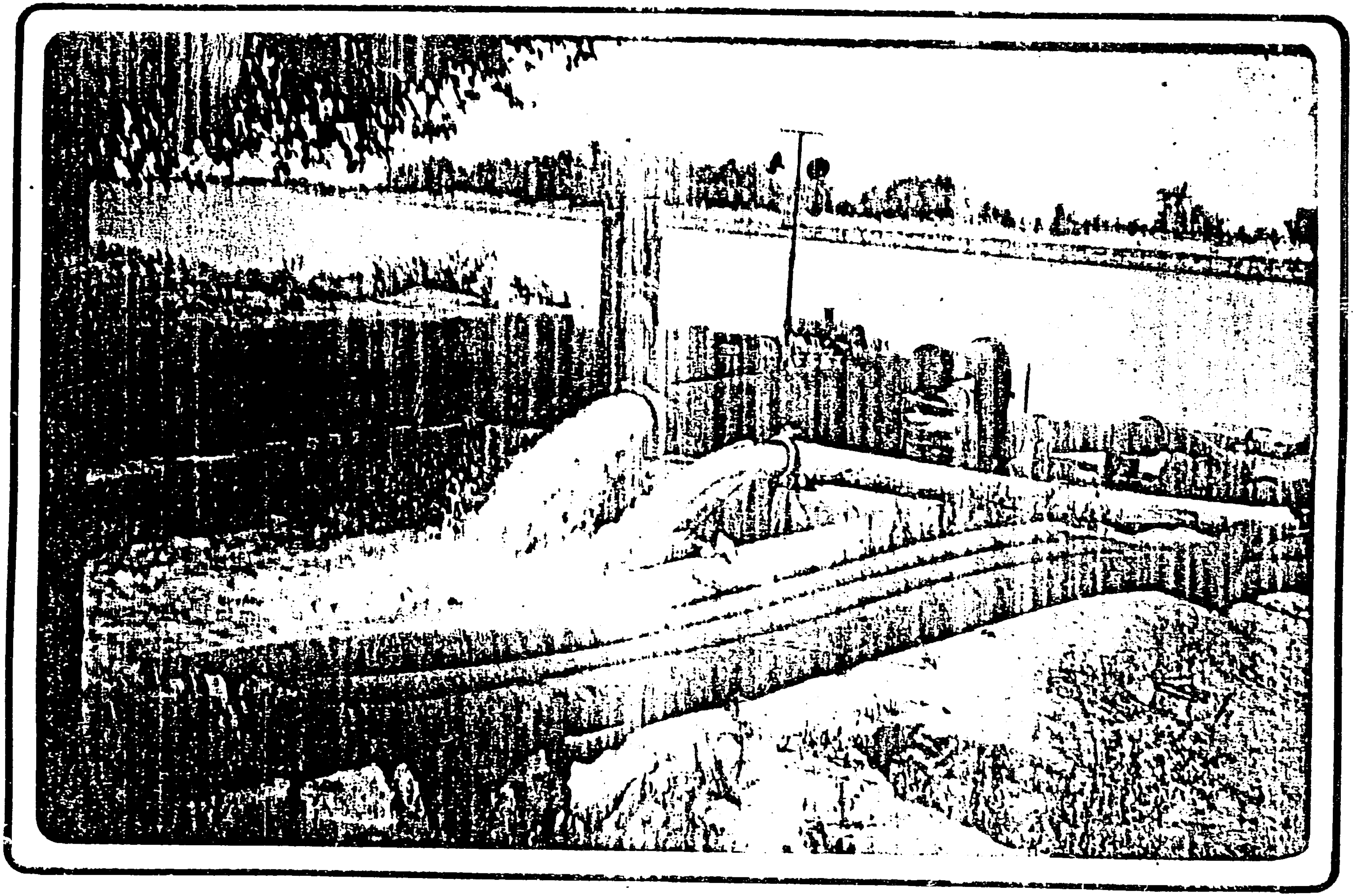
In these cases, the energy content of irrigation pumping will be the same as indicated in Figure 3.2 (thermal equivalent) but the cost of energy will be different for diesel engines (which must burn high quality distillates) and central electric facilities.

TABLE 3.3

FUEL USE BY DIESEL ENGINES AT
SELECTED SITES ALONG THE SENEGAL RIVER
(LITRES PER HECTARE PER CROP)

	PODOR	KAEDI	BAKEL
RICE HIVERNAGE	126	118	113
RICE CONTRA SEASON	315	398	365
MIXED CROPS (RAINY SEASON)	98	36	58
MIXED CROPS (CONTRA SEASON)	155	138	95
GRAIN CROP*	1000+	-	-

*BASED ON THE USE OF GROUNDWATER AT A DEPTH OF 60 M ON HIGHER GROUND AWAY FROM THE RIVER.



3.5a VIEW OF THE SUBMERSIBLE PUMP SYSTEM FLOATING PLATFORM, DISCHARGE
(Note: Pumps are suspended beneath the floating platform and are not visible)

3.5b VIEW OF THE CONTROL PANEL FOR THE SUBMERSIBLE PUMP SYSTEM (4 separate pumps)

