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HANDBOOK FOR COMPARATIVE EVALUATION OF TECHNICAL AND ECONOMIC PERFORMANCE OF WATER PUMPING SYSTEMS

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The whole effort was initiated by Sam Schweitzer, Weston Fisher, and Janine Finnell (all employed by or contracted to USAID). The basic outline for the Handbook was discussed at a workshop held in Sussex in 1986 where staff participated from various international donor agencies, institutes and Government Ministries. A draft version of the Handbook was presented at a conference in Botswana, organized by the Government of Botswana and USAID.

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On behalf of everyone involved in this effort we wish to propose and encourage the use of the handbook in the field. We hope it will be used on a trial basis. Based on actual experiences it is to be refined as a tool in improving the technical and economic performance of pumping systems in the developing world.

We invite you to send your comments and suggestions for its improvement and on its usefulness under real field-test conditions to CWD (address below).

November 1988

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PREFACE

This Handbook aims to be an instrument in standardized collection and processing of data on performances of water pumping systems in the field.

The Handbook results from efforts by various donor agencies and many individuals; its objectives and set-up imply various compromises and many possibilities for further discussions. Issues still under discussion for instance, include the methods of incorporating different benefits, the methods for discounting water output over the project length, types of cost to be incorporated, etc.

The reader should be aware, that a number of assumptions and simplifications had to be made (equal benefits, omission of common cost, not discounting of the water output) and that the resulting "cost per cubic meter" therefore is not a real cost of water. It rather is a relative cost indicator that can be used for comparison of different systems.

However, given the considerable time which has passed since composing, reviewing and redrafting the various chapters, the editors feel that "field testing" of the Handbook would now be appropriate. Errors or ommission must come to the fore once this Handbook is disseminated among users of windpumps and persons knowledgeable about windpumping. We actually look forward to receiving supportive criticism and suggestions which may be included in later versions of this publication.

The present distribution of the Handbook has two purposes. First it means to improve the actual data collection on technical and economic performances of water pumping systems. Secondly it is meant as a trial phase for the Handbook as such, its lay-out, the usefulness of the recommended methods, procedures, sheets, etc.

Simultaneaously with the release of this Handbook, CWD and the Worldbank have agreed on preparing for publication two other publications on windpumping. One of these publications is the "Wind Pumping Handbook", patterned after the "Solar Water Pumping Handbook" produced by Kenna and Gillett (1985).
The section on "testing of windpumps under real field conditions" in the Wind Pumping Handbook is actually taken from the relevant sections of the present Handbook.
We trust that these publications will meet with interest and will assist in clarifying some of the more critical issues involved in disseminating windpumps.

EXECUTIVE SUMMARY

This Handbook describes a field evaluation methodology for six selected water pumping techniques. Later extension to other techniques may be done relatively easily. Standardized and uniform procedures are given for the different pumping techniques in order to enable comparative evaluations.

The methodology for evaluation of pumping systems basically consists of five steps, four of which are dealt with in this Handbook.

1. Through Data collection at the start of the tests the technical system and its environment are described.
2. During the Short term testing phase technical data are gathered over a period of a few days only in order to assess the technical condition of the pumping system.
3. During Long term testing a much broader spectrum of data is gathered over a longer period of time (preferably half a year to one year). The information to be collected relates to a variety of operating performances of the systems, such as the experiences of the owner and operator of the system, costs, reliability, need for maintenance and output, rather than to "technology" only.
4. An Economic evaluation follows the above tests, using the information obtained during Long term testing. It further involves the collection of information on markets and governmental policies.

As a fifth step the effects of the water pumping system on, and its interrelations with, its social, ecological and institutional environment will have to be evaluated. This step is not yet included in this version of the Handbook.

The Handbook is intended to be used by:
- technical staff of projects and institutes when performing tests, making observations and processing data;
- staff at management level or economic experts who will carry out the subsequent economic evaluations.

The results of the evaluations for which procedures are described in this Handbook should contribute to:
- improving existing systems by providing data on actual field performance that may be compared with the predicted performance;
- improved sizing and selection of new systems;
- feedback to suppliers of pumping systems and subsequent improvement of systems and components.

The Handbook has primarily been conceived as a "how to" document; precision and completeness have been sacrificed for the sake of clarity and usability.

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1. OBJECTIVES AND SCOPE OF THE HANDBOOK

1.1. BACKGROUND AND JUSTIFICATION

Many agricultural and other development projects include significant water pumping or water management related components. Therefore it is necessary that field data on technical and economic performance of water pumping systems are available. Such data will be needed for e.g.: improving the performance of existing water pumping systems, selection of new pumping equipment, improving maintenance in water supply schemes, improving water management schemes and reducing their cost, etc..

The present Handbook aims to be an instrument in these processes, by providing a methodology for standardized collection and reduction of technical and economic field data on water pumping systems. The given procedures are uniform for different pumping techniques in order to enable comparative evaluations. As such the present Handbook covers only part of the overall assessment process; it not includes, for example, socio-institutional analyses.

The Handbook responds to a growing recognition among international field workers and agencies of the present limited availability of data on field performances of various pumping systems and the lack of uniformity in collecting, evaluating and presenting field data. It was felt that uniform practical guidelines would be particularly useful in developing and analyzing such information. A uniform methodology would improve comparisons of data among donors, PVOs, NGOs and government institutions. Though various attempts had already been made at developing evaluation guides for different types of pumping systems, a major effort is still required to integrate and adapt the existing guides to the specific problems of comparative assessment of alternative systems. This Handbook aims at filling this gap in giving standardized test practices and standardized procedures for data analysis.

The present version originates from a series of consecutive activities in which a large group of experts has been involved. In 1985 USAID organized a meeting in Washington, D.C. on priorities and cooperation in improving water pumping and water lifting in Africa. The participants, covering a broad range of expertise and institutions, ranked the preparation of a Handbook among the most important actions for the near future.

The methodology was extensively discussed during a workshop in West Sussex, England (1986). The participants included many representatives from international and other donor agencies. Following this workshop several international donors, including

CIDA-Canada, FAO, GTZ-Germany, DGIS-The Netherlands, and USAID, produced a draft Handbook. This draft was presented at the Botswana Conference on Water Pumping and Water Lifting in April 1987. The present edition is derived from this draft, drawing on the discussions during that Conference as well as from various other comments. Moreover the sources of literature as listed in Chapter 7 have been used.

