PN-AAX-121

RENEWABLE ENERGY RESOURCES
FIELD TESTING

APPLICATIONS REVIEW AND CONCEPTUAL DESIGN FOR FIELD TEST #7

PV-POWERED LIGHTING AND IRRIGATION AT BAHARIA OASIS

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FINAL

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Prepared by

Meridian Corporation
Falls Church, Virginia

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FOREWORD
APPLICATIONS REVIEW AND CONCEPTUAL DESIGN

The Egyptian Electricity Authority (EEA), the United States Agency for International Development (USAID/Cairo), and a group of U.S. consultants form a team responsible for conducting a field test demonstration projects for 11 renewable energy applications in Egypt. These demonstration projects include the use of photovoltaic (PV), wind, and solar thermal systems for water pumping, ice making, desalination, industrial process heat, small village electrification, and grid connected electricity generation applications. The specific objectives of the 4-year program are to: (1) demonstrate the viability of renewable energy technologies in Egypt; (2) comprehensively strengthen Egyptian technical and institutional capabilities in the full spectrum of renewable energy planning and decision-making; and (3) establish the infrastructure necessary to ensure that renewable energy technologies that have proven successful are available for widespread use in Egypt.

Each field test demonstration project contains seven generic tasks: technology review, application review, conceptual design, preparation of a statement-of-work for a tender document, proposal evaluation, supervision of hardware installation, and performance evaluation. Results of two of these tasks, the application review and the conceptual design for a photovoltaic village power and irrigation project, are presented in this report.

The photovoltaic-powered applications that will be technically evaluated in this field test consists of four distinct parts: stationary PV-powered water pump(s) of low head wells for irrigation; two portable, low capacity water pumps; twenty individual systems for houses; and 10 PV-powered street lights. These applications will provide a generic test which if judged successful, can serve as a model for other similar installations in other parts of Egypt.

This report is subtask 3.7.1 and 3.7.3 to the field test requirements under Contract AID 263-0123C-00-4069-00, Task Area 3.

1.0 EXECUTIVE SUMMARY

The purpose of this Application Review and Conceptual Design document is to address within the context of the general field test objectives, the applicable technologies and rural village energy demands for irrigation and lighting in order to:

- Assess the needs for specific PV village level applications
- Recommend specific village(s) for the demonstration of PV-powered irrigation and lighting systems in Egypt
- Develop conceptual designs for selected irrigation and lighting systems
- Identify training and unique project implementation requirements
- Identify additional information needs
- Estimate costs of the designed systems

1.1 Purpose of the Field Test

This field test is based on two earlier field tests which were considered for implementation under the overall REFT project but later cancelled. El Ghorieb, near Asyut, was to be a field test location of a 2.5 kW PV-powered irrigation pumping system. A field test of small scale irrigation and lighting for fisherman's shelters at Lake Nasser was also an original field test that was cancelled after it was learned that environmental and social conditions around the lake had changed and the application of PV was not justified.

The current field test of village power and irrigation at the Baharia Oasis combines the objectives of these two earlier candidate field tests:

- Demonstrate the technical and financial viability of photovoltaics for lighting and irrigation systems in Egypt.

- Determine the institutional requirements necessary to support similar applications in other Egyptian locations.
- Determine user technology acceptance and the demand for similar systems.
- Measure the capital costs, operations and maintenance costs of the systems

1.2 Village Selection

The Baharia Oasis was selected by the Egyptian Electricity Authority (EEA) for the demonstration of photovoltaics for village lighting and irrigation. The Bawiti City Council, as the governing body of the Baharia Oasis, is the designated implementing agency. In May 1986, a contractor team plus EEA personnel visited two areas within the Baharia Oasis; El-Haiz and El-Harrah. Five villages in El-Haiz and three villages in El-Harrah were visited:

El-Haiz	El-Harrah
Ayn Gomaa	Ayn Gdid
Tabl-Amoun	Ayn Wadi
Reis	Ayn Joseph
El Ezz	
Ayn Deres	

The Bawiti City Council indicated that there are no plans to supply El-Haiz with electrical service either by grid or remote diesel generators, making it a likely location for this field test. Villages in El-Harrah have been supplied with stand-alone diesel generators. The visits to the El-Harrah villages served as a reference for estimating anticipated household energy consumption in the El-Haiz villages.

1.2.1 Irrigation Applications

From a technical standpoint, each of the villages in El Haiz are

suitable for PV-powered irrigation. Water table depth is less than 5 meters from the surface and flow rates are technically within the capability of several commercially available systems.

Irrigation requirements data for the villages visited are limited because accurate records are not kept from the essentially unregulated flow of water from the artesian wells. Therefore related studies (Ref. 1-1) on water resources and irrigation for the Baharia Oasis were used. It is generally accepted that for agricultural self-sufficiency, a village household must farm a minimum of 3 feddans. The average water requirement per feddan is 25 m^3/day during the summer. This volume of water corresponds closely to that specified by some of the villagers that were interviewed during the site visits. Therefore each household requires approximately 75 m^3/day for self-sufficient farming.

The villages most suited to PV-powered irrigation are those which currently irrigate and have access to farmland capable of being expanded but are restricted due to water availability. Of the five villages visited in the El-Haiz area, only Tabl-Amoun did not qualify under these general criteria because it has water control problems which result in detrimental continuous flooding of irrigated lands. Of the remaining four villages, Ayn Gomaa and El-Ezz are considered as the best candidate villages because of irrigation activity, expressed interest, and water supply limitations. El-Ezz was finally selected over Ayn Gomaa as the village to demonstrate a PV-powered irrigation system because it better satisfied the above criteria.

1.2.2 Lighting Applications

Specific electrical load data for Ayn Gomaa in El Haiz and Ayn Gdid in El-Harrah were collected by talking to villagers and visiting some of the houses to observe current conditions. Households in these villages use

electrical energy primarily for lighting, but there is a growing demand for refrigeration and television. Based on data collected from Ayn Gdid and discussions with EEA, an estimated demand of 1 kwh/day per household is the baseline load used for conceptual designs in this document.

Two methodologies for supplying PV power for village lighting were considered: "decentralized" and "centralized". Both of these techniques have been successfully applied and evaluated in other developing countries. "Decentralized" systems for rural, developing country villages consists of a few PV modules, a small battery storage system, and a simple voltage regulator. They are generally DC systems sized to provide sufficient power for the lighting needs of one household. Each household manages its own energy demand to remain within the limits of its system size and the available energy production.

An alternative method for village lighting is to utilize a "centralized" approach, i.e. one central PV power system supplying power through a distribution grid to the village houses. DC power from the PV array is usually inverted to alternating current (AC) for these generally larger systems to be compatible with standard AC loads.

The criteria for selection of a rural, developing country village for a PV-powered lighting system are very broad. These criteria include, remoteness from the grid distribution system, the psychical layout of the houses in the village, the total energy demand of the houses, and the future plans for rural electrification in the area.

The villages in the El-Haiz area meet all the criteria for demonstration of PV-powered village lighting systems. Villages with dispersed houses are more suited to a decentralized system whereas villages with more dense housing are more suited to a centralized system. El-Ezz was selected for

the demonstration of a decentralized PV-powered lighting system because it is the village with the most spacing between houses. Any of the other four villages visited would be good candidates for a centralized system.

1.3 Field Test #7 Functional Requirements

In August 1986, a Draft-for-Comment Application Review/Conceptual Design was submitted to EEA/USAID based on data collected during site visits in May 1986 by the U.S. project team and discussions at the time with the Baharia Oasis site representatives and the EEA engineers. The functional requirements recommended at that time were:

- Fifteen decentralized PV-powered lighting systems for individual houses in El-Ezz
- One centralized PV-powered lighting system in Ries
- Eleven modular PV-powered irrigation pumping systems in El-Ezz

During August/September 1986, the field test designs were reviewed in the U.S. by the project team, the site representative and the EEA engineers and changes to the original functional requirements were discussed. In December 1986, EEA determined that the village of El-Ezz would be the location of both the PV-powered lighting and irrigation systems and that the final functional requirements were as follows (Appendix G):

o PV-powered Irrigation Pumping System

1. One Fixed Water-Pumping System:

   - A PV-power source to provide sufficient water to flood-irrigate a 60 feddan area every other day plus a total of 10 cubic meters per day for domestic use.
   - A water source with a minimum of two new wells located at an elevation higher than, and far enough from, the existing wells to minimize drawdown.
   - Two inter-connected water storage components; one, to provide two hours of water supply for irrigating early in the day (prior to the PV system becoming operational) with sufficient piping and valving to transport and control flow

of the water into the existing irrigation system; and, (2) storage, to provide up to a one-day supply of water for domestic use.

2. Two Portable Water-Pumping Systems:

In addition to the primary water-pumping system described, the project will provide for an option of two portable PV water pumping units each capable of providing sufficient water to flood-irrigate one feddan per day from shallow wells, or irrigation ditch.

o PV-powered Village Lighting System

1. Twenty PV-Power systems For Household Electrification:

Twenty PV-power systems, each capable of providing an individual household with sufficient power to meet an energy demand of 1000 watt-hours/day. Each system will include: 2-20 watt and 2-40 watt florescent lights with fixtures; 4-220 VAC electrical outlets; batteries; invertor; and sufficient wiring and hardware to allow for a light and outlet in each of four rooms. The Contractor will be required to install the systems, ensure that each is operational, and demonstrate to the user that the systems can be used for appliances such as a television, refrigerator, small power tools, sewing machine and battery charger.

2. Ten PV-powered Street Lights:

Ten individually PV-powered street lights to be located where required in and near the village of El Ezz.

1.4 Conceptual Designs

1.4.1 System Design Criteria

Each of the major PV-powered system types, i.e. fixed irrigation pumping system (from wells), portable irrigation pumping system, individual household lighting, and street lighting, are independent. Further, each major functional system type (pumping, house lighting and street lighting) consists of many small PV systems which are also independent.

The conceptual designs that follow are completely functional, properly sized, and responsive to the direction received in December 1986 from EEA/USAID. However, it is important to note that in two of the designs, specifically the fixed pumping system and the household lighting systems, there are major uncertainties in the engineering assumptions upon which the designs are based. These uncertainties are due in some cases to a lack of site-specific data and in others to the general nature of specific field test parameters. For example, in the case of the fixed irrigation pumping system, the physical location of the new wells with respect to the village and the storage system cause uncertainties in the exact total pumping head for the application which is one of the most essential design parameters in sizing the system. In the case of the individual household lighting systems, the system is sized for a specific load demand and the management of that demand is left to the user. If additional loads are imposed on the system by the use of the receptacles that are included in requirements for household wiring, the array and the battery storage system will not be adequate.

The methodology used for the conceptual design of the PV-powered pumping systems is as follows:

- Determine monthly average daily irrigation water requirements

- o Determine monthly average daily plane of array insolation levels
- o Calculate monthly ratios of irrigation water demand to insolation
- o Select the design month with the highest ratio
- o Determine water lift and volume requirements
- o Determine hydraulic energy requirements
- o Select the type of pump based on the above results
- o Estimate subsystem operating efficiency
- o Calculate daily electrical energy demand
- o Size the PV array to meet the total demand

The methodology used for the conceptual design of the lighting systems is as follows:

- o Determine the average load demand and duration
- o Determine the peak loads and times
- o Determine daily insolation levels and select the design month
- o Size the battery
- o Specify the power conditioning equipment
- o Size the PV array based on the above results

1.4.2 Fixed PV-powered Irrigation Pumping System

The daily demand for water for irrigation during the summer is 750m^3 (25 m^3/day per 60 feddans every other day). An additional 10 m^3/day is required for domestic use for a total of 760 m^3/day.

The recommendation is to supply this volume of water from five new 10.2 cm (4 in) wells near El-Ezz at an elevation higher than and far enough from the existing well in the area to minimize drawdown. This means that if

water flow is equally distributed among the five wells, each will have a daily flow of 152 m^3/day, which according to available information is well within the capability of wells in the Baharia Oasis.

We recommend that the PV-powered pumping system have the following characteristics:

Number of pumps:	10 (identical)
Number of pumps per well:	2
Pump type:	Centrifugal surface mounted pumps
Array size:	576 peak watts for each of the ten PV arrays, one for each pump
Storage:	No battery storage
Power conditioning:	DC motor pumps, i.e. no inverter

PV-powered pumping systems of this type and size are commercially available as prepackaged systems. A sketch of possible well locations at El-Ezz is presented in Exhibit 1-1.

1.4.3 Portable PV Irrigation Pumping System

Two portable PV-powered pumping systems are required for this field test. Each must be capable of irrigating one feddan per day from a low head well or an irrigation ditch. We recommend that these systems be identical to the pumps in the fixed irrigation system described above. This will allow the pump, controller, PV array and pump motor to be interchangeable. To provide portability, we recommend that the arrays, pumps, and electrical hardware be custom mounted on a trailer-bed. Several U.S. government organizations have sponsored similar projects in the past and many design approaches are available from a number of manufacturers.

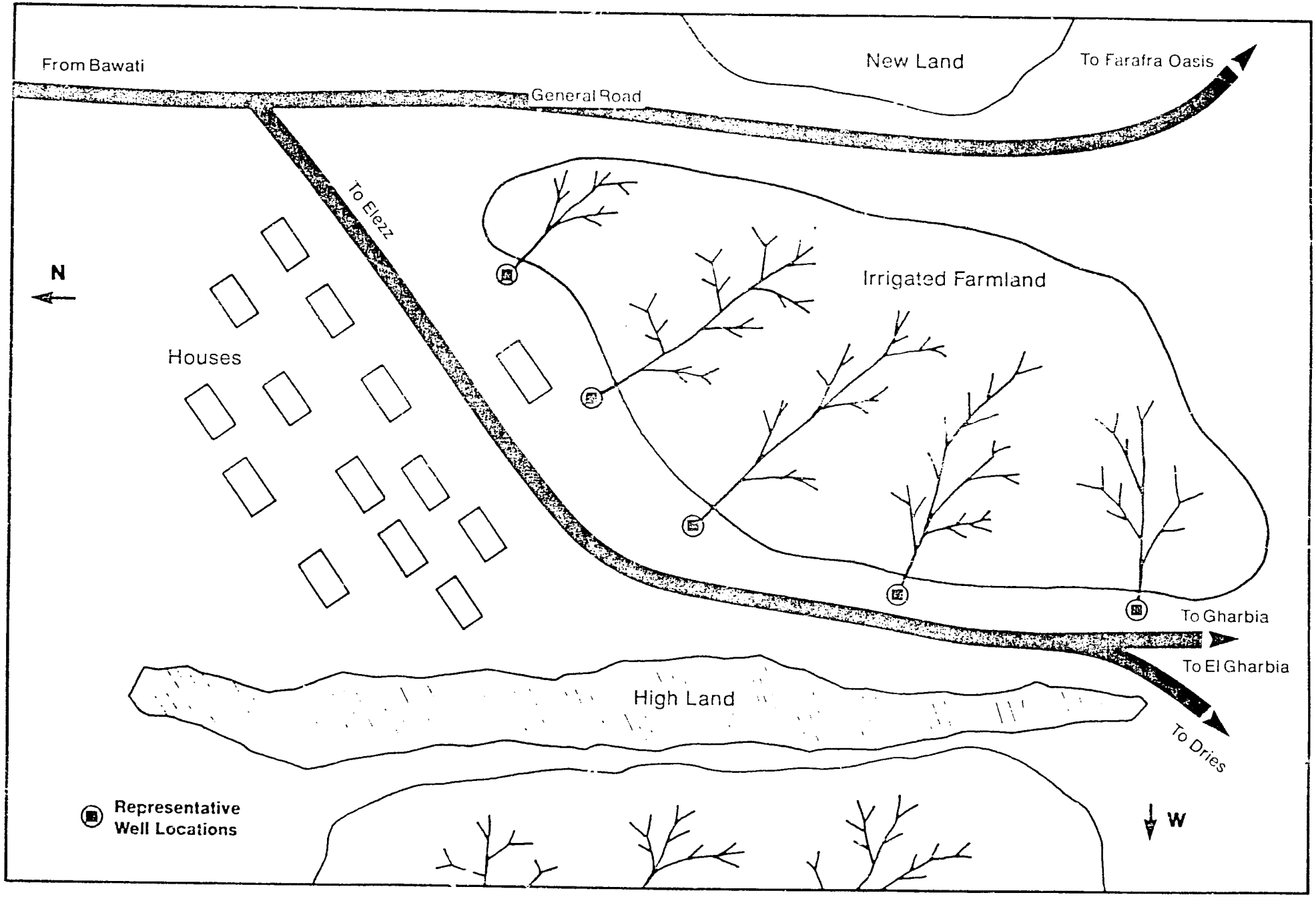


Exhibit 1-1
SKETCH OF EL-EZZ

1.4.4 Individual House Lighting System

The Draft-for-Comment version of this document recommended a centralized AC lighting system and a decentralized DC lighting system. The reasons for recommending DC for the decentralized system are:

- o Higher Efficiency - no power is lost in being inverted to AC and increased to 220 volts
- o Increased Reliability - small inverters in remote applications have not performed as reliably as desired
- o Recent availability of low voltage DC electrical appliances

EEA/USAID direction received in December 1986 specified that the decentralized household lighting systems be 220 volt, 50 hertz AC. The conceptual design is responsive to that direction in that twenty individual houses are to be equipped with a PV-system which is capable of meeting a 1000 watt-hour AC load. In addition, as part of the duties which the winning contractor will perform, receptacles will be installed (one in each room) for future loads such as televisions, sewing machines, refrigerators, small power tools, and a battery charger.

We recommend a system which has the following characteristics:

- o Nine 48-watt peak PV modules (394 Watt PV array)
- o One 470 Amp-hour 12-volt battery
- o One charge controller
- o One inverter capable of handling a nominal 12-volt input and inverting it to 220-volts, 3-phase AC at 50 hertz

The array should be mounted on the ground (as opposed to on the house) for ease of maintenance and because of the unknown structural integrity of each existing house. We recommend strongly that if the introduction of more loads is likely, the array should be easily expandable so that additional modules can be added.

1.4.5 Street Lighting System

We recommend that 10 standard packaged street light systems be purchased. Several American manufacturers have these types of systems available. We recommend an 80 watt (PV peak) array with two batteries which can provide about 1200 lumens for 12 hours per night. This is about the amount of light from a 60 watt incandescent bulb.

1.4.6 Estimated Capital Cost

We estimate the Capital costs of FT #7 as follows (all figures are in U.S. dollars):

Fixed Pumping system	64,000
Portable Pumping systems	16,000
20 Residential Lighting Systems	159,860
10 Street Lighting System	16,700
Subtotal:	256,560
Spare Parts @ 20%	51,312
Total:	307,872

A significant additional cost is the drilling of the wells for the PV pumping system. Based on American experience, the cost could be as much as $28,000 for five 10.2 cm wells 150 meters deep.

1.5 Additional Information Needs

Before a competitive work statement is written, much more detailed information is required about this field test. The most critical information gaps are in the irrigation project, specifically the placement of the wells. EEA has stated a requirement for at least two new wells which do not affect the present system of wells. Fulfilling this requirement may require drilling one or more test wells.

It is not clear what the irrigation pattern will be. EEA/USAID has stated that 60 feddans will be irrigated every other day. It is not clear if that means the same 60 feddans every other day or if it means that six different 10 feddan among many will be irrigated every other day. In general, it is desirable to have the wells as close as possible to the irrigated areas.

All of these considerations make the siting the storage tanks more complex. EEA/USAID requires that the new wells should be located "above" existing wells. If the intent here is to use the same irrigation ditches as are presently being used, then that may prevent use of water from the new wells for new lands.

In addition, the location of the 10 cubic meter tank for domestic use must be discussed with the village residents or a decision must be made by the Bawiti City Council as to where it will be located.

