PN-AAU-329

4210-055

United States Agency for International Development

PHOTOVOLTAIC DEVELOPMENT AND SUPPORT PROJECT

CONCEPTUAL DESIGN OF PHOTOVOLTAIC MEDICAL SYSTEMS FOR RURAL HEALTH APPLICATIONS

REPORT OF PROJECT TEAM

March 1981

Lewis Research Center
Cleveland, Ohio 44135

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

U.S. AID Photovoltaic Development and Support Project

Conceptual Design of PV Medical Systems for Rural Health Applications

Report of Project Team

MARCH 1981

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1.0 SUMMARY

This report presents the conceptual design for a standardized DC photovoltaic (PV) system for meeting the electrical needs of mid-level medical facilities in rural areas of developing countries (hereinafter referred to as a PV medical system). The work was performed by personnel of the Terrestrial Photovoltaic Projects Branch for the U.S. Agency for International Development (AID), Bureau for Development Support, Office of Energy (DS/EY). The system design proposed has the following characteristics:

- o Modular array with peak power outputs ranging from 1.8 - 3.2 kWp (28° C) at 120 V DC:

  Structure
  Wire Harness

- o Battery capacity:

  350 ampere-hours (baseline design)

- o Controls to accommodate up to 4 kWp of array output.

- o Medical loads

  Basic (DC) loads:

  Lights (room and outdoor)
  Refrigerator
  Sterilizer
  Examination Light

  Discretionary loads:

  Dental Drill
  Two-Way Radio
  Water Pump
  Washing Machine
  Sewing Machine
  Ceiling Fan
  Audio/Visual Equipment

The total load requirement is 4200 watt-hours/day with basic loads comprising about 83% of the total load.

Deployment of the PV medical system is planned initially for Ecuador, Guyana, Kenya and Zimbabwe. A total of five systems (2 in Kenya) is planned with a total project cost (i.e., nonrecurring plus recurring) estimated at $1,500,000. A breakdown of this cost estimate is given in Section 6.0.

2.0 Project Overview

The Photovoltaic (PV) Development and Support (D&S) Project is being implemented by the NASA Lewis Research Center (LeRC) for the U.S. Agency for International Development (AID), Bureau for Development Support, Office of Energy (DS/EY). The purpose of the project is to facilitate the use of photovoltaics for a variety of applications in support of development assistance activities.

A Participating Agency Services Agreement (PASA No. NASA/DSB 5710-2-79) authorizing this project was signed by AID August 28, 1979, and by NASA on August 30, 1979.

2.1 Objective

The major objective of the PV D&S Project is to demonstrate the suitability (i.e., cost competitiveness and reliability) of PV power systems for meeting basic electrical requirements in rural areas of developing countries with the initial effort focused on rural health delivery. This document presents the conceptual design of a "standardized" PV system sized to meet the stated electrical needs.

2.2 Approach

The approach being employed to meet the above objective is to establish basic electrical needs and load requirements of representative rural health centers in selected countries (viz., Ecuador, Guyana, Kenya, and Zimbabwe) and to procure under contract to industry, the necessary goods and services to meet those needs. The key activities of the project depicted in the flow diagram of Figure 1, are as follows:

Phase I: Project Initiation

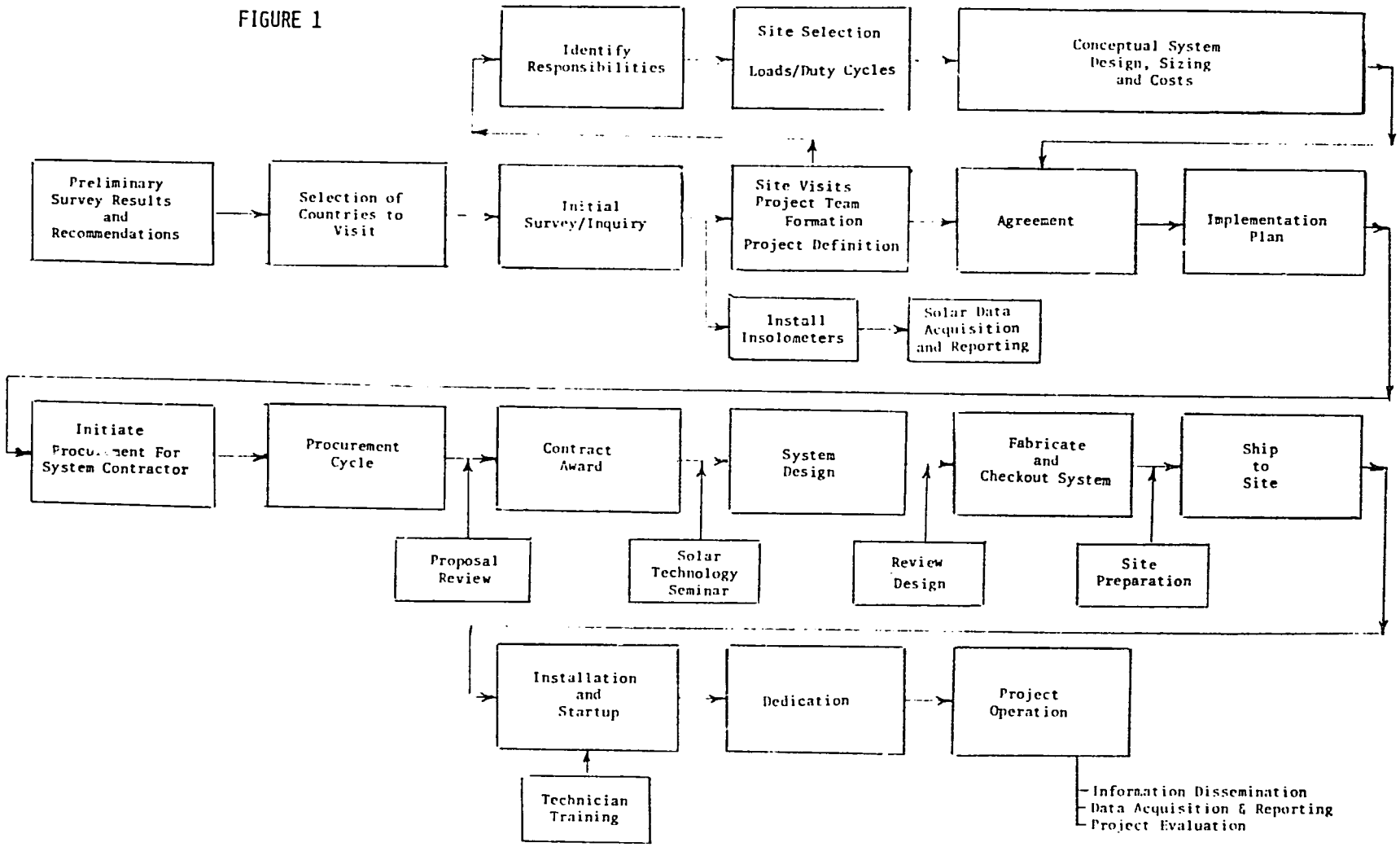
(1) Initial Survey/Inquiry with Potential Users
(2) Site Visit and Project Definition
(3) Agreement
(4) Conceptual System Design and Cost Estimate
(5) Implementation Plan
(6) SOW and RFP for Prime Contractor Procurement Cycle

Phase II: Project Activities

(1) Photovoltaic Technology Seminar in Host Country
(2) System Design
(3) Fabrication and Testing
(4) Shipping, Installation and Checkout
(5) Technician Training
(6) Dedication
(7) Operation, Evaluation and Information Dissemination

Rural Health Care Delivery Photovoltaic Demonstration Project
(Preliminary; Final version will appear in the Implementation Plan)

FIGURE 1



Step 2 of the initiation phase of the project involves inspection of candidate sites in those countries where a PV medical system project is being considered. In the selection of a site for project implementation, the following criteria are used for evaluating how well a particular site will meet the project objectives:

Site Selection Criteria

(1) Remoteness: No access to an electrical power grid or diesel generator for at least the next five years.

(2) Site Accessibility and Visibility: Located so as to permit easy access by planners and decision makers.

(3) Insolation: Above the low average for tropical regions (approx. 300 langleys/day).

(4) User Involvement: Demonstration will receive support of host country government and local personnel.

(5) Relationship to Approved AID Programs: Demonstration will support existing AID project(s).

(6) Value of Demonstration: Potential for replication in similar areas of need in host country and other developing countries.

3.0 Candidate Projects

Candidate projects were identified in four countries namely, Ecuador, Guyana, Kenya and Zimbabwe and site visits made. Summary information resulting from the site visits is given in Appendix A. Appendix A contains, for each site, the following: Locations; a general site description; a map locating the site; a layout plan of the PV power system and medical center; a photograph of the Center; and the load profile. Table I summarizes the load requirements at each site. Based on the information obtained, electrical load requirements were divided into two categories (viz., basic and discretionary) as follows:

Basic (DC) Loads:

Lights (Indoor, Health Center)
Refrigerator
Sterilizer
Examination Light
Outdoor Lights (Safety and Security)

Discretionary Loads:

Dental Drill
Two-Way Radio
Water Pump
Washing Machine
Sewing Machine
Ceiling Fan

TABLE I - Load Requirements for Each Site

Loads	Sites				
	P.V. Maldonado, Ecuador	Waramuri, Guyana	Ikutha, Kenya	Kibwezi, Kenya	Chikwakwa, Zimbabwe
Fluorescent Light	17	13	13	15	18
Low Pressure Sodium Vapor Light	1	1	1	2	1
Examination	1	1	1	3	1
Refrigerator	1	1	1	1	1
Sterilizer	1	1	1		1
Two-Way Radio		1	1	1	
Dental Equipment	1				
Water Pump		1			

The basic loads as defined above represent a major portion (83%) of the energy consumption while those loads which are considered discretionary (i.e., determined by the user) represent the balance.

4.0 Design Considerations

4.1 PV Medical System:

The design of the PV medical system is predicated on the assumption that the load requirements established from surveys in the candidate countries and consultation with members of the international health community are typical of a significant fraction of the rural health facilities in developing countries. As such, the demonstration of a reliable, cost-competitive PV power system at the five candidate project sites would be expected to lead to replication of similar systems elsewhere.

Important design considerations for PV medical systems include cost, reliability, maintenance, repair and replacement modularity and safety. Costs are minimized by standardization of design and by proper sizing and selection of system components. Reliability is maximized by proper design, appropriate selection of components, and conducting qualification and acceptance tests of both components and subsystems. Maintenance, repair, replacement and safety are facilitated by proper design, employment of fault protection and conducting thorough testing under environmental conditions. Modularity is an inherent feature of PV systems and with proper design, allows incremental additions of power capacity as required.

The standardization approach entails a "baseline" design for the PV medical system which is based on the electrical needs of typical rural health facilities (see Appendices) assuming an "average" or "representative" insolation profile. In this context, the health facilities identified herein for Guyana, Kenya and Zimbabwe are considered typical. Appropriate modifications, relative to the baseline, are allowed for areas of lower insolation and/or higher electrical load requirements. The health facility identified herein for Ecuador falls in this category. Design provisions are also to be included to accommodate variations in physical layout of health facilities, e.g., as regards electrical distribution systems and support structure.

Accordingly, the PV medical system as defined herein consists of the following elements:

- o PV Array Components

  Structure
  Wire Harness
  Peak Power Output: Modular from 1.8 to 3.2 kW

- o Controls to Accommodate up to 4 kWp of Array Output Power

- o Battery Storage: Provision for variable capacity where necessary - single capacity, 350 ampere-hours.

o Medical Loads

Basic (Core)

Discretionary - fixed percent of total power allocated to be determined by user priorities.

4.2 AC Option

Since a photovoltaic array supplies DC power, use of a DC-AC inverter would be required for powering AC loads. However, the use of such an inverter results in additional power consumption due to inverter inefficiency and inverter no-load power requirements, both of which can be quite high. Since the PV powered medical system demonstration project has cost-competitiveness as one of its objectives, it is essential that energy conservation be given a high priority in system design. Figure 2 shows the efficiencies of AC and DC motor load systems.

It is clear from Figure 2 that the use of an all DC system permits a significant conservation in energy use (AC requires 96% greater energy input than DC for the same shaft power output). A comparison of array and battery sizes required for AC and DC loads is given in Figure 3 for the site of Pedro Vincente Maldonado in Ecuador. Figure 3 shows graphically the additional array and battery required for an AC system. The specific array size, battery capacity, and incremental cost comparisons for AC and DC loads for the loads being considered for a standard system (Section 4.1) for P.V. Maldonado, Ecuador are shown in Table II. The additional cost of $286 K for an AC system is substantial when compared with the baseline recurring* cost for a single system of $176 K (see Section 6.0). The use of AC loads represents an increase of 60% in the recurring cost of the standard PV system. There is also an additional $69 K of nonrecurring costs required for making the additional design changes to the baseline DC system. These higher costs incurred when using AC loads argue for the use of DC loads.

Table III lists other pro and con considerations of AC and DC load systems.

Note that although DC loads are sometimes slightly more costly than AC loads, the additional cost of a DC load has a small effect on the total system cost (total load cost is approximately 5% or less of system recurring cost) and is more than compensated for by the PV array and battery cost savings resulting from the use of DC loads. While the above considerations dictate the use of DC at this time, it is understood that load availability and user preference and device availability may dictate some usage of AC devices. Hence, the baseline PV system may include one AC outlet with a nominal 1 kW capacity. However, this outlet would be used only on an intermittent basis so that the energy consumption is limited. If this option is selected, the user would be given directions on the use of this outlet as part of the training and education program.

*Recurring cost represents those costs involved in installing a replicate system as opposed to nonrecurring costs (i.e., design, fabrication, and test of a prototype system).

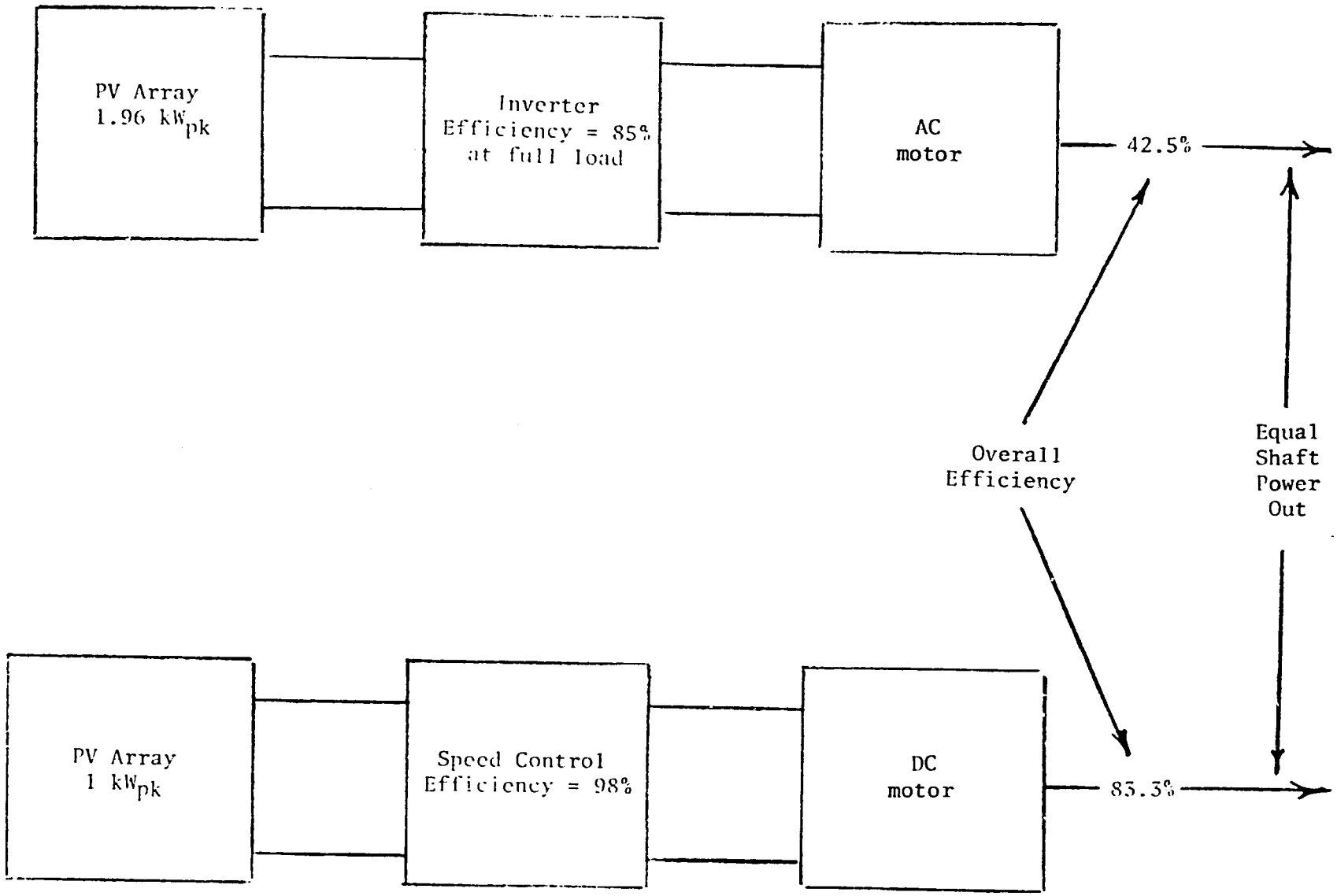


FIGURE 2 - TYPICAL EFFICIENCIES OF EQUAL AC AND DC MOTOR LOAD SYSTEMS AND RESULTING PV ARRAY SIZES

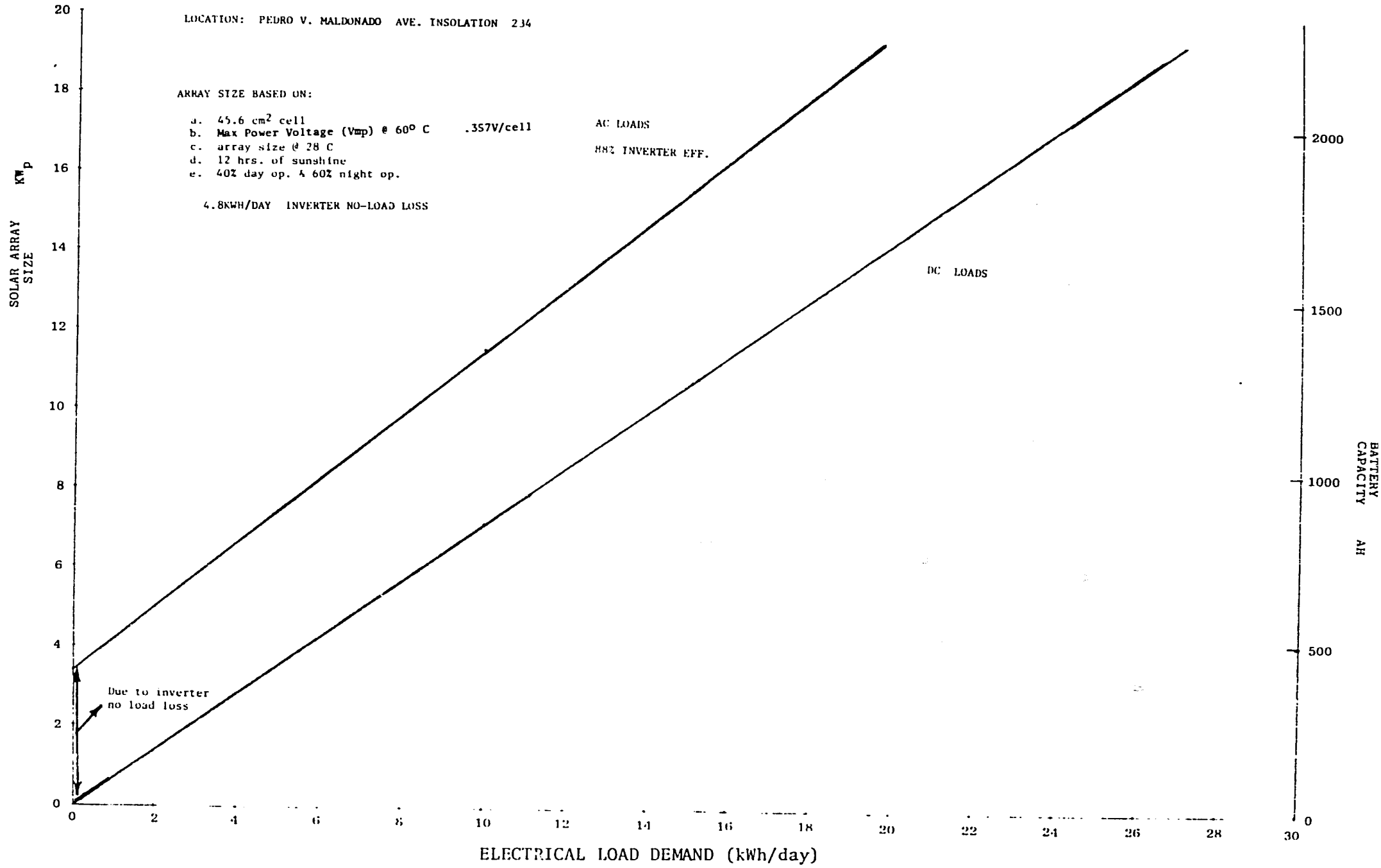


FIGURE 3 - SOLAR ARRAY SIZE/BATTERY SIZE VS ELECTRICAL LOAD DEMAND

TABLE II - Size-Cost Survey for Ecuador Rural Health Delivery Photovoltaic Demonstration Project

System Type	Site	Solar Radiation langleys	NASA/LeRC Proposed Loads				
			Array Size[1] (kW_p)	Battery Size (AH)	Incr. Cost[2] ($K)	kWh/day (load)	kWh/day (array)
AC	P.V. Maldonado	234	10.4	1620	286	8.9	14.9
DC	P.V. Maldonado	234	3.0	350	37	4.2	4.2

[1]Cell Temperature - 28° C

[2]Incremental Recurring Cost Relative to Baseline DC System of 1.8 kW_p (28° C); 350 AH battery.

