LEARNING from SUCCESS
Photovoltaic-Powered Water Pumping in Mali

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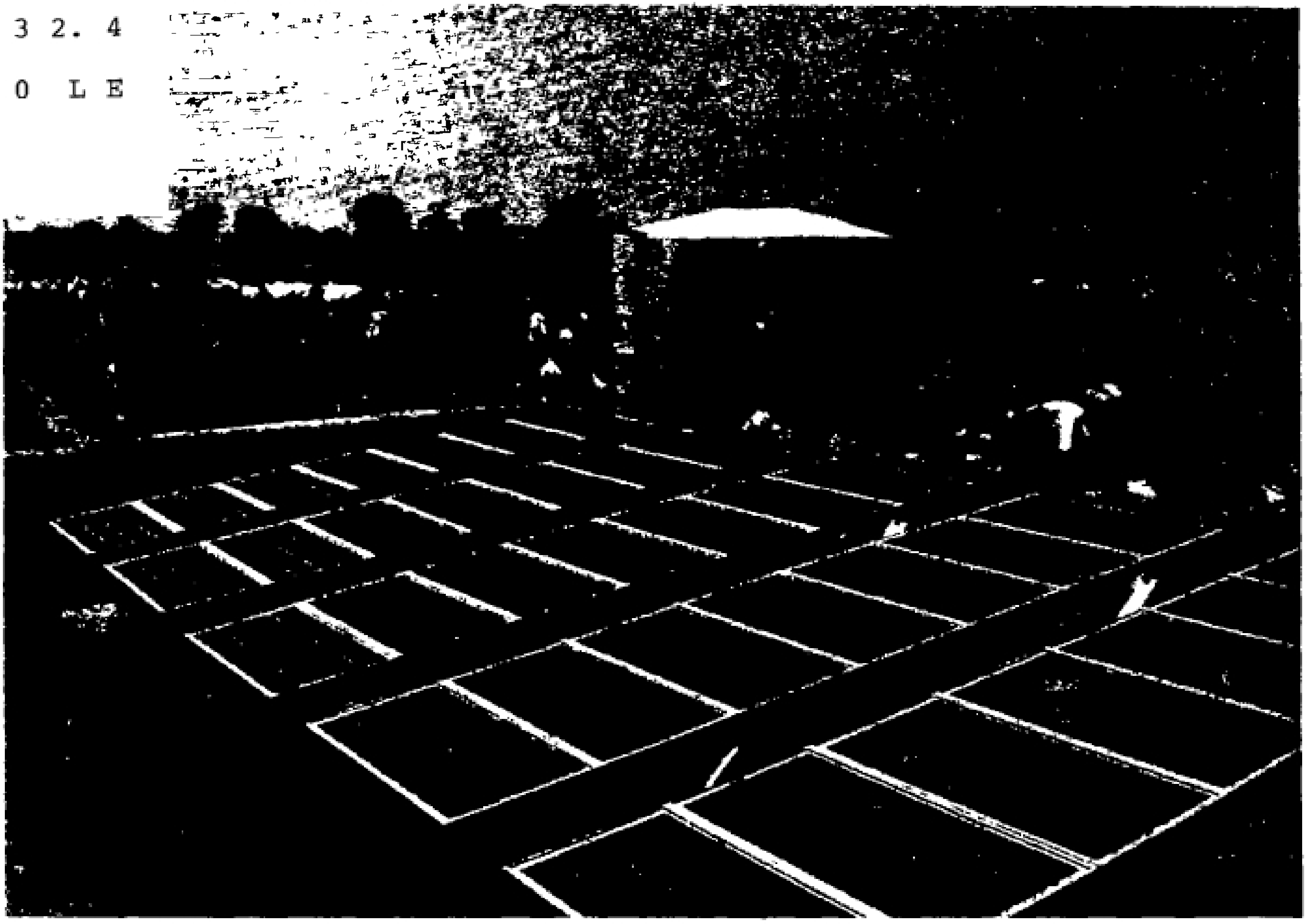

U.S. COMMITTEE on RENEWABLE ENERGY COMMERCE and TRADE

Washington D.C., U.S.A.

DISCLAIMER

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Photovoltaic-Powered Water Pumping in Mali

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Preface

Access to safe water is one of the most basic of human needs. Yet today, over half the people in the world's 127 developing countries do not have access to safe drinking water. Unsafe water accounts for 80% of all sickness in the world and kills 50,000 people a day. Efforts to overcome this problem have made water pumping programs a priority of many developing countries and donor organizations.

Over 5,000 photovoltaic (PV) pumps have now been installed worldwide. Mali has possibly the largest single concentration of PV pumps in the developing world. This evaluation of photovoltaic water pumping systems provides a detailed look at PV under field conditions in a developing country. Rather than reviewing a single showcase example, the report provides actual performance background and statistics for 157 systems, many of them in operation since the mid-1970's. The study reviews the lessons learned by several water-pumping organizations over 13 years, namely: that these systems are inherently simple, are very cost-competitive in a broad middle range of well depths and water requirements, and are very well accepted by the people served. The PV systems in Mali have experienced a very low failure rate, and the failures were seldom in the PV modules. The basic infrastructure requirements for the successful operation of any water pumping program – service, training, and parts availability – are described in detail.

This information is useful for illustrating the high reliability and acceptance rate of PV, and its favorable economics under a broad range of actual conditions. Much of this information is readily transferable to applications in other parts of the developing world. Regardless of your role in development, I encourage you to look at this study. For additional information or program and project design assistance, please feel free to contact myself or the people listed below.

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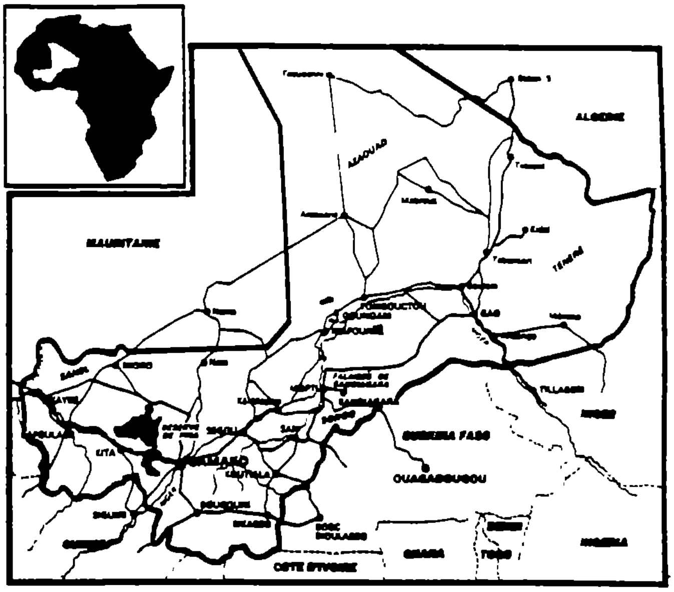
Cover Photo: **Mali Aqua Viva**

Abbreviations

ABN	Autorité du Bassin du Fleuve Niger
AFME	Agence Française pour la Maîtrise de l'Energie
CCCE	Caisse Centrale de Coopération Economique
CEAO	Communauté des Etats de l'Afrique de l'Ouest
CECI	Centre d'Etudes et de Coopération Internationale (Canada)
CEES	Cellule d'Entretien des Equipements Solaires
CIEH	Comité Inter-Etats d'Etudes Hydrauliques
CILSS	Comité Inter-Etats de Lutte contre la Sécheresse au Sahel
CMDT	Compagnie Malienne pour le Développement des Fibres Textiles
COMES	Commissairiat à l'Energie Solaire
CRES	Centre Régional d'Energie Solaire
DANIDA	Danish International Development Association
DHR	Département du Haut-Rhin (France)
DNHE	Direction Nationale de l'Hydraulique et l'Energie
EDF	European Development Fund
FAC	Fonds d'Aide et de Coopération
FED	Fonds Européen de Développement
FMVJ	Fédération Mondiale des Villes Jumelées
FONDEM	Fondation Energies pour le Monde
GTZ	Deutsche Geselschaft für Technische Zusammenarbeit
IDP	Iles de Paix (Belgium)
LESO	Laboratoire de l'Energie Solaire
LQE	Laboratoire de Qualité des Eaux
MAV	Mali Aqua Viva
ODEM	Opération de Développement de l'Elevage dans la zone de Mopti
OMVS	Organisation pour la Mise en Valeur du Fleuve Sénégal
PRODESO	Projet de Développement de l'Elevage au Sahel Occidental
PRS	Programme Régional Solaire (EDF)
SEP	Special Energy Programme
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
UNICEF	United Nations International Children's Fund
USAID	United States Agency for International Development

EXECUTIVE SUMMARY



Conducted for the U.S. interagency Committee on Renewable Energy Commerce and Trade (CORECT), this study documents the Mali experience with photovoltaic (PV) water pumping since 1977, and includes information on system operations and maintenance, economics, and social considerations. The study was undertaken to examine a large number of PV systems under actual (rather than demonstration) conditions. This documented experience can be used to support similar programs in West Africa and other parts of the developing world.

Seasonal fluctuations in surface water resources in Mali have led to extensive ground water development, and there are now nearly 15,000 boreholes and wells in Mali. The majority use hand or foot pumps, and there are about 1,000 diesel irrigation pumps and a like number of diesel village water supply systems.

Photovoltaics were first introduced in Mali in 1977 by the Mali Aqua Viva (MAV) project. Initially financed by non-government organizations, MAV's successes encouraged other organizations such as USAID, FAC, UNDP, EDF, GTZ, and Iles de Paix, to include PV pumps in their water pumping programs. A national organization, the Cellule d'Entretien des Equipements Solaires (CEES), was created in 1987 to coordinate PV water pumping under the supervision of the Direction Nationale de l'Hydraulique et de L'Energie (DNHE). Funded by the French government, the DNHE now plays a central role in Mali water resource development. There are now 157 PV pumping systems in Mali, with a cumulative PV capacity of 220 kWp.

Successes with PV systems in Mali have resulted in a major expansion of PV-powered water system programs. Bid awards have been completed for the EEC/Sahel solar electric pumping project in Africa. As part of this project, 226 PV water pumping units will be added in Mali, and 814 additional pumps in other areas of the Sahel. A GTZ Special Energy Programme is anticipated to add another 7 pumps before June 1990, and has proposed an additional 80 pumps, and a UNICEF project is anticipated to add 19 pumps in the Tomboctou region.

The Systems

The PV systems pump water primarily for <u>human</u> consumption and for livestock. Excess water may be used for vegetable gardens. Typical systems employ a borehole with

30-40 meter head, a submerged motor/pump, and one day's water storage. The average PV array rating is 1500 Wp, and all the systems reviewed are powered by single- or poly-crystalline silicon with the exception of one amorphous silicon system. Installed costs ranged from $8 to $16 per peak watt. The majority of pumps are of the submerged pump/submerged motor type. Surface motor/submerged pump systems are being discontinued due to unacceptably high failure rates.

Reliability

Monitoring of 66 pumps from 1983 to mid-1989 found 37 failures; equivalant to a mean-time-between-failures (MTBF) in excess of 30,000 hours. Given the average repair times encountered in Mali, this MBTF means that average pump availability is more than 99%. Common failures were from dirt, motors or motor brushes, wiring, and inverters. Few problems were found with PV modules, and maintenance is minimal. The most critical component for the sustainability of all water systems, regardless of type, continues to be infrastructure for parts, service, and user training. The provision of this infrastructure has been a critical factor behind the success of PV water systems in Mali. It is important that future PV programs dedicate sufficient resources to supporting infrastructure.

Acceptability

PV pumps have been well-received by villagers, and the systems are proudly shown to visitors. Important components of the programs examined included requiring minimum contributions toward the systems and familiarizing villagers with system operation, both of which helped the communites to think of the systems as their own. One of the principal reasons for the success of Mali PV pumps was the level of attention paid to user education and establishing a responsive network of maintenance and spare parts delivery.

Financing and Economics

As in the case of handpumps and diesel programs in Mali, financing typically requires contributions from outside donors such as UNDP, UNICEF, and CEAO. Boreholes may be provided by one organization, with pumping systems provided by another. There is a trend towards increased contributions from beneficiaries. CEES has proposed a minimum benficiary contribution that -- on a water delivered basis -- is similar to contributions for hand-pump systems. Beneficiary payments and sale of excess water pay for spares and maintenance services.

A cost analysis was performed to compare the relative life-cycle cost of water from PV systems compared to handpumps, animal traction, and diesel pumps. For water table depths greater than 15 meters, and villages with more than 250 people, PV systems have comparable or lower water costs than hand, animal, or diesel pumping. On a per-person initial cost basis, PV systems are $35 to $60/person, inclusive of borehole, pumping system, water distribution, and storage. The corresponding costs for handpumps, inclusive of borehole, ranged from $27 to $136/person depending on water table depth.

1. INTRODUCTION

1.1 Background

The work reported here was conducted for the U.S. interagency Committee on Renewable Energy Commerce and Trade (CORECT). The field work was performed between May 1989 and November 1989. The project was initiated by Mr. Robert Annan, Director of the Photovoltaic Technology Division at the U.S. Department of Energy. Mr. Annan is also Staff Director of CORECT. The CORECT is a working group of U.S. Government agencies, established by the U.S. Congress in 1984 to facilitate the worldwide use of U.S. renewable energy technology products and services.

The purpose of the project was to learn from the experiences gained by Mali in installing, financing, operating and maintaining PV systems. It is hoped that lessons learned through the project will help to improve the affordability, adaptability and sustainability of PV pumping systems, and thus expand their use in developing countries.

The work was undertaken by L. Sylla, M. Dicko, and T.J. Hart (IT Power West Africa); J.P. Kenna (IT Power UK); and T. Kennedy, and R.A. Cabraal (Meridian). The project was conceived and managed by R.A. Cabraal.

1.2 Water Supply and PV Pumps in Mali

Surface water resources in Mali are subject to large seasonal variations. This has prompted Mali to undertake large groundwater development projects and there are now nearly 15,000 boreholes and wells in Mali. Many of these are equipped with hand or foot pumps. There are about 1,000 diesel-powered water supply systems, and about 1,000 diesel-powered irrigation systems.

Solar pumps were introduced in Mali in 1977 by Father Bernard Verspieren, founder of the Mali Aqua Viva (MAV) Project. At first these pumps were financed by non-government organizations (NGO's) and were later financed by international donors with partial funding by the beneficiaries of the pump.

The success of the MAV installations has encouraged other organizations (USAID, FAC, UNDP, EDF, GTZ, Iles de Paix) to include PV pumps in their rural water supply programs.

A national organization for PV pumping the Cellule d'Entretien des Equipements Solaires (CEES) was created in 1987 and is funded by the French Government. The CEES coordinates work in the renewable energy sector under the supervision of the Direction Nationale de l'Hydraulique et de l'Energie (DNHE).

2. CHARACTERISTICS OF PV WATER SUPPLY SYSTEMS IN MALI

2.1 Typical Layout

A typical system in Mali (Figure 1) comprises:

Water source - For nearly 80% of the PV systems in Mali, the water source is a borehole, with a diameter between 125 mm and 200 mm. Nearly 15% pump from surface water sources and 7% from open wells.

The PV pump - Details are discussed in Section 2.2.

Water storage - Water is stored in ground-mounted steel tanks for domestic use and open concrete reservoirs for irrigation or livestock watering. Figure 2 shows the distribution of number of days of water storage. Typically, a site has one day's water storage.

Water distribution system - For those sites that are fitted with a water distribution system, there are typically 5 water stand points and a cattle water trough.

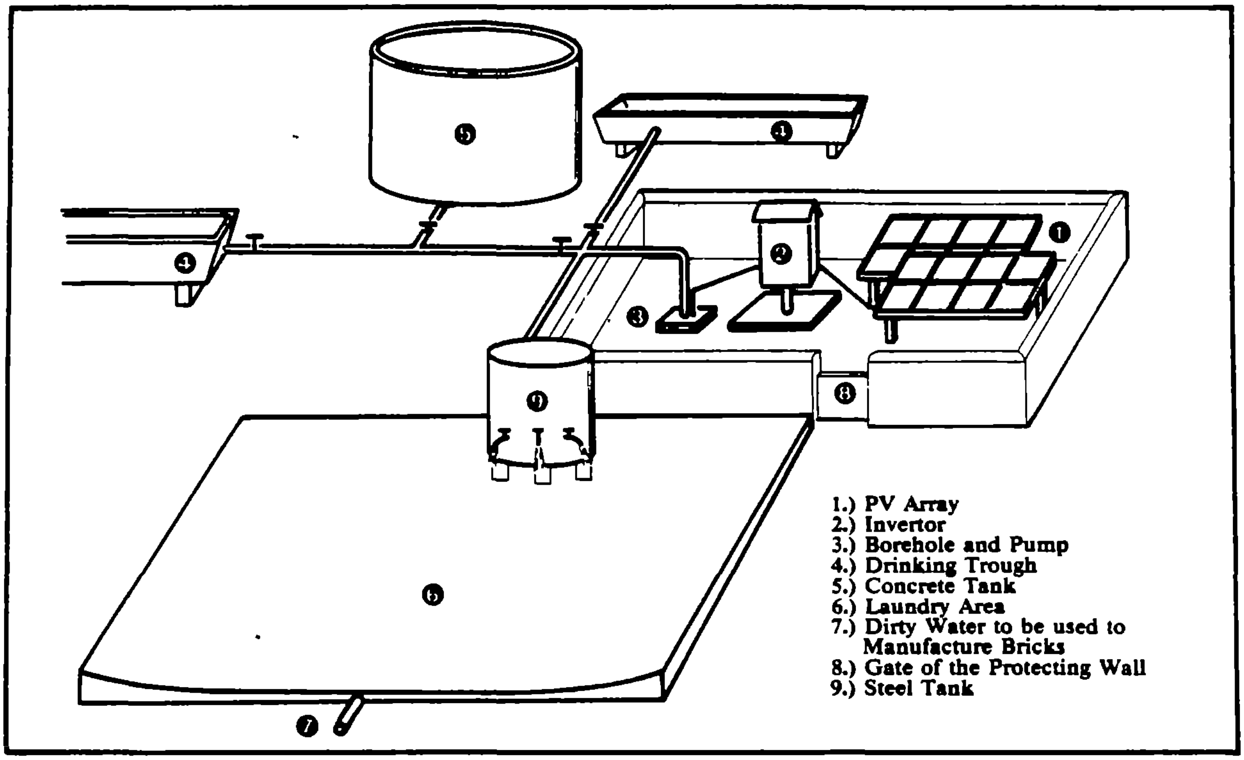


Figure 1. Typical Layout of PV Water Supply System (Source: Mali Aqua Viva)

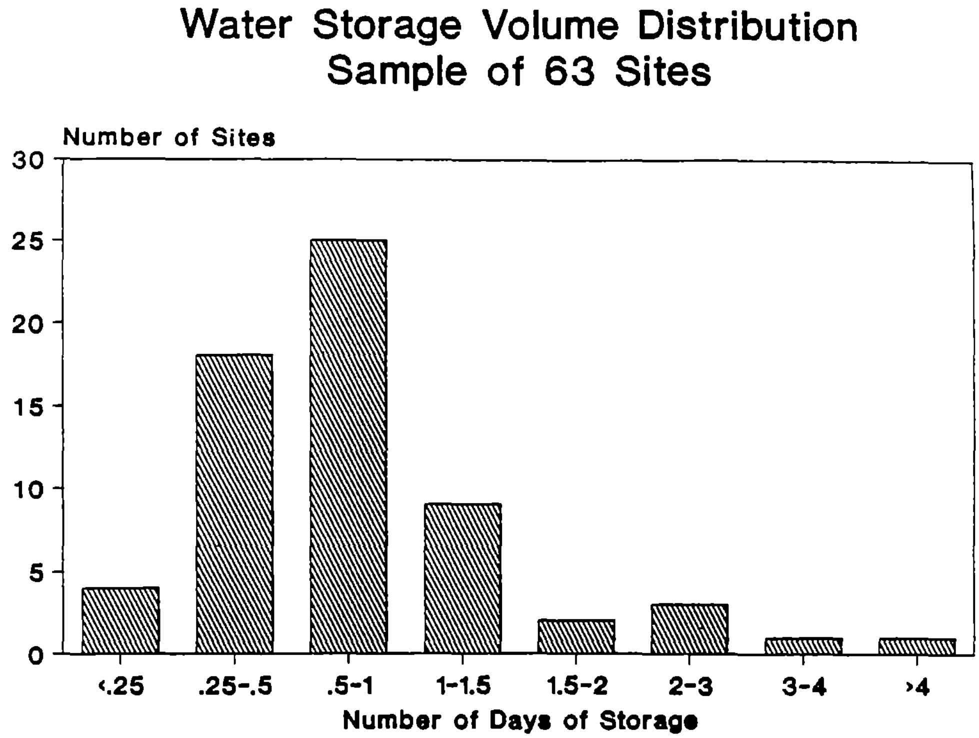


Figure 2. Number of Days Storage for a Sample of PV Pumps in Mali

2.2 Number and Types of Pumps

At present there are 157 PV pumping systems in Mali. A full list is given in Annex 1. Figure 3 shows the number of sites installed each year, together with the cumulative installed array power.

