COMPREHENSIVE TESTING AND EVALUATION
METHODOLOGY FOR WATER PUMPS

Draft Discussion Document

DRAFT

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PREFACE

This report is a joint effort of I.T. Power and ARD, and was funded by the United States Agency for International Development under contract number AFR-0150-C-00-5039-00. The authors are Rick McGowan (ARD), Jeff Kenna (I.T. Power) and Jon Hodgkin (ARD).

The current version has been prepared as a draft discussion document for circulation and critical comments prior to the USAID/IDRC meeting at Sussex University. The authors solicit constructive criticism from interested readers. In some cases, alternative approaches to certain procedures have been suggested in the text. Readers are encouraged to evaluate these testing, analytical and comparative evaluation procedures on the basis of their own experience in field testing and analysis, or to suggest other options which they may feel are more useful or appropriate. The authors with to thank Terence Hart for suggestions in section 3.0.

1.0 INTRODUCTION

1.1 Background

A wide range of equipment and techniques exist to pump water. At present, the most common method used in much of the developing world is the diesel pump, although under many circumstances diesel pumps are not necessarily the best choice of equipment on the basis of cost, fuel availability, and the level of technical skills required to successfully operate and maintain them. Consequently, significant effort has been made to develop several alternatives, primarily solar-, wind-, hand- and animal-powered-pumps.

Small-scale renewable energy technologies (RETs) have been widely promoted as an attractive means to pump water, but their viability is often not well documented. Like all new products, these must be field-proven and evaluated from both technical and economic performance perspectives before they will be purchased and used in any significant numbers. Conventional and traditional technologies (such as diesel, hand and animal pumps) must be similarly tested to determine where they can be used successfully and how they compare with RETs.

Water pumping for irrigation and drinking water supply is of obvious importance to development. Agriculture and water specialists who have to choose between the different techniques have very limited information available to them on the comparative technical and economic performance of water-pumping systems. Thus far, there has been no standard method of field testing water pumps, nor is there a standard procedure for comparatively evaluating the alternatives. Further, few reliable field test data have been collected. Thus, purchase decisions are generally based on inadequate data, thereby reducing the chances of cost-effective pumping programs.

To help fill this information gap, several activities are being carried out under the joint direction of the U.S. Agency for International Development's (AID's) Bureau for Africa Office of Technical Resources, Special Development Programs Division (AFR/TR/SDP), the Regional Economic Development Support Office for East and Southern Africa (REDSO/ESA) and the Science and Technology Bureau, Office of Energy (S&T/EY).

One of the priority tasks identified was the development of guidelines for the Comparative Evaluation of the Technical and Economic Performance of Water-Pumping/Water-Lifting Systems. The need for such a methodology has been recognized by AID, and a first step in this direction was taken by defining evaluation procedures for small scale conventional and RET (wind and solar photovoltaic, or PV) water pumps (Refs. 1 and 5). The purpose of this document is to extend those initial efforts to take into account other proposed methodological approaches, and to more carefully elaborate the procedures for evaluating diesel/gasoline-, animal- and human-powered pumps.

1.2 Review of Previous Methodologies

Several documents have been studied in order to review previous work and, hence, define the scope of the methodology (1-12). Of these, only two are evaluation methodologies per se. The I.T. Power PV pumping methodology (1) describes three field test procedures for solar PV pumps, and the Associates in Rural Development, Inc. (ARD) comparative testing methodology covers field tests of PV, wind and diesel pumps in Botswana (5). Both are substantially in agreement on the data requirements, and both use a life-cycle costing technique as the basis for a comparative evaluation.

Wahby, Quenemoen and Helal (3) and Kenna and Gillett (9) detail procedures for cost comparisons between small-scale pumps, but do not cover actual field test procedures. In each case, the data required for the cost comparison are detailed. There are two key points raised in both of these cost comparisons:

- the alternatives must be compared on the same end-use; i.e., approximately the same level of water demand and pumping head; and
- the systems must be able to meet the peak daily water requirements (particularly important for irrigation pumps).

Arlosoroff et al (2) provide pro-forma sheets for data collection on hand pump performance, but no methodology is given for the collection and processing of the information. The pro-forma sheets are fairly complex for persons without a technical background. As data on reliabilty will have to be collected by the user, it is important to keep the pro-formas as "user friendly" as possible.

References 6-8 and 10-12 give the results of field tests on solar, wind, hand and diesel pumps. The objective of these test programs was to collect data to determine the unit cost of water. This is defined as the life cycle cost per unit volume (m^3) per unit pumping head (m) of water pumped. Generally, there is agreement on the procedures used to determine the unit cost, although it is necessary to define the difference between:

- a test on a pump to determine the potential output (the output if unconstrained by actual demand, downtime, etc.). This is a measure of its technical performance; and

- a calculation of unit cost based on the water that was actually required. This needs to be the basis of the financial/economic comparison, particularly for irrigation pumps where water is not required in some months.

ED/I (4) describes an approach to a methodology and raises two important issues:

- An economic evaluation should seek to quantify the benefits of the water. For irrigation, these should be the <u>incremental</u> benefits due to increased crop output from irrigation. For drinking water supply, the value of benefits is more difficult to quantify. This greatly (and we think unnecessarily) increases the complexity of the methodology and is very site-specific.

- There is a need to perform sensitivity analyses of the major assumptions in the analysis. Again, this increases the complexity, but is useful, particularly when there is some uncertainty in the data, as is often the case.

Several other methodological approaches were reviewed before undertaking the writing of the current paper. We have tried as much as possible to take into account earlier work so that previously collected data will be compatible with this methodology. The scope of the proposed methodology is defined in the following section, taking into account the above issues.

SCOPE OF METHODOLOGY

2.1 Types of Pumps

The methodology covers test and evaluation procedures for the following types of pumps:

- diesel/gasoline (direct drive and electric generators);
- photovoltaic;
- wind (direct drive);
- hand (standard and human traction); and
- animal traction.

It was initially assumed that wind turbine generators would be specifically included. In our experience, wind turbine generators used specifically to drive electric pumps are rare, and have therefore not been specifically included. However, their analysis would simply be a combination of the wind regime monitoring procedure described in the wind pump section, and the electric pump monitoring procedure described in the solar PV section.

2.2 Purpose

The purpose of the methodology is to:

- define a standard procedure to field test the pumps listed in the previous section, and to suggest a form for presentation of results; and
- define a procedure for the comparative evaluation of different pumps.

Thus, it is primarily a test and evaluation methodology and not a methodology for technology choice per se. Rather, it is a procedure to obtain the information necessary to make an informed choice of technology.

2.3 Users and Level of Skills

The procedures described here are aimed specifically at organizations and individuals involved in the field testing of water pumps. The overall supervision of a field testing program and processing of data should be carried out by persons with engineering and social science skills. Data collection is to be undertaken at two levels:

- short-term technical performance to be undertaken by engineers at graduate level; and
- long-term performance and reliability to be undertaken by the pump user, after minimal training.

2.4 Basis for Evaluation

Several types of criteria are appropriate to include in an overall evaluation of pumping alternatives. Technical and financial economic criteria such as water delivery capacity at the required head, reliability in terms of expected levels of maintenance and repair or eventual replacement of major components and the cost of required skilled or semi-skilled labor for installation are important to consider. Equally important (and all too frequently overlooked) are the questions of institutional and social constraints to the use of a particular technology. The cost or technical performance of a particular device matters little if people refuse to use it.

All of the most critical criteria will be summarized in a matrix which will provide the reader, at a glance, with the most important characteristics of each of the systems being compared. The principal evaluative criteria suggested here are:

- limits to technical performance--maximum water lift and hydraulic energy output;
- unit cost of water, calculated using standard life cycle costing methods and based on actual site water requirements;
- recurrent cost intensity, (or its inverse, the capital cost intensity), defined as the ratio of recurrent costs to total life-cycle costs (both not discounted). While very useful, the unit water cost disguises the mixture between capital and recurrent cost components and can be sensitive to discount rate; the recurrent cost intensity will show the proportion of the total costs that occur in the future; and
- institutional constraints and social acceptance. It is proposed to assign a numerical value to summarily indicate whether or not these considerations represent a significant inhibition to the use of the system in question. The method of assigning these

values will no doubt generate considerable discussion.

2.5 Overall Test Schedule

The procedures are undertaken in four stages:

- Collection of socioeconomic data (section 3.0 and the discussion at the end of section 5.0). Proformas are given to collect site details on cost data and relevant social and institutional factors. A format for a site log book to collect recurrent cost, operation, maintenance and repair data is also given. These types of data are quite similar for all technologies.

- Short-term field performance tests at actual sites to determine the potential long-term performance (section 4.4). This test is a measure of the technical performance and shows how the technology should perform, given an adequate support infrastructure, and a pump that is well matched to the end-use. The short-term test requires engineering skills.

- Do long-term field measurements and use this information to determine how well the water pumped is actually used. These results can then be compared to the potential output to determine whether the pump needs maintenance or repair or is oversized for the water demand, and to determine the long-term reliability of the pump. Variations of the site log book are given for each technology.

- Process the results and carry out a comparative evaluation (section 5.0), the main criterion of which is the unit cost of water.

3.0 COLLECTION OF SOCIOECONOMIC DATA

3.1 Site Description

Since it is anticipated that the data collected under this section will generate considerable dicussion, it has been presented only in outline form for convenience. The points that need covering on the questionnaire include:

Introduction of technology:

- context in which the technology operates;
- tasks performed; how they were carried out previously;
- siting;
- availability of an adequate energy resource demand potential;
- impact on established private-sector commerce, if the technology replaces an already commercially available technology;
- impact on local population from noise or pollution;
- security to operator and users; and
- availability of a control and local management structure; also a regional support infrastructure for fuel/spare parts/skilled technicians, etc.

Use of technology:

- numbers and characteristics of users;
- size of catchment area; number of people using or expected to use the water point; borehole yield, water quality;
- technology options still used or currently available which satisfy similar needs;
- estimates of potential increased use levels due to increased availability;
- end-users' understanding of principles of proper operation, maintenance and system limitations; and
- nature of benefits.

Failures:

- system for notifying maintenance/repair crews when breakdowns occur;
- requirements for back-up systems.
- frequency of breakdowns (or percent availbility) and their impact on users; and
- type and response time and duration of outage.

Costs:

- potential for user or local organization to cooperatively invest in technology;
- private- versus public-sector investment; availability of donor support or local financing for capital costs; and
- financial burdens associated with use, operation, servicing, repair and replacement of the equipment.

User training:

- new skills;
- upgrading skills;
- level of skills needed for doing different levels of maintenance (i.e., for simple parts replacement versus actual repair); and
- teaching of system design criteria and local skills necessary for equipment choice and installation.

Quality of service:

- appropriateness and capacity of system to satisfy need.

Adaptability of technology:

- modularity to facilitate expansion if demand increases beyond design limits.
- on-demand water availability.

Follow-up and maintenance:

- procedure established;

- local participation; and
- information transfer.

3.2 Site Log Book

The site log book is the basis for long-term operation and maintenance cost data collection. The log book is completed by the water user--suitable training must be provided. There are four sections in the log book, one double-page per week.

Part A - recurrent cost data, completed each day, or by event (such as whenever a part is replaced, or a fuel delivery is received).

Part B - water-use data from flowmeter reading, completed each day (or, in the case of irrigation, whenever applications are made, or storage tanks are filled).

Part C - pump performance data; this section is different for each technology (see section 4.4).

Part D - reliability and maintenance report, covering descriptions of failures, routine maintenance.

Tables 3.1 and 3.2 show the format for the log book. Cost data can be summarized as shown in Table 3.3.