In its present form the Handbook will be applied and its procedures tested in a number of implementation projects. Using these experiences, a final version will be prepared in the course of 1989. See also Section 1.4.

1.2. OBJECTIVES AND SCOPE OF THE HANDBOOK

As stated, this Handbook aims to offer a standardized and uniform methodology for collection and reduction of technical and (socio-) economic field data on a range of different types of water-pumping systems. Though it has merits on its own in providing standard methods for data collection, the Handbook should mainly be considered an instrument in the generation of relevant data for a series of activities, e.g.:

* it will assist in improving existing systems by providing data on actual field performance, that may be compared with the predicted performance.

* it will assist in sizing and selecting new systems. Though the Handbook on its own is <u>not</u> intended as a guide for selection of pumping systems it will generate field data, that can be used in the process of selecting a pumping system.

* it may be used as a diagnostic tool by providing data on performance.

* it may serve to provide feedback to suppliers of pumping systems on actual field performances of their systems and thus be instrumental in improving the designs.

The target group of this Handbook basically consists of two types of people:
- The people who are going to use it when performing tests, making observations and reducing data;
- Those who will carry out the subsequent socio-economic and socio-institutional evaluations.

The former group will usually consist of technical staff of projects or institutes. The latter more likely will consist of staff at management level or (socio-)economic experts. Obviously the results of the activities will be of interest for a broad user-group (users/owners of the pumping systems, project management staff, regional planners, national planners, international planners, donor organizations, etc.).

It is not envisioned that the handbook will necessarily be used by end-users themselves, but rather by institutions, agencies, etc. Neither is the Handbook meant as a training manual; its users will need a certain minimum level of knowledge on water lifting systems, instrumentation, etc. The use of the Handbook will be strongly enhanced if it is included into a programme of training and strengthening of institutions involved in water pumping programmes.

The Handbook has been conceived as a "how to" document; precision and completeness have been sacrificed for the sake of simplicity and usability. In some cases only orders of magnitude and trends may be expected from the tests and evaluations. For practical reasons the present Handbook is limited to six widely used pumping techniques (see Section 2.1.). However, it will be relatively easy to extend the recommended procedures to a wider range of water pumping techniques in the future.

The primary stimulus for preparing this Handbook came from agricultural uses of water (especially irrigation) in Africa. However, the material can also be applied to projects involving other water uses. This is important because projects often involve multiple water uses.

1.3. KEY TO THE USE OF THE HANDBOOK

In Table 1.1. all phases of a general evaluation process are depicted in a chronological order. As stated the present Handbook only covers the first four of these.

The evaluation procedure starts off with a <u>System Description.</u> During this activity the system in its "as-found" condition is described. System Description is dealt with in Chapter 3 of the Handbook.

The next step, treated in Chapter 4, is the so-called <u>Short Term Test</u>. This test primarily provides technical performance information about the pumping system (i.e. the prime mover, the transmission and the pump). Moreover it is a diagnosis of the technical condition of the system at the start of the evaluation that can be repeated during the testing period as often as desired, e.g. after repairs, overhauls or when the pumping system seems to fail. As a reference, performance data from the manufacturer or designer may be used. Where possible the Handbook indicates the ranges within which values of important parameters normally lie.

TABLE 1.1. Subsequent phases of evaluation programme.

Main activity/ Chapter	Activity	Output
	PRESENT HANDBOOK	
Data collection at the start of tests	Data collection before tests	System definition and description
Short Term Testing	Pre-test inspection Measurements and data collection Data reduction Decision: proceed with evaluation, yes/no	Performance measurements Assessment of condition of technical system Comparison with performance data of manufacturer or standard values
Long Term Testing	Measurements and data collection Data reduction	Long term overall system performance Assessment of system quality Assessment of system costs
Economic evaluation	Data collection Evaluation	Cost per m^3 water pumped Cash flows
	YET TO BE PREPARED	
Socio-cultural and Institutional issues	collection of background information	Assessment of socio-institutional aspects of the use of the system

If the Short Term Tests do not generate contra indications, such as e.g. obvious malfunctioning of the system, a Long Term Test is the next step in the procedure. During a longer period of time (at least one year) information on system performance, operation, quality and costs will be gathered. Long Term Testing produces information on the long term overall system performance expressed in values averaged over longer periods of time, e.g. a water volume pumped of X m^3/month at an monthly average irradiance of Y Watt/m^2.
Long Term Testing also includes recording chronologically all relevant occurrences during the test such as system breakdowns, repairs, running dry of the well, expenses for operation and maintenance of the system, benefits, etc..
Long Term Testing is dealt with in Chapter 5.

Finally Chapter 6 of this Handbook describes an Economic Analysis. Based on the information obtained during the Long Term Test, together with other socio-economic indicators (e.g. interest rates, shadow premiums, exchange rates for foreign currencies, inflation rates, etc.), this evaluation leads up to a price per m3 water pumped. It analyses the impact of the pumping system both from a user (financial analysis) and a governmental (economic analysis) point of view.

To introduce the reader into the general ideas behind this Handbook Chapter 2 explains how the boundaries of the system under observation are defined and how they expand when proceeding in the subsequent phases of the evaluation. It also gives suggestions on how to organize the tests, on manpower required and it prescribes the measuring equipment to be used.

In Chapters 3,4 and 5 many parallel texts occur for the six pumping techniques dealt with in this Handbook. For an easy access these parts are marked by small pictogrammes at the top of each page. A reader interested in the evaluation of e.g. a hand pump system can jump over the pages with other pictogrammes without missing relevant information. Pages without pictogrammes generally refer to aspects relevant to all six techniques.

1.4. FOLLOW-UP OF THE PRESENT EDITION OF THE HANDBOOK

The distribution of this edition of the Handbook has two objectives:

1. It is the intention of the authors and the editors to gain experience with the use of this book in the field. We therefore urgently invite users to give their comments as to the practicality and form of this edition.

2. Moreover the methods laid down in this Handbook are aimed to a standardized data collection on alternative pumping systems under field conditions. The data gathered are primarily meant for local use. However it is also important that these data be collected on one central point for the sake of comparison, analysis and distribution of results. It is hoped that the results of such analysis could be made available again in improving water use and management in developing countries.