The major types of motor-pump subsystems that have been used are surface motor/submerged pump and submerged motor/submerged pump. Table I gives a breakdown of the proportion of each type of subsystem in use.

Most sites have a total head of between 30m and 40 m. Figure 4 shows the distribution of pumped head for a sample of 78 of the 157 PV pumps in Mali.

Power ratings of the installations, shown in Figure 5, range from 160 to 12,960 Wp, with an average of 1500 Wp. The manufacturers specified output in m^3m per day is shown as a function of array rating in Figure 6. Also shown in Figure 6 are measured performance values for the following four systems:

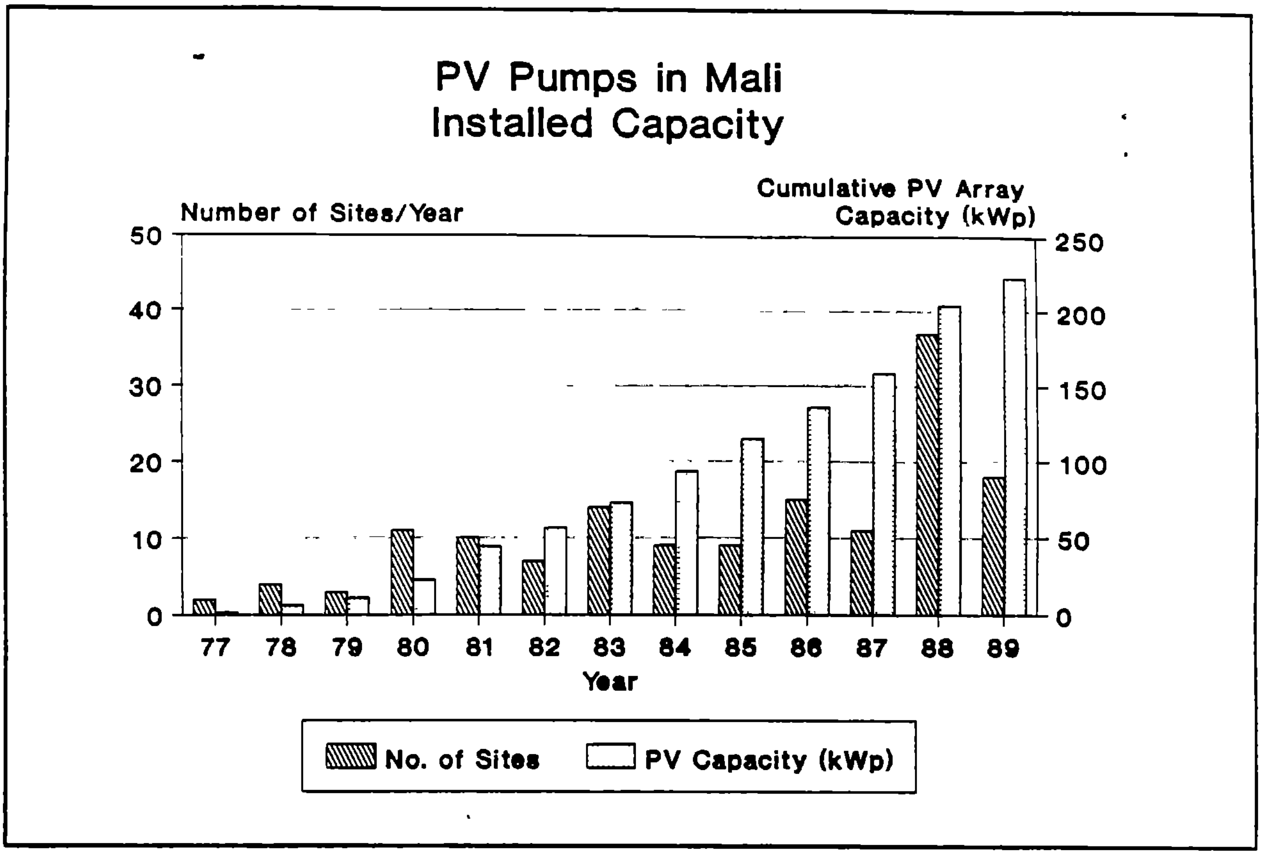


Figure 3. PV Pumps in Mali: Installed Capacity

Table I Analysis of Motor/Pump Types

Sub-system Type	Number	Percent
Surface motor/ submerged pump	40	25
Submerged motor/ submerged pump	68	43
Positive displacement	5	3
Floating motor/pump	13	8
Surface motor/pump	12	8
Unknown	19	12

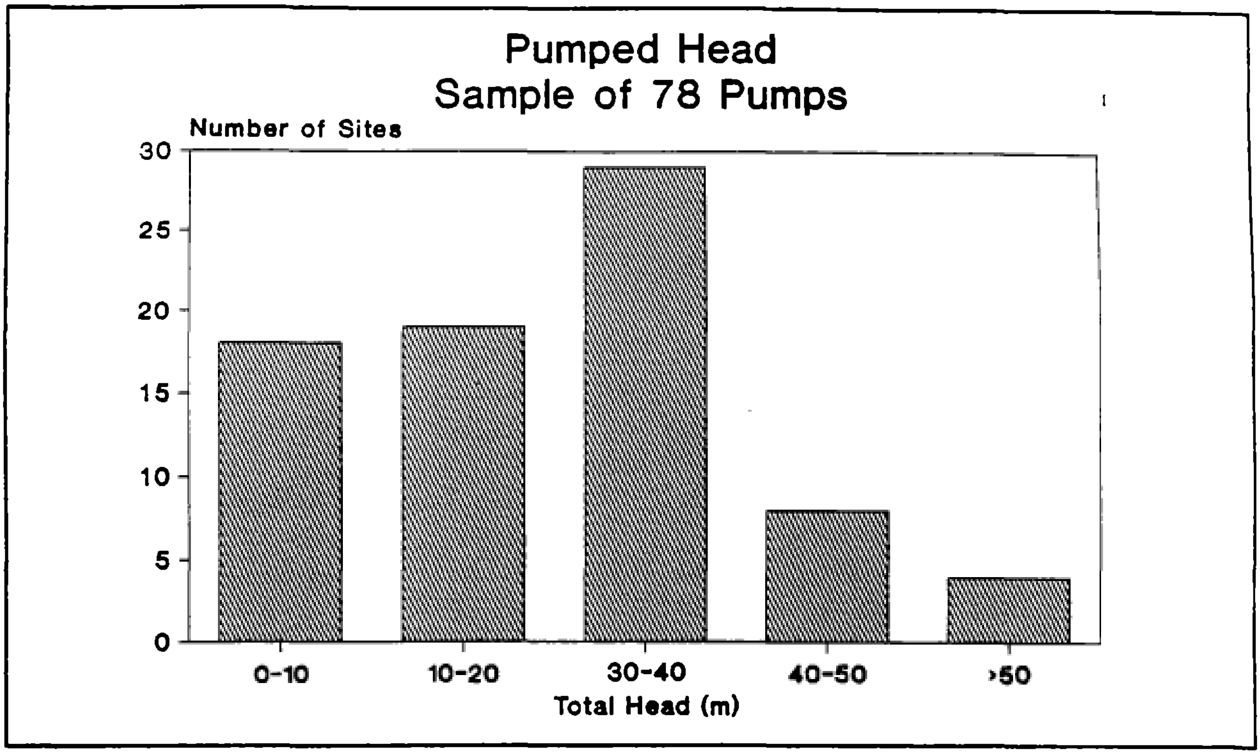


Figure 4. Pumped Head Distribution

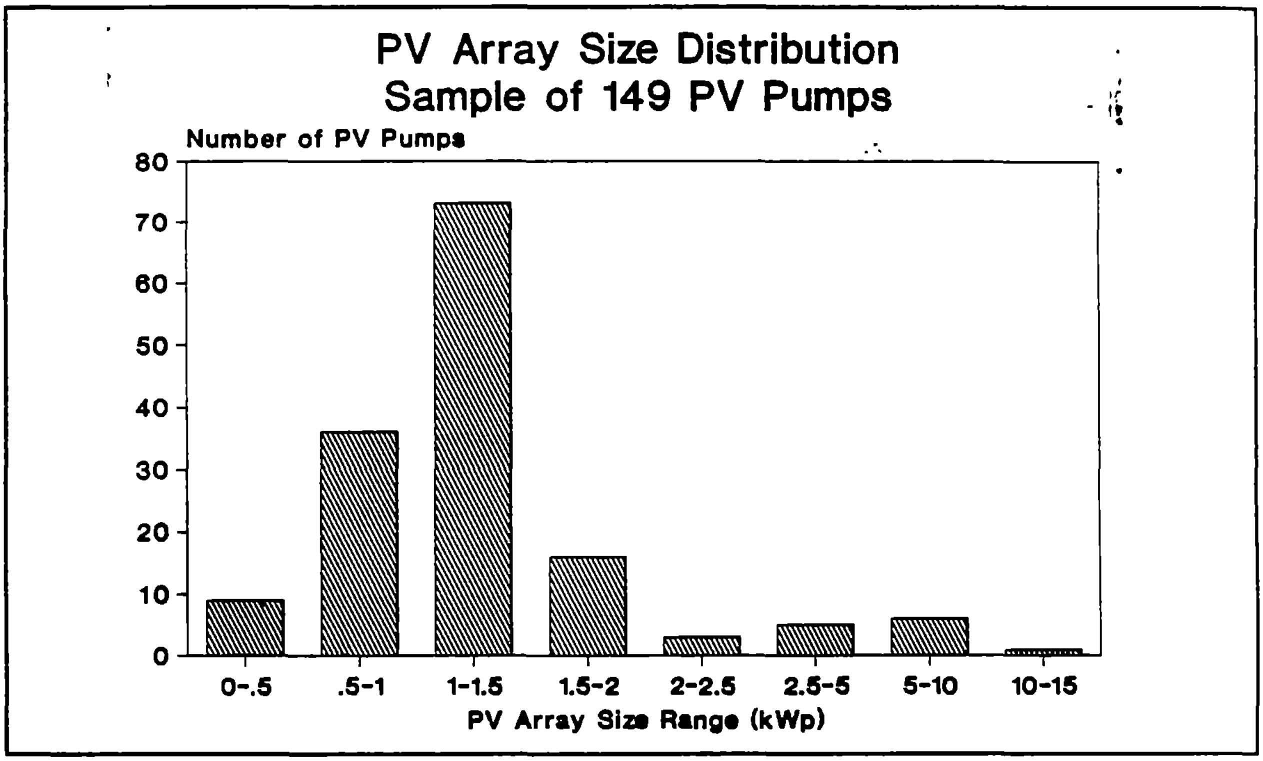


Figure 5. PV Array Size

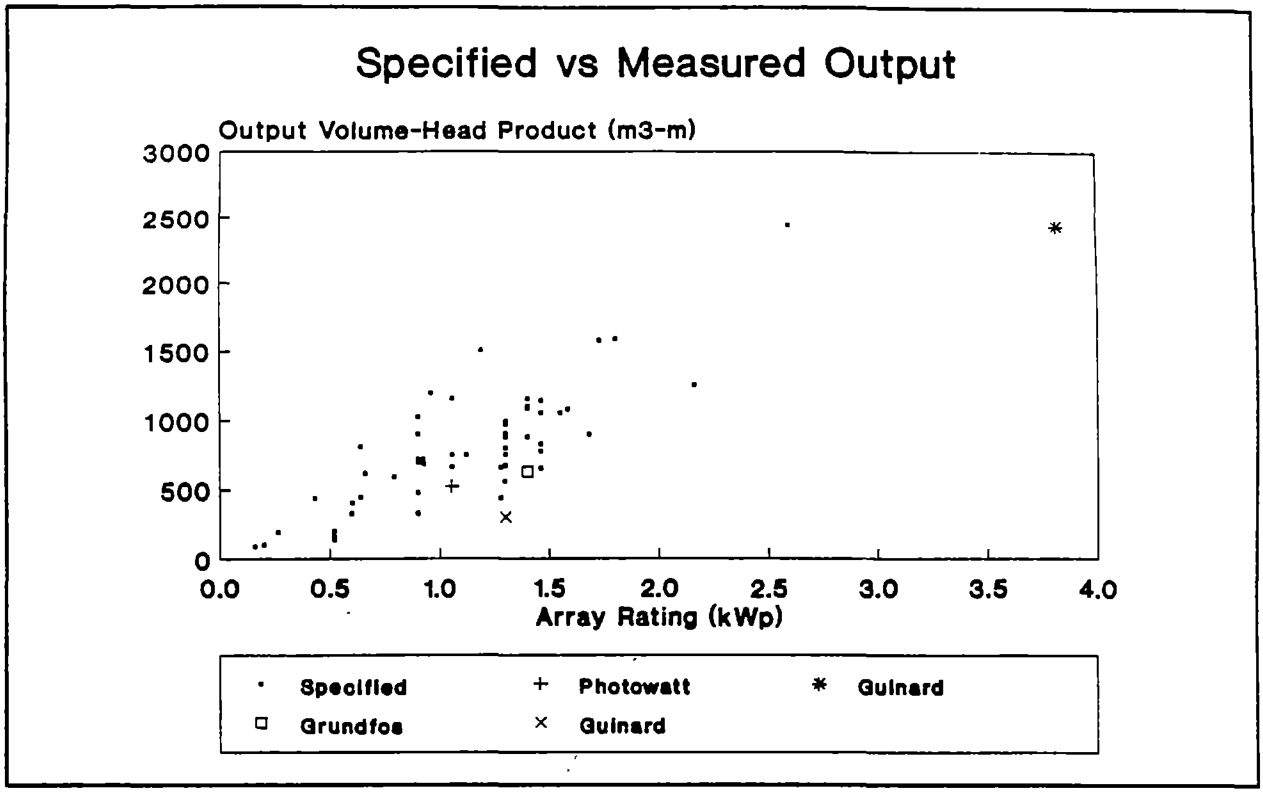


Figure 6. Comparison of Measured Output with Manufacturers Specified Output

- Nonsombougou (Pompes Guinard)
- Tioribougou (Photowatt)
- Tiemena (Grundfos)
- Samanko (Pompes Guinard)

In general the measured output is consistent with manufacturers specification.

Annex 2 gives maps of each region in Mali showing the location of the PV pumps.

2.3 Principal Sources/Suppliers of Pumps

The only organization selling PV pumps in Mali is SOMIMAD (see Table VII). All other pumps are procured outside of Mali by the purchaser or purchaser's agent. The principal sources of PV modules are France Photon, Photowatt and Arco Solar as shown in Table II below. Single and poly-crystalline silicon PV modules are the dominant type of PV being used, although one PV pumping system which uses an amorphous silicon array has been installed by MAV.

Table II Principal Sources of PV Modules

Manufacturer	Sites	%	kWp	%
Photowatt	36	22.9	41.6	18.8
Arco	33	21.0	42.6	19.3
France Photon	30	19.1	70.2	31.8
Kyocera	19	12.1	28.9	13.1
Siemens	11	7.0	5.7	2.6
Pragma	6	3.8	9.0	4.1
Solarex	4	2.5	4.4	2.0
RTC	4	2.5	3.3	1.5
AEG	1	0.7	1.4	0.6
Solar Power	1	0.7	0.9	0.4
Philips/R	1	0.7	5.2	2.4
Chronar	1	0.7	5.2	2.4
IDES	1	0.7	2.5	1.1
Unknown	9	5.7	-	-

The principal sources of motor/pump subsystems installed prior to January 1988, and the suppliers since January 1988 are given in Table III. Guinard pumps are no longer installed since there have been problems with the surface motors.

Table III Motor/Pump Sources - Number of Sites and Percent Distribution

	Total up to 11/89		After Jan. '88	
Manufacturer	No	%	No.	%
Guinard	39	24.8	-	-
Grundfos	39	24.8	18	38.3
Total	28	17.8	17	36.2
Photowatt	12	7.6	-	-
KSB	11	7.0	9	19.1
Solar Force	3	1.9	-	-
TED	3	1.9	-	-
Mono	2	1.3	-	-
Jaccuzi	1	0.6	1	2.1
Trisolar	1	0.6	1	2.1
Loerve	1	0.6	1	2.1
Other	3	1.9	-	-
Unknown	9	5.7	-	-
Abandoned	5	3.2	-	-

2.4 Assessment of Reliability and Availability

Of the 126 pumps observed in mid-1988, nine were stopped. These were all Guinard pumps that were being changed to Grundfos or Total. Five pumps were abandoned, generally because the wells had dried up. The remaining 112 pumps were working.

Sixty-six pump systems were monitored from January 1983 to June 1989. There were a total of 37 failures; the equivalent of one failure in 139 pumping months, or a mean-time-between-failures (MTBF) of over 30,000 hours. The types of system failures were:

- 7 inverters
- 4 motors
- 5 dc motor brushes
- 1 piping
- 6 wiring
- 11 due to dirt
- 3 miscellaneous

Insufficient data on components precluded making firm conclusions about specific equipment life times. The Pompes Guinard Alta-X pumps were replaced after 2 to 5 years but this was due to their unsuitable design rather than a lifetime failure. There were very few problems with the PV modules.

The MTBF of over 30,000 hours for the PV systems compares favorably with the typical MTBF of 1,500 hours for diesel systems and handpumps. MTBF by itself is only a partial indicator of pump reliability; an equally important factor is the period of time required to arrange and complete repair -- the mean down time, or MDT.

The typical time taken to respond and repair a pump was 4 to 10 days with a few cases over 3 months. This means that pumps were available for use an average of 99% of the time. If there are other souces of water available, this rate of down time may be acceptable. If the pumping system is the sole source, a 4-10 day down time will render the system undependable in the eyes of villagers. Some donor organizations have realized the need for a responsive repair service, and have dedicated an increased proportion of time and funds for operations training, parts supply, and service capability.

2.5 Current Installed Costs

Table IV shows the installed costs for PV pumps purchased for the GTZ SEP from 1986-1989. The table shows the costs subdivided into (i) the civil works (including water source), (ii) the PV array, (iii) the motor pump, (iv) accessories including storage and distribution, and (v) other costs including transport. Installed costs range from $7.9/Wp to $16.2/Wp when the civil works cost is excluded. Pumps imported into Mali do not incur taxes and duties.