Table 3.1

Format of Site Log Book

Site Log (front sheet)

Name of Site or
Manager/Operator: ____________________; Date: ________________

Day: 1 2 3 4 5 6 7

Parameter

Part A - Recurrent Cost Data

Site revenue:
- sale of water
- other

Site expenditure:
- maintenance
- salaries
- fuel
- other

Part B - Water Use Data

1. Irrigation
   Area irrigated:
   Time of Day Done:
   Time to irrigate:
   Crop irrigated:
   Method of application:

2. Drinking Water
   Daily Use:

Part C - Pump Performance Data

See section 4.4
for technology-
dependent format

Fuel cost

Table 3.2

Format of Site Log Book

Site Log (reverse sheet)

Part D - Reliability and Maintenance Report

Description of failures: (time to repair, parts used, costs, date):

Labor, transportation, per diem, skill levels required (local or regional skills or called in):

Percent outage or availability:

Routine maintenance (time to perform, parts used, costs, date, skills level):

Table 3.3

Summary Sheet for Cost Data Analysis

Cost Data Sheet

Month: Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

Site: ____________

Capital cost (and breakdown by component): _________________

Installation cost:
- civil engineering:
- labor (skilled/unskilled):
- transportation:

Maintenance cost
- labor:
- spare parts:

Fuel cost:

Operator salary (incl. bonus and other benefits):

Cost to transport fuel:
- distance:
- mode:
- source:

4.0 COLLECTION OF TECHNICAL PERFORMANCE DATA

4.1 Test Objectives, Measurements and Accuracy

4.1.1 Objectives

Two technical performance tests for each technology are described in this section. First, a short-term intensive test is carried out over several days. The objective of this test is to determine the overall efficiency of the pump, and thereby estimate how much water the pump can provide in the long term. For example, the long-term output of solar and wind pumps depends on the solar radiation or windspeed distribution, respectively. Once the overall efficiency of the pump (as a function of energy input) is known, it is possible to estimate long-term output for standard meteorological conditions. Similarly, once the output of animal or hand pumps is known, it is possible to estimate the number of people or animals needed to provide the required water. The short-term test is carried out by a skilled engineer.

Secondly, a long-term test is carried out over a minimum of one year. The short-term test gives a generalized performance description of the pump, whereas the long-term test shows how well the pump performs at a particular site. The energy input and water output are recorded in the site log book by the user. Thus, the long-term test will show how well matched the pump is to the end-use and, coupled with the operation, maintenance and repair data collected in the site log book, will provide information to calculate the unit water costs.

4.1.2 Measurements to Be Made

Table 4.1 lists the parameters that must be measured for each technology. For the short-term test, the energy output is determined by making measures of water volume and pumped head in a 10-minute period. From the measurement of water volume, the average flow rate can be calculated to give the hydraulic output power:

Hydraulic power (watts) = (water flow rate)(g)(pumped head)
where g = the gravitational constant ($9.81\ m/s^2$)

The energy input measurements are dependent on the pumping technology. They are:

- PV pumps - solar radiation;
- windpumps - wind distribution;
- diesel/gasoline pump - fuel consumption;

Table 4.1

Summary of Parameters to Be Measured and Accuracy Required

Parameter (units)	Short-Term Test: Diesel/ Gasoline	Solar	Wind	Animal	Hand	Long-Term Test: Diesel/ Gasoline	Solar	Wind	Animal	Hand	Instrument	Precision Required	Calibration Interval
Volume of water (m^3) in													
• 10-minute period	x	x	x	x	x						see table 4.2	± 2%	each test
• daily						x	x	x	x	x		± 2%	3 months
Static head (m)	x	x	x	x	x	x	x	x	x	x	well dipper	± 1%	each test
Pumped heat (m)	x	x	x	x	x						pressure gauge	± 1%	or 1 year
Solar irradiation (kWh/m2):											class A pyranometer and integrator		
• over 10 minutes		x										± 5%	each test
• daily							x					± 5%	13 months
Windrun (m)													
• over 10 minutes			x								cup counter	± 5%	each test
• daily			x					x			anemometer	± 5%	3 months
Fuel consumption											fuel flow meter		
• in 10 minutes	x												
• daily						x							
Voltage (volts)	x	x									voltmeter		
Current (amps)	x	x									ammeter		
Electrical energy (kWh)	x*	x									energy meter		
Time	x	x	x	x	x						stopwatch		
Speed of rotation (rpm)	x**	x**	x**								tachometer		

* if generator is used
** for derating diesels, or if solar or wind pumps are used to drive vertical turbine or Mono-type pumps.

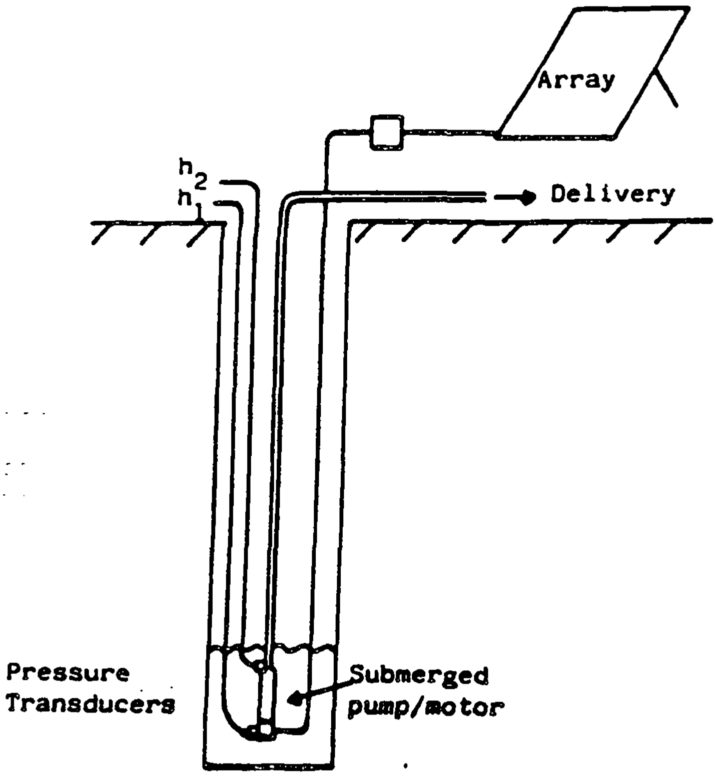


Figure 4.1.a
The static head + friction head is measured by placing pressure transducers on the inlet and outlet of the pump and reading the difference:-

$$h_s + h_f = h_2 - h_1$$

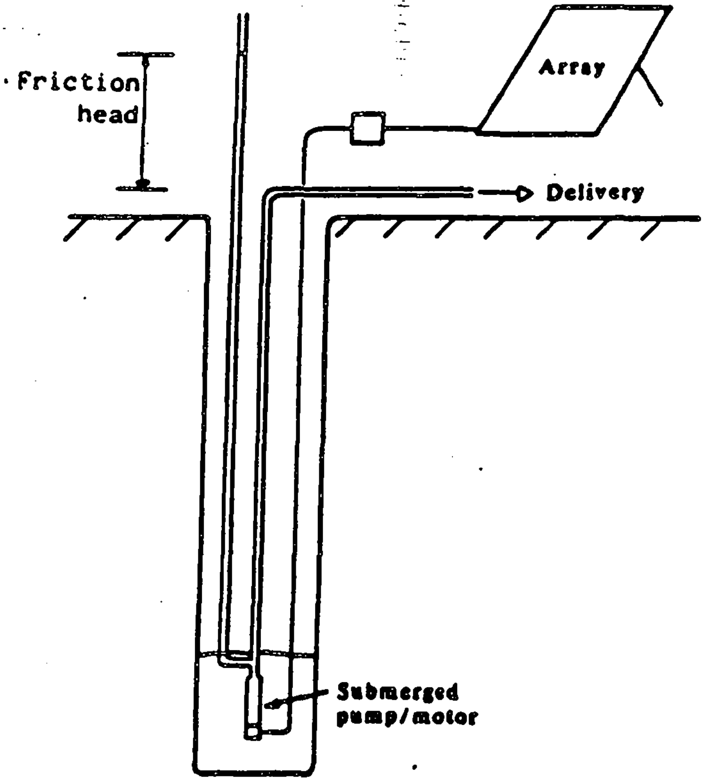


Figure 4.1.b
The friction head is measured by bringing an open pipe above the surface. The water level must also be measured.

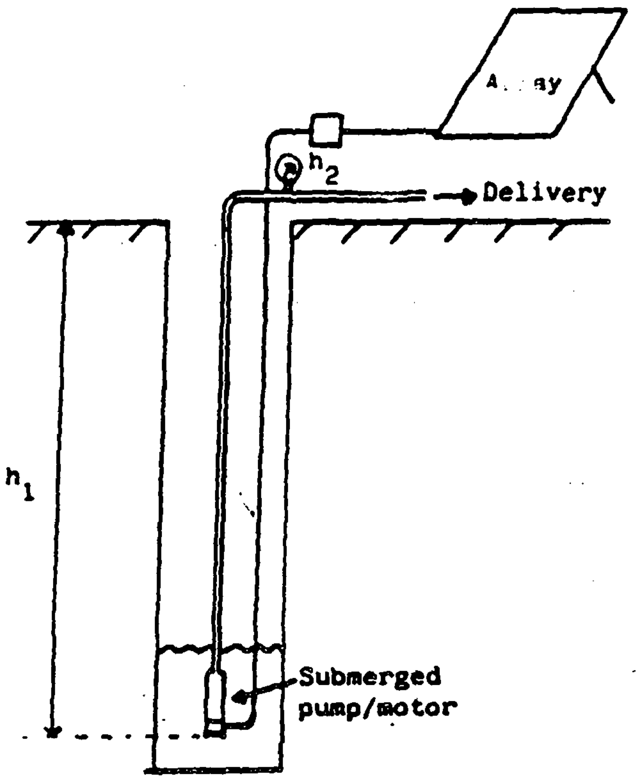


Figure 4.1.c

A pressure guage is placed in pipework at the surface. It measures the friction head downstream of the guage plus the static lift between the pump outlet and guage. The pump depth must be known and the friction head is

$$h_f = h_2 - h_1 + h_3$$

where h_3 is the friction head in the rising main (estimated).

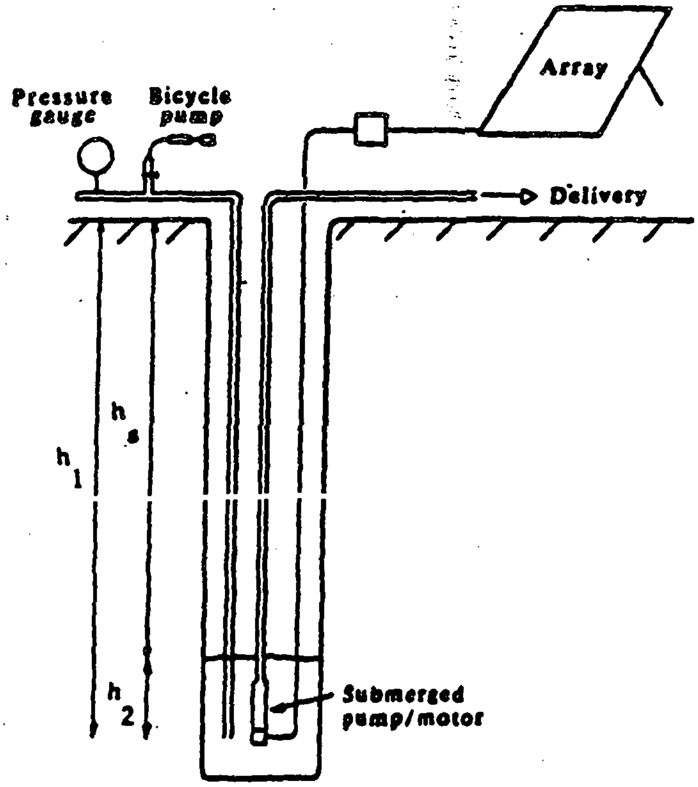


Figure 4.1.d

The static head (hs) can be determined from

$$hs = h_1 - h_2$$

The pressure at the bicycle pump is increased until it is equal to a maximum value (h_2) and h_2 can be read directly from the pressure gauge. The pipe length (h_1) must be measured at installation.

- animal - number of animals times force applied through measured distance;
- hand - force applied times moment arm of handle.