For these reasons the user is kindly requested to mail comments upon the Handbook as well as a copy of the data collected to the editors:

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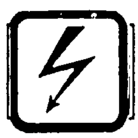
2. SYSTEM DEFINITION, METHODOLOGY AND EQUIPMENT

2.1. SYSTEM DEFINITION

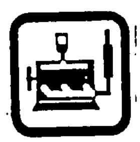
This Handbook deals with the evaluation methodology for six selected pumping techniques. This does not imply that these techniques would always belong to the "top six" for applications anywhere; it is merely a selection of widely used techniques made at the start of the preparation of this Handbook. Extension to other pumping techniques will be relatively easy in a later phase.

The following pumping techniques will be considered:



1. GRID CONNECTED ELECTRIC PUMPS

   In these systems a one or three phase electric motor, powered by the electrical grid, drives a water pump (e.g. centrifugal pump, mono pump, piston pump). Motor and pump may also be one integrated single unit.



2. FUEL ENGINE PUMPS

   A diesel, petrol or kerosene engine is mechanically coupled to a pump.

3. SOLAR PUMPS

   These systems consist of a photovoltaic (PV) array that generates DC (Direct Current) electric energy. The PV array is connected to an electric pump via a power conditioner (DC-AC converter and voltage control). The system may be equipped with a battery storage system (for power conditioning capability). It usually contains a water storage tank.

4. MECHANICAL WIND PUMPS

   In these systems a windrotor is coupled mechanically to a piston pump, a centrifugal pump or a mono pump. Generally the system also includes a storage tank to get through periods of low winds.

5. HAND PUMPS

This group comprises all human powered water pumps including "hand" driven pumps. Examples are the kangaroo pump and the flywheel pump.

6. ANIMAL TRACTION PUMPS

All types of animal driven pumps are included.

The tests and procedures are described basically for pumping systems without back-up systems. If a pumping system including a back-up system is to be evaluated, there are two possibilities:

1. If the back-up system is very small and is only rarely used it should be neglected. Describe its effects qualitatively in the logbook.
2. If the back-up system produces a substantial output compared with the main system, it is recommended to carry out a simultaneous evaluation of the back-up system.
   In most cases the back-up system consists of a diesel pump or a hand pump. The corresponding chapters (4.2., 5.2. and 4.5., 5.5., respectively) can be used accordingly.

2.2. SYSTEM BOUNDARIES

For the various types of tests and evaluations the boundaries of the system under consideration will vary. In Figure 2.1. the pumping system and its environment are depicted, showing sub-systems, inputs, resources, outputs and components. During the tests a number of flows (material, energy, money) and characteristics of (sub-)systems (efficiency, quality, etc.) are measured or observed. The quantities to be measured or registered are shown in Figure 2.2.

During Short Term Testing the emphasis lies on the technical performance of the pumping system. Only the water pumping function is considered. Therefore during Short Term Testing the system only includes the pumping system as represented by the central block in Figure 2.2. (prime mover, transmission and pump). Flows of energy and material are basically measured at the boundaries of this system. The quantities to be measured are marked by an "S" (Figure 2.2.).

During Long Term Testing the system boundaries are chosen wider and include, in addition to the elements already mentioned under Short Term Testing, aspects of operation, maintenance, infrastructure and end-use of the water. Also included are resources (water, energy, manpower, materials and money) and the output of the system (not only in terms of water flows in

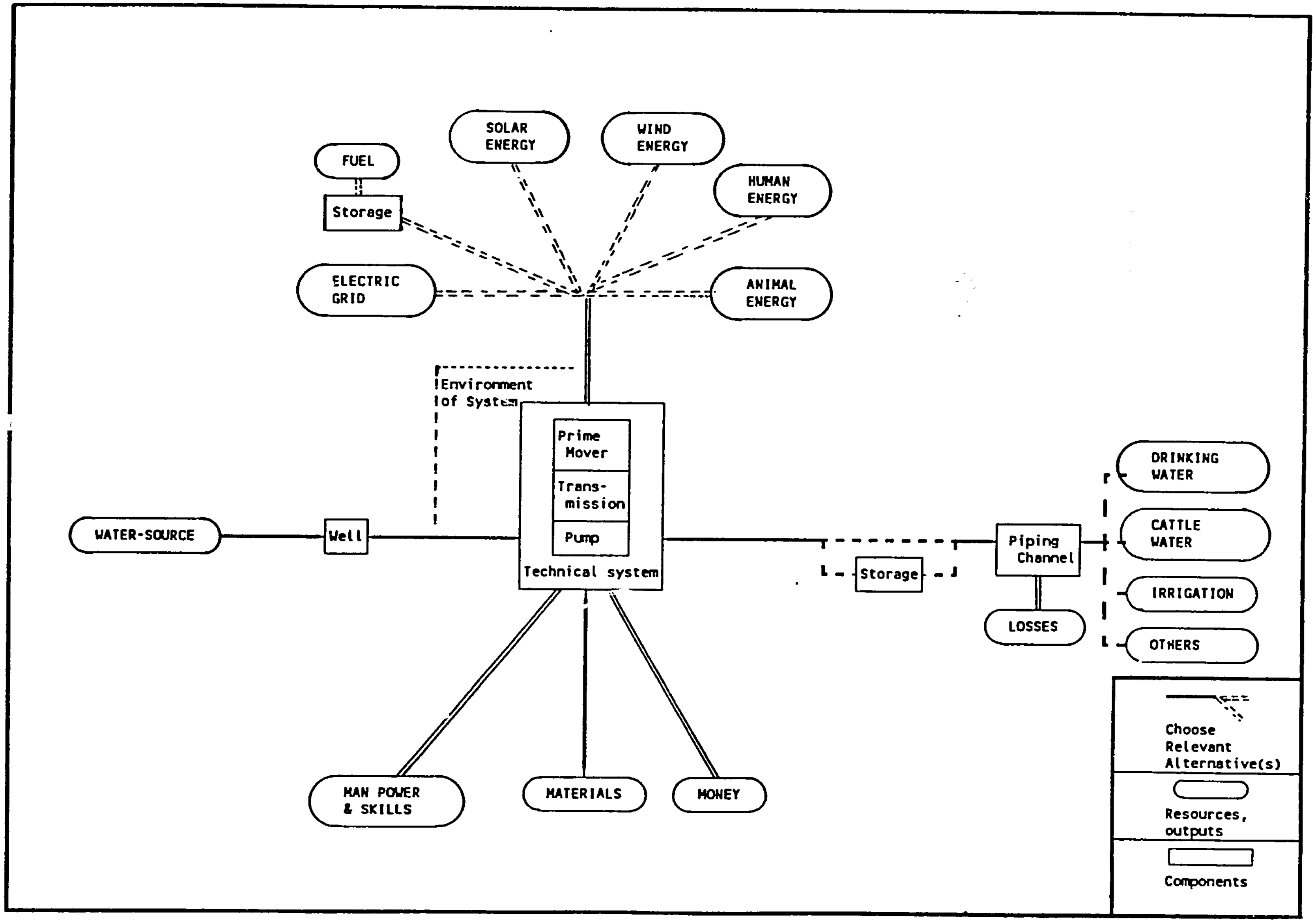


Figure 2.1. Pumping system in its environment.