The specific layout of the village houses needs to be documented by the site representative so that a bidding contractor can accurately determine the specific location of each PV array and other equipment relative to the houses. Since no specific village site was clearly selected at the time of the visit in May 1986, this detailed information was not collected.

In summary, the PV-powered system requirements specified in Appendix G are satisfied by the conceptual designs in this document. PV systems of the type required for this field test are commercially available, therefore, this field test should proceed with the development of detailed, site-specific system specifications for a tender document. Clearly, more data are required from El-Ezz to complete this activity, however, once those data are collected, there is no reason why this field test cannot proceed to a successful demonstration that should have wide applicability throughout Egypt.

2.0 FIELD TEST DESCRIPTION

2.1 Project Objectives

The primary objectives of this field test are to provide EEA with practical working experience with photovoltaic power systems for lighting and irrigation projects, and to provide system design and operational training for Egyptian engineers.

The specific objectives of this field test are to:

1. Demonstrate the technical viability of photovoltaics for lighting and irrigation applications in Egypt.

2. Determine the institutional requirements to operate and maintain these systems.

3. Determine user acceptance.

4. Determine the capital costs and the cost to operate and maintain the systems.

This section reviews the field test location, the Baharia Oasis, and those villages which are candidates for PV system installations.

2.2 Background

This field test evolved from two other earlier field tests specified in the original project paper. The original location for a 2.5 kilowatt PV-powered irrigation system was El Ghorieb near Assyut. A second field test was planned to provide photovoltaic power for lighting fisherman's shelters at Lake Nasser. During the time between the release of the original project paper and site visits in May 1985. conditions had substantially changed that made it no longer practical to use these sites. A decision was made by EEA/USAID to combine features of each of these applications into a single field test for PV-powered village lighting and irrigation at the Baharia Oasis.

2.3 Description of the Field Test

2.3.1 Baharia Oasis

The sites chosen for this field test are located within the Baharia Oasis, an area approximately 380 kilometers southwest of Cairo (see Exhibit 2-1). The Baharia Oasis is in the El-Giza governorate. All ministry level activity occurs in El-Bawiti, the central area and capital village. The Bawiti City Council is the local organization which is participating in this field test. The participating individuals include the Secretary of the Bawiti City Council, the El-Giza Governorate Electrical Engineering Works, the Bawiti Power Systems Office (which is the site representative for this field test) and a public relations officer for the oasis.

The population of the oasis is estimated to be 20,000 - 30,000 people (Ref. 1-1). The oasis consists of the Bawiti center area which is surrounded by several village areas within a radius of 50 kilometers of Bawiti (see Exhibit 2-2). Each village area consists of several individual villages.

The electrical energy supply for the oasis is provided by a 132 kV transmission line from the Aswan Dam. The principal energy user in the oasis is a government owned and operated iron mine with major facilities at the northeastern border of the oasis. Power is stepped down to 33 kV and 6.6 kV for distribution in the village areas of El Qasr and El Aquis, two of six major village areas within the Baharia Oasis. Outside of the El Qasr and El Aquis village areas, several villages have been supplied by the Egyptian government with stand-alone diesel engine-generator sets (see Exhibit 2-2).

According to the Egyptian Rural Electrification Authority, villages of populations greater than 100 will be electrified in the near term, primarily by extension of the national grid network. There are currently no plans for the government to provide electricity to villages of less than approximately 100 people or to moderately sized villages that are long distances from the

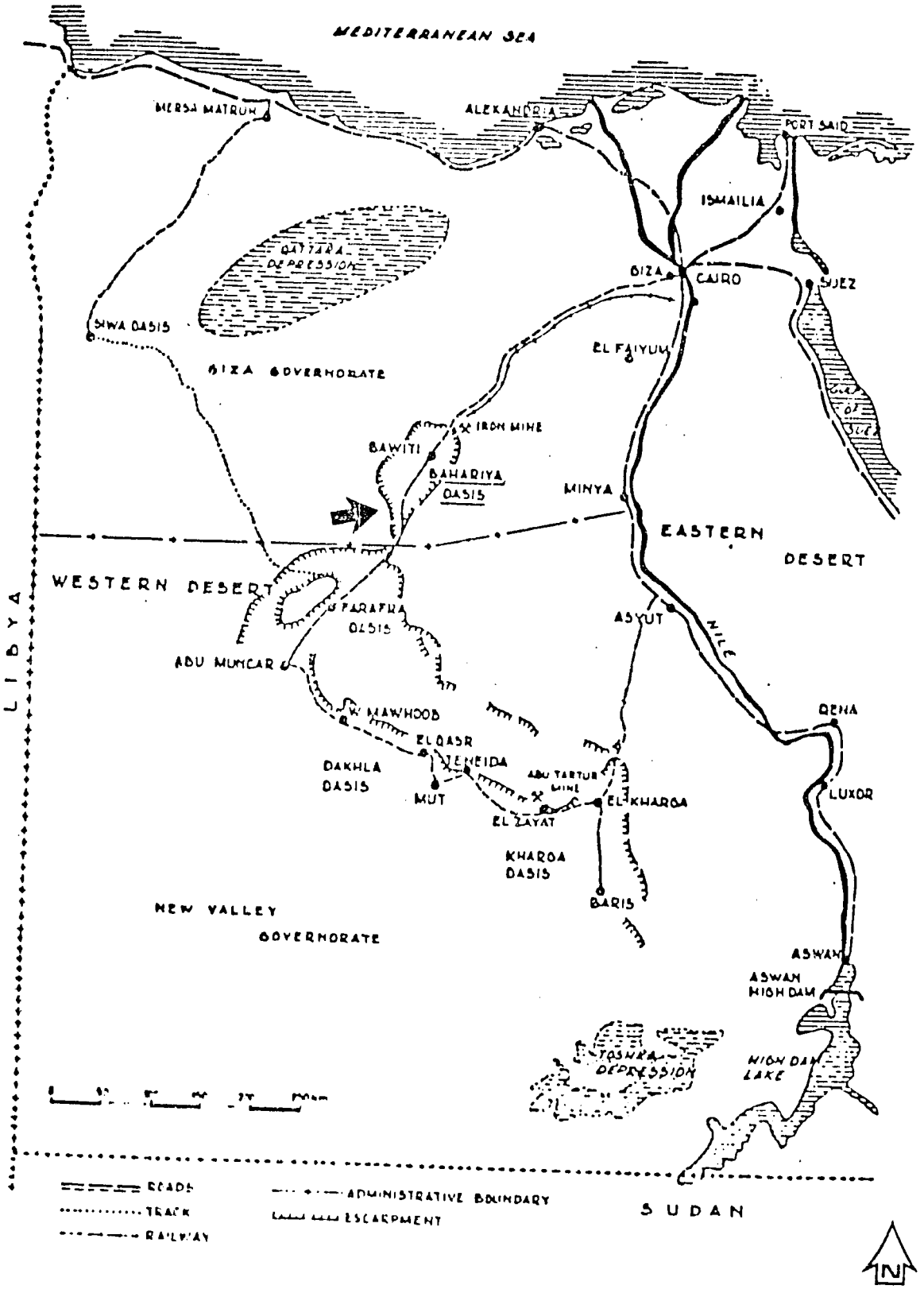


Exhibit 2-1 LOCATION OF THE STUDY AREA

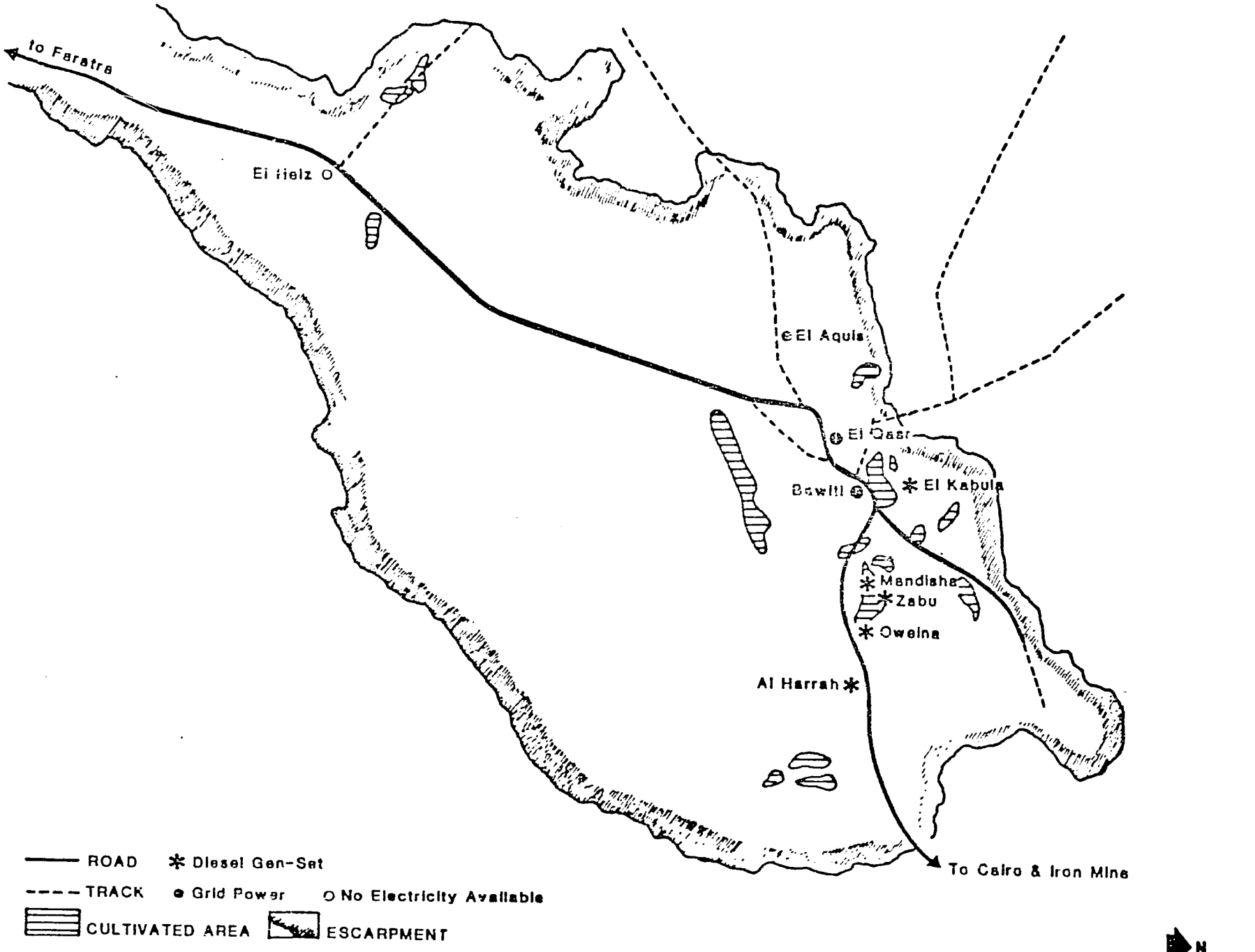


Exhibit 2-2: BAHARIA OASIS MAP

nearest grid intertie. For example, the El-Haiz village area, approximately 40-45 kilometers south of Bawiti (see Exhibit 2-2), will not be electrified using conventional means because of its remoteness from Bawiti, capacity constraints on transmission lines in the surrounding area, and because individual village sites have low populations.

Water supply in the Baharia Oasis is principally from artesian wells (free flowing wells without the aid of pumps). Wells are manually dug and permitted to free flow into small lake reservoirs or earthen canals which distribute water to the village and irrigated fields. Water is used for flood irrigation and potable water supply. Typical wells use 7.6 cm (3 inch) diameter piping and are 75-150 meters deep. Currently ground water will free flow when well casing is installed to depths of 75 meters or more. These wells are manually dug and require from 4 to 9 man-months of labor to construct. A typical well has an artesian production life of 3-years, after which a new well is dug and the old one abandoned. However, wells equipped with pumps can last up to 20 years.

Water table depth is expected to increase gradually over the next 100 years. Projections are for average water table depth to reach 10 meters in shallow aquifers and 5 meters in deep aquifers in the year 2006 in the Baharia Oasis (Ref. 1-1). Exhibit 2-3 is a graph of simulated future ground water levels after planned agriculture and land reclamation development.

Lighting and cooking are the primary energy needs at the village level. Energy sources to satisfy these needs are agriculture wastes, dung, wood, and kerosene. Primary (non-rechargable) batteries are used for portable flashlights and radios. Kerosene is the principal fuel source for lighting. Commercial kerosene hurricane lanterns (non-pressurized) and "bottle" lamps are used. A picture of typical lighting and cooking fixtures is provided in

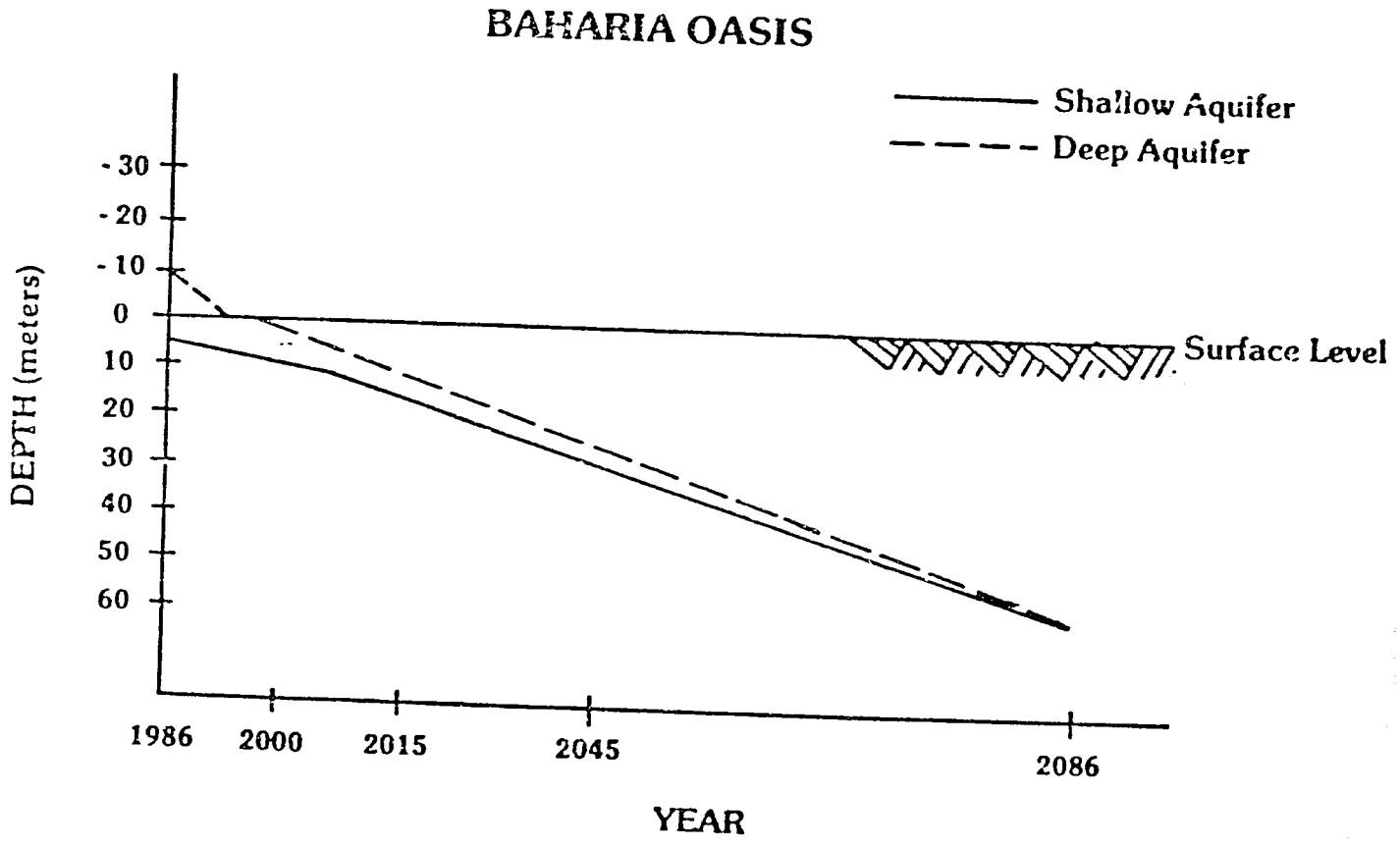


Exhibit 2-3. SIMULATED FUTURE WATER LEVELS AFTER DEVELOPMENT (Regional Development Plan for New Valley, Final Report, 6/83, Arab Republic of Egypt, Ministry of Development

Appendix D.

There are no public telephones in the Baharia Oasis. Although the regional telephone network is adequate, the connection with the national telephone network is poor and unreliable. Remote villages have no telephone link to Bawiti. Radio and television broadcasts from Cairo can be received in the Baharia Oasis and interest is high in obtaining television sets at the village level.

2.3.2 Village Descriptions

Site visits were made to the Baharia Oasis by EEA engineers on January 27, 1986 and by other members of the REFT project team on May 11-12, 1986. A third site visit was made in July 1986. During each visit, meetings were held with the Secretary of the Bawiti City Council and the designated Egyptian project personnel to discuss plans for electrification of rural villages in the oasis and the suitability of using photovoltaic systems as a power source for village lighting and irrigation. Two village areas were identified by the City Council as candidates for the PV system applications; El-Haiz and El-Harrah.

El-Haiz was identified as the village area most likely to use photovoltaics because, as previouly mentioned, there are no plans to provide the village area with power by extention of the grid or by stand-alone diesel generation. El-Haiz is 40-45 kilometers southwest of Bawiti along the main paved road from Bawiti to the El-Farafra Oasis. Five individual villages within the El-Haiz area that were identified as potential field test locations were visited by the REFT project team.

The El-Harrah village area was also visited to serve as an example of small electrified villages in the oasis. Electricity is supplied on a scheduled basis from government-supplied stand-alone diesel generators.

El-Harrah is about 20 kilometers northeast of Bawiti near the main road to Cairo. Three villages in El Harrah were selected by the Baharia City Council for the project team to visit.

A tabulation of village data for the El Haiz and El-Harrah areas is provided in Exhibit 2-4. According to the Field Test #7 site representative, electrical meters are read monthly in the El-Harrah village households and records exist in Bawiti at the Bawiti City Council office. However, these data were not available at the time of the site visits.

The following is a summary of field test specific information gathered during visits to the Baharia Oasis.

El-Haiz Village Area

o Ayn Gomaa

Ayn Gomaa consists of 12 houses and approximately 120 people. There are a total of nine artesian wells in the village which supply potable water and water for irrigation of the village feddans. It requires 2 to 3 months to dig a tube well, principally by manual methods. Well casings made of steel have corroded in the past because of high magnesium and salt contents in the water. Therefore, PVC plastic pipe is replacing steel well casings as funding permits.

Three wells feed a small water reservoir lake which is slightly above the level of the irrigated fields. Water is gravity fed and distributed to the irrigated fields and homes in the village by a series of dirt canals. There are between 60 and 150 feddans under cultivation depending on the season. Approximately 13-18 feddans are irrigated by open channel flood irrigation methods. The villagers all expressed strong interest in increasing access to water and thereby increasing farming productivity through irrigation.

