SOLAR POWERED WATER PUMPS
IN
RURAL TOWNSHIPS IN TANZANIA

FINAL REPORT

NOVEMBER 1985

Norconsult
Kjørboveien 20, 1300 Sandvika, Norway
Telephone +472 47 10 00
Telefax +472 54 70 19
Telex 72075 norco n

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TABLE OF CONTENTS

GENERAL

NOTE: This page replaces the original in the report as submitted by Norconsult to Arco Solar (N.E.) Europe and GRUNDFOS International a/s, and represents the comments of these 2 companies.

This report was prepared according to an agreement signed between Norconsult, Arco Solar (N.E.) Europe, and GRUNDFOS International a/s, and on the initiative of Arco Solar (N.E.) Europe.

The requirement was to follow up on the World Bank Report on small scale solar pumping systems issued in 1983.

Norconsult was asked to carry out this research because

- they are a totally independent body with no bias for or against solar pumping systems
- of their international experience in working with aid organizations
- of their in-depth knowledge and experience of water supply in Tanzania.

Arco Solar (N.E.) Europe and GRUNDFOS contributed to the report with up-to-date prices on solar pumping systems (based on GRUNDFOS price list dated 1.5.1983) that was valid at the time the report was carried out and with dimensioning the solar pumping systems.

All other prices and costs were furnished by Norconsult.

The findings of economic analyses carried out to determine the feasibility of using solar powered pumps for water supply (compared against other alternatives) in rural townships in Tanzania are presented in this report. Two villages, Mashete and Mlenje (selected during Phase 1 of the project), and one institution were chosen as representing typical situations and conditions in Tanzania, and used for analysis purposes. Locations of Mashete and Mlenje, both situated in Rukwa Region in western Tanzania, are shown in Figure 1.1.

In addition to the three cases mentioned, preliminary economic calculations have been performed for a fourth case, that of a rural village having high water demand and a high groundwater table (i.e. similar to Mashete Village, but with pumping height reduced by half) to examine how a significant reduction in total head might affect various pumping alternatives.

Since the introduction of GRUNDFOS solar-powered pumping systems in September, 1982, the development in sales has been as follows:

1982 (months)	1983	1984	1985 (expected)
23 systems	119 systems	142 systems	300 systems

Of these systems, 50% are installed in Africa and are typically sold to bilateral aid projects financed by church aid organizations, refugee aid, United Nations organizations, hospitals, and bush clinics.

As to reliability, we can mention that so far, only 2 modules have been replaced by us (vandalism at a refugee camp in Somalia), and 2 inverters have been replaced because of material faults.

The above sales figures confirm our belief in the future of solar pumping systems, and with the downward trend in solar module prices world-wide, - with the constant improvements in module efficiency, and increases in module output, we can only expect more and more interest in these systems.

In fact, since the report was made, Arco Solar (N.E.) Europe supply new solar modules with an output of 53 Wp compared to the 43 Wp modules used in the price assumption. For Mashete, 28 module systems could be used nowadays instead of the 35 module systems that are basis for the calculation. For Mlenje and the institution, ca. 23% more water can be pumped with the same number of new modules compared to the base modules.

We were not always in agreement with Norconsult as to basic assumptions. For example, 2 points where we agreed to differ were:

- a watchman for solar powered pumps. Here Norconsult have used lower maintenance personnel costs for solar systems compared to the other systems, but we still argue that a watchman is not employed in all countries

- back-up pumps. - These are included in alanyses in the report, but our experience in Africa shows that back-up systems are not universally installed.

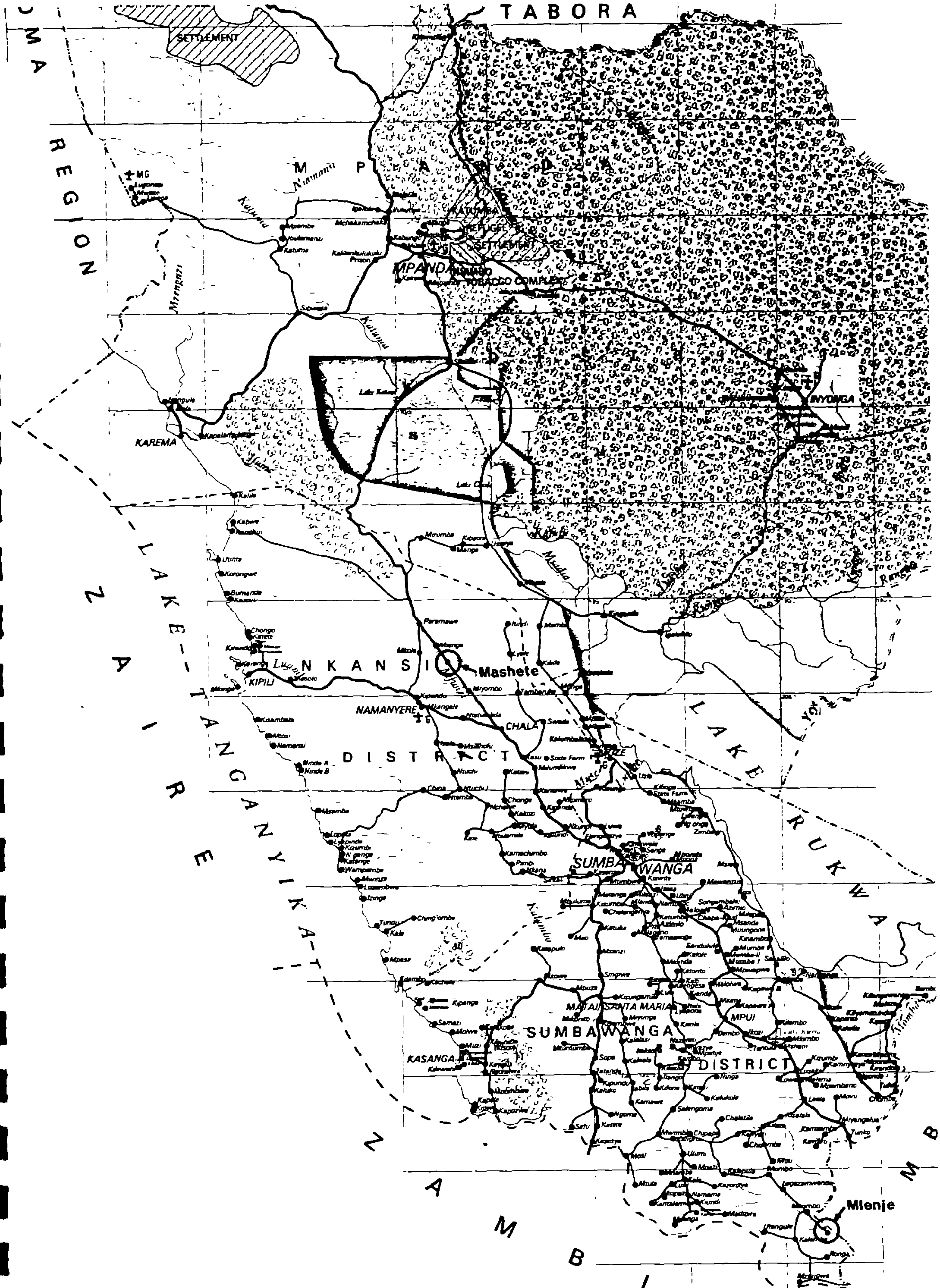
Background information to the report may be found in the Inception Report (January, 1985) titled "Solar Powered Water Pumps in Rural Townships in Tanzania".

Arco Solar (N.E.) Europe
P.O.Box 109
4791 Lillesand
Norway

Tel. No 041-70677
Telex: 21256 janb n

GRUNDFOS International a/s
Poul Due Jensens Vej
8850 Bjerringbro
Denmark

Tel. No 6-681400
Telex: 66287 gfosin dk



LOCATION MAP

FIGURE 1.1

1.2 Organisation of Report

Results relating to the three main cases studied, including details concerning the technical alternatives considered, are included in Chapters 2, 3 and 4, which deal respectively with Mashete Village, Mlenje Village, and water supply for a typical institution. Results of the preliminary economic analysis carried out for the village having high demand and reduced pumping height (known as "Mashete Village - Reduced") are included in Chapter 5.

Chapter 5 presents a summary of results and conclusions and recommendations.

Assumptions used for system layouts and generation of capital investment and operation and maintenance (O&M) costs for the various alternatives considered are described in brief detail in Appendix B. Detailed economic analysis calculations for main alternatives considered for Mashete and Mlenje villages are included in Appendix C.

1.3 Economic and Basic Technical Assumptions

The major assumptions used in carrying out the economic analyses performed as part of this study are listed below:

- Currencies:

  . Local costs (LC) expressed in TAS
  . Foreign costs (FC) expressed in USD

- Exchange rates (April 1985):

  . USD 1 = TAS 16.70 (official rate; see also note below)
  . USD 1 = NOK 8.70
  . USD 1 = DKK 12.22

  <NOTE: The prevailing official rate for TAS is lower than the free market rate of exchange, currently taken as USD 1 = TAS 40. The free market rate has been used for "base case" economic analyses carried out in this study so as to reflect true costs and benefits to society of alternatives considered, i.e. the analyses are based on shadow pricing principles.>

- Calculation period: 30 years

- Method of economic analysis: Present worth

- Discount rate, i.e. the opportunity cost of capital: 10%

- Pricing and costs: Constant over calculation period, i.e. price and cost changes during calculation period proportional to one another, therefore having no significant impact on calculated results

- Lifetimes of major constructed/installed components:

. Concrete structures	40 years
. Non-concrete structures	30 years
. Submersible pumps	10 years
. Well-head pumps (engine-driven)	7 years
. Solar panels	20 years
. Solar subsystems & appurt. equipment	10 years
. Diesel engines	7 years
. Diesel generators	7 years
. Piping	30 years
. Fencing	10 years
. Handpumps	30 years (base case calcs.) 10 years (sensitivity analysis calcs.)

For base case calculations for handpumps (30-year lifetime), it is assumed that all parts and components will be replaced as and when necessary. The long lifetime for handpumps is accompanied by high annual O&M costs relative to capital investment costs.

For sensitivity analysis calculations for handpumps, it is assumed that handpumps must be replaced every 10 years. Associated annual O&M costs will be lower, however.

- Depreciation method: Straight-line

- Residual values at end of calculation period: Based on standard straight-line method of depreciated value

In addition to analyses performed using the above criteria, additional calculations to study the effects and sensitivities of key assumptions have been carried out. Thus, sensitivity tests have been performed for:

. Discount rates of 6% and 14%

. Reduced costs for annual O&M costs associated with:

- Solar pumping (-50%)
- Diesel-powered pumping (-20%)
- Diesel-electric-powered pumping (-20%)

. Reduced costs for solar panels (-25% and -50%)

- No annual replacement of solar panels required (as claimed by the manufacturer)

  (Base case calculations for solar-powered pumping alternatives assume that one solar module per installation must be replaced each year; this could be required for any number of reasons -- vandalism, module defect, careless attendant cleaning practices, etc.)

- For handpump schemes, replacement of entire handpump unit at each installation site once every 10 years

  (Base case calculations for handpump alternatives assume that handpump parts will be shifted out as and when necessary continually over the entired calculation period of 30 years)

- Exchange rates of USD 1 = TAS 20
  and USD 1 = TAS 60

Chapter 2:

MASHETE VILLAGE

2.1 Overview of Village

Mashete Village, with an estimated present population of 2,000, is located approximately 75 km north of Sumbawanga (the regional capital of Rukwa Region) at an altitude of 1,600 m.a.m.s.l. Accessability to Mashete is considered good, as the village lies along one of the main roads in the region.