Table IV Typical Installed Costs for PV Pumps

Site	Power Wp	Water Source	Civil Works ($)	Array ($)	Pump ($)	Accessories ($)	Transport ($)	Total ($)	$/Wp*
Fougadougou	1040	River	3048	5061	3057	2028	0	13194	9.8
Kayo	1560	River	3209	7593	4584	2190	0	17576	9.2
Boky-Wèrè	1560	Canal	600	7593	4584	60	150	12987	7.9
Kendébougou	520	Canal	450	2529	1527	30	90	4626	8.0
Sarro	1300	Bhole	18059	12600	1050	3510	3840	39059	16.2
Tonguè	1300	Bhole	15637	12600	1050	3510	3840	36637	16.2

*The $/Wp costs exclude cost of civil works

As in many West African countries, the cost of borehole drilling and lining is high. Depending on the nature of the ground, borehole costs range from $60 to $200 per meter. With typical depths of 50-150 m, the cost of a borehole can range from $3,000 to $30,000. Thus in many situations, the cost of a PV pump is much less than the cost of the borehole.

2.6 Current Trends

The first systems installed in Mali used surface dc motors with submerged pumps. These systems had quite rapid wear and are no longer used. The introduction of ac submerged motors in 1980 has resulted in much better durability and most new systems for boreholes make use of submerged motor/pumps.

Galvanized rising mains have been abandoned in favor of plastic rising mains (such as Wellmaster). Galvanized rising mains were subject to corrosion and rupture due to vibration. Plastic rising mains do not corrode, have acceptable mechanical strength, and are easier to remove from a borehole since they are lighter and no special equipment is required.

There is a trend to include stand pipes in new PV pumping systems in order to make effective use of the clean water.

The EEC/CILSS project will be installing 226 pumps in the Mopti region in 1990. In addition, a UNICEF project will provide 19 pumps in the Tomboctou region. The GTZ SEP, which has already installed 11 surface pumps and 2 borehole pumps plans, to install another 3 surface pumps and 4 borehole pumps before June 1990. A second phase has been proposed which includes 60 surface pumps and 20 borehole pumps.

The EEC/CILSS Regional Solar Programme for the Sahel

Bid awards have been completed for the EEC/CILSS Regional Solar Programme for the Sahel. This program -- the largest yet of its type -- will provide for the installation of 1,040 PV water pumps as well as PV cooling, lighting, and battery charging systems. The first group of PV pumps was awarded to Siemens Solar ($16.9 million) and Telefunken Solartechnik ($19.85 million), and will be installed in Senegal (110 units), Gambia (63), Guinea Bissau (53), Cape Verde (49), and Mauritania (125). The second group of 421 PV pumping systems, awarded to Italsolar ($8.36 million) and Total/Photowatt ($12.89 million), will provide 226 PV water pumping units over the next five years in the Mopti region in Mali, and 195 systems in Burkina Faso. The third group, awarded to Italsolar ($4.03 million) and Total ($6.81 million), will provide 134 units in Niger and 75 in Chad. While this is an ambitious program, it entails dispersing over 1,000 new PV systems over a large area of West Africa, and it is not clear whether sufficient funds will be dedicated to developing an effective service system for the provision of parts, maintenance, and training. Given the strong existing parts and service support in Mali, greater success with this program may be enjoyed there than in the other countries. In the authors opinion, greater resources may need to be dedicated to establishing a parts and service delivery system if a sustainable PV water pumping program is to be realized.

3. CHARACTERISTICS OF COMMUNITIES SERVED

3.1 Case Studies

3.1.1. Nonsombougou

Nonsombougou village has a 3.9 kWp Guinard system. There are 3,800 inhabitants in the village, 400 cattle and 2 hectare (ha) of irrigated land. In addition to the solar pump there are 3 handpumps and 1 footpump. The PV system was installed in 1984 by ASEM at a total cost of $115,000.

There was one repair in October 1987 at a cost of $200. An operator is employed to clean the modules once per week at a cost of $192 per annum. These costs are paid by charging for water at $1.50 per annum per family, $0.33 per cow per year and $240 per ha per year.

In terms of the impact on the village, the water quality is judged to be excellent, the quantity of water provided is ample and there is a well-stocked vegetable garden. It is estimated that the PV pump provides 80% of the water for the village.

3.1.2. Sarro

Sarro has a 1484 Wp system. The PV system and 10 open wells provide water for 3,600 inhabitants, 4,000 cattle, 500 donkeys, 50 horses and 0.7 ha of gardens. There are also 10 open wells and 2 handpumps.

The system was installed in 1988 by GTZ-SEP and CEES at a cost of $42,000. The village will make a contribution of $5,600 in 3 installments from 1988 to 1990. The operator works without pay but is authorized to use surplus water for irrigating his garden.

The villagers continue to use the open wells and have expanded their market gardening activities. They have decided to construct two additional reservoirs for irrigation. The existing PV pump provides an estimated 35% of the village water supply.

3.1.3. Tonguè

Tonguè has a 1484 Wp PV system and 18 open wells, which provide water for 2,100 inhabitants, 2,000 cattle, 40 horses, 100 goats and 5,000 sheep and goats.

The PV system was installed in 1988 by GTZ-SEP and CEES at a cost of $39,000. The village will make a contribution of $3,200. The operator is paid $8.00 per month.

In this village, the villagers preferred the water from the PV system, and this initially led to arguments among householders and market gardeners, and householders in different quarters of the village about the use of water. Following a public debate, the villagers decided to charge for the water in proportion to the amount used. The introduction of the solar pump has made a positive change in local food availability.

3.2 Acceptability

Acceptability of PV pumps in Mali is very high. The systems are accepted with great enthusiasm and are often a source of pride as they are demonstrated to visiting administrators and politicians. Villagers were pleased to be able to expand output in household vegetable gardens.

3.3 Affordability

The high investment costs for PV pumps mean that outside donors will have to be involved with the financing of village systems for the foreseeable future. However, the villagers accept the principle that they should contribute in some way toward the costs of the system.

For Mali Aqua Viva projects, the contribution by the beneficiary group has increased from 10% of investment costs in 1980 to 20% in 1987. The villagers must also pay for maintenance and repair.

The GTZ-SEP installations require a contribution of $3,000 out of $36,000 for multi-use pumps and a contribution of $5,400 out of $20,000 for floating pumps used for irrigation.

While all pumping systems will continue to require donor contributions, there is a trend toward increased contributions from beneficiaries. CEES has proposed a minimum contribution that should be made by the beneficiary group. This is shown in Table V and is based on the actual contribution made for handpumps in each region and as such is a measure of the level of contribution that the villagers can afford. On a water-supplied basis, the contributions for PV systems are similar to those for hand-pumping systems.

Table V Minimum Village Contributions in US$ for Handpumps and PV Pumps in Each Region of Mali

	Handpump		PV Pump	
	Flow (m3/day)			
Region	8	20	40	70
Sikasso	736	1850	3680	6450
Ségou	640	1600	3200	5600
Kayes	560	1400	2800	5000
Koulikoro	400	1000	2000	3500
Mopti	250	640	1280	2250

Borehole costs, which can be higher than those of the PV pump itself, are generally financed by donor organizations such as UNDP, UNICEF, CEAO, etc. In some cases this can be in the form of a loan that is repaid over a certain time period. Villagers consider this to be acceptable, and similar financing arrangements can be made for PV pumps.

Villagers are willing to pay a significant portion of annual income for a reliable water source that is under their control. Experience with pastoral associations in Mali, with storage wells costing approximately $50,000 and serving approximately 50 families, has shown that families are willing to support a down-payment of 30,000 F CFA ($100) and annual payments of 44,000 F CFA ($147 per family). For comparison, the cost of one heifer in mid-1987 in the Mopti region was 60,000 F CFA, or $200.

4. ORGANIZATIONS SUPPORTING PV WATER SUPPLY SYSTEMS

4.1 Principal Organizations

Table VI shows a complete list of organizations supporting PV water supply systems in Mali.

Table VI List of Principal Organizations Supporting PV Pumps in Mali

Organization		Contact	ACTIVITIES						
Name	Address	Persons	Advice	Fin-ance	Inst-all	Main-tain	Spares	Train-ing	Notes
DNHE	BP 66 Bamako	M S.Traoré, Directeur M K.Dembélé, Chef Div Ag	x		x	x		x	supervision of PV in Mali
CEES	BP 66 Bamako	M S.Kéita, Chef Cellule M J.Billerey, Consultant	x	x	xx	xxx	x	xx	created in 1985
MAV	BP 1 San	M D.Soumare, Directeur Père B.Verspieren	x	x					Activities delegated to CEES in 1988
GTZ	BP100 Bamako	M H.G.Huehn, Chef Mission M L.Sylla, Chef Project		x	xx	x			3 years experience
LESO	BP 134 Bamako	M C.Traoré, Directeur M M.Diarra, Chef Sect.	x		x	x		x	R&D team
UNDP	BP 66 Bamako	M M.Simonot, Admn.Proj M S Diawara, Chef Proj		xx					
I.T.Power	BP Bamako	M T.J.Hart, Directeur M M.Dioko, Direct. Adj	xxx					xxx	10 year experience
SONIMAD	BP 1910 Bamako	M A.Vincent, Directeur			x	xxx	xxx		Private sector
SES Corp	BP 3165 Bamako	M M Coulibaly, Direct.					x		Private sector
UNICEF	BP 120 Bamako	Mlle. G.Senghor,Adm.Proj		xx					
FAC				xxx				x	
CCCE				xx					
Ile de Paix		M B.Andreieu			x				
DANIDA					x				
CRES	BP 1872 Bamako	M R.Foro M I.Cissé	x						
BNDA					x				
CECI	BP 109 Bamako				x				
ASEM	BP 2866 Bamako	M J.P.Boch, Directeur M S.Keita, Ing	x	x	xx	xx		x	Activities stopped in December 1985
FED				xxx					

DNHE plays a central role in the control and execution of solar pumping programs in Mali. It employs 400 staff and comes under the control of the Ministry of Water and Energy. The following organisation work with DNHE : Mali Aqua Viva, LESO, CEES, GTZ-SEP, ASEM, and DANIDA.

The other organizations consist of private enterprises and NGOs. The other principal organizations are:

- Iles de Paix - a Belgian NGO which works in the Tomboctou region. Three PV pumps have been installed between 1978 and 1982 for drinking water and irrigation.
- SOMIMAD - a private enterprise representing external suppliers (Photowatt, Total, etc.) which is installing PV systems for PRODESO.

4.2 Maintenance Organizations

Each of the following organizations involved in maintenance has a central maintenance yard: CEES is in Bamako, MAV in San, UNICEF in Tomboctou, GTZ in Bamako, and SOMIMAD in Bamako. Villagers report breakdowns to these central maintenance yards in three ways: (i) villagers send a messenger by mobylette or bush taxi; (ii) the village informs the nearest administrative office who then sends a radio message to their correspondent in the town where the maintenance yard is based; (iii) villagers inform any official mission visiting the village and ask them to inform the maintenance team.

The EEC Regional Solar Programme plans to install special radio devices on the PV pumps which will automatically send a message to the maintenance team when a fault occurs. Once a fault is reported a maintenance team comprising two to three persons travels to the site in a 4x4 vehicle. They take only measuring instruments and light handling equipment since most of the pumps are now submersibles.

Overhead costs are financed by the donor organizations: FAC (France) for CEES, GTZ for the Special Energy Programme, UNICEF for their team in Tomboctou, etc. The donors have also paid to set up the maintenance facilities, with the exception of SOMIMAD which used its own money. CEES bills the villagers for the direct costs of maintaining their pumps.

The CEES and MAV maintenance teams are very responsive and efficient. SEP and UNICEF do not have much maintenance experience because their pumps are relatively new.

All organizations have made arrangements for the villagers to carry out the following O&M tasks: daily starting and stopping of pumps, panel cleaning, inspection and sometimes replacement of water taps, and where applicable, reading and reporting of measuring instrument readings.

Improvements to maintenance response time can be achieved by a greater involvement of the villagers in the maintenance. This can be achieved by better user training and encouragement. For example, the GTZ-SEP programme proposes to invest 50% of funds in hardware and 50% on better training and related activities such as market gardening, fodder plant growing, etc. In this way the villagers will be more interested in good maintenance in order to keep the pumps working.

Better cooperation between projects operating in the same zones could also bring some improvement. Solar powered radio links between villages or groups of villages and maintenance yards may also reduce the response time.

4.3 Community Participation

Communities are involved with financing of PV pumps for their villages as outlined in Section 3.3. The communities are also involved in the following aspects: familiarization, technical training, management, and socioeconomic issues.

Familiarization usually takes place during two to three meetings between the project promoters and the villagers. The objective is to meet before the system is installed to understand the needs and resources in the village. The meetings take place either with a general assembly of villagers or a committee of village elders.

Technical training is provided by the project promoters covering aspects such as cleaning of PV panels and water tanks/reservoirs, starting and stopping of the pumps, reading the flow meter, and using the water taps.

The village appoints a Comité de Point d'Eau (CPE) responsible for the management of the pump and the water provided. Typically, the CPE comprises at least three people: the President, the Treasurer and the Operator. The committee collects payment for the water on different bases. For example, the payment could be a fixed amount per year (e.g., $1-2 per family) or it could be a payment based on the water supplied (e.g., 3 U.S. cents per 10 liter container; 64 cents per 200 liter drum; 8 cents per cow per month) or a mixture of both methods. Operating costs are financed from these payments. As an example, the CPE in Nonsombougou collected $560 over the 2-year period from 1985 to 1987 and the Goumbou CPE collected $2,000 in an 8-month period.

5. COMPARISON OF ALTERNATIVE WATER SUPPLY METHODS

5.1 Water Sources

Rural communities obtain water from surface sources such as rivers and canals, from underground sources using hand-dug wells, from "modern" wells which are cement-lined wells about 1.5 meter diameter, from PVC-lined boreholes, and from boreholes with adjacent storage wells.

Storage wells are typically 1.8m diameter cement-lined wells that are dug about 5m from a borehole. A connecting tunnel between the borehole and the storage well is drilled below the level of the water table. This allows water to rise to the level of the water table in the wider storage well. Water can be lifted from the storage wells manually or using animals. In the Mopti region, boreholes with storage wells are being used by pastoral associations for livestock watering.

The associations, which consist of 50 pastoral families each, pay for the storage wells over a 10-year period. The wells cost $54,000 each. In spite of the very high cost of the storage wells (which are in addition to the cost of the borehole), the associations prefer these wells over diesels. This is because of the uncertainty of fuel supply and maintenance services, and the high cost of transporting fuel and spares from Mopti (which is about 300 km away), and because they prefer not to depend on outside sources for satisfying their critically important water needs.

5.2 Alternative Water Lifting Methods

In addition to photovoltaic pumps, water is lifted manually, and by using animals, handpumps, foot pumps and diesels. Water is lifted manually using rope and leather buckets. This method is usually feasible only in areas with shallow water tables, and if small quantities are water are needed. Donkeys and camels are used to lift larger quantities of water, or from deeper water tables, again using ropes and leather buckets. Although technologically simple, when the water source is a borehole, animal drawing requires the construction of a large storage well parallel to the borehole. This requirement can increase the total cost to the level of PV. Handpumps or foot pumps are used generally when the water table is no deeper that about 40m. Diesels directly coupled to pumps, or diesel generators powering submersible pumps are used in Mali to lift water from surface sources or boreholes.

5.3 Comparative Costs

An analysis was performed to determine the conditions under which alternative water lifting technologies would provide the lowest cost water on a life-cycle cost basis. Water lifting methods considered were: handpumps, using camels, diesel pumps, and PV pumps. The analysis was performed for water table depths of 15, 25, 40, and 50 meters. Village population sizes ranged from 100 to 2,000 persons. Water demand was assumed to be 20 liters/person/day, 40 liters/cow/day, 7 liters/goat/day. Each family was assumed to consist of 10 persons, and owned 5 cows and 5 goats each. Total water demand was therefore 43.5 liters/person/day.

Figure 7 shows the comparative costs at a 15m water table depth. Handpumps provide the lowest cost water until the village exceeds 1,000 persons, when PV becomes slightly less expensive than handpumps at a water cost of around $0.25/m^3.

Figure 8 shows the comparative costs when the water table is 25m. Photovoltaics is the lowest cost alternative when the village size exceeds 250 persons. At large village sizes, the cost of diesel-powered pumping approaches that of PV pumping. Up to about 500 persons, PV pumping and water lifting using camels have similar costs. For larger villages, handpumped water is about twice as costly as PV pumped water.