3.5c VIEW OF 100 kw DIESEL GENERATOR FOR OPERATING THE SUBMERSIBLE PUMPS

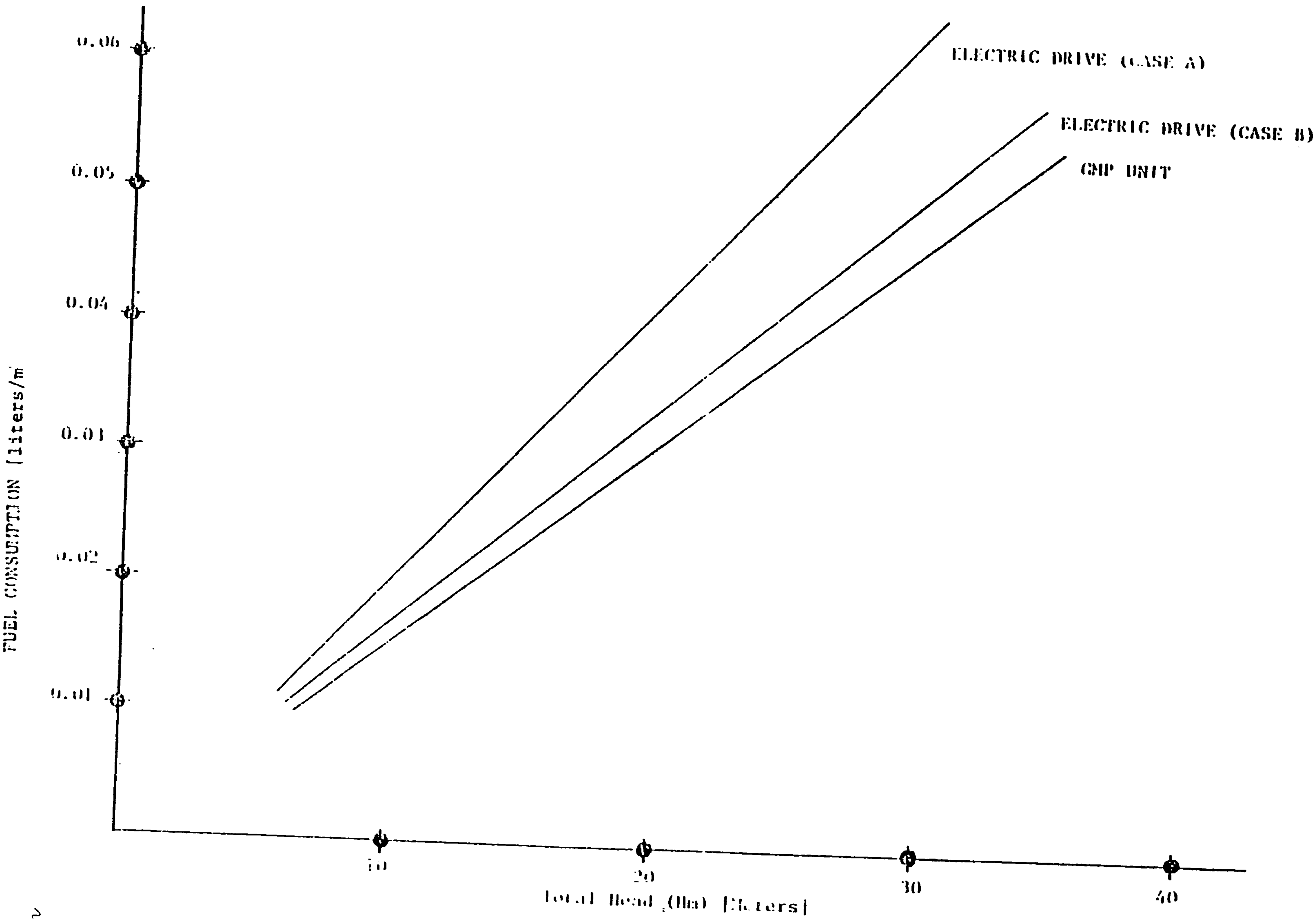


FIGURE 3.2 FUEL REQUIREMENTS OF IRRIGATION PUMPING

4.0 ECONOMICS OF IRRIGATION PUMPING

4.1 Cost of Water Delivery

The costs of pumped irrigation include:

- the cost of fuel required to operate the engine system.
- the O&M costs of the engine/pump system.
- the capital charges (interest and depreciation) on the capital purchases.

For some USAID funded projects the full impact of all these costs is not "seen" by the end users. For example, in Senegal the farmers are required to pay only for fuel and a portion of O&M costs. The attractiveness of irrigation pumping in these projects would be significantly diminished if the farmers had to finance the system at market interest rates. The World Bank also pursues an implicit policy which appears to require the recipient country to pay only recurrent costs and not the investment cost associated with implementing the project. The cost structure of water delivery for irrigation is discussed in more detail in this section for the case of Diesel driven pumps. Reference 2 provides similar analysis for other pumping system options.

a. Fuel Costs:

Previous sections have discussed the fuel requirements for pumping water (per figure 3.2) through specified lifts and the total water requirements per crop type in one area of the Sahel. The associated cost of fuel for water pumping is then dependent on the cost of Diesel fuel (for engine drives pumps) or electricity. There are tremendous variations in these costs between countries and even between regions within a country. Figure 4.1 shows fuel cost per cubic meter at water pumped based on the energy requirements of Figure 3.2. Curves are shown for two levels of Diesel fuel cost:

(i) $1 per gallon ($0.26 per liter) which corresponds roughly to the case in Senegal.