Total water demand in Mashete in 1991 is assumed to be on the order of 100 m3/d, based on an estimated future population of 2,600.

2.2 Presentation of Alternatives

The water supply pumping alternatives that have been considered for analysis in Mashete are:

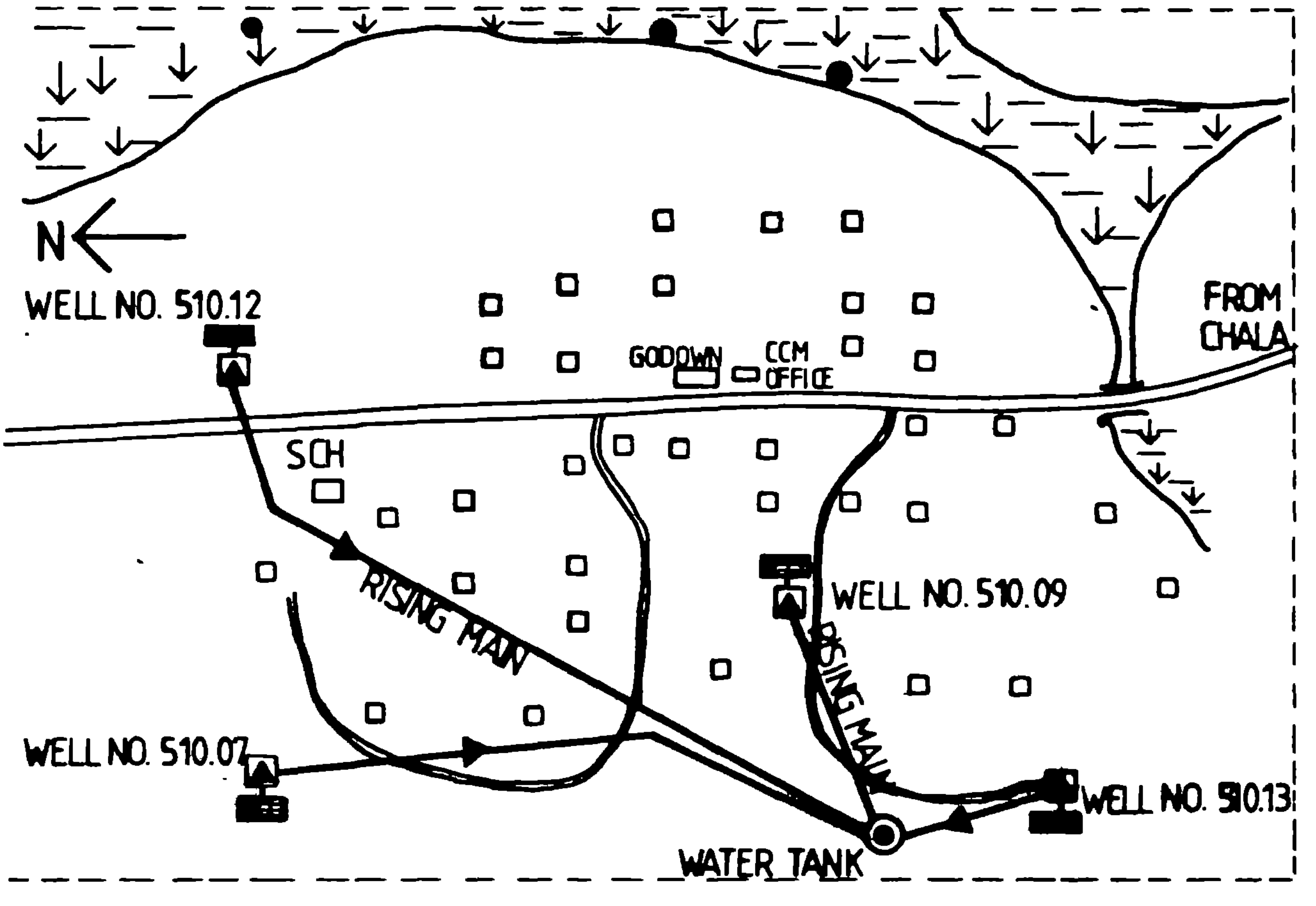
- Alternative A.1. Solar-powered pumps
- Alternative A.2. Diesel-powered pumps
- Alternative A.3. Diesel-electric-powered pumps
- Alternative A.4. Handpumps

The alternatives are shown schematically in Figures 2.1 through 2.3, as referenced in the following subsections. Additional design data and criteria may be found in the Project Inception Report.

2.3 System Descriptions

Brief descriptions of the four systems considered for analysis in Mashete are presented below in Sections 2.3.1 through 2.3.4.

SYSTEM DESIGN - SOLAR PUMPING



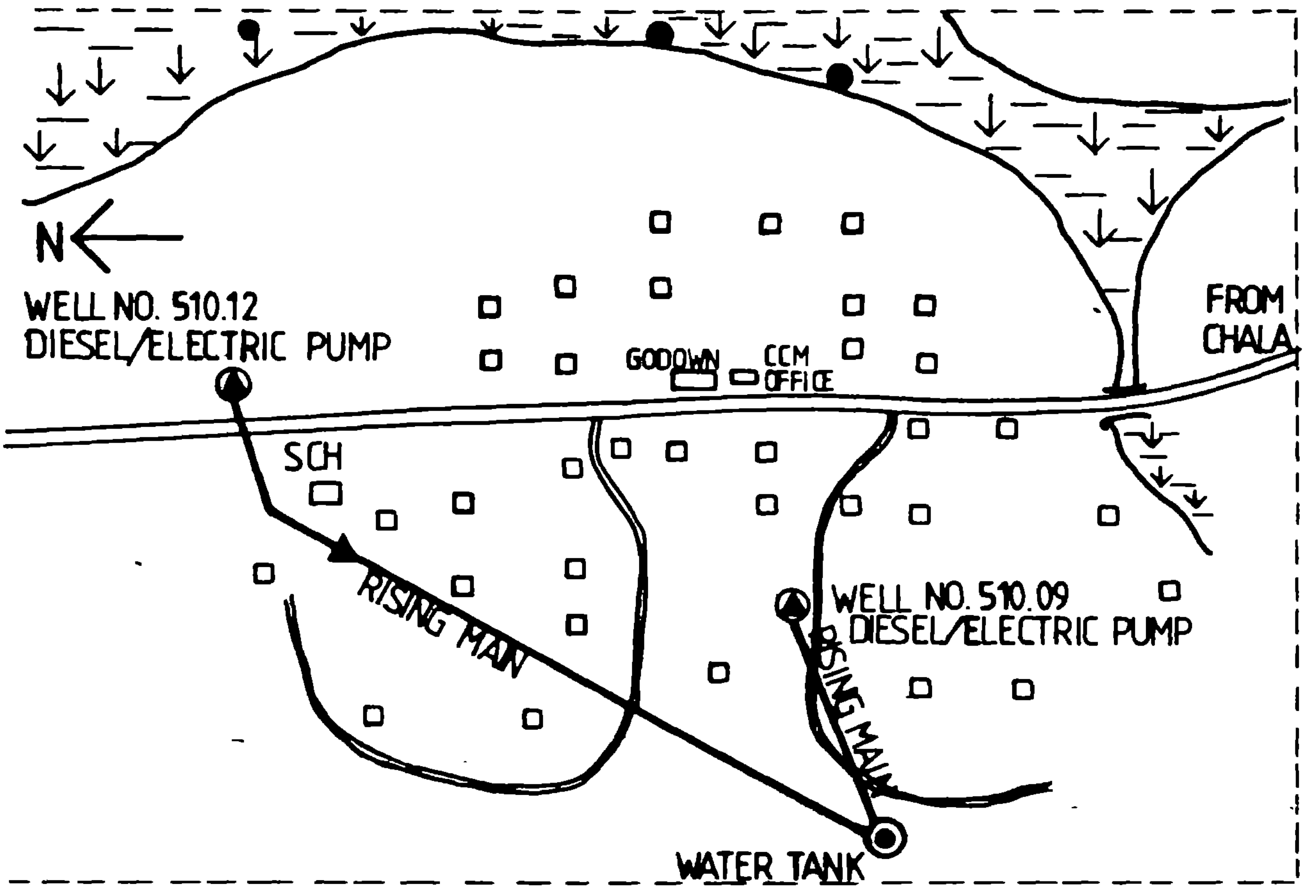
MASHETE VILLAGE

LOCATION MAP. SCALE: APPRX. 1:10 000

 SOLAR ENERGY PUMPING SYSTEM

FIGURE 2.1

SYSTEM DESIGN - DIESEL-/ DIESEL ELECTRIC PUMPING



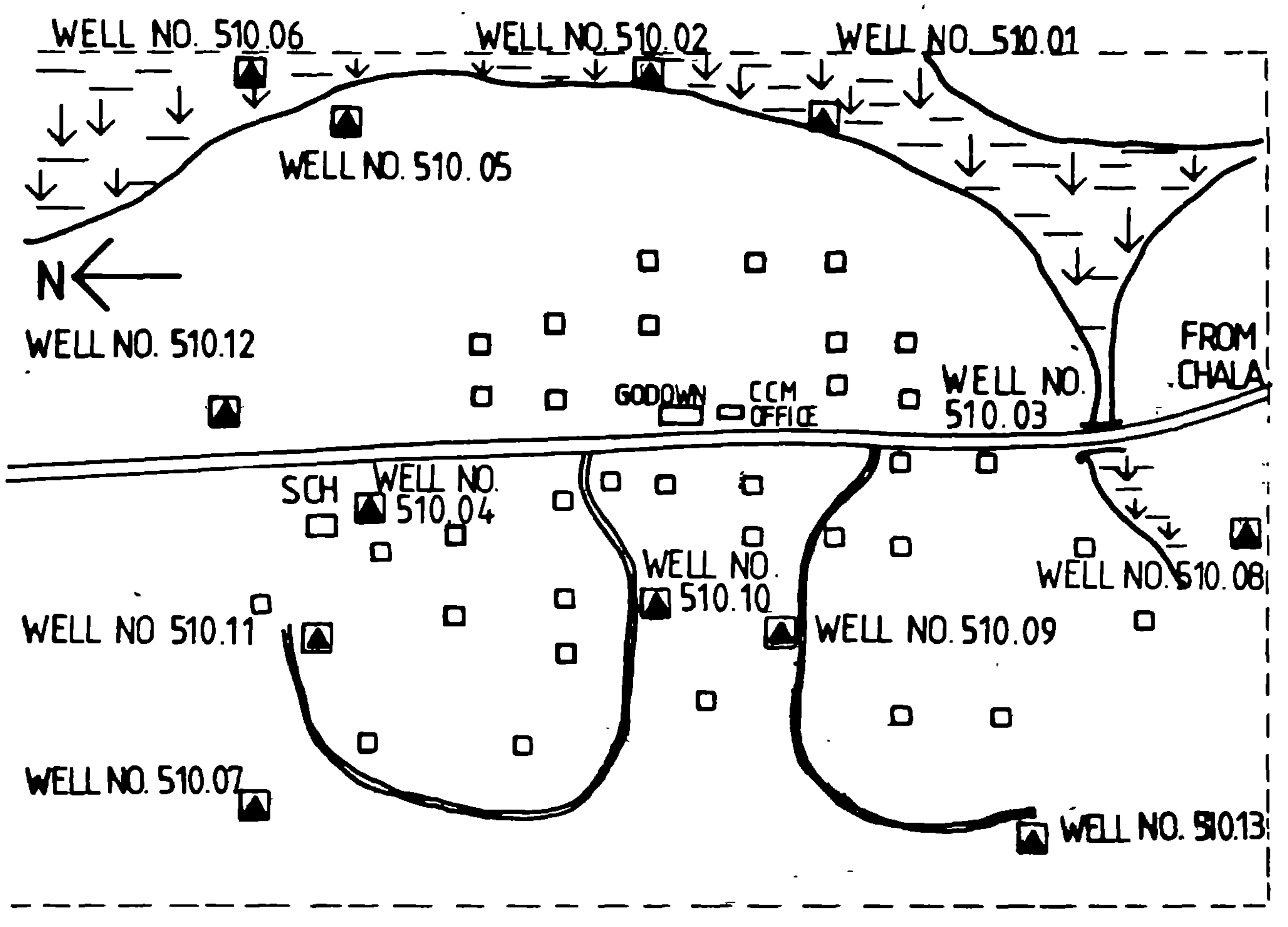
MASHETE VILLAGE

LOCATION MAP, SCALE: APPRX. 1:10 000

WELL HEAD PUMP/ SUBMERSIBLE PUMP

FIGURE 2.2

SYSTEM DESIGN - HANDPUMPS



MASHETE VILLAGE

LOCATION MAP, SCALE APPRX. 1:10 000

HANDPUMP

FIGURE 2.3

2.3.1 Alternative A.1. Solar-powered pumps, Mashete

Alternative A.1 (refer to Figure 2.1) comprises the following major components:

- 4 nos. 8.5/6 in. dia. (8.5 in. in overburden, with casing; 6 in. dia. in bedrock) drilled boreholes ranging in depth from 36 to 57 m; total drilled length for all boreholes = 177 l.m.
- 4 nos. solar-powered water pumping installations (all Type SP2-18/35), complete with pumps, foundations, solar panels, electrical systems, etc.
- Security fencing for 4 installations
- 1 no. 60 m3 storage tank (reinforced blockwork or concrete)
- Force mains from boreholes to storage tank comprising 2,300 l.m. (total length) 63 mm dia. PEH-PN10 pipe
- Distribution piping comprising 4,800 l.m. (total length) 40-63 mm dia. PEH-PN6 pipe
- 12 nos. community standposts (two taps per standpost)

2.3.2 Alternative A.2. Diesel-powered pumps, Mashete

Alternative A.2 (refer to Figure 2.2) comprises the following major components:

- 2 nos. 8.5/6 in. dia. drilled boreholes (one 42 m deep, the other 57 m deep); total drilled length for both boreholes = 99 l.m.
- 2 nos. diesel-powered water pumping installations, complete (excl. pumphouses, listed separately), with pump specifications as follows:

  Pump Station No.1: Q = 3 l/s at 50 m TH
Pump installation depth = 35 m
  Pump Station No.2: Q = 3 l/s at 70 m TH
Pump installation depth = 45 m

- 2 nos. well-head pumphouses
- 1 no. 60 m3 storage tank (reinforced blockwork or concrete)
- Force mains from boreholes to storage tank comprising 1,300 l.m. (total length) 75 mm dia. PEH-PN10 pipe
- Distribution piping comprising 4,800 l.m. (total length) 40-63 mm dia. PEH-PN6 pipe
- 12 nos. community standposts (two taps per standpost)

2.3.3 Alternative A.3. Diesel-electric-powered pumps, Mashete

Alternative A.3 (refer to Figure 2.2) comprises the following major components:

- 2 nos. 8.5/6 in. dia. drilled boreholes (one 42 m deep, the other 57 m deep); total drilled length for both boreholes = 99 l.m.
- 2 nos. diesel-electric-powered water pumping installations, complete (excl. diesel generator, generator house and diesel fuel tank, listed separately), with pump specifications as follows:

  Pump Station No.1: Q = 3 l/s at 50 m TH
  Pump installation depth = 35 m

  Pump Station No.2: Q = 3 l/s at 70 m TH
  Pump installation depth = 45 m

- 1 no. 10 KW diesel-electric generator, with all appurtenant equipment
- 1 generator house (blockwork)
- 1 no. electrical transmission network (from generator to pump stations)
- 1 no. 1,000 l capacity diesel fuel tank
- 1 no. 60 m3 storage tank (reinforced blockwork or concrete)
- Force mains from boreholes to storage tank comprising 1,300 l.m. (total length) 75 mm dia. PEH-PN10 pipe
- Distribution piping comprising 4,800 l.m. (total length) 40-63 mm dia. PEH-PN6 pipe
- 12 nos. community standposts (two taps per standpost)

2.3.4 Alternative A.4. Handpumps, Mashete

Alternative A.4 (refer to Figure 2.3) comprises the following major components:

- 12 nos. 8.5/6 in. dia. drilled boreholes averaging 37 m in depth; total drilled length for all handpump boreholes = 444 l.m.
- 12 nos. handpumps (complete with rising main, pump rods, tools and misc. spares)
- 12 nos. concrete aprons (around handpumps)

2.4 Costs - Capital and Annual O&M

Capital investment costs for Alternatives A.1 through A.4 are presented in Tables 2.1 through 2.4, respectively, while annual O&M costs for the four alternatives are summarised in Table 2.5.

Table 2.1. Capital Costs for Alternative A.1, Solar-Powered Pumps, Mashete

Item	FC, USD	LC, TAS	Total, USD
. Drilling of boreholes	15,045	--	15,045
. Solar pump stations, installed	52,192	120,000	59,377
. Transport of equip. from Dar	1,200	10,000	1,799
. Fencing	--	80,000	4,790
. Force mains	6,348	200,000	18,324
. Storage tank	--	130,000	7,785
. Distribution network	5,796	416,000	30,706
Total Costs	80,581	856,000	137,826

Table 2.2. Capital Costs for Alternative A.2, Diesel-Powered Pumps, Mashete

Item	FC, USD	LC, TAS	Total, USD
. Drilling of boreholes	8,415	--	8,415
. Pumps & diesel engines, install.	15,000	4,000	15,240
. Transport of equip. from Dar	600	5,000	899
. Pumphouses	--	100,000	5,988
. Force mains	5,460	130,000	13,245
. Storage tank	--	130,000	7,785
. Distribution network	5,796	476,000	34,299
Total Costs	35,271	845,000	85,871

Table 2.3. Capital Costs for Alternative A.3,
Diesel-Electric-Powered Pumps, Mashete

Item	FC, USD	LC, TAS	Total, USD
. Drilling of boreholes	8,415	--	8,415
. Pumps, diesel generator & fuel tank, installed	12,150	4,000	12,390
. Transport of equip. from Dar	400	3,500	609
. Generator house	--	50,000	2,994
. Force mains	5,460	130,000	13,245
. Storage tank	--	130,000	7,785
. Distribution network	5,796	476,000	34,299
Total Costs	32,221	793,500	79,737

Table 2.4. Capital Costs for Alternative A.4,
Handpumps, Mashete

Item	FC, USD	LC, TAS	Total, USD
. Drilling of boreholes	37,740	--	37,740
. Handpumps, installed	9,600	74,000	14,031
. Transport of equip. from Dar	600	--	600
Total Costs	47,940	74,000	52,371

Table 2.5. Annual O&M Costs for Various
Mashete Village Water Supply Alternatives

Alternative	FC, USD/yr	LC, TAS/yr	Total, USD/yr
A.1 Solar-powered pumps	1,400	26,000	2,960
A.2 Diesel-powered pumps	4,800	36,000	6,956
A.3 Diesel-electric-powered pumps	5,400	36,000	7,556
A.4 Handpumps	2,397	27,700	4,056

2.5 Economic Analysis of Alternatives

2.5.1 Presentation of Results

Total shadow-priced costs, based on an exchange rate of USD 1 = TAS 40, for the 30-year calculation period for Mashete Village pumping alternatives are presented in Tables 2.6 (capital costs) and 2.7 (annual O&M costs). (The third column of figures in both tables indicates total costs based on the official exchange rate of USD 1= TAS 16.7, and is presented for information only.)

Table 2.6. Shadow-Priced Capital Costs for Mashete Village Water Supply Alternatives

Alternative	FC, USD	LC, TAS	Total, USD (TAS 16.7)	Total, USD (TAS 40)
A.1 Solar-pwred. pumps	80,581	856,000	137,826	101,981
A.2 Diesel-pwred. pumps	35,271	845,000	85,871	56,396
A.3 Diesel-electric-powered pumps	32,221	793,500	79,737	52,058
A.4 Handpumps	47,940	74,000	52,371	49,790

Table 2.7. Shadow-Priced Annual O&M Costs for Mashete Village Water Supply Alternatives

Alternative	FC, USD	LC, TAS	Total, USD (TAS 16.7)	Total, USD (TAS 40)
A.1 Solar-pwred. pumps	1,400	26,000	2,960	2,050
A.2 Diesel-pwred. pumps	4,800	36,000	6,956	5,700
A.3 Diesel-electric-powered pumps	5,400	36,000	7,556	6,300
A.4 Handpumps	2,397	27,700	4,056	3,090

The present value of all costs (capital plus annual O&M) for each alternative over the 30-year calculation period are presented in Table 2.8, assuming discount rates of 10, 6 and 14 percent respectively.

Table 2.8. Present Value of Total Costs, in USD, for Mashete Village Water Supply Alternatives (Base case USD 1 = TAS 40)

Condition/Disc. Rate	A.1 Solar	A.2 Diesel	A.3 Diesel-Electric	A.4 Handpump
Base case, 10%	121,506	113,584	109,311	71,745
Base case, 6%	142,922	149,024	144,050	87,098
Base case, 14%	108,472	93,268	89,490	62,656

Detailed calculations relating to base case alternatives are included in Appendix C (see Tables C1 through C4).

In order to further test the sensitivity of certain key assumptions, and since it seems highly likely that the relative cost of solar panels will decrease in the future as a result of further technical advances and marketing developments (e.g. greater sales, greater competition, etc.), calculations have been performed using the assumptions described at the end of Section 1.3, Chapter 1. Results of these calculations are presented in Table 2.9.

Net present values (NPVs), benefit-cost (B/C) ratios and economic internal rates of return (EIRRs) have been calculated for solar-powered pumping against diesel-powered pumping, assuming various conditions. In these instances, the benefits accrued by solar-powered pumping are taken as the gross savings realised by not having to rely on diesel-powered pumping. Results of the calculations carried out are presented in Table 2.10.