TABLE III - Comparison of DC vs AC Systems

PV System Electrical Design Options	Advantages	Disadvantages
120 V DC bus - all DC loads*	o DC motor efficiency high (∿85%) o Smallest PV array and battery for given load	o Limited availability of 120 V DC switch gear and appliances o DC motor speed controller required for some applications o Users unfamiliar with DC and therefore reluctant to use DC o Sometimes slightly higher costs for DC loads
120 V DC bus with dedicated inverters for selected loads	o AC motors, switchgear, appliances, etc., available off-the-shelf o Users familiar with AC	o Increases cost of system by requiring - larger array - larger battery - inverter o Commercially available AC motor efficiency typically low (∿50%)

*Exception: Fluorescent and sodium vapor lights use commercially available high efficiency inverter/ballasts.

5.0 PV Medical Applications System

5.1 Medical Facility

A mid-level rural health center consists of a relatively small health complex composed of three to ten rooms (fig. 4). Typically common to all centers are a waiting and educational room area, an examination room, a treatment room, a maternity room, inpatient ward(s), and service rooms. At any one center, the number of each type of room may vary. The staff quarters may be an integral part of the health complex or separated but nearby the center.

The centers are staffed by public health nurse(s) and assistant(s) capable of delivering preventive care, emergency services, inoculations, treatment of common illness, low risk obstetric services and limited dental services. The centers may have facilities to communicate with their headquarters or district hospital by two-way radio or telephone.

These centers would typically require electricity to power the following basic loads: a small medical stores refrigerator, room lights, examination light, a small equipment sterilizer, and exterior yard light(s). In addition, each center may need power for additional center specific loads, such as the following: dental equipment, two-way radio, water pump, AC power for education uses, or a washing machine.

Typical functional areas and activities of a center are shown in Table IV.

5.2 PV System Description

Figure 5 is a single line diagram of the proposed baseline DC photovoltaic medical system. This system is composed of the following subsystems:

- o PV Power Subsystem: Composed of the PV array, batteries and controls.
- o Power Distribution Subsystem: Composed of the hardware necessary to distribute the power and the protective equipment for that hardware.
- o Loads Subsystem: Composed of all load devices and their local controls.
- o Instrumentation Subsystem: Composed of all instrumentation devices including panel meters, data loggers, sensors and transducers.

A breakdown of the loads in terms of power and energy utilized per day is given in Table 5. The total system load being considered is 4200 watt-hours/day, with 83% of this for basic loads and 17% for discretionary loads to be determined by the user.

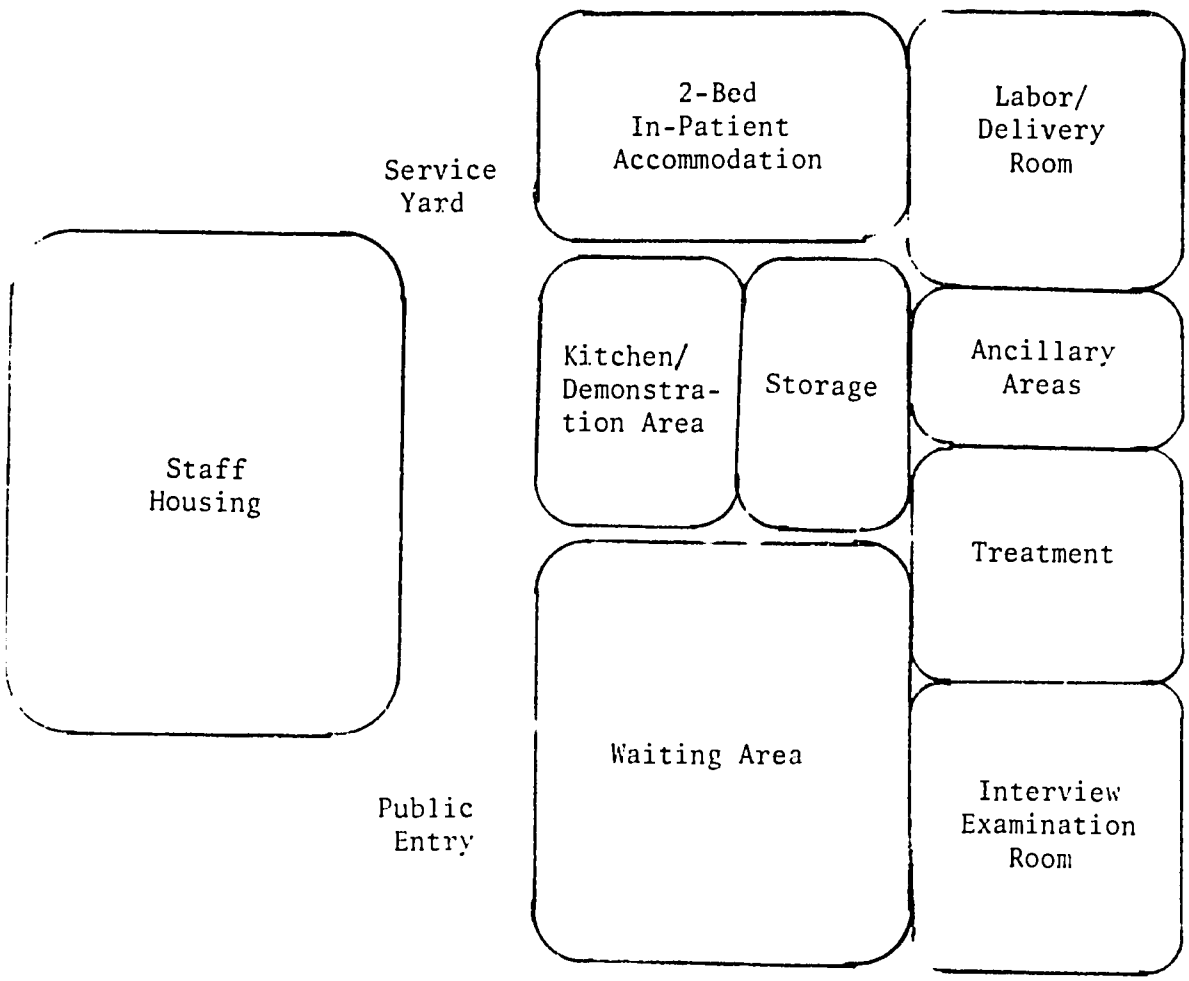


FIGURE 4 - TYPICAL HEALTH STATION FUNCTIONS

TABLE IV - Activities to be Carried Out in Spaces Defined for Health Station

SPACE	ACTIVITY
Waiting area with public toilet	Waiting, Health Education activities, films, etc.
Educational area/ kitchen	Nutrition and child care demonstrations; food distribution; preparation of meals and drinks for in-patients
Storage	Medical supplies, food, equipment, teaching aids, etc.
Interview/Examination room	Physical and health assessment, diagnosis of common illnesses etc.
Treatment room	Emergency services, treatment, dental care
Labor/Delivery room	Low risk deliveries
Ancilliary areas	Wash room, sterilizer room, etc.
In-Patient room	Beds, toilet and bath
Service Yard	Laundry

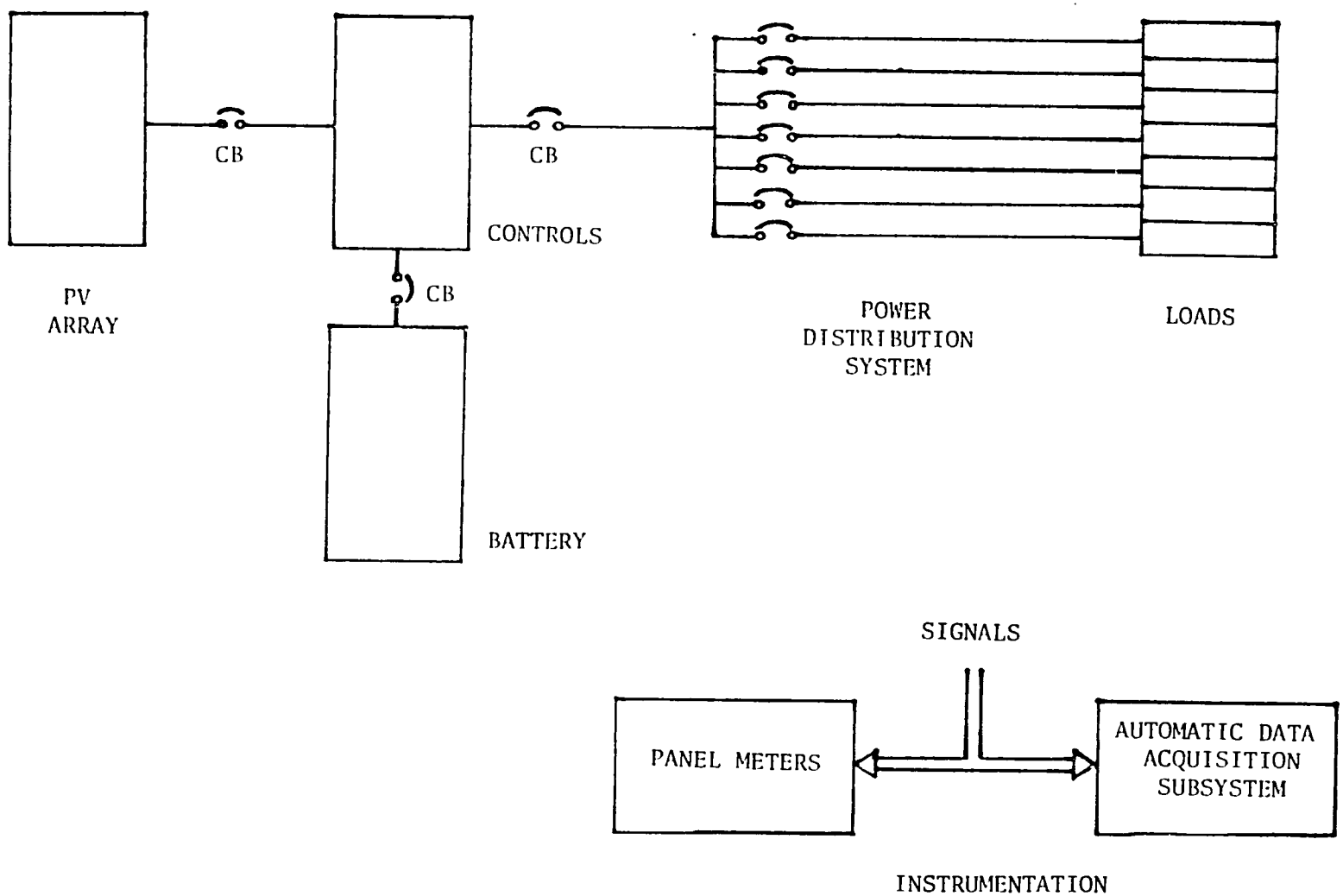


FIGURE 5 - SINGLE LINE DIAGRAM OF THE PV HEALTH CENTER SYSTEM

TABLE V - Baseline PV Powered Medical System Loads

	NO.	SIZE (W)	WH/DAY	HRS/DAY/DEVICE
Basic Loads				
Lights				
Indoor Health Center	10	40 (FL)	700	1.75
Indoor Residence	4	40 (FL)	250	1.56
Yard	1	18 (Na)	180	10.00
Refrigerator (43° C Ambient)	1	80	1310	16.38
Sterilizer	1	1000	1000	1.00
Examination Light	1	100	100	1.00
BASIC ALLOWABLE			3500 WH/DAY	
Discretionary Loads				
Dental Drill	1		350	
Radio	1	25	25	1.00
Water Pump	1	250	750	3.00
Washing Machine	1	300	300	1.00
Sewing Machine	1	75	75	1.00
Ceiling Fan	1	75	600	8.00
DISCRETIONARY ALLOWABLE			700 WH/DAY	
TOTAL LOAD			4200 WH/DAY	

5.3 Solar Radiation

For purposes of sizing the PV systems, i.e., determining the array size (kWp) and battery capacity, average daily insolation data for each month was compiled for Ecuador, Guyana, Kenya and Zimbabwe. This information is given in Appendix B. The insolation data was obtained from referenced values of average horizontal radiation where available. Where only hours of bright sunshine data were available, average insolation was estimated employing the following Angstrom type regression equation:

$$H_{AV} = H_0' \quad a' + \left[\frac{b'n}{N}\right] \qquad \text{Equation (1)}$$

where

H_{AV} = Average horizontal radiation (langleys/day)

H_0' = Clear day horizontal radiation (langleys/day)

n = Average daily hours of bright sunshine

N = Maximum daily hours of bright sunshine

a', b' = Constants

Values of H_0' and N are taken from Figure 3.4.1 and 3.4.2 of reference 1. For the three countries in the region of the equator, assumptions of 0° latitude and N = 12 hours were made. Values of H_0' for 0° latitude are given in Table VI.

The approach taken was to use known country values of H_{AV} and n and linear regression analysis to determine the values a',b' of equation (1) for a given country. Average daily insolation were then calculated using equation (1) and values of n, H_0' (Table IV), for those sites where only hours of sunshine are available. This procedure was used for the site of Pedro Vincente Maldonado, Ecuador. Table IV provides a summary table of the insolation values employed. Insolation data from Gabon is shown for reference as data representative of a typically low insolation area.

5.4 Simplified Sizing Calculations

For purposes of estimating the PV system sizes and costs, a simplified approach for sizing the system was employed. A monthly energy balance was made on the system of battery and photovoltaic array utilizing the insolation data of Table VII. The objective of these calculations was to determine the optimum or minimum total cost of batteries and photovoltaic array. The following input information was utilized in the calculations:

1. Insolation Data for Site: Table VII.

2. Site Location Latitude for Ecuador, Guyana, Kenya, Zimbabwe.

TABLE VI - Monthly Clear Day Horizontal Radiation on a Horizontal Plane for 0° Latitude (Reference 1)

Month	H_o' Langleys/Day
January	609
February	639
March	663
April	651
May	621
June	600
July	606
August	637
September	661
October	650
November	615
December	597
AVERAGE	629

TABLE VII - Monthly Daily Average Insolation Data
(Langleys/Day)

Country	Site	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Ecuador	P.V. Maldonado	243	248	299	295	260	205	226	221	217	206	195	196
Guyana	Waramuri	390	430	440	450	410	400	440	470	490	460	420	370
Kenya	Central	558	595	559	486	416	397	324	366	464	492	486	522
Zimbabwe	Chikwakwa	496	492	514	481	449	399	424	468	523	552	501	488
Typical Low (Gabon)		288	310	320	350	300	240	250	280	320	280	250	280

3. Composite Load Profile:
   average - 4.2 kWh/day
   day/night ratio - 1.68 kWh/2.52 kWh.

4. Solar Cell Characterisics:

   Maximum power voltage - .357 V/cell (60° C)
   Efficiency - 8.1% (@ 60° C cell operating temperature)
   Cell Area - 45.6 cm^2

5. Battery Characteristics:

   Charge Current Efficiency - 95%

   Maximum Depth-of-Discharge (DOD) -

   o 50% for normal operation (maximum battery capacity)

   o 80% for determination of minimum battery capacity, based on manufacturer's suggestion and including three days system operation without array power.

6. System Voltage: 120 volts DC.

7. Array Unit Weight: 1.8 lb/W_p (28° C).

8. Array Unit Cost: \$14.1/W_p - based on in-house survey of manufacturers.

9. Battery Unit Weight: 9 lb/ampere-hour.

10. Battery Unit Cost: \$161-195/kWhr

11. Shipping Costs: \$1440/ton.

The sizing procedure for the photovoltaic array and storage battery is given in Figure 6. The procedure for determining the minimum battery capacity is given in Appendix C. Using the procedure of Figure 6 and allowing for 5% array degradation, different values of array and battery size and system cost were generated for each site. This permitted a determination of the minimum cost system.

Table VIII shows the system sizing results for different size systems for each site. Figure 7 illustrates the distribution of system weights and costs for different size systems for each site. Because of the high cost of batteries and their high shipping costs, both as compared to PV array costs, the minimum cost systems were those for which the array was large enough to recharge the battery each day and the battery capacity was largely that required to power the load system three days in the event of loss of array power. For such a situation and for those systems, minimum battery capacity is 350 ampere-hours (Appendix C). The results of the minimum system costing exercise are given in Table IX.

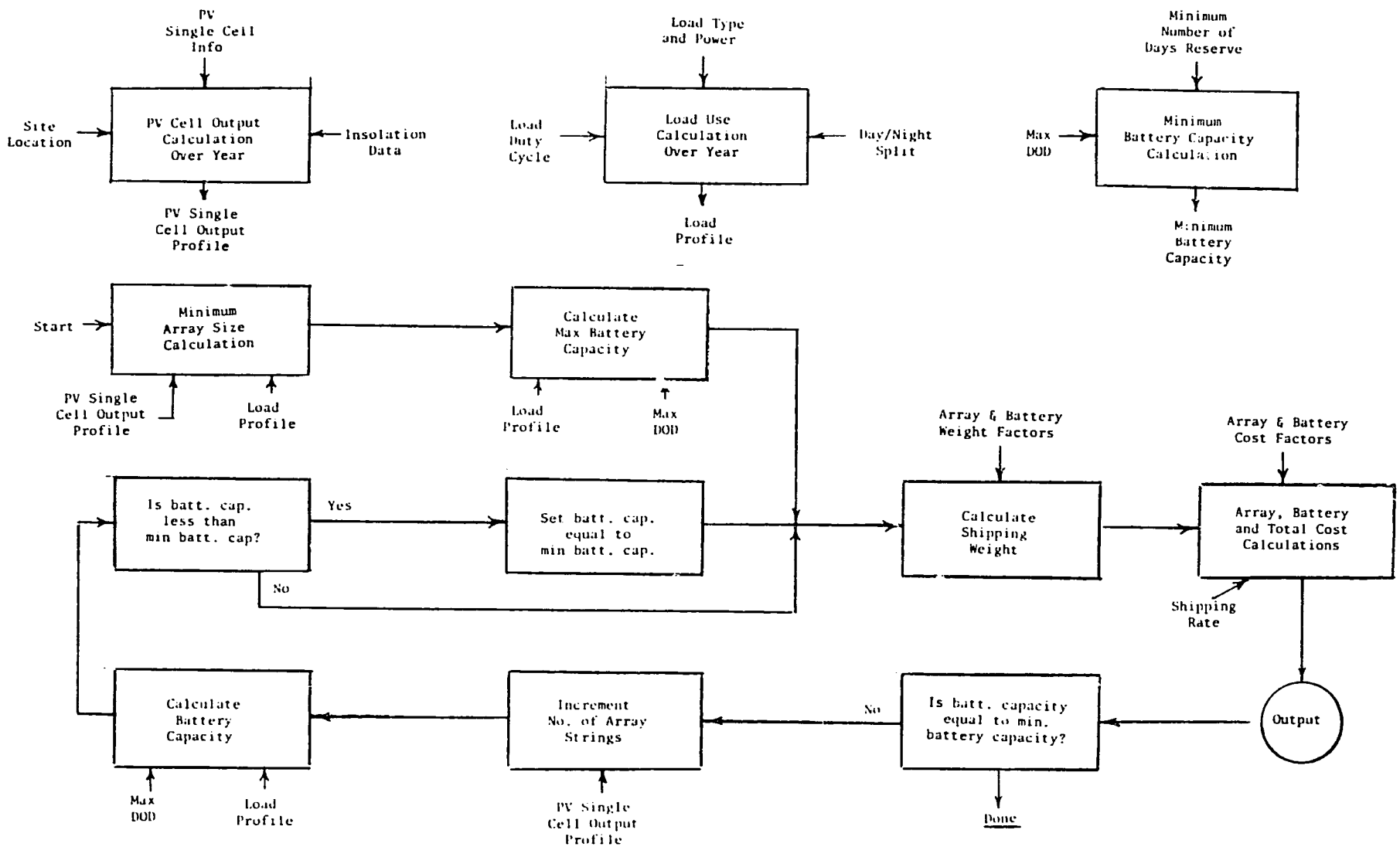


FIGURE 6 - SIZING PROCEDURE FOR PHOTOVOLTAIC ARRAY AND STORAGE BATTERY

TABLE VIII - Array-Battery Results for PV Powered Medical Centers
(4.2 kWh/day Load)

