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A CASE STUDY ON WATER SUPPLY SYSTEMS IN BOERA VILLAGE

AND

EVALUATION AND SELECTION OF SOLAR PHOTOVOLTAIC SYSTEMS IN CENTRAL PROVINCE, PAPUA NEW GUINEA

Based on two reports

By

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1. Purpose

This case study was developed to include:

(1) a general description of the various water systems installed in Boera village together with an assessment of their appropriateness;

(2) an evaluation of the installed solar system; and

(3) the identification of criteria for designing various types of solar photovoltaic systems.

For convenience and ease of reference, the report will be presented in three sections. The terms of reference are included in Annex 1.

SECTION 1

1. Water supply systems in Boera Village

1.1 Introduction

Boera is a small coastal village situated in the Central Province of Papua New Guinea, approximately 30 km by road, north west of Port Moresby, the National Capital City. The environs of the village extend from the coast to 3/4 km inland.

The population of 735 people live in 75 houses of various sizes and types. While some are built over tidal flooded areas, the majority have been built above high tide. Some of the families in the village live by sustenance fishing and gardening and others have family members employed in Port Moresby or other parts of the country. Those employed in Port Moresby commute daily either in their own motor vehicles or via PMV's (Public Motor Vehicles). Boera village has one large church (United), a primary school and a large community hall. The people of Boera are fortunate in having an abundant water supply. The water table is apparently always within 6 m of the ground level. Some village people remember that a bore-well, located near the village community school, was used by the Australian Army during the 1939-1946 Second World War and apparently provided a continuous suppply of good quality water.

1.2 Water supply background

1.2.1 General

During the past 10-15 years, various types of systems have been used to deliver groundwater to the village people. Details of each of the systems are described in the following paragraphs.

1.2.2 Windmill

Background details on this installation are vague. It was installed in the early 1970's, probably by the Council Health Services, and it provided intermittent service until 1978, when it failed. It was not overhauled until 1980 but at that time additional distribution lines were installed for K900. However, within six months of its overhaul, the pump failed and it and some of the lower struts of the tower were removed for repair but the unit was never reassembled. (The Provincial Government intends, however, to repair and relocate the windmill and tower to another village.)

The reasons for the failure of the windmill could not definitely be determined, but discussions with the village people and with some local firms, indicated that the leather buckets were probably damaged by sand and grit which was pumped from the shallow well. In addition, vandalism might also have been a problem because the unit was not in a secure area.

1.2.3 Diesel driven pump

Although the exact date that the diesel driven pump replaced the windmill is not known, the unit was overhauled in 1978 for approximately K600 and was installed at the windmill site. Four fibreglass tanks with a storage capacity of 32 500 were also installed, at that time near the community school. Thus, a 24-hour service was available to the communal faucets. The community was responsible for maintenance and operation of the unit. During the period 1978-81, the system provided intermittent water service to the community. Two-engine seizures occurred because lubricating oil had not been added. The resulting overhaul cost was K1200.

It appears as though adequate operating and maintenance procedures were not instituted by the villagers. Possibly oil was not available because of a lack of cash or alternately the operator did not add the lubricant when it was required. In any case, the system finally broke down and was never repaired.

1.2.4 Handpump

Again, details on the handpump installations are limited. It appears as though the first handpump was installed at the windmill site in 1980 and a second was located at the present solar site sometime thereafter. Both of these units provided irregular service until 1981, the year the solar system was commissioned.

Generally, failures were of two types. Leather washers were damaged by sand, and the operating handles were frequently broken by vandals. In order to ensure system operation, the community established a water committee to administer the installations. Appropriate charges were subsequently levied on the villagers for water used so that the necessary spare parts could be obtained. However, as the handpump at the solar site was close and convenient, the villagers repaired it and abandoned the unit at the windmill site. Thus, 535 (1980 census) people relied on a single handpump for their water needs for the six months preceeding the commissioning of the solar system.

1.2.5 Solar system

(a) General

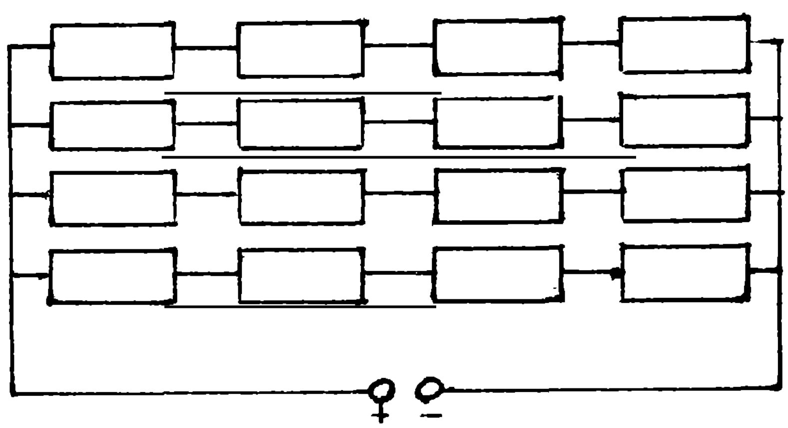
The frequent breakdowns of the various systems, the inconvenient location of the handpump, and the need to stand in line for long periods to obtain their water prompted the village women to initiate a fund raising programme for a solar water system. They raised K500 and requested government assistance for the balance, and the solar system was commissioned in October 1981.

(b) System design

The system design was developed on a provincial standard of 45.5 l/cap/day or a daily flow rate of 24 340 l/day for a population of 535 people (The current population being served is 750 people). The system included a solar array, water storage and a variable speed pump and motor assembly. Operation was automatic as a level switch controlled the discharge of the shallow well pump to the storage tanks. Shower facilities were also provided. The total cost was K10,000.

(c) PVC modules

The modules include 15 ARCO ASI-16-2000 and one ARCO ASI-16-2300. As indicated in the sketch, the four sets are connected in parallel and each set consists of four modules in series. The arrangement provides four times the output voltage and four times the current of a single module. The array is mounted on two separate stands.



Module Connections in PVC Array

(d) Storage

The system consists of the four fibreglass tanks which had originally been located at the windmill site. They have a nominal capacity of 32,500 litres - (3 x 9000 and 1 x 5500 litres). Level controls were included for automatic operation of the pump and motor.

(e) Pumping capacity

The initial system was equipped with a 1/2 HP motor and pump assembly (The pumping rate under the system head conditions is not known). It, however, was subsequently replaced by a 1/3 HP unit due to failure of the first unit.

(f) Operation

The villagers established a water committee to manage the facility. A full time caretaker was employed at K10 per fortnight for controlling the system, checking equipment and collecting water fees. The chairman and treasurer are also paid K5 per fortnight each for their management and supervisory activities.

During the early stages of operation, the village committee charged the villagers 5 to 10 toea for each bucket of water, but a new committee subsequently changed the tariff to a flat rate of 1K per house per fortnight which entitled each family free access to the enclosure for water and for the use of the showers. However, because the gate valves were being damaged by their frequent usage, the committee decided to install a distribution line with regularly spaced faucets from the tanks to the village and to discontinue the shower arrangement. The gates to the compound were locked and the water flow was regulated each afternoon by a member of the water committee. Basically, the system began operation at 2 p.m. and it was closed later in the day to ensure that some storage reserve was maintained.

(g) Operating and maintenance problems

Although the solar system has provided relatively uninterrupted service since it was installed, a number of problems have occurred or been identified during this study.

(1) Motor and pump assembly

The first problem occurred after the system had been installed for 15 months. The first set of brushes in the 1/2 HP motor had worn to the limits of the spring tension and because somebody had attempted to close the gap by placing wooden blocks between the brushes and the springs, the motor burnt out. It was subsequently replaced with a 1/3 HP unit at a cost of K950.

(2) Solar panels

Various problems have also been encountered with the electrical wiring. Apparently, the main switch was removed for repair during the first 12 months of operation but it was never replaced. (The cables leading to the switch are presently twisted and clamped in order to complete the circuit to the motor.) There is, therefore, no quick method for de-energizing the system. In addition, the float level control micro switch malfunctioned during this period and it was replaced. However, the float was later removed and used in a level indicator fabricated and installed by a member of the water committee. When the level indicator was later removed, the float was not reconnected to the float switch. The system is now controlled manually by the members of the water committee. Other technical faults such as the de-lamination of the first set of solar modules occurred within 12 to 18 months of the installation. Fifteen of the modules, however, were replaced under the terms of the warranty. Of the replacements, three developed brown discoloration inside the laminate after six months of operation, but the manufacturer maintained that the colouring was cosmetic and would not affect the performance or the useful life of the modules. Finally, two solar modules were broken when rocks directed at a nearby mango tree hit the units. Replacement cost was approximately K350 each. (This problem might have been avoided if some sort of protective guard such as chicken wire had been installed over the array.)

(3) Water storage

The system consists of four fibreglass tanks with a nominal capacity of 32 500 litres - 3 x 9000 and 1 x 5500. However, the actual capacity is lower. Storage is reduced because of an elevation difference of 0.2555 m between the tops of the smaller and the larger tanks. In effect, the small tank controls the storage level. Also, the location of the overflow pipes in the south-west tank (9000 litres) reduces the effective storage to a height of 1.47 meters. Thus, the actual capacity is 29,300 or 3 200 litres less than nominal, i.e.,

3 x 8000 litres =	24 000	litres
1 x 5300 litres =	5 300	litres
	29 300	

The nominal capacity can be restored by adjusting the relative elevations of the tanks and by blocking the overflows. Alternately, the 5500 litre tank can be replaced with a 9000 litre tank for an estimated cost of K935.

It was also apparent that the tanks were not being maintained. Leaks had developed along the joint between the two sections and water was running over the wooden deck. If this had been allowed to continue, the structure would have, in time, failed due to rotting. The consultant, however, managed to arrange with the tank manufacturer and the members of the committee to repair the tanks.

(4) Spare parts

A list of required spare parts, their retail price and delivery time from the local supplier are listed in Table 1-1.

Table 1-1
Spare Parts List
Solar Systems

Item	Part or Unit	Retail Price	Delivery Time
1.	PVC Module M73 (Replacement for ASI-16-2000	K415.00	Ex-stock
2.	Motor/Pump Unit (1/3HP)	K900.00	Ex-stock normally, otherwise 10 days airfreight - added cost
3.	Motor (1/3HP)	K500.00	As for Item 2
4.	Pump		As for Item 2
5.	Motor Brushes	K20.00/set	Ex-stock

Note: These prices are for equipment only. Daily labour cost would be approximately K30 for a tradesman to visit the site.