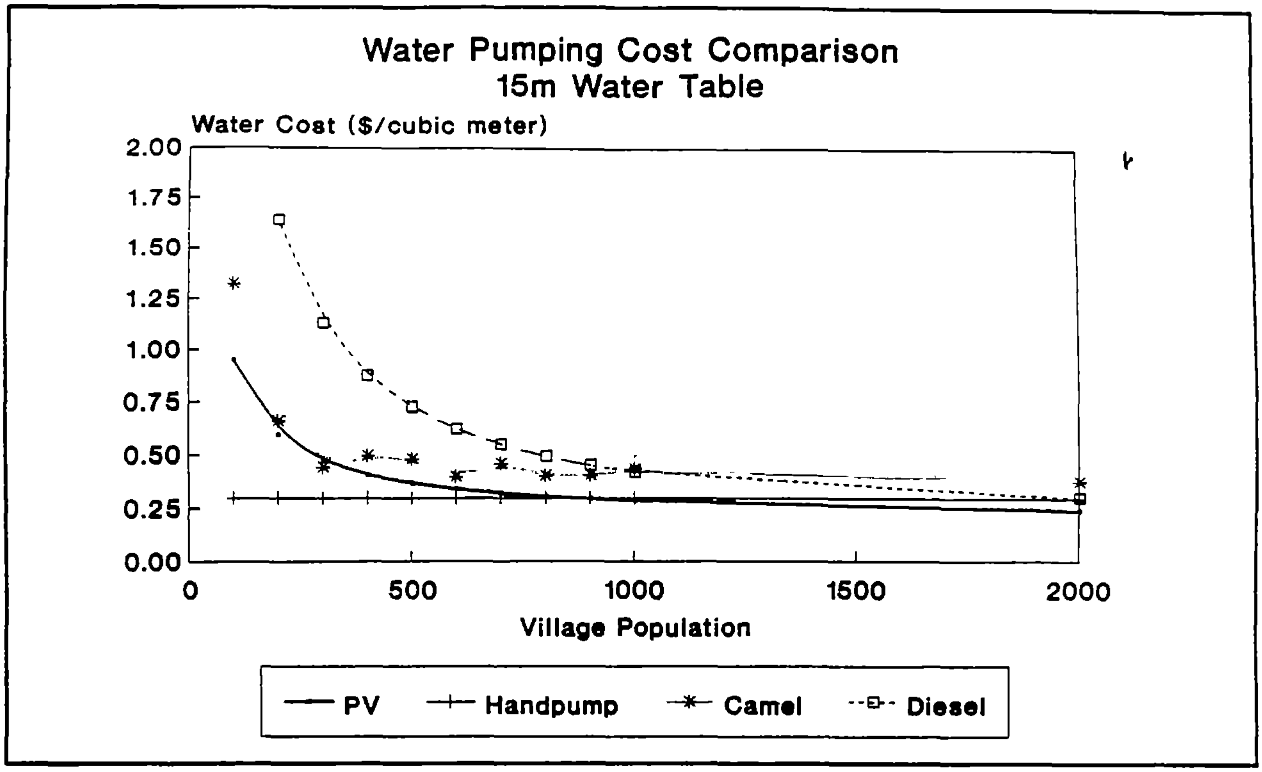


Figure 7. Water Pumping Cost Comparison - 15m Water Table

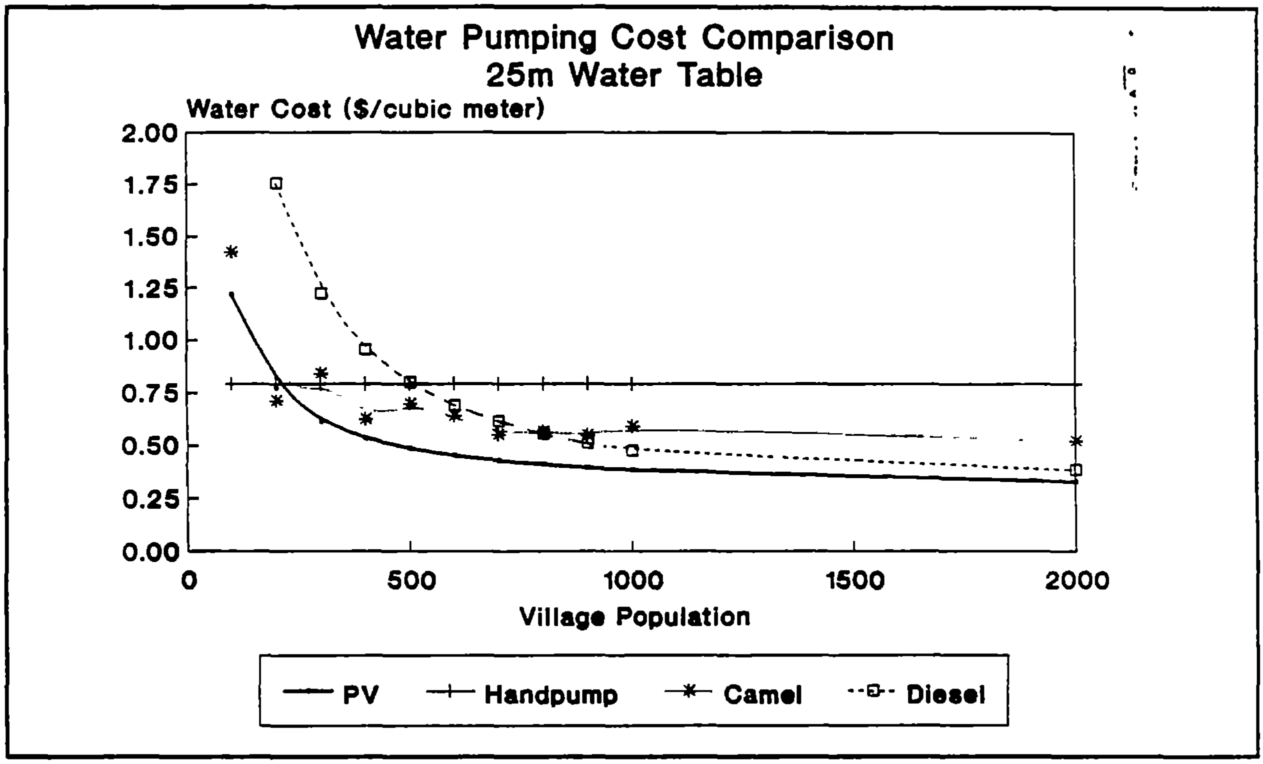


Figure 8. Water Pumping Cost Comparison - 25m Water Table

Figure 9 shows the comparative costs when the water table is 40m. Handpumped water is far more costly than any of the other water lifting methods. Water lifting using PV and camels have <u>similar</u> costs when the village size is less than about 400 persons. For larger villages PV provides the lowest cost water. When the village size exceeds 2,000 persons, diesel pumping becomes marginally cost-competitive with PV pumping.

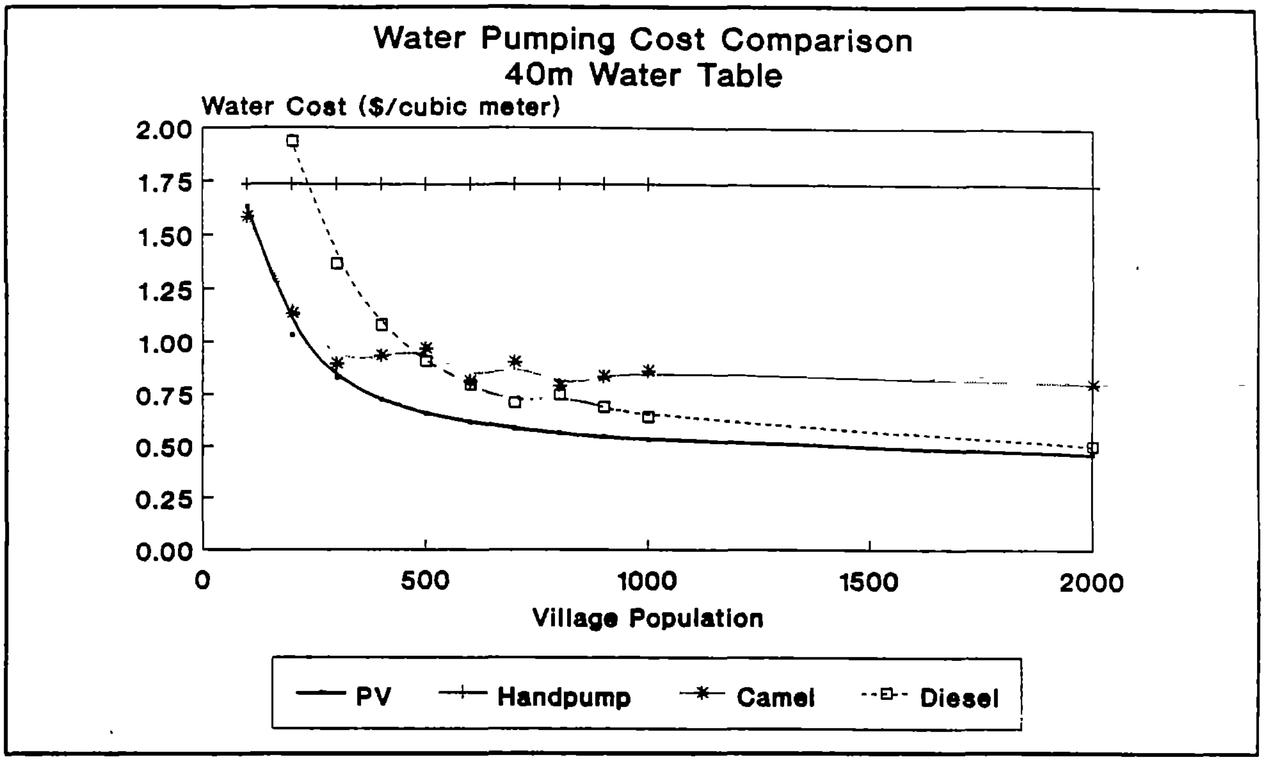


Figure 9. Water Pumping Cost Comparison - 40m Water Table

Figure 10 compares the costs of PV, camel, and diesel-powered water lifting methods when the water table depth is 50m. Water lifting using camels provides the lowest cost water when villages have less than 250 persons. For villages with 250 to 2,000 persons, PV provides the lowest cost water. For villages with more than 2,000 persons, diesels can provide water at approximately the same cost as PV.

An important factor, particularly when comparing PV systems to handpump systems, is the cost of the borehole. Since borehole costs are often the same regardless of whether they will be used for diesel, PV, or handpump systems, and are often paid for by donor organizations, they are often left out of cost comparisons. In reality, financial resources for boreholes are limited, and the number of villagers that can be served by one borehole ultimately affects the per-person cost of the system. For example, if a handpump and PV system each require a $10,000 borehole, the borehole cost/person is $50 for the handpump serving 200 people and $10 for the PV pump serving 1,000 people. In this case, the donor resources dedicated to borehole drilling can be stretched significantly.

Annex 3 includes information on the initial capital costs on a per-capita basis, which average $35-60 per person for photovoltaics. This cost includes the cost of the borehole,

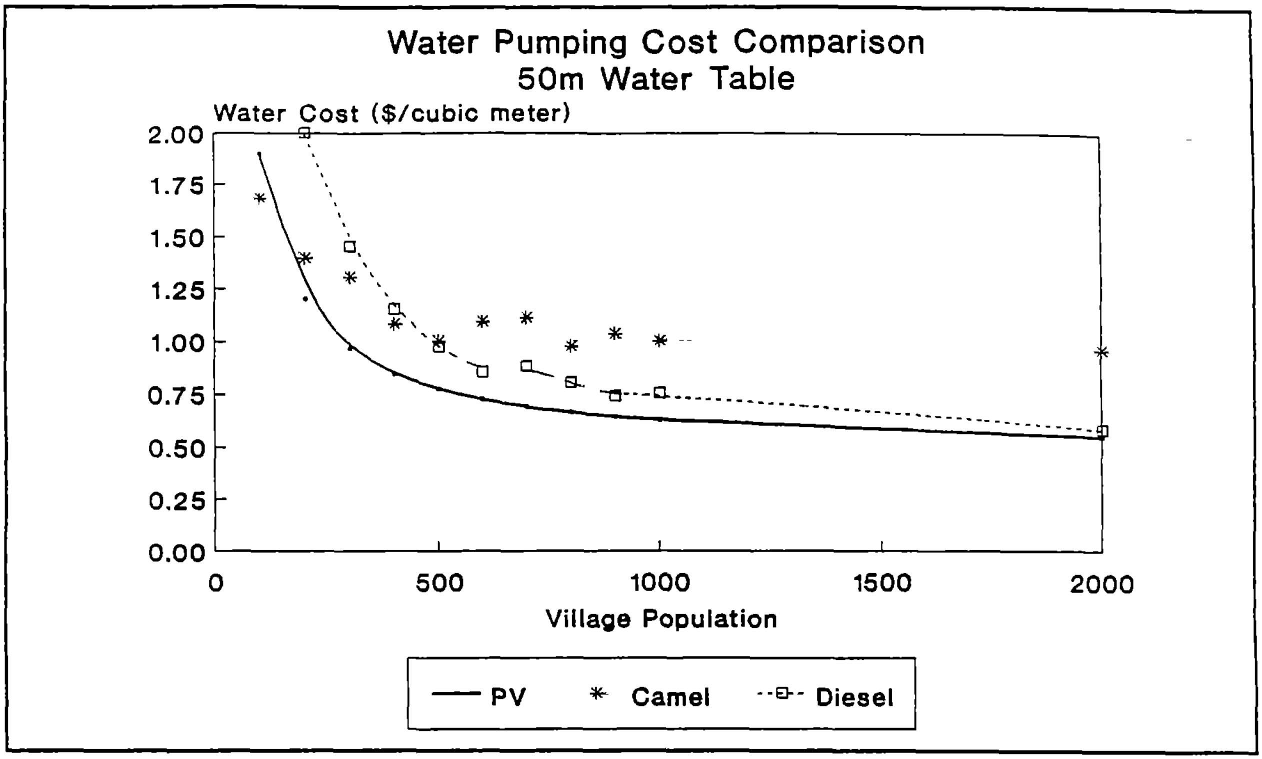


Figure 10. Water Pumping Cost Comparison - 50m Water Table

PV pump, storage, and distribution system. For well depths of 25m or greater, and villages of over 250 people, PV is less expensive on an initial capital cost/person basis than handpumps.

5.4 Assumptions

These analyses assume that the pumping sites are 0-75 km from a central fuel storage depot. Due to poor road conditions in remote rural areas, fuel must often be transported in barrels using 4-wheel drive vehicles. Even so, fuel transport costs add only about 0.1 US cents/liter/km. However, as Mali is a very large country, fuel must often be transported long distances, which can significantly increase the delivered cost of diesel fuel.

Costs and Logistics of Diesel Pumping: An Example

The government operates a livestock watering site close to Boni village in the Mopti region for 5 months of the year. During this period a 15 kVA diesel generator is brought from Boni village (20 km away) and installed at the site. The generator provides power to run a Grundfos SP-8 submersible pump. A full-time operator is stationed at this site for 5 months. Diesel fuel is delivered from Mopti which is 400 km away. The cost of delivered diesel at the pump site is over $1.60/liter, or more than double the cost of fuel in Mopti. In addition, spares and maintenance personnel must be sent from Mopti.

Annex 3 shows the assumptions used, and the detailed calculations used in the comparative cost analyses. Two assumptions in particular are important: (1) Only the cost of water pumping was included, and user costs such as queuing time and water transportation were not considered. World Bank research has indicated that these costs are significant, and even if imputed at the relatively low value of 25 U.S. cents per day, they may exceed the life cycle hardware costs of hand pumps. (2) PV system analysis was done on a "worst-month" solar insolation basis. In actual practice, annual water output from these systems would exceed design requirements. This water has value: a Mali Aqua Viva installation generated $3,600 in one year by selling excess water to outsiders, and other projects have arrangements where the local system caretaker receives excess water for his own use.

Annex 1 - List of Solar Pumps in Mali

The following pages give details of the pumps reviewed in the survey carried out for this project. Each pump is identified by a number, and there are four pages of information for each pump.

The first page shows the region, district, and site name together with the water source type, borehole diameter in mm if appropriate, water tank storage capacity, open reservoir storage capacity, total storage volume, whether cattle troughs and water taps are included, and number of taps or standpipes.

The second page shows the peak watts of the PV array, the PV manufacturer, pump flow rate in m3/day, the total head in m, the year installed, the system status, and the beneficiary.

The third page shows who funded the system, who installed it, and who maintains it, and indicates the number of breakdowns and the number of days the system was inoperable.

The fourth page shows the type of failure.

No	Region	Cercle	Site	Water Source	Borehole Diameter mm	Tank Volume m3	Reservoir Volume m3	Total Volume m3	Cattle?	Number of Taps
1	Bamako	Bamako	Inst. Marchoux	Borehole	140	18	0	18		6
2	Bamako	Bamako	Magnambougou	Borehole	152	20	20	40		5
3	Kayes	Diema	Bema	Borehole	168					
4	Kayes	Kayes	Biladjimi	Borehole	170	150		150	y	3
5	Kayes	Yelimanè	Kiranè	Borehole	125	25		25	y	2
6	Koulikoro	Dioïla	Dioïla	Well		23		23		
7	Koulikoro	Kati	Djoliba	Surface						
8	Koulikoro	Kati	Doeorakoro	Well	5000		0	0	n	
9	Koulikoro	Kati	Kabala	Borehole		10	0	10	n	7
10	Koulikoro	Kati	Kabalabougou	Borehole	127	4	0	4	n	5
11	Koulikoro	Kati	Koursale 1	Surface					n	
12	Koulikoro	Kati	Koursale 2	Surface					n	
13	Koulikoro	Kati	Ouelessebougou	Borehole	150	10	0	10	n	
14	Koulikoro	Kati	Samanko	Borehole	203	30	0	30	n	
15	Koulikoro	Kolokani	Didieni	Borehole	128	6	12	18	y	7
16	Koulikoro	Kolokani	Doubala	Borehole	160				y	7
17	Koulikoro	Kolokani	Kolokani Hopital	Borehole	127	10		10		2
18	Koulikoro	Kolokani	Kolokani Marché	Borehole	127	10		10		4
19	Koulikoro	Kolokani	Koumi	Borehole	125	20	30	50	y	
20	Koulikoro	Kolokani	Manta	Borehole	128	6	12	18	y	7
21	Koulikoro	Kolokani	Nonosombougou	Borehole	175	40	80	120	y	8
22	Koulikoro	Kolokani	Sebekoro 2	Borehole	125	10	20	30	y	
23	Koulikoro	Kolokani	Sirakoroba	Borehole	128	6	12	18	y	7
24	Koulikoro	Kolokani	Tioribougou	Borehole	128	6	16	22	y	7
25	Koulikoro	Kolokani	Fougadougou 1	Surface			23.5	23.5	n	
26	Koulikoro	Kolokani	Fougadougou 2	Surface			23.5	23.5	n	
27	Koulikoro	Kolokani	Karadie	Borehole	175	40	80	120	y	
28	Koulikoro	Koulikoro	Kayo 1	Surface		0	19	19	n	
29	Koulikoro	Koulikoro	Kayo 2	Surface		0	19	19	n	
30	Koulikoro	Koulikoro	Kayo 3	Surface		0	19	19	n	
31	Koulikoro	Nara	Daily	Borehole	125	9	18	27	y	
32	Koulikoro	Nara	Dilly CP Modibo	Borehole	203	20		20	y	
33	Koulikoro	Nara	Dilly D Diawara	Borehole	135	20	1.5	21.5	y	
34	Koulikoro	Nara	Goubou							
35	Koulikoro	Nara	Keybane							
36	Koulikoro	Nara	Medina Kagoro	Borehole		30	50	80	y	
37	Sikasso	Bougouni	Faragouaran	Borehole	145	8	16	24	n	7
38	Sikasso	Bougouni	Keleya	Borehole	145	14	28	42	n	7
39	Sikasso	Bougouni	Kologo	Borehole	145	8	16	24	n	7
40	Sikasso	Bougouni	Manankoro	Borehole	145	6	12	18	n	7
41	Sikasso	Kadiolo	Woroni	Borehole	145		28	28	n	
42	Sikasso	Kolondieba	Kolondieba	Borehole	148	14		14		7
43	Sikasso	Koutiala	Mpebougou							
44	Sikasso	Sikasso	Sikasso St Omn	Borehole	145	100		100		
45	Sikasso	Sikasso	Zangaradougou	Borehole	145					
46	Segou	Baraoueli	Baraoueli							
47	Segou	Bla	Ban Markala	Borehole	160					5
48	Segou	Bla	Bè	Borehole	220	8		8		5
49	Segou	Bla	Bienina			8		8		
50	Segou	Bla	Bla Administ			8		8		5

No	Region	Cercle	Site	Water Source	Borehole Diameter mm	Tank Volume m3	Reservoir Volume m3	Total Volume m3	Cattle?	Number of Taps
51	Segou	Bla	Bla ecole			8		8		5
52	Segou	Bla	Diakoro	Borehole		8		8		5
53	Segou	Bla	Diaramana	Borehole	200					
54	Segou	Bla	Djenna	Borehole	152					
55	Segou	Bla	Dougouwolo							
56	Segou	Bla	Douna	Surface						
57	Segou	Bla	Fandiela	Borehole		8		8		
58	Segou	Bla	Fani 1						y	
59	Segou	Bla	Fani 2							
60	Segou	Bla	Gouala							
61	Segou	Bla	Goulabougou							
62	Segou	Bla	Kampolosso							
63	Segou	Bla	Kazangasso							
64	Segou	Bla	Kemeni 1							
65	Segou	Bla	Kemeni 2			8	50	58		5
66	Segou	Bla	Kokosso				8	8		5
67	Segou	Bla	Koni 1	Borehole	160		30	30		
68	Segou	Bla	Koni 2							
69	Segou	Bla	Mpèbougou			8		8		5
70	Segou	Bla	Nabasso 1	Borehole	140				y	
71	Segou	Bla	Nabasso Ecole			3	20	23		
72	Segou	Bla	Nani							
73	Segou	Bla	Nani-Kokoni							
74	Segou	Bla	Niala			8		8		5
75	Segou	Bla	Ndosso	Borehole		8	30	38	y	5
76	Segou	Bla	Nionina	Borehole		8		8		5
77	Segou	San	Nioguesso	Borehole	200	30	30	60	y	5
78	Segou	San	Ntiesso 1	Borehole	140					
79	Segou	San	Ntiesso 2			8		8		5
80	Segou	San	Ntoba	Borehole	200					
81	Segou	San	Safolo	Borehole	140	5	30	35	y	
82	Segou	San	Sagara							
83	Segou	San	Sagara Daga							
84	Segou	San	Somabogo			8		8		
85	Segou	Bla	Somasso			8		8		5
86	Segou	Bla	Sorofing			8		8		5
87	Segou	Bla	Talo							
88	Segou	Bla	Teriya Bugu 1							
89	Segou	Bla	Teriya Bugu 3							
90	Segou	Bla	Teriya Bugu 4							
91	Segou	Bla	Teriya Bugu 5							
92	Segou	Bla	Teriya Bugu 6							
93	Segou	Bla	Teriya Bugu 7							
94	Segou	Bla	Tla			8		8	y	5
95	Segou	Bla	Tiemena							
96	Segou	Bla	Touba					0		
97	Segou	Bla	Wassasso	Borehole	160	10	30	40	y	
98	Segou	Bla	Weru							
99	Segou	Bla	Woloni	Borehole	200	10	30	40	n	
100	Segou	Bla	Yangasso 1	Borehole	160	8	150	158	y	