Home lighting needs are met by commercial kerosene lamps and

EXHIBIT 2-4. Baharia Oasis Village Data[a]

Village	Population[a]	# of Houses	# of Elec. Connect.	Elec. Connect. Time	Elec. Hours	Diesel GenSet Size	Fuel Cons.	Water Supply
EL-HAIZ								
Ayn Gomaa	75-120	12-15	0	-	-	-	Kerosene	Natural
Talbamun	450-500	35-50	0	-	-	-	Kerosene	Natural
Ries	300-380	30-35	0	-	-	-	Kerosene	Natural
El-Ezz	100-120	15-17	0	-	-	-	Kerosene	Natural
Ayn-Deries	150	15	0	-	-	-	Kerosene	Natural
EL-HARRAH								
Ayn Gdid	1000-1500	350	100	1 yr	6-9	70 kVA	170-200 l/d	Pumped-Distrib. (not function)
Ayn Joseph	500	-	80	1 yr	6-9	350 kVA	80-100 l/d	Natural
Ayn Wadi	500	-	70	1 mo	6-9	35-40 kVA	60-80 l/d	Natural

[a] Verbally reported by Baharia City Council representatives and villagers during the course of the village visits.

open wick kerosene "bottle lamps". In one typical house, there were 2-3 hurricane kerosene lamps. In addition, two kerosene stoves were used for cooking and several (3-4) homemade open wick bottle lamps were used for lighting. There are battery powered radios and battery powered flashlights in most homes. Within the next several months, television broadcasts will be available in the oasis. It was the opinion of the villagers surveyed and the Bawiti City Council project engineers that many people would purchase television sets and operate them with automobile batteries.

The cost for kerosene lamps was reported to be 7-8 L.E. Replacement glass costs are approximately 0.25-0.30 L.E. Three glass replacements per month were estimated as average and kerosene lamp life was estimated between two and three years. Kerosene costs are 3 piasters per liter ($.02/liter). Two "D" size batteries cost 65 piasters and four per month per radio was estimated as an average usage. Finally, average family income was stated at 60-70 L.E. per month (for a family of eight).

Potential applications for PV power in the village are both irrigation and lighting. Replacement of the kerosene lamps by a PV-powered system would reduce family expenditures for fuel and replacement parts. This could be cost-effective depending on the cost of the PV system. Three village objectives would be realized through the use of PV-powered water pumping systems:

1. Increased well water production
2. Extended well life
3. Increased arable land through irrigation

o <u>Tabl-Amoun</u>

Tabl-Amoun is approximately 1.5 km from Ayn Gomaa. There are approximately 50 houses in the village occupied by 450-500 people. The village

water supply is by an artesian well which is located approximately 25 meters below the village (the village is locateds on top of a hill). Water flow from the well is profuse and unregulated. Iadequate drainage of this water has caused significant soil flooding problems. Villagers accompanying the project group explained that capping the wells was not possible as the well casing was not strong enough. As a result of the unregulated flow and low elevation of the valley below the village, farming in the area of the wells is restricted due to flooding.

The villagers requested that water be pumped out of the valley and discharged over the higher land approximately o.5 kilometers away in order to drain their farmland.

For a PV-powered irrigation system to be of value to the village, the well must first be capped to regulate the artesian flow, to reduce flooding, and to provide controlled irrigation. This may require re-lining the well with stronger pipe. A PV powered irrigation pump could then be installed to extend the range of arable land, however, during the site visit it was not possible to identify the extent and location of potential farmlands. A well and PV powered pump for potable water could also be installed in the village to eliminate the need to carry water up the hill to the village.

Lighting applications in Tabl-Amoun are similar to those in Ayn Gomaa.

o <u>Ries</u>

The village of Ries consists of 30-35 closely spaced homes, with a population of approximately 380 people. The village is bounded on one side by a large dune. At least three artesian wells supply the village with potable water and water for irrigation. On the side of the village opposite the dune is an irrigated farming area. This area is served by at least one well which

was reported to be in existence about 100 years. The villagers dig their own well by hand. Well casing is driven into the ground and water is poured into it to soften the ground. By raising and lowering the pipe while using the palm of the hand over the pipe end, a suction is generated which draws mud up the pipe and thereby lowers the pipe casing. At a depth of approximately 20 meters, water begins to seep into the pipe and no additional water is needed to soften the digging. As the well casing gets deeper, water flow increases and at about 100 meters, artesian water flow is firmly established. This water supply,however, is usually murky. At 130 meters clear water is found.

A document prepared by the Bawiti City Council was partially translated into English and is attached as Appendix A. It indicates that artesian flow volumes as high as 4500 m^3/day through a 25.4 cm (10 inch) diameter pipe are possible for 3-5 years. More commonly reported flow volumes are 300 m^3/day with well casings at 100-150 meters depth and pipe sizes of 7.62-10.16 (3-4 inches) in diameter.

Lighting demand in Bies is similar to that in Ayn-Gomaa and Tabl-Amoun.

o <u>El-Ezz</u>

El-Ezz consists of 15 individual houses spaced approximately 200 meters apart. El-Ezz has a population of approximately 120 people. While land is abundant, the water supply is not. Apparently this is due to the limited flow of the wells in the area and the lack of a labor force to dig new wells. Extensive farming is conducted below the village with established flood irrigation metnods. Some houses have their own wells and all use kerosene lighting. The need for more water and the interest of the villagers in farming more land if the water were available makes this village site an excellent location for the demonstration of both an irrigation and a lighting application

of photovoltaic power systems.

o Ayn-Deres

The village of Ayn Deres consists of 150 people living in 15 houses. According to the field test site representative, Ayn Deres is one of the wealthiest villages in the area. At the nearby artesian well, within 50 meters of the village homes, a 55 gallon oil drum is filled as required to provide a siphoned water supply to one village home. This serves the same function as a pressurized water system using an elevated tank. Lighting by kerosene lamps is similar to other villages.

In summary, the visits to five village in the El-Haiz village area indicate that the primary energy use is kerosene for lighting and cooking. Irrigation and potable water is supplied by artesian wells and flow is directed through earthen and, in two cases, concrete canals. In all cases there was no regulation of water supply. Well construction labor costs and the lack of pumps were regarded as a major deterrent to increased water supply and thus to increased agriculture production. PV powered pumps could be installed to meet desired demands for increased irrigation water, especially during the summer when evapotranspiration reduces irrigation water flow by as much as 60% (Ref. 1-1). PV powered lighting and communications systems could also meet existing demand for lighting and related basic social services.

El-Harrah Village Area

o Ayn Gdid

Ayn Gdid is a village of 1000-1500 people and about 350 homes according to the project engineer from the Baharia Oasis. The village has a distributed water and electrical system.

The electrical system consists of a 70 kVA diesel generator operated on a daily schedule from 6 p.m. to 12 p.m. Currently there are 100 metered

connections. Estimates given of electricity consumption per connection were 25-30 kWh/month. Fuel consumption of the diesel generator was estimated as 200 liters per day during Ramadan when operating hours are extended from six to nine hours per day. Fuel consumption is 170 liters per day for the normal six-hour day. The principal use of electrical energy is for lighting. Typically, 60 watt and 100 watt incandescent bulbs are used. The diesel generator is about one year old. Nameplate data on the generator shows 9/84 as the manufactured date, an efficiency of 85.5 percent, and power at three phase and 220 volts. The diesel generator is unavailable 3 to 4 days every 3 months because of repairs and maintenance.

There is also a distributed water supply system at the edge of the Ayn Gdid village powered by a separate diesel driven pump system. Water is available three hours in the morning and three hours in the afternoon. No data were available on the size of the pump or diesel generator or the amount of water consumed.

- Ayn Joseph

The village of Ayn Joseph has a diesel generator that is similar to the one in Ayn Gdid. Fuel consumption was estimated at 100 liters per day during Ramadan by the site representative and the local diesel generator set operator. During non-Ramadan operating hours, fuel consumption is 80 liters per day. The system has been in place about one year and there are 80 metered connections.

- Ayn Wadi

A third village in the El-Harrah area, Ayn Wadi, consists of 500 people. A new diesel generator has been in place for about one year. It was a donation of the Government of Japan. Its rated capacity is 40 kW for the engine and 35 kVA for the generator. Fuel consumption was estimated as 70-80

liters per day during Ramadan and one barrel (200 liters) over 2-3 days during non-Ramadan periods.

A site visit was made to an irrigation power system located outside of the village. A 40 hp diesel-powered irrigation pump provides water for irrigation on a regular schedule to surrounding agricultural land. For a potable water supply, a deep artesian well was constructed by the Egyptian government at the edge of the village at a cost of 250,000 L.E. ($185,000).

A visit was made to an irrigated farm in the El-Harrah area of the Baharia Oasis. Static well water depth was observed to be 1-2 meters and drawdown an additional 3 meters for a total dynamic suction head of 4-5 meters. Pumping volume was roughly estimated at 28.4 liters per second (450 gallons per minute) based on a half full 15 cm (6 inch) diameter pipe cross-section and flow of 3.05 meters/second (10 ft/sec).

Lighting Energy at El-Haiz Villages

The demand for lighting and the cost incurred for the village sites visited in the El-Haiz village area was estimated from data collected during the site visits (Exhibit 2-5).

The estimated cost of lighting for a village family in the Baharia Oasis of between $1.80 and $2.20 per month is based on a subsidized price of kerosene and the usage levels specified. At unsubsidized kerosene prices, the costs of lighting by kerosene are actually between $9.00 and $10.00 per month per family. This compares closely with rural households in other developing countries of the world. Under current subsidies, batteries represent the largest lighting expenditure for village families. This can be expected to increase with the use of small television sets which would be powered by small primary or automotive batteries.

These loads and costs are typical for the application of small

EXHIBIT 2-5. El Haiz Village Sites Energy Use and Cost[a] Estimates for Lighting (per household)

Lighting Fixture	Number	Usage Estimate	Kerosene Consumption liter/day[b]	Capital Cost-$	Life	Subsidized Total Cost[c]	Non-Subsidized Total Cost[d] $/mo.
Kerosene Hurricane Lamp	6	6 hrs/day	.5	$5.00	2 yrs	.30/mo	3.90/mo.[e]
Kerosene "Bottle Lamps"	2	12 hrs/day	.5	0	-	.30/mo	3.90/mo.
Replacement Glass	-	1/mo.	-	.20	1 mo.	.20	.20
Batteries "D" size	-	4/mo.	-	1.00	1 mo.	1.00	1.00
				Totals		$1.80/mo	$9.00/mo.

a Conversion used: 1.6 L.E. = $1.00

b Based on 250 ml kerosene fuel consumption per hurricane lamp over 6 hrs. Feasibility Assessment for PV Cells Replacing Kerosene Lighting in Papua New Guinea Villages, Kipa Maleva, Report 7/81, Energy Planning Unit-Ministry of Mineral and Mines, Konedobu, Papua New Guinea.

c Subsidized price of kerosene of 25-30 piasters/liter or $.02/liter

d Non-subsidized fuel cost of $.25/liter

e Not including a leverlized capital cost for lamps of $.36 per month ($5.00 over 2 yrs at 5%)

photovoltaic power systems of one or two modules, a storage battery, simple controls, and electric lights. There is a proven demand for small PV systems at the village level at an even higher total monthly energy cost. Improvements in lighting quality and convenience are significant incentives to rural villagers for using electric lights compared to kerosene lamps.

Water Irrigation Demand at El Haiz

No quantitative data regarding irrigation data for villages in the El-Haiz area were available at the time of the site visits. Estimates for irrigation water requirements are 20-25 m3/day/feddan according to the Bawiti City Council records. Related studies support these values (Ref. 1-1). Water table projections are for depths of 5 to 10 meters over the next 20 years. According to the "New Valley" study, the minimum farming area per household required for economic self-sufficiency is approximately 3 feddans, thus each household will need 60-75 m3/day of water for irrigation. In the near future (less than 5 years) artesian well flow may subside substantially and pumping would be required for all wells to supply this volume of water. A modular PV-powered irrigation pumping system would serve to meet the current and expanding needs for irrigation in the El-Haiz village area.

Electrical Energy Consumption Data from El-Harrah

In the El-Harrah area, documented data on electrical energy supply from stand-alone diesels generators are limited. Some qualitative data are available from the comments made by the diesel generator operators and the site representative engineer during the site visits. These include village site population, number of "metered" connections (there may be many unmetered connections), fuel consumption, and operating hours. Power ratings of the diesel generator were taken from nameplate ratings where available. Exhibit 2-6 presents the data and resulting consumption rates. Energy production values

EXHIBIT 2-6. Estimate of Electrical Energy Consumption for Visited El-Harrah Village

Village	Average Population	No. of Houses	No. of Connect	Diesel/ Generator Rating-kVa	Daily Fuel Consumption liters/day	Daily Averge Operation Hours	Daily Energy Daily Energy Production kWHr	Daily Consumption Per Connec-tion-kWh	kWh/month Connection
Ayn Gdid	1250	350	100	70 hVA	185 l/d	7.5	185 kWh/day	1.9	60
Ayn Joseph	500	125	80	50 hVA	90 l/d	7.5	90 kWh/day	1.1	30
Ayn Wadi	500	125	70	40 hVA	70 l/d	7.5	70 kWh/day	1.0	30

were calculated using 10.84 kwh per liter times a 10 percent fuel-to-electricity conversion efficiency times the fuel consumption in liters. Using these data and assumptions, monthly energy consumption per metered connection is between 30 and 60 kwh per month as compared to a range of 25-30 kwh per month estimated by the people living in the villages.

Another way to estimate energy usage is to calculate the load of a typical household. Lights are the primary load, usually in 60 or 100-watt sizes. Some families also have refrigeration. Based on the maximum reported hours for the operation of the diesel generator, a single 100 watt lamp operated for 9 hours per day would consume 900 watt-hours. Over a 30 day month, this would equal 27 kwh. High consumption would be obtained if families have refrigeration and more lights. Therefore, a range of 25-60 kwh per month per connection appears to be a reasonable estimate of a lower and upper bound. Diesel generator maintenance and spare parts availability were specified as the major problems associated with supplying electricity.

Summarizing the data collected and evaluated during the site visits to five villages in the El-Haiz area and three villagers in the El-Harrah area results in the following conclusions:

1. The applicability of photovoltaics for irrigation water pumping and lighting is excellent in El-Haiz and may also prove as good at other village areas in the Baharia Oasis.

2. El-Haiz is the priority area for the demonstration of PV power systems because there are no plans to provide electrical service by other means.

3. Water sources for irrigation are free flowing artesian wells. PV powered pumps would increase well production and extend well lifetime resulting in irrigation of more farmland.

4. The primary energy source for lighting is kerosene in villages with no electricity.

5. Non-subsidized monthly energy costs are between $9.00 and 10.00 per household. Subsidized energy costs are between $1.80 and 2.20 per month per household.

6. Villages with stand-alone diesel generators, like those in the

El-Harrah area, receive electricity on a rationed basis and consume at average levels of 1 to 2 kwh/day per household.

2.3.3 Additional Data Requirements

Now that a specific village area,the El-Haiz area, has been selected for the Field Test #7 demonstration of PV systems, more accurate data on existing and future irrigation and lighting requirements is essential to assure that the conceptual designs in this document are applicable for the Statement-of-Work in a Tender Document. These data include:

- o Village Physical Layout- showing all households, sizes, locations, farming areas and all well locations for each candidate village site and the El-Haiz area in general.
- o Village Data- population per household by men, women, children and labor availability for farming.
- o Irrigation Demand- current number and layout of farmland, identification of irrigation systems and practices including schedules and cropping patterns, projected demands for irrigation.
- o Draw Down Patterns - for wells.

It was not possible to obtain this level of detail during the field test site visits because much of the information does not exist in documented form. The Bawiti City Council, in cooperation with the EEA, should examine the candidate conceptual designs in this document in the context of their first hand knowledge of the specific villages in El-Haiz.

Significant non-technical issues which require consideration by EEA as input to developing a Statement of Work are as follows:

- o Verification of water demand for irrigation and electrical demand for village lighting
- o Organization of technical and administrative support for project implementation, field test monitoring and non-technical data collection
- o Selection of specific households to receive the PV lighting systems

- Siting of new wells. EEA has recommended that two (or more) new wells be drilled to provide new sources of water. The decision on where these wells are to be built is a complex one involving draw down rates, sociological factors and environmental considerations.

3.0 VILLAGE SELECTION AND GENERAL SYSTEM DESIGN CHARACTERISTICS

There are several good applications for PV-powered irrigation and lighting systems in the Baharia Oasis. This finding is based on:

1) The information collected during site visits to five villages in the El-Haiz area and three villages in the El-Harrah area,
2) Meetings with the Bawiti City Council related to electrical service expansion plans for remote villages in the Oasis,
3) Relevant reports on groundwater resources and irrigation practices in Egypt,
4) The Technology Review for Field Test #7.

PV powered water pumping systems for irrigation could be used with existing artesian wells to extend well life as the ground water level drops and to increase production. They could also be used with new wells that are drilled specifically for this field test, thereby supplementing the current water supply of the selected village.

There are two options for PV-powered village lighting systems:

1) Decentralized systems, i.e. each household has its own small stand-alone PV system;
2) Centralized systems, i.e. each household in the village is connected to a common PV power system by an electrical distribution network.

3.1 PV Irrigation Pumping Systems

3.1.1. Justification and Scope

PV irrigation pumping systems have demonstrated technical reliability and economic competitiveness with stand-alone diesel powered pumps in many applications. A recently published study, "Evaluation of International Photovoltaics Projects", (Ref. 3-1) reports that PV pumping systems are cost competitive in certain applications that have volume-head products of up to 13,750 m^4 (for example, pumping 2750 m^3 per day from a head of 5 meters is a

volume head of 13,750 m4).

PV-powered irrigation systems are applicable for the Baharia Oasis in small villages with a population of less than 100 people that are currently using artesian wells since these villages will not be electrified and artesian wells have a limited life due to the estimated decline of ground water level with increased use (Ref. 1-1).

The recommended application for this field test demonstration is a turn-key PV powered irrigation water pumping system sized to provide a sufficient volume of water for a village to farm enough feddans to provide agricultural self-sufficiency. The system would be sized for 25 m^3 per feddan every day (Ref. 2-1). This would be a total water demand of 75 m^3/day/household since the minimum farming area required for economic self-sufficiency is, on the average, 3 feddans per household (Ref. 2-1). Using the cost-competitive volume-head value of 13,750 m4 (Ref. 3-1) and assuming a total 5-meter head for the irrigation system, a centralized PV irrigation pumping system may be economically sized to support a village of approximately 36 households (13,750 divided by 375, i.e. 75 m^3/day/household times 5 meter of head).

3.1.2 Village Selection

The location for this field test demonstration was selected by the EEA to be the Baharia Oasis after visits by EEA engineers to small villages throughout the Nile delta and elsewhere. The criteria used by Meridian to select a specific village site in the Baharia Oasis for a PV powered irrigation pumping system are that there be an adequate ground water supply to assure agricultural self-sufficiency, that there be adequate farmland available and that there be sufficient interest on the part of the local villagers to assure that the installation will be properly operated and maintained. These criteria

were equally applied to all the sites visited in the Baharia Oasis by the Project Team.

El-Ezz, in the El-Haiz village area, is the recommended village for the demonstration of a PV-powered irrigation pumping system because, of the eight villages visited, it best meets the criteria specified above.

3.2 PV Village Lighting Systems

3.2.1 Justification and Scope

Village power requirements for lighting observed at the Baharia Oasis are typical of other rural, developing country villages worldwide. These requirements can be addressed by two types of PV power systems; "decentralized" and "centralized".

Decentralized systems for rural, developing country villages consist of a few PV modules, a small battery storage system, and a simple voltage controller. They are sized to provide sufficient power for the lighting needs of one household. They are generally direct current (DC) systems for simplicity of operation, i.e. an inverter and a sophisticated control system are not required. Decentralized PV systems such as this are commercially available from several manufacturers and have been sold privately and offered through formal programs and development cooperatives in several countries for the past 5 years. Decentralized small home PV power systems have been used as a means of supplying electricity to dispersed users and avoiding the inherent difficulties with reading meters, meter reliability and the added management cost of fee collection. Each user is responsible for the regulation of their own energy consumption. Users who desire more energy can increase the size of their system by adding more modules and batteries, thus increased demand by one user does not affect another. Appendix B contains a selection of published papers on small decentralized PV power systems and the programs developed to

encourage their use.