	Array			Battery		Array & Battery Subsystem		
Location	Number of Strings	Rated Peak Power[2] (kW_p)	Cost[3] ($K)	Capacity (AH)	Cost[4] ($K)	Total Weight (lbs)	Estimated Shipping Cost ($K)	Delivered Cost
Ecuador	15	3.0	42.3	350	8.2	8487	6.1	56.5
	14	2.8	39.5	1023	21.2	13972	10.1	70.8
Guyana	8	1.6	22.6	350	8.2	5945	4.3	35.1
Kenya (Ikutha & Kibwezi)	9	1.8	25.4	350	8.2	6308	4.5	38.1
	8	1.6	22.6	525	11.8	7466	5.4	39.8
	7	1.4	19.7	1650	31.9	16880	12.2	63.8
Zimbabwe	7	1.4	19.7	350	8.2	5582	4.0	31.9

[1] Range of system sizes is determined by a minimum battery size and minimum array size.
[2] Module characteristics assumed: 200 Wp/string, 336 series cells/string, cell voltage - .357V, cell efficiency - 8.1%, cell area - 45.6 cm^2.
[3] $14.1/Wp for modules and structures
[4] Cost for 54 cell lead acid battery

FIGURE 7 - ILLUSTRATION OF DISTRIBUTION OF COSTS AND WIEGHTS

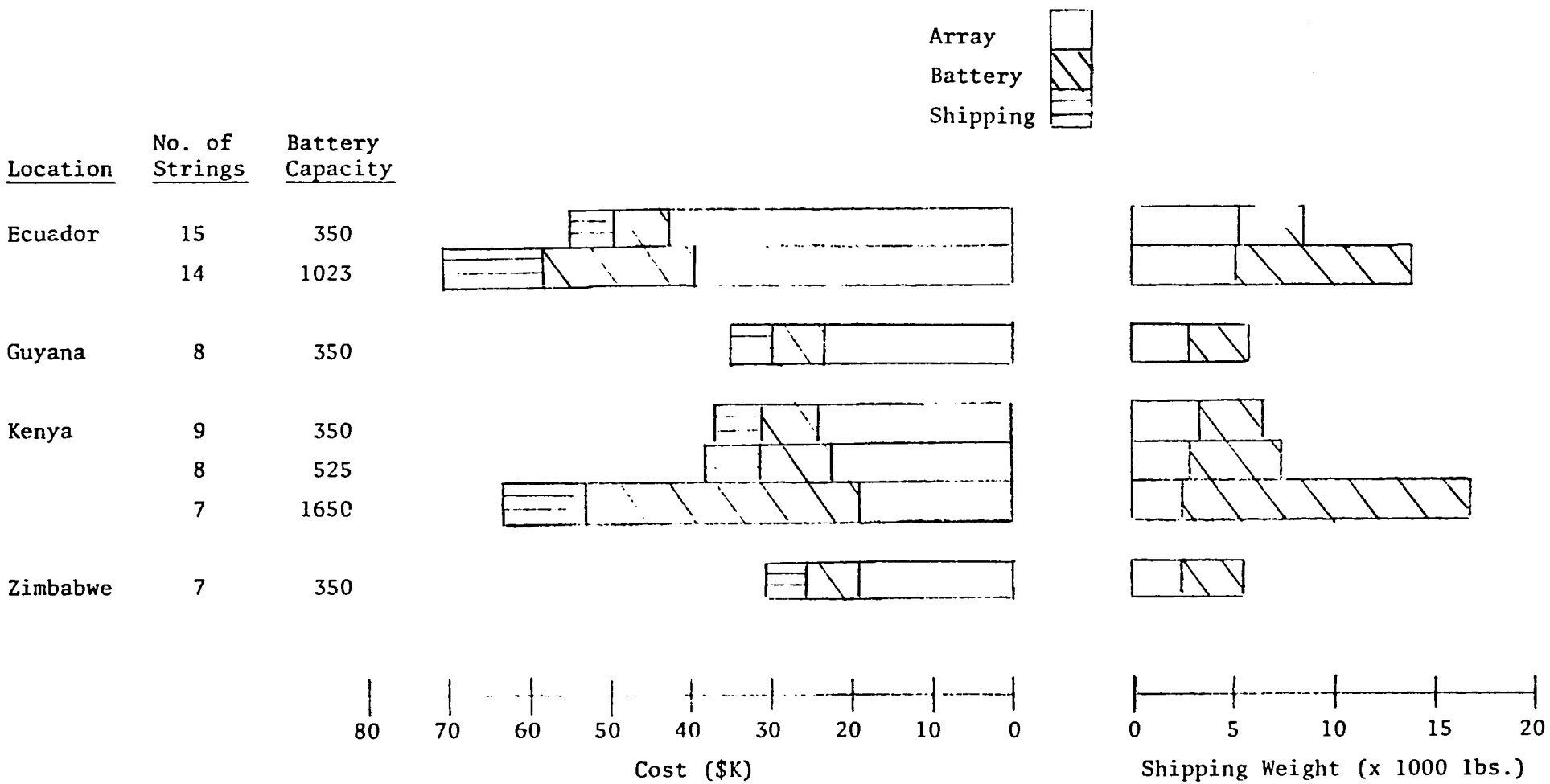


TABLE IX - Optimum Array/Battery Sizes

Country	Location	Array (kW_p) at Cell Temperatures 28° C	60° C	Battery Capacity (AH)
Guyana	Waramuri	1.8	1.35	350
Kenya	Kibwezi	1.8	1.35	350
Kenya	Ikutha	1.8	1.35	350
Ecuador	P.V. Maldonado	3.0	2.25	350
Zimbabwe	Chikwakwa	1.8	1.35	350
Typical Low Insolation (Gabon)		2.6	1.95	350

6.0 System Cost Estimates

Appendix D presents the cost estimates for the design, deployment and operation of the PV medical system described in Section 5. These costs are expressed in terms of recurring and non-recurring costs for a baseline system and for systems that differ from the baseline (incremental costs). The non-recurring cost is that cost which is required for the design, fabrication and testing of a prototype baseline PV medical system. The recurring costs are for replicating and installing a few additional systems of proven design. As indicated in Appendix D, non-recurring and recurring costs both include direct labor, materials, travel, shipping, G&A and profit. A summary of the cost estimates of Appendix D is given in Table X. Included in the cost estimates are costs for system monitoring and service, and contingency funds.

If one were to employ a custom design approach, i.e., a different design for each selected site, it would add significantly to the non-recurring cost, which is a substantial portion of the total for a given system ($184 K or more than 100% of the total cost for a single PV system). With the standardized system approach, the non-recurring cost can be shared among the five selected sites ($36.9 K per site as shown on Table X). An additional cost benefit is obtained by the use of a modular design for the PV array. Modularity allows the designer to fit the array size to the amount of sunshine available at a site. A fixed array size for all systems would require an array size that would meet the power needs of all the selected sites. Using the array size for a typical low insolation location (Table VIII) as the array size would result in a 5% additional expenditure for array that would not be required for the higher insolation locations of Kenya, Guyana and Zimbabwe. This percentage would be further increased if the array size for the Ecuador site is used as the fixed size.

The total cost estimate for the design, deployment and operation of five PV medical systems for rural health applications is approximately $1,500,000, exclusive of NASA project management costs.

TABLE X - Summary of Cost Estimates for Five PV Medical Systems

A. Non-Recurring Cost			
1.0 Baseline	$ 184.4 K		
2.0 Option			
Subtotal	184.4		184.4
B. Recurring Cost			
1.0 Baseline (5 x 175.6)	878.0		
2.0 Incremental	33.2		
Subtotal	911.2		911.2
TOTAL SYSTEM COST INSTALLED		1095.6	
C. System Monitoring and Service (5 x 56.2)	281.0		281.0
D. Contingency			
1.0 Non-recurring	16.8		
2.0 Recurring (16.0 x 5 + 3.0 + 5.1 x 5)	108.5		
Subtotal			125.3
GRAND TOTAL			$1,502 K

7.0 References

1. Duffie, J. A.; Beckman, W. A.: Solar Energy Thermal Processes, John Wiley and Sons, 1974.

8.0 APPENDICES

8.1 - APPENDIX A

SITE INFORMATION FOR GUYANA, ECUADOR, ZIMBABWE AND KENYA

Table A.1 - Site Information - Chikwakwa Rural Hospital

LOCATION

Country Zimbabwe, Africa

City (Town, Province or Area) Chikwakwa

Language(s) Spoken English, Shona (Official language: English)

Latitude 17° 33' S Longitude 31° 29' E Elevation 3800'

Description of Access to Site (Transportation Means, Seasonal Considerations, etc.)

2 Km of all-weather unpaved road from paved road. This unpaved road has a bridge/dam with day-to-day possibility of impassibility during rainy season.

[Note: Labeled as Mavudzi Clinic on map, Figure A.2]

Distance and Time from Major City 61 Km to Salisbury, approximately 45 minutes.

Distance, Time, and Location of Accommodations Hotels and restaurants available in Salisbury.

NATURAL FEATURES

Topography Rolling uplands.

Vegetation Trees, small shrubs, grass - clear area for PV array available.

General Climate (Seasonal) 1 rainy season (Nov-Mar).

SITE FACILITY

Type Rural hospital staffed by a health orderly and three medical assistants.

Existing Facilities 21 beds; wards: outpatient, male inpatient, female inpatient, isolation, maternity, labor; kitchen, residences, telephone, water pump (diesel) and water tank, conduit and wires installed in facility.

Services Provided Outpatient, maternity, child care.