1.2.6 Appropriate Technology

(a) General

In order to establish the appropriateness or otherwise of the four systems, it is necessary to evaluate the following criteria for each of the technologies: is it affordable to the people? is it maintainable by the village technical resources? does it satisfy the social and the cultural habits? and is it acceptable to the members of the community? If it does not satisfy all this criteria, the technology is inappropriate and should not have been installed.

(b) Handpump

The handpump installation did not provide sufficient water to meet the needs of the community, it was inconvenient as the women were required to stand in line for long periods, and the villagers were not, apparently, prepared to technically or financially support the installation. It was therefore inappropriate.

(c) Diesel engine

The diesel engine was expensive to operate and to maintain. The villagers were apparently not trained to look after the installation and funds were not available to cover the operating costs nor to provide for its regular maintenance. Its subsequent failure due to a lack of engine oil proved its inappropriateness.

(d) Windmill

The windmill system was also imposed on the community. While this system can provide reliable service at least cost, it does require a degree of maintenance. However, as the people were not motivated or trained to provide the support, the system failed through lack of maintenance.

(e) Solar system

On the other hand, the solar system was selected by the village. They were sufficiently motivated to establish a committee to manage the facility, and they financially support the system as the stipends for the chairman and the treasurer and the salary of the caretaker and the maintenance and repair needs are supported through monthly contributions by the village people.

The village cultural and social habits have also been satisfied. As machinery is alien to the traditional culture of the people, the apparent simplicity of the solar system, its very low noise level, and the natural phenomena of utilizing the sun's energy, fits well with the natural mode of living of these village people. Clearly, the appropriateness of this technology for Boera vilage cannot be denied. It requires little essential maintenance and is therefore suitable to the available technical resources, the operating costs are minimal and it has basically provided continuous and reliable service to the community for over two years, something none of the other schemes were able to do.

(f) Human resources development

It appears that system failures can, in part, be attributed to a lack of training. The responsible people were not advised on system operation. Instruction was not given on the basic steps of adding oil and lubricants to the diesel engine in accordance with usage and running needs. Training was not provided on: the characteristics of windmill operation, the need for routine greasing of the bearings, and the requirement to maintain built-in safety equipment to prevent damage during excessive winds. Finally, the responsible people were not advised on the routine maintenance and repair needs of the various components of the solar system. It is very evident that the people who carried out repairs and modifications were not qualified to attempt the work. The training and abilities of staff employed by equipment suppliers also require attention.

(g) Community education and participation

A review of the four water systems indicates that while the community was involved in the operation of the three systems, their participation was never sustained. As fees were not paid regularly, funds were not available for spare parts and fuels. Maintenance of the facilities was not consistently carried out because spare parts were lacking and the village workers were not adequately trained.

Of the four systems, the community seemed to be most involved in the solar system. They selected the technology, they contributed funds for its construction and they formed a 3-man village water committe to manage its operations. Most certainly, the village participated in the early stages of the project and for that time, it can be considered a successful community venture.

However, the committee has started to experience difficulty in collecting the water fees. The original charges of one Kina/fortnight/house for 75 homes, or a gross income of K75/fortnight less the salaries per fortnight of K20 provided for a net income of K55/fortnight. This amount was adequate to cover routine maintenance needs. The recent collections, however, have dropped to a gross income of K30-40 per fortnight. The net collections of K10-20/fortnight is not sufficient to cover the maintenance requirements. The reason for the reduction in commitment is not known, but representatives of the provincial government should meet with the people and attempt to solve the problems.

1.3 Cost comparisons

1.3.1 General

The investment costs of the four systems will be compared on the basis of present worth and equivalent annual costs over a five-year and a ten-year period. In order to compare the costs of the various systems, a number of assumptions have been made. All prices are based on contract costs (no community labour), similar levels of services are provided (the same quantities of water are provided by each system, using the solar system as the base) and 1982 prices are used. All systems, except the wells, are reticulated. Each includes a shallow well, storage tanks and a distribution system utilizing communal taps. While it is recognized that the system components have different economic lives - i.e., pipelines - 50 years, and tanks - 30 years, an average 20-year service life has been used for simplicity. It is not considered that significant errors will result with this approach.

Cost estimates for the various systems are detailed in Annex 3. These figures are summarized in Table 1-2.

Table 1-2
Cost Summary
Water Systems
Boera Village

	Windmill	Diesel	Handpump	Solar
Equipment Costs	9250	9430	10 800	12 400
Economic Life - years	20	20	20	20
Replacement Costs	(2 yrs)450	-	(5 yrs) 1800	(2 yrs) 200
Operation and Administration	1140	2000	1640	1140
Interest Rate - %	10%	10%	10%	10%

1.3.2 Present worth calculations

Present worth calculations will be determined from the following equation:

$$PW = P_A D_o + R_a(D_{R1} + D_{R2}) + M_a D_a - S_v - S_r$$

In which:

(i) PW - Present Worth

(ii) P_A - Capital Costs

(iii) D_o - Present worth discount factor for year 0 - 1

(iv) $R_a(D_{R1} + D_{R2})$ = R_a - replacement costs and $(D_{R1} + D_{R2})$ refer to the present worth single payment discount factor for successive replacement periods

(v) M_aD_a Ma - annual maintenance costs and D_a - the discount rate for a uniform ~~period~~ series of payments (annuity) for the period being considered

(vi) S_v - Salvage value of the equipment discounted back to year 0

(vii) S_r - Non-chargeable replacement value

(a) Present worth - 5 years

(1) Windmill

$P_A D_o + R_A(D_2 + D_4) + maD_5 - S_{v5} - S_r$

$= 9250 \times 1 + 450\ (.8264 + .6830) + (1140 \times 3.791) - (3/4 \times 9250) \times .6209 - (1/2 \times 450 \times .6209)$

$= 9250 + 679.23 + 4321.74 - (4307.49 + 139.70)$

= K9803.78

(2) Diesel

$P_A D_o + R_A(0) + maD_t - S_{v5}$

$= 9430 + 0 + (2000 \times 3.791) - (3/4 \times 9430) \times .6209$

$= 9430 + 7582 - 4391.32$

= K12620.68

(3) Handpump

$P_A D_o + R_A D_5 + maD_t - S_{v5}$

$= 10{,}800 + (1800 \times .6209) + 1640 \times 3.791 - (3/4 \times 10\ 800)\ .6209$

$= 10{,}800 + 1117.62 + 6217.24 - 5029.29$

= K13105.57

( ) Solar

$P_A D_o + R_A(D_2 + D_4) + maD_t - S_v - S_R$

= 12400 + 200 (.8264 + .6830) + 1140 x 3.791 - (3/4 x 12400).6209 -

(1/2 x 200) x .6209

= 12400 + 301.88 + 4321.74 - 5774.37 - 62.09

= K11,187.16

(b) Present worth - 10 Years

(1) Windmill

$P_A D_o + R_A(D_2 + D_4 + D_6 + D_8 + D_{10}) + maD_{10} - S_5 - S_r$

= 9250 x 1 + 450 (.8264 + .6830 + .5645 + .3855 + .4665) +

(1140 x 6.144) - (1/2 x 9250) .3855

= 9250 + 1316.66 + 7004.16 - 1782.94

= K15 787.88

(2) Diesel

$P_A D_o + maD_{10} - S_{v5\ 10}$

= 9430 + 2000 x 6.144 - (1/2 x 9430) .3855

= 9430 + 12,288 - 1817.63

= K19900.37

(3) <u>Handpump</u>

$P_A D_o + R_A(D_5 + D_{10}) + MaD_{10} - S_v$

= 10,800 + 1800 (.6209 + .3855) + 1640 x 6.144 - (1/2 x 10800) x .3855

= 10,800 + 1811.52 + 10,076.16 - 2081.70

= K20,605.98

(4) <u>Solar</u>

$P_A + R_A(D_2 + D_4 + D_6 + D_8 + D_{10}) + maD_{10} - S_v D_{10}$

= 12400 + 200 (.8264 + .6830 + .5645 + .4665 + .3855) + 1140 x 6.144 -

(1/2 x 12400).3855

= 12400 + 585.18 + 7004.16 - 2390.10

= K17 599.24

Table 1-3
Summary
Present Worth Calculations

	Windmill	Diesel	Handpump	Solar
5 years	9 803.78	12 620.68	13 105.57	11 187.16
10 years	15 787.87	19 900.37	20 605.98	17 599.24

1.3.3 Annual equivalent cost (AEC)

Annual equivalent costs will be determined for five and ten years by applying the following equation

$$AEC = P_A(crf) + R_A(D_{R1} + D_{R2}) \times Crf + Ma - S_v(sff_t)$$

crf - capital recovery factor

sff - sinking fund factor

R_a - replacement costs

Ma - annual maintenance costs

D_R - single payment discount factor

S_v - salvage value

(a) Annual equivalent cost - five-year period

(1) Windmill

$$AEC = P_A \times crf_5 + R_A(D_2 + D_4) \times crf_5 + ma - S_{v5} \times Sff_5$$

$$= (9250 \times .264) + (679.23 \times .264) + 1140 - (4447.19 \times .164)$$

$$= 2442 + 179.32 + 1140 - 729.34$$

$$= 3031.98$$

(2) Diesel

$$AEC = P_A \times crf_5 + ma - S_{v5} \times Sff$$

$$= 9430 \times .264 + 2000 - 4391.32 \times .164$$

$$= 2489.52 + 2000 - 720.18$$

$$= 3769.34$$

(3) Handpump

$$AEC = P_A \times crf + R_a D_5 + ma - S_{v5} \times sff_5$$

$$= 1117.62 \times .264 + (10{,}800 \times .264) + (1117.62 \times .264) + .1640$$

$$(5029.29 \times .164)$$

$$= 2851.20 + 295.05 + 1640 - 824.80$$

$$= 3961.45$$

(4) Solar

$$AEC = P_A \times crf_5 + R_A (D_2 + D_4) \times crf_5 + ma - S_v \times sft_5$$