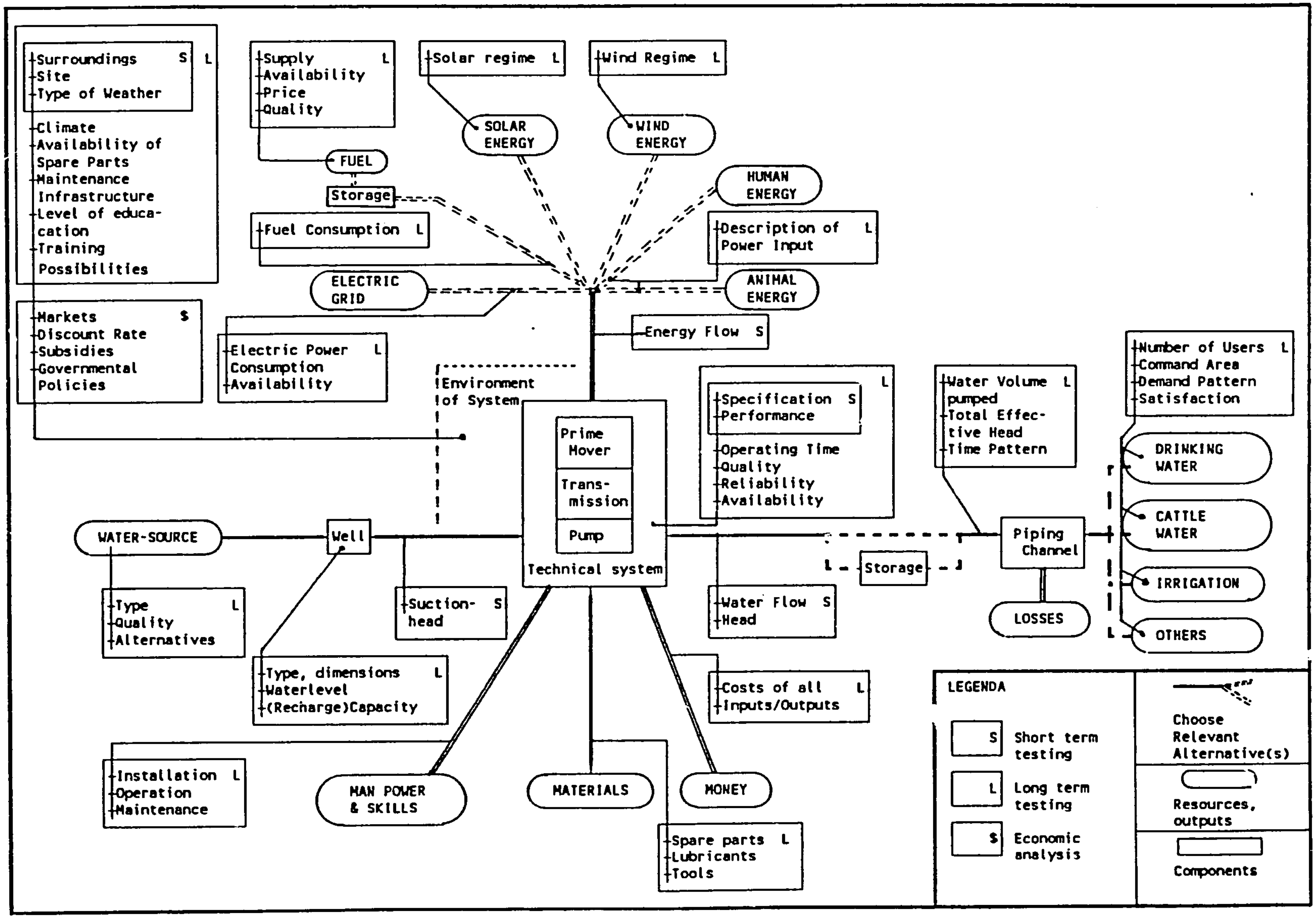


Figure 2.2. Pumping system in its environment and quantities to be measured or monitored.

[m^3/s], but also in terms of availability of water in relation to the need for water).
Some pumping systems are equipped with a water storage tank in order to compensate for large energy input fluctuations. From the above it will be clear that in such cases during Long Term Testing the storage tank is to be included in the system under observation; it has a predominant effect on the availability of water. Consequently the water volume actually used will be measured behind the storage tank. Additionally the water volume entering the storage tank will be measured for solar and wind pumps. This represents the water volume pumped; compared to the water volume actually used it gives information on the effect of the storage tank on the performance of the system.

The extra quantities to be measured or monitored during Long Term Testing are marked by an "L" (Figure 2.2.).

In the Economic evaluation the system boundaries need to be widened still further: The "economic environment" of the pumping system should be added to the system under observation. The related quantities are indicated in the blocks marked by an "$" (Figure 2.2.).

2.3. METHODOLOGY

The methodology for evaluation of pumping system performance basically consists of five steps, four of which are dealt with in this Handbook.

Through <u>Data collection at the start of the tests</u> the technical system and its environment will be described. This should be carried out by a technician.

During the <u>Short Term Testing</u> phase technical data are gathered over a period of only a few days. It is preferred that these tests are also carried out by skilled technicians, who will also be able to do the subsequent data reduction and analysis in this phase.