(As an explanatory note to Table 2.10, a project can generally be considered feasible if it meets one or more of the following criteria:

- The NPV (i.e. the present value of benefits minus the present value of costs) is positive

- The B/C ratio is greater that 1.0

- The EIRR is greater than the discount rate)

Table 2.9. Sensitivity Analysis for
Mashete Village Water Supply Alternatives.
Present Value of Total Costs, in USD, Using 10% Discount Rate

Case	A.1 Solar	A.2 Diesel	A.3 Diesel-Electric	A.4 Handpump
Base case * (for ref.)	121,506	113,584	109,311	71,745
Red. ann. O&M costs:				
-50% for solar alt.	112,722	113,584	109,311	71,745
-20% for dies-bsd alts.	121,506	103,815	98,513	71,745
Red. sol. panel costs:				
-25%	108,938	113,584	109,311	71,745
-50%	92,525	113,584	109,311	71,745
Red. sol. panel (-25%) & ann. O&M (-50%) costs	100,154	113,584	109,311	71,745
No sol. pan. replacement	107,767	113,584	109,311	71,745
Handpump rplcmnt. (compl. unit) every 10 yrs.	121,506	113,584	109,311	67,103
USD 1 = TAS 20	147,822	140,671	135,737	79,357
USD 1 = TAS 60	112,782	104,626	101,014	69,204

* 10%, TAS 40

Table 2.10. Project Feasibility Economic Indicators for
Solar-Powered vs. Diesel-Powered Pumping in Mashete Village
(Brackets < > Indicate Negative Numbers)

Case	NPV, USD	B/C Ratio	EIRR, %
Base case *	<7,922>	0.94	7.4
Red. ann. O&M costs for:			
-50% for solar alternative	863	1.01	10.3
-20% for diesel-powered alt.	<17,691>	0.85	3.9
Red. sol. panel costs:			
-25%	4,646	1.04	11.9
-50%	21,059	1.23	21.2
Red. solar panel (-25%) & ann. O&M (-50%) costs for sol. alt.	13,430	1.13	15.4
No solar panel replacement	5,817	1.05	11.8

* 10%, TAS 40

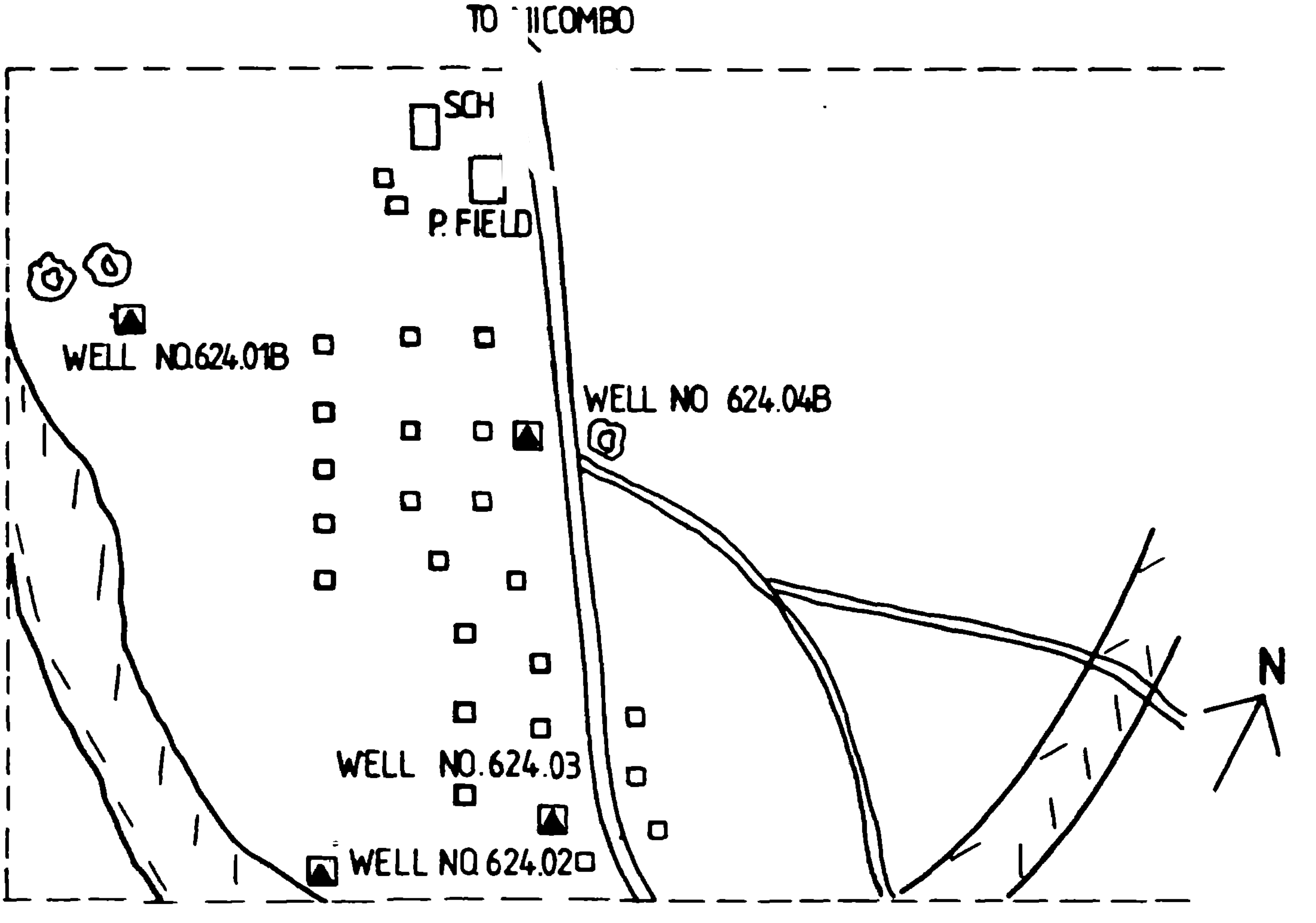
2.5.2 Main Conclusions

As seen from Tables 2.8 and 2.9, handpumps installation in a village such as Mashete is the solution of least cost, given base case assumptions. Diesel-based pumping systems are the next best economic choices, while solar-powered pumping is the highest-cost solution.

It is interesting to note that under different assumptions, solar-powered pumping (while still not able to compete on an economic basis against the handpumps alternative) does compare very favourably with diesel-based pumping. This occurs, for example, if the discount rate is lowered to 6 percent or less (see Table 2.8), or (from Table 2.9) when it is assumed that solar panel costs will drop significantly in the future and/or that annual O&M costs for solar-powered pumping have perhaps been estimated too conservatively in this analysis.

From Table 2.10, it is evident that diesel-based pumping is economically more feasible than solar-powered pumping in the base case or when lower annual O&M costs associated with diesel pumping are assumed. When lower solar panel costs and/or lower solar-related annual O&M costs are assumed, however, the results are reversed.

SYSTEM DESIGN-HANDPUMPS



MLENJE VILLAGE

LOCATION MAP, SCALE APPRX. 1:10 000

HANDPUMP

FIGURE 3.2

3.3.1 Alternative B.1. Solar-powered pump with backup handpump, Mlenje

Alternative B.1 (refer to Figure 3.1) comprises the following major components:

- 1 no. 8.5/6 in. dia. 15 m deep drilled borehole (for solar-powered pump)
- 1 no. solar-powered water pumping installation (Type SP4-8/14), complete with pump, foundation, solar panels, electrical system, etc.
- Security fencing for 1 installation
- 1 no. 20 m3 storage tank (reinforced blockwork or concrete)
- 900 l.m. 75 mm dia. PEH-PN10 force main from borehole to storage tank
- Distribution piping comprising 1,900 l.m. (total length) 32-50 mm dia. PEH-PN6 pipe
- 4 nos. community standposts (two taps per standpost)
- 1 no. 8.5/6 in. dia. 27 m deep drilled borehole (for backup handpump)
- 1 no. handpump (complete with rising main, pump rods, tools and misc. spares)
- 1 no. concrete apron (around backup handpump)

3.3.2 Alternative B.2. Diesel-powered pump with backup handpump, Mlenje

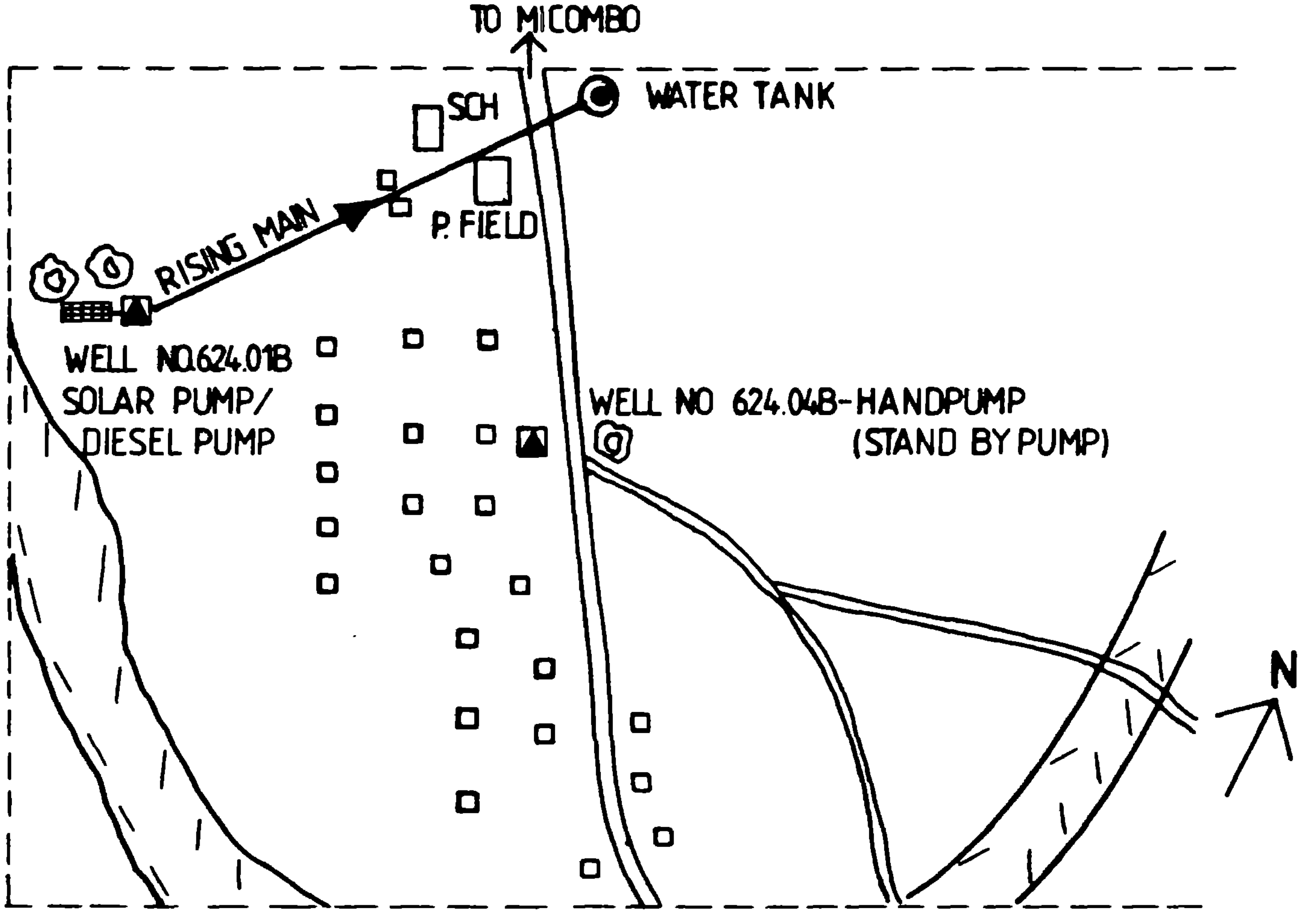
Alternative B.2 (refer to Figure 3.1) comprises the following major components:

- 1 no. 8.5/6 in. dia. 15 m deep drilled borehole (for diesel-powered pump)
- 1 no. diesel-powered water pumping installation, complete (excl. pumphouse, listed separately), with pump specification as follows:

  Q = 1.5 l/s at 30 m TH
  Pump installation depth = 13 m

- 1 no. well-head pumphouse
- 1 no. 20 m3 storage tank (reinforced blockwork or concrete)
- 900 l.m. 75 mm dia. PEH-PN10 force main from borehole to storage tank
- Distribution piping comprising 1,900 l.m. (total length) 32-50 mm dia. PEH-PN6 pipe
- 4 nos. community standposts (two taps per standpost)
- 1 no. 8.5/6 in. dia. 27 m deep drilled borehole (for backup handpump)

SYSTEM DESIGN SOLAR-/DIESEL PUMPING



MLENJE VILLAGE

LOCATION MAP, SCALE APPRX. 1 : 10 000

SOLAR ENERGY PUMPING SYSTEM

FIGURE 3.1

Chapter 3:

MLENJE VILLAGE

3.1 Overview of Village

Mlenje Village, with an estimated present population of 600, is located approximately 140 km south of Sumbawanga at an altitude of 1,500 m.a.m.s.l. Accessability to Mlenje is considered reasonably difficult for medium and heavy vehicles, in that the village lies off the main transport network of the region.