Centralized PV power systems have also been demonstrated worldwide. These more conventional, and generally larger, power systems are usually alternating current (AC) and incorporate an inverter and some battery storage capacity. Standard power distribution networks, electric meters and revenue collection methods are used to allocate the cost of energy to users. Appendix C is a description of some centralized PV power projects.

A comparison of the essential components of small, decentralized PV systems with centralized PV systems is shown below.

	Decentralized	Centralized
o Electricity Type (most often)	DC	AC
o System Size		
- Array	One or Few Modules	Multiple Modules (central array)
- Storage	One or Few Batteries	Multiple Batteries
- Controls	Simple Regulator	
Controller/Inverter		
o Power Distribution	By user in home	Conventional Village Grid
o Management	By user	By operating organization
o Financing	By user	By operating organization
o Revenue	Monthly Payment	Metered ($/Kwh)

Institutional issues are inherently different between the two types of PV power systems. Decentralized systems =, i.e.small PV power systems, require more user training, careful control over dispersed spare parts and the establishment of an institutional management capability to collect equal monthly payments if the users are to pay for the power system. Operation and maintenance can vary greatly since they are performed by the user. Failure of

the power system results in the loss of lighting for a single household.

Centralized PV power systems can be operated in a more conventional institutional manner where users are billed for their energy usage at some established rate. Spare parts and operation and maintenance are controlled at a central point. Failure of the power system means a total loss of lighting for the village, but more control over its repair.

3.2.2 Village Selection

The location for the demonstration of a PV-powered village lighting system was selected by the EEA to be the Baharia Oasis in conjunction with the demonstration of a PV-powered irrigation pumping system. The criteria for the use of PV power systems for rural, developing country village lighting in the Baharia Oasis are broad. A remote village may be suitable for either a decentralized or centralized PV power system depending on how far the village is from the grid distribution system and the physical layout of the village. The criteria used by Meridian for village selection are shown below.

Criteria	Required Conditions
Remoteness	Uneconomic for central grid extension
Physical layout	Dispersed houses are better suited to decentralized systems; closely spaced houses are better suited to centralized systems.
Low Energy Demand	Demand less than 2 kwh/day and up to 16 kWh/day under specific conditions of high diesel price, short diesel life, and good solar conditions.
No Rural Electrific-trification Plan	No plans to electrify by central grid or stand-alone diesel generators.

Exhibit 3-1 is a tabulation of the villages in the El-Haiz village area that were visited by the project team and recommendations for the type of PV-powered village lighting system that would be most suitable for them.

Exhibit 3-1 El Haiz Village Site Selection

	DATA		CRITERIA				RECOMMENDATION	
Village Site	Population	No. of Houses	Remoteness	Physical Layout	Energy Demand	No Rural Electricity	Decentralized	Centralized
Ayn Gomaa	120	12	x	closely spaced	low	x		x
Table-Amoan	450-500	50	x	closely spaced	medium	x		x
Ries	380	30-35	x	closely spaced	medium	x		x
El-Ezz	120	15	x	dispersed	low	x	x	
Ayn Deres	150	15	x	closely spaced	low	x		x

The El-Haiz area meets all the criteria for PV-powered village lighting systems. Villages with dispersed houses would be most suitable for a decentralized PV power application. Villages with a more centralized layout or larger populations (and therefore greater energy demands) would be more suitable for the centralized approach.

The most suitable village for a decentralized PV-powered lighting system is El-Ezz because it has the most dispersed layout. It is therefore recommended as the field test village for the demonstration of a village lighting system for this field test, since the EEA directed that a decentralized PV-Powered lighting system be used (Appendix G).

3.3 General System Recommendations

In summary, both the PV-powered irrigation pumping system and the PV-powered lighting system should be located in the village of El-Ezz. The lighting system should be decentralized, i.e. small PV systems should be installed for indivdual households.

A conceptual design for each of these systems is presented in Section 5. The designs conform with general requirements specified by the EEA/USAID (Appendix G) as follows:

o PV-powered irrigation pumping system

1. One Water-pumping system with:

   a. PV-power source to provide sufficient water to flood-irrigate a 60 feddan area every other day plus a total of 10 cubic meters per day for domestic use.

   b. A water source with a minimum of two new wells located at an elevation higher than and far enough from the existing wells to minimize drawdown.

   c. Two inter-connected water storage components;one component to provide two hours of water supply for irrigating early in the day, prior to the PV-system becoming operational with sufficient piping and valving to transport and control flow of the water into the existing irrigation system; and a second component to provide up to a one-day supply of water for domestic use with piping to allow a central location of a single, manually-operated valve for extracting the domestic water.

2. In addition to the primary water-pumping system described above, the project will provide for an option of two portable PV water pumping units each capable of providing sufficient water to flood-irrigate one feddan per day from shallow wells or an irrigation ditch.

o Decentralized PV-powered village lighting system

1. Twenty PV-power systems, each capable of providing an individual household with sufficient power to meet an energy demand of 1000-watt florescent lights with fixtures; 4-220 vac electrical outlets; batteries; inverters; and sufficient wiring and hardware to allow for a light and outlet in each of four rooms. The Contractor will be required to install the systems, assure that each is operational, and demonstrate to the user that the systems can be used for appliances such as a television, refrigerator, small power tools, sewing machine and battery charger.

2. Ten individually PV-powered street lights to be located where required in and near the village of El Ezz.

4.0 TECHNOLOGY REVIEW SUMMARY

Field Test #7 involves two distinct applications of PV technology: water pumping and decentralized systems for village lighting. Different technology, operational and economic factors are involved in integrating PV with each application. These factors incude:

- Commercial availability of hardware systems
- Hardware performance/system reliability
- Capital cost and cost of energy
- Operation and maintenance costs
- Potential for widespread use in Egypt

A detailed review of the component and system technologies involved in this field test was completed and presented in a technology review document submitted in June 1986. This section is a brief summary of the conclusions of that review.

4.1 PV Water Pumping

PV water pumping technology is commercially available. There are estimated to be over two thousand systems installed worldwide. Packaged systems including both the PV power system and the pumping hardware are available from a variety of manufacturers. Development efforts are currently focusing on making the systems more cost-effective by improving hardware and increasing system relability.

Design refinements focus on making PV pumping systems simpler and reducing the number of components. Especially important is the use of direct current (DC) pump motors, which eliminate the need for expensive and unreliable DC-to-Alternating current (AC) inverters. Many designs also eliminate the use of costly battery storage by directly connecting the pumps to the PV array.

The choice of pump type, i.e. either jack pump, submersible turbine,

or surface mounted centrifugal, depends on the water flow and head characteristics at the well.

This points out the critical need for accurate hydrologic information for the design of a successful PV pumping system. A successful design also depends to a great degree on careful matching of the load demand with (1)the available solar resource, (2)the PV power production equipment and controls, (3)the pump and motor, and (4) the actual hydrologic conditions.

4.2 Decentralized PV Power System

Decentralized village lighting technology is also commercially available with more than 1000 systems currently in operation. A large number of manufacturers and system integrators offer packages that include both the PV power system and the lighting system.

Most PV village lighting systems use small PV arrays (30-50 watts), batteries, charge controllers, and one or two highly efficient gas vapor lamps (fluorescent, sodium, or halogen) that operate on DC current.

Technical factors that are critical to the implementation of successful projects include (1) reliable charge controllers, and (2) availability of spare parts and a distribution system for them.

4.3 Street Lighting Systems

Pre-packaged PV street lighting systems are commercially available from a number of manufacturers. They are in use in many parts of the developing world as stand-alone area lighting systems for security lighting and safety lighting in public places. These systems are DC powered lights using one or two small PV modules, battery storage, a simple charge controller, and timing controls. They can be shipped with their own light poles and pole-mounted weather-proof containers for the battery and electronics.

4.4 Manufacturers and Hardware Systems

A selection of manufacturers, integrating contractors and hardware system specifications are provided in Sections 7 and 8 of the Technology Review for Field Test #7 submitted in June 1986.

4.5 Conclusions and Recommendation

The findings in the Technology Review support the recommendation to proceed with Field Test #7 based on the growing commercial availability of proven hardware and the potential for widespread use of the technology in Egypt. There should be no insurmountable technical problems associated with this demonstration project. The following conclusions can be made:

1. Packaged [illegible] water pumping system, decentralized PV power system technologies and PV street lighting systems applicable for this field test are proven, reliable and commercially available.

2. The most important design trade-offs in this field test are the choice between flexible, but somewhat unreliable AC systems, and more limiting, but more reliable DC systems.

3. Many of the factors that will determine the success of these PV applications are not strictly technical. Consideration of adequate user training, the local availability of spare parts, and the degree of local interest in maintaining and operating the systems are other crucial items.

4. Lessons drawn from this field test will be applicable to a wide set of potential users of PV technology facing similar conditions in unelectrified rural villages throughout Egypt.

5.0 CONCEPTUAL DESIGNS

5.1 Background

This document is an update of the draft-for-comment document submitted in August, 1986. In that document the recommended composition of the field test was:

- o Fifteen decentralized PV power systems for individual houses in El Ezz;
- o One centralized PV power system in Ries;
- o A PV pumping system for irrigation in El-Ezz consisting of eleven modular pumping systems.

During the summer and fall of 1986, there were a series of discussions among the organizations involved in formulating the composition of Field Test #7 (Meridian Corporation, Louis Berger International, Inc., EEA, and USAID). Some of these discussions involved the EEA Photovoltaics Task Manager, the Field Test #7 trainees and the USAID project manager. A decision was communicated to Meridian in December, 1986 (Appendix G) that the entire field test is to be located in the village of El-Ezz. The composition of the field test is four different systems:

1. One water pumping system capable of irrigating 60 feddans on alternate days. Capacity should be sufficient to supply an additional 10 cubic meters per day for domestic use. The water source (with a minimum of two new wells) should be located at an elevation higher than and far enough from existing wells to minimize drawdown.

2. Two portable pumping systems which are capable of flood irrigating one feddan per day from shallow wells or an irrigation ditch.

3. Separate lighting systems (220V, 50 Hz AC) to power twenty houses in the village. Energy demand is 1000 watt-hours per day. Included as part of each system are:

   - 2-20 watt and 2-40 watt fluorescent lights (with fixtures)
   - battery
   - inverter

- 4 individual 220V, 50 Hz outlets. These outlets are for additional loads such as television, refrigerator, small power tools, sewing machine, and a battery charger.

4. Ten individually powered PV street lights to be located where required in and near the village of El Ezz.

Additional tasks include:

- Construction of tanks for water storage
- Installation of wiring and electrical receptacles to the 20 houses in the village and demonstration that they will work for television, refrigerators, small tools and battery chargers.
- Piping from wells to storage tank.

The conceptual design that follows is completely responsive to that guidance. However, in two cases, (the fixed pumping system and the house lighting system), there are serious uncertainties about the premises on which the design is developed. In the case of the fixed pumping system, the physical arrangement of the wells with respect to the village and the storage system and the resulting pumping head calculation uncertainty, could make the conceptual design as presented here inaccurate when the final physical layout is determined. In the case of the individual house lighting system, the PV array is sized to provide enough energy to power a 1000 watt-hour daily load. Whenever additional loads are added (which is sure to happen because additional receptacles are added to accommodate them), the array and battery storage system will not be adequate.

5.1.1 System Design Criteria

Several basic assumptions and engineering decisions were made in the development of the conceptual designs. For system flexibility, each of the major systems groupings, i.e. (1) fixed irrigation system (from wells), (2) portable irrigation system, (3) house lights, and (4) street lighting are independent; that is each of the systems is not susceptible to breakdowns from

other systems should they occur. Further, each of the pumping, house lighting, and street lighting systems are composed of many smaller systems which in turn are also independent.

5.1.2 Engineering Assumptions

Because there are no known data on temperature and insolation at El Ezz, engineering assumptions must be made regarding insolation and ambient temperature. Insolation and ambient air temperatures for Baharia were estimated based on published research (Ref 5-1). The methodology used is based on relative levels of insolation for Siwa, Minya and Kharga. Insolation data were available only for Kharga. Siwa and Minya are at approximately the same latitude as Baharia and are considered best and worst case insolations because Siwa is a desert environment and Minya is in the Nile Valley. Annual sunshine-hour data for Siwa and Minya were averaged to provide sunshine-hour data estimates for the Baharia Oasis. This value was compared to the sunshine-hour data from Kharga. The estimated number of sunshine-hours per day per year for Baharia is approximately 4% less than for Kharga. On this basis, Kharga average monthly daily insolation values were reduced 4% to obtain the monthly insolation value estimates for the Baharia Oasis. Average daily ambient temperatures by month were assumed to be the same as Kharga. Exhibit 5-1 presents the resulting insolation and ambient temperature values.

EXHIBIT 5-1. Estimated Insolation and Ambient Temperature at Baharia Oasis

Month	Solar Insolation on Horizontal Surface kWh/m2-day	Ambient Temp. (°C)
JAN	4.4	13.9
FEB	5.4	16.2
MAR	6.3	20.2
APR	7.2	25.3
MAY	7.8	29.2
JUN	8.0	32.2

EXHIBIT 5-1. Estimated Insolation and Ambient Temperature at Baharia Oasis (Continued)

Month	Solar Insolation on Horizontal Surface kWh/m2-day	Ambient Temp. (°C)
JUL	7.9	31.9
AUG	7.5	31.7
SEP	6.8	28.4
OCT	5.8	27.1
NOV	4.9	20.5
DEC	4.3	15.5

5.2 Fixed PV-Powered Irrigation Pumping System

5.2.1 Methodology

To illustrate the method used to size a PV-array, two approaches w be used. In the first, the classic approach will be used in which the loads are calculated, estimated efficiencies and losses are factored in, amount of available sun hours are considered and finally an array size is calculated. This is a theoretical design which may not be possible to actually build because pumps, motors, PV modules, and other components are built in only standard, discretely sized models. Nevertheless, it is a useful approach to scope the general requirements of a system.

In the second method, the data sheet for an available pumping system is consulted in which the calculations and matching of components have already been done by the vendor. Buying components in this manner also takes advantage of that company's experience and possible warranty. It also provides some assurance that there are other similar systems somewhere from which the vendor has learned.

The methodology used to perform the conceptual design for a theoretical PV powered irrigation pumping system is as follows.

1. Determine Monthly Average Daily Irrigation Water Requirements

2. Determine Monthly Average Daily Plane of Array (POA) Insolation Levels
3. Calculate Monthly Ratios of Irrigation Water Demand to Insolation
4. Select Design Month
5. Determine Lift and Total Volume Requirements
6. Determine Hydraulic Energy Requirements
7. Select Type of Pump
8. Estimate Subsystem(s) Operating Efficiency
9. Calculate Daily Electrical Energy Demand
10. Size the PV Array

5.2.2 Conceptual Design

Step 1. Determine Monthly Average Irrigation Water Requirement.

Monthly irrigation water demand has been estimated by comparing historical evapotranspiration factors (Ref 5-2) to the commonly accepted values used in Bawiti to estimate water usage.

Using the data in Ref 5-2, the data in Exhibit 5-2 can be derived. Note that the months of June and July are the highest water use months and that this value (25 m^3) is the same as that given by the people of Baharia during the site visit.

EXHIBIT 5-2. Estimated Monthly Water Demand

Month	Evapotranspiration Factor	Water Demand m^3/Feddan-day
JAN	3.26	13
FEB	3.61	14
MAR	4.27	16
APR	5.17	20
MAY	6.08	23
JUNE	6.52	25
JUL	6.57	25
AUG	6.25	24
SEP	5.17	20
OCT	4.88	19
NOV	4.05	16
DEC	3.42	13

Sixty feddans are to be irrigated every other day with 25m^3/day as the rate of water supply per feddan.

$$\text{Daily Irrigation Water Required} = \frac{60 \text{ Feddans}}{2 \text{ Days}} \times \frac{25 m^3}{\text{Feddan}}$$

$$= 750 \ m^3/\text{day}$$

An additional 10 m^3/day is required for domestic use (Appendix G) resulting in a total requirement of 760 m^3 of water daily.

Step 2. Determine Monthly Average POA Insolation Levels.

The insolation in the plane of the array (POA) is calculated by the use of the PV-F Chart computer model. Exhibit 5-3 illustrates the monthly average insolation at 28° tilt, the approximate latitude of the site.

EXHIBIT 5-3. Average Daily Plane-of-Array Insolation, kWh/m^2-day for a 28° Tilt.

JAN	6.1
FEB	6.8
MAR	7.0
APR	7.2
MAY	7.1
JUNE	7.0
JUL	7.1
AUG	7.2
SEP	7.3
OCT	7.1
NOV	6.7
DEC	6.2

Step 3. Calculate Monthly Ratios of Irrigation Water Demand to Insolation

The purpose of this step is to determine the worst case month from a PV-powered pumping standpoint. It is implicit in this method that water pumped is proportional to insolation (which it very nearly is). This step combines the data from steps 1 and 2. The resulting data are summarized in Exhibit 5-4.

EXHIBIT 5-4
Ratio of Water Demand to Insolation

	Water Demand m^3/Feddan/day	Insolation of 28° Tilt kwH/m^2-Day	Ratio
JAN	13	6.1	2.1
FEB	14	6.8	2.1
MARCH	16	7.0	2.3
APR	20	7.2	2.8
MAY	23	7.1	3.2
JUNE	25	7.0	3.6
JULY	25	7.1	3.5
AUGUST	24	7.2	3.3
SEPT	20	7.3	2.7
OCT	19	7.1	2.7
NOV	16	6.7	2.4
DEC	13	6.2	2.1

Step 4. Select Design Month

From Step 3, it can be seen that the most demanding month is June (a ratio of 3.6), followed closely by July (3.5). These figures are dominated by the water demand rate. For purposes of designing the PV array, the month of June will be used.

This chart can also be used to illustrate another feature of the system. In the summer months, the water requirements are nearly two times as much as in January and December. This means that to make efficient use of the wells and to conserve water, the wells to be dug must be capable of being shut off when water is not required (assuming that the new wells will be artesian).

Step 5. Determine Lift and Total Volume Requirement

The next step of the conceptual design process is to determine lift and total volume requirements as a prerequisite to calculating the total hydraulic energy demand. Having an accurate measurement of the head is essential to size the system accurately, since the size of the PV array is

directly proportional to the head. In this case, depending on the location of the wells and the storage tanks, the head could vary from as low as zero (in the case of very good free-flowing wells) to perhaps 20 meters (if the storage tanks were located a long distance from the wells and/or the elevation was significantly higher than the wells. We will make the (somewhat arbitrary) assumption that the storage tanks are nearby and are elevated four meters. We will further assume that there is an additional one meter of head from the friction losses in the various water flow channels of the system. This is consistent with the data as illustrated in Exhibit 2-3.

Step 6. Determine Hydraulic Energy Requirements

Hydraulic energy requirements are calculated using the following formula:

$$\text{Hydraulic Energy (kWh/day)} = \frac{9.8 \times (\text{Volume}) \times (\text{Head})}{3600}$$

Where - Volume is expressed in cubic meters per day (760 m^3)

- Head is expressed in meters (5m)
- 9.8 and 3600 are constants to make the units consistent.