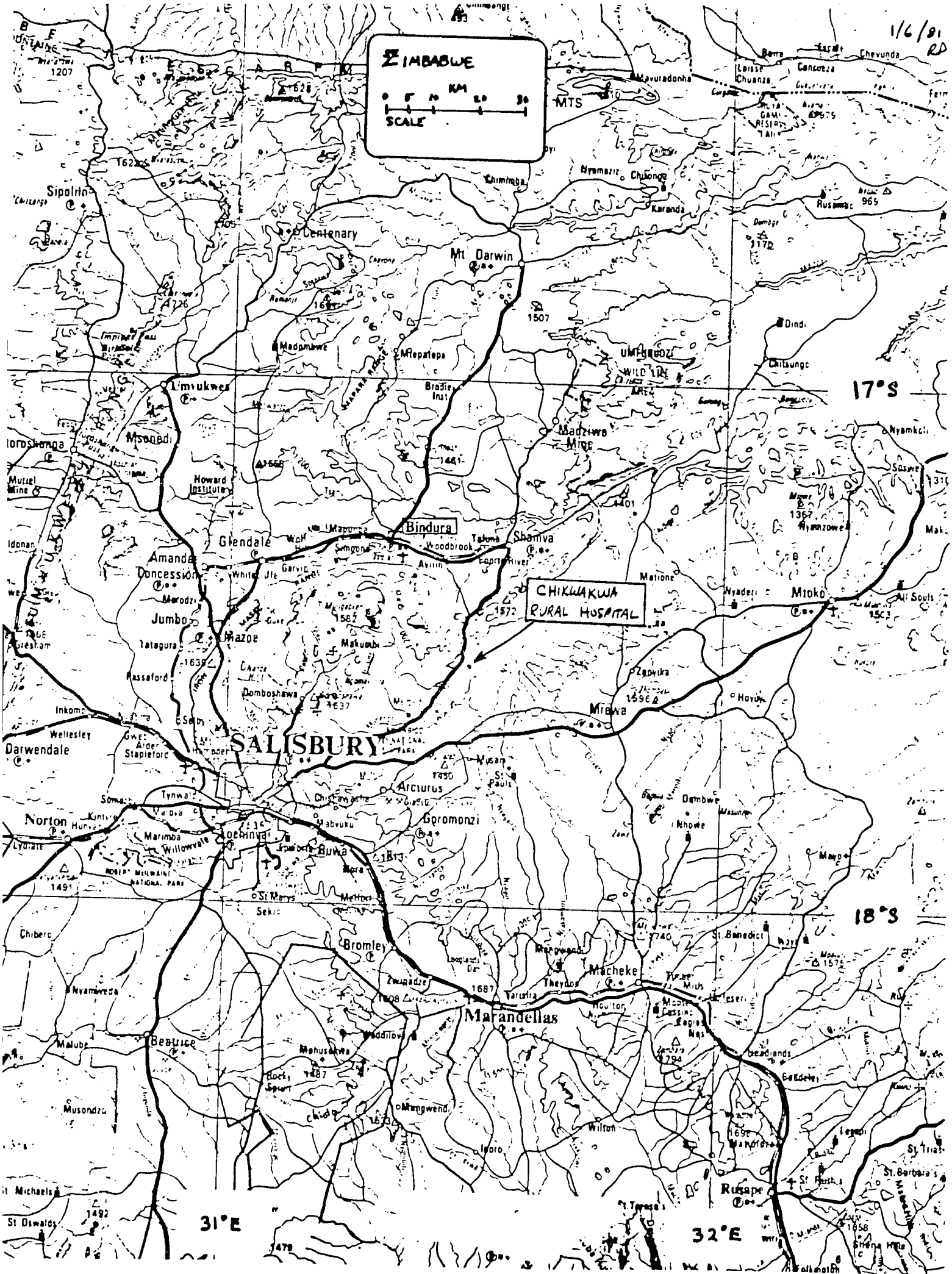


Figure A.1 -Geographic Location of Chikwakwa Rural Hospital, Zimbabwe

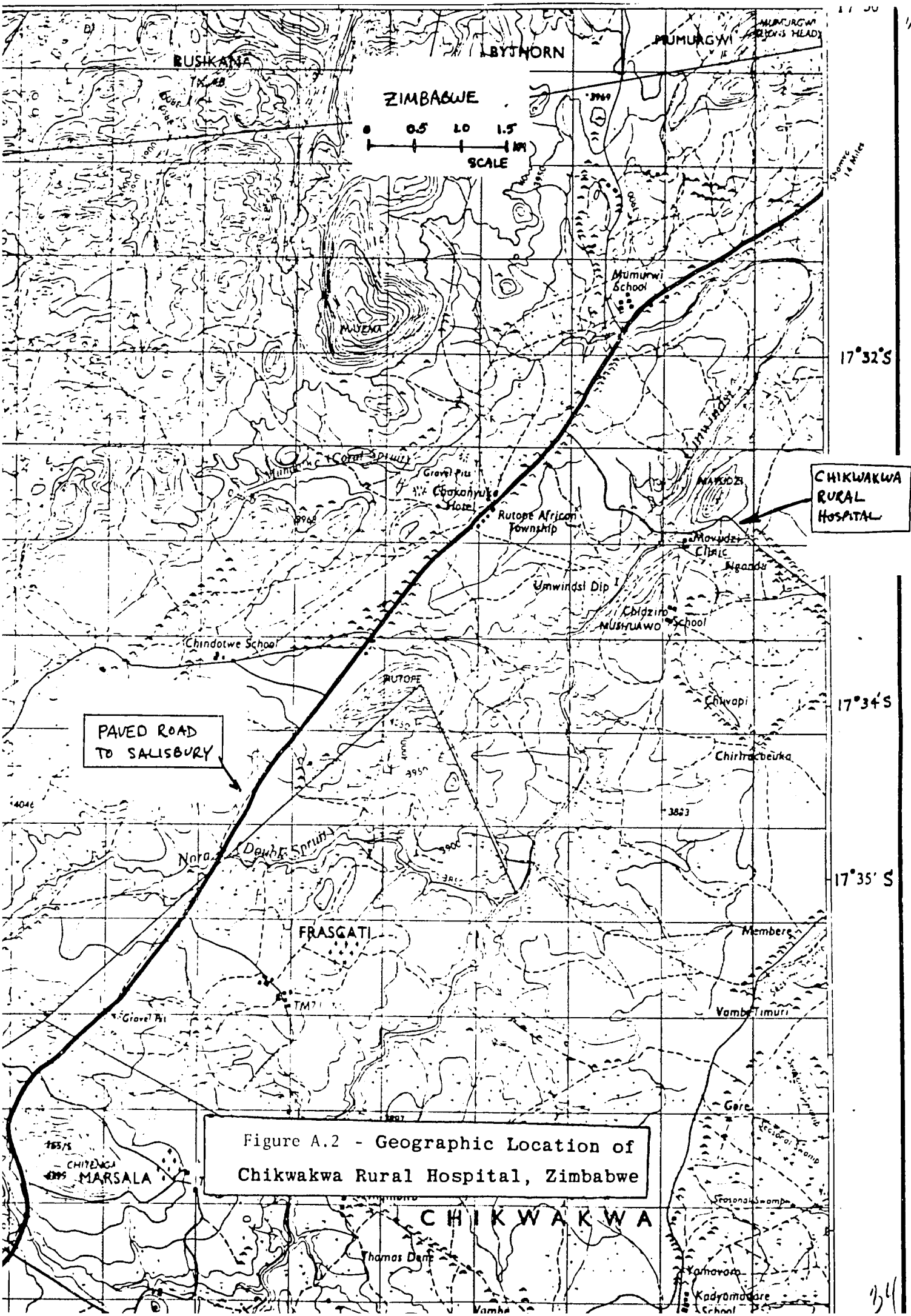


Figure A.2 - Geographic Location of Chikwakwa Rural Hospital, Zimbabwe

1/6/81 RD

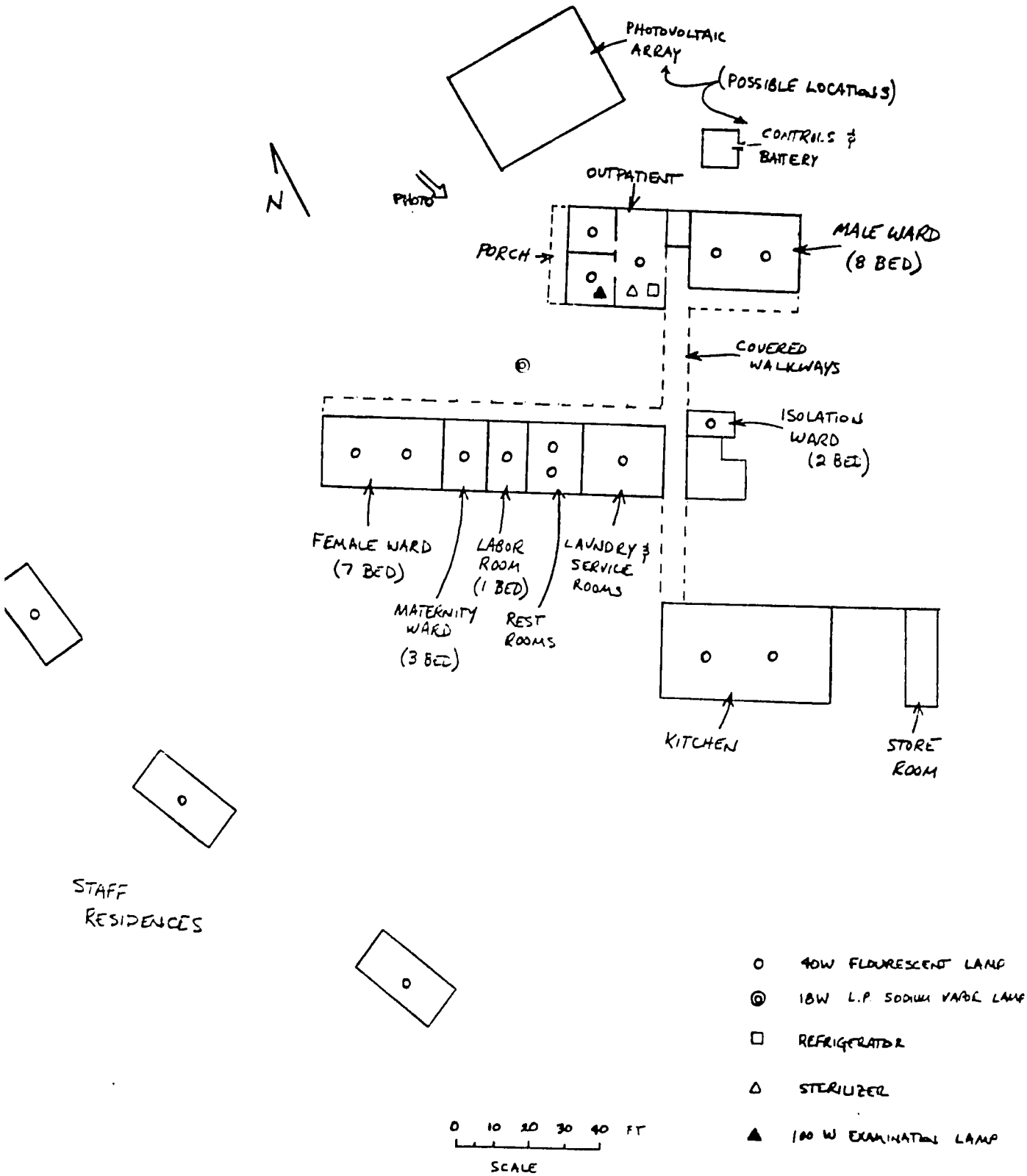


Figure A.3 Site Plan and Load Locations, Chikwakwa Rural Hospital, Zimbabwe

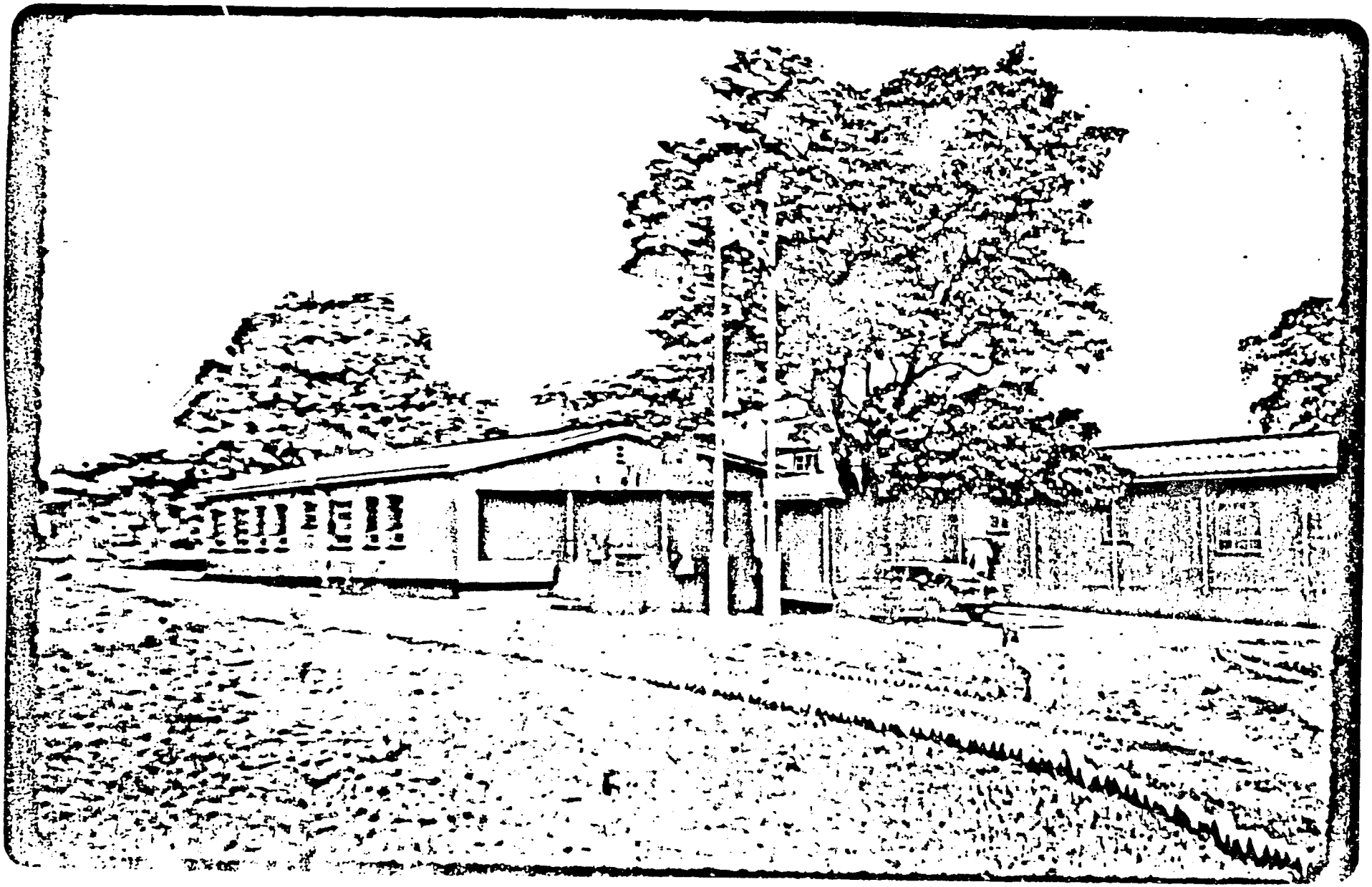


Figure A.4 - Chikwakwa Rural Hospital, Zimbabwe

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RD

Table A.2 - Proposed Load Profile for Chikwakwa, Zimbabwe

Load Device	Location	No.	Power (W)	Usage (hrs/day)	Usage (WH/day)
Fluorescent Lamp	Outpatient	3	40	3	360
	Male Ward	2	"	2	160
	Female Ward	2	"	2	160
	Maternity Ward	1	"	2	80
	Labor Room	1	"	2	80
	Rest Rooms	2	"	1	80
	Laundry & Service	1	"	1	40
	Isolation Ward	1	"	1	40
	Kitchen	2	"	1	80
	Residences	3	"	1	120
Examination Lamp	Outpatient	1	100	2	200
LP Sodium Vapor Lamp	Exterior	1	18	12	216
Refrigerator(1)	Outpatient	1	86.7	14.4	1248
Sterilizer	Outpatient	1	1200	1	1200
Discretionary - TBD					125
	TOTAL				4189

(1) Steady-state cycling in 43° C ambient environment, freezer and refrigerator loaded with simulated vaccine and frozen cold packs.

Table A.3 - Site Information - Kibwezi Health Center

LOCATION

Country Kenya, Africa

City (Town, Province or Area) Kibwezi

Language(s) Spoken Englisn, Swahili (Official language: English)

Latitude 2° 25' S Longitude 38° 0' E Elevation 3000'

Description of Access to Site (Transportation Means, Seasonal Considerations, etc.)

Situated on main (hard top) road, Class A International Trunk Road, year-round accessibility, railroad stop in Kibwezi [railroad from Nairobi to Mombosa].

Distance and Time from Major City 200 Km (124 mi) from Nairobi, 2-1/2 hours.

Distance, Time, and Location of Accommodations Hunter's Lodge, 24 miles by paved road, 30 minutes. Hotels and restaurants available in Nairobi.

NATURAL FEATURES

Topography Rolling uplands.

Vegetation Thorn scrubs and trees of game plants - not very dense - clean area for PV array available.

General Climate (Seasonal) 2 rainy seasons (April/May - Oct/Nov). 2 dry seasons, warm days/cool nights.

SITE FACILITY

Type Health center with health care training

Existing Facilities (under construction) inpatient, outpatient, operation theatre, water supply from nearby railroad supply, septic tanks, dormitory, classroom, laundry, kitchen, staff housing.

Services Provided Inpatient, outpatient, operation theatre, training.