$$= (12400 \times .264) + (301.88 \times .264) + 1140 - (5774.37 + 62.09) \times .164$$

$$= 3273.60 + 79.70 + 1140 - 957.18$$

$$= 3536.12$$

(b) Annual equivalent cost - ten-year period

(1) Windmill

$$AEC = P_A \times crf_{10} + R_A (D_2 + D_4 + D_6 + D_8 + D_{10}) \times crf_{10}$$

$$+ ma - S_v \times sff$$

$$= (9250 \times .163) + (1316.66 \times .163) + 1140 - (1782.94 \times .063)$$

$$= 1507.75 + 214.62 + 1140 - 112.32$$

$$= 2750.05$$

(2) Diesel

$$AEC = P_A \times crf_{10} + ma - S_{v10}$$

$$= (9430 \times .163) + 2000 - (1817.63 \times .063)$$

$$= 1537.09 + 2000 - 114.51$$

$$= 3422.58$$

(3) Handpump

$$AEC = (P_A \times crf_{10}) + Ra(D_5 + D_{10}) \times crf_{10} + ma - S_v \times Sff$$

$$= (10\ 800 \times .163) + (1811.52 \times .163) + 1640 - (2081.70 \times .063)$$

$$= 1760.40 + 295.28 + 1640 - 131.15$$

$$= 3564.53$$

(4) Solar

$$AEC = P_A \times crf_{10} + R_A\ (D_2 + D_4 + D_6 + D_8 + D_{10}) \times crf_{10}$$

$$+ ma - s_v \times Sff_{10}$$

$$= (12400 \times .163) + (585.18 \times .163) + 1140 - (2390.10 \times .063)$$

$$= 2021.20 + 95.38 + 1140 - 150.58$$

$$= 3106$$

Table 1-4
Summary of
Annual Equivalent Costs

	Windmill	Diesel	Handpump	Solar
5 years	3 031.98	3 769.34	3 961.45	3 536.12
10 years	2 750.05	3 422.58	3 564.53	3 106.00

1.3.4 Analysis

It is evident from the foregoing calculations for both 5 and 10-year periods that the windmill provides the best investment of the four systems. The second most attractive is the solar system followed by the diesel engine and the handpump. It is also apparent that the handpump installations are not financially attractive when similar levels of service are provided.

1.4 Conclusions

Of the four systems installed, the solar installation was the most appropriate. As it satisfied the needs of the community and was socially acceptable, it was enthusiastically accepted and financially supported by the people. However, as with the other systems, sufficient training was not given to the responsible people on the need to ensure that only qualified tradesmen be employed to effect repairs. The present state of the installation is almost entirely due to inappropriate maintenance and repair practices.

1.5 Recommendations

It is recommended that the Central Government begin a series of education meetings with the community and water committee in order to resolve the problems of finance and maintenance/repair.

SECTION 2

2. Evaluation of solar system - Boera Village

2.1 General

The second phase of the assignment was to evalute the suitability of the solar system in respect to its appropriateness, reliability and performance. Field measurements of water flows, solar insolation values, and power developed by the solar array were established over a relatively short period as time and money available did not allow for an in-depth evaluation. The basic intent was to carry out a practical yet reasonable evaluation of system performance.

Two approaches were used. The first compares actual power generated by the solar array with the theoretical power required to meet the systemhead conditions. The second method compares the performance of the solar system with manufacturer's performance specifications for a similar installation. The evaluation was based on performance tests carried out on two different days, 28 February 1984 and 13 May 1984.

2.2 Measuring equipment and test results

2.2.1 General

The instrumentation selected for the study was relatively simple, of low cost and reasonably accurate and reliable. While the limitations of the electrical and solar equipment were known before testing, the specific details of the water meter only became available after the tests had been completed. (Details of the adverse effects which the meter had on the evaluation phase are presented in Annex 2.)

2.2.2 Water meter

The meter installed for the study was model GMK-25 of Asahi-Phil Water meters. It operates with an accuracy of $\pm$ 2% over a flow range from 2.3 to m^3/hr to 10 meters for a nominal rating of $7m^3$/hr. The pressure drop curve for the unit is shown in Figure 2-1. It was installed on the pump discharge and the recorded pumping rates for the period 18 January to 1 February 1984 averaged approximately 27 646 litres per day while readings on 2 and 3 February 1984 were 24 850 and 26 033 litres/day, respectively. These results are summarized in Table 2-1. Instantaneous pumping rates of 74 and 80 litres/min were also established on 28 January and 13 May 1984.

FIGURE 2-1

ASAHI PHILIPPINE WATER METERS

Pressure Drop Curves

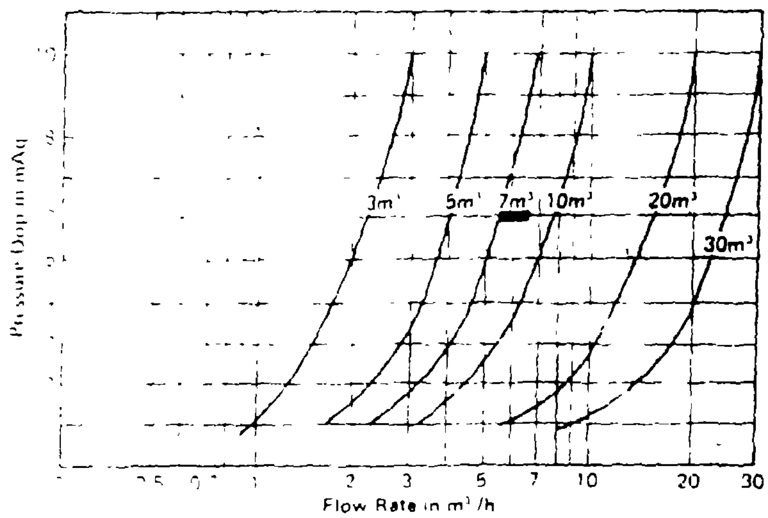


Table 2-1
Test Results
Solar Energy and Pumping Rates
Boera Village
18 January - 1 February 1984

Period	Solar Energy $kwh/m^2/day$	Water Pumped litres/day	litres/$kwh/m^2/day$
11 a.m. - 18/1/84 to 12 a.m. - 1/2/84	Average value 5.86	27 646	4718
6 p.m. - 2/2/84	5.40 (1)	24,850	4602
6 p.m. - 3/2/84	5.40 (1)	26 033	4821

2.2.3 Solar energy integrator

To measure the solar energy, a simple solar energy integrator was devised using an ampere - hour meter (having a 4 digit cyclometer read-out) and a small high quality PV~~C~~ module. The unit was tested, modified and calibrated at the Physics Department of the UPNG. The calibration constant was 1.14 MJ/m^2 per unit digit count. The accuracy of the instrument could be expected to be approximately 5%. The solar insolation level was measured in mw/cm^2 with hand held meter (2-5%) in the same plane as the array (approximately 22° to the horizontal). Readings taken from 18 January to 1 February 1984, averaged 5.86 $kwh/m^2/day$. These results are also summarized in Table 2-1. In addition, instantaneous values of 93 and 95 mw/cm^2 were determined on 28 February and 13 May 1984. These are included in Table 2-2.

NOTE (1): The variation in litres/day on 2 & 3 February 1984 for the apparent same value of solar energy was due to the limited daily register resolution (i.e., the register difference for each day was 17 with each unit equal to a calibrated value of 1.14 MJ/m^2). This means that the resolution here was 1 in 17 whereas for the period 18-1-84 to 1-2-84 the register difference was 222 (i.e., a resolution of 1 in 222).

The relationship between water pumped and the solar energy per day over the period 18 January - 1 February 1984, established an average rate of 4718 litres/$kwh/m^2/day$.

2.2.4 Power

These tests were carried out on various days using a digital multimeter (accuracy ± 0.2%) to measure the PV∅ array and motor voltage an ammeter (accuracy ± 2%) to measure current and an electronic tachometer. The measurements determined for flowrates of 74 and 80 litres/min on 28 January and 13 May are listed in Table 2-2.

Table 2-2
Test Results
Boera Village
28 February 1984 and 13 May 1984

Date	Time	Solar Insol	PVC Array	Motor	Motor	Motor	Total Head	Flow Rate l/min	m^3/sec
		mw/cm^2	volts	volts	amps	rpm	m		
28/2/84	1:40 p.m.	93	59.2	58.2	5.75	2680	11.48	74	.00123
13/5/84	11:48 a.m.	95	57.8	56.5	5.75	2603	11.72	80	.00130

NOTE (2): Voltages on 13 May were lower inspite of the higher solar insolation because some epoxy resin from a recent tank repair had remained on some of the module faces. (The consultant had previously helped the workman remove larger deposits of the resin, but the remaining work had not been completed. Time and materials were not available on 13 May to complete the cleaning.)

2.2.5 Head conditions

System head conditions listed in Table 2-3 were also determined for pumping rates of 74 and 80 litres/min on 28 January and 13 May, respectively. The various components are defined as:

Hsg - depth to water under drawdown conditions
Hsv - head losses suction pipe (6m long, 40mm diameter)
Hdg - height above pump discharge
Hdv - head losses for discharge pipe - (1104 meters of 25 mm dia rigid PVC pipe, 25 mm gate valve and various fittings
Hdm - Head loss - water meter
Het - Total effective head

Table 2-3
System Head Conditions
28 February and 13 May 1984

Date	Q l/min	Hsg	Hsv	Hdg	Hdv	Hdm	Het
28 Feb 1984	74	1.87	0.21	2.90	2.70	3.8	11.48
14 May 1984	80	0.66	0.24	2.72	3.40	4.7	11.72

2.2.6 Water consumption

The water consumption rates for 735 people averaged 27 646 litres/day during the period 18 January to 1 February 1984 or a per capita usage of 37.6 litres/cap/day. This is lower that the design criteria of 45.5 litres/cap/day which, of course, indicates that the general provincial standards are a very good approximation of the water needs of the people.

2.2.7 Pumping rate

The measured output of the 1/3 HP pump on 13 May 1984 was approximately 80 litres/min. If this is an average rate, it is apparent that a 27 646 litres/day output would require approximately 5.75 hours operating period under optimum solar conditions. Assuming that the design was based on an 8-hour effective pumping period, it appears at this time that some excess capacity remains. However, the authorities should occassionally monitor flow and consumption so that the unit can be replaced by a 1/2 HP motor and pump assembly when it is necessary.