(see Appendix E for derivation of this formula)

Substituting the values into the formula:

$$\text{Hydraulic Energy} = \frac{(9.8)\ (760)\ (5)}{3600}$$

$$= 10.3 \text{ kWh/day}$$

Step 7. Select Type of Pump

The selection of the water pump and related subsystem(s) technologies is based on the total dynamic lift, in this case estimated to be 5 meters. Exhibit 5-5 shows that in the range of zero to 10 meters lift or system head, centrifugal pumps are the choice. Surface mounted centrifugal pumps are

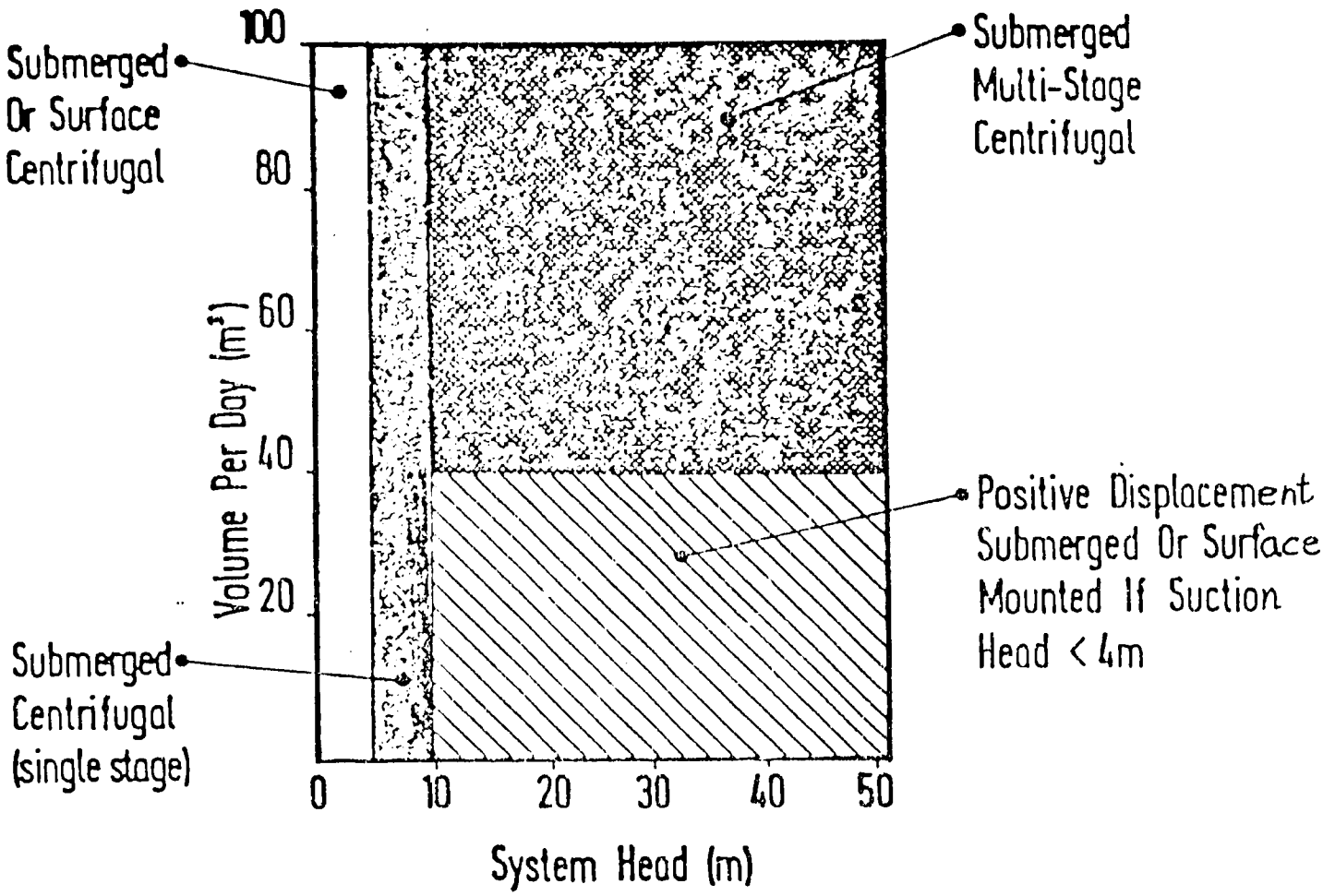


Exhibit 5-5. Pump Types Suitable for a Range of Pumping Applications

capable of handling suction lifts of up to 5 meters. Beyond 5 meters, a submerged centrifugal pump is required. In both cases the drive motor is mounted on the surface. A surface-mounted pump is the preferred system since any motor maintenance can be performed without extracting the pump motor from the well. Over the life of this pumping system, it is reasonable to assume more than one motor/pump set will be used. Therefore, as the water table drops it may be appropriate to use submersible pumps.

NOTE: It is absolutely critical that enough preliminary testing is done to give confidence that the proposed new wells do not draw down beyond five meters at the pumping rate necessary to provide the required amount of water.

Step 8. Estimate Subsystem(s) Operating Efficiency:

The input data used to estimate efficiency are as follows:

- Type of pump, i.e.-horizontal turbine, horizontal centrifugal, positive displacement (jack pump) or vertical turbine.
- Type of motor, AC or DC, brushless or brush motors

The guiding philosophy on this project is to use the simplest, most reliable system components. Therefore we recommend:

- A centrifugal pump because it performs best at low head and high volume. The pump will be located above ground.
- A DC motor to avoid the necessity of an inverter which have consistently caused problems in PV applications, especially in remote areas.
- A brush motor because it is a more proven design. Since the motor is located above ground it is relatively easy to replace brushes.
- A direct connection between the PV array and the pump with no battery storage.

The efficiency gains in using battery storage (constant power to the

motor) are usually outweighed by the cost and complexity of the control system (battery protection, pump auto start/stop, etc). Based on experience with this type of system, an overall efficiency of the pump/motor of 35% is assumed. (Ref 5-4).

Step 9. Calculate Daily Electrical Energy Demand

The daily electrical energy demand is calculated by dividing the hydraulic energy by the pump/motor efficiency.

Daily Electrical Energy Demand = Hydraulic Energy (from Step 6) divided by Pump/Motor Efficiency (from Step 8)

$$= \frac{10.3 \text{ kWh/day}}{0.35}$$

$$= 29.4 \text{ kWh/day}$$

Step 10. Size the PV Array

A first approximation of the PV array size is provided by the following formula (See Appendix F for derivation).

$$\text{PV Array Size} = \frac{\text{Load} + \text{Losses}}{(\text{Time})\ (\eta_{\text{Operating}})\ (\eta_{\text{P.C.}})}$$

Where:

PV Array Size	=	Rated Power at Standard Conditions at a given tilt angle (watts)
Time	=	No. of full sun hours equivalent (Hours)
η Operating	=	Efficiency factor that takes into account a derating because of temperature effects and wiring losses in the array field (dimensionless)
η P.C.	=	Efficiency that takes into account the losses associated with channeling power through the power conditioning equipment (dimensionless)
Load	=	Load (Watt) times duration (Hr) yielding kW-Hr

Losses = Miscellaneous Losses (Kw-Hr)

- The "Load + Losses," term has been calculated to be 29.4 KwHr (from Step 9)
- The number of sun hours equivalent = 7.0 for June, the design month (from Step 4)
- η Operating = 0.88 (From temperature effects and wiring losses)
- η P.C. = 0.90 (From manufacturer's data)

$$\text{PV Array Size} = \frac{29.4}{(7)\ (.88)\ (.90)}$$

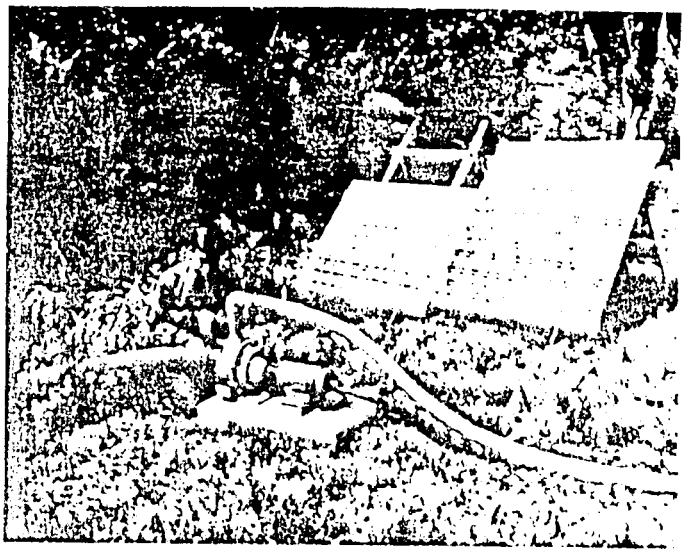
$$= 5.30 \text{ kw}$$

As was stated before, the preceding analysis is for a theoretical system. There is an inherent assumption that there is a single array, single pump, and single motor, all perfectly matched. These conditions do not exist in actual operation.

An alternative method of approximating the size of the PV array and number of pumps is to consult a manufacturer's literature for performance of commercially available, prepackaged PV pump systems. To illustrate this method, consider the performance as described in the Chronar/Tri-Solar data sheet, a copy of which is reproduced as Exhibit 5-6. If one considers the curve marked "MP 480" and then draws a horizontal line from 5 m on the Total Dynamic Head axis to the intersection of that line and then draws a vertical line to the flow rate (cubic meters/day) the flow rate is about 70 cubic meters per day. But the curve was drawn with an insolation of 6 kw hrs/day and 25°C temperature whereas the insolation in the Baharia Oasis in the design month of June is 7.0 kw hrs per day and the temperature is much higher. One can scale the flow up in proportion to the insolation by a factor of 7.0/6.0 and decrease the flow approximately 3% due to using a different temperature reference. In June (Exhibit 5-1) the ambient temperature is 32.2°C, which is 7.2°C above the 25°C reference listed in Exhibit 5-6. Power degradation is 0.4% per °C or

SOLAR POWERED LOW LIFT PUMP

Chronar TriSolar, Inc.
10 DeAngelo Drive
Bedford, MA 01730
(617) 275-1200



The Chronar TriSolar Low Lift Micro Irrigation Pump is a solar powered, surface mounted centrifugal pump that is available in two power ranges: 320 watts and 480 watts. These self priming, high efficiency pumping systems are suitable for situations with a total dynamic head (TDH) of up to 34 feet (10 meters), including a suction lift of up to 15 feet (4.5 meters). Depending on which model is employed, up to 21,000 U.S. gallons (80 cubic meters) per day will be delivered. The actual amount of water delivered, however, will depend on the geographical location of the pump site, the amount of sunlight available on a daily basis, and the actual head conditions.

description

The models MP 320 and MP 480 consist of two major components: a photovoltaic array that produces DC electricity and a pumpset which consists of a self-priming centrifugal pump, a permanent magnet DC motor, and an ON/OFF switch. In addition, this unit is supplied with other accessories: a suction hose with a foot valve, a discharge hose, hose adaptors, and fittings to connect the hoses to the pump. Hose clamps and a tool kit are also provided. As an option, a switch box can be supplied that has a low level cut-off switch that will turn the pump OFF if the water level in the well gets too low.

The pump is supplied with 8 or 12 PV modules, depending on the model number ordered. These modules are mounted on two portable subarrays with adjustable tilt angles. The pump and motor are directly coupled and mounted on a rigid steel basep'ate. The motor is covered to protect it from the elements and is completely weatherproof.

Exhibit 5-6

REPRESENTATIVE PUMP SYSTEM DESCRIPTION

specifications

Array	MP320	MP 480
• Number of panels	8	12
• Peak power (watts)	320	480
• Dimensions	5' x 4' (1.5 m x 1.2 m)	7' x 4' (2.1 m x 1.2 m)
• Weight	60 pounds (27 kg)	90 pounds (41 kg)
Motor Pumpset		
• Horse power	1/2	3/4
• Voltage	60	90
• Dimensions	12"W x 30"L x 14"H (30 cm x 76 cm x 36 cm)	12"W x 30"L x 14"H (30 cm x 76 cm x 36 cm)
• Weight	90 pounds (41kg)	95 pounds (43kg)

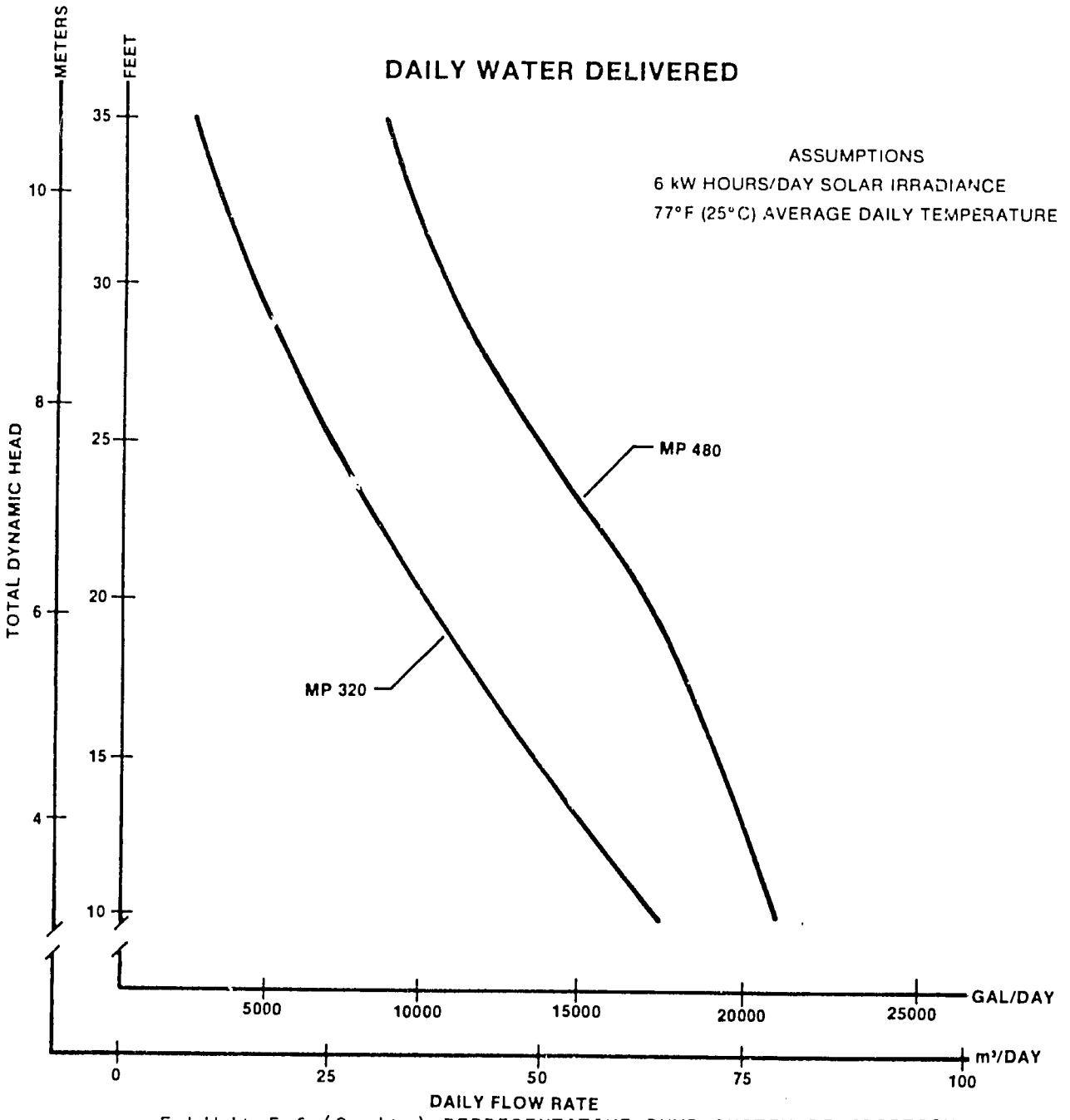


Exhibit 5-6 (Con't.) REPRESENTATIVE PUMP SYSTEM DESCRIPTION

2.88%. The corrected estimated flow rate is 79.2 cubic meters/day.

If there were 10 pumps of this size at the stated insolation and head, the flow rate would be 792 (10 x 79.2) cubic meters per day during the month of June. Given the uncertainty of the head, this is sufficiently accurate for a conceptual design. It is also interesting to compare this PV-pump array size with the estimation of a theoretical single large system in Step 10.

	Theoretical Single System	10 Individual Systems
Predicted Flow Rate (m^3/day)	760	79.2
Array Size (kW)	5.3	5.76
Flow Rate/kw (m^3/day/kw)	143.4	137.5

The total array size estimation is within 5%, indicating that the manufacturer's performance curves are reasonable.

5.2.3 Determination of Number of Wells

One of the stated requirements of this project is that there be at least two new wells and that each well not affect the existing well system (Appendix G). The placement of these wells is discussed in Section 5.2.4. As a matter of principle and to avoid possible damage to the water supply, the wells should be spread over as much area as possible and there should be as many wells as possible to avoid the drawdown of an individual well. In an effort to examine the sensitivity to cost of different options, several options are presented below.

During a field visit to the Baharia Oasis, the Bawiti City Council furnished the following guidance for well yields:

Well Size (dia.)	Depth	Production (artesian)
3-4 in. (8-10 cm)	100-150 meters	300 m^3/day
10 in. (25.4 cm)	200-300 meters	4500 m^3/day
6-20 in. (15-50 cm)	8000-1000 meters	4500 m^3/day

Power well drilling costs in Egypt are not readily available but one data point in the literature is published by the U.S. National Water Well Association for 1979. (Ref 5-5) These are:

Casing Size	Drilling Cost $/m	Casing Cost $/m	Total Well Cost $/m
4 in. (10.2 cm)	23	14	37
6 in. (15.2 cm)	28	21	49
8 in. (20.3 cm)	42	28	70
10 in. (25.4 cm)	64	61	125

If we assume that there will be 10 pumping systems, and the wells are 150 m deep, the following cost matrix for drilling can be derived:
Required

Number of Wells	Casing inside dia (cm)	Well Drilling Cost ($)	Peak Production per well m^3/day
5	10.2	27,750	158
4	15.2	29,400	198
3	15.2	22,050	253
2	20.3	21,000	380

According to the sparse data received on empirical performance of artesian wells in this area, all of the wells postulated will probably produce enough water in the near term. But there is also the possibility that the larger capacity wells could produce considerable drawdown of neighboring wells. Because the cost of five - 10.2 cm wells is not significantly greater than fewer larger diameter wells, we recommend that there be five wells of approximately 10.2 cm diameter. These costs of course must be verified in Egypt.

5.2.4 Well Location Determination

The decision of how many and where the wells are to be located is

d the scope of this document. To complete this task, many factors must

o-sidered:

- o Technical factors such as size and condition of the aquifer, nearness to other wells, and drawdown characteristics (of the new wells and the existing wells.)
- o Sociological factors such as nearness to present or planned farmland, desires of the people in the village of El-Ezz, and the desires of the Bawiti City Council.
- o Economic factors, specifically what amount of money can be spent, and by whom, to drill the wells.

The location, topography, elevation, and distances from the wells to each ther, to the fields and to the village, must be known before an accurate conceptual design can be completed. The only data available are a sketch from memory (of the site representative) on which to base a design. Exhibit 1-1 is a recreation of that sketch with representation of possible well locations on it.

5.2.5 Calculation of Storage Tank Size

It is stated in Appendix G that the size of the storage tank should be big enough so that water for two hours' irrigation can be done before the sun gets strong enough to start the pumps. If one assumes that irrigation flow takes place for 6 hours per day (6 a.m. to noon), then the storage requirement would be 250 cubic meters (1/3 of 750 cubic meters). However, we recommend that the storage should be one day's production or 750 cubic meters (plus the separate 10-cubic-meter tank for domestic use). This would provide the people of the village greater flexibility as to when to irrigate and would provide a safety margin should there be a cessation of pumping due to weather, equipment breakdown, or other reasons. We suggest that the tanks be constructed of concrete of similar construction techniques as that of the tanks at El Kasr Central, which was visited as part of the Field Test #8 site visit.