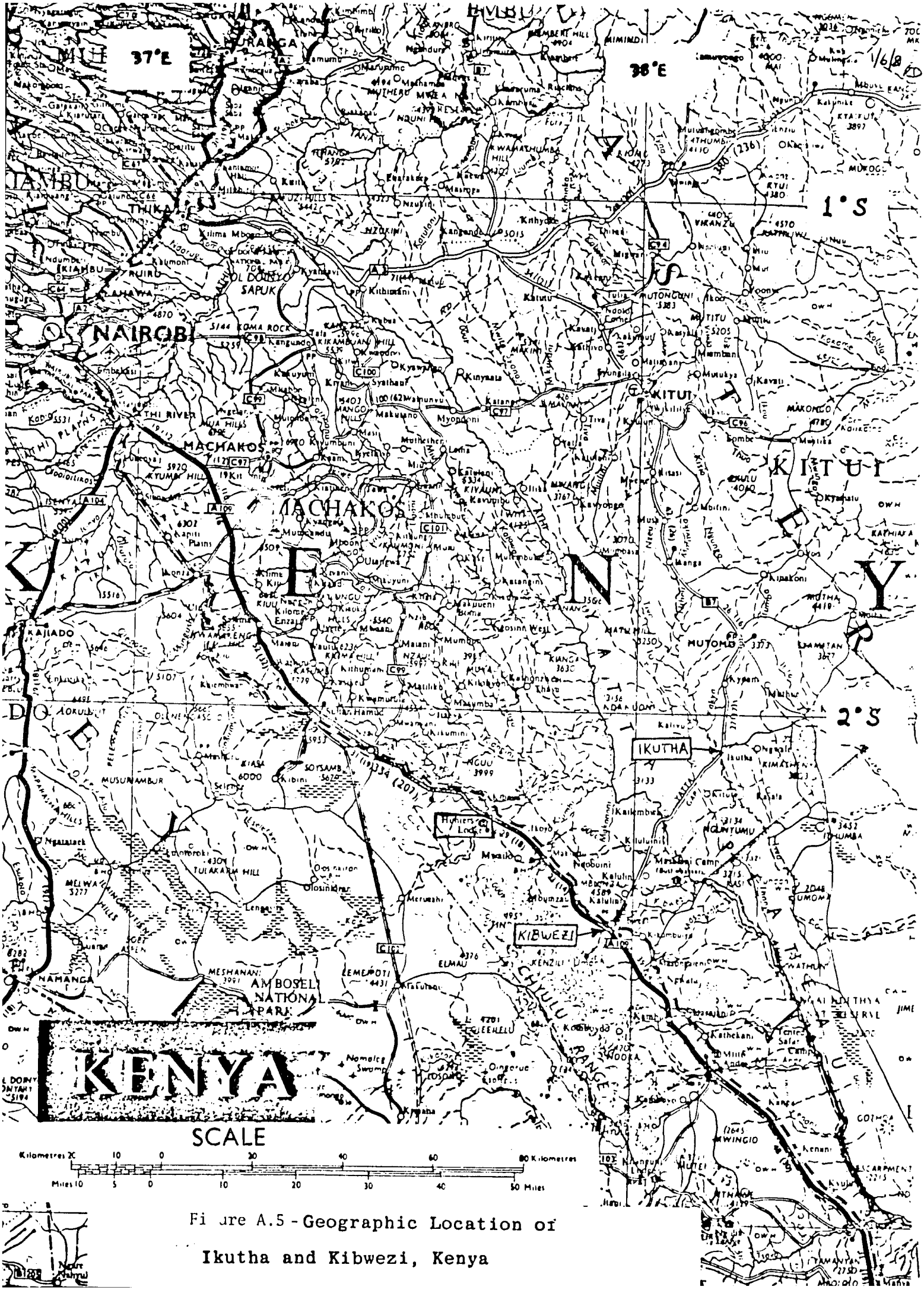

Figure A.5 - Geographic Location of Ikutha and Kibwezi, Kenya

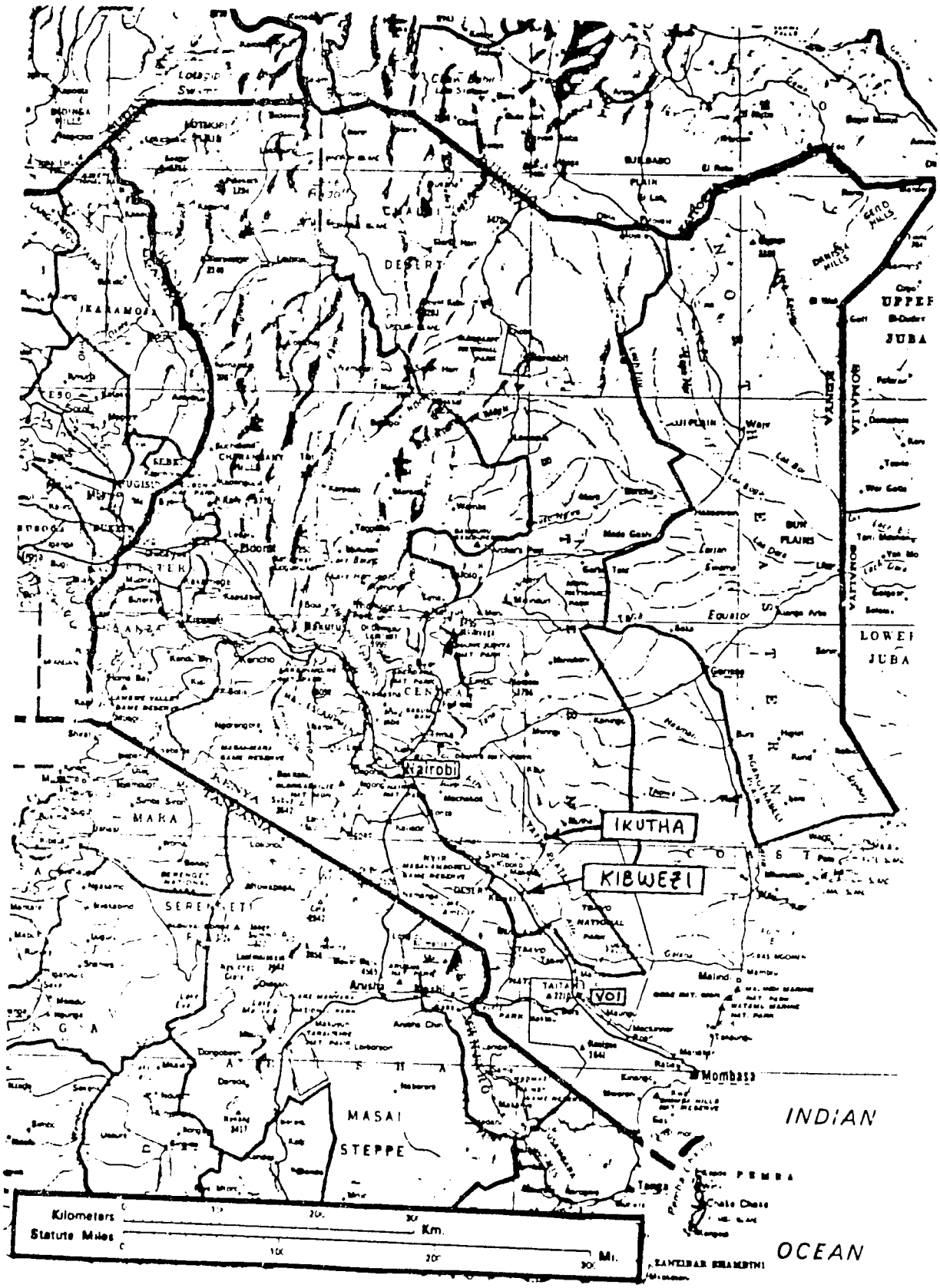

Figure A.6 - Geographic Location of Ikutha and Kibwezi, Kenya

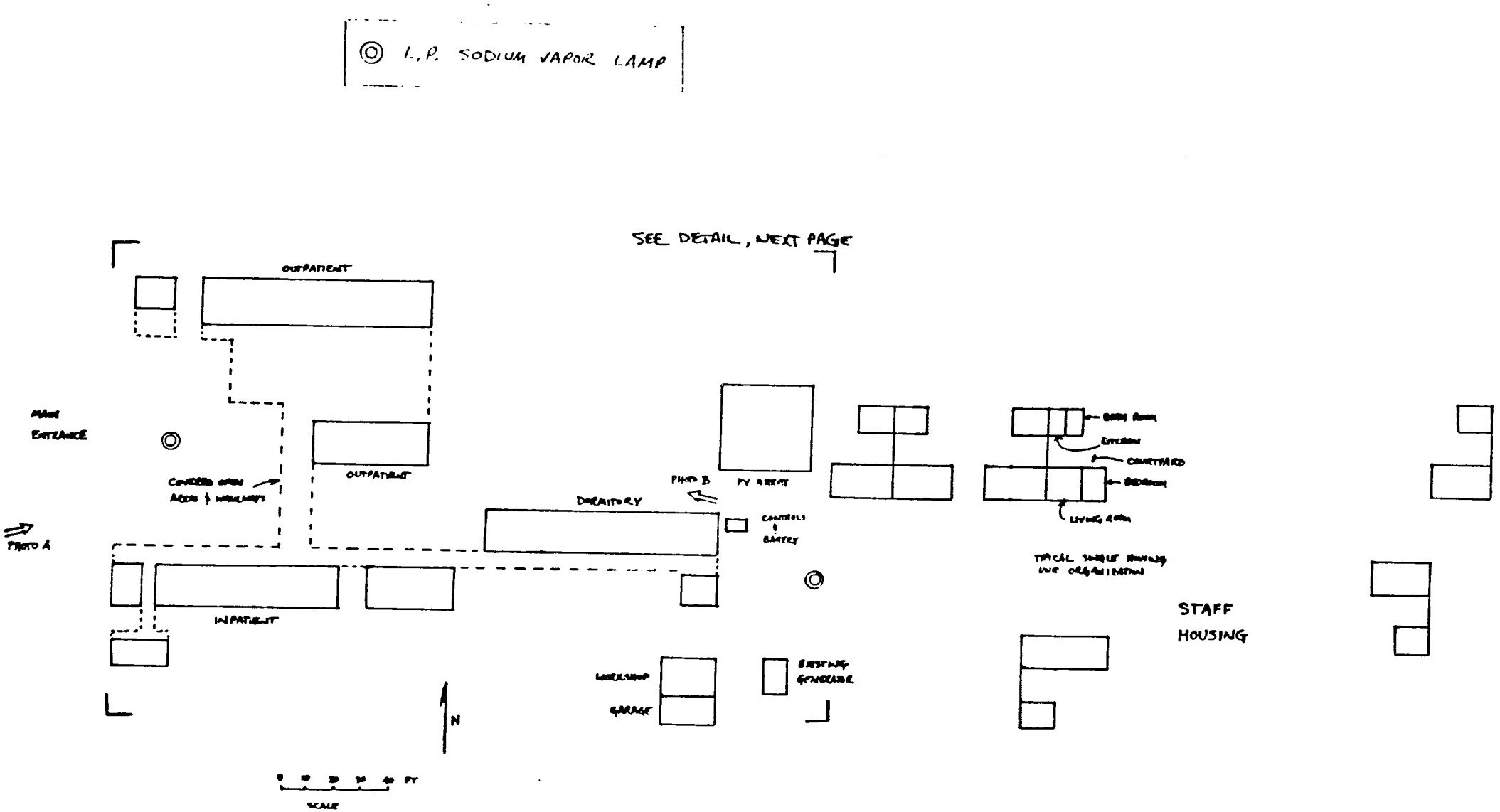

Figure A.7 - Site Plan, Kibwezi Health Center, Kenya

1/6/81 RD

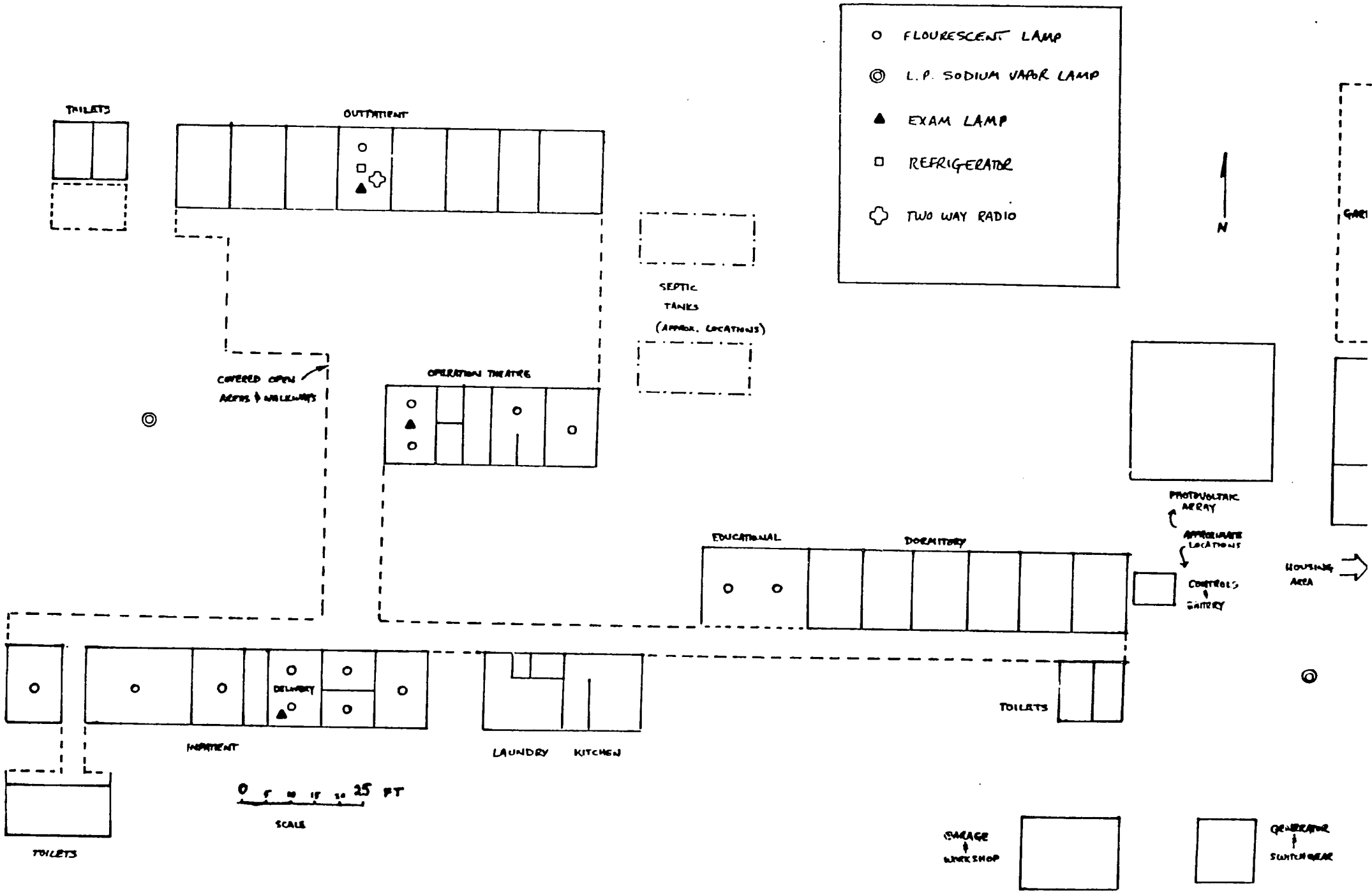

Figure A.8 - Load Locations, Kibwezi Health Center, Kenya

Figure A.9 - Kibwezi Health Center (Front, Photo A), Kenya

Figure A.10 - Kibwezi Health Center (Rear, Photo B), Kenya

Table A.4 - Proposed Load Profile for Kibwezi, Kenya

Load Device	Location	No.	Power (W)	Usage (hrs/day)	Usage (WH/day)
Fluorescent Lamp	Outpatient	1	40	4	160
	Operation Theatre	4	"	2	320
	Inpatient	8	"	3	960
	Educational Room	2	"	3	240
LP Sodium Vapor Lamp	Exterior - Front	1	18	12	216
	" - Middle	1	"	12	216
Examination Lamp	Outpatient	1	100	3	300
	Operation Theatre	1	"	1	100
	Inpatient	1	"	2	200
Refrigerator(1)	Outpatient	1	86.7	14.4	1248
Two-Way Radio	Inpatient	1	25	1	25
Discretionary - TBD					125
	TOTAL				4110

(1) Steady-state cycling in 43° C ambient environment, freezer and refrigerator loaded with simulated vaccine and frozen cold packs.

Table A.5 - Site Information - Ikutha Health Station

LOCATION

Country Kenya, Africa

City (Town, Province or Area) Ikutha

Language(s) Spoken English, Swahili (official language: English)

Latitude 2° 4' S Longitude 38° 11' E Elevation 2500' (approx.)

Description of Access to Site (Transportation Means, Seasonal Considerations, etc.)

Situated on Class B National Trunk Road (unpaved but relatively good surface) - accessible year-round with day-to-day possibility of impassability during rainy season. Railroad access through Kibwezi.

Distance and Time from Major City 50 Km (31 mi) from Kibwezi, 1 hour. 250 Km (155 mi) from Nairobi, 3-1/2 hours.

Distance, Time, and Location of Accommodations Hunter's Lodge (food and lodging) 55 miles (24 miles paved, 31 miles unpaved), 1-1/2 hours. Hotels and restaurants available in Nairobi.

NATURAL FEATURES

Topography Rolling uplands

Vegetation Thorn scrubs (not very dense) - clear area of PV array available.

General Climate (Seasonal) 2 dry seasons - warm days/cool nights, 2 rainy seasons (April/May - Oct/Nov).

SITE FACILITY

Type Health Station staffed by medical officer and nurse.

Existing Facilities Maternity ward, labor room, maternity child care and family planning, examination room, dressing room and injections, pharmacy, registration and statistics.

Services Provided Maternity, maternal child care and family planning, outpatient clinic.

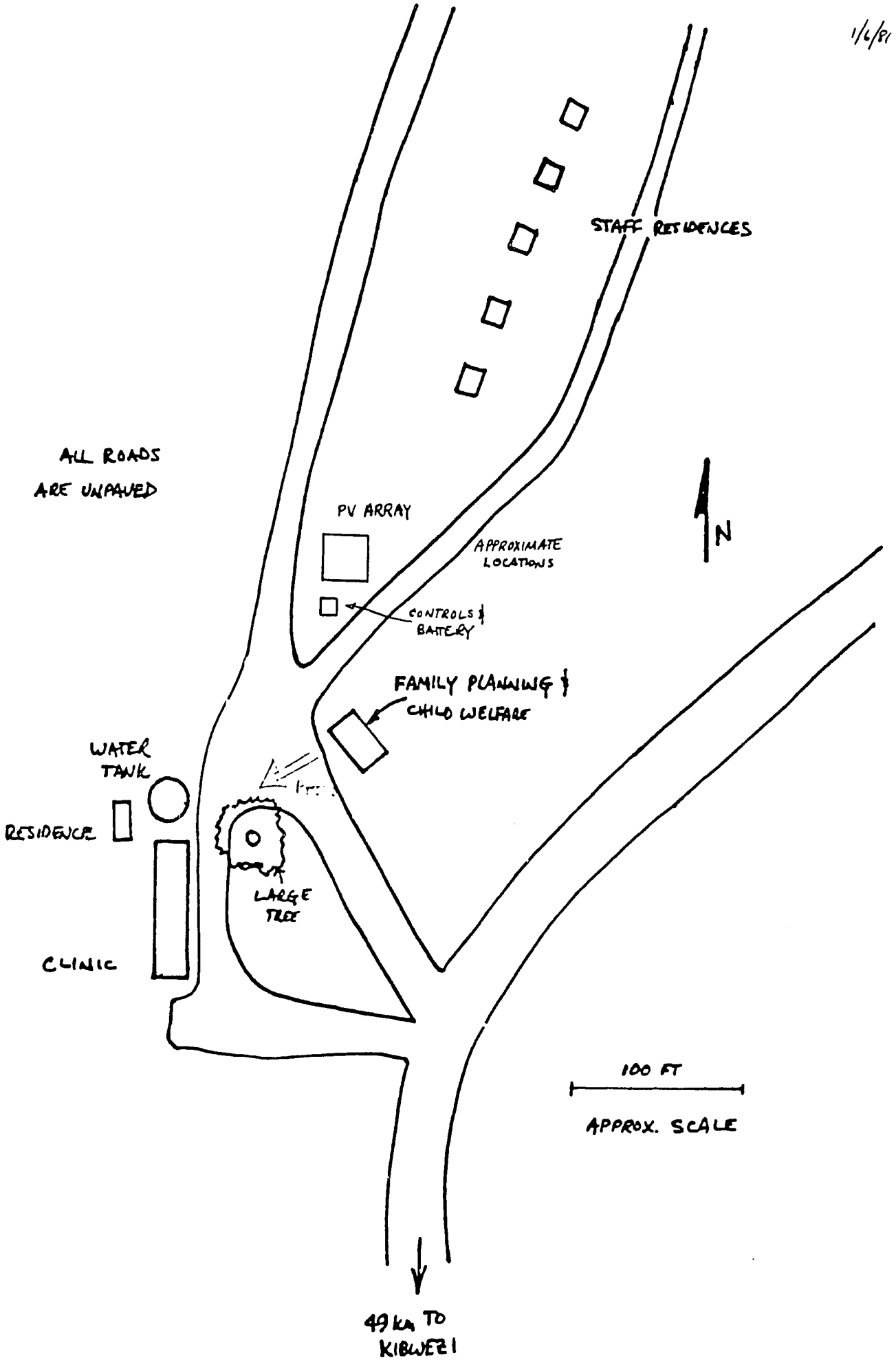

Figure A.11 - Site Plan, Ikutha Health Station, Kenya

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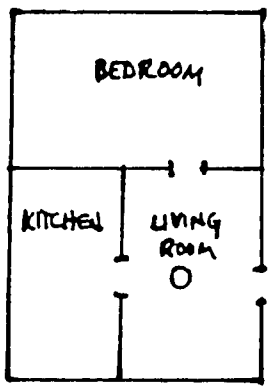
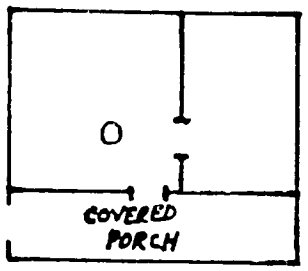
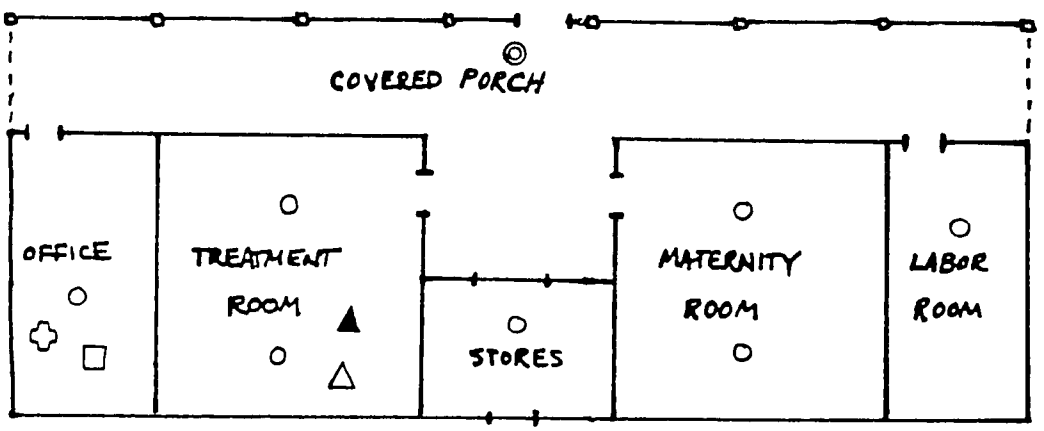
12D



STAFF RESIDENCE
(TYPICAL ONE OF FIVE)



FAMILY PLANNING & CHILD WELFARE



CLINIC

APPROX. SCALE

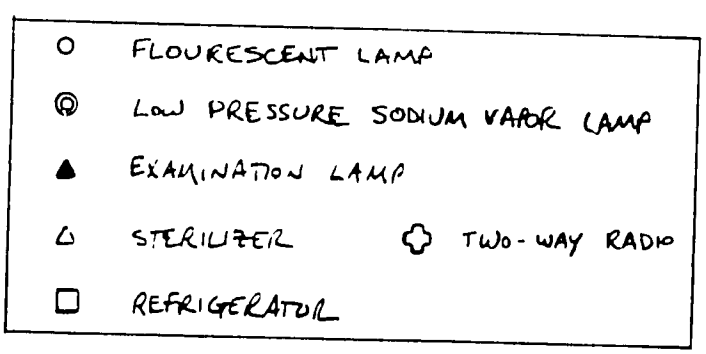


Figure A.12 - Load Locations, Ikutha Health Station, Kenya

Figure A.13 - **Ikutha Health Station, Ikutha, Kenya**

Table A.6 - Proposed Load Profile for Ikutha, Kenya

Load Device	Location	No.	Power (W)	Usage (hrs/day)	Usage (WH/day)
Fluorescent Lamp	Office	1	40	2	80
	Treatment Room	2	"	3	240
	Store Room	1	"	1	40
	Maternity Room	2	"	3	240
	Labor Room	1	"	3	120
	Family Planning	1	"	3	120
	Residences	5	"	1-1/2	300
Examination Lamp	Treatment Room	1	100	2	200
LP Sodium Vapor Lamp	Exterior	1	18	12	216
Refrigerator(1)	Office	1	86.7	14.4	1248
Sterilizer	Treatment Room	1	1200	1	1200
Two-Way Radio	Office	1	25	1	25
Discretionary - TBD					125
	TOTAL				4154

(1) Steady-state cycling in 43° C ambient environment, freezer and refrigerator loaded with simulated vaccine and frozen cold packs.

Table A.7 - Site Information - Pedro Vicente Maldonado Health Sub-center

LOCATION

Country Ecuador, South America

City (Town, Province or Area) Pedro Vicente Maldonado

Language(s) Spoken Spanish (Official language: Spanish)

Latitude 0° 5' N Longitude 79° 5' W Elevation 1500'

Description of Access to Site (Transportation Means, Seasonal Considerations, etc.)

Transportation by road, ≈90% paved roads, ≈10% gravel road from Quito (city) to Pedro Vicente Maldonado.

Distance and Time from Major City Quito - Santo Domingo de Los Colorados, 2.25 hrs. and 80 KMS. Santo Domingo de Los Colorados to Pedro Vicente Maldonado 2.75 hrs. and 80 KMS.

Distance, Time, and Location of Accommodations Hotel in Santo Domingo de Los Colorados.

NATURAL FEATURES

Topography foot hills.

Vegetation Tropical trees, bushes, grasses.

General Climate (Seasonal) Tropical areas.

SITE FACILITY

Type Health sub-center staffed by medical officers.

Existing Facilities (to be constructed) general consultory, dental consultory, gynecology, hydration, observation.

Services Provided Outpatient, dental care, child care, vaccination, family planning.

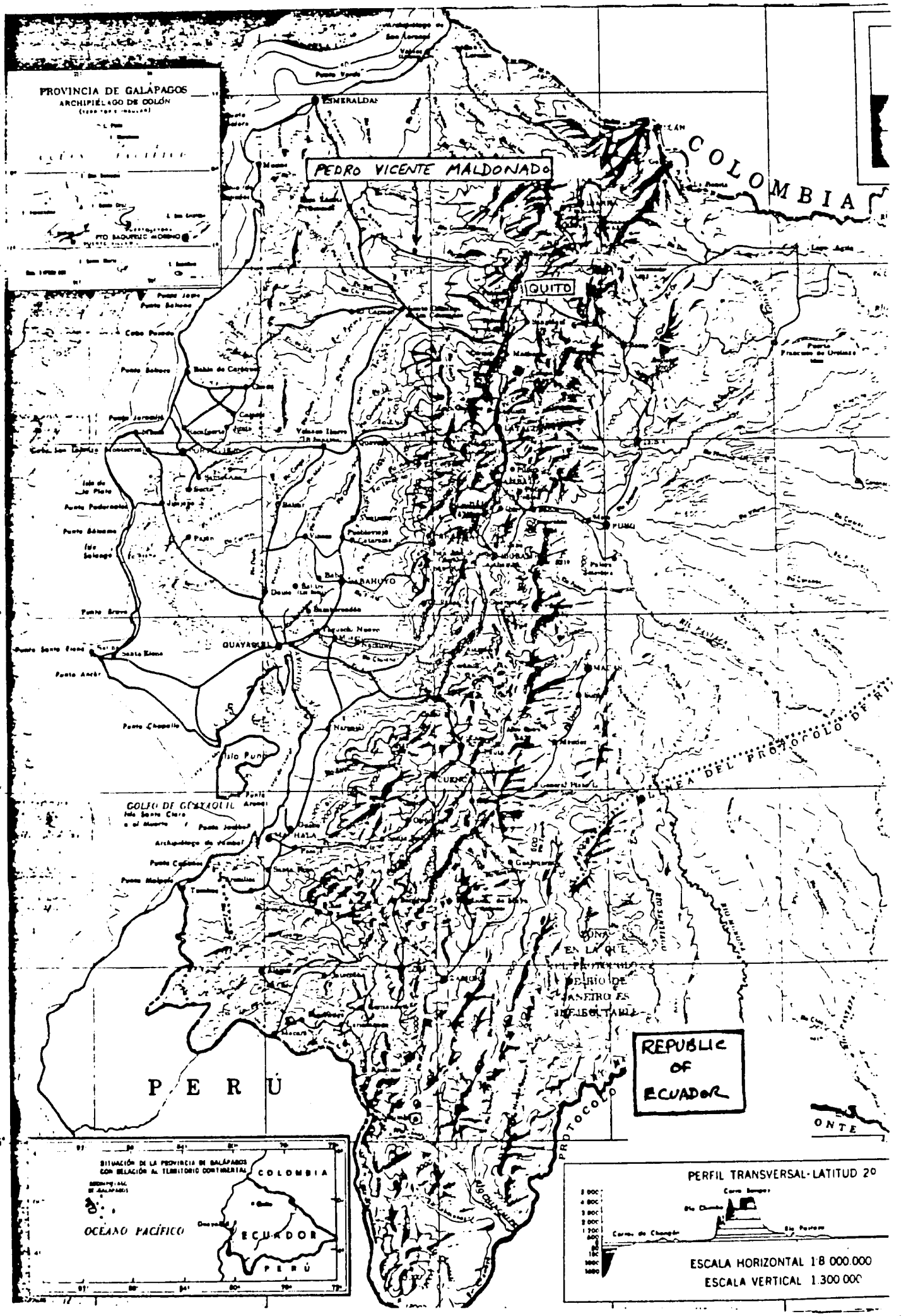
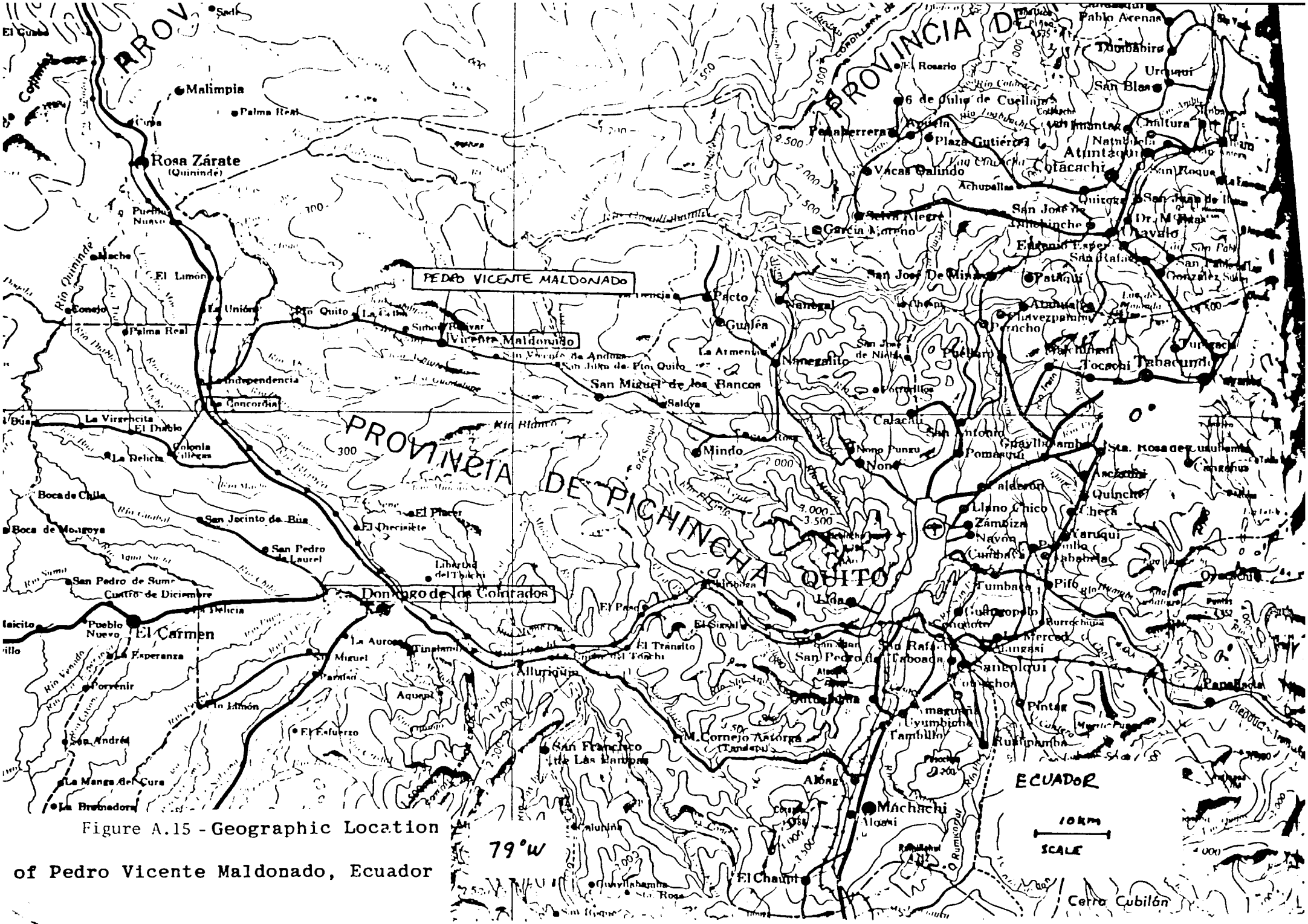