2.2.8 Storage capacity

30 m^3

The present nominal storage capacity of 29 300 litres is sufficient to provide one day's average consumption. It is, however, desirable to use the storage available by making the adjustments to the tank arrangements suggested in paragraph 1.2.5 g(3). There is no need at this time to replace the 5500 litre tank with a 9000 litre tank.

2.2.9 Electrical safety

The Boera array system has a maximum operating voltage of 65 volts DC but the open circuit voltage may reach 80 volts DC. These voltages, therefore, fall into the Extra Low Voltage classification by the Papua New Guinea Electricity Commissions (ELCOM).

Reference has been made to the lack of a main switch for de-energizing the system (paragraphs 1.2.5 g(2)) but in addition, all the modules except one have exposed metal post terminals on the rear side. While they are not recommended by the manufacturer for installations with a voltage greater than 50 volts, the manufacturer also recommends that when they are installed (up to 50 volts) they should be fitted with insulating boots to cover the cable lugs, screws and terminals completely to guard against physical contact and accidental metallic bridging of the contacts by a person working on or inspecting the back of the array.

It is therefore important that workmen exercise caution when working on the system for low voltages can cause mild electric shocks particularly in the high humidity and the high ambient temperatures in Boera. In addition to those direct effects, there are the secondary effects of an electric shock such as muscle contraction or overreaction which could cause a fall or dropped tools with possible bodily injury.

2.3 System performance

2.3.1 Actual vs Theoretical

To determine the relationship between the actual and theoretical power generated by the array on 28 February and 13 May 1985, the following equation was used:

$$Pmt = \frac{Y_1 Q_v Het}{102\ N_m N_p} \quad - \quad (1)$$

In which: Pmt = theoretical, electrical power into motor terminals

Y_1 = specific weight of water (1000 kg)

Q_v = flow rate in m^3/sec

Het = total effective head - meters

N_m = efficiency of motor

N_p = efficiency of pump

102 = a constant

by transposing, equation (1) becomes

$$N_m N_p = \frac{Y_1 Q_v Het}{102\ Pmt} \quad - \quad (2)$$

As the actual power into the motor terminals is

$$Pma = V_m \times I_m \text{ (kw)} \quad - \quad (3)$$

where 1) V_m - Motor terminal voltage (DC) is approximately equal to the voltage of PVC array and 2) I_m - motor DC current in amps.

If $No = N_m N_p$ = efficiency of pump and motor

The equation becomes $N_o = \dfrac{Y_1 Q_v Het}{102\ V_m I_m}$

(a) First evaluation

(1) Solving for No on 28 February 1984 (see table 2-2)

$$N_o = \frac{1 \times .00123 \times 11.48}{102 \times .0582 \times .00575}$$

$$= 0.414 = 41.4\% = \text{combined efficiency of the motor and pump assembly at 2680 rpm}$$

(2) As a check on this calculation, the system performance determinations on 13 May 1984 can be used to determine the power supplied to the motor.

$$Pmt = \frac{Y_1 Q_v Het}{102\ No}$$

$$= \frac{1000 \times .00130 \times 11.72}{102 \times 0.414}$$

$$= 0.360\ kw_1$$

but actual $P_{ma} = V_m I_m$
$= 56.5 \times 5.75$
$= 324.8$ watts $= 0.325$ kw at 2603 rpm

(3) The difference between theoretical and actual power can be determined as follows:

$$\text{Difference} = \frac{Pmt - Pma \times 100}{Pma}$$

$$= \frac{0.360 - 0.325 \times 100}{0.325}$$

$$= 10.0\%$$

This is an acceptable variance in view of the rpm (2680 on 28 February 1984 and 2603 on 13 May) developed on the different days largely due to the difference in total head conditions.

(b) Second evaluation

(1) A second calculation will be used to compare system performance with a manufacturer's model CSB 50D. This latter system consists of 16 ASI-16-2000 modules (presumably connected as the Boera system) and is equipped with a 1/2 HP motor pump unit. As the Boera system uses 16 modules and a 1/3 HP pump and motor, its performance under similar head conditions should be a little less than the CSB 50D.

(2) The comparison will be based on the existing head and flow conditions at Boera for 28 February 1985. Converting to English units

Flow rate = 74 l/min = 19.5 US gal/min

Total head = 11.5 m = 37.8 ft.

Insolation = 93 mw/cm^2

Using the manufacturer's curves at Figure 2-2, the flow rate at a solar insolation of 90 mw/cm^2 is approximately 25 US gal/min or 92.7 litres/minute. The relative performance of the two systems is indicated in Table 2.4.

Table 2-4
Performance of Boera System vs
CSB 50D

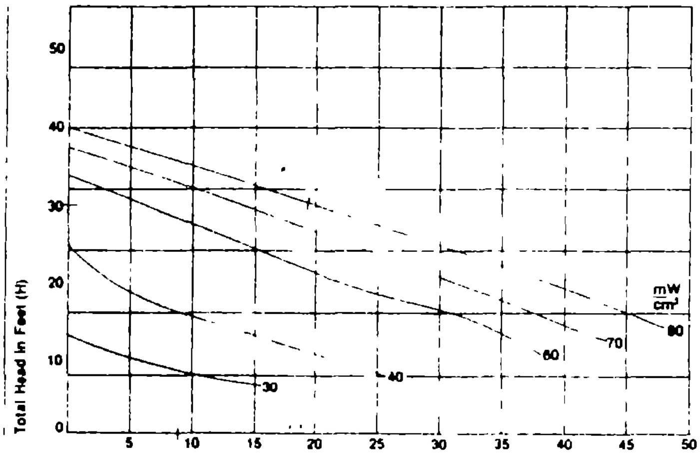
	Insolation mw/cm	Head-m	Flow l/min
Boera	93	11.5	74
CSB 50D	90	11.5	92.7

Again, the results are reasonably comparable and it can be concluded that the Boera system is providing the expected performance.

FIGURE 2-2

Specifications CSB 33D / CSB 50D

Performance of CSB 33D at various sunlight levels



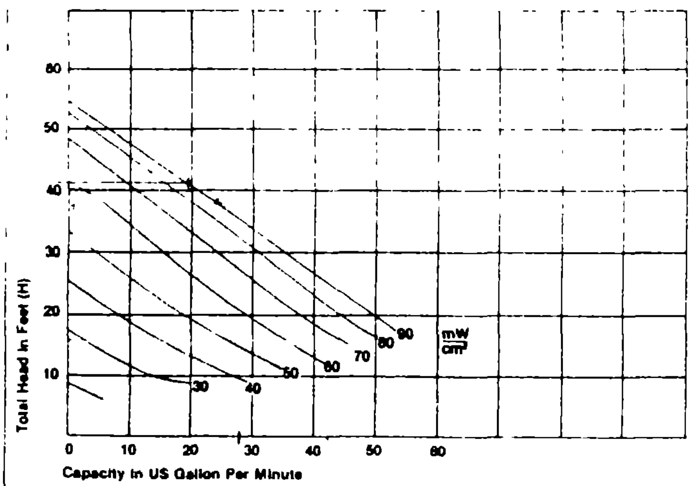
Nominal Operating Characteristics,

CSB 33D

Rated BHP	One Third @ 2400 RPM
Pump	Self Priming Centrifugal
	Suction 1" NPT
	Discharge 1½" NPT
Operating Voltage	58 VDC
Operating Current	6.75 amperes*

FIGURE 2-2

Performance of CSB 50D at various sunlight levels



Nominal Operating Characteristics,

CSB 50D

Rated BHP	One Half @ 2800 RPM
Pump	Self Priming Centrifugal
	Suction 1½" NPT
	Discharge 1½" NPT
Operating Voltage	58 VDC
Operating Current*	9.0 amperes*

*Measured at 100mW/cm² and 25°C

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2.4 Solar energy and water consumption

2.4.1 General

While solar systems are reasonably reliable they are only appropriate if there is sufficient sunlight to supply the water requirements of the people. Certainly, storage provisions can mitigate the reduced pumping capacity during periods of low solar insolation, but the amount of capital required to overcome such shortages could, of course, rule out the use of these systems.

2.4.2 Solar insolation

Boera Village and University of Papua New Guinea

(a) General

In order to determine the appropriateness of the solar system in Boera it was therefore necessary to identify the range of solar insolation values over a reasonable time frame. However, as the period of this study did not permit long-term recording, it was decided that values established at the University of Papua New Guinea (UPNG) could be used as representative of conditions in Boera. UPNG is located approximately 16 km., in a straight line, from Boera. Unlike the village which is on the coast, the University is situated on a plateau about 33 meters above mean sea level, it is near the mountains, and is about 5 km from the coast. Solar insolation values determined at the University of Papua New Guinea from 18 January to 1 February 1984 indicated an average value of 6.14 kwh/m^2/day while values at Boera for the same period were 5.86 kwh/m^2/day (see Table 2-5).

In effect, this means that values at UPNG are approximately higher by 0.28 kwh/m^2/day. However, it was decided that the values were reasonably comparable and could be used to depict long-term solar conditions at Boera village.

Table 2-5
Comparison of Conditions
Boera - UPNG

Time & Date	Solar Energy $kwh/m^2/day$ Boera	UPNG	Water Pumped litres/day	litres/$kwh/m^2/day$
11.10 a.m. on 18-1-84 to 11.56 a.m. on				
1-2-84	5.86	6.14	27 646	4 718
6 p.m				
2-2-84	5.4	5.61	24 850	4 602
3-2-84	5.4	6.63	26 033	4 821

(b) Water consumption and solar energy - Boera

The next step was to relate the solar insolation values to water consumption so that minimum required levels of solar energy could be established. In this regard, measurements were taken at Boera from 18 January 1984 to 1 February 1984. The results are detailed in Table 2-5.

The average value of 5.86 $kwh/m^2/day$ at Boera for a pumping rate of 27,646 litres per day can be equated to solar energy as 4718 litres/$kwh/m^2/day$. Thus, a water consumption range from 24 850 to 28,000 litres/day (Table 2-1 refers) will require solar energy limits from 5.26 to 5.93 $kwh/m^2/day$.

(c) UPNG solar conditions

A review of the statistics at UPNG indicated the following solar conditions for 1979 and for a part of 83/84.