For the <u>long-term test</u>, the volume of water pumped is determined as a function of average daily energy input. This requires measurement of daily water volume, daily static head and solar irradiation, windspeed distribution or fuel consumption.

4.1.3 Errors

There are three sources of error that arise in the tests:

1. <u>Systematic error due to the instruments.</u> The typical error in a calculated parameter, such as efficiency, is given by the square root of the sum of the squares of the error in each measurement. For example, using instruments of the accuracy given in Table 4.1, hydraulic power can be measured to a typical accuracy of:

$$\sqrt{(2\%)^2 + (1\%)^2} = 2.2\ \%,$$

since hydraulic power is the product of flow rate and head. Similarly, other calculated parameters can be measured to the accuracies given in Table 4.2.

2. <u>Random error due to experimental technique.</u> This can be reduced by taking a statistically significant number of measurements. For this reason, a minimum number of measurements are stipulated for each test.

3. <u>Error due to variations in environmental conditions.</u> This will result in scatter on the efficiency characteristics and is not an experimental error as such. However, it governs the confidence limits in the efficiency for a particular value of input energy.

Likely estimates of the overall error bounds are given in Table 4.2.

Table 4.2

Estimated Systematic and Overall
Error Bounds for Each Parameter

Technology Parameter	Systematic Error	Est. Overall Error Bound
PV pump:		
PV efficiency	± 5.1%	7%
Subsystem efficiency	± 3.0%	6%
System efficiency	± 5.7%	10%
Irradiance	± 5.7%	5%
Water volume	± 2.0%	5%
Irradiation	± 5.0%	5%
Windpump:		
System efficiency	± 5.5%	10%
Windspeed	± 5.0%	10%
Water volume	± 2.0%	5%
Diesel/Gasoline pump:		
System efficiency	± 5.5%	6%
Engine/gen efficiency	± 2.6%	3%
Motor/pump efficiency	± 2.6%	3%
Hand pump:		
Subsystem efficiency	± 5.0%	
Animal pump:		
Subsystem efficiency	± 5.0%	

4.2 Instruments and Calibration

This section specifies the type of instruments and measurement techniques that should be used to achieve the instrument accuracy given in Table 4.1. Calibration procedures and intervals are also discussed.

4.2.1 Measurement of Volume of Water

Fluid flow rate should be measured to an accuracy of within ± 2%. It is recommended that the flow meter be calibrated before each short-term test and at intervals of three months for long-term tests. The calibration can be undertaken with the flow meter in-situ by diverting the water flow to a vessel and measuring the volume delivered in a measured time period (standard bucket and stopwatch method). A container of sufficient volume to hold water for a 10-minute period should be used.

There are five parameters which influence the choice of flow meter:

- Flow meter type. Under pulsed flow, as in positive displacement pumps (wind, hand/animal), for example, the positive displacement type of flowmeter is the best option, although it is susceptible to dirt and, hence, depending on water quality, can require a filter. Under these conditions, the turbine type of flow meter gives the least accuracy, although it has the lowest head loss. Since diesel pumps have high constant flow rates, the usual choice is a turbine flow meter. Under certain circumstances, such as measuring the output of a low-lift ladder pump into a channel, a V-notch weir might have to be used. The principles of operation of weirs are available in any standard engineering reference.

- Flow range. Needs to match the flow range of the pump under test in order to achieve sufficient accuracy.

- Resolution. For the 10-minute short-term test on typically sized pumps, a resolution of one litre is preferable.

- Accuracy over flow range. An accuracy of ± 2 % is desirable.

- Head loss. Must be as low as possible, particularly for pumps without stuffing boxes.

Table 4.3 summarizes the properties of the main types of flow meters and shows the technologies for which they are suited. It is essential that the flow meter is fitted so that the flow meter pipe always runs full of water.

Table 4.3

Properties of the Main Types of Flowmeters

Type	Min Flow for 2% acc. (ls/sec.)	Head Loss @2.7 ls/sec.	Particle Resistance	Typical Use
In-line turbine	0.25	good, 0.2m	good	diesel, dirty water for others
Pelton wheel	0.22	poor, 2.5m	medium	
Positive displacement	0.03	poor, 3m	poor	wind, animal, hand, clearwater
Paddle wheel	0.17	negligible	good	solar, diesel

4.2.2 Measurement of Pumped Head

Head can be the most difficult parameter to measure, as pumps are usually submerged and boreholes often enclosed. The total pumped head comprises the static lift plus the head loss in the pipes plus the velocity head at the outlet:

$$h_p = h_s + h_f + v^2/2g$$

where h_p = pumped head
h_s = static head
h_f = head loss in the pipework due to friction
$v^2/2g$ = velocity head at the outlet, and
v = velocity of the water at the outlet.

Three options are given below for measuring pumped head:

1. The preferred method is to place pressure transducers on the inlet and outlet of the pump and measure the pressure increase across the pump (see Figure 4.1a). This pressure increase is equal to the static head plus the head loss in the pipework. The total pumped head is then the sum of pressure increase plus the calculated velocity head. Hence, to use this method, pressure taps should be fitted to the pump before installation.

2. If there is only a small static head above ground level, a pipe may be brought to the surface to measure the pumped head, as indicated in Figure 4.1b. Alternatively, an electrical pressure transducer can be fitted to the pump outlet and

electrical wires brought to the surface. The water level must also be measured, and the velocity head must be calculated.

3. If it is impossible to place a pressure tap down the borehole, a pressure gauge can be fitted in pipework above ground (Figure 4.1c). However, this method will not record the pressure loss in the rising main and a correction must be made. The water level must be measured, and the velocity head calculated. For most applications, the velocity head component will be negligible compared to friction and elevation head.

For cases 2 and 3 above, the water level must be measured using a well dipper. A small pipe should be installed in the borehole if possible so that the dipper wire will have easy access to the borehole. Alternatively, the water level can be measured by inserting an air pipe into the borehole, as indicated in Figure 4.1d.

Where only the static head can be measured, the head loss in the pipework may be estimated from knowledge of the flowrate and pipe sizes, as shown in any standard engineering text. In all cases, the velocity head is not measured by pressure transducers, so it must be calculated from the flowrate and pipework size and added onto the static head and the head loss in the pipes.

4.2.3 Measurement of Solar Irradiance and Irradiation

The instrument for the measurement of solar irradiance should be a WMO Class A pyranometer. While silicon pyranometers are considerably less expensive, they have not in our experience been particularly accurate or reliable. The pyranometer should be mounted so that the detector is located in the plane of the array. Prior to testing, the transparent cover should be cleaned. For measurement of solar irradiation, an integrator with an accuracy of ± 1% should be used with the pyranometer. The pyranometer should be calibrated by returning the instruments to the manufacturer (or sending it to a national meteorological institute with calibration facilities) at annual intervals.

4.2.4 Measurement of Electrical Energy, Voltage and Current

Electrical energy, voltage and current can be measured relatively easily and accurately by commercially available equipment. These parameters should be measured to an accuracy of ± 1%, and the instruments must be recalibrated annually.

4.2.5 Measurement of Wind Distribution

There are several commercial cup counter anemometers available. Anemometers should be mounted on separate towers (at the same height as the wind pump rotor hub) at least two rotor diameters away from the wind pump. Binoculars are required to read mechanical anemometers on towers, so while more expensive, an electronic pulse-output anemometer with a ground-mounted integrator is considerably more convenient. There is considerable variation in accuracy between various manufacturer's products, so care should be taken to obtain a sufficiently accurate model.

4.2.6 Measurement of Fuel Flow

The fuel flow meters need to be accurate at low flow rates (down to 1.0 ls/hour for standard diesels, and as low as 0.3 ls/hour for small petrol generators) and have a resolution of one cubic centimeter. Calibration should be carried out by collecting fuel in a calibrated container and comparing with the meter reading. Fuel flowmeters which can measure such low flows are difficult to find and can be quite expensive. The main problem is that the pressure drop across such a small yet accurate flowmeter can be great enough to impede the flow of fuel, and can choke off the engine.

An alternative to using a flowmeter is the use of a separate calibrated fuel container attached to the injector inlet. The container has two marks, one, say, 100 ml above the other. After the engine is warmed up as before, fill the separate fuel container up to a pre-marked upper level. Note the water flowmeter reading and record the RPM (see below). Run the engine until the fuel level reaches a lower pre-marked level, then again note water flowmeter reading and RPM. Try to run the engine at steady state (constant RPM) during this test so that the load is constant. This procedure is normally repeatable to within 5%.

4.2.7. Measurement of Time

Nearly all the other measurements require a time measurement. A simple stopwatch is entirely adequate for this.

4.3 Short-Term Test Procedure

The primary objective of the short-term test procedure is to answer the following questions:

- How close to its performance specification is the system working?

- Is the system correctly sized for the output required of it?

- Are there any indications of component or operational shortcomings that may be corrected or improved?

- What is the energy input per unit of output?

While these questions are important to the characterization of a pumping system, it can be argued that there are more important cost drivers (for example, the recurrent cost of labor in some countries). At some remote sites, the rate of fuel consumption can be a relatively small cost consideration compared to transportation or the cost of scarce skilled labor required for major overhauls. Bear in mind that technical criteria are not necessarily the most important cost drivers of a pumping system.

4.3.1 Diesel/Gasoline Pumps

Rigorous testing of a diesel or gasoline engine is a complex and costly procedure and, as there are many types and configurations of pumping systems (all demanding different variations in instrumentations), this methodology is limited to a relatively simple procedure, which does not require the use of sophisticated measuring devices. A more sophisticated procedure would be technically feasible, but it would probably cost more than any savings that could result from implementing it. Therefore, the recommended procedures will not allow a detailed technical fault analysis to be carried out, but any significant performance shortcomings should be clearly detected, and a troubleshooting guide is provided to establish the most likely causes of any symptoms that are detected.

The test consists of taking measurements of:

- fuel consumption rate in a 10-minute period;

- volume of water pumped in a 10-minute period;

- pumped head at start and finish of the test;

- electrical energy, when electrical generators are used (depending on the system); and

- engine speed. It is necessary to know operational RPM so that the % derating from the full load rated condition can be determined.

Instruments

- fuel flow meter (or calibrated container as described in the alternative procedure);
- integrating water flow meter;
- energy meter (electrical generator or grid inter-tied systems only). For grid-connected electric pumps, the already installed kWh meter is more than adequate for energy input measurements;
- pressure gauge and/or well dipper;
- clipboard and blank format sheets;
- stopwatch;
- calibrated container (approximately 100 cc); and
- a tachometer (rpm counter).

Procedure

- Calibrate all instruments.
- Install the fuel meter between filter and injection pump on a diesel engine at the carburetor inlet on a gasoline engineer (Figure 4.2, to be inserted). On diesel engines, disconnect the return from the injectors and collect the unburned returned fuel in a calibrated container (often this amount is negligible, but can be up to 5% of total fuel consumption). Install the water flow meter in a straight run of pipework at the outlet of the pump. Allow at least 10 pipe diameters at either side of the flow meter.
- For pumps with electrical transmission, connect the energy meter to the generator output.
- Run the system until it has fully warmed up (at least 30 minutes), and obtain steady operating conditions (constant speed, head and water output).
- The test should be carried out over a period of several hours to obtain at least 20 data points. Results should be recorded on the format sheet shown in Table 4.4.

Table 4.4

Format Sheet for recording and analysis of short term diesel test

SHORT-TERM DIESEL GASOLINE PUMP TEST

Description

Diesel engine make and rating

Generator make and rating

Pump make and rating

Fuel flowmeter Reading	Water flowmeter Reading	Energymeter Reading	Static lift	Pressure Guage Reading	Hydraulic Power W	Power Output W	Fuel Power	Engine Generator Efficiency	Motor/ Pump Efficiency	System Efficiency

- Record meter readings at 10-minute intervals. Engine speed should be recorded with the tachometer. On diesel engines, the fuel returned (if any) should be subtracted from the fuel meter reading. Make sure that the manufactuer's rated conditions for the engine are recorded.