Figure A.14 - Geographic Location of Pedro Vicente Maldonado, Ecuador


PROVINCIA DE PICHINCHA
PEDRO VICENTE MALDONADO
Rosa Zárate
(Quinindé)
Malimpia
Palma Real
Puerto Nuevo
El Limón
Conejo
La Unión
Palma Real
Rio Quinindé
Rio Blanco
Rio Quito
Vicente Maldonado
Independencia
La Concordia
La Virgencita
El Diablo
Colonia Villegas
La Delicia
Boca de Chila
Boca de Montoya
San Jacinto de Buá
El Placer
El Diecisiete
San Pedro de la Laurel
Libertad del Toachi
San Pedro de Sumo
Cuatro de Diciembre
Santo Domingo de los Colorados
Pueblo Nuevo
El Carmen
La Esperanza
Porvenir
La Aurora
Tinalandia
Aquepi
El Esfuerzo
San Andrés
La Manga del Cura
La Bramadora
Pacto
Gualea
Nanegal
La Armenia
Nanegalito
San Miguel de los Bancos
Saloya
Mindo
Nono
Calacalí
San Antonio
Pomasqui
Gualchamba
Sta. Rosa de Cuzubamba
Cangahua
Ascazubi
Quinche
Checa
Caruqui
Llano Chico
Zámbiza
Navón
Cumbayá
Tumbaco
Pifo
Yaruquí
Oyacachi
QUITO
Lloa
El Tránsito
Alluriquín
San Francisco de Las Barrancas
M. Cornejo Astorga
(Tandapi)
Aloag
Machachi
Aloasí
El Chaupi
Cerro Cubilán
Pedro Vicente Maldonado
Pedro Moncayo
Cayambe
Tabacundo
Otavalo
Ibarra
Atuntaqui
Cotacachi
Urcuquí
San Blas
Tulcán
Pablo Arenas
Quito
Pomasqui
Sangolquí
Machachi
Latacunga
Ambato
Riobamba
Cuenca
Quito
Ibarra
Otavalo
Cayambe
Tulcán
Pedro Vicente Maldonado
Santo Domingo de los Colorados

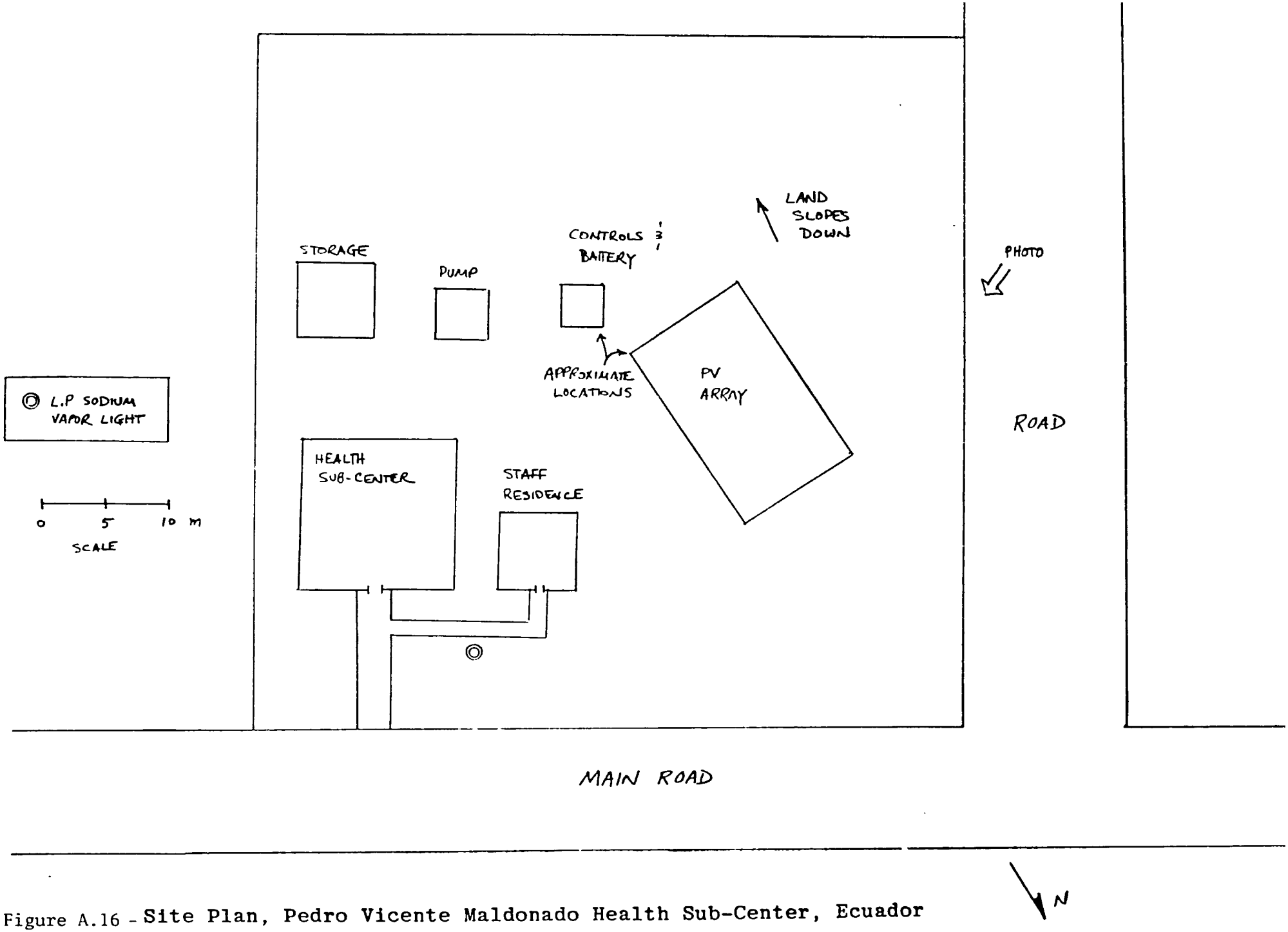


Figure A.16 - Site Plan, Pedro Vicente Maldonado Health Sub-Center, Ecuador

1/6/M RD

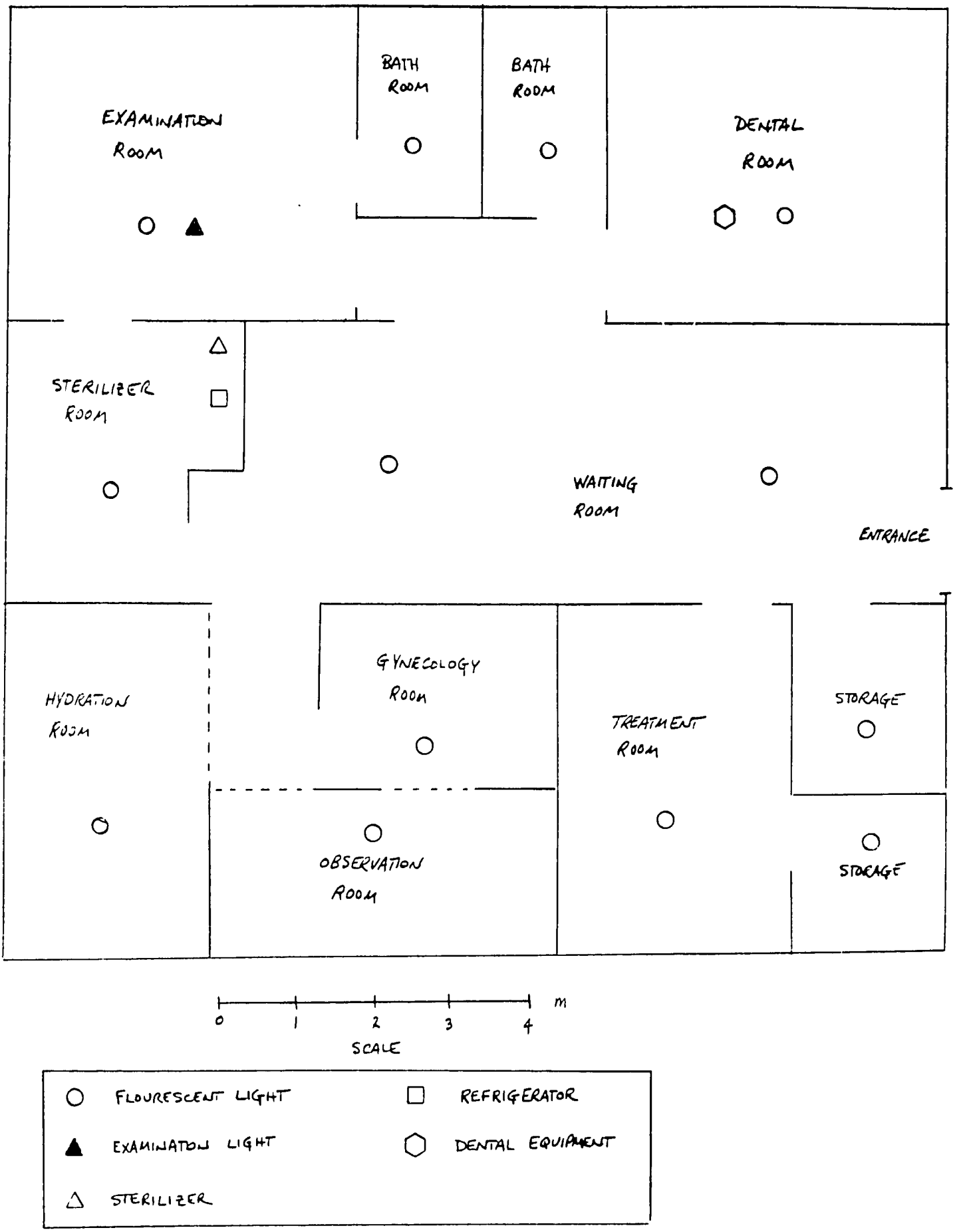


Figure A.17 - Load Locations, Pedro Vicente Maldonado Health Sub-Center, Ecuador

1/6/81 RD

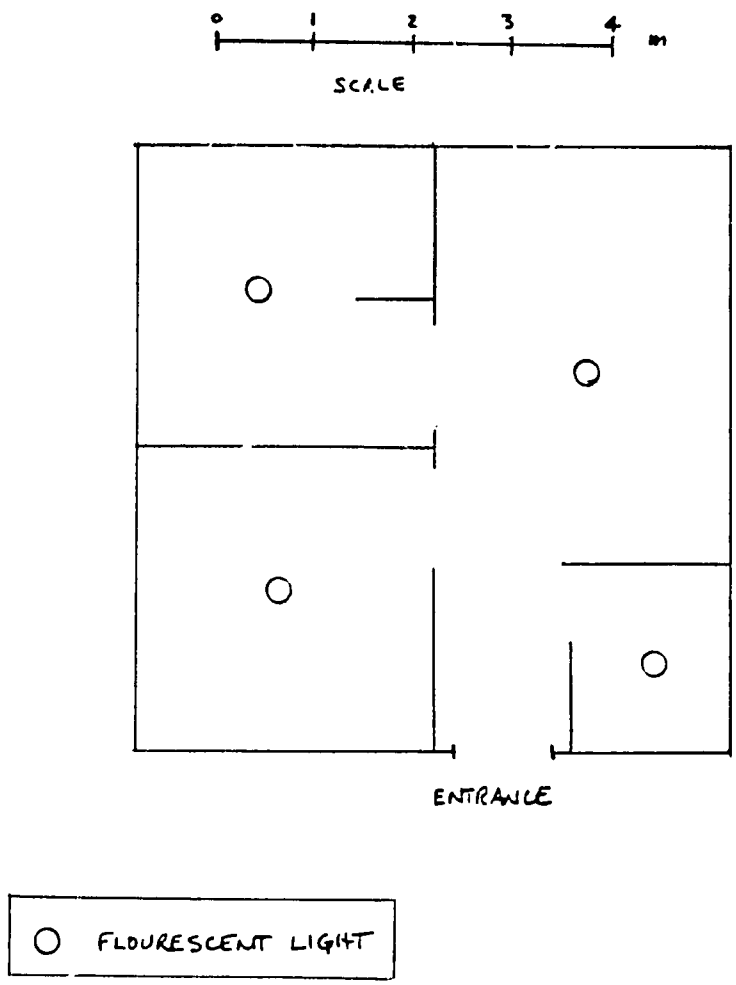


Figure A.18 - Staff Residence Load Locations, Pedro Vicente Maldonado Health Sub-Center, Ecuador

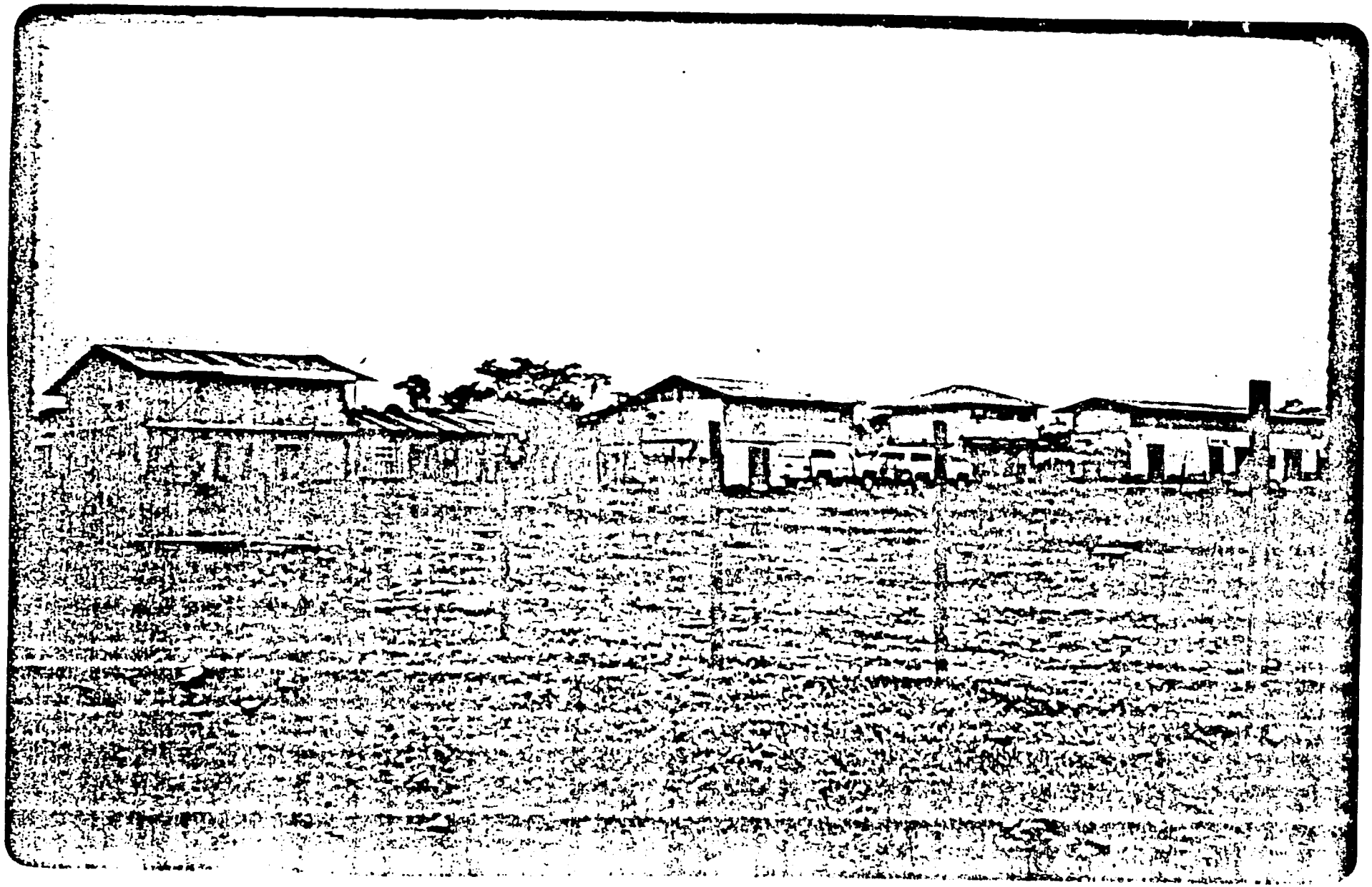


Figure A.19 - Health Sub-Center Site (Foreground), Pedro Vicente Maldonado Health Sub-Center, Ecuador

Figure A.20 - Standard Health Sub-Center, Guayllabamba, Ecuador

Table A.8 - Proposed Load Profile for P. V. Maldonado, Ecuador

Load Device	Location	No.	Power (W)	Usage (hrs/day)	Usage (WH/day)
Fluorescent Lamp	Waiting Room	2	40	3	240
	Examination Room	1	"	3	120
	Dental Room	1	"	3	120
	Sterilizer Room	1	"	1	40
	Hydration Room	1	"	1	40
	Observation Room	1	"	1	40
	Gynecology Room	1	"	1	40
	Treatment Room	1	"	3	120
	Service Rooms	4	"	1	160
	Residence	4	"	1-1/2	240
Examination Lamp	Examination Room	1	100	1	100
LP Sodium Vapor Lamp	Exterior	1	18	10	180
Refrigerator (1)	Sterilizer Room	1	86.7	14.4	1248
Sterilizer	Sterilizer Room	1	1200	1	1200
Dental Drill	Dental Room	1	279	0.7	200
Discretionary - TBD					125
	TOTAL				4213

(1) Steady-state cycling in 43° C ambient environment, freezer and refrigerator loaded with simulated vaccine and frozen cold packs.

Table A.9 - Site Information, Waramuri Health Station

LOCATION

Country Guyana, South America

City (Town, Province or Area) Waramuri Mission

Language(s) Spoken English (official language: English)

Latitude 7°30'N Longitude 59° W Elevation 60'

Description of Access to Site (Transportation Means, Seasonal Considerations, etc.)

Fly from Georgetown to Akwero, or drive to Akwero, boat to Waramuri. Rainy seasons: April to August and November to January. Heavy equipment possibly shipped by barge from Georgetown.

Distance and Time from Major City 75 miles to Georgetown, 1/2 hour by air to Aquero; 1/2 hour by boat to Waramuri

Distance, Time, and Location of Accommodations Guest house at Akwero, bring own food.

NOTE: Present construction contractor has set up own facilities at site. Possibility of houseboat on Maruka River.

NATURAL FEATURES

Topography Flat, sloping land (6-7°) down from structure in southerly direction.

Vegetation Topical vegetation, medium height trees

General Climate (Seasonal) Tropical year around. Rainy seasons: April to Aug. and November to January.

SITE FACILITY

Type 1 story hollow tile and brick structure, 8 rooms, storage and bath facilities, attached 4-room living quarters.

Existing Facilities (under construction) staff quarters, maternity, out-patient, family planning and education.
Water & sewer.