No	Region	Cercle	Site	Water Source	Borehole Diameter mm	Tank Volume m3	Reservoir Volume m3	Total Volume m3	Cattle?	Number of Taps
101	Segou	Bla	Yangasso 2	Borehole	160	8	77	85	n	5
[illegible]	Segou	Ke-Macina	Boky-Wèrè 1	Surface		0	0	0	n	
103	Segou	Ke-Macina	Boky-Wèrè 2	Surface		0	0	0		
104	Segou	Ke-Macina	Boky-Wèrè 3	Surface		0	0	0		
105	Segou	Ke-Macina	Madumanso	Borehole						
106	Segou	Ke-Macina	Sarro	Borehole		8	9	17		6
107	Segou	Ke-Macina	Tonguè	Borehole		8	9	17		6
108	Segou	Niono	Kendebugu	Surface						
109	Segou	Niono	Sokolo	Borehole		150		150		
110	Segou	San	Dieli Ecole							
111	Segou	San	Kimparana	Borehole	200		15	15	n	
112	Segou	San	Koro	Borehole	160				n	
113	Segou	San	Kotobe	Borehole	200	30	0	30		
114	Segou	San	Niamana-Bankuma	Borehole		8		8		
115	Segou	San	San Ecole							
116	Segou	San	San Hopital	Borehole	140		0	0	n	
117	Segou	San	San Maraich 1							
118	Segou	San	San Maraich 2							
119	Segou	San	Sinzara	Borehole	200	0	0	0	y	
120	Segou	San	Sourountouna	Borehole	200	0.4		0.4	n	
121	Segou	Segou	Babougou	Well	1200	1.5	0	1.5	n	
122	Segou	Tominian	Bossoni	Borehole	200	8	30	38	y	
123	Segou	Tominian	Dobwo							
124	Segou	Tominian	Kanian							
125	Segou	Tominian	Kio							
126	Segou	Tominian	Mandiakuy							
127	Segou	Tominian	Tion							
128	Segou	Tominian	Tominian 1				0	0	n	
129	Segou	Tominian	Tominian 2							
130	Segou	Tominian	Tominian 3							
131	Mopti	Bandiagara	Sangha							
132	Mopti	Bankass	Bankass 1	Borehole	300				y	
133	Mopti	Bankass	Bankass 2							
134	Mopti	Bankass	Koporo Kenie PE							
135	Mopti	Douentzan	Boni Yassa						y	1
136	Mopti	Douentzan	Fombori							
137	Mopti	Mopti	Mopti	Well	1800					
138	Mopti	Mopti	Nantaga							
139	Tombocto	Dire	Bourem Sidi Amar							
140	Tombocto	Dire	Kondi							
141	Tombocto	Goundam	Douetire							
142	Tombocto	Goundam	Tin aïcha							
143	Tombocto	Gourma-Rh	Mandiakoye							
144	Tombocto	Niafunke	Niafunke	Surface						
145	Tombocto	Tomboctou	Araouane							
146	Tombocto	Tomboctou	Ber							
147	Tombocto	Tomboctou	Bourem in Aly	Well	1800	10		10		
148	Tombocto	Tomboctou	Kabara	Well	1800	5		5		3
149	Tombocto	Tomboctou	Tassakan							
150	Tombocto	Tomboctou	Tin Taylout							
151	Segou	Bla	Siela	Borehole		8	0	8	n	
152	Segou	Bla	Garangata	Borehole		8	0	8	n	
153	Segou	Bla	Tala	Borehole		8	0	8	n	
154	Segou	Bla	Toforola	Borehole		8	0	8	n	

No	Peak Watts	PV Manufacturer	Pump Manufacturer	Pump Flow m3/day	Total Head m	Inst. Year	Status	Beneficiary
1	640	Photowatt	TED	30	15	88	u	Gardeners
2	1300	Photowatt	Guinard	15	45	81	a	village 7300
3	1548	Arco	Jaccuzi	42	25	89	u	village
4	1120	Photowatt	Grundfos	30	25	85	u	Comite Eleveurs
5	602	Arco	Trisolar	12	34	88	u	village
6	900	Photowatt	Sofretes	19		82	a	
7	2160	Photowatt	Total	140	9	88	u	marcaicher
8	480	Solarex	Loervre		5	89	u	marcaicher
9	1400	Arco	Grundfos	55	20	88	u	assoc eminine de maraichag
10	160	Photowatt	TED	6	15	88	u	ecole + village
11	1468	Kyocera	TED		7	86	u	groupe 60 femmes
12	2160	Photowatt	Total		7	86	u	groupe hommes
13	264	Photowatt	Photo	8.5	22	83	u	centre sanitaire + ecole
14	1300	F/Photon	Guinard	33	30	82	u	centre post-cure (180)
15	924	Photowatt	Photo	24	30	83	u	
16	1188	Photowatt	Photo			83	u	
17	530		Total			87	u	hopital
18	1716			25		83	u	village 9500
19	1680	F/Photon	Solar Force	50		84	a	village
20	660	Photowatt	Photo	23	27	83	u	village 650
21	3885	F/Photon	Guinard	120		84	u	village
22	1680	F/Photon		32	28	84	u	
23	927	Photowatt	Photo	23	30	83	u	village 2000
24	1056	Photowatt	Photo	23	29	83	u	village (2200)
25	520	Siemens	KSB floating	20	7	88	u	
26	520	Siemens	KSB floating	20	7	88	u	
27	4320	F/Photon	Guinard	120		84	u	village (760)
28	520	Siemens	KSB floating	27	6	89	u	maraicher
29	520	Siemens	KSB floating	27	6	89	u	maraicher
30	520	Siemens	KSB floating	27	6	89	u	maraicher
31	1470	F/Photon	Solarforce sub	25		84	a	village
32	2592	F/Photon	Guinard	70	35	83	bad	village
33	1728	F/Photon	Guinard	63	25	81	bad	village
34	1120	Arco	Grundfos			86	u	
35	1400	Arco	Grundfos			86	u	
36	3888	F/Photon	Guinard	80		84	u	
37	1056	Photowatt	Photo	58	20	83	u	village 1500
38	1188	Photowatt	Photo	56	27	83	u	village 870
39	1056	Photowatt	Photo	29	28	83	u	village 900
40	792	Photowatt	Photo	23	28	83	u	village 1900
41	1400	Arco	Grundfos	55	21	88	u	
42	1584	Photowatt	Photo	49	22	83	u	village 6200
43	640	Photowatt	Total					
44	1400	AEG	Grundfos	55	20	88	u	Stade Omn
45	1400	Arco	Grundfos	55	20	88	u	
46								
47	1300	Arco	Guinard	32	25	80	u	village 520
48	1300	F/Photon	Guinard	30	30	80	u	village 350
49	960	Kyocera	Total	30	40	88	u	
50	1462	Kyocera	Total	30	38	88	u	

No	Peak Watts	PV Manufacturer	Pump Manufacturer	Pump Flow m3/day	Total Head m	Inst. Year	Status	Beneficiary
51	1280	Photowatt	Total	30	22	87	u	
52	432	F/Photon	Grundfos	15	29	85	u	village 620
53	900	Arco	Guinard		15	84	u	
54		F/Photon	Guinard	32	35	80	u	village 170
55	1400	Photowatt	Grundfos			88	u	
56	1400	Photowatt	Guinard			87	a	
57	1090	Kyocera	Total			89	u	village
58	1400	Photowatt	Grundfos			86	u	
59	1400	Photowatt	Grundfos			86	u	
60	1400	Photowatt	Grundfos			85	u	
61							removed	
62	1400	Arco	Grundfos			87	u	
63	1400	Arco	Grundfos			85	u	
64	1400	Arco	Grundfos			85	u	
65	1400	Arco	Grundfos		17	86	u	Generale Biscuit
66	1400	Arco	Grundfos	40	27	87	u	
67	900	F/Photon	Guinard	30	30	77	u	CFAR
68	900	F/Photon	Guinard			80	removed	
69	640	Photowatt	Total	15	54	87	u	village 2200
70	900	Solar Power	Guinard	35	20	77	remove	school
71	1280	Photowatt	Total	20	22	86	u	
72	5300	Kyocera	Total	360		87	u	
73	1400	Photowatt	Grundfos	40		88	u	
74	1400	Photowatt	Grundfos	25	35	86	u	
75	1800	F/Photon	Guinard		18	81	a	village 700
76	1462	Kyocera	Total	30		89	u	village
77	1300	Arco	Guinard	40	20	81	u	village 550
78	900	Arco	Guniard	38	27	82	u	village 950
79	1462	Kyocera	Total	25	26	88	u	village 950
80	900	Arco	Guinard	32	15	82	u	village
81	1300	F/Photon	Guinard			80	u	village 730
82	1400	Photowatt	Grundfos			86	u	
83	550	Kyocera	Total			88	u	
84	1462	Kyocera	Total	25	31	88	u	
85	1462	Kyocera	Total	25	42	88	u	
86	1462	Kyocera	Total	25	33	88	u	
87	1484	Arco	Grundfos			88	u	
88	5200	F/Photon/Photo	Guinard			81	u	
89	1280	Photowatt	Total			85	u	
90	5200	Philips/RTC	Total			87	u	
91	360	Photowatt	Omera surface			88	u	
92	520	Siemens	KSB			88	u	
93	5200	Chronar (a)				89	u	
94	1484	Arco	Grundfos	40		87	u	
95	1484	Arco	Grundfos			84	u	
96	1484	Arco	Grundfos			86	u	
97	1300	F/Photon	Guinard	50	15	80	a	village 1320
98	1400	F/Photon	Guinard			84	u	
99	1300	Arco	Guinard	44	22	81	u	
100	1300	Solarex	Guinard	40	20	78	bad	CAR

No	Peak Watts	PV Manufacturer	Pump Manufacturer	Pump Flow m3/day	Total Head m	Inst. Year	Status	Beneficiary
101	1300	Solarex	Guinard	35	25	79	u	Village 1500
102	520	Siemens	KSB floating	80	2	89	u	Assoc Maraichiere
103	520	Siemens	KSB floating	80	2	89	u	Assoc Maraichiere
104	520	Siemens	KSB floating	80	2	89	u	Assoc Maraichiere
105	1400	Photowatt	Grundfos			86	u	village
106	1484	Arco	Grundfos	45		88	u	village 3400
107	1484	Arco	Grundfos	35		88	u	village 1700
108	520	Siemens	KSB floating	100	2	89	u	grp Maraicher
109	12960	France Photon		75		85	u	comite eleveurs
110						89	u	
111	1300	Arco	Guinard		15	80	u	village 4310 +ecole
112	1300	France Photon	Guinard	90	10	80	a	village
113	900	Arco	Guinard	29	24	81	a	village
114	1462	Kyocera	Total			88	u	village
115	430	France Photon	Solar Force			85	a	
116	900	RTC	Guinard	15	22	79	u	hopital + MAV
117	1462	Kyocera	Total			88	u	
118	1462	Kyocera	Total			88	u	
119	1800	Arco	Guinard	53	30	81	theft	village
120	200	RTC	Photo	2	10	82	repairs	school + village
121	456	Arco	Briau	1	5	78	a	centre sememcier
122	1300	France Photon	Guinard	40	20	80	u	village + eleveurs
123	1300	France Photon	Grundfos			85	u	
124	1600	Photowatt	Total			87	u	
125	1400	Photowatt	Grundfos			86	u	
126	1462	Kyocera	Total			88	u	
127	600	France Photon	Guinard	22	15	80	removed	
128	1300	Solarex	Guinard	40	20	78	u	Village 2180
129	900	Arco	Guinard	36	20	81	u	Village 2180
130	800	RTC				83	u	
131	1400	Photowatt	Grundfos			86		
132	5200	France Photon	Guinard			81		
133						89		
134	1400	Arco	Grundfos			88		
135	2600	France Photon	Guinard	80	70	79		village
136	1540	Arco	Grundfos			88		
137	1296	France Photon	Guinard	80	7	80		maraichers
138	365	Kyocera	Total			88		
139	900	France Photon	Guinard			86	?	
140	1680	Pragma	Grundfos			88	u	UNICEF
141	1680	Pragma	Grundfos			88	u	UNICEF
142	1680	Pragma	Grundfos			88	u	UNICEF
143	1680	Pragma	Grundfos			88		UNICEF
144	520	Siemens	KSB floating					
145	2000	Kyocera	Total			87	u	MAV/CEES
146	2500	IDES	Monolift			82	u	Ile de Pais
147	5760	France Photon	Guinard	30	8	82	remove	village - 1550
148	1400	RTC	Monolift			78	u	cantonnement eaux et forets
149	650	Pragma	Tamagnini surface			88		
150	1680	Pragma	Grundfos			88	u	
151	1480	Arco	Grundfos			89		village
152	1480	Arco	Grundfos			89		village
153	1462	Kyocera	Total			89		village
154	1090	Kyocera	Total			89	u	village

No	Funded by	Installed by	Maintained by	No of Breakdowns	Failure Duration Days
1	AFEM/AMRF	CEES	CEES	1	
2					
3	USAID	LESO	LESO		
4	Fonds Saoudien/PRODESO	SONIMAD	SONIMAD	1	
5	USAID	LESO	LESO		
6	FAC/AFME	LESO			
7	FOMDEM	CEES	CEES		
8	GTZ (PSE)	PSE	PSE		
9	SOS Sahel + PBV	MAV	CEES		
10	AFME+ALAD	CEES	CEES		
11	FONDEM	CEES	CEES		
12	FONDEM	CEES	CEES		
13	FED+SNEA	ASEM	ASEM/CEES		
14	USAID/AFME	LESO/CEES	LESO/CEES	5	
15	PNUD/FENU	ASEM/CEES	LESO/CEES	2	
16	PNUD/FENU	ASEM/CEES	LESO/CEES		
17	FED	Electricite 200	CEES		
18	AFME/FAC	Electricite 200	CEES		3
19	FED	ASEM	ASEM/CEES		
20	PNUD (FENU)	ASEM	ASEM/CEES	1	6
21	FED	ASEM	ASEM/CEES		
22	FED	ASEM	ASEM/CEES		
23	PNUD/FENU	ASEM	ASEM/CEES		
24	PNUD	ASEM	ASEM/CEES	2	17
25	GTZ+CECI	PSE	PSE		
26	GTZ+CECI	PSE	PSE		
27	FED	ASEM	ASEM/CEES		
28	GTZ+CECI	PSE	PSE		
29	GTZ+CECI	PSE	PSE		
30	GTZ+CECI	PSE	PSE		
31	FED	ASEM	ASEM/CEES		
32	USAID/PRODESO	LESO	LESO		
33	USAID/PRODESO	LESO	LESO		
34					
35		MAV/CEES			
36	FED	MAV/DNHE	ASEM/CEES		
37	PNUD/FENU	ASEM	ASEM/CEES		4
38	PNUD/FENU	ASEM	ASEM/CEES		4
39	PNUD/FENU	ASEM	ASEM/CEES		5m
40	PNUD/FENU	ASEM	ASEM/CEES		4
41	Cooper Danoise	Project Danes	Project Danes		
42	PNUD/FENU	ASEM	ASEM/CEES		7
43					
44	Gouver del la 3 region	CEES	CEES		
45	Coper Danoise	Project Dane	Project Dane		
46					
47	CFCMCF/MAV	MAV	MAV		
48	AFVP/CEE/MAV	MAV	MAV		
49	CEAO/CEE/CMDT/MAV	MAV	MAV		
50	DHR	MAV	MAV		

No	Funded by	Installed by	Maintained by	No of Breakdowns	Failure Duration Days
51	DHR	MAV	MAV		
52	village + MAV	MAV	MAV		
53	MAV/Pere Sores	MAV	MAV		
54		MAV	MAV		
55		MAV	MAV		
56		MAV	MAV		
57		CEES	CEES		
58		MAV	MAV		
59		MAV	MAV		
60		MAV	MAV		
61		MAV	MAV		
62		MAV	MAV		
63		MAV	MAV		
64		MAV	MAV		
65	MAV	MAV			
66	MAV	MAV			
67	M Tissot/CEE/CCFD/FED/MAV	MAV	MAV		
68	Dev Paix Comrade	MAV	MAV		
69		MAV	MAV		
70	Maire d'Oullins	MAV	MAV		
71		MAV	MAV		
72		MAV	MAV		
73		MAV	MAV		
74	Maire d'Oulinns	MAV	MAV		
75	CMDT/CEAO/CEE/MAV	MAV	MAV		
76		CEES	CEES		
77	Femmes d'Arg/CEE/CMDT/SOS Sahel/Village/	MAV	MAV		
78	SOS Sahel/CEE/CMDT/MAV/Village	MAV	MAV		
79		MAV	MAV		
80	SOS Sahel/CEE/MAV/Village	MAV	MAV		
81	SOS Sahel/CEE/MAV/Village	MAV	MAV		
82		MAV	MAV		
83		MAV	MAV		
84		MAV	MAV		
85		MAV	MAV		
86		MAV	MAV		
87		MAV	MAV		
88		MAV	MAV		
89		MAV	MAV		
90		MAV	MAV		
91		MAV	MAV		
92		MAV	MAV		
93		MAV	MAV		
94		MAV	MAV		
95		MAV	MAV		
96		MAV	MAV		
97	CEAO/MAV/Village/FED/CMDT	MAV	MAV		
98		MAV	MAV		
99		MAV	MAV		
100	CCFD/FED/FDF/MAV/Village	MAV	MAV		3.5m