Data Analysis

The data should be analyzed and recorded on the format sheet shown in Table 4.4. The measured values are divided by the time period (10 minutes) and converted into standard units for convenience. For each 10-minute test point, calculate:

- average fuel consumption rate (ls/sec) = $(q_2-q_1)/600$
- average water flow rate (ls/sec) = $(Q_2-Q_1)/0.6$
- average generator output (W, if any) = $(E_2-E_2)/0.167$
- the average pumped head (meters) = $0.5\ (h_{s1} + h_{f1} + v_1/2g + h_{s2} + h_{f2} + v_2^2/2g$

where Q is the water flow meter reading in cubic meters,
q is the fuel flow meter reading in litres,
h_s is the static head in meters,
h_f is the head loss in the pipes in meters,
E is the energy meter reading in Wh, and
v is the velocity at the pipe outlet and is given by

$$v = 4Q/\mathrm{pi} \times d^2$$

with Q the flow rate in cubic meters per second, and
d the pipe diameter in meters.

The subscripts 1 and 2 refer to the readings before and after the 10-minute period, respectively. Now calculate the hydraulic power using the equation:

hydraulic power (w) = water flow rate x pumped head x g
with g = gravitational constant (9.81 m/s^2).

The power in the fuel is then equal to:

fuel power = fuel flow rate x C (w)
with C = the calorific value of the fuel @ 38 MJ/litre for diesel, and 32 MJ/litre for petrol.

Calculate the overall system efficiency (n_s), the motor pump efficiency (n_m) and the engine/generator (n_g) efficiency as follows:

n_s = (hydraulic power)/(fuel power);

n_m = (hydraulic power)/(generator power); and

n_g = (generator power)/(fuel power).

Then determine the average efficiencies for at least twenty 10-minute test points. The overall efficiency of a diesel pumping system is a strong function of the load (measured as a function of engine RPM) on the engine. Similarly, n_m and n_g will be dependent on how well matched these components are. When operating at a rated power, a direct drive diesel pumping system should achieve an overall efficiency of 15 percent to 20 percent. A diesel generator pumping system should achieve an overall efficiency of 10 percent to 15 percent. If the measurements indicate that the efficiencies are not in these ranges, either the system is improperly sized for theload, the components are not properly matched, or maintenance or repair is required.

4.3.2 Solar Pumps

The objective of this test is to determine the operating efficiency of the PV array, the motor/pump subsystem and the overall system as a function of solar irradiance. By integrating the efficiency/irradiance characteristic with typical daily solar irradiance profiles, it is possible to obtain an estimate of the volume of water pumped as a function of daily solar irradiation. This can then be used to estimate the unit water cost for a particular location and, combined with a long-term test, shows how well the water is used.

The test is undertaken by taking measurements of:

- solar irradiation in a 10-minute period;
- PV array energy output in a 10-minute period;
- volume of water pumped in a 10-minute period; and
- pumped head at the start and finish of the 10-minute period.
- the RPM of the motor or pump if applicable (e.g., for Monos).

If information on component performance is not required, measurements of PV array energy are not necessary. A 10-minute period is used to allow for the thermal time response of the solar cells (typically 5 minutes). This period ensures that the output from the system corresponds to the input. Since three of the measurements made are integrated values (i.e., irradiation rather than irradiance, volume of water rather than flow rate, electrical energy rather than power), they must be divided by the time period (10 minutes) to determine the average values of irradiance, PV array power output and flow rate. From these, the PV array efficiency, the subsystem efficiency and the overall system efficiency can be calculated.

Instruments

- pyranometer and integrator (in wh/m^2);
- integrating flow meter (liters or m^3)
- energy meter (wh)
- pressure gauge(s) and/or well dipper (in meters);
- clipboard and blank format sheets (Tables 4.5 and 4.6); and
- watch.

Procedure

1. Connect the instruments, as indicated in Figure 4.3. The pyranometer should be in the plane of the PV array. The flow meter should be installed in a straight run of pipework at the outlet side of the pump. Allow at least 10 pipe diameters on either side of the flow meter. For open wells, the static head is easily measured using a well dipper. For closed boreholes, a pressure gauge and air pipe may be used to determine the head, as shown in section 4.2. The delivery head should be measured using a pressure gauge or open pipe, as shown in Figure 4.1. Where the delivery pipes are short and less than two meters above ground level, the delivery head can be estimated (indicate reference).

2. Clean the surface of the array.

3. The test should be carried out over a complete day, under clear sky conditions. Results should be recorded on the format sheet, shown in Table 4.5.

4. The objective of the test is to obtain 10-minute average performance data for a range of solar irradiance from start-up to at least 800 W/m^2. The solar irradiance level must not change by ± 50 W/m^2 during the period of a 10-minute test.

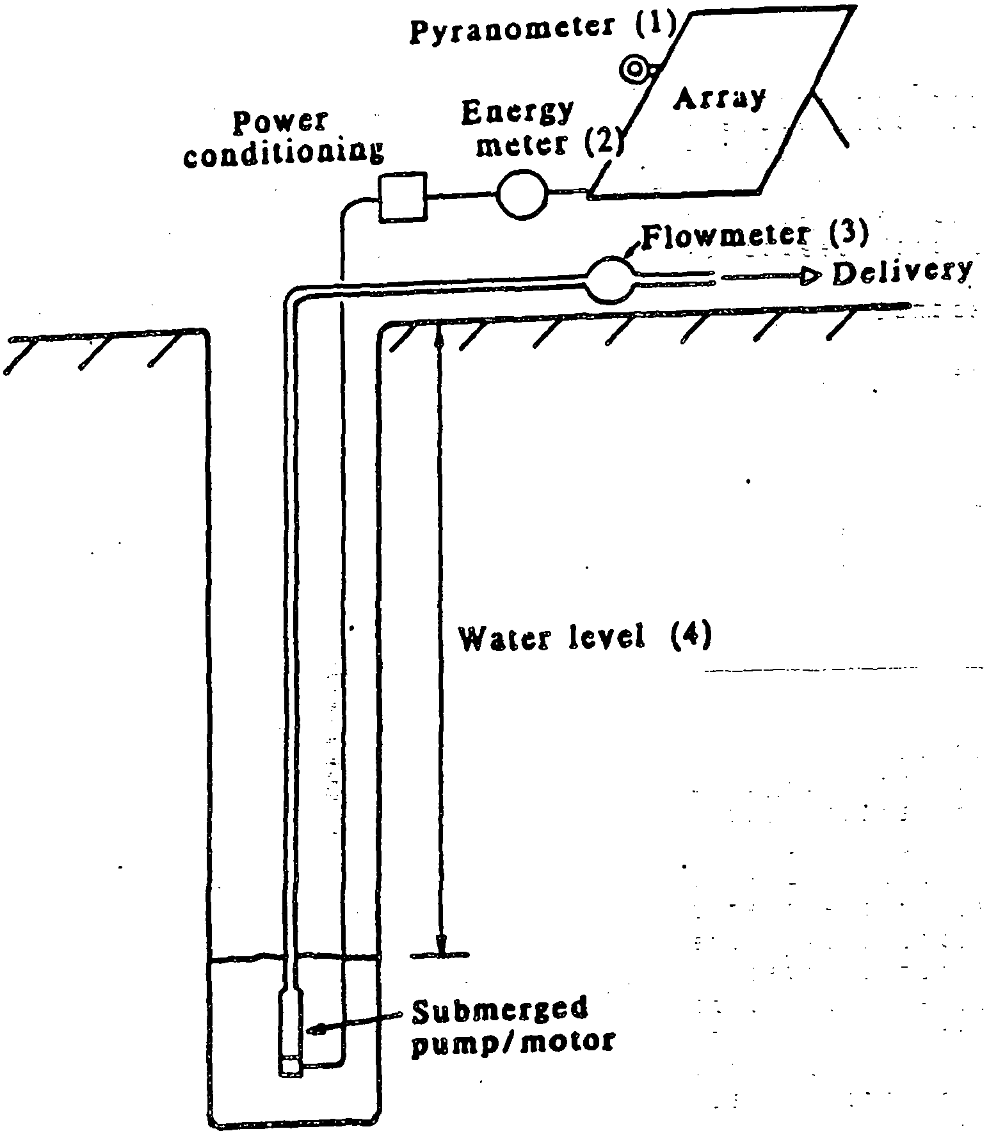


Figure 4.3 Test circuit to determine Short Term System Performance.

5. When the pump starts to pump water, record:

- the pyranometer reading;
- the flow meter reading;
- the energy meter reading; and
- tachometer reading (rpm, if appropriate);
- the pressure gauge and/or water level.

Make a note of both the irradiance at which the pump starts and shuts down. Take a further set of reading 10-minutes later. Take repeat readings at intervals throughout the day, such that there is a minimum of twenty 10-minute test points, i.e., a minimum of 40 readings.

Data Analysis

The data should be analyzed and recorded on the format sheet shown in Table 4.6. Therefore, for each 10-minute test point, calculate:

- average irradiance = $(H_2-H_1)/0.167$ (W/m^2)
- average array output power = $(E_2-E_1)/0.167$ (W)
- average flow rate = $(Q_2-Q_1)/0.6$ (ls/sec)
- average head = $0.5\ (h_{s1} + h_{f1} + v_1^2/2g + h_{s2} + h_{f2} + v_2^2/2g)$ (m)

where H is the solarimeter reading in Wh/m^2,
E is the energy meter reading in Wh,
Q is the flow meter reading in m^3,
h_s is the static head in meters,
h_f is the head loss in the pipes in meters, and
v is the velocity of the water at the pipe outlet and is given by: $v = 4Q/(pi \times d^2)$
where Q is the flow rate in m^3/sec,
d is the pipe diameter in meters.

The subscripts 1 and 2 refer to the reading before and after the 10-minute period, respectively. Then calculate the hydraulic power using the equation:

hydraulic power (watts) = flow rate x pumped head x g
where g is the gravitational acceleration ($9.81\ m/s^2$)

SHORT TERM SOLAR PUMP TEST
DATA SHEET

Location:

Latitude:

Date:

Tester:

Time	Pyranometer Reading Start	Pyranometer Reading Finish	Energy Meter Reading Start	Energy Meter Reading Finish	Flow Meter Reading Start	Flow Meter Reading Finish	Static Head Reading Start	Static Head Reading Finish	Friction Head Reading Start	Friction Head Reading Finish

Table 4.5 Format Sheet for recording short term performance data

SHORT TERM SOLAR PUMP TEST

Location:
Latitude:
Date:
Array make and rating:
Tester:
Motor make and rating:
Cell Area:
Pump make and rating:
Water Rest Level:

Time	Irradiance W/m^2	Array Output W	Flow l/sec	Head m	Hydraulic power W	Array efficiency %	Subsystem efficiency %	System efficiency %

Table 4.6 Format sheet for presentation of short term test data

4. Calculate the following efficiencies (n):

array n = (array output power)/(irradiance x A_{cell});

subsystem n = (hydraulic power)/(array output power); and

system n = (hydraulic power)/(irradiance x A_{cell}).

If the array power has not been measured, only the system efficiency can be calculated. A_{cell} is the cell area. Plot graphs of efficiency versus irradiance, using the format sheet shown in Figure 4.4.

The response time of the module temperature to changes in irradiance is typically five minutes. Hence, ~~it is~~ more appropriate to measure 10-minute average performance than instantaneous performance. The array and system efficiency are based on the array cell area, since this is a more representative parameter of the physical performance of the system. An alternative definition of array and system efficiency would be to base them on gross array area. The subsystem efficiency is an important characteristic of the pump because it determines the size of array that is required to perform a given hydraulic duty. The definition of subsystem efficiency given above means that power conditioning losses are included in the subsystem. The array efficiency is not simply a property of the array. It also depends on the subsystem, since the operating point on the curren/voltage curve (and, hence, array efficiency) is dependent on the load on the array. A well-matched subsystem will lead to a more efficient array.