Services Provided

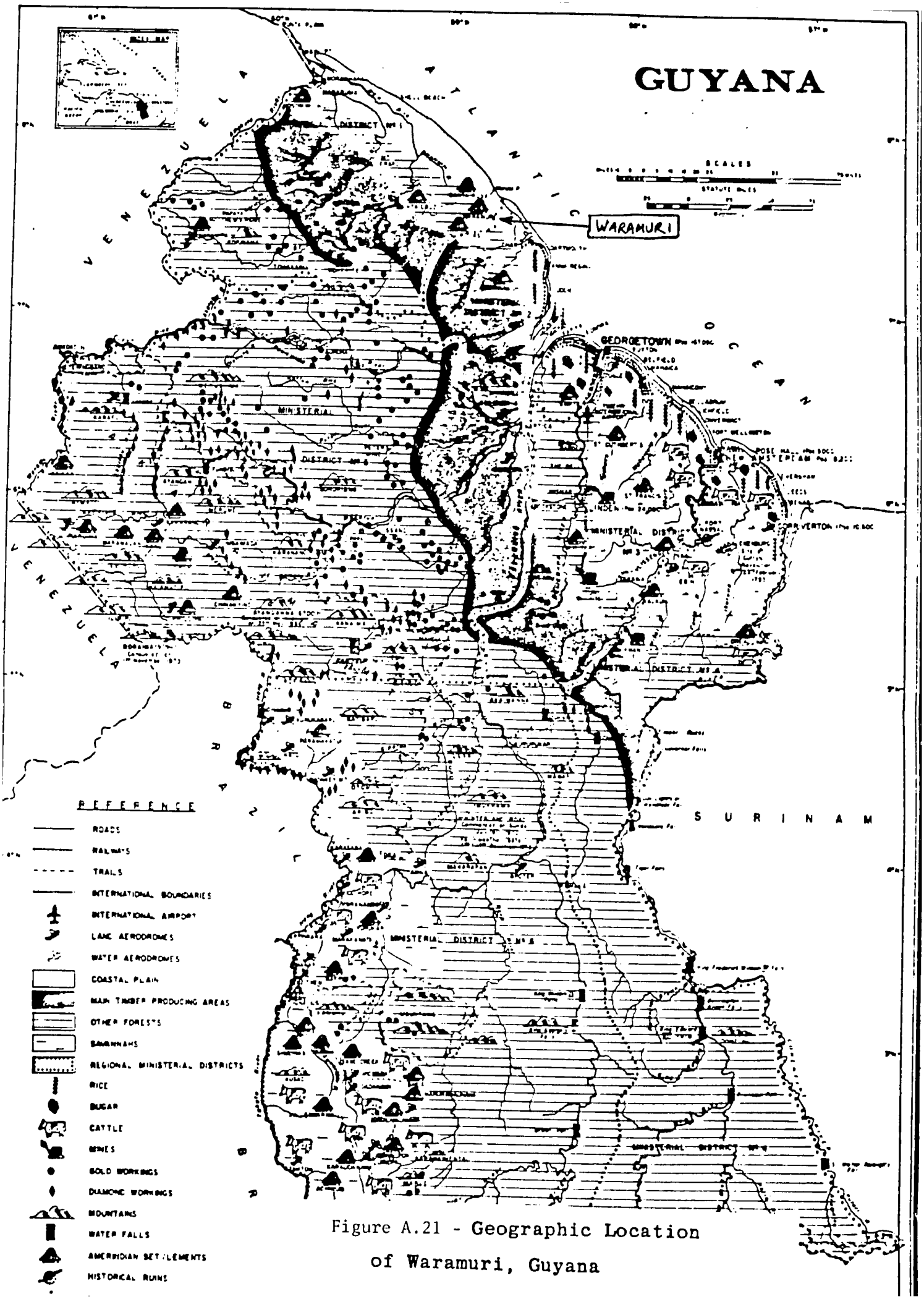


Figure A.21 - Geographic Location of Waramuri, Guyana

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RD

GUYANA

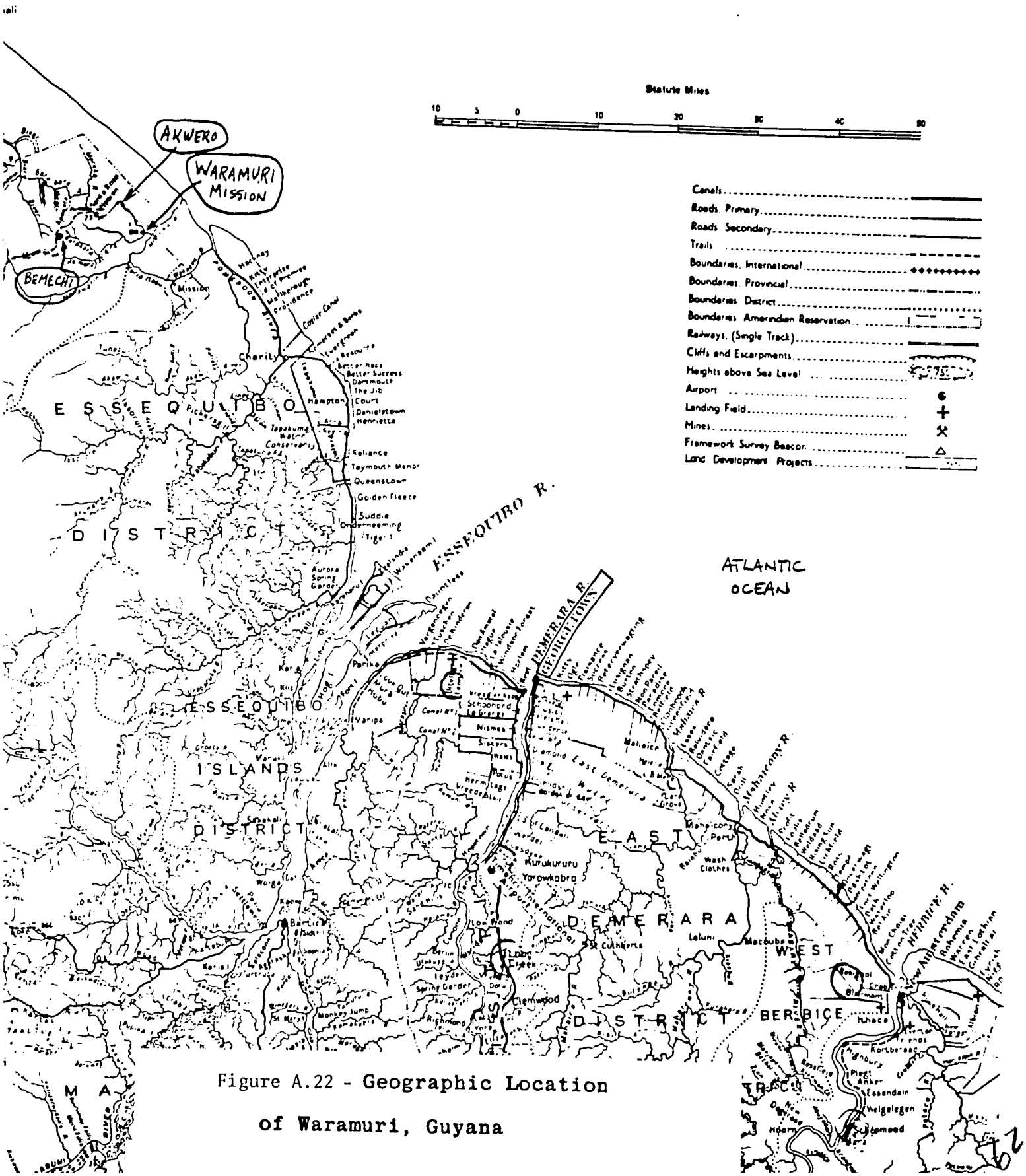

Figure A.22 - Geographic Location of Waramuri, Guyana

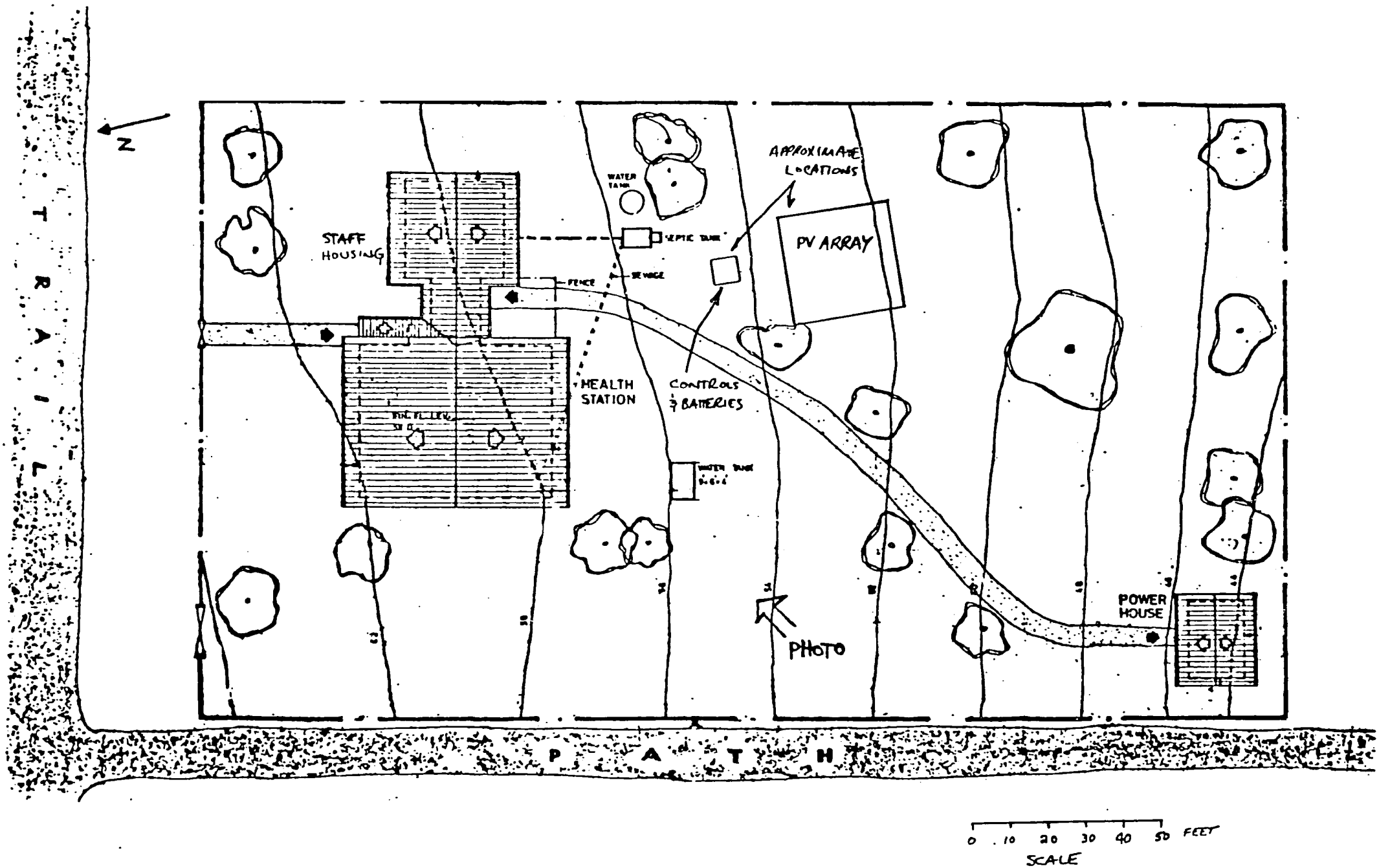

Figure A.23 - Site Plan, Waramuri Health Station, Guyana

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1/6/81 RD

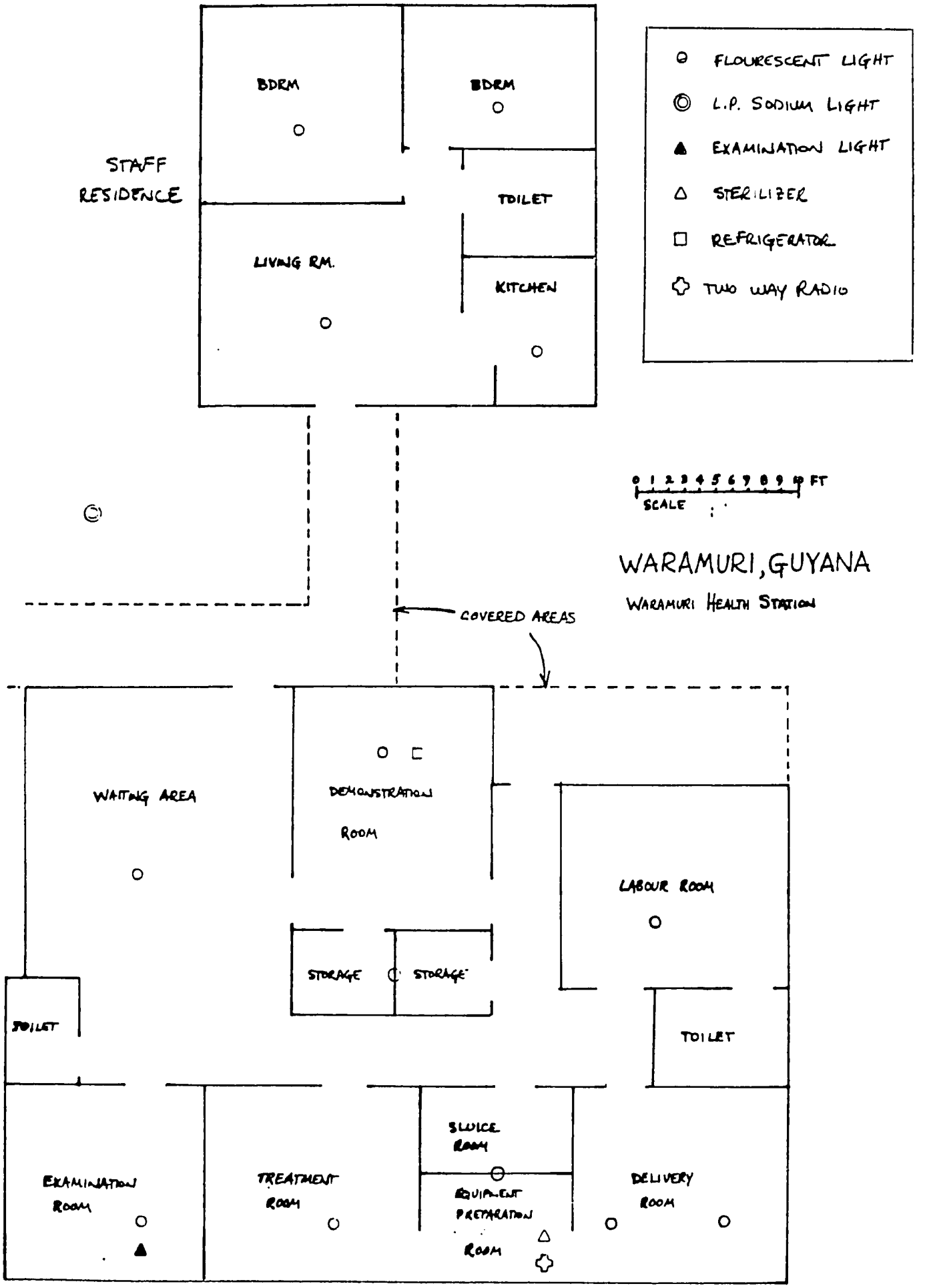

Figure A.24 - Load Locations, Waramuri Health Station, Guyana

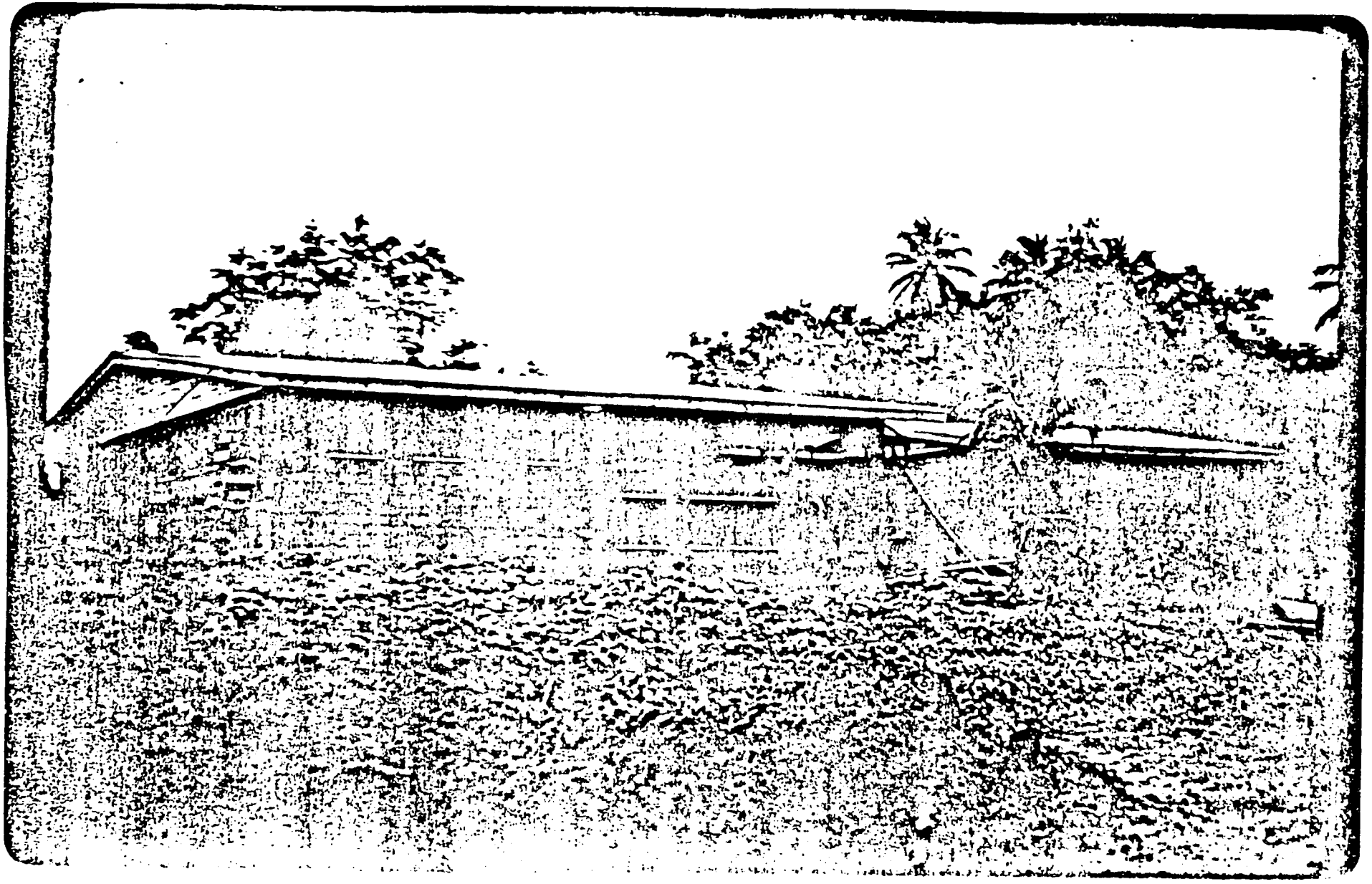

Figure A.25 - Waramuri Health Station, Waramuri, Guyana

Table A.10 - Proposed Load Profile for Waramuri, Guyana

Load Device	Location	No.	Power (W)	Usage (hrs/day)	Usage (WH/day)
Fluorescent Lamp	Examination Room	1	40	3	120
	Treatment Room	1	"	3	120
	Sterilizer Room	1	"	2	80
	Delivery Room	2	"	2	160
	Labor Room	1	"	1	40
	Demonstration Room	1	"	3	120
	Storage Rooms	1	"	1	40
	Waiting Area	1	"	3	120
	Residence	4	"	2	320
Examination Lamp	Examination Room	1	100	2	200
LP Sodium Vapor Lamp	Exterior	1	18	12	216
Refrigerator(1)	Demonstration Room	1	86.7	14.4	1248
Sterilizer	Sterilizer Room	1	1200	1	1200
Two-Way Radio	Sterilizer Room	1	25	1	25
Discretionary - TBD					125
	TOTAL				4134

(1) Steady-state cycling in 43° C ambient environment, freezer and refrigerator loaded with simulated vaccine and frozen cold packs.