No	Funded by	Installed by	Maintained by	No of Breakdowns	Failure Duration Days
101		MAV	MAV		
102	GTZ+Assoc Mar	PSE	PSE		
103	GTZ+Assoc Mar	PSE	PSE		
104	GTZ	PSE	PSE		
105		MAV	MAV		
106	GTZ+Village	PSE/CEES	PSE		
107	GTZ+Village	PSE/CEES	PSE		
108	GTZ+village	PSE	PSE		
109	Fonds Saoudien/PRONESO	SOMIMAD	SOMIMAD		
110	Freres du Sacre-Couer	MAV	MAV		
111	FMVJ+CEE+MAV+village	MAV	MAV		
112	CEAO+CEE+CMDT+MAV+Village	MAV	MAV		
113	CEAO+CEE+CMDT	MAV	MAV		
114		CEES	CEES		
115		MAV	MAV		
116	FAC/COMES/CEE	MAV	MAV		
117		MAV	MAV		
118		MAV	MAV		
119	Figaro/CEE/CMDT/SOS SahelMAV/Village	MAV	MAV		
120	Phot prototype	MAV	MAV		
121	World Bank	Halcrow/ITP	LESO		
122	CEAO/CEE/CMDT/MAV	MAV	MAV		
123		MAV	MAV		
124		MAV	MAV		
125		MAV	MAV		
126		MAV	MAV		
127	CEAO/CEE/CMDT/MAV	MAV	MAV		
128	CCFD/FED/CCF/FDF/MAV	MAV	MAV		
129	CEE/SOS Sahel/CMDT/MAV/Village	MAV	MAV		
130		MAV	MAV		
131		MAV	MAV		
132	USAID/OMM	USAID/CEES	USAID/CEES		
133	USAID	CEES			
134		MAV	MAV		
135	World Nabk	Guinard	LESO		
136	ecole+EUMC	CEES	CEES		
137	USAID/ODEM	MAV/USIAD/G	LESO		
138		MAV	MAV		
139					
140	CEES	CEES			
141	CEES	CEES			
142	CEES	CEES			
143	CEES	CEES			
144					
145					
146					
147	FAC/AFME	Iles de Paix	Iles de Paix		
148	FED	Ile de Paix			
149	UNICEF	CEES	CEES		
150	UNICEF	CEES	CEES		
151		CEES	CEES		
152		CEES	CEES		
153		CEES	CEES		
154		CEES	CEES		

No	Type of Failure
1	1 module broken,
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	dc diodes, motor/pump,electric wire
15	electronics + blocked motor;Grundfos installed 85
16	Grudfoss pump installed in 85
17	
18	motor problem
19	
20	motor replaced by Grundfos
21	3 modules broken; motor problem
22	
23	motor replaced with Grundfos 85
24	motor replaced with Grundfos 85
25	
26	
27	
28	
29	
30	
31	
32	
33	
34	
35	
36	
37	replaced with Grundfos
38	replaced with Grundfos
39	replaced by Grundfos
40	replaced by Grundfos
41	
42	replaced with Grundfos
43	
44	
45	
46	
47	replaced with Grundfos
48	replaced with Grundfos
49	
50	

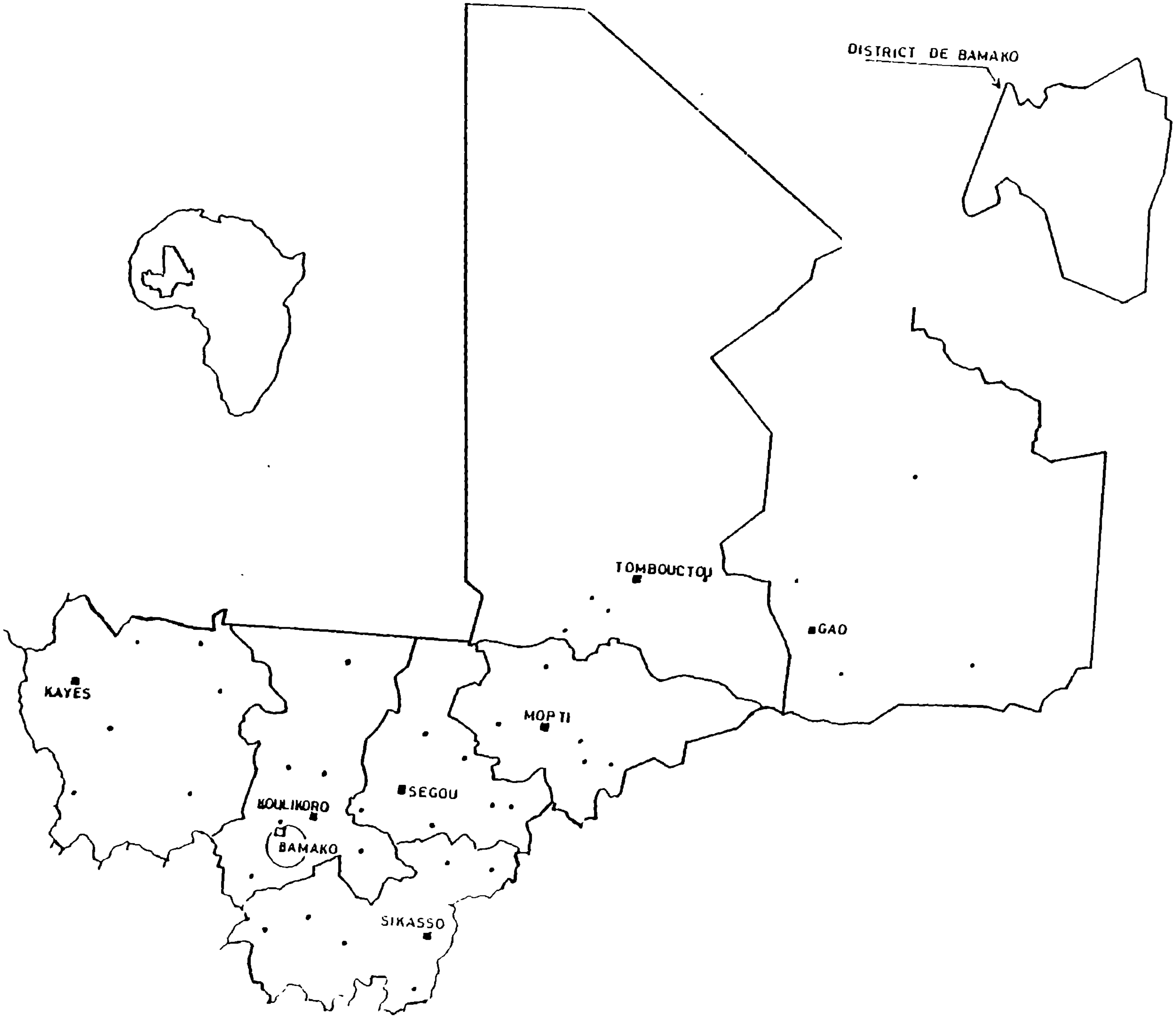
No	Type of Failure
51	
52	
53	
54	replaced by Grundfos in 86
55	
56	
57	
58	
59	
60	
61	
62	
63	
64	
65	
66	
67	replaced by Grundfos in 86
68	moved to Tominian
69	demonte
70	
71	changed in 88
72	
73	
74	
75	
76	
77	changed to Grundfos in 85
78	changed to Grundfos in 86
79	
80	
81	
82	
83	
84	
85	
86	
87	
88	
89	
90	
91	
92	
93	
94	
95	
96	
97	
98	
99	
100	transmission + +

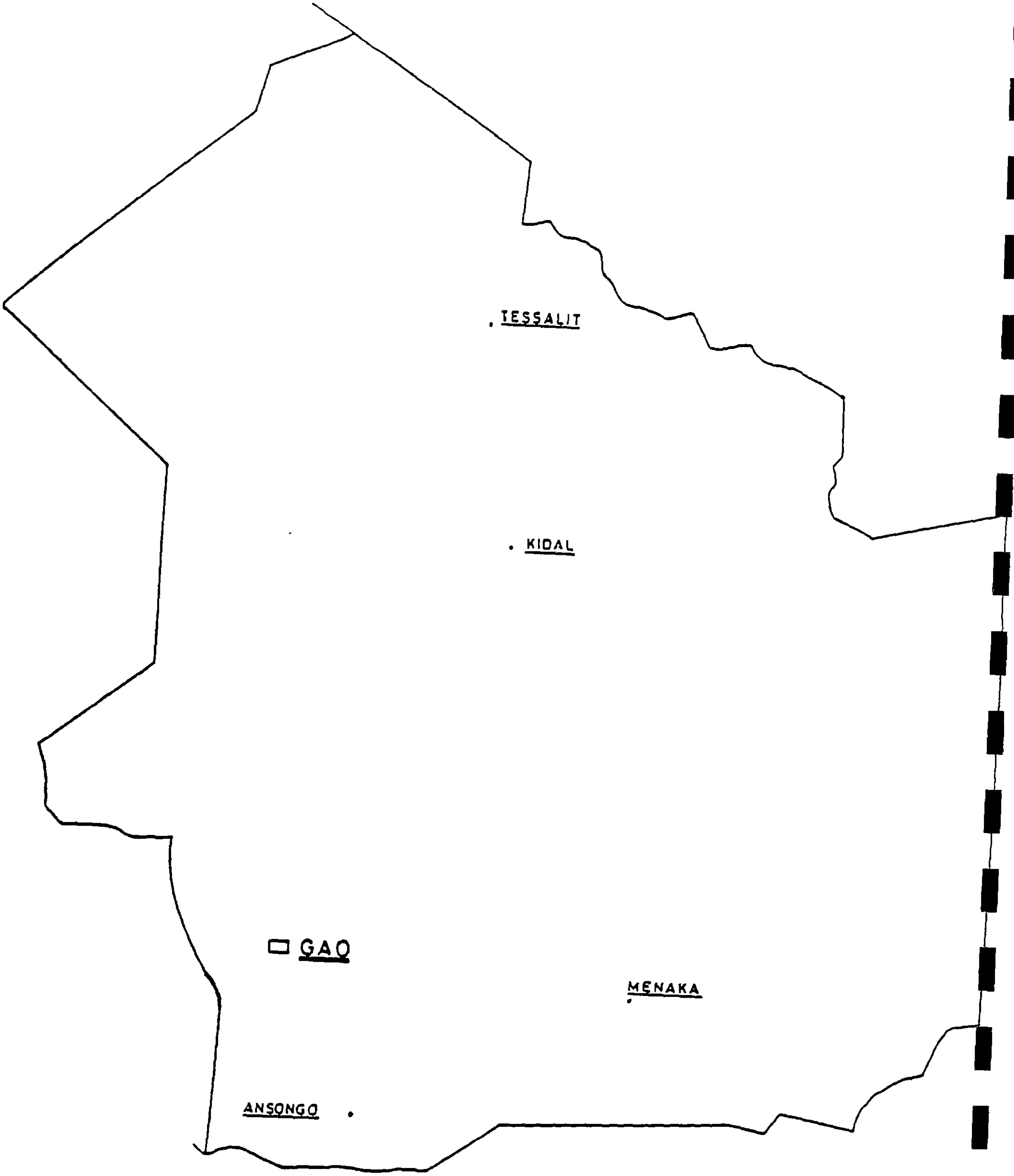
No	Type of Failure
101	mod. moved/changed to Arco; Grundfos
102	
103	
104	
105	
106	
107	
108	
109	
110	
111	
112	
113	
114	
115	
116	
117	
118	
119	
120	
121	
122	
123	
124	
125	
126	
127	
128	
129	
130	
131	
132	
133	
134	
135	
136	
137	pump replaced in 81, bad module encapsulation
138	
139	
140	
141	
142	
143	
144	
145	
146	
147	
148	stopped in 83
149	
150	
151	
152	
153	
154	

Annex 2 - Site Maps

The following maps show site locations for each region of Mali :

Map of Mali
Gao
Bamako
Kayes
Koulikoro
Sikasso
Segou
Mopti
Tomboctou


DISTRICT DE BAMAKO
TOMBOUCTOU
GAO
MOPTI
KAYES
SEGOU
KOULIKORO
BAMAKO
SIKASSO

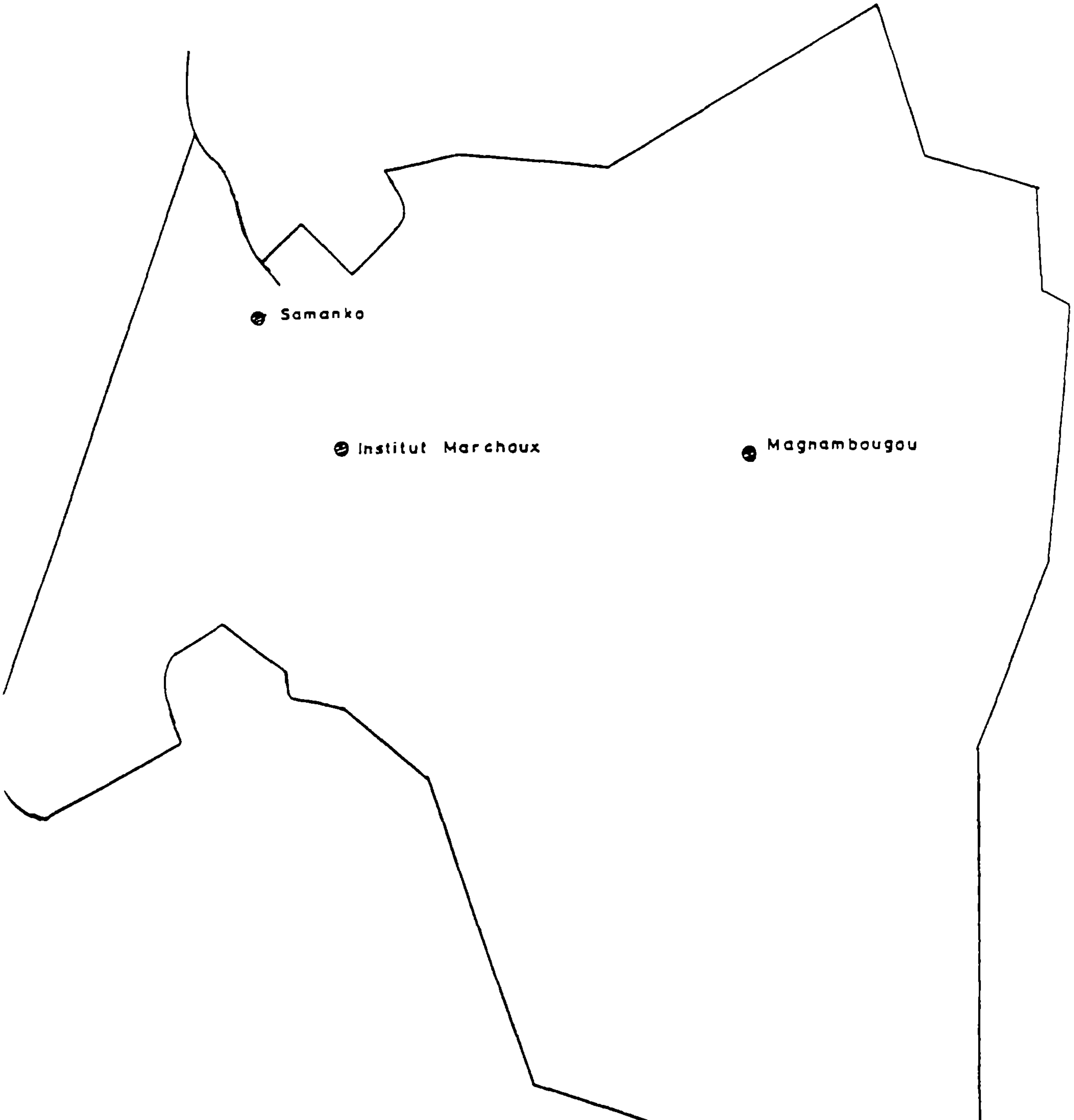


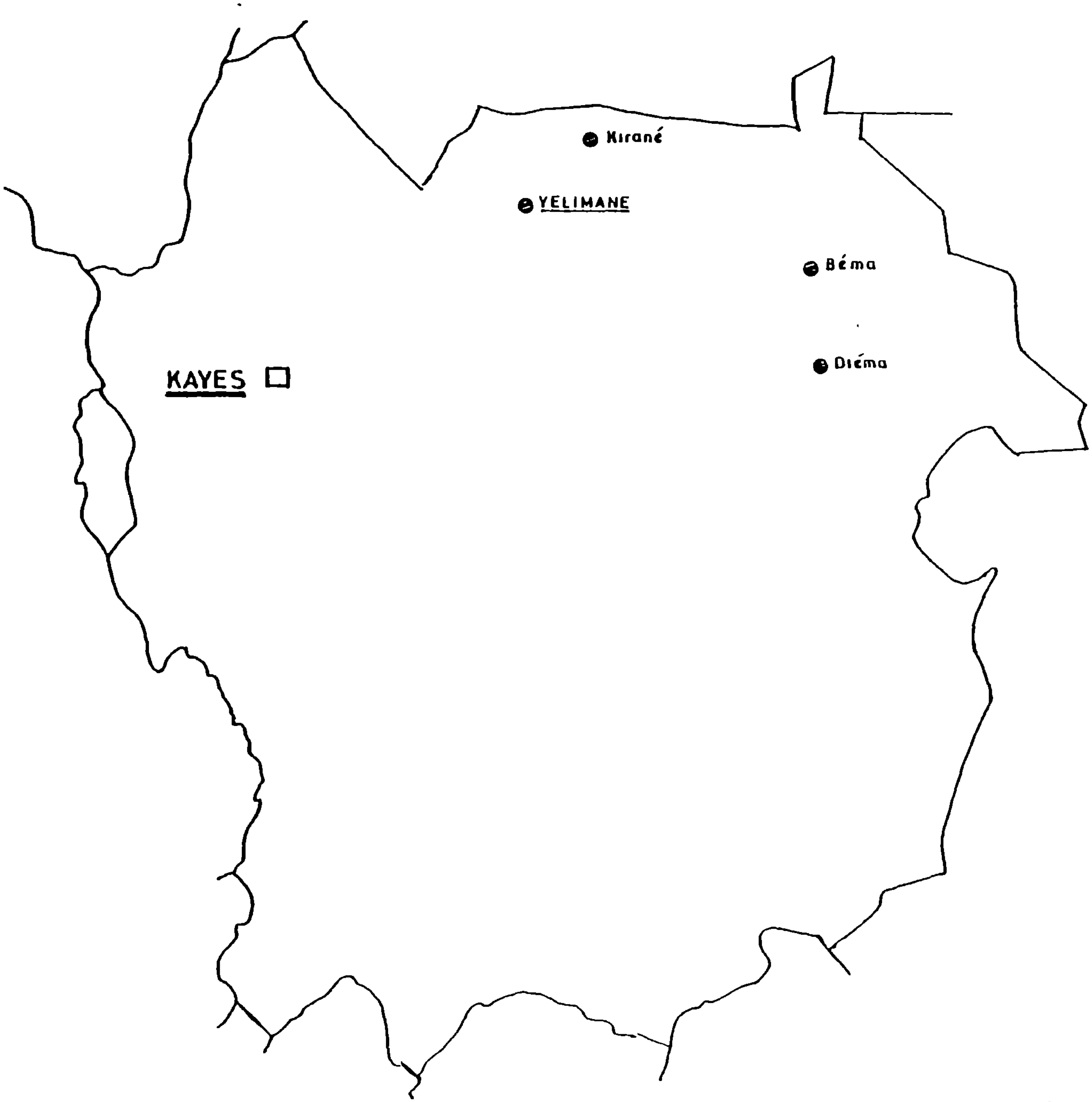
REGION DE GAO

●— Sites équipés de pompes photovoltaïques.

DISTRICT DE BAMAKO

● _Sites équipés de pompes photovoltaiques.