Total water demand in Mlenje in 1991 is assumed to be on the order of 30 m3/d, based on an estimated future population of 700.

3.2 Presentation of Alternatives

The water supply pumping alternatives that have been considered for analysis in Mlenje are:

- Alternative B.1. Solar-powered pump with backup handpump
- Alternative B.2. Diesel-powered pump with backup handpump
- Alternative B.3. Handpumps

In Alternatives B.1 and B.2, since there is only a single motorised pump unit, a handpump installation has been provided as backup.

The alternatives are shown schematically in Figures 3.1 and 3.2, as referenced in the following subsections. Additional design data and criteria may be found in the Project Inception Report.

3.3 System Descriptions

Brief descriptions of the three systems considered for analysis in Mlenje are presented below in Sections 3.3.1 through 3.3.3.

- 1 no. handpump (complete with rising main, pump rods, tools and misc. spares)
- 1 no. concrete apron (around backup handpump)

3.3.3 Alternative B.3. Handpumps, Mlenje

Alternative B.3 (refer to Figure 3.2) comprises the following major components:

- 4 nos. 8.5/6 in. dia. drilled boreholes averaging 27 m in depth; total drilled length for all handpump boreholes = 108 m
- 4 nos. handpumps (complete with rising main, pump rods, tools and misc. spares)
- 4 nos. concrete aprons (around handpumps)

3.4 Costs - Capital and Annual O&M

Capital investment costs for Alternatives B.1 through B.3 are presented in Tables 3.1 through 3.3, respectively, while annual O&M costs for the three alternatives are summarised in Table 3.4.

Table 3.1. Capital Costs for Alternative B.1, Solar-Powered Pump with Backup Handpump, Mlenje

Item	FC, USD	LC, TAS	Total, USD
. Drilling of boreholes	2,295	--	2,295
. Solar pump station, installed	6,387	30,000	8,183
. Transport of equip. from Dar	600	5,000	899
. Fencing	--	20,000	1,197
. Force main	2,500	90,000	7,890
. Storage tank	--	60,000	3,593
. Distribution network	2,195	152,000	11,296
. Handpump, installed	800	7,000	1,219
Total Costs	14,777	364,000	36,572

Table 3.2. Capital Costs for Alternative B.2, Diesel-Powered Pump with Backup Handpump, Mlenje

Item	FC, USD	LC, TAS	Total, USD
. Drilling of boreholes	2,295	--	2,295
. Pump & diesel engine, installed	6,000	2,000	6,120
. Transport of equip. from Dar	600	5,000	899
. Pumphouse	--	50,000	2,994
. Force main	2,500	90,000	7,890
. Storage tank	--	60,000	3,593
. Distribution network	2,195	152,000	11,297
. Handpump, installed	800	7,000	1,219
Total Costs	14,390	366,000	36,307

Table 3.3. Capital Costs for Alternative B.3, Handpumps, Mlenje

Item	FC, USD	LC, TAS	Total, USD
. Drilling of boreholes	9,180	--	9,180
. Handpumps, installed	3,200	25,000	4,697
. Transport of equip. from Dar	200	--	200
Total Costs	12,580	25,000	14,077

Table 3.4. Annual O&M Costs for Various
Mlenje Village Water Supply Alternatives

Alternative	FC, USD/yr	LC, TAS/yr	Total, USD/yr
B.1 Solar-powered pump with backup handpump	390	16,350	1,369
B.2 Diesel-powered pump with backup handpump	1,120	36,350	3,297
B.3 Handpumps	629	13,250	1,422

3.5 Economic Analysis of Alternatives

3.5.1 Presentation of Results

Total shadow-priced costs, based on an exchange rate of USD 1 = TAS 40, for the 30-year calculation period for Mlenje Village pumping alternatives are presented in Tables 3.5 (capital costs) and 3.6 (annual O&M costs). (The third column of figures in both tables is presented for information only.) Present value costs (capital plus annual O&M) for each alternative over the 30-year period, assuming 10, 6 and 14 percent discount rates, are presented in Table 3.7.

Table 3.5. Shadow-Priced Capital Costs for
Mlenje Village Water Supply Alternatives

Alternative	FC, USD	LC, TAS	Total, USD (TAS 16.7)	Total, USD (TAS 40)
B.1 Sol-pwrd. pump w/ hp	14,777	364,000	36,572	23,877
B.2 Diesl-pwrd. pump w/ handpump (backup)	14,390	366,000	36,307	23,540
B.3 Handpumps	12,580	25,000	14,077	13,205

Table 3.6. Shadow-Priced Annual O&M Costs for Mlenje Village Water Supply Alternatives

Alternative	FC, USD	LC, TAS	Total, USD (TAS 16.7)	Total, USD (TAS 40)
B.1 Sol-pwred. pump w/ hp	390	16,350	1,369	799
B.2 Diesl-pwrd. pump w/ hp	1,120	36,350	3,297	2,028
B.3 Handpumps	629	13,250	1,422	960

Table 3.7. Present Value of Total Costs, in USD, for Mlenje Village Water Supply Alternatives (Base case USD 1 = TAS 40)

Condition/Disc. Rate	B.1 Solar	B.2 Diesel	B.3 Handpump
Base case, 10%	30,152	44,583	20,232
Base case, 6%	35,709	57,955	24,924
Base case, 14%	26,779	36,889	17,480

Detailed calculations relating to base case alternatives are included in Appendix C (see Tables C5 through C7).

Results of sensitivity calculations performed using the assumptions described at the end of Section 1.3, Chapter 1 are presented in Table 3.8.

As was done for Mashete Village, NPVs, B/C ratios and EIRRs have been calculated for solar-powered pumping in Mlenje Village against diesel-powered pumping, assuming various conditions. Results of the calculations carried out are presented in Table 3.9.

Table 3.8. Sensitivity Analysis for
Mlenje Village Water Supply Alternatives.
Present Value of Total Costs, in USD, Using 10% Discount Rate

Case	B.1 Solar	B.2 Diesel	B.3 Handpump
Base case * (for reference)	30,152	44,583	20,232
Reduced annual O&M costs:			
-50% for solar alternative	26,732	44,583	20,232
-20% for diesel alternative	30,152	43,721	20,232
Reduced solar panel costs:			
-25%	28,817	44,583	20,232
-50%	25,372	44,583	20,232
Reduced solar panel (-25%) & ann. O&M (-50%) costs for sol. alt.	25,397	44,583	20,232
No solar panel replacement	26,724	44,583	20,232
Handpump replacement (complete unit) every 10 years	30,152	44,583	19,830
USD 1 = TAS 20	42,282	60,853	23,645
USD 1 = TAS 60	26,096	39,154	19,100

* 10%, TAS 40

Table 3.9. Project Feasibility Economic Indicators for
Solar-Powered vs. Diesel-Powered Pumping in Mlenje Village

Case	NPV, USD	B/C Ratio	EIRR, %
Base case *	14,431	1.48	> 50
Red. ann. O&M costs for:			
-50% for solar alternative	17,851	1.67	> 50
-20% for diesel-powered alt.	13,569	1.45	> 50
Red. sol. panel costs:			
-25%	15,766	1.55	> 50
-50%	19,211	1.76	> 50
Red. solar panel (-25%) & ann. O&M (-50%) costs for sol. alt.	19,186	1.76	> 50
No solar panel replacement	17,859	1.67	> 50

* 10%, TAS 40

3.5.2 Main Conclusions

As seen from Tables 3.7 and 3.8, handpumps installation in a village such as Mlenje is the solution of least cost, given base case assumptions. Solar-powered pumping is the next best economic alternative, while diesel-powered pumping is the highest-cost solution.

When compared against diesel-powered pumping only, solar-powered pumping ranks extremely favourably (see Table 3.9).

Chapter 4:

WATER SUPPLY FOR AN INSTITUTION

4.1 Overview of Institutional Water Supply Scheme

As study purposes, water supply to a large institution has been included for analysis, with the following assumptions made:

- Total water demand = design Q = 30 m3/d.
- Groundwater being the only feasible source of safe water supply
- Pump installation depth = 13 m
- System comprising a single borehole, one submersible pump and a power source
- Diesel generator associated with Alternative C.2 (see next section), also to be used for institution's electricity supply
- No backup system or pumping unit(s) to be installed

4.2 Presentation of Alternatives

The pumping alternatives that have been considered for institutional water supply are:

- Alternative C.1. Solar-powered pump
- Alternative C.2. Diesel-electric-powered pump

No backup system is provided in either case.

4.3 System Descriptions

Brief descriptions of the two institutional water supply systems considered for analysis are presented below in Sections 4.3.1 and 4.3.2.

4.3.1 Alternative C.1. Solar-powered pump, institutional water supply

Alternative C.1 comprises the following major components:

- 1 no. 8.5/6 in. dia. 15 m deep drilled borehole
- 1 no. solar-powered water pumping installation (Type SP4-8/14), complete with pump, foundation, solar panels, electrical system, etc.
- Security fencing for 1 installation
- 1 no. 20 m3 storage tank (reinforced blockwork or concrete)
- 900 l.m. 75 mm dia. PEH-PN10 force main from borehole to storage tank
- Distribution piping comprising 300 l.m. 63 mm dia. PEH-PN6 pipe and 2 taps

4.3.2 Alternative C.2. Diesel-electric-powered pump, institutional water supply

Alternative C.2 comprises the following major components:

- 1 no. 8.5/6 in. dia. 15 m deep drilled borehole
- 1 no. diesel-electric-powered water pumping installation, complete (excl. diesel-generated electricity supply assumed already available), with pump specification as follows:

  Q = 3.0 l/s at 30 m TH
  Pump installation depth = 13 m

- 1 no. generator house (blockwork)
- 1 no. 20 m3 storage tank (reinforced blockwork or concrete)
- 900 l.m. 75 mm dia. PEH-PN10 force main from borehole to storage tank
- Distribution piping comprising 300 l.m. 63 mm dia. PEH-PN6 pipe and 2 taps

4.4 Costs - Capital and Annual O&M

Capital investment costs for Alternatives C.1 and C.2 are presented in Tables 4.1 and 4.2, respectively, while annual O&M costs for the two alternatives are summarised in Table 4.3.

Table 4.1. Capital Costs for Alternative C.1, Solar-Powered Pump

Item	FC, USD	LC, TAS	Total, USD
. Drilling of borehole	1,275	--	1,275
. Solar pump station, installed	6,390	30,000	8,186
. Transport of equip. from Dar	600	5,000	899
. Fencing	--	20,000	1,197
. Force main	2,500	90,000	7,889
. Storage tank	--	60,000	3,593
. Distribution network	650	46,000	3,404
Total Costs	11,415	251,000	26,443

Table 4.2. Capital Costs for Alternative C.2 Diesel-Electric-Powered Pump

Item	FC, USD	LC, TAS	Total, USD
. Drilling of borehole	1,275	--	1,275
. Pump, installed	2,000	2,000	2,120
. Diesel generator (1/2 share)	3,800	4,000	4,040
. Transport of equip. from Dar	400	3,500	609
. Force main	2,500	90,000	7,889
. Storage tank	--	60,000	3,593
. Distribution network	650	46,000	3,404
Total Costs	10,625	205,500	22,930

Table 4.3. Annual O&M Costs for Institutional Water Supply Alternatives

Alternative	FC, USD/yr	LC, TAS/yr	Total, USD/yr
C.1 Solar-powered pump	150	5,000	449
C.2 Diesel-electric-powered pump	1,100	9,000	1,639

4.5 Economic Analysis of Alternatives

4.5.1 Presentation of Results

Total shadow-priced costs, based on an exchange rate of USD 1 = TAS 40, for the 30-year calculation period for institutional water supply pumping alternatives are presented in Tables 4.4 (capital costs) and 4.5 (annual O&M costs). (The third column of figures in both tables is presented for information only.) Present value costs (capital plus annual O&M) for each alternative over the 30-year period, assuming 10, 6 and 14 percent discount rates, are presented in Table 4.6.