We do not have enough data to make the determination of where the 10 cubic meter tank (to serve the village potable water needs) should be located. If the location of the village is at a higher elevation than that of the other bigger irrigation tanks, then a small PV-powered pump could be added to the field test. This pump would be used to pump water to the smaller tank in the village.

Exhibit 5-6a is a representation of the suggested storage tank system.

5.2.6 Description of Recommended System

The fixed PV-Powered irrigation pumping system should be made up of the following:

- 5 wells (approximately 10.2 cm diameter)
- 10 - 576 watt array system (2 per well)
- Each system capable of pumping approximately 79 cubic meters/day in June
- Wells must be capped.

5.3 Portable Water Pumping Systems

5.3.1 Methodology

The second type of pumping system for Field Test #7 is a portable pumping system. Two of these are required. Each pump is to be capable of irrigating one feddan per day where the water source is a low head well or irrigation ditch.

Using the same assumptions on water needs in the most demanding month (June), the required flow is 25 cubic meters per day. The total dynamic head is probably considerably less than 5 meters; three meters would be a good approximation assuming the irrigated areas are reasonably close to the water

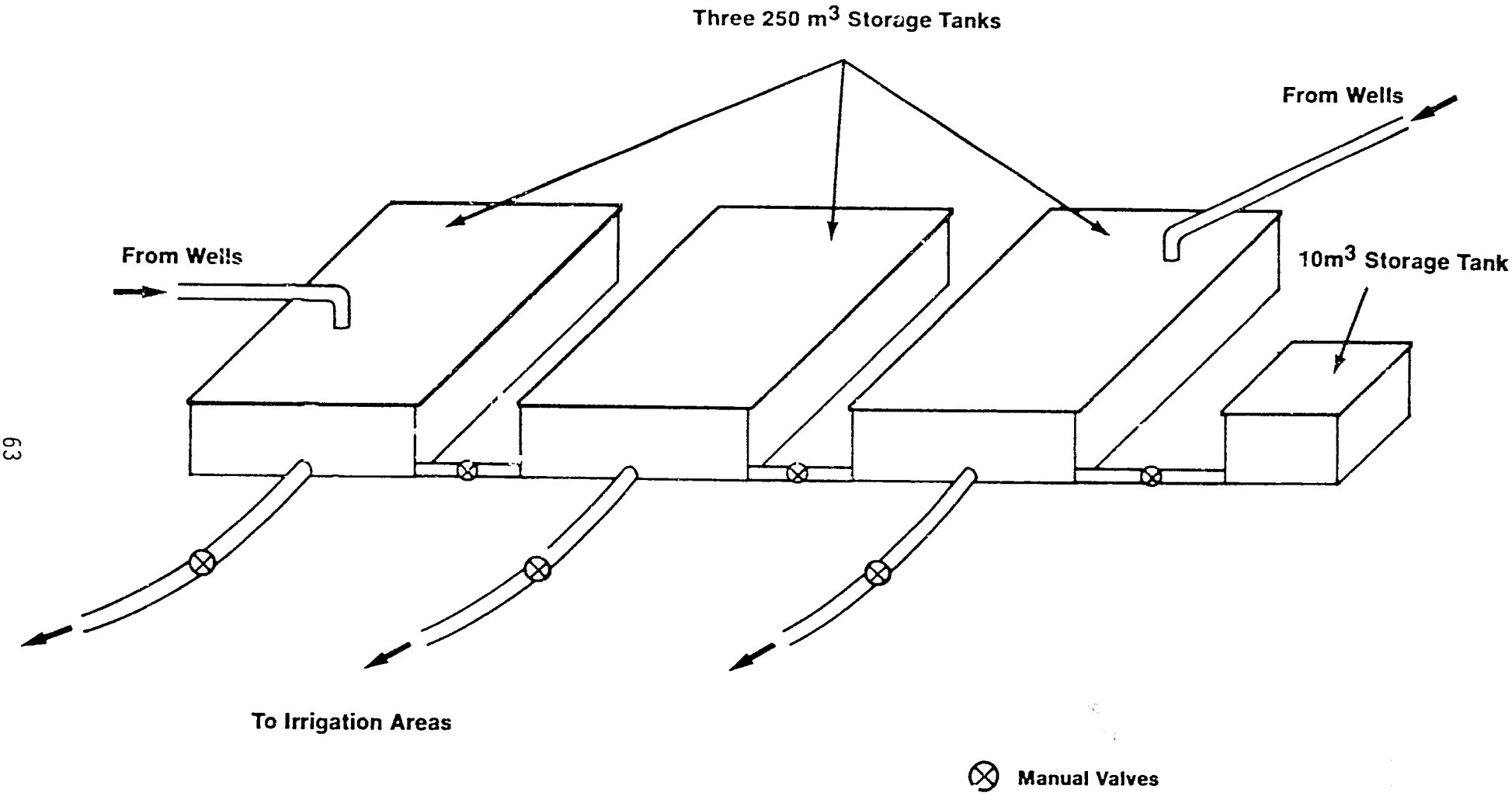


Exhibit 5-6a

REPRESENTATIVE STORAGE TANK SYSTEM

source. Using the same analytical technique as the previous section would lead to a theoretical array size of 105 watts.

However, we recommend that the pump system be of the same size and configuration as the pumping systems described in the previous section. This would result in a somewhat oversized system for the stated requirements. However the advantage of making them functionally interchangeable with the other systems or components and avoiding the problem of two sets of spare parts and components is worth the added expense.

To make the systems portable, we recommend that the system be mounted on a trailer which could be towed. The array could be mounted on the trailer by a simple collapsible structure which would lie flat on the trailer when not in use and could be pointed toward the sun to get maximum insolation. The array could also be lifted from the trailer and carried to the pumping site when access is not good.

The pump, motor, controller, and associated wiring and plumbing would also be hauled on the trailer. Exhibit 5-7 is a representation of such a trailer. Several US government organizations have sponsored similar developments in the past, and several approaches to this design problem were discussed with the Field Test #7 trainees in September, 1986, during their training in the US.

5.3.2 System Description

Two identical portable systems are recommended. Each system should have the following features:

- Array, pump set, and control package identical to the fixed pump array hardware
- Each system mounted on a flat bed trailer
- Trailer should be designed to be towed by oxen, a truck or by people.

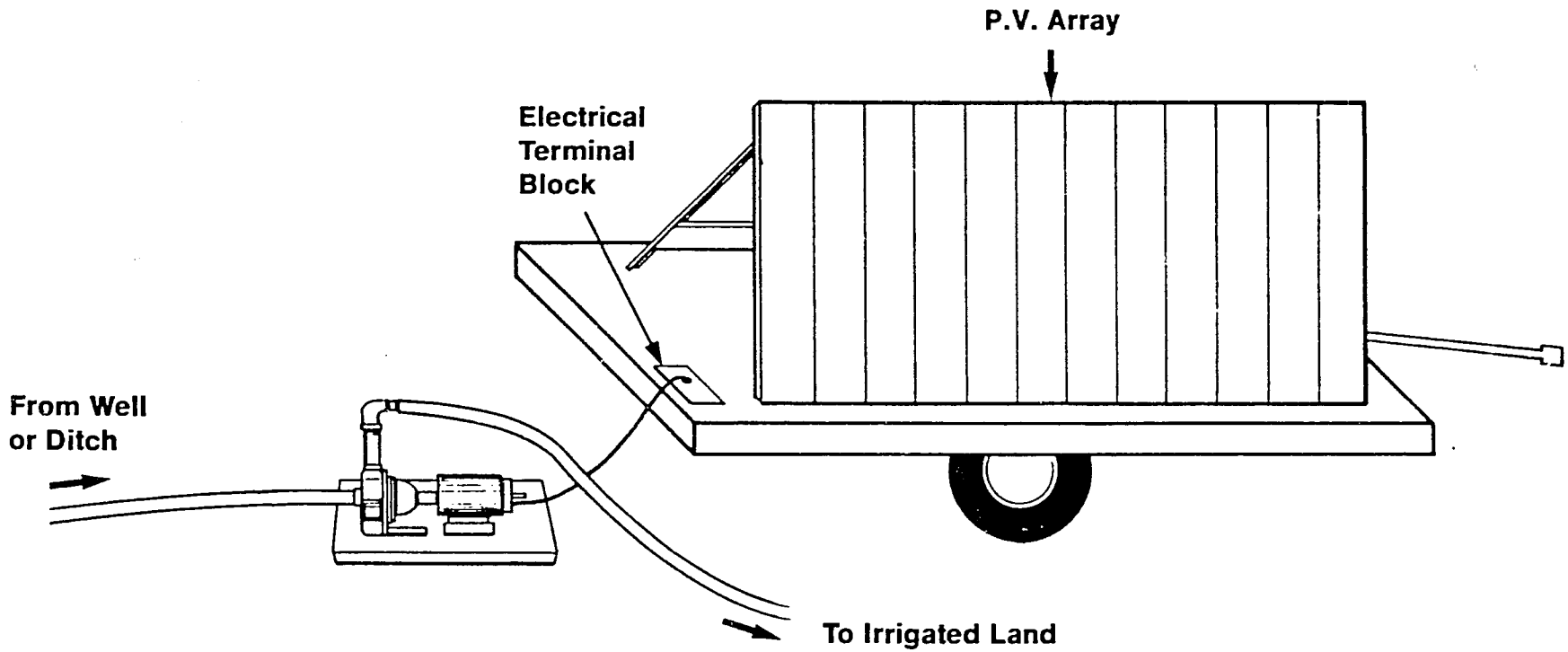


Exhibit 5-7

SKETCH OF SUGGESTED PORTABLE PUMPING SYSTEM

5.4 House Lighting Systems

Appendix G indicates that the household electrical loads are to be 1000 watt-hours per day and consist entirely of lights. Further, the system is to be 200 V AC, 50 Hz.

Previously, in the Draft-for-Comment AR/CD FT #7 document, we had recommended that there be two different village power systems, one centralized (which was to be AC), and one decentralized (which was to be DC). The reasons for recommending DC on the decentralized version are:

- Efficiency - no power is lost in being inverted and increased to 220 V.
- Reliability - Inverters in remote applications have not performed as reliably as desired.
- Better commercial availability of equipment to appliances and loads which until recently were not available in low voltage DC models.

On the other hand, 220 V, 50 Hz AC loads are readily available and standard in Egypt. There should never be an availability problem. The potential reliability problem with inverters can be addressed by having an ample number of spares as part of the procurement package and having people trained on how to replace them should the need arise. The decision made by EEA was to use the AC option and avoid a potential supply problem with loads.

The conceptual design developed in this document is fully responsive to the directions contained in Appendix G. However, we caution that the size of the system (photovoltaic array and battery storage) is not capable of handling sustained use of appliances and other additional loads beyond and the 1000 watt-hours specified.

5.4.1 Methodology

The conceptual design procedure used for the house PV lighting systems planned for this field test is provided in Exhibit 5-8.

EXHIBIT 5-8: Conceptual Design Methodology for Decentralized Power Systems

1. Determine Average Load Levels and Duration
2. Determine Peak Loads and Times
3. Determine Daily Insolation Levels and Select the Design Month
4. Size Battery
5. Specify Power Conditioning Equipment
6. Size the PV Array

Step 1. Determine Average Levels and Duration

Loads have been defined as 1000 watt-hours per day and would consist of 2-20 watt and 2-40 watt fluorescent lights with fixtures. The system is to be 50 Hz AC with 220 V outlets.

Step 2. Determine Peak Loads and Times

With the loads of 1000 watt hours per day consisting of light bulbs, a worst (reasonable) case scenario would be 10 hours of continuous use with a 100 watt bulb. However peak demand is estimated to be 50% more for the month in which Ramadan occurs, (which could coincide with the worst insolation month, January) making the worst case load 1500 watt hours daily.

Step 3. Determine Daily Insolation Levels and Select the Design Month

Exhibit 5-1 illustrates the average daily insolation. If the array is designed for the worst case insolation, we would use the month of January which has a plane-of-array insolation of 6.1 kWh/m^2.

Step 4. Size the Battery

To size a battery in an optimum manner, one must make some engineering judgement as to the reliability required, the number of days that the sun is likely not to shine and the acceptable cost.

In general, the larger the battery capacity and size of the PV array, the more reliable the system. The larger the system, obviously the more

expensive the system. We make the following engineering recommendations:

- o During the worst case month, there may be little or no insolation for three days so that there can be little recharging of the battery. The usable capacity of the battery must be at least 3 x 1500 watt-hours or 4500 watt-hours.

- o We want a type of battery that will require little or no maintenance. Such a battery (the GNB Absolyte) has been in use for several years in many applications. One of its more attractive features is that 80% of its energy can be discharged before recharging with no appreciable loss of performance.

- o We assume that the output voltage of the battery is nominally 12 volts. Therefore the useful output capacity must be 4500 watt-hours/12 Volts or 375 amp hours. Considering an 80% depth of discharge the battery amp-hour capacity must be 375/0.8 or 469 amp-hours. The discharge rate tolerance of the battery must be 375 amp-hours per 30 hours or 12.75 amps.

Having made those decisions and calculations, one can then consult the battery manufacturer's literature to select an appropriate battery. One such battery is the GNB Absolyte 6-75A13 which has the following characteristics:

o	Capacity	470 Amp-hours (at c/8 discharge rate)
o	Nominal Output	12 Volts
o	Weight	220 Kilograms
o	Length	89.3 cm
o	Width	21.8 cm
o	Height	62.3 cm

Step 5. <u>Specify Power Conditioning Equipment</u>

Power conditioning equipment in this application consists of a battery charge controller and an inverter. The requirements for the charge controller is that it be capable of handling 12-18 volts input and have cut-off switches when the battery becomes fully charged. Many companies have battery chargers which are compatible with these requirements.

The choice of an inverter must be carefully considered because no American inverter manufacturers have much experience in 220V-50 Hz output inverters, which is required. Audio noise should not be annoying. One such piece of equipment is the Trace Model 1512E, which will provide 100 watts (the present load) at 90+% efficiency. It also has enough capability to handle additional loads should they be added to the system later.

Step 6. Size the PV Array

The same formula as in Section 5.2 is used:

$$\text{PV Array Size} = \frac{\text{Load} + \text{Losses}}{(\text{Time}) \times (\eta\ \text{Operating}) \times (\eta\ \text{P.C.})}$$

Where:

PV Array Size	=	Rated Power at Standard Conditions at a given tilt angle (watts)
Time	=	No. of full sun hours equivalent (Hours)
η Operating	=	Efficiency factor that takes into account a derating because of temperature effects and wiring losses in the array field (dimensionless)
η P.C.	=	Efficiency that takes into account the losses associated with channeling power through the power conditioning equipment (dimensionless)
Load	=	Load (Watt) times duration (Hr) yields Kw-Hr
Losses	=	Miscellaneous Losses (Kw-Hr)

- The "Load" is assumed to be 1500 watt-hours
- The "Losses" term is 20% of the "load" term or 300 watt-hours. This is a conservative estimate which assumes that all energy produced by the PV array goes through the battery
- The number of sun hours equivalent = 6.0 for January, the design month
- η Operating = 0.88 From temperature effects and wiring losses
- η P.C. = 0.81 - assumes 90% inverter efficiency and 90% P.C. efficiency

$$\text{PV Array Size} = \frac{1500 + 300}{(6)\ (.88)\ (.81)}$$

$$= 420 \text{ Watts}$$

Assume that we use the same sized PV module as is recommended for the pumping system (48 watts). Nine modules would provide 432 watts peak.

5.4.2 System Description

Summarizing, each house lighting system consists of:

- Nine 48-watt PV modules
- One 470 Amp-hour, 12 V battery
- One charge controller
- One inverter capable of handling nominal 12 Volt input and inverting it to 220 Volt, 3 Phase AC, 50 Hz.
- Ample spares - we recommend 20 percent.

A circuit diagram for the photovoltaic array is shown in Exhibit 5-9. A sketch of the physical arrangement is shown in Exhibit 5-10.

5.5 Street Lighting

The fourth type of application for Field Test #7 is that of street lighting in and near the village of El Ezz. Ten identical street lights are to be purchased.

For economy, we recommend that a prepackaged system be bought which consists of a PV module, battery, charge controller, a high efficiency DC light, mounting hardware, and associated wiring and connectors. Many American companies have competitively priced packages consisting of those components. One such system is shown in Exhibit 5-11. We recommend that the two PV modules be of the same model as the modules in the other applications in Field Test #7. We further recommend that these systems not be installed by the contractor but by the people of the village charged with administration of the system. These