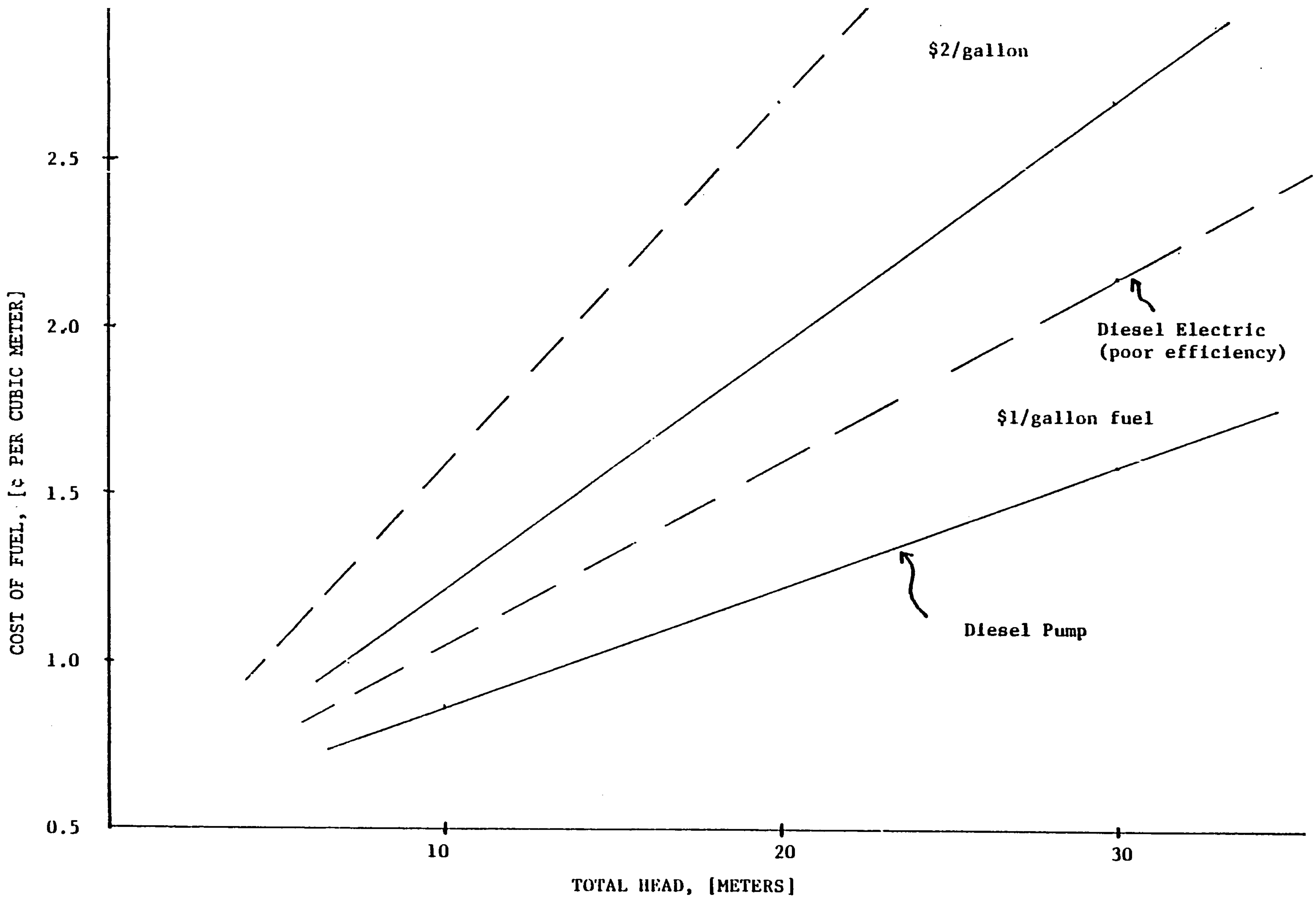


FIGURE 4.1: "FUEL COST" OF WATER PUMPING FOR DIESEL AND DIESEL/ELECTRIC PUMPING SYSTEMS

(ii) $2 per gallon ($0.52 per liter) which is consistent with delivered costs in many regions of Africa - particularly those with poor road access.

It should be noted that many regions of Africa have even higher delivered fuel costs than that indicated above. As a practical matter, irrigation pumping probably should not be encouraged in such areas.

Using $1/gallon fuel, the fuel cost alone for water pumping using a diesel pump is roughly 0.4 ¢ per cubic meter assuming a 10 meter lift. The use of a "lossy" electric drive, higher lifts, or higher cost fuel can easily increase this cost to over 1.5 ¢ per cubic meter of pumped water - a cost level for fuel alone which is probably unacceptable in many cases.

b. O & M (non fuel) Costs:

Operations and maintenance (O&M) costs can be divided into three segments:

- Operational personnel who undertake routine chores such as changing oil, filling the gas tank, etc. (referred to as a "Pompiste" in Senegal)

- Parts and materials for undertaking needed field maintenance (oil, filters, etc.)

- Parts, materials, and labor for undertaking periodic overhauls (usually every 4,000 hours even for robustly built, well maintained engines)

Operations and maintenance costs are among the more difficult to estimate. They depend on who does the O&M, the degree to which manufacturers maintenance schedules are adhered to, and the local cost of replacement parts.

TABLE 4.1

O&M COST SUMMARY FOR THREE DIESEL PUMP SYSTEMS

ENGINE MODEL	RATED CAPACITY (Hp)	TOTAL ANNUAL COST $	WATER COST (¢M^3)	
			BAKEL	PODOR
HR-2	22.6	530	0.4	0.1
HR-3	33.9	760	0.35	0.076
HR-6	75.5	1350	0.27	0.062

Assumptions:

1.0 Annual operating hours 1200

2.0 Cost of overhauls annualized assuming a 10% discount rate.

Appendix 2 presents estimates of O&M costs based on field experience in Senegal and the maintenance schedule at one of the leading manufacturers of high variability Diesel pumps. The resultant overall O&M costs for this specific area are shown on Table 4.1. The variation in pumping costs by region is due to large variations in water flow due to different pumping heads.

The annual cost indicated are approximately 15% of the initial capital cost of the engine/pump assembly (i.e. those parts requiring maintenance). If anything, this is on the lower end of O&M experience and reflects the reasonably effective infrastructure developed in Senegal to service the pumping units. Also maintenance costs were estimated based on about 1200 hours of operation per year which corresponds to a single cropping season. Annual O&M costs would increase if pumps are used throughout the year i.e. more hours per year. The primary contributors to the maintenance costs indicated are lubrication oil and parts. The O&M costs are, therefore, similar to fuel costs in being primarily associated with foreign exchange.

c. Capital costs:

Capital costs depend on a range of parameters including investment cost, useful life, salvage values, and interest rates. There are several approaches for estimating annual capital costs. The approach used herein is to assume that a fixed amount of money must be set aside each year to cover replacement of equipment (i.e. a replacement fund). In addition, if the equipment is purchased on credit, there will be additional annual outlays to cover financing charges. Table 4.2 shows the annual replacement fund charges assuming funds set aside are invested at 10%.

These would be the only charges in the situation where the equipment is initially provided free to the irrigation perimeter owners and they are only required to replace it as it wears out. This is the case in many doner funded irrigation projects such as the USAID program in Senegal.

FIGURE 4.2

SUMMARY OF ANNUALIZED REPLACEMENT COSTS FOR
THREE DIESEL PUMP SYSTEMS

ENGINE TYPE	CAPACITY (Hp)	INVESTMENT COST $	ANNUAL REPLACEMENT COST $	COST OF WATER (BAKEL) ¢/M^3
HR-2	22.6	16,000	620	0.42
HR-3	33.9	20,450	800	0.36
HR-4	75.5	31,800	1,250	0.26

Assumptions:

- Life of engine drives of 7 years with other subsystems of between 10 - 15 years.
- 20% salvage value.
- Discount rate of 10%.

It should be noted, however, that one of the persistent management problems with pumped irrigation projects is the establishment of and consistent contributions to a replacement fund. A source of serious concern to donors is that when the initial equipment (provided by the donors) wears out that insufficient funds will be available for pump replacement leading to collapse of the irrigation project unless additional donor support is provided.