Table 2-6

Daily solar energy in kwh/m²/day UPNG 1979												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	5.04	5.43	5.21	4.50	4.33	4.09	4.49	4.77	5.32	5.4	6.04	5.92
Max.	6.62	6.82	6.4	6.09	5.20	5.00	5.18	5.66	6.74	6.82	6.87	7.52
Min.	1.54	2.87	6.29	1.44	2.87	1.55	1.81	2.45	3.17	2.79	4.88	2.47

Daily solar energy in kwh/m²/day UPNG 1983/84				
	Jan	Feb	1984	1983 Dec
Mean	6.28	5.37		5.64
Max.	8.07	7.20		7.76
Min.	2.97	2.16		2.80

(d) <u>Annual solar conditions</u>

Using the range of desirable solar energy established earlier (5.26 to 5.93 kwh/m^2/day), it is obvious from a review of Table 2-6 that the most unfavourable annual solar conditions will, most probably, occur at Boera from April to Aug. However, short-term shortages can also be expected to come about throughout the year as the monthly minimum values are well below the minimum solar requirements.

(e) <u>Water production</u>

Another way of expressing the situation is to determine the water supply potential under various solar conditions. To arrive at this solution, the minimum, mean and maximum values of daily solar energy and the corresponding water supply potential are detailed in Table 2-7. (The water supply potential was calculated by multiplying the solar insolation values by the constant 4718 litres/kwh/m^2/day which was developed earlier.)

Table 2-7
Solar Insolation
and
Potential Water Supply

	May 1979		June		July	
	Solar kwh/m^2/day	litres/ day	Solar kwh/m^2/day	litres/ day	Solar kwh/m^2/day	litres/ day
Min	2.87	13 540	1.55	7 313	1.81	8 540
Mean	4.33	20 428	4.09	19 296	4.49	21 183
Max	5.20	24 533	5.00	23 590	5.18	24 439

The figures clearly show that the minimum water consumption needs of 24 000 litres/day can be provided only under maximum conditions. It is therefore obvious that storage will be required to offset the shortages in production.

(f) Low periods of solar energy

In addition to assessing the annual variations, it is also necessary to consider consecutive periods of low solar energy in order to establish if the available storage and the pump output is sufficient to cover the average daily water needs. The information shown in Table 2-8 indicates that low solar energy occurred on two successive days - the 7 and 8 January 1979.

Table 2-8
Consecutive Days of
Low Solar Energy

Date	Solar Energy kwhr/m^2/day	Water Pumped litres/day
5-1-79	4.76	22 460
6-1-79	6.36	30 010
7-1-79	1.54	7 270
8-1-79	2.23	9 330
9-10-79	4.14	19 530
10-1-79	5.90	27 820

Over these two days, approximately 16 600 litres of water were delivered. If it is assumed that the tanks were full on the morning of 7 January, the total water available during the two days was 29 300 litres (nominal storage capacity) plus 16 600 or 45 900 litres or an average daily availability of 22 950 litres. This quantity is not quite sufficient to cover the minimum consumption needs of 24 000 litres. In summary, it is obvious that a large variation in the daily pumping rate is possible and judicious control of the daily consumption is required to ensure that sufficient volume is stored to compensate for variations in daily water use.

1 NOTE: The daily volume was arrived at by multiplying 4718 litres/per kwh/m^2/day by the solar insolation values. It should be noted that the constant is an average value determined on the basis of a relatively high solar insolation value 5.86 kwhr/m^2/day and may not exactly apply to lower solar values during which motor speed is reduced and the pump output is also lowered.

2.5 Conclusions

The solar system is operating within technical expectations. Sufficient water is being provided to meet the needs of the people under the majority of conditions and the pump and storage facilities provided are sufficient to ensure a continuous supply under the known conditions of available solar energy.

SECTION 3

3. Selecting solar photovoltaic systems

3.1 Background

Many of the small remote health posts in Papua New Guinea do not have electrical power supplies for water systems, lighting, medical refrigeration or water heating.

Generally, water is obtained from rainwater tanks or shallow wells, lighting is provided by kerosene pressure lamps, which require a supply of mantles and spare parts and fuel is reasonably expensive (up to K2.50/litre). Refrigeration of medical supplies is usually by kerosene or gas refrigerations but these systems have not been particularly successful because of wick and burner problems. In addition, regular supplies of fuel are required.

Photovoltaic systems can be a cost-effective approach to providing these amenities to such remote facilities. They require little maintenance and there is no need to provide regular logistical support services.

3.2 Definition

Basically, a photovoltaic system provides electrical energy for periods during 24 hours per day through a combination of solar panels and a battery bank. The energy collected by the panels directly powers equipment, such as a water pump and motor during the day and the remaining energy is used to charge the batteries. Lighting needs are supplied from the battery during the evening hours. Lead acid batteries are normally used for PVC storage systems. Two arrangements are normally used either block batteries which have an output of 6 or 12 volts and ratings up to 100-150 ampere-hours, or large 2 volt cells with ratings of 250-600 ampere-hours. In the latter case, 6 x 2 volt cells are connected in series to give a large 12-volt battery.

3.3 Introduction

It must be stressed from the outset that this is not a comprehensive guidelines for the design of solar photovoltaic systems. It is only intended to provide very broad guidance to health personnel in the preliminary identification of solar systems. The final design, however, should be the responsibility of a professional engineer with appropriate experience in both PVC and water pumping systems and with an empathy for the needs of the village people.

It should be pointed out that the comments are confined to photovoltaic systems and do not include solar systems, such as at Boera, where the pump motor is powered directly from the solar array during the daylight hours. However, for convenience, a design example of this particular application is included at Annex 4.

Basically, the guideline discusses the stepped procedure associated with project development. It begins with the identification of the different data needs and then proceeds to identifying the water and lighting needs for a remote health centre, selecting the pump and the number and type of lighting fixtures and then identifying the matching solar array. A similar approach is applied to solar-powered medical refrigeration. Illustrative design examples are also included.

3.4 General project details

The following information is required to adequately develop a solar project and should be obtained by the responsible health officer.

3.4.1 Identification

The name of the community (or village), its population, rate of growth, the name of the Province and its approximate location in the Province.

3.4.2 Geographical details

(a) Latitude, longitude and elevation above mean sea level (if available).

(b) General description of the location with photographs of the village area, the pump site (if known) from both the ground and the air if possible.

(c) Possible obstruction to the sun's direct radiation to the North, East and West of the pump site including high trees, hills and mountains. If trees are possible obstructions, it should be established if the people in the community will allow the trees to be removed. Also, solar modules should not be located near fruit trees as people throw rocks or bricks or sticks to dislodge the fruit and these items might damage the glass.

3.4.3 Climatic

(a) Rainfall

Ascertain if there are wet and dry periods and, if so, determine their approximate duration. If available, obtain precipitation data.

(b) Temperatures and relative humidity

Obtain data on monthly maximum, minimum and average daily temperatures and the relative humidity.

(c) Wind

Establish the wind regime and the average and maximum wind velocities.

(d) Solar Energy Available

Determine how many consecutive days of rain and heavy cloud can occur in the area. How many hours of bright sunlight generally occur each day?

3.4.4 Details of water supply

(a) Is there an existing bore well or hand dug well? If so, what type of pump (if any) is used, i.e., wind, hand or diesel?

(b) Establish the total population of the village and the population growth likely in the next ten years and the total number of houses to be served.

(c) If no bore well or well exists, how and where do the people obtain water at present? Who will fund the investigation for groundwater and installation of bore well?

(d) Is the existing bore well in a potential site in the village? If not, how far from the village? What is the distance to the nearest source of good quality water?

(e) Are the village people willing to elect a water committee to maintain and operate the PVC water pumping system and are they willing to pay an adequate fortnightly water fee?

3.5 Daily water needs

Daily water requirements are determined on the basis of the number of people expected to use the facility over the design period and the daily per capita consumption. All or a part of the supply may have to be provided by the solar system. If rainwater storage for example is available, the system will only have to supply the excess. The relationship can be expressed as follows:

$Q_T = 1.20\ N_o \times q - Q_{rs}$

Q_T = water to be supplied

1.20 = expected increase in population over the design period

N_o = present population

q = per capita usage for drinking, cooking, bathing, washing (a 45.5 litres/cap is the established average for central province)

Q_{rs} = rainwater storage

3.5.1 Illustration

(1) If N_o = 700, q = 45 litres/cap/day

$Q_T = 1.20 \times 700 \times 45 - Q_{rs}$

$= 37\ 800 - Q_{rs}$

Now, if there is a rainwater catchment system consisting of 10 tanks each with a capacity of 9000 litres which are filled each week the daily volume available $= \frac{10 \times 9000}{7} = 12\ 857$ litres/day and

$Q_T = 37\ 800 - 12\ 857 = 18\ 643$ litres/day

3.5.2 Illustration II

A more likely application for a health centre would be a pump discharging into a roof mounted tank. This example of a Novia pump discharging into a 500-litre roof tank against a total effective head of 4 metres (13 ft), (5.7 psi) indicates the flow rate (refer to Annex 5) would be 3.3 US gpm or 12.5 litres/min., with a current drain of 3.2 amp. or an ampere/hour = 3.2 Ahp.

The operating period $= \frac{500}{12.5} = 40$ min to fill the tank

and the ampere/hour consumption $= \frac{40}{60} \times 3.2 = 2.13$ Ahp

At a voltage of 12.8, the power equals $2.13 \times 12.8 = 27$ watts

3.6 Storage requirements

As a pump is not selected to provide a continuous water supply under all conditions, storage is usually provided to ensure that sufficient water is available during peak demand periods which occur in the morning and the early evening.

The storage tank should be selected in accordance with the environmental conditions. For example, steel tanks may not be favourable in a coastal village because of the corrosive effects of the salt air. A fibreglass tank may be a better alternative. In any case, corrugated galvanized tanks are available in Papua New Guinea as are fibreglass tanks. Concrete tanks can also be used.

The selection of the storage volume is an engineering decision based on the population and the habits of the particular village. In many cases, one day's consumption is considered sufficient.