Interpretation of Results

Subsystem efficiency should peak at between 30-40%. Measured values significantly below this indicate that there is a fault in the subsystem or that it is not well matched to the PV array. A well-matched motor/pump subsystem should have a relatively constant subsystem efficiency (except during start-up and shut-down). The array efficiency should be eight to 10 percent or greater. Values below this indicate that the array is not operating near its maximum power point, and the motor is not well matched to the array.

The potential volume of water pumped in m^3/day should be estimated using the following formula:

$$V = \sum_{i=1}^{24} \frac{(n_s \times Gi \times A_{cell} \times \Delta t)}{\text{rho} \times g \times h}$$

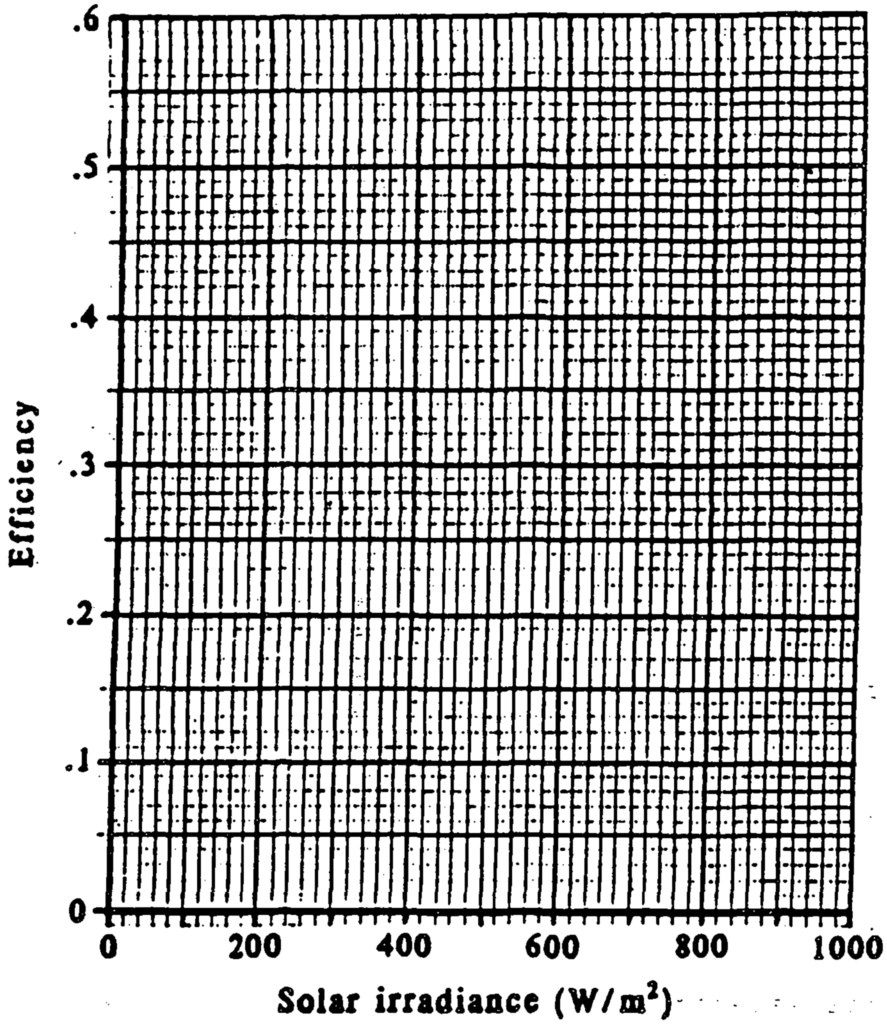


Figure 4.4 Efficiency versus solar irradiance.

where G_i is the solar irradiance at hour (i) - standard values for 12 hour days with 2-6 kWh/m^2 solar irradiation are given in Table 4.7,

A_{cell} is the array cell area (m^2),

n_{sys} is the system efficiency at the irradiance Gi and is obtained from the measured performance (Figure 4.7),

rho is the density of water (1000 kg/m^3),

g is the gravitational acceleration 9.81 m/s^2, and

Δt is the number of seconds in an hour.

The numerator in the above equation is the hydraulic energy output of the pump in a day. The volume pumped per day can be calculated for solar irradiation levels between 2-6 kWh/m^2-day. A plot of potential volume pumped per day versus solar irradiation should be made using the format sheet given in Figure 4.5. This gives the characteristic performance curve for the solar pump, which can be used to determine the unit water cost.

	Solar Irradiance (W/m^2)				
Solar Irradiation (kWh/m^2)	2	3	4	5	6
HOUR					
6	1	1	1	1	1
7	57	81	105	160	154
8	118	173	229	286	343
9	177	267	357	447	537
10	232	352	471	589	708
11	271	410	548	686	824
12	285	431	576	721	865
13	271	410	548	686	824
14	232	352	471	589	708
15	177	267	357	447	537
16	118	173	229	286	343
17	57	81	105	130	154
18	1	1	1	1	1

Table 4.7. Specification of standard days, showing hourly values of solar irradiance in W/m^2 for a range of daily solar irradiation levels.

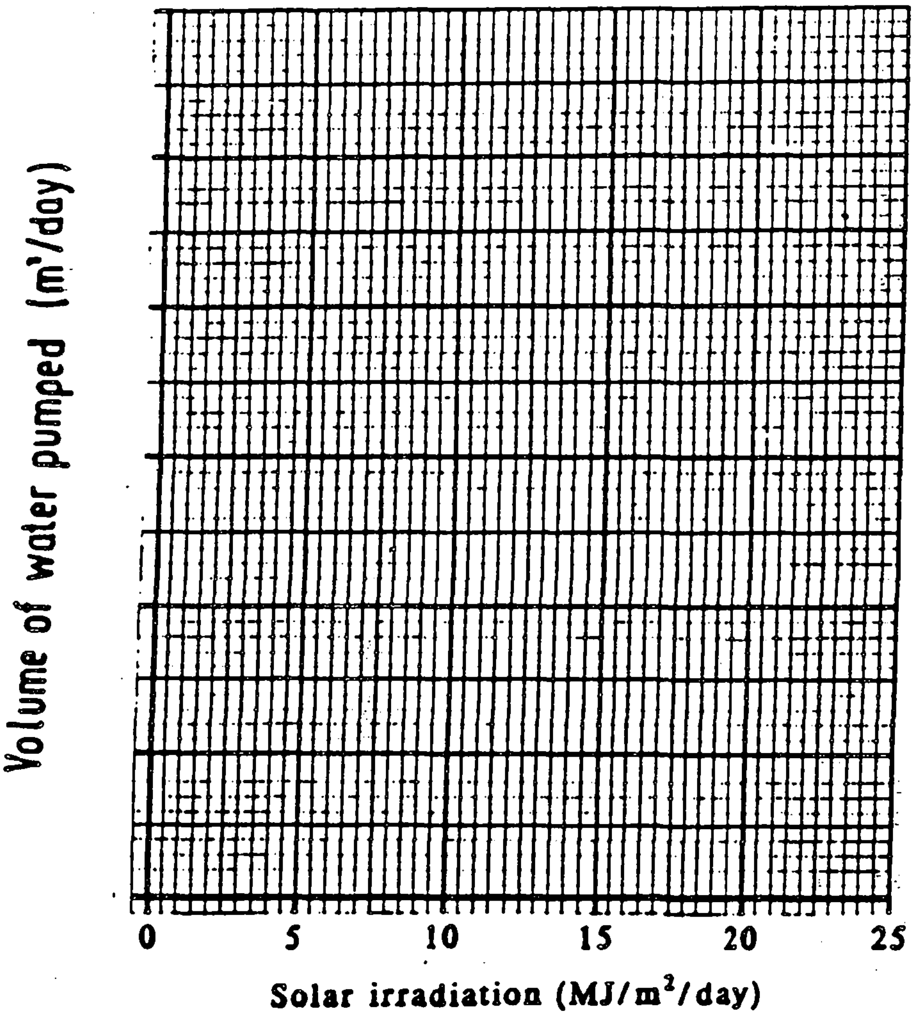


Figure 4.5 Volume of water pumped versus solar irradiation (The user should scale the y axis as appropriate to the solar pump under test).

4.3.3. Wind Pumps

Life-cycle cost (LCC) comparisons for windpumps require knowledge of the pump's water output as a function of windspeed, and an annual windspeed distribution for the site in question. The critical design month is the month where the ratio of water demand to average windspeed (the measure of wind energy availability) is the greatest. For drinking water systems, demand is usually assumed constant over the year, so the design month is the month with lowest average windspeed. For irrigation systems, determination of peak demand is more critical since it may fall in any month. Determination of peak irrigation demand is a function of several variables (evapo-transpiration rate, method of application, type of crop, time of application (day/night), etc.), and will not be dealt with here.

The short term test described below is used to generate the pump curve of potential output as a function of the windspeed at a given pumping head. The long-term test determines the monthly and annual output as a function of the monthly average windspeeds at the site, and this data is used in the life cycle cost analysis. A third optional test is also described, which can be used to calculate more precisely whether or not the wind pump is properly suited for the site where it is being tested.

The pump curve for a wind machine is a function of several variables, all of which are measured during the short term test. The mechanical output of a wind pump is a function of its tip speed ratio (lambda), which is the ratio of the velocity of the rotor tip to the instantaneous wind velocity. Wind pumps are sized such that the pumping load forces the wind pump to operate at or near its design tip speed ratio, where efficiency is highest. Wind pumps are chosen for a specific site so that they operate most efficiently at or near the site average windspeed.

While actual measurements vary for each of the tests, the following parameters must be measured in all cases: total pumping head (including elevation, friction and velocity head); the system descriptive parameters (pump installation level, air density (from site elevation), sucker or drive rod diameter, length, rising main diameter and length); the general site characteristics, such as wind exposure, trees, tower height and topography should also be noted.

The short term test should be performed during a period when the widest possible variation in windspeeds occurs, or if necessary, at several different times during the year in order to obtain values for the entire range of windspeeds likely to be encountered over the year.

Instruments

- totalizing cup anemometer, w/optional instantaneous reading (mounted on tower at wind rotor hub height and >2 but <8 rotor diameters away from rotor;
- integrating flow meter (positive displacement type if pulse flow, turbine flowmeter can be used if uniform flow). If turbine flowmeter is used, allow ten pipe diameters straight flow before meter for uniform flow profile;
- well dipper and in-line pressure gauge;
- stroke counter (this could be done visually and manually recorded), optional;
- stopwatch to measure time.

Procedure

The goal is to collect data pairs of short term water output as a function of windspeed over that short period. The data should be recorded at as wide a range of windspeeds as possible. At higher windspeeds the number of samples will be fewer as the winds are less frequent. Although water output is much higher at these high windspeeds, the winds are considerably less frequent, so that the volume of water pumped at these windspeeds will be small and the data are of less importance. These higher windspeeds are defined as speeds above the onset of wind pump furling (v_r), when the rotor is rotated out of the wind to prevent overspeed damage.

- At 10-minute intervals, record the anemometer windrun and flowmeter water output readings. Calculate the average "V" (windspeed in m/s) and Q (water flowrate in ls/sec).
- Note the start-up windspeed (v_2), the windspeed when the wind pump stops ($_{v1}$), and v_r should be recorded, if they occur.
- Record the number of pump strokes over the ten minute period.