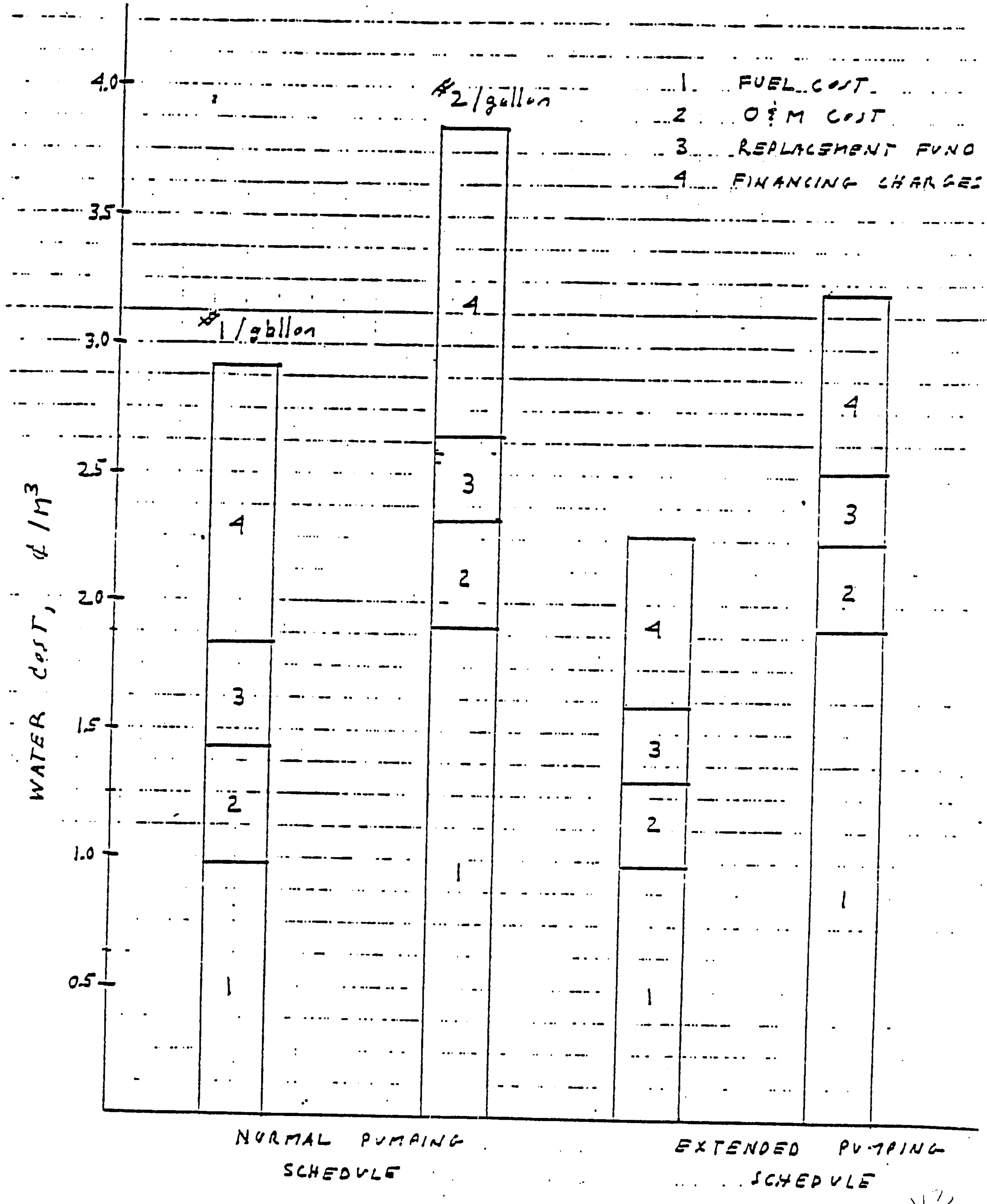
As indicated by Table 4.2, the annualized replacement fund costs are about $620 per year for the HR-2 system. The replacement fund cost only represents about 4% of total pumping system cost. This relatively low figure reflects the long life (10-15 years) associated with such static assets as platforms and piping. As a practical matter most of the replacement fund is associated with the engine. The replacement fund represents about 20% of initial engine investment costs.

The contribution of capital costs to water costs ranges from .26 ¢/M^3 to .42 ¢/M^3 depending on financing assumptions.

Figure 4.2 shows the impact of fuel, O&M, and capital costs on the overall delivered cost of water for Bakel in Senegal. As indicated, fuel cost is a major component of the cost structure, particularly with $2/gallon fuel. However, capital costs associated with financing and depreciation are also major cost components and, as previously indicated, often not realistically accounted for in assessing the long term viability of irrigation projects. The cost of water is seen to range between 2¢/M^3 to 3¢/M^3 for the cases cited. This corresponds to about $400 per hectare per rainy season rice crop assuming 20,000 M^3 of water per crop.

As indicated in Figure 4.2, capital charges represent a major portion of overall pumping costs for the case considered. One of the major assumptions in the analyses leading to Figure 4.2 was that pumping occurred during an 8 to 10 hour period through the day as is now normal practice on the small perimeters in Senegal. This pumping schedule is certainly the path of least resistance since

COST OF DELIVERED WATER SUMMARY
(HR-2 GMP., BAKEL)



it corresponds to existing living patterns of the local population. However, capital costs could be significantly reduced if the pumps were operated for longer durations and thereby each pumping unit could irrigate more lands. For example, Figure 4.3 indicates pumping costs assuming a 16 hour/day pumping schedule. This schedule results in a % reduction in the overall cost structure.

Particularly if electrified pumps are used, it may be necessary to improve the utilization of costly generating/transmission equipment by insisting on nighttime pumping schedules.

This certainly adds to the complexity of the social and institutional problems associated with organizing and implementing irrigation projects. In cases with marginal local farmer support, the need for nighttime irrigation might even tip the balance against project implementation. However, the realities of the efficient utilization of high capital cost power and pumping systems have lead to day long (or nearly so) pumping in many LDC'. For example, in Kaedi (Mauritania) over 1.000 HA were irrigated as a 24 hour cycle using electric power provided by a local grid (total capacity of 500 KW). Similarly, 16 hour pumping cycles are under consideration in Sudan to ensure efficient use of regionally supplied electric power.

4.2 Impact on Crop Economics

The impact of the pumping costs of Section 4.1 on overall crop economics depends on a number of factors including:

- the requirements for other cash impacts such as fertilizers, purchased seeds, and labor.
- the increased value of crops grown as the result of the pumped irrigation.
- the alternatives for using capital available to the farmers.

The second item above is particularly critical in many countries of the Sahel. Most of these countries set official prices for major crops. These prices are often set at levels which make it unprofitable to grow cash crops even without the additional expenses of pumped irrigation. Such situations exist for example in Mali. In Senegal the official price of rice is set at 130 CFA/kg (___/__).

This price is roughly comparable to the cost (at the dock) of imported rice from southeast Asia (usually Thailand). The official price in Senegal is not truly reflective of overall importation costs if all handling and transportation charges are taken into account. Nevertheless, the pricing policies in Senegal are more realistic than in some of its neighbors which makes it a reasonable example for assessing the impact of pumped irrigation costs on agricultural profitability.

Table 4.3 is a cost summary for rice farming in Bakel and for a similar operation in Podor. The figures for fertilizers, labor, and seed were obtained from a recent study by M. Meita of the Senegal Mission (ref. 9) which apply to Bakel only. The Podor figures assume only pumping costs are different between the two locations.