During <u>Long Term Testing</u> relatively little work has to be done, be it over a much longer period of time. The information required strongly relates to the experiences of the owner or operator of the system (costs, reliability, need for maintenance, etc.) rather than to "pure technology"; Long Term Tests will be executed while the pumping system is being used and water is supplied to its specific end use.
The owner/operator will be the major resource person during Long Term Testing. He takes daily care of the pumping system and he will be asked to keep a regular logbook of all relevant data. The owner/operator needs to be properly motivated to perform this task and some training might be required to ensure proper logbook keeping. This is an important issue, because an owner/operator will often not be convinced of the need and usefulness of the data to be collected or of the accuracy

required. Also it may interfere with his own priorities. Establishing a contract with him might be a solution. Regular visits by the team leader and/or the technician for cross-checking the accuracy and relevance of the data will be required to assess which logs are properly being kept and to assure that inadequate records will not be included in the data analysis.
Other resource persons may be the mechanics/technicians taking care of maintenance and repair and extension staff providing guidance/advice in the use of the water. Such persons may fill in relevant information in the logbook and comment on the quality and functioning of the system.

Generally the data reduction and analysis of the Long Term Tests will not be done by the tester (the owner or operator). It is recommended that the technical part of data reduction and analysis is performed by the technician involved in the Short Term Testing. However, it might be very motivating for an interested tester to involve him in part of the data handling as described in Chapter 5. Always be sure that in such cases all original data are handed over to the person in charge of the final evaluation in order to prevent "unwanted data reduction". The reduction and analysis of the non-technical data should be done by a socio-economist following the procedures of the Socio-economic evaluation.

Chapters 4 and 5 extensively prescribe procedures for data gathering during Short and Long term Testing and describe the use of data sheets and check-lists. All information is to be recorded in the logbook.

An <u>Economic Evaluation</u> follows the above tests. The evaluation uses the information gathered during Long Term Testing. It further involves the collection of extra information of a specialist nature requiring insight in markets and governmental policies. Therefore this information will have to be collected by the socio-economic expert in charge of the final evaluation.

As a final step the effects of the water pumping system on and the relevant interrelations with its social, ecological and institutional environment will have to be evaluated. This step is not described in this Handbook.

2.4. PERSONNEL QUALIFICATIONS

Table 2.1. gives a survey of the staff required for the system evaluation. Because this Handbook is not a training manual, it is assumed that the users are sufficiently educated in the related fields.

For the technician the following skills are required:
= general knowledge of water lifting systems,
= experienced in measuring techniques and in the installation, calibration and use of measuring instruments,
= experienced in simple data reduction techniques.
It is recommended to appoint someone as team leader during the testing activities. Because it is the task of the economist to elaborate all data it might be appropriate to charge him with this task. An important task of the team leader is to organize additional training for the technician and owner/operator, if necessary.

TABLE 2.1. Personnel requirements

Activity	Handbook Chapter	Qualification
<u>Data Collection at the start of the Tests</u>		
General information	3.1 to 3.4	Team leader
System description	3.5.x.*)	Technician
Description of the site	3.6.x.*)	Technician
<u>Short Term Testing</u>		
Data collection	4.x.2.*)	Technician
Technical data reduction	4.x.3.*)	Technician
<u>Long Term Testing</u>		
Daily observations	5.x.2.*)	Owner/operator
Periodical visits to the site		Team leader
Preliminary data reduction	5.x.3.*)	Technician
<u>Economic Analysis</u>	6	
All activities		Economist

*) In the section numbers given in this Table "x" indicates the various pumping techniques:
x = 1 : Grid-connected electric pumps
x = 2 : Fuel engine pumps
x = 3 : Solar Pumps
x = 4 : Mechanical wind pumps
x = 5 : Hand pumps
x = 6 : Animal traction pumps

2.5. MEASUREMENT EQUIPMENT REQUIRED

In the following the measurement equipment required for Short Term Testing and Long Term Testing is described. The selection is based on accuracy, reliability, availability and ease of operation of the equipment.

Subsection 2.5.1. deals with instruments needed for all pumping systems, subsection 2.5.2. gives details on specific equipment per technique.

Apart from the recommendations given in these sections, one should consider thoughtfully the instructions for installation, calibration and use provided by the manufacturer of the instruments.
The various instruments are arranged according to the quantities to be measured.

2.5.1. Measurement equipment for all pumping systems

Time

To time the start and completion of each measurement a clock should be used. For the timing of the 10-minute periods during Short Term Testing a clock with seconds hand, a digital watch or a stopwatch is required.

Head

a. suction head
For surface water sources or dug wells, the suction head should be measured directly with a measuring stick or tape. Where the horizontal distance between water source and pump is long, a level should be used to get a more accurate reading of the vertical distance. For example a U-shaped transparent hose partly filled with water can be used to indicate points of constant height, even at large distances apart. For bore holes where the water surface is not accessible, a well dipper should be used to measure the suction head.

b. discharge head
The discharge head should be measured directly using a measuring stick or tape.
During Short Term Tests for systems using rotating pumps and particularly for systems with long or small diameter discharge lines a pressure gauge at the pump discharge should be used.

c. pressure head
The pressure head should be measured at the boundary of the pumping system by means of a bourdon type pressure gauge.

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Water volume pumped

a. for all pumping techniques except hand pumps
Water flow should be measured using an integrating flow meter that is able to measure irregular and pulsating flow. Because meters of this kind are usually rather sensitive to clogging, they have to be checked, cleaned and calibrated regularly to prevent errors, especially when the water is not too clean (e.g. when pumped from open dug wells).
In order to avoid these problems as much as possible, it is strongly recommended to use a turbine flow meter of the dry running type, characterized by a turbine axis parallel to the piping in which the water flows more or less straight without change of direction. This will reduce sensitivity to pollution to a high degree. Finally, in order to keep friction losses as low as possible it is important to select a flow meter with a capacity that can easily meet the maximum water flow.
Especially for systems with strongly varying output like solar or wind pumps care should be taken to select the meter for the maximum system output to be expected.

For a proper functioning of the flow meter it is very important to prevent air from entering into the meter. The piping should be such that the flow meter can not run dry when the pumping system is in operation.
As an example Figure 2.3 shows two flow meters (indicated by "F") installed in such a way that when measuring they are always full of water. For this reason flow meters should never be installed at positions "A" or "B". Please mind the length of straight pipe upstream of the flow meters.
When there is a risk of a certain air content in the water pumped (e.g. when part of the system is sub-atmospheric or when an air chamber is fitted with an air supply system), a deaeration vessel is recommended (Figure 2.3). Its diameter should at least be three times the diameter of the discharge pipe in order to generate a sufficiently low vertical water velocity for the air bubbles to escape. In order to minimize turbulence in the vessel, the pipe entering it should be bended at its end towards the wall (see "C" in Figure 2.3).
When the pump is of the reciprocating type, the vessel might have a second function in that the flow fluctuations in the meter are damped. As a result a smaller flow meter can be used (selected on maximum average flow in stead of maximum peak flow) and the accuracy of the meter will be improved as well.