Data Analysis

The data should be recorded and analyzed and recorded on the format sheets shown in Tables 4.8, 4.9 and 4.10 at the end of this section. Then, for each 10-minute test point, calculate:

- average windspeed = $(Wr_2 - Wr_1)/600$
- average flow rate = $(Q_2 - Q_1)/0.6$ (ls/sec)
- average head = $0.5\ (h_{s1} + h_{f1} + v_1^2/2g + h_{s2} + h_{f2} + v_2^2/2g)$ (m)

where Wr is the anemometer reading of windrun
Q is the flow meter reading in m^3,
h_s is the static head in meters,
h_f is the head loss in the pipes in meters, and
v is the velocity of the water at the pipe outlet and is given by:

$$v = 4Q/(pi \times d^2)$$

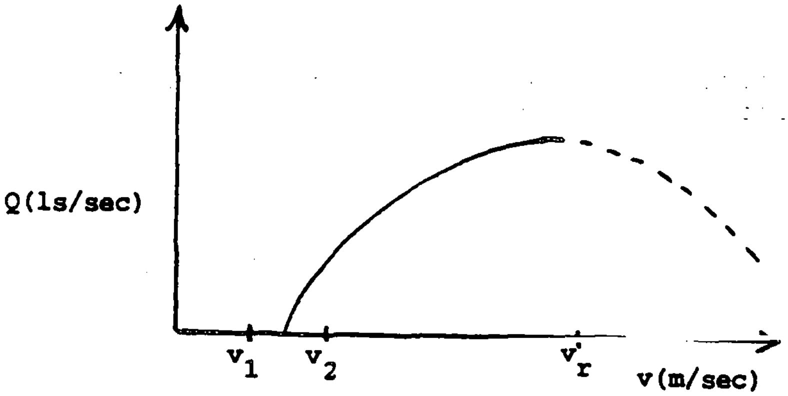
where Q is the flow rate in m^3/sec,
d is the pipe diameter in meters.

The subscripts 1 and 2 refer to the reading before and after the 10-minute period, respectively. Then calculate the hydraulic power using the equation:

hydraulic power (watts) = flow rate x pumped head x g
where g is the gravitational acceleration (9.81 m/s^2)

Interpretation of Results

Plotting the water flowrate/windspeed data pairs, the form of the pump curve will be as follows:

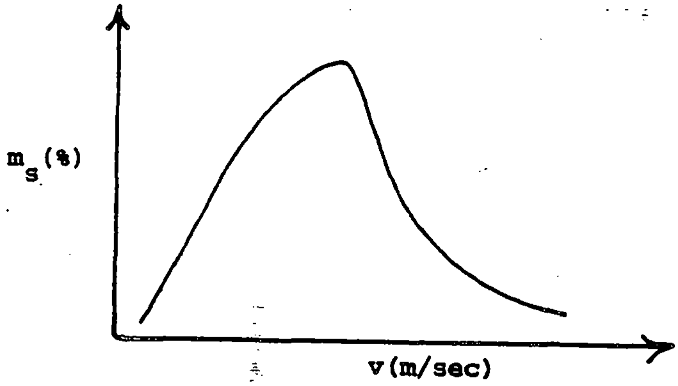


From the data collected it is possible to determine the overall system efficiency (n_s) as a function of windspeed, which should be between 10-25 percent. The (n_s) is defined as the hydraulic power required for lifting the water divided by the power available to the wind pump rotor. The formula is given by:

$$n_s = \frac{q \times rho_w \times g \times h_p}{0.5 \times rho_a \times A \times V^3}$$

where q = average water flow rate (ls/sec)
rho_w = density of water (kg/m^3)
g = gravitational constant (m/sec^2)
h_p = total pumped head (m)
rho_a = density of air (kg/m^3)
A = rotor swept area (m^2)
V = average windspeed (m/sec)

The 10-minute measurements described above provide enough information to calculate n_s and plot it as a function of windspeed. The resulting plot should resemble the following:



If the curve does not resemble that shown (or the efficiencies calculated do not fall between 0.10-0.25), check for errors in instrument calibration or system set up (such as wind pump misalignment over borehole, brake dragging, excessive water level drawdown, leathers in poor condition, misadjustment of the furling mechanism, etc.). Further, if the peak efficiency occurs at a windspeed significantly different from the site average windspeed, then the system is improperly loaded. The major factor affecting load is the pump cylinder size. If the average windspeed is less than the windspeed at peak efficiency, the wind pump is overloaded and a smaller cylinder or pump should be chosen to increase output. While the choice of cylinder can significantly affect performance (hence, the economic results), proper cylinder selection is beyond the scope of this paper. For a full explanation, consult references 14 and 15.

Once a short term test has established the pump curve, projections of longer term output (which are necessary for financial/economic analysis) under differing wind conditions at the site are possible. Anemometry data on the wind distribution at the site should be collected in 1 m/sec bins centered on the even values (i.e., 0.5 to 1.5 m/s values are placed in 1 m/s bin, and 3.5 to 4.5 values are placed in 4.0 m/s bin). This allows output projections to be made over the different seasons if the annual wind resource is known on a monthly basis. The total monthly water output can be calculated as follows:

The monthly output (in liters) then equals:

$$\text{Volume} = \frac{0.5 \times rho_a \times A \times \sum_{i=1}^{b} \frac{n_{si} \times V_i^3 \times \text{delta } t_i}{h_{pi}}}{rho_w \times g}$$

where rho_a = air density (assumed constant)
A = rotor area
n_{si} = overall system efficiency at the average windspeed of the i_{th} bin.
V_i = average windspeed of the i_{th} bin.
delta t_i = number of seconds in i_{th} bin.
h_{pi} = total pumping head at windspeed V_i.
rho_w = water density
g = gravitational constant
b = number of bins

If the actual distribution is not known, but the Weibull shape factor ("k") is known (see Refs. 2,3), it can be used to calculate the water output. If not, use an assumed shape factor equal to the square root of the site average windspeed. Knowing the average monthly windspeed for the site, determine the water output (ls/sec) at the windspeed from the pump curve. Multiply the "k" value by that output. Then multiply that value by the number of seconds in the month to get total monthly output in liters. Repeat for each month to get annual totals.

For the longer-term evaluation, daily instrument readings should be collected over at least a one-month period, and monthly total values should be collected for at least one year. The evaluation of cost factors requires keeping a log book record of operation and maintenance costs and repair costs for the wind pump. The purpose of these tests is to determine if system is performing as designed, and to gather data on the long term performance (and performance degradation). It requires the measurement of integrated flow and longer term (monthly and daily) average windspeed.

Monthly values should be tabulated after calculating average windspeed and determining the shape factor statistically or with Weibull paper. These values can then be compared to values calculated after determining the pump curve. This comparison allows an estimate of the accuracy of calculated values.

Optional Test

For a more complete characterization of wind pump performance, it is necessary to calculate several other parameters: the tip speed ratio vs. windspeed, and; the pump volumetric efficiency vs. windspeed. These can both be computed by recording strokes during the 10-minute test periods. A plot of lambda vs. windspeed provides, in a non-dimensional form, useful information about wind pump system design and performance. Average rotor speed in RPM can be calculated over 10-minute periods by knowing the gear ratio and the number of strokes over the 10-minute test interval. The tip speed ratio (lambda) is then defined as the ratio of the rotor tip speed to the windspeed, and can be calculated by:

$$\text{lambda} = 2 \times \text{pi} \times \text{rpm}/(60 \times V_{\text{wind}})$$

Cylinder efficiency (n_c) can be calculated from:

$$n_c = 4Q/(\text{pi} \times D^2 \times h \times S)$$

where D = cylinder diameter (m)
Q = measured water output (m^3)
S = stroke count
h = stroke length (m)

Cost Data Collection

As the ultimate goal of testing and evaluation is to generate information for the comparative financial/economic analysis, the reliability of the system, in terms of O&M and repair costs, must be recorded. For this purpose, a site log book is used. The site log book will contain all information relevant to the long-term performance of the wind pump. Each time the site is visited an entry in the log book is made. The entry will include: name; date; purpose of visit; adjustments or repairs made (materials used); time spent; vehicle used; other work performed on the same vehicle trip; number of workers involved; status of wind pump (operating or not). Relevant dates and times for failures and completion of repairs should also be included. Readings of all instruments for the long-term testing (windspeed, water output) should also be made at each visit.

The information contained in the log book should be distilled to include the following items: % availability for the wind pump; O&M trips--labor, transport, materials; repairs--labor, transport, materials; and a detailed description of failures and reasons if known. This will allow a firm accounting of the long term recurrent costs associated with operation of the wind pump.

Table 4.8

Wind Pump Data Collection Sheet (Front)

Wind Pump Site: ____________________

Bin	#samples	Q ave	V ave	S	% of total samples
0					
1					
2					
3					
4					
5					
6					
7					
etc.					

Table 4.9

Wind Pump Data Preliminary Analysis Sheet (Back)

Wind Pump Site: ________________________ **Name:** __________

Head: ________________ **Date:** _____

Time	Water Meter Q_1	Q_2	Anemometer Wr_1	Wr_2	Q_2-Q_1	Wr_2-Wr_1

etc.

observations of:

V_1 = ______m/s; V_2 = ______ m/s; V_r = ______ m/s

Table 4.10

Site and Equipment Description

Wind Pump Site: ____________________

wind pump make:

wind pump model:

rotor diameter:

tower height:

gear ratio:

cylinder size:

size of drop pipe:

length of drop pipe:

size of rod:

stroke length:

site elevation:

rest water level:

total head (including elevation):

4.3.4 Hand-Operated Pumps

The primary objective of short-term testing of hand pumps is to determine the amount of water that can be pumped in a day by an individual or group of individuals. The size of the group may be small for garden-plot size irrigation, and likely large for potable water supplies. Characterization of the technical performance of hand pumps (or animal traction pumps, discussed in the next section) is not as clear cut as the other pumps discussed thus far. There can be considerable variation in the operation of the same hand (or foot) pump used by different people, so a series of tests are suggested to obtain a clearer characterization of the performance of the pump under "standard" operating conditions.

The first test attempts to define an upper bound on the volume of water pumped and to define the efficiency of the pump. The remaining tests provide a sense of the realistic daily water output of the pump given the diversity of people likely to be using it.

Instruments

The following instruments will be used to make measurements:

- a positive displacement water flowmeter (pulsed flow). Although recommended, it is not essential. Alternatively, accurately calibrated containers for measuring up to 200 liters of water can be used.
- a stroke counter. Alternatively, the strokes can be counted visually and manually recorded.
- a spring balance to measure force;
- A pressure gauge or well dipper;
- a watch is necessary to time the tests.

The last requirement is a cross-section of users to act as the power source for the pump. This group should be sure to include women and children, depending on local practice. Often, women and children fetch drinking water, and men would do irrigation pumping. Although this introduces some subjectivity into the tests, a mixed group to reflect local custom is the best approach. A description of the group should be included with the test data. For drinking water supply, people normally just pump enough to fill up whatever container they have available. Therefore, the stroke rate and consequent water output per pumper will also be strongly dependent upon the prevailing container size (about 20 liters is a common size).

Several tests are proposed, based both on our field experience and influenced by the series of World Bank Rural Water Supply Handpumps Project reports. The first test is a fairly straightforward efficiency test. Tests 2 and 3 are to determine a maximum flow rate for the pumps. These provide an upper bound for performance, a measure of system efficiency, and an upper bound for a comfortable pumping rate in strokes/minute. For drinking water supply, considerable time is normally spent between users, as one retrieves their full pail and the next user places theirs and moves to the pump handle to start pumping. Test 5 is an attempt to quantify the effect of this lag time between users.

Procedure

Test 1: Efficiency

- measure the pumping head first.
- attach the load cell or spring balance to the end of the handle. Use a steady pull through the distance of handle travel from stop to stop, and record the average value of the force required.
- record the volume of water pumped and measure the handle travel distance.
- repeat the above procedure 10 times.

Efficiency is the ratio of the theoretical work necessary to pump the water to the work actually required:

$$n_s = \frac{\text{rho} \times V \times g \times H}{F \times D}$$

where n_s = overall system efficiency
rho = water density (kg/m^3)
V = volume pumped in one stroke (m^3)
g = gravitational constant (m/sec^2)
H = head (m)
F = force required at the end of the handle (N)
D = handle travel distance per stroke at the point of application of force (m)

Average the values of force and water volume output obtained above, and substitute into the above equation. Efficiencies should range from 30 to greater than 50 percent.

Test 2: Maximum output - Irrigation

- measure the time it takes a group of five men (or whoever normally does these chores) to pump 200 liters with the pump.
- use a flow meter or 200-liter drum set up in such a way that it need not be moved while 200 liters are being pumped.
- measure the time and number of strokes it takes for each person to pump 200 liters of water.
- repeat the test two times immediately with the same five pumpers so that 15 sample times are accumulated. If the average of the third set of times differs by more than 10% from the first, repeat a fourth time and use the last 15 samples to determine a maximum flow rate for the pump (ls/min).