8.2 - APPENDIX B

SITE METEOROLOGICAL DATA

TABLE B.1

METEOROLOGICAL DATA

PROJECT LOCATION: Chikwakwa, Zimbabwe

PARAMETER	① * INSOLATION AVE: 505	② * AVE: 482	① * SUNSHINE MEAN HRS/DAY AVE: 8.0		① * RAINFALL MEAN TOTAL (YEAR TOTAL = 814.8)	② * (YEAR TOTAL = 918.7)							
UNIT	L/DAY	L/DAY	HRS/DAY		mm	mm							
JAN	533	496	6.2		189.3	229.1							
FEB	511	492	6.4		172.2	185.8							
MAR	506	514	7.4		100.2	140.5							
APR	477	481	8.0		33.1	36.4							
MAY	444	449	8.5		11.0	8.2							
JUN	411	399	8.6		3.2	2.5							
JUL	438	424	9.2		0.6	1.2							
AUG	503	468	9.6		2.8	0.5							
SEP	569	523	9.7		6.5	2.8							
OCT	593	552	9.1		29.7	21.3							
NOV	559	501	6.8		93.8	92.3							
DEC	519	488	6.0		172.4	199.1							

NASA

*DATA STATION LOCATIONS:

① SALISBURY

② BINDURA

TABLE B.2

METEOROLOGICAL DATA

PROJECT LOCATION: WARAMURI, GUYANA

PARAMETER	① * INSOLATION AVG: 431		① * HOURS of SUN AVG: 6.8		① * RAINFALL 1973/1977 (TOTAL 108.5/112.3)								
UNIT	L/day		HOURS		INCHES								
JAN	390		6.2		2.16/4.73								
FEB	430		6.7		0.9/3.11								
MAR	440		6.3		0.62/3.16								
APR	450		6.6		4.04/5.00								
MAY	410		5.9		5.18/14.8								
JUN	400		5.7		11.6/15.8								
JUL	440		7.0		8.77/11.7								
AUG	470		7.7		8.25/13.7								
SEP	490		8.3		15.0/4.27								
OCT	460		7.8		13.7/6.41								
NOV	420		7.1		9.69/12.1								
DEC	370		6.0		28.2/17.6								

NASA

*DATA STATION LOCATIONS:

① GEORGETOWN

TABLE B.3

METEOROLOGICAL DATA

PROJECT LOCATION: PEDRO VINCENTE MALDONADO, ECUADOR

PARAMETER	INSOLATION ** AVE = 234		AMBIENT TEMP		RELATIVE HUMIDITY		CLOUD COVER						
	①*		①*		①*		①*						
UNIT	L/day		°C		%		OCTAVE						
JAN	243		23.8		88.3		7.7						
FEB	248		23.9		88.0		8.0						
MAR	299		24.5		86.7		7.0						
APR	295		24.5		87.7		7.3						
MAY	260		24.1		87.7		7.7						
JUN	205		23.4		89.3		6.7						
JUL	226		22.5		88.0		8.0						
AUG	221		22.2		89.0		7.7						
SEP	217		22.4		89.0		7.7						
OCT	206		22.3		87.7		8.0						
NOV	195		22.2		88.3		8.0						
DEC	196		22.5		88.0		8.0						

NASA

*DATA LOCATIONS:

① LA CONCORDIA, ECUADOR

** INSOLATION CALCULATED FROM HOURS OF SUNLIGHT

TABLE B.4

METEOROLOGICAL DATA

PROJECT LOCATION: KIBWEZI AND IKUTHA, KENYA

PARAMETER	INSOLATION AVE = 472	INSOLATION AVE = 448	HOURS OF BRIGHT SUN		AVG MONTHLY TEMPERATURE (RANGE)			AVG MONTHLY RAINFALL (RANGE)		LONG PERIOD MEAN RAINFALL			
	① *	② *	① *		① *	② *		① *	② *	③ *			
UNIT	L/day	L/day	hrs.		max min °C	max min °C		inches	inches	mm			
JAN	558	489	8-10		26 13	31 20		0-2	0-2	40			
FEB	595	519	8-10		27 13	33 20		0-2	0-2	29			
MAR	559	509	8-10		27 14	33 20		4-6	2-4	90			
APR	486	459	6-8		26 15	31 20		6-8	2-4	118			
MAY	416	412	4-6		24 15	30 20		4-6	0-2	26			
JUN	397	404	4-6		23 13	29 18		0-2	0-2	6			
JUL	324	360	4-6		23 12	28 17		0-2	0-2	1			
AUG	366	373	4-6		23 12	28 17		0-2	0-2	2			
SEP	464	403	4-6		26 13	29 17		0-2	0-2	3			
OCT	492	446	6-8		26 14	31 18		0-2	0-2	21			
NOV	486	500	6-8		25 14	31 20		4-6	2-4	158			
DEC	522	509	6-8		25 14	31 20		2-4	4-6	147			

NASA

* DATA LOCATIONS:

① NAIROBI

② VOI

③ KIBWEZI

8.3 Appendix C - Procedure for Calculating the Minimum Battery Capacity

- Required Information:
  - Absolute allowable maximum depth of discharge, DOD_A; $DOD_A \leq 100\%$
  - Maximum depth of discharge encountered through year for normal operation, DOD_0; $DOD_0 < DOD_A \leq 100\%$
  - $\Delta DOD - DOD_A - DOD_0$
  - Required reserve for "no-sun" operation, RSV (ampere-hours)
- Minimum battery capacity, BATTCAP, in ampere-hours, is then;

$$BATTCAP = \frac{100 \cdot RSV}{\Delta DOD}$$

Example:

$DOD_A = 80\%$ $\qquad$ $DOD_0 = 50\%$

$\Delta DOD = 30\%$

$$RSV = \frac{4200 \text{ Whr/day}}{120 \text{ volts}} \times 3 \text{ days}$$

= 105 AH (for 3 days operation of the medical center without PV array power)

$$BATTCAP = \frac{100 \times 105 \text{ amp hrs}}{80\ (DOD_A) - 50\ (DOD_0)}$$

= 350 AH

APPENDIX D

PHOTOVOLTAIC TERRESTRIAL PROJECTS BRANCH

Preliminary Contract Cost Estimate

Design, Deployment, and Operation of Baseline
(title)
PV Packages for Rural Health Applications

FOR INTERNAL USE ONLY

NOT TO BE DISSEMINATED OUTSIDE OF NASA-LERC

APPENDIX D

PRELIMINARY CONTRACT COST ESTIMATE

Design, Deployment and Operation of Baseline PV Packages for Rural Health Applications
(title)

Date: February 1981

** Baseline System: Array Size (28° C) 1.8, kW_p Voltage DC 120, volts

Battery Size 350 AH 42, kWhr.

Insolation (Av. Annual) 390, langleys

Load (Av. Daily) 4.2, kWhr./day

I. Nonrecurring Costs	Hours	Rate*	Cost	
A. Baseline System				
1.0 Direct Labor				
1.1 Design				
1.1.1 Engineering	1050	16-19	$18.0 K	
1.1.2 Drawings (100 hrs./dwg)	800	10	8.0	
1.1.3 Failure Modes/Effects	200	16	3.2	
1.1.4 Review	120	16-19	2.0	
1.2 R&QA	100	10	1.0	
1.3 Fabrication/Assembly	700	10	7.0	
1.4 Proof of Design Testing	160	10	1.6	
1.5 Operation/Maintenance & Training Manuals (2K/Manual & 0.5K Manual Translation)			8.0	
1.6 Contractors Project Management	250	20	5.0	
Subtotal				53.8
Overhead (150%)			80.7	
1.0 Subtotal				134.5

*See Table I

**Applicable to Kenya, Guyana, Zimbabwe

2.0	Materials	1.0	
	Overhead (15%)	0.2	
3.0	Travel	4.0	
4.0	Other Direct Costs		
	_____	_____	
	_____	_____	
	_____	_____	
	(1.0 - 4.0 Subtotal)		(139.7)
5.0	G&A (20%)	27.9	
		Subtotal	167.6 *
6.0	Profit (10%)	16.8	
		Subtotal	184.4
	Baseline System Nonrecurring Costs	TOTAL (1.0 - 6.0)	184.4
	*Contingency (10%, excluding profit)		16.8

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B. Incremental Increase for Other Options

1.0	Increase in Item A 1.0	_____	
	Overhead (150%)	_____	
2.0	Incremental Materials	_____	
	Overhead	_____	
3.0	Travel	_____	
4.0	Other Direct Costs		
	_____	_____	
	_____	_____	
	_____	_____	
	(1.0 - 4.0 Subtotal)		(_____)
5.0	G&A (20%)	_____	
	Subtotal		_____ *
6.0	Profit (10%)	_____	
	Subtotal		_____
	Options, Nonrecurring Costs	TOTAL (1.0 - 6.0)	_____
	*Contingency (10%, excluding profit)		_____

II. Recurring Costs (per location)	Hours	Rate	Cost	
A. Baseline System				
1.0 Direct Labor				
1.1 Assembly of Array (Factory): 0.08 hrs/watt x 1800 watts = 144 hr.	144	10	$ 1.4 K	
1.2 Controls & Instrumentation (Factory)	200	10	2.0	
1.3 Power Conditioning				
1.4 R&QA/Acceptance Testing (Factory + Field)	150	10	1.5	
1.5 Packaging	100	10	1.0	
1.6 Field Installation & Checkout (Site Preparation, Array, Battery, Loads, Enclosure, Power Distribution)	1360	1-16	10.0	
1.7 Site Specific Survey	40	16	1.6	
1.8 Training	40	16	0.6	
1.9 Contractor's Project Management	200	20	5.0	
Subtotal				23.1
Overhead (150%)			34.7	
1.0 Subtotal				57.8

2.0 Materials

2.1 Array Field

2.1.1 Modules (28° C, including 5 % spares), 1.8 kW_p:

$ 11 K/kW_p x 1.8 kW_p = 20.8

2.1.2 Frames, Support, Wiring, Signs, Fencing:

$3.1K/$kW_p$ x 1.8 kW_p + $0.5K = 6.1

2.2 Battery (including 5 % spares), 44.1 kWhr:

[$.195K/kWhr* x 44.1 kWhr] +

Battery Rack $ .3 K** = 8.9

2.3 Controls & Instrumentation	4.0	
2.4 Power Conditioning**		
2.5 Loads and Spares**	4.0	
2.6 Enclosures (Battery, Controls, etc.): $0.01K/$ft^2$ x 100 ft^2 =	1.0	
2.7 Electrical Distribution, Length 500 ft: $0.001K/ft x 500 ft) =	0.5	
2.8 Packaging (5% of material cost)	2.3	
Subtotal		47.6
Overhead (15%)	7.1	
2.0 Subtotal		54.7

*See Figure I
**See Table II

3.0 Shipping			
3.1 Array		2.4	
3.2 Battery		2.6	
3.3 Auxiliary Hardware		1.4	
	Subtotal		6.4
Overhead (15%)		1.0	
	3.0 Subtotal		7.4
4.0 Travel			
4.1 Site Specific Survey		1.4	
4.2 Field Installation/Training		10.0	
	Subtotal		11.4
Overhead (15%)		1.7	
	4.0 Subtotal		13.1
5.0 Other Direct Costs			
_____		_____	
_____		_____	
_____		_____	
	5.0 Subtotal		_____
	(1.0 - 5.0 Subtotal)		(133.0)
6.0 G&A (20%)		26.6	
	Subtotal		159.6 *
7.0 Profit (10%)		16.0	
	Subtotal		175.6
Baseline System Recurring Costs	TOTAL (1.0 - 7.0)		175.6
*Contingency (10%, excluding profit)			16.0

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B. Incremental Increase for Other Options

Site Specific For Pedro Vincente Maldonado, Ecuador

Array Size 3.0, kW_p Voltage 120, volts

Battery Size 42, kWhr.

Insolation (Av. Annual) 234, langleys

Load (Av. Daily) 4.2, kWhr./day

1.0 Additional Labor	Hours	Rate	Cost	
1.1 Array Assembly	96	10	$ 1.0K	
1.2 Controls/Instrumentation				
1.3 R&QA/Acceptance Testing	50	10	0.5	
1.4 Packaging	80	10	0.8	
1.5 Field Installation & Checkout				
1.6 Site Specific Survey				
1.7 Training				
1.8 Operations				
1.9 Contractor's Project Management				
Subtotal				2.3
Overhead (150%)			3.6	
1.0 Subtotal				5.9

2.0 Additional Material		
2.1 Array	13.9	
2.2 Battery		
2.3 Controls/Instrumentation		
2.4 Power Conditioning (Inverter, etc.)		
2.5 Loads		
2.6 Enclosure		
2.7 Electrical Distribution		
2.8 Packaging	0.7	
Subtotal		14.6
Overhead (15%)	2.2	
2.0 Subtotal		16.8
3.0 Additional Shipping		
3.1 Array	2.2	
3.2 Battery		
3.3 Auxiliary Hardware		
Subtotal		2.2
Overhead (15%)	0.3	
3.0 Subtotal		2.5
4.0 Additional Travel		
Overhead (%)		
4.0 Subtotal		
5.0 Other Additional Costs		
5.0 Subtotal		
(1.0 - 5.0 Subtotal)		(25.2)

6.0 G&A (20%)		5.0	
	Subtotal		30.2 *
7.0 Profit (10%)		3.0	
	Subtotal		33.2
Options, Recurring Costs	TOTAL (1.0 - 7.0)		33.2
*Contingency (10%, excluding profit)			3.0

C. Operations

	Hours	Rate	Cost	
1.0 Monitoring/Reporting	320	16	5.0	
2.0 Service	320	10-16	4.0	
3.0 Contractor's Project Management	64	20	1.3	
4.0 Travel			11.0	
1.0 - 4.0 Subtotal				21.3
Overhead (100%)			21.3	
Subtotal				42.6
5.0 G&A (20%)			8.5	
Subtotal				51.1 *
6.0 Profit (10%)			5.1	
Operations Costs TOTAL (1.0 - 6.0)				56.2
*Contingency (10%, excluding profit)				5.1

COST SUMMARY

1. Nonrecurring			
Baseline System		$184.4 K	
Options		0	
	Subtotal		184.4
2. Recurring			
Baseline System		175.6	
Options		33.2	
	Subtotal		208.8
3. Operations			56.2
4. Contingency			
Nonrecurring		16.8	
Recurring		19.0	
Operations		5.1	
	Subtotal		40.9

TABLE 1

WAGE AND SALARY RATES AS ESTIMATED ON DECEMBER 1980*

Labor Type	Rate (1980$/hr)	Sources
Project Manager	$20	(1) Modular System Proposals 5/80
Lead Design Engineer	19	
Mechanical Engineer	16	(2) Occupational Outlook Handbook 1980-81 Ed.
Electrical Engineer	16	(3) Statistical Abstracts of U.S. 1979
Junior Engineer	13	
Test Engineer	16	(4) Price Analysis Proposal Check (AVCO-Lycoming of Stratford, Connecticut).
R&QA Engineer	15	
Draftsman	10	Eng. $15-19/hr Des. Sup. $12/hr Mfg. Lab. $10/hr
Technician	10	
Fabricator	8-10	(AiResearch of Phoenix, Arizona)
Electrician	8-11.50	Eng. $15-19/hr
Packaging (Carpenter)	8-10	
Financial Management	10	
Assembler	8-10	

*Note: Apply an escalation rate of 10% per annum for years beyond 1980

SQUARE 10 X 10 TO THE HALF INCH AS-1113 01

Fig 1

BATTERY COST VS RATED STORAGE CAPACITY
P&D LEAD CALCIUM PHOTOVOLTAIC BATTERIES
500 HR DISCHARGE RATE @ 77°F
COMMERCIAL PRICES — NOV. 25, 1980

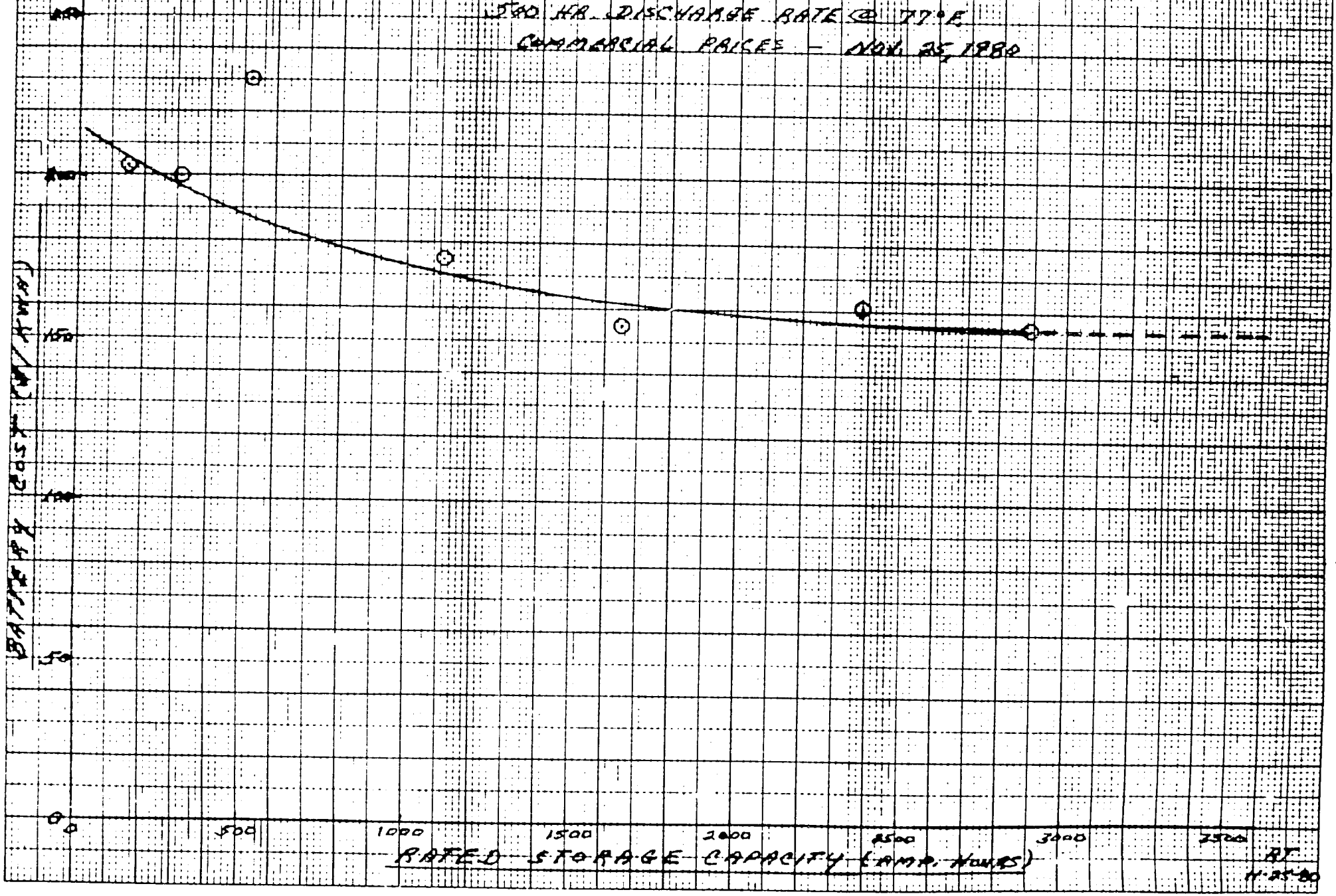

Table II

Description	Cost	Reference
2.2.1 Battery Racks		
A. "Small" Battery Size - Upper Volta C&D, KCDSD-7, 76 lb., 540 Amp-Hr., $\frac{7.1 \text{ Amp-Hr.}}{\text{lb}}$	$2.58 x ___ volts	R. Thomas
B. "Large" Battery Size - Schuchuli C&D, LCPSA-19, 294 lb., 2380 Amp-Hr., $\frac{8.1 \text{ Amp-Hr.}}{\text{lb}}$	$8.30 x ___ volts	R. Thomas
2.3 Controls and Instrumentation		
A. Data Logger	$4K	R. Vasicek
B. Meters	$50/Meter	R. Vasicek
2.4 Power Conditioner		
A. DC/AC Inverter, Sinewave, 60 HZ, 6 KVA, Abacus, 120 VDC Input	$8,500 + 5%	J. Stover
B. DC/AC Inverter, Sinewave, 60 HZ, 8 KVA, Abacus, 120 VDC Input	$11,100.00	J. Stover
C. DC/AC Inverter, Sinewave, 60 HZ, 4 KVA, Abacus, 120 VDC Input	$6,100 + 5%	J. Stover
D. DC/AC Inverter, Quasi-Square Wave, 60 HZ, 6 KW, Best, 120 VDC Input	$2,595.00	J. Stover
E. DC/DC Converter, 120 In/12 Out, Bikor, Model DDR 11012, Regulated Output, 70% Eff., 4 A	$220.00	J. Stover
F. DC/DC Converter, 120 In/12 Out, Bikor, Model DDU 1001, Unregulated Output, 90% Eff., 4 A	$152.00	J. Stover
G. DC/DC Converter, 120 In/12 Out, Wilmore, Model 1295-125-13-10, 80-85% Eff., 13 A	$423.00	R. Vasicek

Table II

Description	Cost	Reference
2.5 Loads and Spares		
A. 40W Fluorescent Light (Lamp Fixture, Inverter-Ballast, Bulb), 120 VDC	$88.00/Unit	R. Vasicek
B. 18W Sodium Vapor Light (Lamp Fixture, Inverter-Ballast, Bulb), 120 VDC	$100.00/Unit	L. Thaler
C. Sterilizer, Ozone Type, 120 VDC/12 VAC	~$2,000.00/Unit	J. Toma
D. Sterilizer, Regular Type, 120 VAC		
F. Refrigerator, Western Solar, 12 VDC Input	$1,000/Unit	R. Thomas
G. Dental Equipment		
H. Composite Radio-Telephone System (Radio System & Antenna)	$3,000/System	R. Vasicek
I. Water Pump		
Other		
Solar Collector (Water Heater System)	$2,000/Unit	R. Vasicek