Note: For solar pump and windpump systems with a storage tank two integrating flow meters are required.

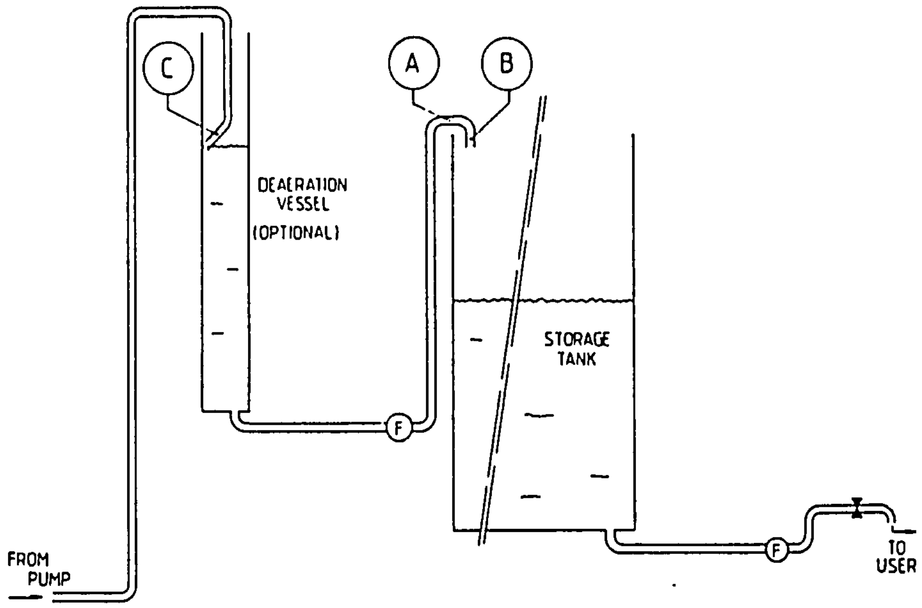


Figure 2.3. Installation of flow meters.

b. for hand pumps

To measure the volume pumped per person a calibrated container should be used. Its capacity should be larger than the maximum volume pumped per person. It should be calibrated with a scale in liters.

To measure the flow over longer periods, two or more larger containers with a known volume should be available. Preferably these containers should have such a capacity as to contain at least the water volume pumped by five persons.

If the hand pump system is equipped with a storage tank, an integrating flow meter should be installed at the outlet of the storage tank (see Figure 2.3 and explication above!).

c. for animal traction pumps

There is a large variety of animal traction pumps. Usually the water volume pumped cannot simply be measured by means of an integrating flow meter as described under a. Many animal traction pumps have buckets or the like, delivering discontinuous bulks of water. Here the water volume pumped should be measured by means of a small tank receiving the water and connected in such a way to the flow meter that the latter can not run dry when the pumping system is in operation. In Figure 2.4. an example is given (note the length of straight pipe upstream of the flowmeter).

Alternatively the water volume pumped could be measured by counting the revolutions of a shaft, if any, and relating the result to the number of buckets of water lifted. However care should be taken because this method is indirect and less reliable; it "measures" also a full flow when the well is empty or when the buckets are only filled partially with water.

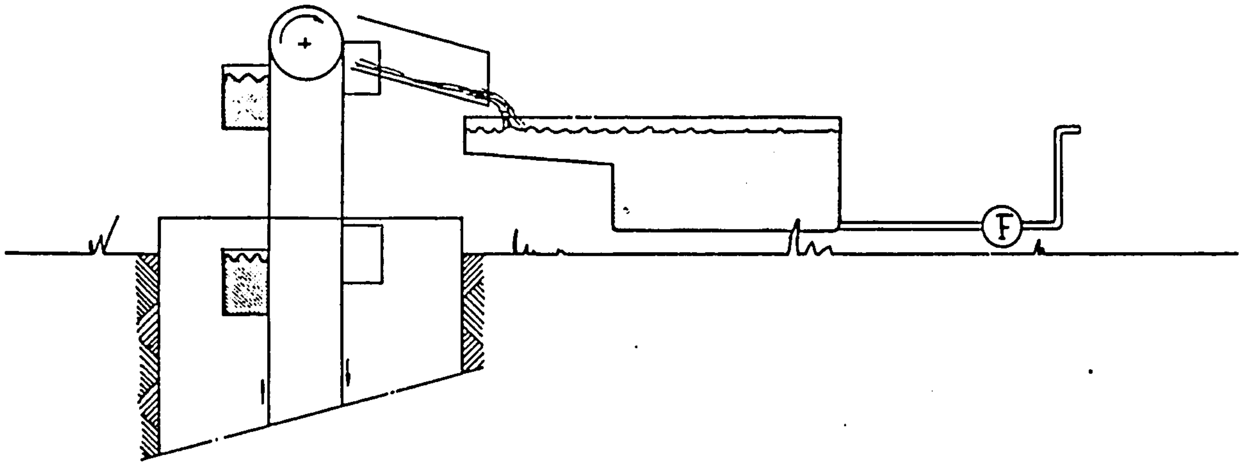


Figure 2.4. Measurement of water volume pumped for intermittent flows.

Pump strokes or rotations

a. reciprocating pumps
For a reciprocating pump a stroke counter attached to the pump rod should be used. This could be done by means of a simple button actuated mechanical counter, driven by a disk mounted on the pump rod. Also an internal powered electronic LCD counter could be applied (at least 8 digits). Alternatively the number of strokes can be obtained by visual observation.

b. rotational pumps
For centrifugal or screw pumps a revolution counter should be used (e.g. a car odometer attached to any shaft. Take into account the transmission ratio between that shaft and the pump shaft).
For pumps with an essentially constant speed, the rotational speed should be measured by means of a vibrating reed or other mechanical tachometer.

2.5.2. Measurement equipment per pumping technique

2.5.2.1 Grid connected electric pumps:

Motor energy consumption

An integrating electric power meter (A common Energy meter or kWh meter) should be used. The meter leads should be connected to the power leads as close to the motor as possible. For single phase motors the power across the two power leads should be measured. For three phase motors, which have three power leads, a three phase meter should be used. In case this is not available, first a single phase meter should be connected subsequently to each of the three power leads and the neutral (or ground) and the power recorded and noted down in the logbook with identification of the connected lead. Subsequent power measurements need to be taken from one lead and the neutral (or ground) only, with identification of the chosen lead in the logbook.