As indicated by Table 4.3, in Bakel the cost of irrigation pumping for the rainy season crop account for over 24% of crop value if capital costs are considered. Even in the rainy season the growing of rice on pumped irrigated areas is only marginally profitable and allows very little margin of error in yields or unexpected operational difficulties (pump breakdown). As a result, most farming in this region is still done on a subsistance basis with little economic incentive to product marketable surplusses.

If a dry season crop were to be produced in Bakel, the irrigation related costs would increase to over 35% of total production costs. The resultant cost would about equal crop value making such second season crops unprofitable. In such regions as Bakel (characterized by high lifts) the merits of double cropping will require careful examination.

By contrast, irrigation pumping accounts for only about 17% of crop value in Podor in either the rainy or contrasaison due to the much lower pumping heads. This is still a heavy burden to bear but results in much larger margins of safety than in regions with higher pumping lifts and allows for profitable multiple cropping.

Figure 4.4 shows estimates for agricultural costs in Bakel and Podor if the cost of Diesel fuel were to increase to $2.00/gallon - a cost which is more representative of real costs on a delivered basis to many regions of the Sahel. In this case, the cost of pumping is so high that it would not be only. marginally economical to farm rice even in the rainy season in high lift areas. This suggests the extreme sensitivity to energy costs of agriculture which is highly dependent on pumped irrigation, particularly in regions with high pumping heads.

The above discussion applies only to one region of the Sahel. Nevertheless, the results provide useful insights into the major role that pumping costs can play for irrigated agriculture in the Sahel and other regions of subsahara Africa.

In particular, for projects where pumped water is a major portion of overall water needs, pumping costs will be a, if not, the major factor in determining economic viability. The situation will be mitigated somewhat where pumped water

TABLE 4.3

IMPACT OF PUMPING COSTS ON
ECONOMICS OF RICE PADDY PRODUCTION

(CFA/Kg)

		HIVERNAGE*	CONTRASAISON*
A.	BAKEL		
	o PUMPING COST	14.4	25.8
	o OTHER COSTS	45.0	45.0
	TOTAL	59.4	70.8
B.	PODOR**		
	o PUMPING COST	9.2	16.6
	o OTHER COSTS	45.0	45.0
	TOTAL	54.2	61.6
	OFFICIAL SELLING PRICE	70	70

* Assumes 5 ton yield per hectare

** Assume "other costs" same as for Bakel

TABLE 4.4

IMPACT OF PUMPING COSTS ON ECONOMICS OF RICE PADDY PRODUCTION

(CFA/Kg)

	HIVERNAGE*	CONTRASAISON*
A. BAKEL		
o PUMPING COST	19.5	35.0
o OTHER COSTS	45.0	45.0
TOTAL	64.5	80.0
B. PODOR**		
o PUMPING COST	12.5	22.5
o OTHER COSTS	45.0	45.0
TOTAL	57.5	67.5
OFFICIAL SELLING PRICE	70	70

* Assumes 5 ton yield per hectare

** Assume "other costs" same as for Bakel is only supplemental to gravity feed water due to significant (<300 mm) rainfall.

As a result, each case would have to be examined based on project specific conditions, to ensure that the recurrent costs associated pumping can be sustained by the local farmers after the donor organizations have completed their infrastructure development activities.

4.3 Potential for Electrification

The prior discussion focuses on the impacts of pumping costs on crop economics assuming the use of direct drive Diesel pumps which are now in prevalent use along the Senegal River and elsewhere in Subsahara Africa. The aforementioned pumping study for this region also closely examined the potential for electrifying the pumps and the economic implications of so doing. Two general options were considered:

- o Electrifying specific pumping units using Diesel generated electricity from nearby local grids.
- o Extending the grid along the valley to make use of central power generated by thermal means (on the coast using lower cost fuels) or, in the future, by low cost hydropower from the Manantalli Dam. Only generalized long term implications of this option were provided within the limited scope of the Senegal River study.

The impacts of each option we discussed briefly below:

- o Diesel Generated Electricity:

  The electrification of pumping units at both Bakel and Podur would require the installation of roughly 3 km of 15 kVA electric transmission lines with associated interface transformers and controls. In each case is was assumed the submersible pumps on floating platforms would be utilized. Power would be provided by existing Senelic facilities (500 kw) which are currently operated at very low capacity factors due to small household loads in these regions. The analyses indicated that this option was lower cost by about 15% than the use of direct drive Diesels due to a combination of:

- lower O&M costs (as a unit output basis) on the margin since O&M staff were already needed for a system operation to service non pump loads.
- reduced capital costs due to the longer life of larger, well maintained, stationary Diesel units, and the fact that new units were not required to serve the incremental pumping loads.

The modest estimated difference in pumping costs between local electrification and direct drive Diesels is probably, in itself, not very important in affecting the general conclusions arrived at in previous sections and, as a practical matter, fall well within the range of calculational errors used in the estimation process i.e. the conclusion that local electrification is lower cost than direct drive Diesels is not a very firm one and certainly not generally applicable.

There are, however, several other significant advantages associated with the local electrification option in addition to possible lower costs. These include:

- the engine systems can be maintained by trained technicians thereby better ensuring reliable, long term, engine operation.
- the operation of the pumping units is greatly simplified from the farmers viewpoint thereby adding to the flexibility and desirability of implementing smaller scale pumped irrigation projects.
- the floating platforms can be placed further out in the river since daily access to the pumps is not required (as in the case with Diesel pumps). This results in simplified pump operation and

reduced possibilities for clogged inlet lines (an advantage on the Senegal River which will be applicable only in other locations with floating pump systems).

- the pump electrification provides base load to the utilities which improves the operation efficiency of the local generating plants and provide additional incentives to expand the electric grid. This expansion often has other productive and social benefits in addition to energizing the pumping units.

The above factors, combined with a highly competitive cost structure, resulted in the Senegal River study recommending electrifying the pumps in those two locations with good access to available electric generation capacity. Although the results are by no means universal, pump electrification merits serious consideration wherever similar situations exist.

Central Grid Expansion:

The Senegal River Valley currently has only scattered electric service in three of the larger towns. The total installed capacity is roughly 1,500 kW of Diesel generators. Even this is operated at only about a 15% capacity factor attesting to the low level of normal household and light commercial loads in these areas. By contrast, the approximately 300 Diesel pumps already in use along the river have approximately 7,000 kW of capacity.

Some work has been done to assess the potential for transmitting hydropower from the Manantalli Dam across central Senegal to Dakar. Little attention was given to extending power from this source down the Senegal River valley in part due to the very low electric loads now prevalent in the region. However, consideration of the possible loads have not taken into account the major potential impact associated with electrifying the pumps. Based on current plans to bring an additional 50,000 hectares under cultivation by 2,000 and 100,000 hectares by 2010 the potential pumping load alone along the river could exceed 100 MW or roughly 50% of Senegal's allocation of Manantalli power (also equal to present nationwide generating capacity).