Test 3: Maximum Output - Potable Water

The purpose of this test is to determine the maximum expected output for short term pumping, which is usally the way people pump drinking water. It is unreasonable to assume that this amount of water will be pumped on any regular basis, except under extremely heavy conditions of use. Most pumpers will pump no more than 20 liters (or whatever the standard container size), and will therefore pump at a faster rate than would be the case for people pumping continuously over a longer period. The users should be a mix a ten women and five children.

- Measure the time and the number of strokes it takes to fill each 20 liter pail; and
- average the time and strokes to calculate an average stroke rate and flowrate (in ls/min).

These tests should give an upper bound to the amount of water which can be delivered by the pump per day or per hour. The following two tests will then provide a more realistic value for the water that can be pumped per hour or day under normal circumstances.

Test 4: Average Output - Irrigation

During this test, five men will pump as much as they can comfortably in shifts of whatever duration they choose.

- operate the hand pump for one hour. During the one-hour period, note the lengths of shift chosen by each and at the end of one hour record the total water pumped.

- repeat the tests with a separate set of five pumpers. Then repeat the entire procedure on a different day.

- average this set of four hours output to arrive at an hourly rate of pumping in m^3/hour.

- calculate the average output from this test divided by the output in Test 2 to give the percent of maximum output that this average represents.

Test 5: Average Output - Potable Water

Pick a group of women and children (10 and 5) to fill 20-liter buckets.

- over a one-hour period, have each individual (in a particular order) fill a 20 liter container. Repeat the procedure in the same order.

- measure the total water pumped over the one-hour period. As before, repeat with another set of 15 pumpers.

- repeat the test on a separate day. Average these four sets of data to determine an hourly rate of pumping.

Although these tests will define a (somewhat arbitrary) hourly water output, the output under actual use conditions will depend on many social factors beyond the scope of these tests. Among these factors are the number of users, use of the water, the distance the water must be carried. These and other difficult-to-quantify variables will affect how much water each user will pump and how many hours per day the pump is used. The number of users may also even affect the individual pumping rate. For example, if there is a line waiting, the pumper would likely pump a bit faster than if they were the only user. It is very difficult to isolate these variables during field tests.

4.3.5. Animal Drawn Pumps (ADPs)

Draft power is a variable source of energy dependent on a large number of factors, including the species, age, training, physical development and temperament of the animals. Who owns the animals and whether they are used exclusively for pumping or have other tasks to perform are particularly important variables. All of these factors will affect the power output of the animals and the consequent output of the pump. The effects of some of these factors can only be measured over a very long monitoring period.

However, by using different teams of animals, some sense of the variation can be assessed. The normal draft power of animals ranges considerably, both in terms of the speed at which they work and the force they exert. Horses, for example, exert from 60 to 80 kgs at about 1 m/sec (1 Hp), and donkeys exert 30 to 40 kgs at about 0.7 m/sec (0.3 Hp). In addition, some work effort is lost as animals are assembled in teams. It has been estimated that 7-8% of the combined total output is lost when two animals are used as a pair. These losses increase as the teams get larger.

The primary objective of the short-term testing of ADPs is to characterize their performance as a function of the work input to the pump, water output and mechanical efficiency. The way in which the pump operation is organized in terms of labor and the provision of animals by the users can have a large impact on system economics. The human labor cost of operating the pump and the cost for feeding and care of the animals are the major recurrent costs, so determination of these costs is at least as important as the technical performance of the pump itself.

Test 1 is a measure of the pump's initial starting torque. This is the point of maximum required effort on the part of the animals during operation, and is usually the determinant of the minimum number of animals that must be used. Tests 2 and 3 examine the issues of work speed and number of animals.

Instruments

- water flow meter. Under some circumstances, it may be necessary to use a V notch weir (if using open pumps such as an Egyptian sakia discharging to an open channel);

- pressure gauge and/or well dipper;

- stopwatch for timing.

- load cells or spring balances are required to measure the force exerted by the animals;

- tape measure to measure the distance the animals travel and the moment arm (either by measuring directly or by measuring the radius of travel and the number of revolutions and calculating);

- depending on the type and speed of the pump, a tachometer. While usually measured in rpm, ladder pumps are measured in m/sec (optional).

- In addition, for longer term tests, the following will be required: pump-on timer (or reliable operator to manually record this information); total number of animals used; total number of animals used per sh [illegible] average length of shift;
  number of people r [illegible] rate the pump and
  the local labor ra [illegible] equired to round up
  and harness the an [illegible] e of the animals;
  age at training an [illegible] espan; the expected
  cost of veterinary [illegible] available); the
  harness cost and [illegible] ement intervals;
  food intake rate [illegible] s; the type and cost
  of food (if not [illegible] percent food
  foraged (by seaso [illegible] oods not foraged;
  the percent of th [illegible] animals which can be
  attributed to pum [illegible] asonally dependent).

testg

<u>Procedure</u>

Test 1: Starting Torque

This is purely a te [illegible] equipment, hence the use of the traction animals is not strictly required. However, animals can be used if desired.

- measure head before, during and after the test.

- connect the load cells or spring balances at all points of force and slowly start to exert force. Once the pump begins to turn, the force will decline to an operating point. Record the maximum values as the force increases.

- if more than one point (or moment arm) is used, sum the forces applied.

- repeat the test 10 times and average the values.

- if a lever arm is part of the ADP design, then multiply the average force by the lever arm to obtain a torque value (in N-m).

Test 2: Average Performance

- assemble and harness the draft animals.
- at each point of connection of the animals to the pump, place a load cell or spring balance. Be sure that the flow meter is in place and the head is measured. Begin operation of the pump.
- after five minutes of operation, take the first reading of head, water meter, force on each hitch, and location of the animals. Beginning at this point, at five-minute intervals, repeat the above readings so that a measure of water pumped, average force exerted, distance traveled (revolutions) and average head can be calculated.
- collect 25 sets of the above data so that 24 five-minute interval values (over two-hour period) can be calculated.
- change animals and repeat.
- on a separate day, repeat all of this procedure.

Data Analysis

Referring to the sample data collection sheet given as Table 4.11, the calculations to complete are:

1. Average flow rate: average the time and volume pumped columns and divide volume pumped by elapsed time to get flowrate (in m^3/hr).
2. Average horsepower exerted: average the summed forces and calculate the average speed traveled over the test duration from time and distance. Traction horsepower is the product of draft force and speed (in constant units).
3. Average efficiency: average the head and the summed forces times distance of each moment arm and sum the volume pumped:

$$n_s = \frac{\text{rho} \times V \times g \times hp}{\text{sum of } (\text{force} \times D)}$$

where rho = density of water
V = volume of water (m^3)
g = gravitational constant (m/sec^2)
h_p = pumped head (m)
D = moment arm length (m)

4. If the head is nearly constant, a plot of output as a function of draft horsepower can be computed and plotted. This provides a measure of the deterioration of animal performance and hence pump performance over a longer period of time.

5. It might also be useful to measure these quantities using both fresh and tired animals to compare the results. Presumably, rpm would decrease somewhat with the tired animals, which may well affect the efficiency of the pump element. Plot n_s (overall system efficiency) as a function of rpm.

Test 3 (optional):

Consider repeating Test 2 with fewer and more animals. This will provide a measure of the horsepower loss or gain with fewer or more animals and assist in determining if the optimum number of animals is being used.

Table 4.11

Sample Data Collection Sheet for ADP

Time	Head	Volume Pumped	Distance	Sum of Forces

4.4 Long-Term Test Procedures

The long term tests should be carried out in conjunction with the collection of socio/economic data discussed in Section 3.1. Essentially, the long term tests are extensions of the short term tests, and are primarily concerned with measuring the energy output (in terms of water volume pumped at a given head) in terms of the magnitude and distribution of the energy input to the system, in terms of fuel consumption (diesels), wind distribution (wind pumps), or solar radiation (PV pumps), etc.

The required long term measurement instrumentation is therefore (in addition to the site log book data discussed above);

- for diesels: water flowmeter, fuel flowmeter, and head measurement;
- for wind: binned anemometer, water flowmeter, and head measurement;
- for PV: integrating pyranometer, water flowmeter, and head measurement;
- for hand pumps: water flowmeter and head measurement;
- for animal traction pumps: water flowmeter and head measurement.

The data analysis procedures for the long term measurements and the procedure for extrapolating long term performance predictions from short term tests have already been presented in the short-term test sections, and will not be repeated here.

One general point should be mentioned here regarding the entire data collection and analysis procedure: Try to initiate data analysis as soon as possible after data collection. This will quickly point out any problems with either the pumping system or the data collection instrumentation. System efficiencies which do not fall within the reasonably expected range should prompt a careful investigation of the equipment. Early discovery of any anomalies in the data will not only lead to more reliable data, but will also eliminate potential problems resulting from incorrect equipment installations or design oversights.

5.0 COMPARATIVE EVALUATION

5.1 Technical/Economic Analysis

Life-cycle cost (LCC) analysis, which calculates the present worth of all costs, capital, operation and maintenance, and replacement parts over the lifetime of the system, is the standard method used for the financial and economic comparison of water pumping alternatives. The costs considered in this example analysis do not include the costs of well drilling or development, the water distribution system or storage tanks. In general, any system components which are common to both systems are not included in the costing.

Economic analyses attempt to place a "true" value (cost to the national economy) on various cost components, which is not necessarily what these costs would be in the marketplace. They attempt to quantify such real costs to the overall economy as the cost of government subsidies (hidden or otherwise), anomalies in the marketplace, imbalances in exchange rates or scarcity in the availability of foreign exchange. The costs of conventional energy sources such as diesel and grid electricity are often subsidized in many countries.

While the real economic cost of subsidies would not be taken into consideration by the average consumer, it should be taken into account by government planners who are concerned about the scarcity of foreign exchange, much of which is caused by importing fossil fuels.

The primary figure of merit calculated in the analysis is the annualized LCC per cubic meter of water delivered per unit head or the unit cost ($\$/m^3*m$). The energy required for pumping water is directly proportional to both the volume of water pumped and the head (or lift) through which it is pumped. This tends to normalize the performance of pumps at different sites and reflects the additional energy input required to pump water from a deeper borehole.

Although a benefit/cost ratio, net present value, or internal rate of return could also be used to evaluate the pumping options, the value of a delivered unit of water would have to be assumed (unless, for example, a specific government water tariff rate were being used), introducing yet another avoidable assumption into the analysis. A benefits section is nonetheless included for illustrative purposes.

A number of assumptions have to be made when performing the LCC analysis. Input variables such as the discount and real inflation rates, assumed (or measured) system lifetimes, shadow pricing of labor and foreign exchange, and expectations about the availability of capital all can dramatically affect the outcome of the analysis, either individually or synergetically. Sensitivity analyses should be performed to see what effects variations in the base level assumptions can have on the overall analysis.

Assumptions in the analysis should include the following:

- Separate analyses should be performed for private (financial) and public (economic) sector purchasers. If the government is assumed to be the primary purchaser of pumps, no import duties were assessed against the equipment. Import duties and restrictions can vary depending on the product being imported. For example, agricultural machinery is admitted duty-free. Determine under which duty category pumping equipment falls for the country in question.

- For financial analyses, loan interest charges (if any) must be included in the life cycle costs, as should any variations between official government wage rates and those applicable to the private sector. Interest rates should be analyzed for sensitivity. Depreciation and other tax-related considerations should be included where applicable.

- For economic analyses, shadow pricing of local labor, foreign exchange, and any other variable which the government choses to shadow price must be included in the analysis. Typical values in developing countries are 0.5 and 1.1, respectively, to reflect often abundant local labor and a scarcity of foreign exchange. Sensitivity analyses should be performed on these assumptions as well.