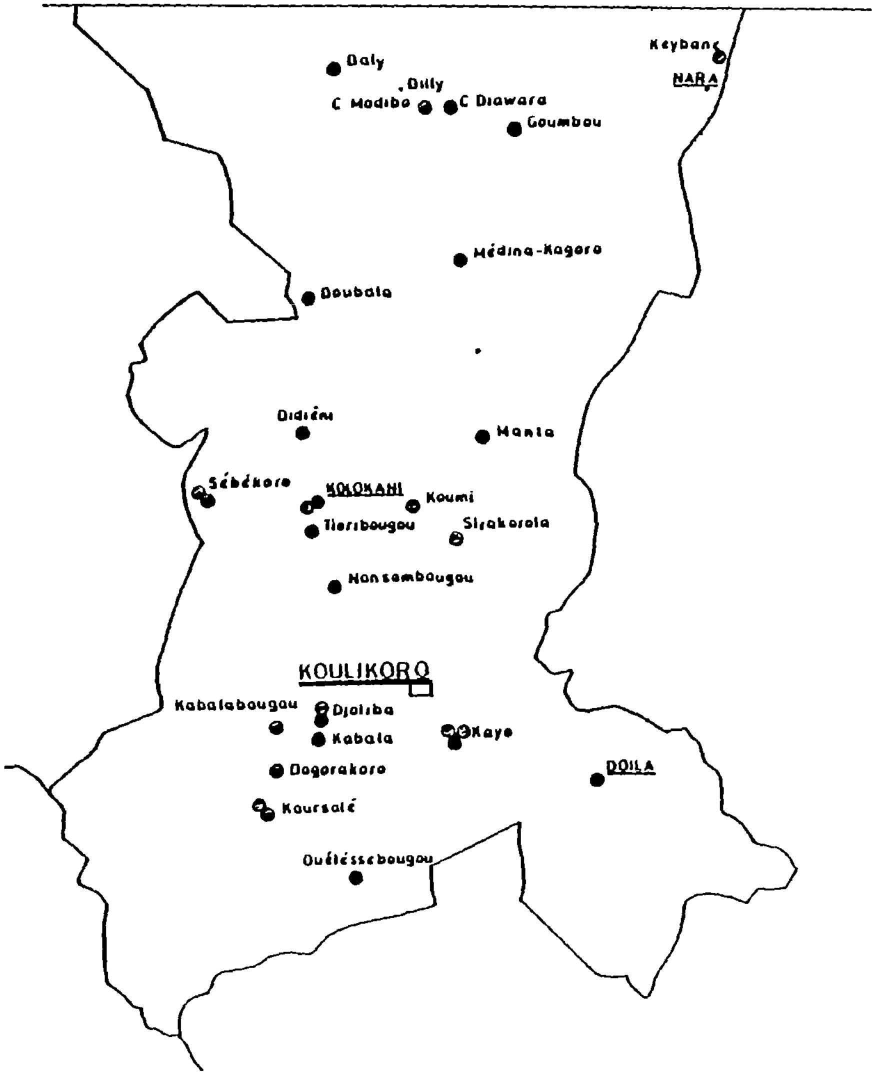


REGION DE KAYES

● — Sites équipés de pompes photovoltaïques.

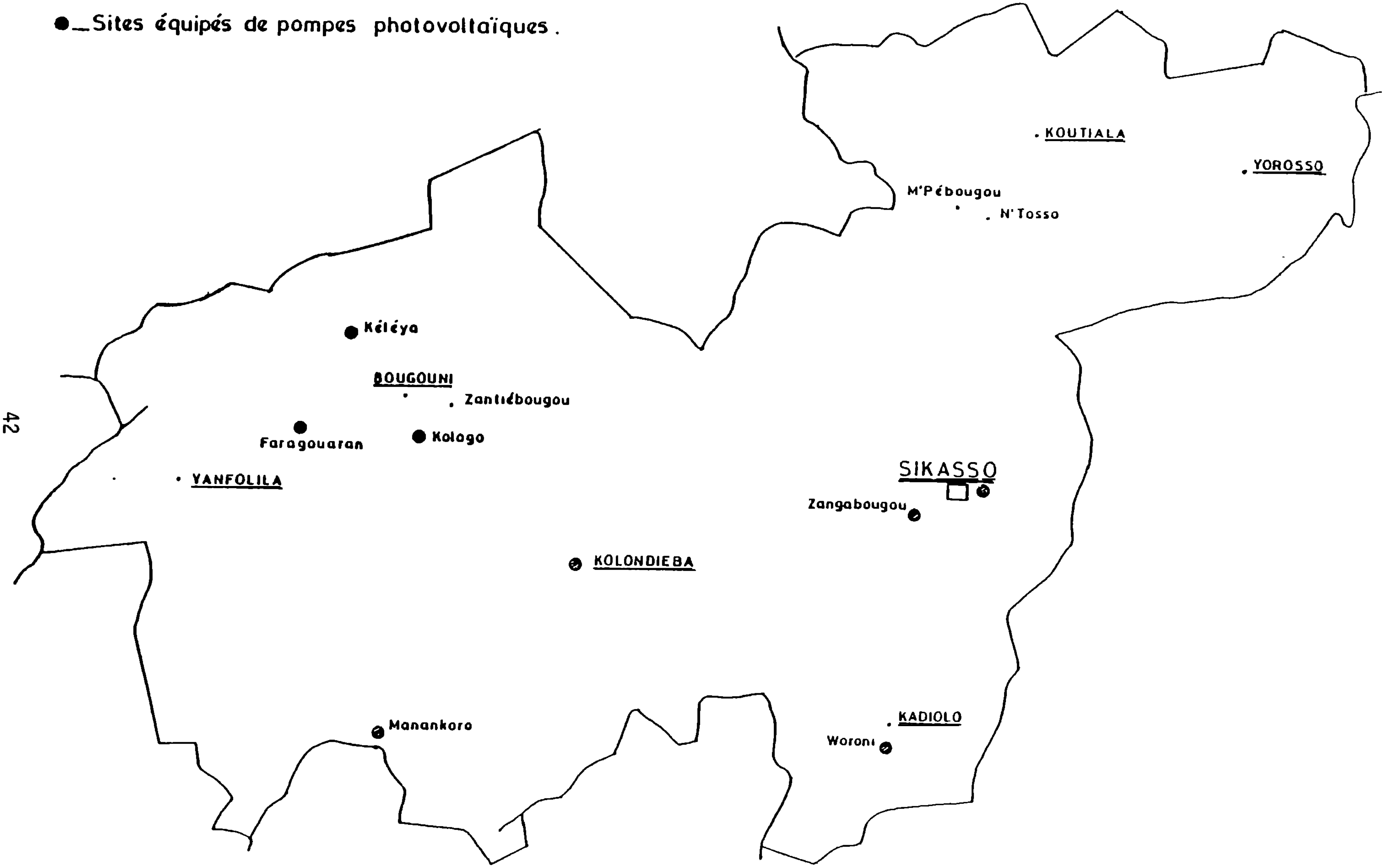
REGION DE KOULIKORO

● _ Sites équipés de pompes photovoltaïques



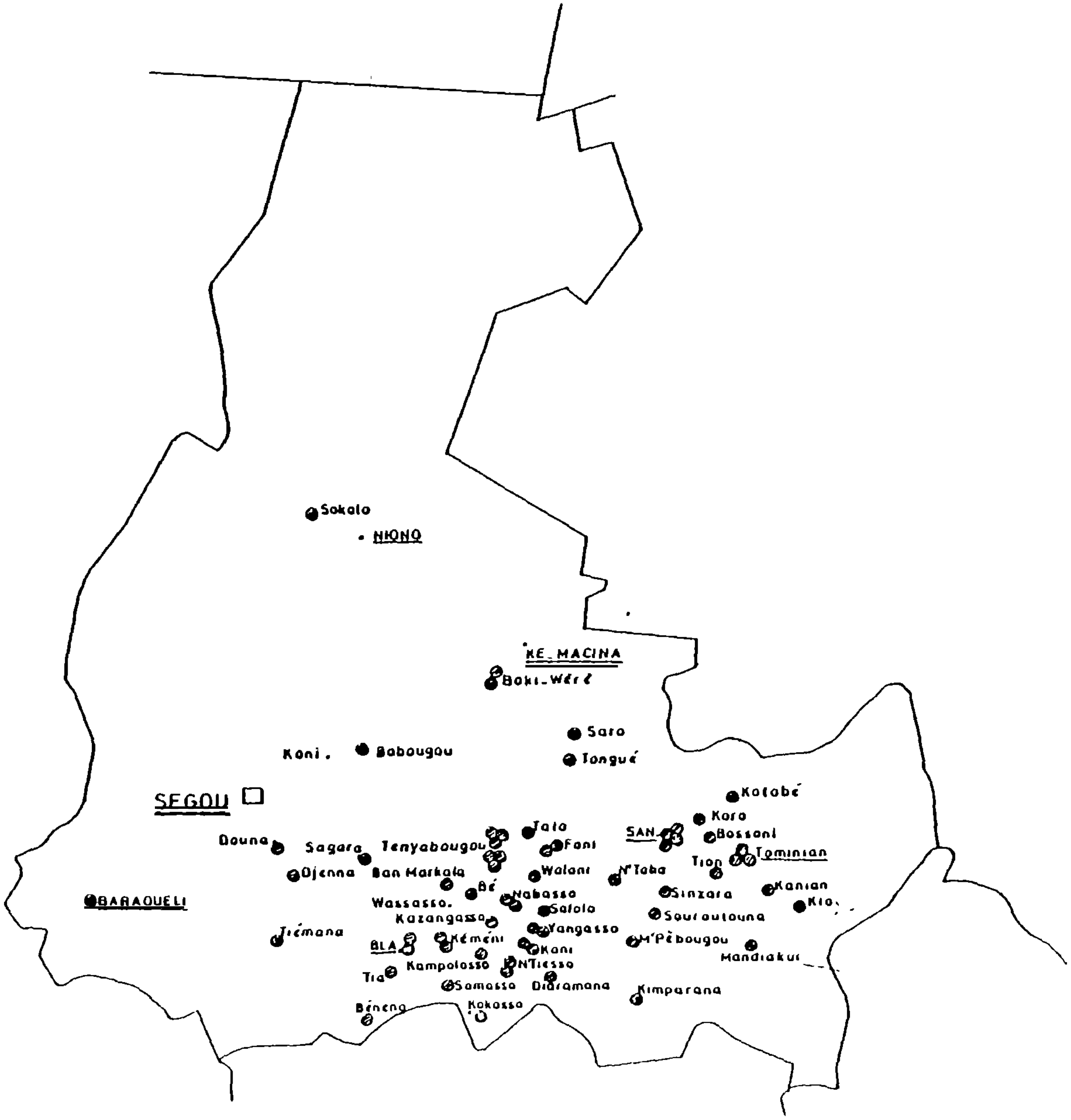
REGION DE SIKASSO -

● _ Sites équipés de pompes photovoltaïques.



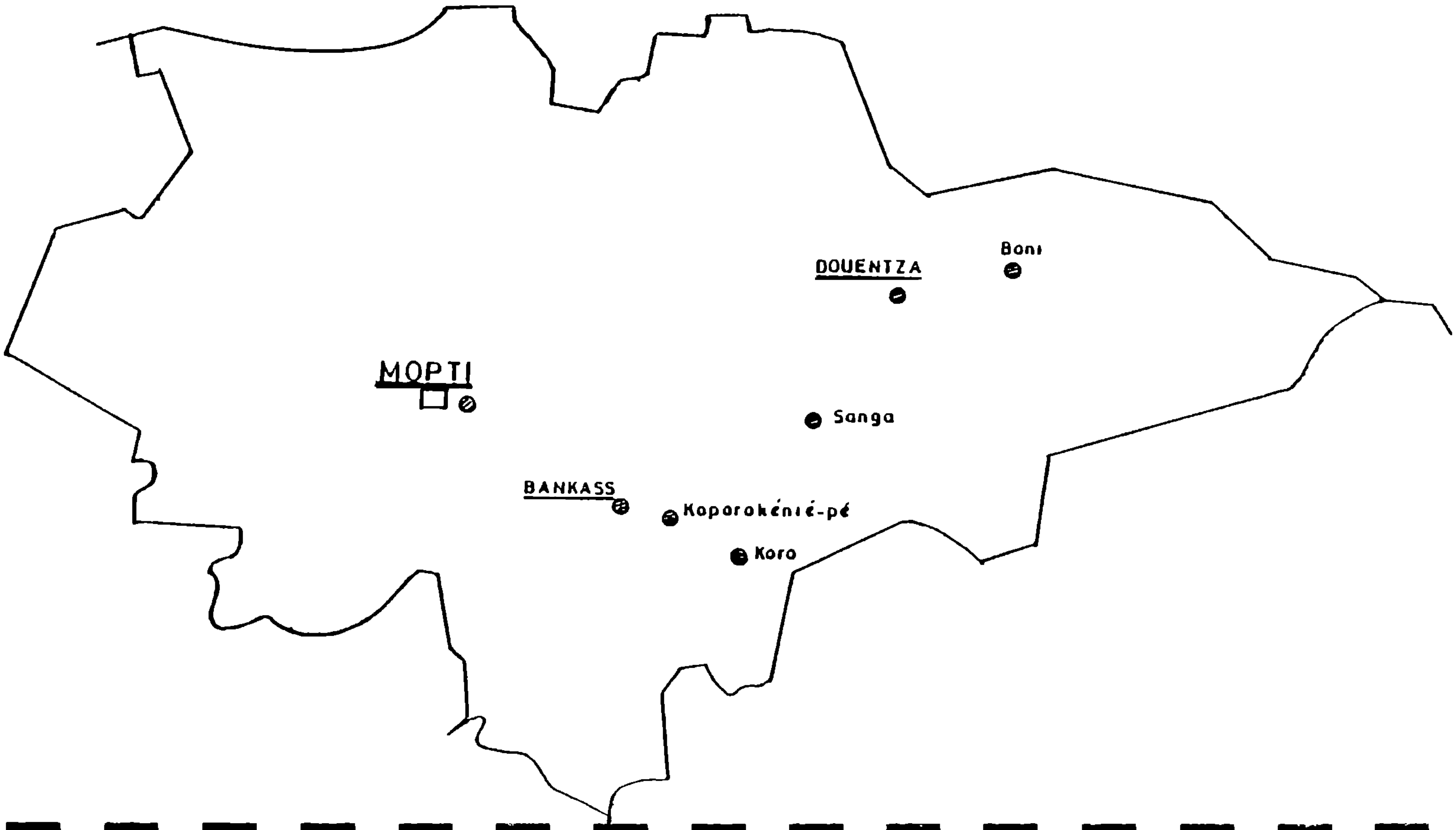
REGION DE SEGOU

●_Sites équipés de pompes photovoltaiques.



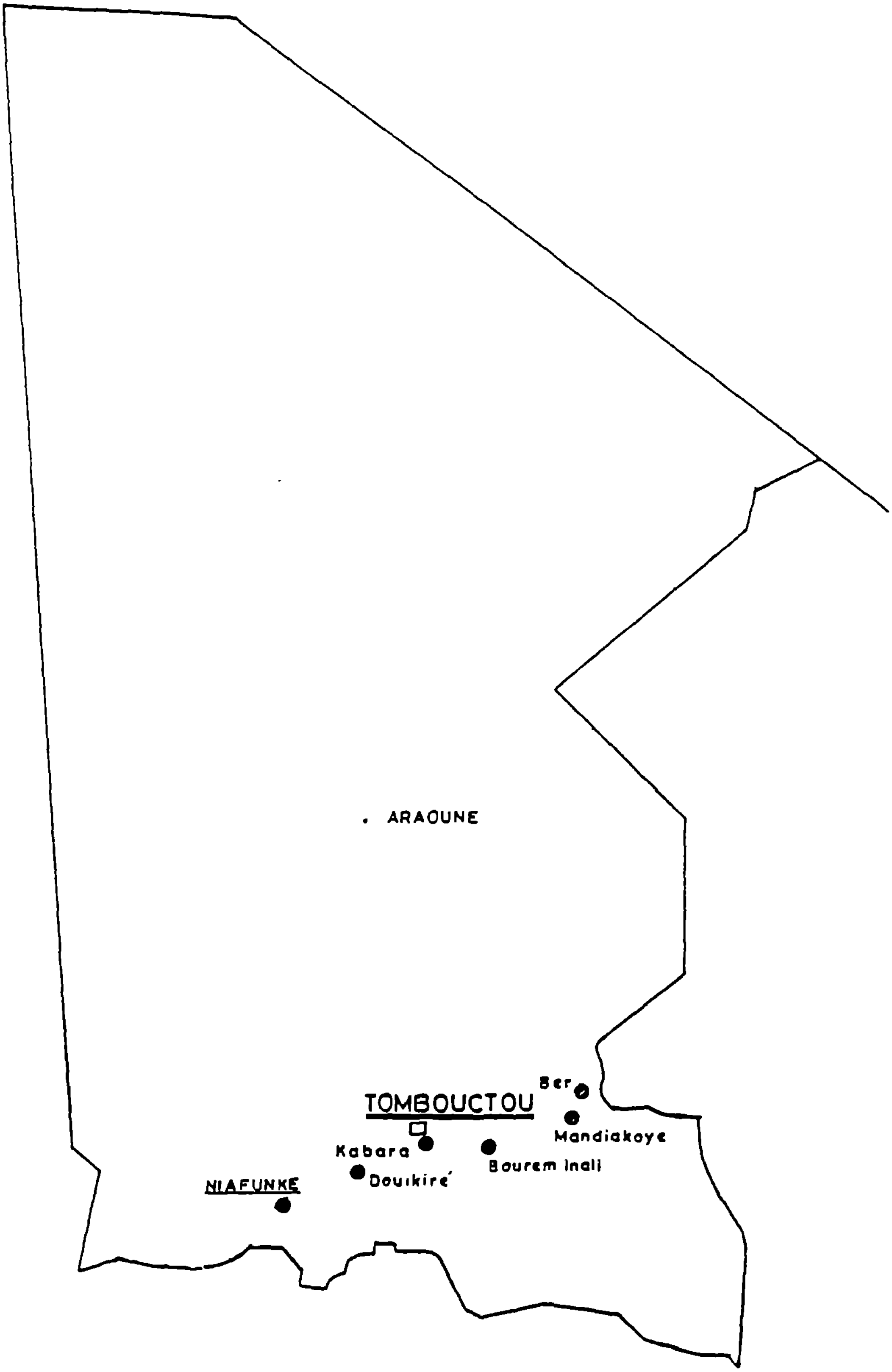
REGION DE MOPTI -

● — Sites équipés de pompes photovoltaïques.



REGION DE TOMBOUCTOU

● — Sites équipés de pompes photovoltaïques.



Annex 3 - Comparative Cost Analysis

This annex includes sample cost calculation and sensitivity analyses for PV, handpumps, camel and diesel water pumping.