Table 4.4. Shadow-Priced Capital Costs for Institutional Water Supply Alternatives

Alternative	FC, USD	LC, TAS	Total, USD (TAS 16.7)	Total, USD (TAS 40)
C.1 Solar-powered pump	11,415	251,000	26,443	17,690
C.2 Diesel-electric-powered pump	10,625	205,500	22,930	15,763

Table 4.5. Shadow-Priced Annual O&M Costs for Institutional Water Supply Alternatives

Alternative	FC, USD	LC, TAS	Total, USD (TAS 16.7)	Total, USD (TAS 40)
C.1 Solar-powered pump	150	5,000	449	275
C.2 Diesel-electric-powered pump	1,100	9,000	1,639	1,325

Table 4.6. Present Value of Total Costs, in USD, for Institutional Water Supply Alternatives (Base case USD 1 = TAS 40)

Condition/Disc. Rate	C.1 Solar	C.2 Diesel-Elec.
Base case, 10%	20,219	30,345
Base case, 6%	23,426	39,714
Base case, 14%	18,234	24,966

Results of sensitivity calculations performed using the assumptions described at the end of Section 1.3, Chapter 1 are presented in Table 4.7.

Table 4.7. Sensitivity Analysis for Institutional Water Supply Alternatives. Present Value of Total Costs, in USD, Using 10% Discount Rate

Case	C.1 Solar	C.2 Diesel-Elec.
Base case * (for reference)	20,219	30,345
Reduced annual O&M costs:		
-50% for solar alternative	19,045	30,345
-20% for diesel alternative	20,219	28,074
Reduced solar panel costs:		
-25%	18,886	30,345
-50%	16,111	30,345
Reduced solar panel (-25%) & ann. O&M (-50%) costs for sol. alt.	17,712	30,345
No solar panel replacement	18,719	30,345
USD 1 = TAS 20	26,878	34,663
USD 1 = TAS 60	17,635	27,006

* 10%, TAS 40

As in the cases of Mashete and Mlenje villages, NPVs, B/C ratios and EIRRs have been calculated for solar-powered pumping for institutional water supply against diesel-electric-powered pumping, assuming various conditions. Results of the calculations carried out are presented in Table 4.8.

Table 4.8. Project Feasibility Economic Indicators for Solar-Powered vs. Diesel-Electric-Powered Pumping, Institutional Water Supply

Case	NPV, USD	B/C Ratio	EIRR, %
Base case *	10,126	1.50	> 50
Red. ann. O&M costs for:			
-50% for solar alternative	11,300	1.59	> 50
-20% for dies.-elec.-powrd. alt.	7,855	1.39	47.8
Red. sol. panel costs:			
-25%	11,459	1.61	> 50
-50%	14,234	1.88	> 50
Red. solar panel (-25%) & ann. O&M (-50%) costs for sol. alt.	12,633	1.71	> 50
No solar panel replacement	9,355	1.50	> 50

* 10%, TAS 40

4.5.2 Main Conclusions

As seen from Tables 4.6 through 4.8, for all assumptions made, solar-powered pumping for the case defined is clearly the preferred economic choice over diesel-electric-powered pumping.

Chapter 5:

SUMMARY OF RESULTS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of Results

With reference to Section 2.5, Chapter 2, it is apparent that solar-powered pumping has difficulty competing on an economic basis with other modes of pumping when conditions are similar to those defined for Mashete Village. However, when certain assumptions are varied (e.g. solar panel costs and/or solar-related annual O&M costs are reduced while costs associated with other alternatives are held the same), solar-powered pumping becomes economically competitive with diesel-based alternatives. For a situation such as Mashete, however, solar-powered pumping is still significantly less feasible than handpumps.

In terms of economic feasibility, it is clear that the solar-powered pumping option suffers in a rural village like Mashete where there is relatively large water demand and a relatively low groundwater table. This is largely due to available solar system package configurations. Additionally, total pumping head appears to be quite a significant factor.

As an example, if in Mashete, total pumping head were reduced from 60 m to 30 m, only two (rather than four) solar-powered pumps would be required to handle the required amount of water; considering the high initial investment costs associated with solar-powered pumping equipment, this would significantly affect the results of an economic analysis.

With this in mind, an analysis to study the effects of reduced pumping head on the same four Mashete Village pumping alternatives identified earlier in Chapter 2 (but modified as necessary) has been carried out. Details and results of this separate analysis are reported in Section 5.2.

With reference to Section 3.5, Chapter 3, given the conditions defined for Mlenje Village, it can be concluded that solar-powered pumping is more economically feasible than diesel-powered pumping, but still significantly less economically attractive than handpumps, the top-rated choice.

With reference to Section 4.5, Chapter 4, given the conditions defined for the institutional water supply scheme, it can be concluded that solar-powered pumping is more economically feasible than diesel-electric-powered pumping.

5.2 Mashete Village - Reduced

It emerged from the analyses conducted that total pumping height can be a design parameter with major consequences on resulting system economics. In order to determine how significant the consequences might be, an additional rural township was defined for analysis purposes.

Mashete Village was used as the basis for the new case, with all given conditions (i.e. water demand, layout, etc.) remaining the same EXCEPT for total pumping head, which was reduced from 60 m to 30 m. The four pumping system alternatives for Mashete, redefined as necessary to conform to the new set of design conditions, are identified as follows:

- Alternative D.1. Solar-powered pumps
- Alternative D.2. Diesel-powered pumps
- Alternative D.3. Diesel-electric-powered pumps
- Alternative D.4. Handpumps

The most significant change occuring under the new set of conditions is that the required number of solar-powered water pumping installations (including drilled boreholes) is halved, from four to two, representing a major reduction in system capital costs. The two diesel-based alternatives are less drastically affected, though they do realise substantial savings in annual O&M costs resulting from lower fuel consumption. The handpumps alternative remains basically unchanged.

Base case results for Mashete Village - Reduced are presented in Table 5.1.

Table 5.1. Present Value of Total Costs, in USD, for Mashete Village - Reduced Water Supply Alternatives (Base case USD 1 = TAS 40)

Condition/Disc. Rate	D.1 Solar	D.2 Diesel	D.3 Diesel-Electric	D.4 Handpump
Base case, 10%	68,859	90,768	82,771	71,745
Base case, 6%	80,392	115,127	104,421	87,098
Base case, 14%	61,788	76,576	70,146	62,656

Project feasibility economic indicators for solar-powered pumping (base case, compared against diesel-powered pumping) calculated for Mashete Village - Reduced are:

- NPV : USD 21,909
- B/C ratio : 1.32
- EIRR : > 50%

As seen from Table 5.1, in situations where relatively large amounts of water are required and total pumping head is relatively low, solar-powered pumping can be considered an economically viable alternative. For the conditions defined for Mashete Village - Reduced, solar-powered pumping not only is less expensive than diesel-based pumping, but can compete very favourably against even handpumps, particularly when solar panel and/or annual solar-related O&M cost reductions are assumed.

5.3. Other Considerations

It should be noted at this point that the analyses carried out for this study are strictly economic. Other factors (socio-economic, cultural, practical and financial), which can be identified (as done below) but are difficult to quantify and value at this point, can and should be examined when further, detailed-level analyses and evaluations of solar-powered pumping feasibility are conducted. It is believed that many factors can work in favour of solar-powered pumping, though some clearly will not. The net impact on total (not just economic) feasibility results is expected to be situation-dependent.

A partial listing of some factors with potential relevance to water supply pumping in rural villages in developing countries is included below. It should be recognised that the relative importance of each factor, and thus the level of investigative detail required for study of any given factor, will vary from case to case:

- Community acceptance of water supply facilities provided (including willingness to keep the system in good working order, prevent vandalism, etc.)

- Community participation and involvement in planning, construction, village-level O&M, ownership, etc. of water supply facilities

- Operation, maintenance and repair aspects (including ease of maintenance, routine maintenance procedures, cost and local availability of spare parts, training requirements of O&M personnel, funds to pay staff salaries, funds for payment of spares and transportation expenses, etc.)

- Other planned or potential uses for water supplied (e.g. large-scale irrigation, irrigation of community/kitchen gardens, watering of animals, bathing, etc.)

- Other potential uses for electricity generated or specially supplied for water pump units (including supplementary township or institutional power supply, water supply treatment (e.g. disinfection by ultraviolet radiation), etc.)

- Time savings, i.e. the amount of human time and energy saved as a result of more convenient access to safe water

- The value of human and other resources used in connection with water supply (e.g. manpower, fuel, construction materials, foreign exchange, etc.) if productively used in other types of infrastructural/societal development projects

- Financial aspects (e.g. funding possibilities, cash flow, ability of villagers and/or local authorities to raise capital investment funds and/or ongoing O&M funds, etc.)

With particular reference to the point concerning ability of villagers and/or local authorities to raise necessary funds for construction and ongoing O&M, it can be argued that it is often much easier for governments of developing countries to finance initial capital costs (with bilateral/multilateral assistance or long-term, low-interest loans) than ongoing recurrent costs. With this thought in mind, some economists argue strongly for the use of a "weighting factor", i.e. giving increased value to future recurrent funds in long-term economic analyses performed on projects in developing countries. Obviously, such an approach favours alternatives with lower recurrent costs, e.g. solar power, wind power, etc.

5.4 Conclusions and Recommendations

The objective of this project has been to study the economic feasibility of solar-powered water pumps in rural townships in Tanzania. From the results of the economic analyses carried out, it is apparent, as a main conclusion, that solar-powered pumping is a viable alternative in certain, but not all, cases.

As a main recommendation, it is proposed that Grundfos carefully define the situations in which solar-powered pumping is most competitive, against all other pumping alternatives likely to be considered by water supply planners and engineers, then establish the "niches" where job and sales prospects appear most promising.

In undertaking this work, it will be necessary to focus on anticipated annual O&M expenses associated with solar power in much greater detail. In particular, it is suggested that

documentation of running expenses and field installation experiences be prepared to serve as conclusive proof to skeptics jaded by years of exposure to equipment advertisements. (It is felt that very few planners and engineers will simply accept undocumented claims of negligible O&M requirements and costs without question, no matter true the claims might actually be).

<NOTE: It may be argued that perhaps too conservative a view regarding O&M costs associated with solar-powered pumping has been taken in this report. However, since solar technology is relatively new and untried in developing countries, and based on Norconsult's experiences with public water supply systems in Tanzania and other countries, it did not seem entirely reasonable at this time, for the base cases at least, to assume as maintenance-free systems as originally suggested by Grundfos. (Sensitivity tests of various O&M cost assumptions have been included in this report, though, to indicate how analytical results might be affected when different assumptions, e.g. lower annual solar-related O&M costs, are made.)>

One possible, and perhaps the most convincing, method of developing actual O&M cost documentation would be to install a solar-powered pump in a rural township in a developing country, either side-by-side in the same village or in closely neighbouring communities, an existing diesel-driven pump and existing handpumps, and then record/monitor such information as

- Reliability, i.e. number of days installation usable/-out-of-service
- Routine maintenance and major repair requirements
- Actual O&M costs
- Community acceptance levels and preferences, if given a choice
- Instances and types of major breakdown and vandalism incurred

for all installations for, say, a one-year period. (Further, if a solar-powered pump station is installed, it will be very useful, in addition, to record complete construction costs.)