- Incremental training costs for pump technicians dealing with hitherto unfamiliar equipment should somehow be factored into the recurrent operation and maintenance costs of the systems. The magnitude of this incremental cost is often difficult to evaluate. In areas where the de facto standard is diesel pumping, the training expenses associated with the diesel pump maintenance infrastructure are sunk costs, but estimates of their value should nonetheless be included in the comparative evaluation of pumping technologies.

- The price of diesel or other conventional fuels often varies dramatically depending upon such variables as the distance from the prospective pump site to the nearest storage depot, whether the fuel is obtained through official or parallel market channels, and whether fluctuations in availability of fuel on a national or regional level have generated local scarcity of supplies. Such factors should be born in mind when doing analysis for a specific site.

- Salvage values for all equipment are most conveniently assumed to be zero. However, this can be varied to fit local practice as required.
- Calculations should be made in constant dollars rather than local currency where possible to avoid the difficulties associated with varying time-dependent rates of exchange.
- In order to give a feel for the division of upfront capital expenditure and long-term recurrent operation and maintenance costs, the ratio of installed capital equipment costs to LCC was calculated for each pumping system. This reflects the need for the availability of capital in each case. An alternative formulation would be the ratio of recurrent costs to LCC, which is simply the inverse of the above.
- Assumptions of discount rates and any real cost increases (or decreases) of equipment, labor, materials or fuel above the general rate of inflation rates should be taken to be six percent and zero percent respectively, reflecting fairly standard assumptions for public-sector financing. Local government figures for these assumptions can be used in subsequent analysis. Private-sector discount rates will be somewhat higher (16 percent interest rates for private-sector financing are common). Assumptions of lower discount rates tend to bias the analysis in favor of technologies with higher initial capital costs and lower long-term recurrent costs (i.e., PV and wind will seem relatively more favorable than diesel because of such an assumption).

The spread-sheets (Table 5.1, "Illustrative Example of Financial/Economic Analysis for Water Pumps," and Table 5.2, "Recurrent Cost by Year for Each System") presented on the following two pages list the components of a conventional LCC analysis. A graphical interpretation is given as well. These results are based on estimated data and should be viewed only as illustrative of the analytical process.

Table 5.1

Illustrative Example of Financial/Economic Analysis for Water Pumps

Value of Water ($/m3) = $0.30

System/Site	Solar#1	Solar#2	Wind#1	Wind#2	Dies.#1	Dies.#2	Dies.#3
Water (m3/day):	17	27	22	60	67	67	67
Total Head (m):	37	24	37	37	80	80	80
Vol*Head Prod.:	629	648	814	2220	5360	5360	5360
Amortiz.Period:	20	20	20	20	20	20	20
Discount Rate :	5%	5%	5%	5%	5%	5%	5%
COSTS							
Capital Cost :	$9,891	$6,556	$12,638	$23,016	$12,000	$12,000	$12,000
Installation M:	$80	$80	$262	$411	$1,000	$1,000	$1,000
Installation L:	$200	$211	$319	$913	$1,000	$1,000	$1,000
PW Recurr.Cost:	$4,728	$4,285	$4,945	$6,757	$68,062	$76,333	$93,861
Life Cyc. Cost:	$14,699	$10,921	$17,845	$30,184	$81,062	$89,333	$106,861
BENEFITS							
Annual Volume :	6205	9855	8030	21900	24455	24455	24455
Value of Water:	$1,862	$2,957	$2,409	$6,570	$7,337	$7,337	$7,337
PW of Benefits:	$23,198	$36,845	$30,021	$81,877	$91,429	$91,429	$91,429
Ben/Cost Ratio:	1.58	3.37	1.68	2.71	1.13	1.02	0.86
Inst.Cost/LCC :	0.69	0.63	0.74	0.81	0.17	0.16	0.13
Ann.LCC ($/m3):	0.1901	0.0889	0.1783	0.1106	0.2660	0.2931	0.3506
Ann.LCC ($/m4):	0.0051	0.0037	0.0048	0.0030	0.0033	0.0037	0.0044

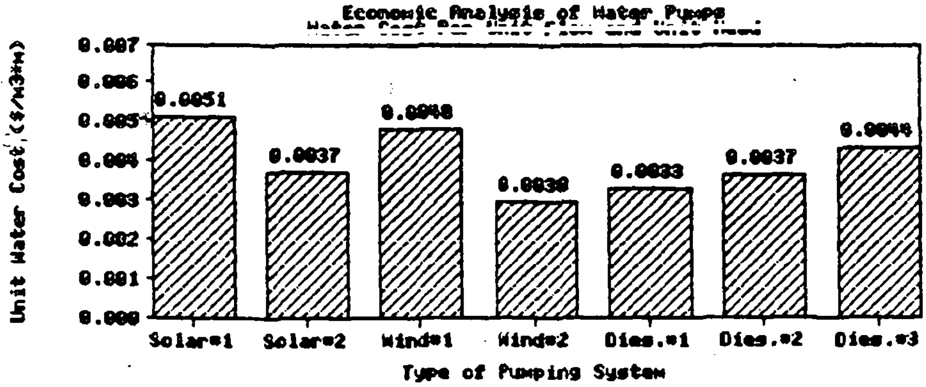


Table 5.2

Recurrent Cost by Year for Each System

Year	1	2	3	4	5
PV #1					
Pumper	$100	$100	$100	$100	$100
Annual O+M	$75	$75	$75	$75	$75
Non.Ann.Main.	$0	$260	$0	$260	$0
Annual Total	$175	$435	$175	$435	$175
PV #2					
Pumper	$100	$100	$100	$100	$100
Annual O+M	$75	$75	$75	$75	$75
Non.Ann.Main.	$0	$172	$0	$172	$0
Annual Total	$175	$347	$175	$347	$175
Windpump #1					
Pumper	$100	$100	$100	$100	$100
Annual O+M	$250	$250	$250	$250	$250
Non.Ann.Main.	$0	$0	$200	$0	$0
Annual Total	$350	$350	$550	$350	$350
Windpump #2					
Pumper	$100	$100	$100	$100	$100
Annual O+M	$400	$400	$400	$400	$400
Non.Ann.Main.	$0	$0	$200	$0	$0
Annual Total	$500	$500	$700	$500	$500
Diesel #1					
Pumper	$0	$0	$0	$0	$0
Annual O+M	$1,389	$1,389	$1,389	$1,389	$1,389
Non.Ann.Main.	$0	$0	$4,221	$0	$0
Annual Total	$1,389	$1,389	$5,610	$1,389	$1,389
Diesel #2					
Pumper	$0	$0	$0	$0	$0
Annual O+M	$1,389	$1,431	$1,474	$1,518	$1,563
Non.Ann.Main.	$0	$0	$4,221	$0	$0
Annual Total	$1,389	$1,431	$5,695	$1,518	$1,563
Diesel #3					
Pumper	$0	$0	$0	$0	$0
Annual O+M	$1,389	$1,431	$1,474	$1,518	$1,563
Non.Ann.Main.	$0	$0	$4,221	$0	$12,000
Annual Total	$1,389	$1,431	$5,695	$1,518	$13,563

The labor charges have been broken out for convenience in shadow-pricing both labor and imported materials. The economic analysis differs from the financial only in that the former shadow-prices local labor using a 0.5 multiplier, and imported materials and components with a 1.1 multiplier. No import duties, depreciation, or interest charges were used for this example. Again, costs that are common to all of the systems (such as borehole drilling charges) were not included in the cost comparisons.

The categories in the spreadsheet are as follows:

- There are seven systems analyzed. These are typical cost systems for solar, wind and diesel installations, (although they are not necessary similarly sized.) The upper section of the spreadsheet gives the technical performance summation in terms of annual average water output (the daily average in terms of m^3/day) and the total pumped head. The volume*head product is also shown, giving an indication of the magnitude of the hydraulic energy demand. The assumed amortization period and discount rate are then listed.

- initial capital cost--including such items as the major system components (for PV: modules, support structures, batteries, controller, lights, etc; for diesel: pump, engine, fuel storage, pump house, etc.) as well as wiring, crimp connectors, cable ties, etc.; for wind, the rotor, head, drop pipe, sucker rod, tower, etc;

- installation cost--all labor and transportation costs incurred during the installation;

- present worth (PW) of recurrent costs--present value of all expected operating and maintenance costs over the lifetime of the system, including any spare or replacement parts or labor and transportation charges which will be incurred;

- LCC--present value of all costs incurred in the purchase, installation, operation, maintenance and repair over the system lifetime;

- installation/LCC cost is the ratio of installed capital cost to total LCC and is a measure of the capital cost intensity of each system.

- the next section gives the benefits: annual volume of water pumped; the value of that water at the rate assumed ("Value of Water" near the top), the present worth of that value calculated over the amortization period, and the Benefit/Cost Ratio based on that assumption.

- annualized LCC (ALCC)--the LCC divided by the present worth factor for the discount rate and system lifetime assumptions, and divided by the estimated annual volume of water pumped. This is often more conveniently termed the "Unit Cost".

The graph simply graphically presents the annualized life-cycle (unit) cost calculated for each of the systems. Costs were separated into two categories, capital and recurrent. The rows in the recurrent cost spread-sheet are as follows:

- Pumper--direct labor charges from system day-to-day operation;
- Annual O&M--annual recurrent cost of materials used for routine operation and maintenance, and transportation charges since the shadow-pricing of labor does not affect transportation costs; and annual recurrent labor and transport charges and maintenance;
- Non-Annual Maintenance--non-annual recurrent costs for expected maintenance and repair procedures, such as cylinder replacement on a five-year basis and the replacement of down-hole piping every 10 years; this includes associated labor and transport charges;
- Annual Total--total recurrent costs for each year, the sum of the figures in the first four rows.

It has been mentioned that the value of a unit of water is somewhat arbitrary. While governments often collect a fixed tariff per unit volume for water pumped by government-owned equipment, this tariff is usually heavily subsidized and scarcely covers operational costs, let alone the capital equipment replacement cost or maintenance and repair. Therefore, the benefit analysis must of necessity rely on a rather arbitrary assumption of benefit worth when speaking of drinking water supplies.

This is not the case when dealing with irrigation. There is a definitely quantifiable value which can be assigned to the crops grown because of the irrigation provided. While this can sometimes be difficult to evaluate, it is nonetheless a real, not arbitrary value. The purchase of an irrigation system must result in greater life cycle benefits (in terms of the incremental value of crops grown) than life cycle costs, or it is not a reasonable investment. The same can not necessarily be said about potable water supplies.

In addition to the information collected in the log book that relates to economic and reliability issues, it is necessary to compile a base of cost and policy information on which a complete financial and economic evaluation can be made. These fall into four areas, equipment, labor costs, transportation costs and economic policies.

Within the first of these is all information pertaining to the cost of pumping equipment (including shipping and taxes), all piping, rods, cylinders, cement, and so on required for system installation. (For an example of such a listing, see Reference 6). Included in this should be the current exchange rate in the country of interest.

Labor costs should also be quantified. The range of government rates for supervisory, skilled and unskilled labor and the government policy on allowances (for per diem, etc.) should be included. Also included should be private-sector labor rates as they may vary significantly from government pay scales and may have a significant impact on the economics of public- versus private-sector installations.

Transportation costs are difficult to quantify when wear and tear on vehicles is included (as it should be). Some reasonable values for transportation costs are necessary as they can play a significant role, particularly in the recurrent costs of system operation. In many cases, government economists have set rates for the cost per km (or mile) of various types of vehicles over various types of roads. Where available, these should be recorded.

Government labor and economic policies can have a significant impact on the relative economic performance of various pumps. This is particularly true of labor shadow pricing policy, but also true of other shadow pricing policies as well. Also, import duties and taxes play a role. These should all be determined and used where appropriate. Labor policies can also play a significant role in the economic and financial analysis. If drivers are required for government vehicles or pumpers must be hired full-time for pumps, the financial and economic costs are affected, sometimes critically. These policies should be noted and considered in the analysis.

Standard economic assumptions such as discount rate and the commercial interest rate should be determined from government economists or commercial bankers.

5.2 Social/Institutional

This section will be completed following discussion of the issues listed in section 3.1

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