STAND-ALONE PV WATER PUMPING SYSTEM

LATITUDE	15 DEG 20	MIN. NORTH
DESIGN MONTH	DECEMBER	
DESIGN DATA LOCATION	HOMBORI	
AMBIENT TEMPERATURE	24	DEGREES C
DESIGN INSOL	4.5	KWH/M2/DAY
LOLP	0.01	

	LOW	HIGH	
WATER DEPTH	25.0	25.0	M
TANK HEIGHT + LOSSES	5	5	M
PUMP HEAD	30	30	
VILLAGE POPULATION	1000	1000	
NO PER FAMILY	10	10	
CATTLE PER FAMILY	5	5	
GOATS/SHEEP/FAMILY	5	5	
WATER DEMAND	43.5	43.5	M3/DAY
WATER TANK SIZE	87	87	M3

EFFICIENCIES	
ARRAY	0.1
MAX PWR TRACKER	0.95
CONTROLLER/INVERTER	0.9

	LOW	HIGH
PUMP EFFICIENCY	0.35	0.3

CURRENCY (F CFA = 1, $ = 0)		1
EXCHANGE RATE	280	F CFA PER $

PUMPING RATE M3/DAY	PUMP COST EX-BAMAKO (F CFA)			
	WATER DEPTH (M)			
	15	25	40	50
5	536,417	586,417	661,417	711,417
10	551,417	601,417	676,417	726,417
20	581,417	631,417	706,417	756,417
30	611,417	661,417	736,417	786,417
40	641,417	691,417	766,417	816,417
80	761,417	811,417	886,417	936,417

FOB COSTS	LOW	HIGH	
PV ARRAY	1,260	1,680	F CFA/Wp
INVERTER AND CONTROLS	210	280	F CFA/Wp
PUMP	671,000	782,833	F CFA
BOS	10	10	% OF ARRAY
CONCRETE WATER TANK	1,520,363	1,520,363	F CFA INSTALLED
WELL COST	16,800	56,000	F CFA/METER DEPTH

TRANSPORT MARGIN	5	10	%
INSTALLATION MARGIN	10	15	%
CONTINGENCY	5	10	%
FEE	10	15	%
ARRAY/BOS LIFE	20	20	YEARS
PUMP, INVERTER & CONTROLS LIFE	7	5	YEARS

TANK LIFE	20	20	YEARS
PUMP O&M COST	2	3	%
PV, BOS, TANK O&M COST	0.5	1	%
ATTENDANT COST	300	500	F CFA/DAY (PART-TIME @ 10 DAYS/MONTH)
DISCOUNT RATE	10	10	%
MODULE SIZE	30	30	Wp

STAND-ALONE PV WATER PUMPING SYSTEM ANALYSIS

EFFICIENCY IN	0.0855		
	LOW	HIGH	
EFFECTIVE LOAD	10.16	11.85	KWH/DAY

INSTALLED COSTS	LOW	HIGH	
PV ARRAY	1,681	2,688	F CFA/Wp
INVERTER & CONTROLS	293	468	F CFA/Wp
PUMP	895,131	1,252,709	F CFA
WATER TANK	1,756,019	1,756,019	F CFA
WELL	16,800	56,000	PER M OF DEPTH

ANNUALIZING FACTORS

	LOW	HIGH
PV/BOS	0.11746	0.11746
PUMP/INVERTER.CNTRL	0.20867	0 26380
TANK	0.11746	0.11746
WELL	0.11746	0.11746

ANNUALIZING FACTORS. F(LIFE)			
5 YEAR	7 YEAR	10 YEAR	20 YEAR
0 26380	0.20867	0.16275	0.11746

	LOW	HIGH	
INSOL. AT 15 DEG TILT	5 00	5.00	KWH/M2/DAY
DAYS OF STORAGE	2	2	DAYS
PV ARRAY SIZE	23.77	27.73	M2
PV ARRAY SIZE	2,370	2,760	Wp
WATER TANK SIZE	87	87	M3

INSTALLED COSTS			
PV ARRAY COST	3,983,665	7,419,923	F CFA
INVERTER & CONTROLS	695,561	1,292,865	F CFA
WATER TANK COST	1,520,363	1,520,363	F CFA
BOS COST	398,367	741,992	F CFA
PUMP COST	895,131	1,252,709	F CFA
WELL COST	588,000	1,960,000	F CFA
TOTAL COST	8,081,087	14,187,853	F CFA

ANNUAL COST			
ANNUALIZED CAPITAL COST	1,094,282	2,039,014	F CFA/YEAR
O&M COST	47,415	121,877	F CFA/YEAR
ATTENDANT COST	36,000	60,000	F CFA/YEAR
TOTAL ANNUAL COST	1,177,697	2,220,891	F CFA/YEAR
RECURRENT COST	83,415	181,877	F CFA/YEAR
WATER COST	74	140	F CFA/M3

STAND-ALONE PV WATER PUMPING SYSTEM SENSITIVITY ANALYSIS

AVERAGE WATER COST ($/M3)

VILLAGE	WATER TABLE DEPTH (M)			
POPULATION	15	25	40	50
100	0.949	1.219	1.627	1.897
200	0.595	0.773	1.030	1.200
300	0.474	0.614	0.827	0.967
400	0.408	0.533	0.719	0.846
500	0.368	0.484	0.655	0.775
600	0.342	0.450	0.614	0.725
700	0.322	0.427	0.584	0.690
800	0.307	0.409	0.561	0.663
900	0.296	0.394	0.543	0.643
1000	0.287	0.382	0.529	0.624
2000	0.242	0.329	0.460	0.547

STAND-ALONE PV WATER PUMPING SYSTEM SENSITIVITY ANALYSIS

AVERAGE PER CAPITA INITIAL COST ($/PERSON)

VILLAGE	WATER TABLE DEPTH (M)			
POPULATION	15	25	40	50
100	109.72	112.11	115.68	118.06
200	72.93	74.12	75.91	77.10
300	59.50	60.30	61.49	62.28
400	52.58	53.17	54.06	54.66
500	48.31	48.79	49.50	49.98
600	45.40	45.80	46.39	46.79
700	43.38	43.72	44.23	44.57
800	41.75	42.04	42.49	42.79
900	40.46	40.72	41.12	41.38
1000	39.41	39.65	40.00	40.24
2000	34.64	34.76	34.94	35.06

HANDPUMP WATER PUMPING

1, 30 90

VILLAGE POPULATION		1000	1000	
NO PER FAMILY		10	10	
CATTLE PER FAMILY		5	5	
GOATS/SHEEP/FAMILY		5	5	
WATER DEMAND		43.5	43.5	LITERS/PERSON/DAY
HANDPUMP WATER PUMPING RATE				
AT	15 M		16	LITERS/MIN
AT	25 M		10	LITERS/MIN
AT	40 M		7	LITERS/MIN
NUMBER OF OPERATORS PER PUMP				
AT	15 M		1	
AT	25 M		1	
AT	40 M		1	
EFFECTIVE USE OF PUMP				
AT	15 M		90	% OF THE TIME WHEN OPERATING
AT	25 M		90	% OF THE TIME WHEN OPERATING
AT	40 M		90	% OF THE TIME WHEN OPERATING
NUMBER OF OPERATING MIN./DAY			480	MINUTES FOR 15M PUMPS
NUMBER OF OPERATING MIN./DAY			480	MINUTES FOR 25 & 40M PUMPS
EFFECTIVE OPERATING TIME				
AT	15 M		432	MINUTES/DAY
AT	25 M		432	MINUTES/DAY
AT	40 M		432	MINUTES/DAY
WATER OUTPUT				
AT	15 M		6,912	LITERS/DAY
AT	25 M		4,320	LITERS/DAY
AT	40 M		3,024	LITERS/DAY

	LOW	HIGH	
TRANSPORTATION MARGIN	5	10	%
INSTALLATION MARGIN	10	15	%
CONTINGENCY	5	10	%
FEE	10	15	%
OPERATOR COST	0	0	F CFA/PERSON/DAY
O&M COST OF HANDPUMP	10	20	% OF CAPITAL COST
PUMP LIFE	7	5	YEARS
BOREHOLE LIFE	20	20	YEARS
BOREHOLE COST	16,800	56,000	F CFA/METER (BOREHOLE 10M DEEPER THAN WATER TABL
40M HANDPUMP COST	560,000	560,000	F CFA EX-FACTORY BAMAKO
25M HANDPUMP COST	350,000	350,000	F CFA EX-FACTORY BAMAKO
15M HANDPUMP COST	200,000	200,000	F CFA EX-FACTORY BAMAKO
DISCOUNT RATE	10%	10%	

HANDPUMP WATER PUMPING

ANALYSIS

	LOW	HIGH	
INSTALLED COST			
40M HANDPUMP	747,054	896,126	F CFA
25M HANDPUMP	466,909	560,079	F CFA
15M HANDPUMP	254,100	290,950	F CFA
BOREHOLE - 50M	840,000	2,800,000	F CFA
BOREHOLE - 35M	588,000	1,960,000	F CFA
BOREHOLE - 25M	420,000	1,400,000	F CFA
ANNUALIZING FACTOR			
HANDPUMP	0.2054055	0.2637975	
BOREHOLE	0 1174596	0.1174596	

——40M HANDPUMP——

	LOW	HIGH	
ANNUALIZED CAPITAL COST	252,115	565,283	F CFA
OPERATOR COST	0	0	F CFA
O&M COST	74,705	179,225	F CFA
TOTAL ANNUAL COST	326,820	744,508	F CFA
WATER COST	296	675	F CFA/M3

AVERAGE INITIAL COST	136	$/PERSON
AVERAGE WATER COST	485	F CFA/M3
AT 40 M	$1.73	PER M3

——25M HANDPUMP——

	LOW	HIGH	
ANNUALIZED CAPITAL COST	164,972	377,968	F CFA
OPERATOR COST	0	0	F CFA
O&M COST	46,691	112,016	F CFA
TOTAL ANNUAL COST	211,663	489,984	F CFA
WATER COST	134	311	F CFA/M3

AVERAGE INITIAL COST	64	$/PERSON
AVERAGE WATER COST	222	F CFA/M3
AT 25 M	$0.79	PER M3

——15M HANDPUMP——

	LOW	HIGH	
ANNUALIZED CAPITAL COST	101,527	241,195	F CFA
OPERATOR COST	0	0	F CFA
O&M COST	25,410	58,190	F CFA
TOTAL ANNUAL COST	126,937	299,385	F CFA
WATER COST	50	119	F CFA/M3

AVERAGE INITIAL COST	37	$/PERSON
AVERAGE WATER COST	84	F CFA/M3
AT 15 M	$0.30	PER M3

CAMEL-POWERED WATER PUMPING

VILLAGE POPULATION	1000	
NO PER FAMILY	10	
CATTLE PER FAMILY	5	
GOATS/SHEEP PER FAMILY	5	
WATER REQUIREMENT	43.5	M3/DAY

WATER LIFTED PER LOAD	30	LITERS
AVERAGE WALKING SPEED	5	KM/HOUR
CAMEL USEAGE	8	HOURS/DAY

	LOW	HIGH	
OPERATING PERIOD	365	365	DAYS/YEAR
NO OF OPERATORS /CAMEL	3	3	
EFFECTIVE USE OF CAMEL	75	60	% OF THE TIME WHEN OPERATING
MAXIMUM NO OF CAMELS	4	2	PER WELL AT ONE TIME

	LOW	HIGH	
COST OF BUCKET	2,000	2,000	F CFA
COST OF ROPE	100	100	PER METER
COST OF CAMEL	100,000	100,000	F CFA
COST OF WELL	16,800	56,000	F CFA PER METER
OPERATOR COST	300	500	F CFA/PERSON/DAY
WELL LIFE	20	20	YEARS
ROPE & BUCKET LIFE	0.5	0.3	YEARS
USEFUL LIFE CAMEL	6	4	YEARS
DISCOUNT RATE	0.1	0.1	

ANALYSIS

WATER DEPTH (M)	WATER LIFTING TIME (MIN/LOAD)		CAMELS REQUIRED		WELLS REQUIRED	
	LOW	HIGH	LOW	HIGH	LOW	HIGH
15	0.80	1.00	3	4	1	2
25	1.12	1.40	4	5	1	3
40	1.60	2.00	5	7	2	4
50	1.92	2.40	6	8	2	4

ANNUALIZING FACTOR	LOW	HIGH
WELL	0.1175	0.1175
CAMEL	0.2296	0.3155
ROPE & BUCKET	2.1488	3.5476

COSTS			
CAMEL COST	22,961	31,547	F CFA/CAMEL/YEAR
BUCKET COST	4,298	7,095	F CFA/CAMEL/YEAR
ROPE COST	215	355	F CFA/METER/CAMEL/YEAR
WELL COST - 15M	420,000	1,400,000	FCFA (ASSUMES WELL DEPTH = WATER TABLE + 10M)
WELL COST - 25M	588,000	1,960,000	
WELL COST - 40M	840,000	2,800,000	
WELL COST - 50M	1,008,000	3,360,000	

CAMEL-POWERED WATER PUMPING

RESULTS

WATER DEPTH	ANNUALIZED WELL COST		ANNUALIZED CAMEL COST		AN BUCKT, ROPE, & OPERTR COST		TOTAL ANNUAL COST		WATER COST (F CFA/M3)	
M	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH
15	49,333	328,887	68,882	126,188	1,020,955	2,268,047	1,139,171	2,723,122	72	172
25	69,066	690,663	91,843	157,735	1,369,869	2,852,797	1,530,778	3,701,195	96	233
40	197,332	1,315,548	114,804	220,830	1,728,452	4,031,165	2,040,588	5,567,542	129	351
50	236,799	1,578,657	137,764	252,377	2,087,036	4,635,427	2,461,599	6,466,461	155	407

SENSITIVITY ANALYSIS
CAMEL-POWERED WATER PUMPING

AVERAGE WATER COST ($/M3)

VILLAGE POPULATION	WATER TABLE DEPTH (M)			
	15	25	40	50
100	1.322	1.425	1.579	1.681
200	0.661	0.712	1.131	1.393
300	0.441	0.838	0.892	1.305
400	0.499	0.628	0.932	1.083
500	0.481	0.690	0.965	1.004
600	0.401	0.643	0.805	1.095
700	0.466	0.551	0.899	1.115
800	0.408	0.567	0.787	0.976
900	0.408	0.550	0.834	1.039
1000	0.434	0.588	0.856	1.004
2000	0.380	0.521	0.797	0.963

SENSITIVITY ANALYSIS
CAMEL-POWERED WATER PUMPING

AVERAGE INITIAL COST/PERSON ($/PERSON)

VILLAGE POPULATION	WATER TABLE DEPTH (M)			
	15	25	40	50
100	39.73	52.77	72.32	85.36
200	19.87	26.38	37.99	46.36
300	13.24	20.01	26.55	45.13
400	10.84	15.01	28.95	34.77
500	9.39	17.28	24.63	28.55
600	7.83	15.01	20.52	31.52
700	9.55	12.86	23.28	33.64
800	8.35	11.71	20.37	29.43
900	7.83	10.81	22.53	31.31
1000	7.41	12.37	23.89	28.55
2000	7.04	10.87	20.46	26.42

DIESEL WATER PUMPING

	LOW	HIGH	
VILLAGE POPULATION	1,000	1,000	
WATER DEMAND	43.5	43.5	LITERS/PERSON (INCL. LIVESTOCK /PERSON)
WATER DEMAND	43.5	43.5	M3/DAY
WATER DEPTH	25	25	M
TANK HEIGHT + LOSSES	5	5	M
PUMPING HEAD	30	30	M
PUMP EFFICIENCY	60%	50%	
WATER STORAGE	1	1	DAY DEMAND
MAXIMUM PUMP USAGE	5	5	HOURS/DAY
RELIABILITY	90	90	%
SPARE DIESEL GEN-SET?	NO	NO	
FUEL TANK SIZE	3	3	MONTH SUPPLY

PUMPING	PUMP COST EX-BAMAKO (F CFA)			
RATE	PUMPING HEAD (M)			
M3/DAY	15	25	40	50
5	203,000	273,000	378,000	448,000
10	224,000	294,000	399,000	469,000
20	266,000	336,000	441,000	511,000
30	308,000	378,000	483,000	553,000
40	350,000	420,000	525,000	595,000
80	518,000	588,000	693,000	763,000

PUMP POWER REQUIREMENTS	1.19	1.42	KW
POWER FACTOR	0.8	0.8	
CAPACITY FACTOR	0.75	0.60	
DIESEL GENSET SIZE	3	3	KVA
GEN-SET EFFICIENCY	0.15	0.1	

DIESEL GEN-SET COST	
KVA	F CFA
3	1,500,000
5	2,350,000
8	2,710,000
10	3,500,000
15	4,250,000

COSTS IN BAMAKO

DIESEL GENSET	1,500,000	1,500,000	F CFA
PUMP	469,700	469,700	F CFA
WATER TANK (AT SITE)	1,081,654	1,081,654	F CFA INSTALLED
FUEL TANK	150,000	200,000	F CFA/M3
WELL (AT SITE)	16,800	56,000	F CFA/M DEPTH
DIESEL COST AT NEAREST CENTRAL DEPOT		210	F CFA/LITER
TRANSPORT MARGIN	5	10	%
INSTALLATION MARGIN	10	15	%
CONTINGENCY	5	10	%
FEE	10	15	%

DIESEL COST AT SITE	243	277	F CFA/LITER
DIESEL GEN-SET O&M	10	20	% CAPITAL COST/YR
PUMP O&M	2	3	% CAPITAL COST/YR
ATTENDANT COST	300	500	F CFA/DAY
LIFE OF GEN-SET(S)	10	10	YEARS
PUMP LIFE	7	5	YEARS
TANK AND WELL LIFE	20	20	YEARS
ANALYSIS PERIOD	20 YEARS		
DISCOUNT RATE	10%		

(DIESEL FUEL COST INCLUDES 50 KM (LOW), 100 KM (HIGH) TRANSPORT TO SITE FROM CENTRAL DEPOT. COST IS 1/3 F CFA/LITER/KM)

DIESEL WATER PUMPING ANALYSIS

WATER TANK SIZE	43.5	43.5 M3
DAILY ENERGY DEMAND	5.93	7.11 KWH/DAY
DAILY FUEL CONSUMPTION	3.76	6.77 LITERS
FUEL TANK SIZE	339	610 LITERS
WELL DEPTH	35	35 METERS

	ANNUALIZING FACTORS	
	LOW	HIGH
GEN-SET	0.16275	0.16275
PUMP	0.20867	0.26380
TANKS AND WELL	0.11746	0.11746

ANNUALIZING FACTORS· F(LIFE)			
5 YEAR	7 YEAR	10 YEAR	20 YEAR
0.26380	0.20867	0.16275	0.11746

CAPITAL COSTS		
ONE DIESEL GEN-SET	2001038	2400338 F CFA
	LOW	HIGH
GEN-SET(S)	2,001,038	2,400,338 F CFA
WELL	588,000	1,960,000 F CFA
PUMP	626,592	751,626 F CFA
WATER TANK	1,081,654	1,081,654 F CFA
FUEL TANK	67,771	195,106 F CFA
TOTAL INITIAL COST	4,365,054	6,388,724 F CFA

ANNUALIZED COST	LOW	HIGH
GEN-SET	325,660	390,644 F CFA
WELL	69,066	230,221 F CFA
PUMP	130,748	198,277 F CFA
WATER TANK	127,051	127,051 F CFA
FUEL TANK	7,960	22,917 F CFA
O&M COST	212,636	502,616 F CFA
ATTENDANT COST	109,500	182,500 F CFA
FUEL COST	334,226	684,018 F CFA
TOTAL COST	1,316,846	2,338,244 F CFA
RECURRENT COSTS	546,861	1,186,634 F CFA /YEAR
WATER COST	83	147 F CFA/M3

DIESEL WATER PUMPING
SENSITIVITY ANALYSIS

AVERAGE WATER COST ($/M3)

VILLAGE POPULATION	WATER TABLE DEPTH (METERS) 15	25	40	50
100	2.514	2.710	3.005	3.201
200	1.323	1.441	1.618	1.736
300	0.923	1.015	1.152	1.244
400	0.722	0.801	0.919	0.997
500	0.601	0.672	0.778	0.848
600	0.520	0.585	0.683	0.749
700	0.461	0.523	0.616	0.757
800	0.418	0.477	0.634	0.693
900	0.383	0.440	0.587	0.644
1,000	0.356	0.411	0.549	0.638
2,000	0.259	0.335	0.438	0.510

SENSITIVITY ANALYSIS

AVERAGE INITIAL COST/PERSON ($/PERSON)

VILLAGE POPULATION	WATER TABLE DEPTH (METERS) 15	25	40	50
100	150.28	151.94	154.44	156.11
200	78.38	79.21	80.47	81.30
300	54.02	54.58	55.41	55.97
400	41.69	42.11	42.74	43.15
500	34.22	34.55	35.05	35.38
600	29.19	29.46	29.88	30.16
700	25.56	25.80	26.16	26.40
800	22.82	23.03	23.35	23.55
900	20.68	20.87	21.14	21.33
1,000	18.95	19.12	19.37	19.54
2,000	13.73	13.81	13.94	14.02