Another area that can possibly considered for further investigation, either in connection with solar-powered water pumping or separately, is the use of solar panels to power a small-scale rural water supply ultraviolet (UV) disinfection plant. (Presently, when disinfection is carried out, it is done with the use of chemicals; obviously, this is an expensive, resource-demanding process, especially for a developing country. A number of other problems (e.g. improper dosage levels, chemical storage, shelf-life and theft) are also associated with chemical disinfection practices.)

Given this situation, disinfection by UV radiation, a relatively new technology, may present a reasonable alternative if it can be installed and operated cheaply enough. In a situation where

electricity is not available, coupling a low energy-consuming UV radiation unit to a solar energy system may prove a desireable combination well-worth considering.

APPENDIX A

PROJECT AGREEMENT

APPENDIX B

MAIN ASSUMPTIONS

3080/cw.wd3

Appendix B

ASSUMPTIONS

B.1 General

Major assumptions used in preliminary water supply planning and design layout work are indicated below:

* Per capita demand = 30 lpcd
* Peak demand = 2.5 x average demand
* Storage capacity = 60% of daily demand
* Distribution system design: pipeline length based on 1,900 l.m. per sq. km
* No. of taps = (peak demand)/10
* Max. walking distance to nearest tap point = 400 m

B.2 Capital Investment

Major assumptions used for development of investment and construction costs are indicated below. Except as noted, costs given are based on actual costs being experienced in implementation of a comprehensive water supply programme in Rukwa Region.

* Drilling: USD 85 per l.m. drilled
  FC/LC split: FC 100%; LC negligible, say 0%

  Based on assumed success rate of 70% and average borehole depth of 50 m. Unit cost includes materials, equipment, transport, local labourers and expatriate drilling staff.

* Local transport (general): TAS 30,000 per lorry load
  FC/LC split: FC 67%; LC 33%
  i.e. FC = USD 1,200;
  LC = TAS 10,000

  Based on rented lorry from Dar es Salaam. Major portion of cost is for diesel fuel, which must be purchased using foreign exchange.

* Solar pumping systems: As quoted from Grundfos in letter dated 13 March 1985
FC/LC split: FC 100%; LC 0%

For Mashete Village:	Type SP2-18/35 system	=	USD 12,373
	Freight	=	400
	Total CIF Dar	=	USD 12,773
For Mlenje Village:	Type SP4-8/14 system	=	USD 5,939
	Freight	=	180
	Total CIF Dar	=	USD 6,119
For institut. w.s.:	Type SP4-8/14 system	=	USD 5,939
	Freight	=	180
	Total CIF Dar	=	USD 6,119

* Local transport (solar pumping equipment):

For Mashete Village: One full load at TAS 30,000 per lorry load i.e. FC = USD 1,200; LC = TAS 10,000
For Mlenje Village: One partial load (1/3 load) at TAS 30,000 per lorry load, i.e. FC = USD 400; LC = TAS 3,330
For institut. w.s.: One partial load (1/3 load) at TAS 30,000 per lorry load, i.e. FC = USD 400; LC = TAS 3,330

* Foundations for solar panels: TAS 25,000 per foundation
FC/LC split: FC 0%; LC 100%

* Assembly & installation of solar pumping system:

. Per village or location, 10 local skilled labourers, ea. 5 days, incl. "night out" allowances = TAS 5,000 (LC)
. Per village or location, 1 expatriate engineer, 1 day for electrical installation and final check = USD 270 (FC)

* Fencing (chicken wire) for solar panel installations:

For Mashete Village:	4 installations	=	TAS 80,000
For Mlenje Village:	1 installation	=	TAS 20,000
For institut. w.s.:	1 installation	=	TAS 20,000

FC/LC split: FC 0%; LC 100%

* Storage tanks: TAS 3,750 per m3 concrete (reinforced)
  FC/LC split: FC 0%; LC 100%

  Calculated values: 60 m3 capacity tank = TAS 130,000
  20 m3 capacity tank = TAS 60,000

* Pipes (for force mains and distribution network):

  Based on purchase order prices (incl. fittings at approx. 30% of pipe costs).
  FC/LC split: FC 100%; LC 0%

* Trenching & pipelaying: TAS 100 per l.m.
  FC/LC split: FC 0%; LC 100%

  Based on local labour contracted from village.

* Community standposts (2 taps): TAS 8,000 per standpost
  FC/LC split: FC 0%; LC 100%

* Diesel-powered well-head pumps:

For Mashete Village:	Pump, diesel engine & all appurt. equip., CIF Dar	= USD 7,500
For Mlenje Village:	Pump, diesel engine & all appurt. equip., CIF Dar	= USD 6,000

  FC/LC split: FC 100%; LC 0%

* Local transport (diesel-powered pumping equipment):

For Mashete Village	One partial load (1/2 load) at TAS 30,000 per lorry load, i.e. FC = USD 600; LC = TAS 5,000
For Mlenje Village:	One partial load (1/3 load) at TAS 30,000 per lorry load, i.e. FC = USD 400; LC = TAS 3,330

* Assembly & installation of diesel-powered pumping system:

  . Per village, 5 local skilled labourers, ea. 4 days, incl. "night out" allowances = TAS 2,000 (LC)

* Pumphouses and generator houses: TAS 50,000 per building, compl.
  (all bldgs. 3 m x 4 m) FC/LC split: FC 0%; LC 100%

* Diesel-electric-powered submersible pumps:

For Mashete Village:	Pump & all appurt. equip., CIF Dar	= USD 2,500
For institut. w.s.:	Pump & all appurt. equip., CIF Dar	= USD 2,200

FC/LC split: FC 100%; LC 0%

* Diesel generators:

For Mashete Village:	10 kw generator & fuel tank CIF Dar	= USD 5,750
For institut. w.s.:	10 kw generator & fuel tank CIF Dar (1/2 share)	= USD 2,875

FC/LC split: FC 100%; LC 0%

* Local transport (diesel-electric-powered pumping equipment):

For Mashete Village:	One partial load (1/3 load) at TAS 30,000 per lorry load, i.e. FC = USD 400; LC = TAS 3,330
For institut. w.s.:	One partial load (1/3 load) at TAS 30,000 per lorry load, i.e. FC = USD 400; LC = TAS 3,330

* Electrical transmission line: USD 1,000 per l.m.
FC/LC split: FC 100%; LC 0%

For Mashete Village:	1,000 l.m. line = USD 1,000
For institut. w.s.:	900 l.m. line = USD 900

* Assembly & installation of diesel-electric-powered pumping system:

. Per village or location, 8 local skilled labourers, ea. 5 days, incl. "night out" allowances	= TAS 4,000 (LC)
. Per village or location, 1 expatriate engineer, 1+ day for electrical installation and final check	= USD 400 (FC)

* Handpumps:

For each complete unit installed:

. Handpump, incl. pump assembly, rising main, pump rods, tools and misc. spares	= USD 800 (FC)
. Constr./install. costs, incl. transport	= USD 50 (FC) + TAS 6,200 (LC)

B.3 Annual Operation and Maintenance

Major assumptions used for development of annual O&M costs are indicated below under the various technical option headings.

Solar-Powered Pumping

- Local pump attendant (annual full-time salary TAS 24,000):

  - For Mashete Village: 1/2 time position required, i.e. cost of TAS 12,000/yr (LC)
  - For Mlenje Village: 1/3 time position required, i.e. cost of TAS 8,000/yr (LC)
  - For institut. w.s.: 1/6 time position required, i.e. cost of TAS 4,000/yr (LC)

- Inspection visits by Min. of Water and Energy (MAJI) O&M Engineer:

  - Routine visit to each village/location every two months
    TAS 1,000/visit (LC)

- Repair and replacement:

  - Replacement (incl. installation, transport, etc.) of one solar module per installation per year
    FC: USD 350/installation
    LC: TAS 2,000/installation

Diesel-Powered Pumping

- Local pump attendant (annual full-time salary TAS 24,000):

  - For Mashete Village: full-time position required, i.e. cost of TAS 24,000/yr (LC)
  - For Mlenje Village: full-time position required, i.e. cost of TAS 24,000/yr (LC)

- Inspection visits by MAJI O&M Engineer:

  - Routine visit to each village/location every month
    TAS 1,000/visit (LC)

- Repair and replacement:

  . Spares (incl. transport, etc.) = 2% of capital costs (FC 100%)

  . For Mashete Village: USD 300/yr
  . For Mlenje Village: USD 120/yr

  . Work to be performed by pump attendant and O&M Engineer

- Diesel fuel:

  . Cost per l = USD 1 (FC 100%)

  . For Mashete Village: annual usage = 4,500 l
  . For Mlenje Village: annual usage = 900 l

Diesel-Electric-Powered Pumping

- Local pump attendant (annual full-time salary TAS 24,000):

  . For Mashete Village: full-time position required, i.e. cost of TAS 24,000/yr (LC)
  . For institut. w.s.: 1/3 time position required, i.e. cost of TAS 8,000/yr (LC)

- Inspection visits by MAJI O&M Engineer:

  . Routine visit to village/location every month TAS 1,000/visit (LC)

- Repair and replacement:

  . Spares (incl. transport, etc.) = 2% of capital costs (FC 100%)

  . For Mashete Village: USD 150/yr
  . For institut. w.s.: USD 100/yr

  . Work to be performed by pump attendant and O&M Engineer

- Diesel fuel:

  . Cost per l = USD 1 (FC 100%)

  . For Mashete Village: annual usage = 5,400 l
  . For instit. w.s. (1/2 share): annual usage = 1,000 l

Handpumping

- Local pump attendant (annual full-time salary TAS 24,000):

  . For Mashete Village: full-time position required, i.e. cost of TAS 24,000/yr (LC)
  . For Mlenje Village: 1/2 time position required, i.e. cost of TAS 12,000/yr (LC)

- Repair and replacement:

  - For base case calculations (30-year lifetime for handpumps)

    . Spares (incl. transport, etc.) = 5% of total investment costs (FC 100%)
    . Work to be performed by pump attendant

  - For sensitivity analysis calculations (replacement of handpump units every 10 years)

    . Spares (incl. transport, etc.) = 5% of capital costs of handpumps (FC 100%)
    . Borehole maintenance = 2% of borehole installation costs (primarily LC, say 100%)
    . Work to be performed by pump attendant

APPENDIX C

ECONOMIC ANALYSIS CALCULATIONS

NORCONSULT AS.   DATE : 15. 5.85

TABLE C1. EVALUATION OF SOLAR POWERED WATER PUMPING.
SOLAR ENERGY PUMPING SYSTEM. MASHETE.
USD 1.0 = TAS 40.0

****

YEAR	INVESTM. COST	OPERATION COST	TOT.CO. DISC.	BENEFIT	BENEFIT DISC.	NET DISC.
1	101981.	0.	92710.	56396.	51269.	-41441.
2	0.	2050.	1694.	5700.	4711.	3017.
3	0.	2050.	1540.	5700.	4282.	2742.
4	0.	2050.	1400.	5700.	3893.	2493.
5	0.	2050.	1273.	5700.	3539.	2266.
6	0.	2050.	1157.	5700.	3218.	2060.
7	0.	2050.	1052.	5700.	2925.	1873.
8	0.	2050.	956.	21475.	10018.	9062.
9	0.	2050.	869.	5700.	2417.	1548.
10	0.	2050.	790.	5700.	2198.	1407.
11	13443.	2050.	5430.	5700.	1998.	-3432.
12	0.	2050.	653.	5700.	1816.	1163.
13	0.	2050.	594.	5700.	1651.	1057.
14	0.	2050.	540.	5700.	1501.	961.
15	0.	2050.	491.	21475.	5141.	4650.
16	0.	2050.	446.	5700.	1240.	794.
17	0.	2050.	406.	5700.	1128.	722.
18	0.	2050.	369.	5700.	1025.	656.
19	0.	2050.	335.	5700.	932.	597.
20	0.	2050.	305.	5700.	847.	543.
21	56142.	2050.	7864.	5700.	770.	-7093.
22	0.	2050.	252.	21475.	2638.	2386.
23	0.	2050.	229.	5700.	637.	408.
24	0.	2050.	208.	5700.	579.	371.
25	0.	2050.	189.	5700.	526.	337.
26	0.	2050.	172.	5700.	478.	306.
27	0.	2050.	156.	5700.	435.	278.
28	0.	2050.	142.	5700.	395.	253.
29	0.	2050.	129.	21475.	1354.	1225.
30	0.	2050.	117.	5700.	327.	209.
31	0.	2050.	107.	5700.	297.	190.
32	-22607.	0.	-1071.	-12696.	-601.	469.
	148959.	61500.	121506.	277800.	113584.	-7922.