2.5.2.2 Fuel engine pumps:

Fuel consumption

a. Short Term Tests
During Short Term Tests the fuel tank should be replaced by a transparent plastic cylinder. If this cylinder is calibrated in cubic centimetres, the fuel consumption during a short period can be read directly. If alternatively the cylinder has only a level mark, the fuel volume consumed should be measured by refilling the cylinder up to the mark with a measuring cylinder.

b. Long Term Tests
The fuel consumption over a longer period of time should be determined by measuring the amount of fuel to be added to the fuel tank of the engine in order to refill it to a well defined level. This amount should be measured by weighing or by means of a calibrated container.

Operating time

The operating time of the engine pump should be measured by means of an engine hour meter. It is a clock that runs during the time it "observes" vibrations of an engine. It does not need any external energy source.

2.5.2.3 Solar pump:

Solar irradiation

An integrating pyranometer, reading in [Wh/m^2] should be used. The pyranometer should be set at the same angle to the sun as the PV array. It should be calibrated before and after the tests according to the manufacturer's instructions.

Array energy output

An integrating electric power meter (a common energy meter or kWh meter) should be used.

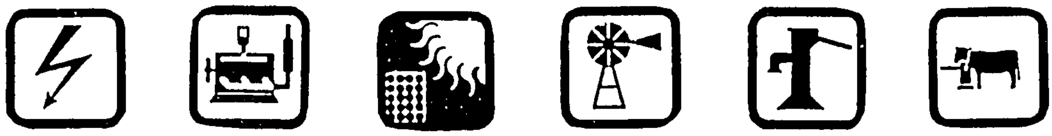
2.5.2.4 Windpump:

Wind speed.

An integrating rotating cup anemometer (e.g. wind run meter) should be used. It should be positioned at the height of the rotor shaft and at such a place that it is outside the wake of the windpump during most of the time. This can be achieved by two different methods:

1. If the terrain is flat and without major obstacles (resulting in windspeeds not varying very much over larger distances), place the anemometer at a distance of about 20 times the rotor diameter away from the windpump: then wake effects for all wind directions can be considered negligible.
2. If the terrain does not meet these conditions, place the anemometer at a distance between 2 and 8 times the rotor diameter away from the windpump and at such a place with respect to the windpump, that it is outside the wake of the windpump for the predominant wind directions.

To avoid the disturbance of the windspeed measurements by the tower in which the anemometer is mounted, the tower height should be chosen such that the anemometer can be installed on top of it.



3. DATA COLLECTION AT THE START OF THE TESTS

This chapter describes the data collection at the beginning of the tests. In Sections 3.1., 3.2., 3.3., and 3.4. general aspects are treated, while Sections 3.5. and 3.6. deal with those aspects that differ with the pumping technique.

The chapter concerns information that is available at the start of the tests; no measurements are required at this stage.

3.1. GENERAL INFORMATION

Through completion of Data Sheet 3.1. a general identification of the system under consideration and the persons that carry out the tests will be obtained.

DATA SHEET 3.1. General Information on Pumping System
(to be completed by team leader)

General	
Type of pumping system :	
Year of installation :	
Owner of the Pumping System	
Name :	
Address :	
Telephone :	
Location of the Pumping System	
Town/village :	Latitude :
District :	Longitude :
Country :	Altitude :
Supplier of the Pumping System	
Name :	
Address :	
Telephone :	
Institution supporting the evaluation	
Name :	
Address :	
Telephone :	
Names of persons in charge of the tests and evaluation	
Team leader :	
Technician :	

DATA SHEET 3.2. Persons involved in daily care for the system
(to be completed by team leader)

Persons	Function	Experience
1. Name : (see data sheet 3.1.) Address : __________ Telephone: __________	Owner	______ ______ ______
2. Name : __________ Address : __________ Telephone: __________	Operator	______ ______ ______
3. Name : __________ Address : __________ Telephone: __________	Guard	______ ______ ______
4. Name : __________ Address : __________ Telephone: __________	______	______ ______ ______
5. Name : __________ Address : __________ Telephone: __________	______	______ ______ ______

	1. Owner	2. Operator	3. Guard	4.	5. ....
Operation					
Guarding					
Maintenance					
Repair					
Selling of water					
Cleaning of site					
__________					
__________					
Basis of involvement					

3.2. PERSONS INVOLVED

It is important to determine the persons involved in keeping the pumping system in running order and their respective tasks and responsibilities. In Data Sheet 3.2. such information will be noted down. It contains three suggestions for functions and six ideas on tasks. Others may be added if deemed appropriate. Further information relates to the basis on which persons involved contribute to the operation of the system (direct beneficiary, family member, paid, etc). In the logbook more information on the types of tasks of the various persons involved may be noted down.

3.3. WATER SOURCE AND WELL CONSTRUCTION

Data sheet 3.3. shows a summary of quantitative information on the water source. Not all items are relevant for all types of water sources; please skip them if not applicable.

DATA SHEET 3.3. Water Source
(to be completed by technician)

Source type	: dug well/river/tube well/______ *)
Identification Number	: ______________________
Diameter	: _______ [m]
Depth	: _______ [m]
Static ground water level	(i.e. without water extraction)
Maximum value	: _______ [m below ground level]
Minimum value	: _______ [m below ground level]
Capacity	: _______ [m^3/hour] or [m^3/day] *
Corresponding lowering of ground water level	: _______ [meter draw down]
*) circle or complete the correct answer	

Because every water source or aquifer has a limited recharge capacity, its capacity should be recorded together with the corresponding lowering of the ground water level, if available.

To enable a proper assessment of longer term developments and the use of the water additional information is required that does not refer directly to the pumping system but may provide a framework for explanation of certain aspects. Information on the following items may therefore be useful and added into the logbook.

-Quality of the water
- =Salt contents (taste!). Include a copy of lab tests, if available.
- =Temperature.
- =Presence of solid particles.

-Variations of the water level
- =What are the normal seasonal variations in water level.
- =Reasons for these variations.
- =Long term variations of the water level over the past years, if any. Known or possible causes.
- =Is the well at times pumped dry?
- =Does salt content change appreciably if water level drops?