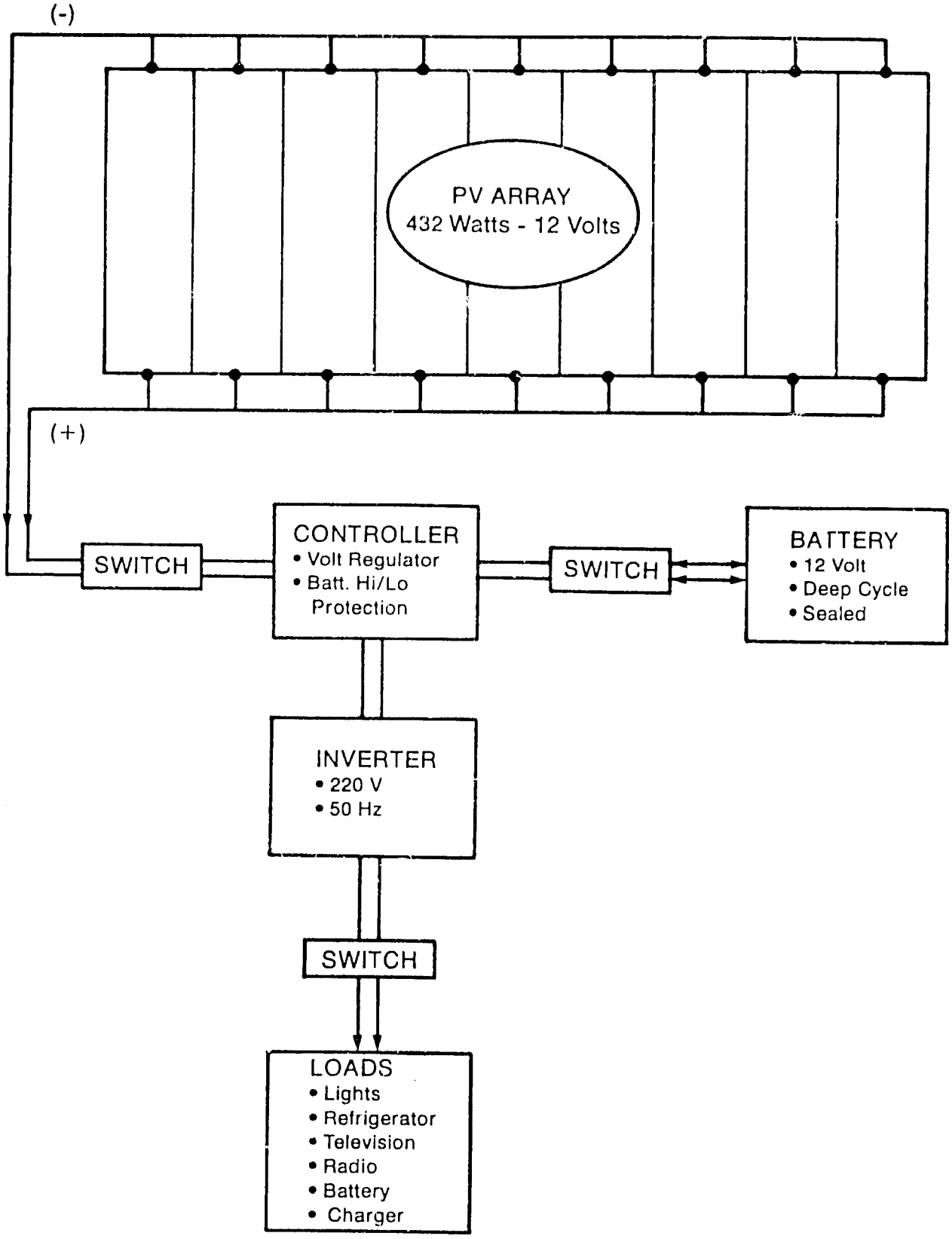


Exhibit 5-9
CIRCUIT DIAGRAM OF HOUSE LIGHTING SYSTEM

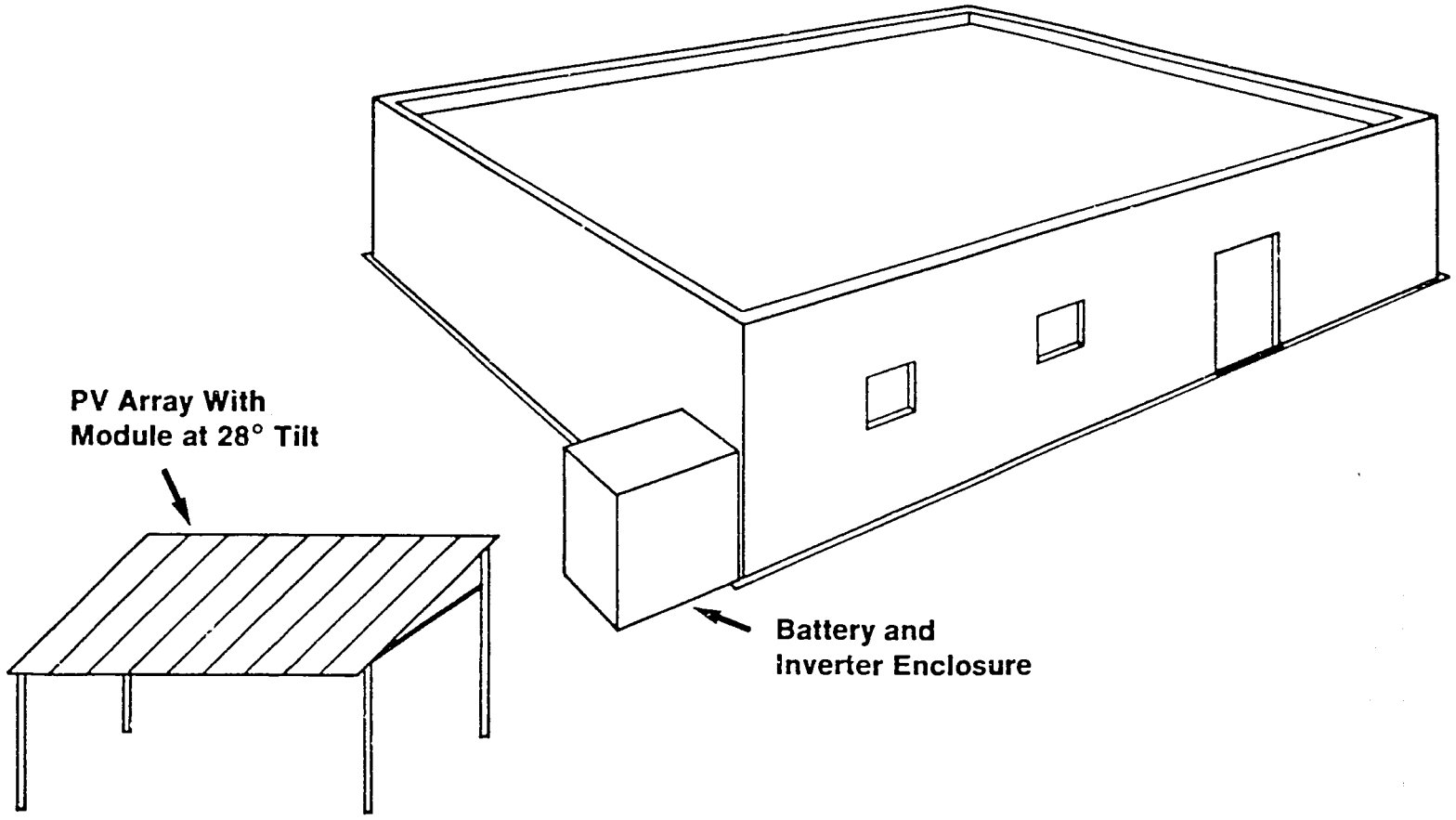
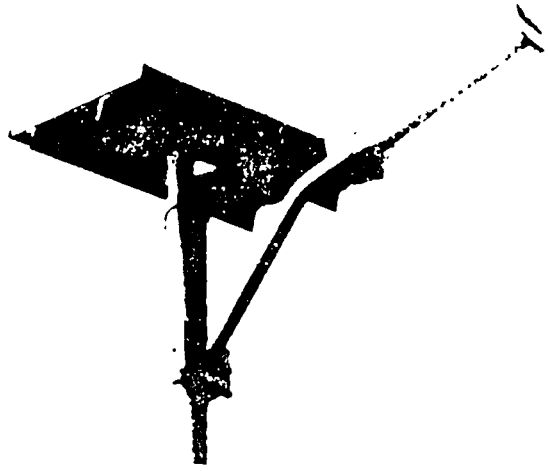


Exhibit 5-10

SKETCH OF REPRESENTATIVE HOUSE IN EL-EZZ VILLAGE WITH PV ARRAY MOUNTED OUTSIDE HOUSE

SOLAR POWERED FLUORESCENT OUTDOOR LIGHT

Chronar TriSolar, Inc.
10 DeAngelo Drive
Bedford, MA 01730
(617) 275-1200



Chronar TriSolar now offers a solar powered fluorescent lighting system which uses the sun to charge a sealed, maintenance-free battery during the day. At dusk, the system draws on the power of the battery to illuminate the lights from between 6 hours and the entire night, depending on the model employed. This rugged, reliable package is ideal for lighting bus stops, parking lots, and recreation areas, resulting in enhanced access and better security. The fluorescent lighting package comes with single or dual 2 foot (0.61 m) 1350 lumen bulbs, one to three 40 watt photovoltaic panels and one or two 100 amp hour batteries. Self-contained and maintenance-free, these dependable units are easily installed with no trenching and conduiting, sharply minimizing installation costs that come with conventional utility powered lights. Unlike other systems, Chronar TriSolar's Solar Powered Fluorescent Lights have only a one time cost, completely eliminating electrical bills and power line service and maintenance fees.

description

The systems are mounted onto a steel pole that is set into the ground. The batteries and electronic controls are placed into a weatherproof enclosure that protects the components against vandalism and prevents battery damage that may result from water leakage. Included in the package are:

Solar Panels These sturdy, protected modules change sunlight into electricity, safely, silently, and efficiently.

Battery Charge Regulator This is an all-solid state, high reliability regulator using MOSFET technology. It will disconnect the battery at twenty percent state of charge and protect against overcharge.

Light Sensitive Switch A light sensor is provided with circuitry that automatically turns the light on at dusk and shuts the light off at sunrise. An optional timer "is available" that can turn off one or both bulbs after a predetermined time period.

Steel Pole and Arm The standard pole is 15 feet (4½ m) high. Longer or shorter mounting poles are also available. Consult the factory for additional choices. An extension arm to support the lamp is standard and optional roof mounting and wall mounting kits are also available.

Exhibit 5-11

REPRESENTATIVE STREET LIGHTING SYSTEM

specifications

PV Panels	40 watt nominal peak power.
Batteries	90 amp/hour completely sealed, maintenance-free battery.
Light	Exterior street/security light fixture with automatic photoelectric cell and timer. High efficiency fluorescent bulbs using double coated phosphor technology. are used. These bulbs are 2 feet (0.61 m) in length, 1 inch (2.54 cm) in diameter and produce 1350 initial lumens and 1215 average lumens at 17 watts.
Regulator	All solid state battery regulator; battery low voltage protective disconnect relay; overvoltage series switching disconnect.
Pole	Supplied by the customer or Chronar TriSolar, this includes a steel pole, base mounting flange, and light hanging extension.
Miscellaneous	All fittings and structure to mount PV panels and light to pole; battery enclosure with mounting structure to pole (lockable); all wire, connectors, and switches. Optional mounting kits are available for roof or wall mounting.

performance

MODEL	DESCRIPTION	TYPICAL PERFORMANCE
FL 111	Single Bulb Fixture One PV Panel One Battery	6 hours/night
FL 122	Single Bulb Fixture Two PV Panels Two Batteries	12 Hours/night
FL 222	Dual Bulb Fixture Two PV Panels Two Batteries	6 Hours/night with both bulbs **OR** 3 hours/night both bulbs plus 6 additional hours/night with one bulb (add "S" after model number).
FL 233	Dual Bulb Fixture Three PV Panels Three Batteries	9 Hours/night with both bulbs **OR** 5 hours/night both bulbs plus 8 additional hours/night with one bulb (add "S" after model number)

Mounting

Add proper letter after model number

P = Pole and arm assembly
R = Roof mounting kit
W = Wall mounting kit

The number of hours of light operation is dependent on location and level of sunshine. Average performance given above is based on five hours/day of peak sunshine. Winter months will be less, summer months will be more.

Exhibit 5-11 (Con't.) REPRESENTATIVE STREET LIGHTING SYSTEM

systems are an excellent learning tool to teach the basics of what a PV system is and the basics of connecting them. They are low voltage and low power (and therefore safe).

5.6 System Monitoring and Instrumentation Requirements

There are four distinctly different types of systems in Field Test #7, all of which have multiple independent systems. This situation does not lend itself to extensive instrumentation.

We recommend the following:

- Fixed Pumping Application: No permanent instrumentation. Periodically (at least every two months), personnel from EEA should travel to Baharia to inspect the system and complete a performance measurement. Data that should be gathered is:
  - the flow rates per day by use of accumulating flow meters
  - the depth of the well water surface
  - the performance of a representative number of PV arrays using a portable I-V curve tracer.
- Portable Pumping System: No instrumentation.
- House Lighting: We recommend that each house have a watt-meter which should be read periodically (once per week). It is impractical and too expensive to instrument each house. However we recommend that one system be instrumented to gather the following data:

Parameter	Channel Type*	Output Interval
Array Power (kW)	P	10 min.
Array Current (Amps)	A	10 min.
Array Voltage (volts)	A	10 min.
Ref. Cell Temp. (^{o}C)	A	10 min.
Battery Charge and Discharge Current (Amps)	A	10 min.
Battery Voltage (volts)	A	10 min.
Battery Temp. (^{o}C)	A	10 min.

* P - Pulse
A - Analog

- Street Lighting: No instrumentation recommended.

The most pressing need is to get accurate insolation data. It would be suitable if an instrument could be placed in the general vicinity of the village to get accurate insolation data. The data on which this conceptual design is built are based on an estimate of extrapolated data from locations several hundreds of kilometers distant.

6.0 PROJECT MANAGEMENT

6.1 Organization

This field test consists of demonstrating and evaluating the performance of four different types of photovoltaic systems in El Ezz. Coordinated and conscientious field management of these demonstrations is critical to achieving the overall REFT objectives for this field test. A field project management organization should be set up to handle this field test. A field project management organization should be set up to handle these field tests. It should be capable of performing the following functions:

- o overall field project management
- o technical support
- o training
- o data collection.

Overall project Management of field activities requires active communication, monitoring and data management with REFT personnel in Cairo. It also requires a small staff of field technicians to provide technical support to the village, for each system. This support should be available full time. Concurrent with this technical support function, system performance monitoring and data collection can be performed. Considerations should be given to developing a strict monitoring program and reporting format for quantitative and qualitative data collections. The assistance of an experienced social/economic analyst would be advisable.

A field project team is recommended to consist of an overall project manager and on or two field technicians who are assigned to monitoring and technical support and data collection responsibilities for each village site.

6.2 Training

Training requirements for the field project team should consist of design, operation, and maintenance of all the specific PV systems, pumping

equipment, batteries, controls and loads involved with the field test. Fully detailed repair manuals and parts lists should be supplied. Training should be formal and hands on, conducted with the actual equipment for the field test. Field technicians qualifications should be four years as an electrical technician and two years for a mechanical technician.

6.3 Technical Support

Backup technical support to the field project team should be provided by the contractor for the system. Provision must be made for direct communication and responsive technical support. Spare replacement pumps/ motors, batteries inverters, and loads should be provided. Provisions for maintaining, parts inventory and control, and long term storage of spare parts must be developed.

7.0 FT #7 ESTIMATED CAPITAL COST AND AMOUNT OF PV POWER REQUIRED

We estimate the cost of the system described in Section 5.0 as follows (all figures in U.S. Dollars):

o Fixed Pumping Station (assuming using the packaged system described in Section 5.2)	
10 systems @ $6,400 ea.	64,000
o Portable Pumping Systems	
2 systems @ $8,000 ea.	16,000
o Home Lighting Systems	
9 48-watt PV modules	4,320
1 Controller	425
1 Inverter	2,000
1 12 V Battery - 370 Amp Hours	666
Structure for Array Support	432
Assorted wire, fasteners, receptacles, lights	150
Total (1 System)	7,993
20 systems @ $7,993 ea.	159,860
o Street Lighting Systems	
10 systems @ $ 1670 ea.	16,700
SUBTOTAL	256,560
SPARE PARTS @ 20%	51,312
	307,872

It should be emphasized that this cost does not take into account other cost factors such as:

- o Well Drilling
- o Training
- o Contingency Costs for Working Overseas

o Reservoirs (tanks) for the Fixed Pumping Station.

The amount of PV peak power (peak watts) is:

Fixed Pumping	5,760
Portable Pumping	1,152
Home Lighting Systems	8,640
Street Lighting Systems	960
Spares	3,302
Total	19,814

APPENDIX A

Baharia Oasis Data

Data about El-Bahriyah

Oasis

El-Bahriyah oasis is located at the south west of Cairo between 27.5°, 28.5° latitude.

The water can be found in three different layers as follows:

1). At the depth of 100 - 150 meter, with discharge rate of 300^3/day. The diameter of this type of wells is about 3-4 inches and they have long life time.

2). At the depth of 200 - 300 meter, with discharge rate of 4500 m^3/day. The diameter of this type of wells is about 10", and its life time is about 3-5 years.

3). At the depth of 800 - 1000 meter, with discharge rate of 4500 m3/day. The diameter of this type of wells is about 6-20, and its life time is about 15 years.

- The amount of water required per feddan is 20 m^3/day in winter and 25 m^3/day in summer and the only method of irrigation used is the flood method.

- El-Haiz region consists of 9 villages and only later changed one village of them will be chosen to implement the project in it.

- The number of wells in El Haiz region is 84 well which are digged manually.

- The area of the agricultural area El-Haiz region is 514 feddan, and there is about 8500 feddan which is suitable for agriculture.

APPENDIX B

Selected PV Decentralized Power Projects

(Reference: Evaluation of International Photovoltaic Projects, Volume II: Technical Report, Meridian Corporation, May 1986)

Papua New Guinea

The field operating experience with PV systems in rural applications in Papua New Guinea has provided important insight into technical and financial aspects of PV lighting systems. Charge controllers were previously found to be complex in circuit design and operation and were unreliable. In 1980, as a result of Papua New Guinea field experience, fully "tropicalized" charge controllers were made available and have since been proven reliable. For safety and reliability reasons, a policy was adopted to use 12-volt DC PV lighting systems for village and government patrol post lighting. As to the quality of lighting, a 20-watt fluorescent bulb provides a light intensity of 100 lux at one meter below the lamp. A kerosene pressure lamp provides 12 lux, measured one meter below the lamp and outside the lamp's shadow. In addition to these obvious improvements in quality, the high cost of kerosene (about $1/liter) result in paybacks of from two-to-four years for simple PV lighting kits.

A number of PV systems have been installed in Papua New Guinea for communications, lighting, water pumping, and medical refrigeration. The total installed capacity in 1982 was approximately 50 kW. Over half of the amount was for telecommunications systems. The remaining systems were for mission radios and lights, mobile radios, village water pumping, and village house lighting. The potential for village house lighting systems over the next 10 years was estimated at 500,000 single module units (35 watts each), or 17.5 megawatts.

In related work, the Appropriate Technology Development Institute of the University of Technology in Lae, Papua New Guinea has started testing fluorescent tube "lanterns" powered by rechargeable Ni-Cad batteries. The lanterns are designed to look like their kerosene counterparts but to be

charged by PV. A photo is provided in Exhibit 6-3.

PV Versus Kerosene Lighting - Papua New Guinea

A survey was conducted among 30 village houses to assess the cost components of kerosene-fueled lighting as experienced in rural villages. The cost and performance of a comparable PV lighting system were analyzed over a 5-year period.

A typical household was found to use two kerosene powered lights, a hurricane lamp and a pressurized lamp. The cost of operating these lamps was found to be 196 Kina (1 Kina=$1.34) for the first year. A 5-year expenditure of 817 Kina could be anticipated, using a 10% discount rate.

The comparative PV system was a single ARCO panel (ASI 16-2000), a Delco 2000 battery, a regulator and two 20-watt fluorescent lamps. It was capable of delivering 160 watt-hours/day. The array was guaranteed for five years and the batteries for three years. The installed cost of the PV system in 1981 was 655 Kina.

The following excerpts were taken directly from the reference:

> ...the PVC kit is less expensive to operate over a 5-year period. It would take under five years to recover its cost through savings on kerosene lighting. Undoubtedly this may be too long a period for a villager to pay for a commodity which does not in return derive an income for him, with unknown performance and reliability. However costs alone should not be used to determine the favorability of either of the lighting systems. Hence other comparative criteria are taken into account.
>
> Quality of Lighting
> ...with the PVC lighting quality at least five times better than the kerosene light there is reason to pay extra money....
>
> Initial Lighting and Convenience
> ...the PVC kit merely provides light at the flick of the switch. For the kerosene pressure lamp it takes at least five minutes to refuel the tank, clean the glass and then to actually light it....
>
> ...the costs and benefits are compared [and] it is clear that benefits out-weigh the costs. Thus from a national point of view, the replacement of kerosene lighting of the type described with a PVC kit and hurricane lighting is worthwhile,

although the high capital requirement for the PVC kit makes it unlikely that many people will take up the PVC option.

The reference suggests that the government should finance and encourage lending institutions in Papua New Guinea to provide loan opportunities to customers willing to purchase PV kits.

Zimbabwe

A 1983 report by PTA Consulting Services of Harare, Zimbabwe addressed the economic viability of PV for water pumping and lighting. A comparison is made between lighting by candles, gas, or kerosene and a single PV module, battery and two fluorescent lamps (40 watts each). The cost to a family for conventional lighting was between $24 and $144 per year depending on the affluence of the residents. The capital cost of the PV system was $660. Portability of the lamps was stressed as an important design parameter. Six-to-seven year payback periods were noted. Another comparison was made between a 500-watt petrol generator and PV system to supply equal amounts of lighting. The capital cost of $2000 for the PV system was compared to the $550 initial cost and $975 annual running cost of a petrol generator. Payback of less than two years was calculated.

The report does not provide sufficient detail for an analytical critique. However, it is probable that the operating assumptions used for the petrol generator relate more to actual conditions than to ideal.

Mali School Lighting

In November 1980, a classroom received PV-powered fluorescent lighting for use during evening classes. The competing alternative is gas lamps. PV has performed well and with little maintenance; however, the reference stated that despite the risks of bottled gas, the use of PV could only be regarded as an interesting experience. The conclusion reached was that the use of PV cannot be developed further unless there is a substantial reduction in the cost

of systems and/or a substantial increase in the budget devoted to rural education.