3.7 Electrical lighting

Recommended lighting levels, for various job functions, have been established over the years to ensure that sufficient lighting is available to avoid eyestrain and fatigue. They are expressed in lux (lumens/m^2). Some recommended levels are:

Wards	-	300 lux
Medical examination room	-	500 lux
Office desk	-	400 lux

Fluorescent lights are used in PVC lighting systems because of their higher efficiency, i.e., light output/watt input or lumens/watt. A range of fluorescent light fittings are available which operate from 12-volt DC and use standard 8, 13, 18 and 20-watt tubes. (In nominal 20-watt fittings, it is suggested that the new standard 18-watt high efficiency tubes be used rather than the older standard 20-watt tubes.)

The electrical needs to be supplied by the solar system will depend on the usage rate (hours/night) and the number of nights per week the lights are required. Also, some allowances should be made to cover emergency requirements.

3.7.1 Illustration example

Assuming that an 18-watt unit uses an average of 1.7 amps from a 12.5V DC battery, the power consumption is approximately 12.5 x 1.7 = 21.3 watt hours for each 18-watt fixture.

3.8 Design example - water and lighting

For purposes of illustration, the following conditions have been established for a remote health centre. A design example follows which details the step-by-step procedures which are required to select an appropriate solar system to provide the health centre with water and with lighting.

3.8.1 Operating data

(a) Water Pumping

Quantity of water pumped/day	-	500 litres
Motor pump unit	-	Noria Model RV 1000
Motor terminal voltage	-	12.8 volts DC
Motor current	-	3.2 amps DC
Pumping time/day	-	40 mins.
Total head	-	4 metres (5 p.s.i.g)
Ahp - Ampere hours/day at 12.8 volts	-	2.1

(b) Lighting

Number of lights	-	4
Wattage of lamps	-	18 watts
Nominal light fitting voltage	-	12.5 volts
Nominal light fitting current	-	1.7 amps
NUmber of hours/night operation	-	2
Number of days/week	-	6
Ampere hours/light fitting/hr.	-	1.7 Ah

(c) Solar conditions

Maximum solar radiation level	-	1 kW/m^2
Average daily solar energy	-	5 $kWh/m^2/day$

3.8.2 Determine electrical load

(a) Pump

Ampere hours/day
Ahp = 2.1 at 12.8 volts

(b) Lighting

Ampere hours/day required by the 4 lights (Ah_1)

Ampere hours/hour/18 watt light - 1.7 Ah

Ampere hours/hour/4 x 18 watt light 4 x 1.7

= 6.8 Ah

Ampere hours/2 hours/4 x 18 watt lights - 2 x 6.8

= 13.6 Ah/day

(c) Total load (Aht)

$$Aht = Ahp + Ah_1$$

$$= 2.1 + 13.6$$

$$= 15.7 \text{ Ah}$$

say = 16 Ah/day approx.

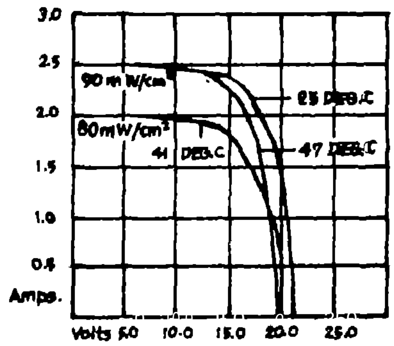
3.8.3 Select solar panels

The ampere hour output of a module can be determined in two ways: the current method and the power method.

(a) Current method

By referring to the module IV curves shown

Figure 3-1
Typical PVC Module IV Curve at Cell Temperature 47°C



Module peak power rating = 37 watts

in Figure 3-1 and using the 1 kw/m^2 solar radiation curve for 47°C, an average battery charging voltage of 13.6 volts, the output current = 2.35 amps/hour.

If 2.35 amps is used for 5 hours per day then

Ah/day = 2.35 x 5 or current provided by each module
= 11.75 Ah/day/module

Alternately by the:

(b) Power method

With a module area of $0.37m^2$	
and a module conversion efficiency	= 8.5%
and an average daily solar energy	= 5 kWh/m^2/day
the output energy/day/module	= 5 x 0.37 x 0.085
	= 157 watt hrs/day
and the output Ah/day/module at an operating voltage of 13.5 volts	= 157/13.5
	= 11.6 ah/day

Note: This value of 11.6 Ah by the power method checks approximately with the value of 11.75 Ah obtained by the current method.

.:. Assume a current output of 11 Ah/day/module

3.8.4 Determine number of modules

The total electrical load, A_{ht} = 16 Ah/day.
As the batteries used in this system would have an AH charge/discharge efficiency of approximately 90%, the Ah into the batteries would be

$$\frac{16}{.9} = 17.8 \text{ Ah} = 18 \text{ Ah}$$

The number of modules required, with each providing 11 Ah/day under an average solar energy value of 5 $kWh/m^2/day$, would be:

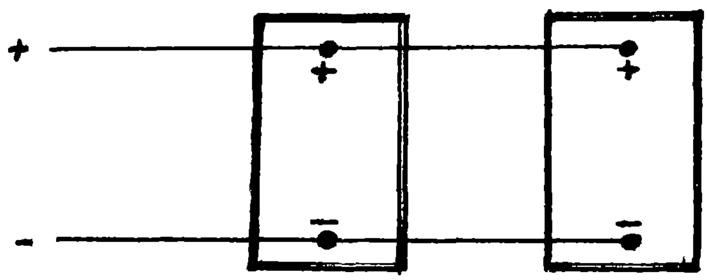
$$\frac{18 \text{ Ah}}{11 \text{ Ah}} = 1.64 \text{ modules}$$

This means 2 modules each of 37 watt peak power rating at 47°C would be required, thus, giving some reserved capacity.

3.8.5 Select batteries

Number and size (Ah) of batteries required
Daily ampere hours discharge = 16 Ah/day
Either shallow or deep discharge lead acid batteries can be used. Assuming that a shallow discharge is used, i.e., 10% per day. The total battery Ah capacity = 16.10
= 160 ah

These requirements can be provided by 2 x 100 Ah capacity 12 volt block batteries connected in parallel as in the sketch below. This will allow for some reserved capacity.



3.9 Solar photovoltaic - medical refrigeration

3.9.1 General

Health officers know that vaccines and certain medical supplies should be kept at between 2-8°C in order to retain their potency. To do this a 'cold chain' is required from the time of manufacture through delivery from overseas to the time when the vaccine or drug is used. A break in this chain could render these essential supplies impotent and, as there is no simple means to test their potency, lives could be lost because of an interruption in the cold chain.

There are some simple and low-cost means for detecting when a medical preparation has been outside the 'cold chain'. One method uses patches which change colour when the temperature exceed 10°C. Others react at temperatures of 38 and 48°C.

At present, small health posts are provided with these essential medical supplies from a larger post where refrigeration is available.

Solar refrigerators have been undergoing field trials for a number of years but the results have been disappointing. The basic problem has been to select the combination of batteries and modules which will adequately cover periods of low solar energy. It has not yet been resolved. Usually, the storage cabinets range in size from 20 to 40 litres. The smaller size reduces any misuse of the unit, overloading with carbonated drinks or bottles of water, etc., and, of course, reduces the cooling requirements.

PVC medical refrigeration systems should be independent of other loading, such as lights and pumps, so that the load exerted is predictable.

The load represented by a refrigerator is expressed as:

Ampere-hours/day = Normal operating current
x 24 hrs. x duty cycle

and watt-hours/day = ampere-hours/day x average battery voltage.

3.10 Design example - medical refrigeration

The following example will select the modules and the battery bank required to sustain a 2°C temperature within a 40-litre refrigeration at a remote health centre.

3.10.1 Operating date

Refrigerator Capacity	-	40 litres
Motor voltage	-	12 volts DC
Motor current	-	4 amps DC
Ambient temperature	-	32°C
Inside temperature	-	2°C
Duty cycle for given no. of kg of load/day and given total lid open time	-	20% (0.2)
Average daily solar energy	-	5 $kWh/m^2/day$

3.10.2 Determine electrical load

Ampere hours/day consumption
Ah/day = normal operating current x 24 hours x duty cycle
= 4 amps x 24 hours x 0.2
= 19.2 Ah/day = 20 Ah/day

Watt hrs/day = Motor voltage x Ah/day as the motor voltage may be 12.5 volts:

Watt hrs/day = 12.5 x 20
= 250 Wh/day

3.10.3 Select module

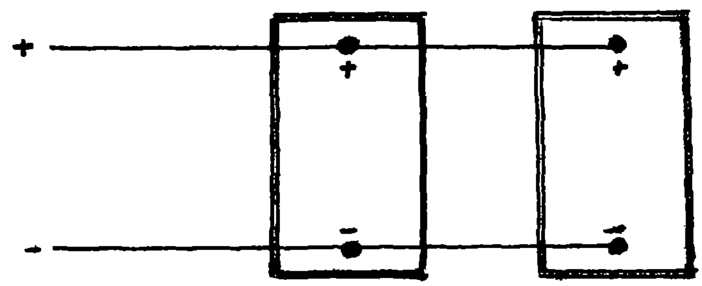
As determined in 3.7.4, the average output in ampere hours per day (Ah/day) of a 37 peak watt module using the current and the power method is 11 Ah/day.

Calculation of the number of 37 peak watt modules required. Electrical load of the refrigerator = 20 Ah/day at 12.5 volts. If we take the ampere hour charge/discharge efficiency of the batteries into account (i.e., say 90%) the Ah required from the modules = $\frac{20}{.9}$ = 22.2 Ah

$$\therefore \text{ the number of modules required } = \frac{22.2}{11} = 2 \text{ modules}$$

3.10.4 Select batteries

Calculation of the size and number of batteries
Ampere hour discharge/day = 22 Ah at 12.5 volts.
If we use shallow discharge lead acid batteries, i.e., 10%/day, then battery total capacity = 22 x 10 = 220 Ah. Thus, 2 x 100 Ah 12 volt batteries would be required connected in parallel:



3.11 Solar water heating systems

The National Government adopted a policy some years ago to eventually replace the electric water heaters in Government houses with solar water heaters. This started in the National Capital District to reduce the peak loading on the Rouna Hydro System and the Moitaka Gas Turbine Generators. As a result of this policy, the National Government, through the Department of Works and Supply, grants two-year contracts for the supply of solar water heaters to the successful tenderer. The contractor then supplies the heaters and arranges for their installation for both the national and provincial governments. The Rheem agent won both the first and second (current) contracts. Thus, only Rheem equipment is discussed here. Other systems available on the market include Solarhart, Beasley and Edwards.