Preliminary studies have indicated that hydropower from Manantalli could have one third to half the cost of thermally generated power when serving loads with high capacity factors. This could be the case for pumping in the valley and, if so, would significantly improve the economics of pumping irrigation agriculture in the long term. VErifying this potential would, however, require detailed engineering cost studies which take into account actual transmission line costs, and projections.

The important issue is, however, that the economic viability of electrifying the valley (whether by thermal or hydropower means) is strongly dependent on the major, steady, loads which would result from pumped irrigation. This exemplifies the important linkages between agricultural expansion plans (based, in part, on pumping) and electric sector expansion which may often exist in regions of subsahara Africa.

5.0 POLICY ISSUES - OVERVIEW

Experience in several countries referenced in this report indicate that there are a number of important policy issues which must be considered when considering expansion of irrigation based on pumped water and the often associated role of rural electrification. Only by considering the costs and benefits of irrigation pumping within a broader context of agricultural and energy sector planning can reasoned assessments be made of overall economics and, in particular, the true nature of recurrent costs both on a project basis and a national basis.

These policy issues include those associated with:

- Diesel vs Electrified Pumping
- Electricity Pricing
- Grid Extension Economics
- Role of Distributed Power Systems
- Crop Selection - Irrigation System Design
- Coordination of Agricultural Expansion and Energy Sector Planning
- Food Pricing Policies

Clearly, there will be a wide variation in the importance of different policy issues between countries. Nevertheless, each of the policy issues can be addressed in a consistent manner to ensure that the right questions are being asked and to provide a general framework for project specific decision making.

Each of these policy issues is briefly discussed below.

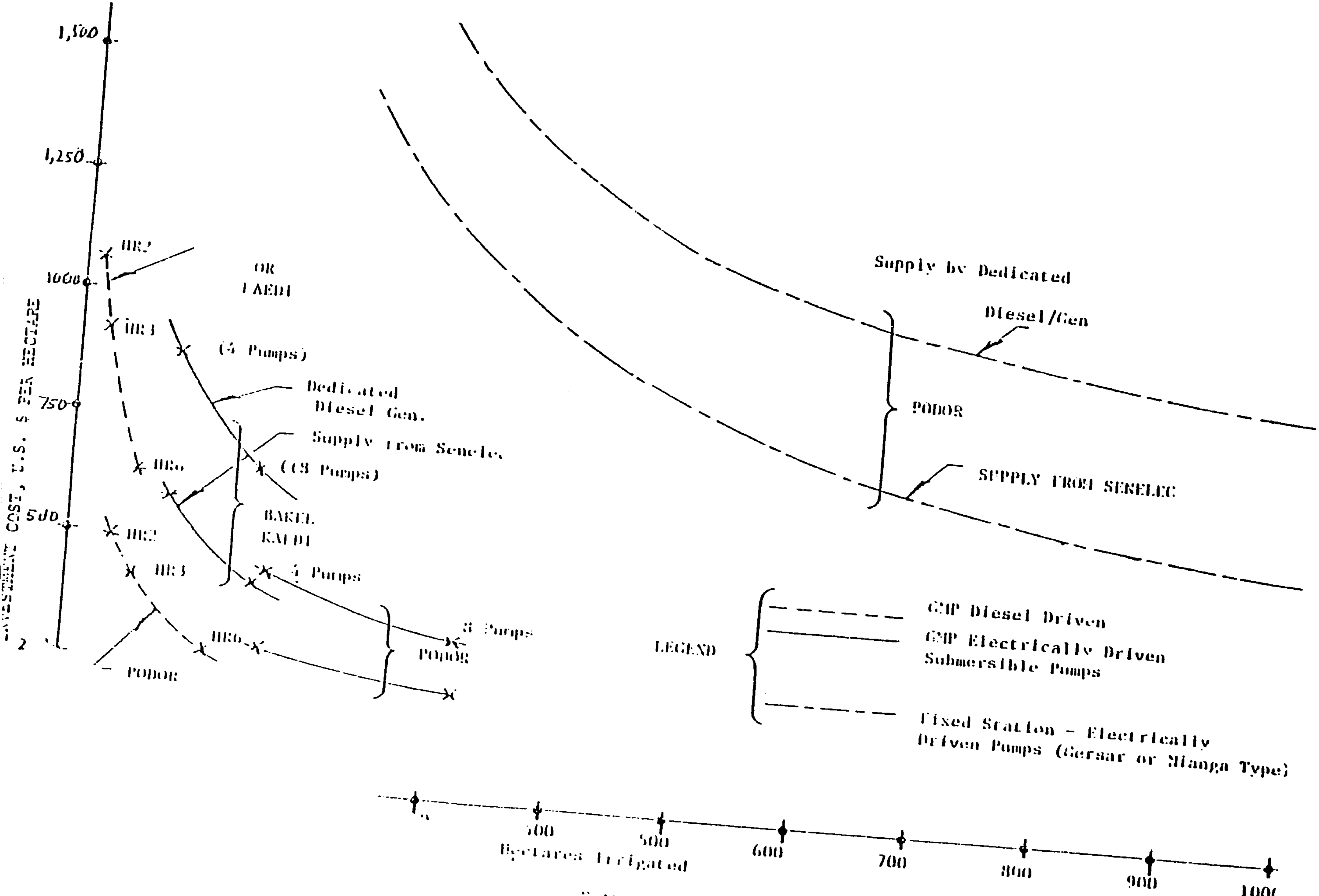
5.1 Energy Pricing

There is a tendency to provide rural areas, in general, and farmers, in particular, with electric tariffs, and Diesel fuel costs which are, in effect, subsidized. For example, this was an overt policy in Pakistan and was a defacto policy in Senegal.

suggests that such large projects are difficult to properly manage. In addition, as indicated in Figure 3.7, there is no incentive to pursue large projects based on the capital costs of the pumping systems. In fact, the fixed pumping systems are considerably more costly than either Diesel or electrically driven floating units. This is due to the extensive civil work required to install fixed pumping systems, particularly along waterways with large seasonal fluctuations in water level. The costs for fixed pumping units will certainly be site specific. However, the implications of these previous studies is that any assumptions relative to inherent economies of scale in pumping systems should be examined very closely during the design of projects.