NET PRESENT VALUE 10 % -7921.649
BENEFIT-COST RATIO 10 % 0.935
INTERNAL RATE OF RETURN 7.400

NORCONSULT AS.   DATE : 15. 5.85

TABLE C2. EVALUATION OF SOLAR POWERED WATER PUMPING.
DIESEL PUMPING SYSTEM.   MASHETE
USD 1.0 = TAS 40.0

YEAR	INVESTM. COST	OPERATION COST	TOTAL COST	COST DISC.
1	56396.	0.	56396.	51269.
2	0.	5700.	5700.	4711.
3	0.	5700.	5700.	4283.
4	0.	5700.	5700.	3893.
5	0.	5700.	5700.	3539.
6	0.	5700.	5700.	3218.
7	0.	5700.	5700.	2925.
8	15775.	5700.	21475.	10018.
9	0.	5700.	5700.	2417.
10	0.	5700.	5700.	2198.
11	0.	5700.	5700.	1998.
12	0.	5700.	5700.	1816.
13	0.	5700.	5700.	1651.
14	0.	5700.	5700.	1501.
15	15775.	5700.	21475.	5141.
16	0.	5700.	5700.	1240.
17	0.	5700.	5700.	1128.
18	0.	5700.	5700.	1025.
19	0.	5700.	5700.	932.
20	0.	5700.	5700.	847.
21	0.	5700.	5700.	770.
22	15775.	5700.	21475.	2638.
23	0.	5700.	5700.	637.
24	0.	5700.	5700.	579.
25	0.	5700.	5700.	526.
26	0.	5700.	5700.	478.
27	0.	5700.	5700.	435.
28	0.	5700.	5700.	395.
29	15775.	5700.	21475.	1354.
30	0.	5700.	5700.	327.
31	0.	5700.	5700.	297.
32	-12696.	0.	-12696.	-601.
	106800.	171000.	277800.	113584.

NORCONSULT AS.   DATE : 15. 5.85

TABLE C3. EVALUATION OF SOLAR POWERED WATER PUMPING.
DIESEL ELECTRIC PUMPING SYSTEM. MASHETE.
USD 1.0 = TAS 40.0

****

YEAR	INVESTM. COST	OPERATION COST	TOTAL COST	COST DISC.
1	52058.	0.	52058.	47325.
2	0.	6300.	6300.	5207.
3	0.	6300.	6300.	4733.
4	0.	6300.	6300.	4303.
5	0.	6300.	6300.	3912.
6	0.	6300.	6300.	3556.
7	0.	6300.	6300.	3233.
8	6244.	6300.	12544.	5852.
9	0.	6300.	6300.	2672.
10	0.	6300.	6300.	2429.
11	5494.	6300.	11794.	4134.
12	0.	6300.	6300.	2007.
13	0.	6300.	6300.	1825.
14	0.	6300.	6300.	1659.
15	6244.	6300.	12544.	3003.
16	0.	6300.	6300.	1371.
17	0.	6300.	6300.	1246.
18	0.	6300.	6300.	1133.
19	0.	6300.	6300.	1030.
20	0.	6300.	6300.	936.
21	5494.	6300.	11794.	1594.
22	6244.	6300.	12544.	1541.
23	0.	6300.	6300.	704.
24	0.	6300.	6300.	640.
25	0.	6300.	6300.	581.
26	0.	6300.	6300.	529.
27	0.	6300.	6300.	481.
28	0.	6300.	6300.	437.
29	6244.	6300.	12544.	791.
30	0.	6300.	6300.	361.
31	0.	6300.	6300.	328.
32	-5098.	0.	-5098.	-241.
	82924.	189000.	271924.	109311.

NORCONSULT AS. DATE : 15. 5.85

TABLE C4. EVALUATION OF SOLAR POWERED WATER PUMPING.
HANDPUMPS. MASHETE.
USD 1.0 = TAS 40.0

****

YEAR	INVESTM. COST	OPERATION COST	TOTAL COST	COST DISC.
1	49790.	0.	49790.	45264.
2	0.	3090.	3090.	2554.
3	0.	3090.	3090.	2322.
4	0.	3090.	3090.	2111.
5	0.	3090.	3090.	1919.
6	0.	3090.	3090.	1744.
7	0.	3090.	3090.	1586.
8	0.	3090.	3090.	1442.
9	0.	3090.	3090.	1310.
10	0.	3090.	3090.	1191.
11	0.	3090.	3090.	1083.
12	0.	3090.	3090.	985.
13	0.	3090.	3090.	895.
14	0.	3090.	3090.	814.
15	0.	3090.	3090.	740.
16	0.	3090.	3090.	672.
17	0.	3090.	3090.	611.
18	0.	3090.	3090.	556.
19	0.	3090.	3090.	505.
20	0.	3090.	3090.	459.
21	0.	3090.	3090.	418.
22	0.	3090.	3090.	380.
23	0.	3090.	3090.	345.
24	0.	3090.	3090.	314.
25	0.	3090.	3090.	285.
26	0.	3090.	3090.	259.
27	0.	3090.	3090.	236.
28	0.	3090.	3090.	214.
29	0.	3090.	3090.	195.
30	0.	3090.	3090.	177.
31	0.	3090.	3090.	161.
32	0.	0.	0.	0.
	49790.	92700.	142490.	71745.

NORCONSULT AS.   DATE : 15. 5.85

TABLE C5. EVALUATION OF SOLAR POWERED WATER PUMPING.
SOLAR ENERGY PUMPING SYSTEM. MLENJE.
USD 1.0 = TAS 40.0

****

YEAR	INVESTM. COST	OPERATION COST	TOT.CO. DISC.	BENEFIT	BENEFIT DISC.	NET DISC.
1	23877.	0.	21706.	23540.	21400.	-306.
2	0.	799.	660.	2029.	1677.	1017.
3	0.	799.	600.	2029.	1524.	924.
4	0.	799.	546.	2029.	1386.	840.
5	0.	799.	496.	2029.	1260.	764.
6	0.	799.	451.	2029.	1145.	694.
7	0.	799.	410.	2029.	1041.	631.
8	0.	799.	373.	8804.	4107.	3734.
9	0.	799.	339.	2029.	860.	522.
10	0.	799.	308.	2029.	782.	474.
11	2056.	799.	1001.	2029.	711.	-290.
12	0.	799.	255.	2029.	647.	392.
13	0.	799.	231.	2029.	588.	356.
14	0.	799.	210.	2029.	534.	324.
15	0.	799.	191.	8804.	2108.	1916.
16	0.	799.	174.	2029.	442.	268.
17	0.	799.	158.	2029.	401.	243.
18	0.	799.	144.	2029.	365.	221.
19	0.	799.	131.	2029.	332.	201.
20	0.	799.	119.	2029.	302.	183.
21	7738.	799.	1154.	2029.	274.	-879.
22	0.	799.	98.	8804.	1082.	983.
23	0.	799.	89.	2029.	227.	137.
24	0.	799.	81.	2029.	206.	125.
25	0.	799.	74.	2029.	187.	114.
26	0.	799.	67.	2029.	170.	103.
27	0.	799.	61.	2029.	155.	94.
28	0.	799.	55.	2029.	141.	85.
29	0.	799.	50.	8804.	555.	505.
30	0.	799.	46.	2029.	116.	70.
31	0.	799.	42.	2029.	106.	64.
32	-3558.	0.	-169.	-5219.	-247.	-79.
	30113.	23970.	30152.	106291.	44583.	14431.

NET PRESENT VALUE 10 %   14431.477
BENEFIT-COST RATIO 10 %   1.479
INTERNAL RATE OF RETURN   116.650

NORCONSULT AS.   DATE : 15. 5.85

TABLE C6. EVALUATION OF SOLAR POWERED WATER PUMPING.
DIESEL PUMPING SYSTEM.   MLENJE.
USD 1.0 = TAS 40.0

****

YEAR	INVESTM. COST	OPERATION COST	TOTAL COST	COST DISC.
1	23540.	0.	23540.	21400.
2	0.	2029.	2029.	1677.
3	0.	2029.	2029.	1524.
4	0.	2029.	2029.	1386.
5	0.	2029.	2029.	1260.
6	0.	2029.	2029.	1145.
7	0.	2029.	2029.	1041.
8	6775.	2029.	8804.	4107.
9	0.	2029.	2029.	860.
10	0.	2029.	2029.	782.
11	0.	2029.	2029.	711.
12	0.	2029.	2029.	647.
13	0.	2029.	2029.	588.
14	0.	2029.	2029.	534.
15	6775.	2029.	8804.	2108.
16	0.	2029.	2029.	442.
17	0.	2029.	2029.	401.
18	0.	2029.	2029.	365.
19	0.	2029.	2029.	332.
20	0.	2029.	2029.	302.
21	0.	2029.	2029.	274.
22	6775.	2029.	8804.	1082.
23	0.	2029.	2029.	227.
24	0.	2029.	2029.	206.
25	0.	2029.	2029.	187.
26	0.	2029.	2029.	170.
27	0.	2029.	2029.	155.
28	0.	2029.	2029.	141.
29	6775.	2029.	8804.	555.
30	0.	2029.	2029.	116.
31	0.	2029.	2029.	106.
32	-5219.	0.	-5219.	-247.
	45421.	60870.	106291.	44583.

NORCONSULT AS.   DATE : 6.11.85

TABLE C7. EVALUATION OF SOLAR POWERED WATER PUMPING.
HANDPUMPS. MLENJE.
USD 1.0 = TAS 40.0

****

YEAR	INVESTM. COST	OPERATION COST	TOTAL COST	COST DISC.
1	13205.	0.	13205.	12005.
2	0.	960.	960.	793.
3	0.	960.	960.	721.
4	0.	960.	960.	656.
5	0.	960.	960.	596.
6	0.	960.	960.	542.
7	0.	960.	960.	493.
8	0.	960.	960.	448.
9	0.	960.	960.	407.
10	0.	960.	960.	370.
11	0.	960.	960.	336.
12	0.	960.	960.	306.
13	0.	960.	960.	278.
14	0.	960.	960.	253.
15	0.	960.	960.	230.
16	0.	960.	960.	209.
17	0.	960.	960.	190.
18	0.	960.	960.	173.
19	0.	960.	960.	157.
20	0.	960.	960.	143.
21	0.	960.	960.	130.
22	0.	960.	960.	118.
23	0.	960.	960.	107.
24	0.	960.	960.	97.
25	0.	960.	960.	89.
26	0.	960.	960.	81.
27	0.	960.	960.	73.
28	0.	960.	960.	67.
29	0.	960.	960.	61.
30	0.	960.	960.	55.
31	0.	960.	960.	50.
32	0.	0.	0.	0.
	13205.	28800.	42005.	20232.