Two standard Rheem sizes are available, a 160-litre and a 300-litre unit.

As the selection of water heaters depends, therefore, on the capacity of the available units, this report will not discuss the design approaches which are used. It is important, however, for health officers to realize that water heaters must have a positive pressure at the inlet for the unit to function. In remote areas, where there are no water mains, adequate pressure can be supplied by installing a water tank one meter above the unit.

4. Operating and maintenance practices

4.1 Module care

4.1.1 Wipe and wash modules' glass faces, say, every one or two months in light dusty conditions. In cases of heavy dust, i.e., situated near a dusty road, more frequent washing may be required. In areas with very little dust, a wash every 6 months should be sufficient.

> NOTE: During rainy seasons module should be relatively self-cleaning if sloped at about 15° to the horizontal.

4.1.2 If modules are situated near mango trees, a mesh screen is required to protect the modules from stones thrown to dislodge mangoes from the tree. Chicken or bird-cage wire is satisfactory as it will give very little shading.

4.2 Pump and refrigerator DC motors

If these motors use carbon brushes running on a commutator, the brushes should be checked for wear at least every 6 months and replaced if wear is excessive.

4.3 Batteries

4.3.1 If sealed no-maintenance batteries are utilized and are protected by a low-volt relay, very little checking or maintenance is required. Battery voltage should be checked using a suitable voltmeter at least every three months during the first year of operation.

4.3.2 If batteries with filler caps are utilized, the electrolyte level should be checked, say, every 2 months and distilled water added if required.

4.4 Regulators

Regulators should be checked for upper charge limit operation during routine visits to the site. Low volts relays require a special test set or should be returned to the maintenance shop for checks.

5. Conclusion

This report has summarized the information which should be supplied by the health officers, so that experienced solar photovoltaic engineers can evaluate and produce reliable, simple and economic PVC system designs for solar water pumping for small remote communities and solar systems for small remote health posts.

The 'real world' of developing countries like Papua New Guinea presents a challenge to manufacturers, designers and implementors of PVC equipment and projects. Because of this, the various equipment available, and their applications, require expert evaluation to ensure that their potential long-term reliability is achieved on an economic basis.

The National Standards Council of Papua New Guinea has arranged for a sub-committee of its Electrical Engineering Committee to investigate and prepare a standard for PVC modules, firstly, then systems, secondly. Such a standard will assist manufacturers and designers in the preparation of specifications and allotment of contracts in this relatively new field. The writer is a member of the PVC Standards Sub-Committee.

Solar hot water systems in 100-300 litre storage capacity are established, well-proven, commercially available systems which can be successfully applied by a supplier with full knowledge regarding their equipment, correct installation practices, and available solar energy in different areas.

Simple design guides have been presented to indicate some of the processes involved in engineering design procedures.

With the full cooperation of health officers, manufacturers, suppliers, design engineering consultants, installation and maintenance staff and the users, the utilization of solar energy in remote areas of developing countries promises economic and reliable solutions to many existing problems.

6. References and acknowledgements

6.1 References

1. G.H. Kinnell, 'Application of Solar Systems Technology: Part I - a study of Boera Village Solar Photovoltaic Water Supply System in Papua New Guinea'. Report: No. WHO - GAK 1/1/84 for WHO IDWSSD Advisory Services Project ICP/CWS/006 (RAS/81/024).

2. G.H. Kinnell, 'Solar Photovoltaic Systems in the Development of Papua New Guinea', paper presented at the Fourth E.C. Photovoltaic Solar Energy Conference in Italy, 10-14 May 1982.

3. G.H. Kinnell, 'Standards in the Manufacturing Industry - Energy Conservation' paper delivered at the Papua New Guinea National Standards Council Seminar on Standardization, 13-15 April 1981.

6.2 Acknowledgements

The writer wishes to thank all those people who cooperated with him in four years of pioneering solar photovoltaic systems for the rural areas of Papua New Guinea and to all those who issued challenges to be overcome. The results of these four years are summarized in this report.

He would also like to thank his part-time typist for her diligent and accurate typing and the part-time artist who prepared the photographic display sheet.

6.3 Further reading

World Bank Report - Small-scale Solar-powered Pumping System: The Technology, Its and Economics and Advancement by Sir William Halcrow and Partners. (UNDP Project GLO/80/003 Main Report.)

ANNEX 1

TERMS OF REFERENCE

ANNEX 1

1. TERMS OF REFERENCE

1.1 Solar Technology

1.1.1 General

The study area is the village of Boera, which is located in Central Province, Papua New Guinea. The water system being used by the population is driven by solar energy. Basically, the study will:

(a) Discuss the history of water supply in the village and describe the various systems which have been installed up to and including the introduction of the solar system. Identify the reasons for each system failure in respect to: operation and maintenance; community education and participation; human resource development; and the appropriateness of the technology selected. Detail and compare the capital and operating and maintenance costs for each installation.

(b) Describe the solar water system and assess the suitability of the solar components in respect to their appropriateness, reliability and performance by:

(1) determining the adequacy of the design;

(2) establishing the sufficiency of the control system including both water level and voltage controls;

(3) evaluating and comparing the operating and maintenance practices which have been instituted with recommended practices;

(4) considering the availability and the cost of spare parts;

(5) Simple performance checks only as follows:

(i) Solar integrator and water meter daily readings for 5 days (Note: Water meter to be provided and installed by other);

(ii) Simultaneous readings of solar insolations, motor voltage and current and water levels source and tank taken at two values of solar insolation 300 - 1 000 mw/cm^2 and 400 - 600 mw/cm^2.

(6) Provide:

(i) Manufacturers date (if procurable) for efficiency of PVC modules, motor and pump, and

(ii) Calculation of system performance based on above data for various source and tank water levels.

Annex 1

(c) In the light of the studies carried out under paragraphs (a) and (b) above, evaluate the appropriateness of the solar water system for the village of Boera.

(d) Design Principles. To guide national staff in the selection of solar sytems develop a design manual detailing criteria relative to conditions in Papua New Guinea, and by design examples indicate:

(i) the design of the simpliest type of solar system supplying water to a health post;

(ii) the design of a complete service solar sytem for a health post which provides power for the combined activities of: water supply; electrical lighting; hot water heating; and refrigeration. Prepare detailed designs for each system.

(iii) describe the maintenance and operating practices which are required to sustain maximum system reliability.

ANNEX 2

PERFORMANCE OF WATER METERS

ANNEX 2

PERFORMANCE OF WATER METER

This meter imposed very high head conditions on the system and as a result, prolonged the completion of the report. The extent of its influence was suspected when the measured DC power input to the motor did not correspond with the theoretical calculated power (see paragraph 2.1.7), however, its effect was not known until the head loss curves were received after the field result had been completed.

An examination of figure 2-1 indicates that its head losses of 3.8 and 4.7 meters for 74 and 80 litres/min respectively represent 33 and 40% of the total system head.

To further illustrate the effect which the meter would exert on a similar system, we will compare the output of the CSB 50D system (Figure 2-2) with and without the unit. A review of the following calculations indicates that the flow rate of the system would increase by 71% without the meter: A similar increase therefore would be expected of the Boera village system.

	Total Eff Head		Solar Insol		Water Flow	
	m	ft	kw/m^2	mw/cm^2	litres/min	US gal/min
With meter	11.4	37.4	0.93	90	92.7	24.5
Without meter	7.83	25.7	0.90	90	159	42

ANNEX 3

COSTS FOR VARIOUS WATER SYSTEMS

BOERA VILLAGE

ANNEX 3

Systems Costs

Windmill Costs

1) Equipment

Double geared windmill head with 8 ft. dia. blade assembly	K 1 932	
Syphon pump	450	
Steel latticed tower	476	
Installation	1 000	
Bore hole	1 500	
Tanks	3 000	
Distribution	900	
Total Capital	K 9 258	appx. 9 250

2) Replacement - every 2 years

Syphon pump - 450	K 450	K 450

3) Maintenance and Administrative Costs - Annual

Labour Costs - caretaker (K10 per fortnight) and committee chairman and treasurer (K5 each per fortnight)	K 1 040	
Routine maintenance	100	
Total O and M and Adm		K 1 140

4) Economic life of facilities - 20 years

5) Interest rate - 10%

Diesel System Costs

1) Equipment

3 1/2 HP, EFD Diesel Engine	K 1 663	
Piston Pump	1 167	
Installation (includes concrete base and shelter)	1 200	
Tanks and pipes	3 000	
Distribution line	900	
Bore hole	1 500	
Total Capital Cost		K 9 430

2) Annual Operating & Maintenance Costs

Diesel fuel - 2.5 l/day	K 300
Lubricating oil	60
Routine maintenance	600
	K 960

Annex 3

3) Administrative Costs

Caretaker and committee	K 1 040	

4) Total annual operating, maintenance and admministration — K 2 000

5) Economic life of facility - 20 years

6) Interest rate - 10%

Handpump Costs

1) Equipment

Handpumps - 6 each K300 (six are required to supply 27.3k litres per day)	K 1 800	
Bore holes - 6 each 1500	9 000	
		K10 800

2) Replacement Costs

6 Handpumps every 5 years	K 1 800	

3) Annual Maintenance and Administrative Costs

Routine maintenance - 6 pumps each 100	K 600	
Caretaker and committee	1 040	
Total		K 1 640

Solar Hand Pump Costs

1) Equipment

16 - 2000 PVC Modules and frame Installed	K 6 000	
Tanks and piping	3 000	
Distribution line	900	
1/2 HP Pump and motor	1 000	
Bore Hole (1)	1 500	
Total		K12 400

2) Replacement Costs

Pump replacement every 2 years 200	K 200	

Annex 3

3) Annual Maintenance and Administrative Costs

Routine maintenance	K 100	
Caretaker/committee	1 040	
Total Cost		K 1 140

ANNEX 4

SELECTION OF SOLAR PHOTOVOLTAIC WATER PUMPING SYSTEMS FOR SMALL COMMUNITIES

ANNEX 4

1. Selection of Solar Photovoltaic Water Pumping Systems for Small Communities

1.1 General

The first step is to determine the electrical characteristics and the power needs of the pump to supply the water requirements and then to select the matching solar array.