If each increment of irrigated area is considered as a separate project, the most flexible and lowest cost option for providing pumping is probably a GMP unit (whether floating or positioned on a river bank). However, if the expansion of irrigated areas is considered on a regional basis over time, then consideration should be given to electrifying the pumps. As indicated in Figure 3.7, floating platform electric driven submersable pumps can often be the lowest cost option. Additional practical advantages associated with this option include:

- A multiplicity of pumping units can be served from a "central" power system serving local or regional needs. Even if using Diesel fuel, the "central" power unit can be professionally run and maintained, thereby improving reliability and better ensuring efficient operation. Also, in some cases the central power unit might provide the flexibility to be able to utilize locally available fuels for the operation with significant reductions in fuel costs.
- The basis of many pumped irrigation projects has been the inability of local farmers to consistently maintain and operate small Diesel pumps. By comparison, the operation of small electric pumps is quite straightforward and relieves the farmers of the onerous need to gain significant mechanical skills. As such, the farmers can focus their attention on the difficult enough task of managing the irrigation system itself. The use of electrified pumps served by local or regional grids could therefore improve the chances of success in the irrigated perimeters.



INVESTMENT COSTS OF PUMPING OPTIONS

Energy pricing policies can have a dramatic affect on the perceived overall economics of irrigation projects and strongly influence the choice of pumping systems. For example, the switch from Diesel to electric pumps in Pakistan was due primarily to heavily subsidized electric tariffs specifically tailored to irrigation pumps.

One can question the wisdom of subsidized energy inputs for agriculture, however, in fact, rural America owes much of its earlier growth to what was, in effect, a heavily subsidized expansion of rural electrification. It is important, however, to understand before hand the extent and impact of subsidies in place or being contemplated. Otherwise, inappropriate policies relative to both the agriculture and energy sector could be inadvertently implemented, and encouraged by donor assistance.

Two such examples are cited below:

(a) Pakistan: One of the general policies guiding the rural electrification expansion in Pakistan was to focus on those areas where electricity would be used to displace Diesel pumps with electrified ones. The rationale for this was the much lower cost (to the farmers) of operating the electric pumps and the perceived national benefits of reducing Diesel fuel use. As indicated in Reference 1, this policy was seriously flawed. All new additions to rural load had to be accompanied by additional, costly, fuel fired (mostly oil) electric generating capacity and expansion of already strained transmission systems.Consequently, the real costs of electrifying the pumps were considerably higher than allowing existing Diesel pumps to continue operating. National policies to encourage electrifying the pumps merely shifted costs from the agricultural sector to an already strained electric sector with the additional costs hidden by the subsidies to the farmers on electricity purchased for pumping.

(b) Senegal: As indicated in Reference 2, the pump survey team recommended that consideration be given to electrify irrigation pumps in two specific locations using locally produced electric power. The report clearly stated, however, that the "apparent" favorable economics of the option were in part the result of national policies to have uniform tariffs throughout the country which, in effect, subsidized relatively high cost rural power produced by autonomous Diesel generators. A policy of large scale electrification of the pumps would impose a large financial burden on the utility unless accompanied by a program to electrify the valley with low cost hydropower (possibly from Monentali) or thermal power produced using lower cost fuels.

As suggested by these examples, it is important that USAID (or other donors) does not adopt policy positions which, in effect, justify irrigation projects based on highly subsidized energy costs. So doing will only hide the true value of recurrent costs and jeopardize the longer term viability of the projects if energy costs are raised to more financially viable levels.

5.2 Crop Pricing Policies

Many countries have crop pricing policies which tend to undervalue agricultural produce in order to provide cheaper food for urban residents. Although politically popular, such policies are usually destructive of rural economies and hence we a frequent source of "policy dialogue" between USAID and host governments. This situation is particularly severe in some countries of Africa.

Such policies can also make irrigated agriculture highly uneconomic from the point of view of the farmers - even in cases where it would be profitable if the increased production were priced at realistic levels. This was exemplified by the case in Senegal where the official price for rice was such that pumped irrigation using the Senegal River valley was only marginally attractive (at best) if all costs were actually accrued by the farmers. As a result, most farmers with access to an irrigated perimeter along the middle and upper valleys still engage in subsistence farming producing very limited marketable surpluses - a situation common in Africa and one contributing to food shortages in this region. The marginal profitability of irrigated agriculture is responsible for the limited interest in commercial scale farming in this region on the larger irrigated perimeters, which would contribute to increased food production for marketing in urban areas.

In countries, therefore, where increases in agricultural output will depend on large part on pumped water, the need for rationale food pricing policies will be even more critical than when dealing with low capital input traditional forms of agriculture.

USAID and other donors should, therefore, reinforce policies which tie support for expanding agricultural output based on irrigation projects to food pricing policies which can make such agriculture potentially profitable while allowing for paying the substantial recurrent costs associated with irrigated agriculture.

5.3 Agricultural Expansion - Energy Sector Planning Coordination

There is a tendency for agricultural sector planning to take place with little, if any, reference to overall national energy impacts or rural electrification plans. The reverse of this is also true, i.e., energy sector planning often is done with little awareness of the impact of agricultural sector projects.

As a result, irrigation projects tend to be implemented without regard to or overall energy supply strategy which could lower costs in the long term. For example, in Senegal it appears that the long term agricultural expansion plans along the Senegal River could strongly influence the projects for electrification using hydropower. Due to the lack of coordination between the sectors this issue has not been adequately considered. Similarly, as suggested by the experience in Pakistan, the impacts of irrigation pumping needs on rural electrification infrastructure, central station generating capacity, expansion and fuel impacts are often not considered and rarely quantified.

Significant expansions of irrigated agriculture requiring pumping should be done consistent with overall energy sector planning to potentially lower costs, provide inputs as to selection of pumping system technologies, ensure that all the infrastructure and fuel cost factors are accounted for in the evaluation process, and to ensure that the energy related inputs are, in fact, available to the project.

5.4 Role of Distributed Power Systems

As a practical matter, the irrigation pumps will often be the largest load associated with rural development projects in LDC. This is certainly the case throughout the rural regions of Pakistan and along the Senegal River Valley. It also appears to be the case in many regions of the Sudan and several other African countries. The issue of energizing the pumps and providing rural power in general are therefore, often highly intertwined.

Implementing rural development projects is a complex undertaking involving myriad social, institutional, and technical issues and problems. The inclusion of irrigation with associated pumping further complicates an already difficult undertaking. The questions associated with how best to energize the pumps are understandably often relegated to secondary states in the overall planning process. The choice is usually made based on two options: individualized Diesel pumps or extending an already established electric utility grid.

However, as previously discussed, the recurrent costs associated with irrigation pumping can have a major impact on overall crop economics and, therefore, rural development prospects. As a result, donor organizations should give increased attention to alternative means of providing critical power needs in rural development projects; including the role of larger distributed power systems using minigrids to serve regional needs.