Traffic Lighting - United Arab Emirates

Twenty-one PV-powered street lights and a high-mast, traffic-circle light were installed in June 1983 in Dubai, United Arab Emirates by Mobil Solar Energy Corporation. Each street light consists of a 20-watt fluorescent tube, two 35-watt modules and a 12-VDC ballast. The high mast light consists of eight 400-W, high-pressure sodium vapor (HPS) lamps powered by a 15-kW array.

During the design of the street lights, five commercially available tubes were tested. The test results showed large differences in efficiency (lumens per watt). The most efficient ballast was chosen. The customer has been pleasantly surprised at the illumination delivered by the 20-W fluorescent systems. The light level is sufficient to read a newspaper while standing on the roadway, 18 feet beneath the lamps. Through the first 10 months of operation, the street lighting performed reliably.

There were initial problems with the HPS light because of the inherent difficulty with operating HPS lamps with modified square-wave inverters. The solution was to use a ferroresonant inverter at 77% efficiency compared to a 90% efficient, modified square-wave inverter. Development of high-efficiency, high-power, DC ballasts for these lamps was mentioned as vital to optimizing these PV lighting systems.

French Polynesia

The activity in PV applications in French Polynesia is significant. Over 1000 home power systems have been installed to provide lighting, television, and fans for individual houses. The efforts are supported by the French Atomic Energy Commission (CEA), the French Agency for Energy Management (AFME) and the Government of French Polynesia. The program in which systems

are being provided is similar to that practiced worldwide for rural electrification--subsidization. Studies as long ago as 1980 showed that it would be more cost-effective to support the introduction of PV power systems than to extend the grid.

A typical system consists of three 13-watt lights, an 80-watt television, a fan, and a small refrigerator. The cost of the system is approximately 17,600 Ff ($2000), including taxes. The modules are 50 percent subsidized by the program. End-users can pay the balance up-front or over a 5-year period at 9 percent interest. The conclusions of the recent work are that PV is economically justified where the user is more than 200 meters from the grid. By 1982, 50 kW (representing 300 huts) had been installed under this program. Another 120 kW were expected in 1983, representing 25 percent of French PV production at that time. The South Pacific Commission was encouraged by this program and has proposed the development of such a rural electrification scheme throughout the South Pacific.

APPENDIX C

Selected PV Centralized Power Projects

(Reference: Evaluation of International Photovoltaic Projects, Volume II: Technical Report, Meridian Corporation, May 1986)

Tunisia

Significant multi-use projects have been performed by NASA-Lewis Research Center over the last two years. Included in these is a 27-kWp system in Tunisia. This village electrification project of PV, wind, and solar heating has been operating since February 1983. The PV system consists of a 29-kW, 220-volt, 50-Hz system to serve public and commercial sectors of a village of 120 persons. Additionally, a 1.4-kW remote farm house system for lighting, R/F, TV and radio and two 1.4-kW drip irrigation systems were installed. Operation and evaluation is the responsibility of the Societe Tunisienne de L'Electricite et du Gas (STEG). There is very little instrumentation included, although there are kilowatt-hour meters on the system and for individual users. Users are billed for specific consumption. Project participants believe that STEG has been recording basic production data.

The 1-kW inverter in the farm house system has had numerous problems, and extensive time was required to effect repairs. The village system inverter experienced a failure brought on by what appeared to have been improper switch sequencing during manual start-up. Some array wiring has deteriorated due to abrasion and sunlight damage. It is believed that the wrong wire sheathing was specified or procured.

Gabon and the Marshall Islands

NASA-Lewis Research Center also managed the 8-kWp, 120-VDC village electrification system in the Marshall Islands on Utirik Atoll and the series of 17 separate community service DC systems for 4 villages in Gabon. The Gabonese community service systems for each village include a water pump (0.7 - 3.2 kWp), a school system (560 Wp), community light (80 Wp), and a health dispensary (640 Wp). The Utirik Atoll system and the Gabon systems became operational in 1984 and 1985, respectively. So far, both PV systems have had

100 percent availability.

Minor problems have occurred with control systems and with street light inverter ballasts in Gabon. The fluorescent lights have an integral inverter for each lamp that has experienced a failure rate that is proportional to outdoor storage time in the moist tropic environment before installation. Inverters that were installed in fixtures directly, (i.e., not stored in unairconditioned areas) have not had any failures. All fixtures that were stored in Gabon prior to installation were replaced. Failed inverters are being analyzed. The Gabon systems are completely instrumented, and data collected over the next few years should provide a valuable indicator of that system's overall performance.

Basaisa Village - Egypt

A PV village electrification system was introduced in Basaisa in November 1977 under the sponsorship of the American University in Cairo and the National Science Foundation. The initial 33-Wp system powered a 12-inch screen black and white television, a 12-V radio cassette recorder and a 12-V manual slide projector. The storage system consisted of a 12-V car battery. In December 1978, another 33 Wp was added to power a 12-V loudspeaker and a 12-V, 60-W emergency light. In 1981, solar pumps were added for irrigation.

The village has established a community cooperative, community club, technical center and community clinic. A fee is charged for membership in the cooperative or club. Members of the cooperative may use the community audio-visual (AV) equipment, emergency light and irrigation pumps. Members of the club may use the TV, AV equipment and light. The technical center uses the AV equipment and pumps, and the clinic uses the light. Members of the cooperative and club must pay rent for the pumps and AV equipment during times of use.

As of September 1983, the system was operating satisfactorily. The

initial pump that was used in the system was not designed well for the given application--low lift pumping. However, a new pump was developed and was in use as of September 1983. Operation and maintenance activities include cleaning the array every two weeks and monitoring battery state-of-charge with a multimeter and hydrometer.

Operation, maintenance and repair is performed by volunteers in the community. In the case of system breakdowns, the villagers first attempt to correct the situation themselves; the project team only intervenes if the villagers cannot fix the system. The energy cooperative not only provides for the basic energy needs of the community but also establishes an educational atmosphere and a type of community spirit. There has not been much conflict over the use (and scheduling of the use) of the various equipment. However, some farmers still prefer using their animals to pump water for irrigation rather than the PV-powered pumps.

Charsarati, West Bengal, India

In December 1980, a 200-Wp PV system was installed to power a community center. One of the main functions of the center is to provide adult education. The loads for this system include a 65-W television, two 40-W fluorescent lamps and one 20-W fluorescent lamp. A DC-DC converter (24VDC-110VDC) is used for he television, and an inverter (24VDC-150VAC) is used for the lamps. Storage consists of two 12-V, 120-Ah lead-acid batteries. In October 1981, a 300-Wp water pumping system was installed for irrigation. The pump is a DC centrifugal model rated at 96 V and 400 W. A maximum power point tracker and five 42-V, 60-Ah leadacid batteries are included in the system. This project was originated and is administered by the University of Kalyani. All modules were supplied by CEL, an Indian manufacturer.

As of 1984, the system seemed to be operating smoothly. The principal

investigator of PV projects at the University of Kalyani feels PV systems have been proven technically feasible in India. Futhermore, the community center was economically viable. BOS costs (per peak watt) are less in India than in the U.S., due to low labor costs. The cheaper BOS costs allow for the use of low efficiency (5%) solar cells.

There were some problems when modules failed after three years due to the cracking of cell interconnects. They could (as of 1984) only be replaced by physically taking them to CEL. Motor-pump set problems were also encountered, mainly with the carbon seals and commutators. This project, nevertheless, has generated "tremendous enthusiasm," even attracting people from neighboring villages in the evenings. The villagers manage security, operation and maintenance on a cooperative basis.

Niaga Wolof Energy Centre - Senegal

Niaga Wolof is a village of 1500 inhabitants. In February 1983, a PV-wind hybrid system (5 kW PV; 4.5 kW wind) began powering a public lighting system. In April 1983, a water pump (20 to 25 m3/day) was connected to the system. The system was officially considered operational in January 1984, after 9 months of preliminary tests. By January 1984, the system also powered two refrigerators and two fluorescent tubes. The system is intended to also eventually supply residential lighting, a communal TV, carpentry and sewing equipment, a grain mill and an ice maker.

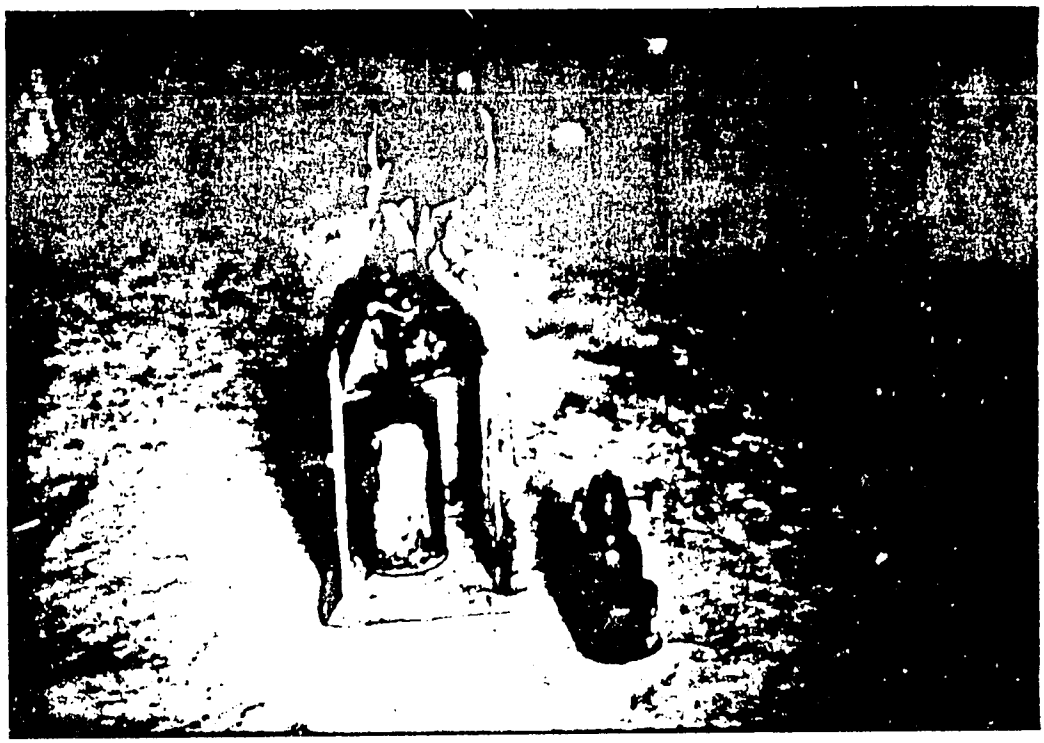
As of October 1984, no problems with the PV portion of the system had been reported. According to the reference, the system "confirmed the reliability of photovoltaic solar energy." The system also demonstrated that a full-time system operator is not necessary and that periodic inspections suffice. The cost-competitiveness of this system versus diesel has not been determined yet since the grid is still undergoing expansion and more accurate

instrumentation is needed.

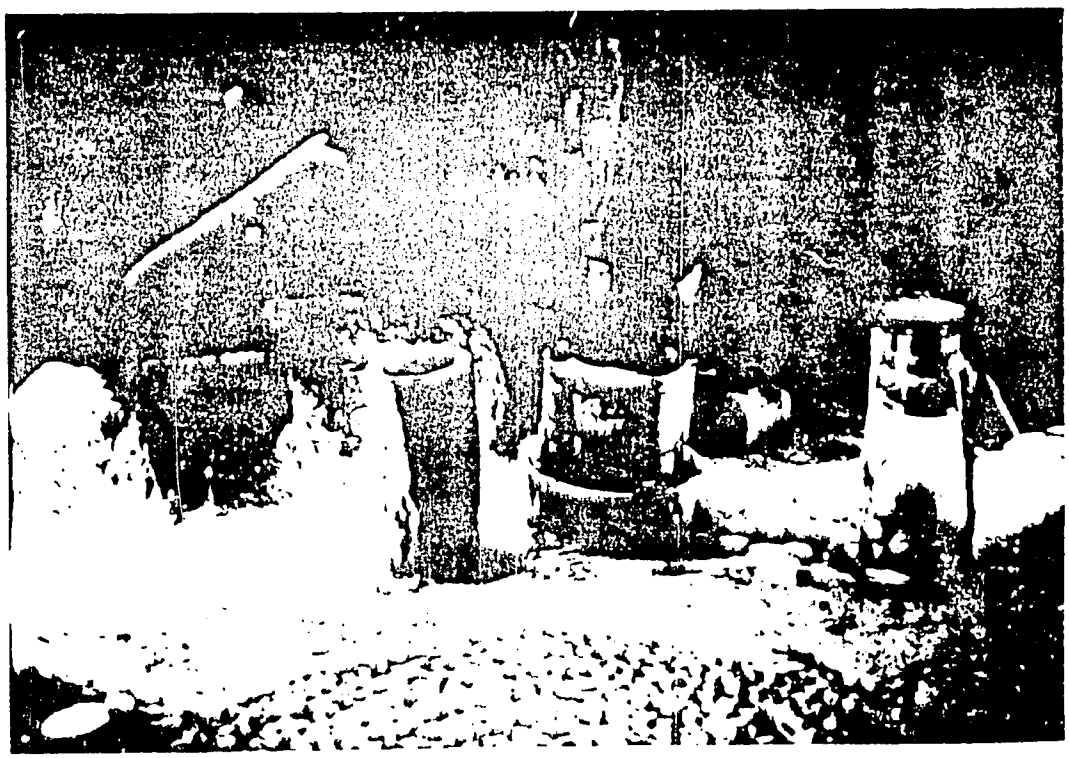
The system is located near Dakar and is thus close to technical support. Users of the system are billed according to an established tariff structure. Residences are billed at the cheapest rate, whereas a tourist center in the village is charged a higher rate.

APPENDIX D

Selected Pictures of Baharia Villages



Ayn Gomaa: Kerosene Bottle Lamps



Ayn Gomaa: Kerosene Hurricane Lamp (right)
Kerosene Cook Stoves (center)

Tabl-Amoun: Low Land Well Area

Reis: Typical Artesian Well Site
(Note lever acting well construder equipment)

Ayn Gomaa: Open Canal Distribution

Ayn Gomaa: Flood Irrigation Canal

Ayn Joseph: Concrete Water Distribution Canal

El-Ezz: Irrigated Farming Lands

APPENDIX E

Derivation of Hydraulic Energy Formula

In the metric system, the basic unit of energy is the joule and it is defined:

$$1 \text{ Joule} = 1 \text{ newton} \times 1 \text{ meter}$$

Where:

A Newton is the basic unit of force

A Meter is the basic unit of length

But 1 Newton is also equal to 9.8 kg-force.

The density of water is very near to 1000 Kg mass per cubic meter. At the earth's surface we make the simplifying assumption on that a Kg force = Kg mass.

Substituting these expressions in the basic formula yields:

$$1 \text{ Joule} = \frac{9.8}{1000} \text{ m}^3 \times \text{m}$$

Electrical energy is usually expressed in Kw-Hr. We therefore substitute the conversion formula:

$$1 \text{ Joule} = 3.6 \times 10^{-6} \text{ KwHr}$$

Substituting these yields

$$\text{Energy} = \frac{9.8}{3600} \text{(Flow Rate)} \times \text{(Head)}$$

Where:

Energy is expressed in Kw-Hr

Flowrate is expressed in m^3/unit time

Head is expressed in meters

APPENDIX F

APPENDIX F

Derivation of Array Power Formula

An Energy Balance on a PV system can be done starting with the general formula:

Energy Produced x Efficiency Factors = Energy Consumed by Load + Losses.

The left side of the equation can be expressed as:

Array Power x Time x η operating x η P.C.

Where:

Array power	=	Rated Power at Standard Conditions at a given angle
Time	=	No. of full sun hours equivalent (Hours)
η Operating	=	Efficiency factor that takes into account a derating because of temperature effects and wiring losses in the array field (dimensionless)
η P.C.	=	Efficiency that takes into account the losses associated with channeling power through the power conditioning equipment (dimensionless)
Energy Consumed	=	Load times duration (kw-Hr)
Losses	=	Miscellaneous Losses (Kw-Hr)

Rearranging terms, the general formula can be expressed as follows:

$$\text{PV Array Size} = \frac{\text{Load + Losses}}{(\text{Time})\ (\text{PV Oper. Eff.})\ (\text{Power Cond. Eff.})}$$

APPENDIX G

MC

DEC 1 0 1986

RENEWABLE ENERGY FIELD TESTING PROJECT

(A.I.D. 263-0123.2)

TO: Deepak Kenkeremath, MC

From: Robert C. Spongberg, LBII

Through: Michael Ford, LBII

Date: 10 December 1986

Ref.: ARE 0652/86 C

Subject: Result of Discussions Regarding AR/CD-7 and AR/CD-8 In Response to MC Letter # 429-86-TA Dated 12 November 1986

Reference Meridian's letter # MC-429-86-TA dated 12 November 1986 requesting approval of Conceptual Designs for Field Tests. The following directions for FT-7 and FT-8 are an outgrowth of meetings held at AID with the EEA Task Leader and the Project Officer on 8 December 1986. A similar meeting will also be held to discuss the questions raised regarding FT-9 and FT-10.

Field Test # 7 - PV Lighting and Water-Pumping

In light of the USAID letter dated 24 November 1986 attached no further discussions were held regarding a centralized system for the village of Ries. Discussions are underway between EEA and AID on the possibilities of doing such a system under the New Initiatives Task.

A PV/Lighting-water pumping system will be developed for and installed in the village of El Ezz in the Baharyia Oasis and will consist of the following major sub-systems:

1. One water-pumping system with:

   a. PV-power source to provide sufficient water to flood-irrigate a 60 feddan area every other day plus a total of 10 cubic meters per day for domestic use.

b. A water source with a minimum of two new wells located at an elevation higher than and far enough from the existing wells to minimize drawdown.

c. Two inter-connected water storage components; one, to provide two hours of water supply for irrigating early in the day, prior to the PV-system becoming operational with sufficient piping and valving to transport and control flow of the water into the existing irrigation system; and, two, to provide up to a one-day supply of water for domestic use with piping to allow a central location of a single, manually-operated valve for extracting the domestic water.

2. In addition to the primary water-pumping system described the project will provide for an option of two portable PV water pumping units each capable of providing sufficient water to flood-irrigate one feddan per day from shallow wells, or irrigation ditch.

3. Twenty PV-power systems, each capable of providing an individual household with sufficient power to meet an energy demand of 1000 watt-hours/day. Each system will include: 2-20 watt and 2-40 watt florescent lights with fixtures; 4-220 vac electrical outlets; batteries; inverter; and sufficient wiring and hardware to allow for a light and outlet in each of four rooms. The Contractor will be required to install the systems, assure that each is operational, and demonstrate to the user that the systems can be used for appliances such as a television, refrigerator, small power tools, sewing machine and battery charger.

4. Ten individually PV-powered street lights to be located where required in and near the village of El Ezz.

Field Test # 8 - PV-Powered Desalination Plant

The PV-desalination system will be required to produce 25 cubic meters of water per day with a maximum of 500 ppm of salt using the reversed osmosis technology and having sufficient battery storage to assure that the r.o. unit is levelized. The system will also contain a storage tank capable of holding a one-day (25m3) supply of desalinated water and make provisions for a water source in addition to the Roman wells. The AR/CD should discuss clearly the following:

1. The advantages of R.O. vs E.D. technologies taking into consideration the two different water sources (i.e. Roman wells and Mediterranean Sea).

2. The quantities of feed water required, again considering the different sources.

3. The disposition of the salt residue depending on source.

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cc.: Chrono
EO Office (for files)
IPH Technical File
MC Corres. Files

Talaat El Tablawi, EEA
Reda Botros, EEA
Rafik Georgy, EEA
Eric Peterson, USAID

APPENDIX H

Appendix H

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