1.2 Motor/Pump Unit

The type and size of the motor/pump is selected on the basis of the overall system head, the total daily water requirements of the community and the maximum, average and minimum daily solar energy available. Also, cost factors such as the reliability and life of the unit have to be considered.

1.3 Total Effective Head (Het)

The total head requirements are determined from the equation:

$$Het = Hsg + Hsv + Hdg + Hdv + Hdm^*$$

Where:

Hsg = geometric suction head including 'draw-down'
Hsv = effective head loss for suction pipes and fittings, at a given water flow rate
Hdg = geometric delivery head
Hdv = effective head loss for delivery pipes and fittings at a given water flow rate
Hdm = effective head loss in water meter for a given water flow rate.

Notes: 1. All the above terms are in metres.
2. If no water meter is included Hdm = 0.

1.3 The Motor Shaft Power (Pms) and the D.C. Electrical Power Input (Pmt) to the Motor Terminals is determined from

$$Pms = \frac{Y_1 \; Qv \; Het}{102 \; Np}$$

Where:

Pms = shaft power output of motor in K.W. (Volts x Amps)

Y_1 = specific weight of water (use a value of 1000 kg/m^3)

Qv = rate of flow of water in m^3/sec.

Het = total effective head in metres

Np = efficiency of pump

Annex 4

The equation for Pmt is:

$$Pmt = \frac{Pms}{Nm}$$

where:

Nm = efficiency of motor

Note: The above would be calculated for maximum load conditions.

1.4 Photovoltaic Array

Having calculated the electrical power taken by the motor under maximum load conditions, the electrical output (Ppva) required from the photovoltaic array can be determined from the following equation:

$$Ppva = Pmt + Plo$$

where:

Plo = electrical power losses in connecting cable, switches, meters, etc. between the motor terminals and output terminals of the PVC array.

The PVC array size, i.e., peak power output and the number of modules depend upon the voltage rating of the motor, the value of 'Ppva' for maximum motor loading conditions, the available maximum solar radiation level and the maximum, mean and minimum values of daily solar energy, the type, rating and make of the modules and the overall efficiency of the array.

1.5 Calculation of Pump Motor Power Input (in kW) for a given set of conditions

1.5.1 Data

Time - Noon

Solar insolation	-	95 mW/cm^2 (0.95 kW/m^2)
Water Flow Rate	-	80 litres/min (0.00133 M^3/sec)
Water Suction Depth (Hsg)	-	0.66 metres
Water Height in Tank	-	0.72 metres
Motor Voltage	-	Assume 58 volts
Motor/Pump Overall Efficiency (NmNp)	-	0.41

1.5.2 Calculation of Total Effective Head

Het = Hsg + Hsv + Hdg + Hdv + Hdm

where

Hsg = 0.66 metres

Hsv = 0.8 metres (calculated for 6m - 40mm galv. pipe and foot valve)

Hdg = 2.72 metres

Hdv = 2.03 metres (calculated for 11.4 metres Rigid PVC Pipe, Grade 12 + 25 mm gate valve and various fittings)

Hdm = 0

Het = 0.66 + 0.8 + 2.72 + 2.03 + 0

= 6.21 metres

1.5.3 Calculation of Motor Input Power (Pmt)

a) Normal running conditions

$$Pmt = \frac{Y_1 \; Qv \; Het}{102 \; nmNp} \quad kW$$

$$= \frac{100 \times 0.00133 \times 6.21}{102 \times 0.41} \quad kW$$

$$= 0.197 \; kW$$

b) Maximum Head Conditions

The maximum power input to the motor and, hence, the maximum photovoltaic array output power and the actual motor rating (shaft output power) required, in kW, should be calculated on the basis of maximum flow rate and the maximum total effective head (i.e., low water table and near full tanks).

Assume Het max. = 11 metres

Qv max. = $0.00133 m^3$/sec.

Then Pmt $= \dfrac{1000 \times 0.00133 \times 11}{102 \times 0.41}$

= 0.35 kW

1.5.4 Photovoltaic Array Output Power ($P_p$va)

$P_p$va = Pm + Plo

= 0.35 kW + electrical losses in current between array output terminals and motor terminals

= 0.35 + 0.006 (for Boera)

= 0.356 kW

Annex 4

1.5.5 Motor Rating (Shaft Output) in kW (Pms)

If we assume motor efficiency = 80%, then Nm = 0.8

Pms = 0.35 x 0.8
= 0.28 kW

1.5.6 Selection of Module Size and Number of Modules

As Pmt (max) = 0.35 kW
and Ppva = 0.356 kW
we need to make simplifying assumptions because manufacturers' data were not available.

If the motor rated terminal voltage (Vm) = 58 volts DC, then for a power input of 0.35 kW the motor current

$$Im = \frac{Pmt}{Vm} = \frac{0.35}{58} \times 1000 \text{ (Pmt in watts)}$$

$$= 6 \text{ amps}$$

If Plo is estimated on the basis of a 1 Volt drop between the array output and the motor input when the array output voltage is:

Vpva = 58 + 1
= 59 volts
and Ipva = Im
= 6 amps

Thus, we require a PVC array which will provide 59 volts at 6 amps.

As PVC Modules can have max. output power between 14-16 volts choose 15 volts/module.

$$\text{Number of modules in series} = \frac{Vpva}{15} = \frac{59}{15} = 3.93$$

This means 4 modules would be required in series.

If module current = 2 amps at 15 Volts, then for 6 amps the number of modules in parallel $= \frac{6}{2} = 3$

PVC array = 4 modules in series x 2 parallel banks
= 4 x 3 = 12 modules

ANNEX 5

SPECIFICATIONS FOR NORIA MODEL 1000
WATER PUMP

ANNEX 5

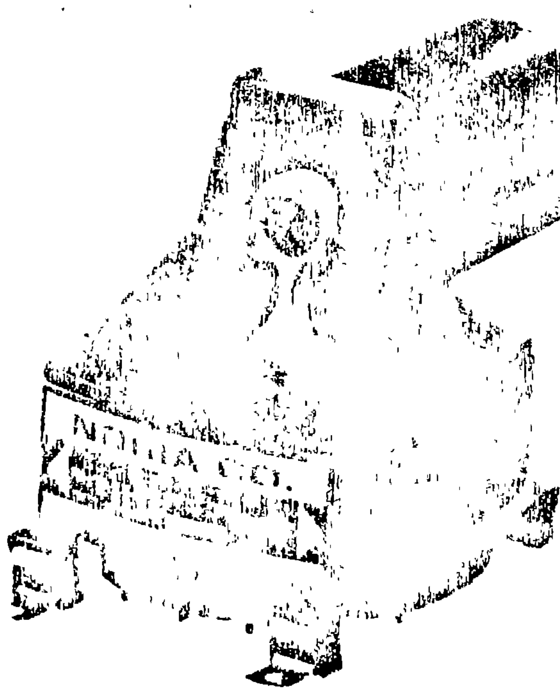
NORIA MODEL 1000 WATER PUMP

THREADED CONNECTIONS

QUIET

4 GPM
2.8 AMP

SELF PRIMING



6 TO 24 VOLTS DC

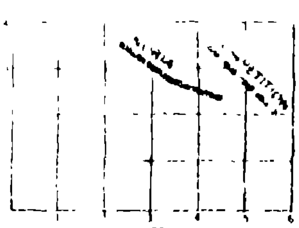
RUNS DRY

PRESSURE SWITCH

WATER INSTANTLY

WATER AT YOUR FINGERTIPS INSTANTLY THE **NORIA** MODEL 1000 WATER PUMP IS A HIGH QUALITY LOW COST, **DIRECT DRIVE** DIAPHRAGM PUMP QUIET EFFICIENT DEPENDABLE THE **NORIA** PUMP WILL DRAW LESS CURRENT AND DO A FAR SUPERIOR JOB DUE TO IT'S UNIQUE PERMANENT MAGNET MOTOR DESIGN WITH THE ABILITY TO RUN FROM 5 TO 24 VOLTS DC COMPETITORS MUST RUN AT 11 TO 13 VOLTS WITH IT'S 1/2 INCH FEMALE THREADED CONNECTIONS THE **NORIA** PUMP WILL ACCEPT BARB ADAPTERS, ELBOWS AND NIPPLES FOR ADAPTABILITY WITH ANY WATER SYSTEM EASY TO INSTALL EASY TO MAINTAIN COMPACT FITS ANYWHERE CAN BE MOUNTED IN ANY POSITION BUILT IN FILTER SCREEN ACCUMULATOR AND BACK FLOW PREVENTER THE NORIA PUMP WILL WITHSTAND HIGH TEMPERATURES FREEZING TEMPERATURES AND CITY WATER PRESSURE IDEAL FOR MULTIFIXTURE SYSTEMS WITH NO NOTICEABLE PRESSURE DROP WHEN MORE THAN ONE TAP IS ON LESS NOISE LESS TROUBLE LESS COST I A P M O. APPROVED

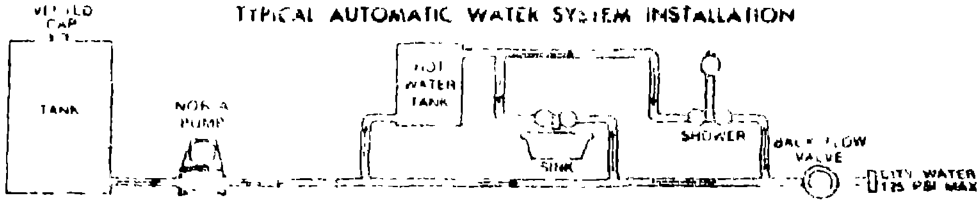
MORE WATER
LESS AMPERAGE



PERFORMANCE DATA

GPM AND CURRENT @ 12.8 VOLTS D.C. DISCHARGE PRESSURE					SHUT OFF PSIG	OUTLETS	SUCTION LIFT MAX	DISCHARGE HEAD MAX
FREE FLOW	5 PSIG	10 PSIG	20 PSIG	25 PSIG				
4.0 GPM	3.3 GPM	2.7 GPM	2.4 GPM	2.1 GPM	27	5	12 FT	15 FT
2.8 AMP	3.2 AMP	3.6 AMP	4.4 AMP	6.0 AMP				

TYPICAL AUTOMATIC WATER SYSTEM INSTALLATION



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