Although modest by U.S. or European standards, the regional power needs in LDC are often still measured in the megawatts. For example, providing sufficient power for 50 irrigation pumps along the Senegal River would necessitate about 2 megawatts of power. Similarly, the regional needs in the proximity of a medium size town (10,000) in Pakistan is often in excess of 10 MW. As a practical matter, regional development involving pumped irrigation will often require power generation capacities in the range of 1-50 MW. The common approach for serving regional load centers of this magnitude is to extend the central grid (high capital costs) or possibly, to install conventional diesel or gas turbine generating capacity which requires the consumption of high cost, imported distillate fuels. For this intermediate range of power levels, more consideration should be given to an expanded technology base of distributed power system using some combination of:

- Biomass fired power systems;
- Coal or peat fired power systems;
- Local hydropower power systems;
- Hybrid power systems which combine the above or solar/wind systems with diesel generators (to conserve on imported fuel needs).

The use of distributed power system in this capacity range has several distinct advantages:

- The size is large enough to result in the efficient operation of a number of technological options which would be impractical at lower power levels. The economics of scale are associated with capital equipment costs and, perhaps more important, the ability to afford trained staff responsible for O&M and the management of the facility.

- The size is small enough to:

  a) Provide additional flexibility to use indigenous energy resources (wood, peat coal, etc.) which may not be (and is often not) available in sufficiently large quantities to support conventional (multi hundred megawatt) power plants.

  b) Provide appropriate capacity to serve regional load centers with local grids and often still be installed in multiple units to provide backup capability.

c) Be available in prepackaged systems which can be readily transported to the site and installed in a short period with a minimum of site labor.

d) Be made available in standard units resulting in interchangeable parts and a common O&M training program.

Utility planners in LDC were often trained in the U.S. or Europe where the bias is strongly in the direction of central grid expansion based on large central generating facilities. The option to use a variety of intermediate scale generating facilities with associated fuel flexibility, siting flexibility, and possibly lower capital costs (particularly if transmission and distribution networks are considered) is, therefore, not usually considered by LDC utility planners or by those in donor organization responsible for designing rural development or rural electrification programs.

5.5 Crop Selection - Irrigation System Design

This report dealt primarily with the mechanics and costs of pumped irrigation assuming water use patterns as a given. These water use patterns are, in turn, a function of crop selection, irrigation system design, and climate. The latter factor is beyond the control of project designers. The first two can, however, within some limits be influenced by proper policies and system design guidelines.

A. Irrigation System Design

Both the literature and discussions with field workers indicate that the amounts of water used for irrigation are usually well in excess of that needed. This is due to two primary factors:

(a) Poor design of irrigation system distribution and water management systems resulting in large losses of water by evaporation, runoff, and leakage.

(b) Over irrigation of crops by individual farmers based both on a desire to ensure adequate water within an unreliable system (better get it while it's available) and a lack of knowledge of proper irrigation practice.

Excess water use, in turn, has several deleterious affects:

- It directly increases pumping costs which, as indicated earlier, can be a major cost factor in crop economics.

- It can harm crop production by increasing salinity problems and waterlogging.

In the countries addressed in this report, irrigation distribution systems were in general open, unlined, ditches which had high losses, - probably underestimated in projecting crop water requirements. Losses from such systems run from 30% to 60% depending on soil conditions, canal maintenance, and water management practices. This situation is common throughout Africa and is probably a reasonable, low cost, choice where gravity fed irrigation is used. However, where pumped water is used the high losses associated with such rudimentary irrigation distribution systems adversely (and significantly so) affects overall pumping costs. These losses could be greatly reduced by such measures as lining canals, using piping for distribution, and various forms of drip irrigation (for some crops). However, these measures increase the initial cost of implementing irrigation projects. No sources were identified during this project where the tradeoffs between reduced pumping cost and increased capital costs for improved irrigation systems have been made. USAID and other donors should consider a policy whereby such tradeoffs are made early in the planning stages of rural development projects incorporating pumped irrigation. This could help ensure that irrigation project designs represent a reasonable compromise between initial capital costs and recurrent costs. Since the latter costs are the Achilles' heal of many irrigation projects, these tradeoffs could well indicate that more funds spent in reducing water losses would represent an appropriate approach in many cases - particularly in Africa.

LIST OF REFERENCES

1. General Policies and Implementation Guidelines - Rural Electrification Program, Pakistan, USAID, PAKISTAN, March 1983.

2. Assessment of the Relative Economy of Alternative Options For Irrigation Pumping in Identified IDP Project Areas (Pador, Bakel Collerga, Bakel - Bulon, Dirul Plain), USAID Report, Senegal Mission, November 1984.

3. Irrigation and AID's Experience: A Consideration Based on Evaluations, August 1983, U.S. Agency for International Development.

4. Country Development Strategy Statements, SAHEL, FY 1984, Agency for International Development.

5. Annual Budget Submission, FY 1986, MALI, June 1984, Agency for International Development.

6. Prospects for Small-Scale Irrigation Development in the Sahel, USAID, Water and Management Synthesis II Project, WMS Report 26.

7. Accelerated Development in Sub-Saharan Africa, World Bank Report, 1981

8. Senegal: Issues and Options in The Energy Sector, July 1983, World Bank Report, No. 4182-SE

9. The Bakel Small Scale Irrigation Perimeters: An Economic Analysis of Agricultural Production, M. Keita, USAID/ADO, Senegal, June 1983

10 Development of Irrigated Agriculture in Niger, Club Du Sahel/CILSS, SAHEL D(79) 46, Oct. 1979.

11. Same Series of Reports as above Reference for Mouritania, Mali, Upper Volta, Cape Verde, and Senegal.

12. The Development of Irrigated Agriculture in the Sahel, Review and Perspectives, Club Du Sahel, SAHEL D(80) 75, April 1980.

13. Conference On The Development Directions in the "After the Dam" Period, OMVS, Dakar, 19-23 November, 1984, Summary of Proceedings.

14. Water Pumping For Irrigation In Africa: An Analysis Of Project Problems and Energy Options, A. Borst, AFR/TR/SDP, Sept. 1984.

15. Recurrent Costs of Development Programs in the Countries of the Sahel, Club Du Sahel, August 1980.

16. Sudan: The Rohud Irrigation Project, USAID Project Impact Evaluation Report No. 31, March 1985.

17. Irrigation Pumping, Planning Guide No. 3, Water Management Synthesis Project

18. The Impact of Irrigation on Development: Issues For a Comprehensive Evaluation Study, Office of Evaluation, USAID, OCT. 1980.