-Source construction
- =Please add a drawing of the source. In case special filters or filter pipes are used, specify their length, diameter, depth and porosity, kind of filter gravel used, etc.
- =Describe the protection of the well against pollution of different origin, such as spill water return flow into the source, non-hygienic treatment of water carrying equipment, pollution by natural, human or animal waste or contamination of the aquifer by dung pits, latrines etc.

3.4. SUMMARY OF OPERATING EXPERIENCE

A serious attempt should be made to describe the history of operating and maintenance experience in the logbook, covering, if possible, the past operating years. Any routine inspections and maintenance carried out should be noted, describing the type of maintenance and how frequently it was done.

The history should summarize any breakdowns and repairs to the pumping system. If possible, it should include for each failure its description, the date of occurrence, time that the system was out of service, descriptions of the cause of failure (if known), and of the maintenance action (repair, replacement, or modification) that was carried out.

A note should be made in the logbook as to whether the average water flow rate or the system efficiency may have changed over time from the nominal values supplied by the manufacturer, or as measured when the system was new.

3.5. PUMPING SYSTEM

3.5.1. System Description Grid Connected Electric Pumps

Data Sheet 3.5.1. serves to describe the pumping and storage system.
The capacity of the storage tank may be calculated by L * W * H for rectangular tanks or by $\pi/4 * D^2 * H$ for cylindrical tanks. Use the line "Capacity" for deviating shapes.

In addition to Data Sheet 3.5.1. supply the following information:

- Make a sketch or drawing of the pumping system. The sketches should indicate the distance above or below a reference ground level of the water intake, the electric motor, the pump, the water storage tank (if used) and the water discharge pipe. The sketches should show the dimensions (lengths and diameters) and locations of piping fittings, including valves, tees, elbows etc..
  In certain cases the electricity supply may be irregular, creating the need for additional on-site water storage or the use of stand-by equipment. These should be included in the system description and layout.

- Add photographs showing details of the components of the system as mentioned in the previous paragraph.

- Describe the measurement equipment applied during the tests. Give relevant parameters like make and type, (maximum and minimum) capacity, resolution (smallest unit indicated), accuracy (%) and address of supplier. Indicate the position of the instruments in the drawing of the pumping system mentioned above.

- Describe the availability of electricity from the grid, including any daily, weekly or seasonally planned shutdowns.

- Give details on the kind of voltage and frequency fluctuations, if any. Give reasons for their occurrence.

- Give a listing and the location of available documentation, describing the system, e.g. assembly drawings, instruction books, performance test results, etc..

DATA SHEET 3.5.1. System description Grid Connected Electric Pump (to be completed by technician).

<u>Electric Grid</u>	
Extent of the grid : local/regional/ _ *	
Voltage and variation : ____ [Volt], +/- _____ [Volt]	
Frequency and variation : ____ [Hz], +/- _____ [Hz]	
<u>Electric motor</u>	
Year of manufacture : ____	Manufacturer
Make, type : ______________	Name : ______________
Nominal shaft power : ____ [kW]	Address : ______________
Voltage : ____ [Volt], single/three phase *	Serial no.: ______________
Nominal rotational speed: ____ [revs/min]	
Rated power : ____ [kW] / [kVA] *	
Power factor (cos ϕ) : ____ [-]	
<u>Transmission</u>	Manufacturer
Type : ______________	Name : ______________
Transmission ratio : ____ [motor revs / pump rev]	Address : ______________
<u>Pump</u>	
Year of manufacture : ____	
Make : ______________ *	Manufacturer
Type : Centrifugal/Mono/ ________	Name : ______________
Position : ____ [meters below ground level]	Address : ______________
Nominal rotational speed: ____ [rev/min]	Serial no.: ______________
Nominal capacity : ____ [kW]	
Nominal efficiency : ____ % at ______ [revs/min]	
<u>Storage tank</u> (if any)	
Year of manufacture : ____	Manufacturer
Type, structure : ______________	Name : ______________
Length, Width, Height : ... * ... * ... = ... [m^3]	Address : ______________
or: Diameter, Height : 0.7854 * (...)^2 * ... = ... [m^3]	Serial no.: ______________
or: Capacity : ____ [m^3]	
Minimum water level : ____ [meters above ground level]	
<u>Back-up system</u> (if any)	Manufacturer
Year of manufacture : ______________	Name : ______________
Make, type : ______________	Address : ______________
Capacity : ______________	Serial no.: ______________

*) circle the correct answer

(continued on next page)

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DATA SHEET 3.5.1. System description Grid Connected Electric Pump (to be completed by technician)

(continued)

Initial investments (specify currencies: ______________)

ITEM	(a) Cost, insurance, freight (CIF) OR: off-works	(b) Import duties taxes	(c) Handling, storage, overheads, etc.	(d) Subsidies	(a+b+c-d) TOTAL
Pump	____	____	____	____	____
Motor and starter	____	____	____	____	____
Piping and meters	____	____	____	____	____
Electric controls	____	____	____	____	____
Pumphouse and works	____	____	____	____	____
Storage tank	____	____	____	____	____
Other ________	____	____	____	____	____
Installation/site preparation:					
* skilled labour	____	____	____	____	____
* unskilled labour	____	____	____	____	____
* transport	____	____	____	____	____
TOTAL INSTALLED COST	____	____	____	____	____

*NOTE: in case of local manufacture of pump, motor, etc. one may distinguish where possible between: material, low skilled labour, high skilled labour and overhead cost to enable the different economic calculations as mentioned in Chapter 6.

*NOTE: if changes of the well construction were needed, because of the choice of a particular technology, the additional costs for well adaptation need to be included. Common costs for the well construction that would be needed for all technologies are not to be included (see also chapter 6).

3.5.2. System Description Fuel Engine Pumps

Data Sheet 3.5.2. serves to describe the pumping and storage system.
The capacity of the storage tank may be calculated by $L * W * H$ for rectangular tanks or by $\pi/4 * D^2 * H$ for cylindrical tanks. Use the line "Capacity" for deviating shapes.

In addition to Data Sheet 3.5.2. supply the following information:

- Make a sketch or drawing of the pumping system. The sketches should indicate the distance above or below a reference ground level of the water intake, the internal combustion engine (IC), the pump, the water storage tank (if used) and the water

discharge pipe. The sketches should show the dimensions (lengths and diameters) and locations of piping fittings, including valves, tees, elbows etc..
In certain cases the fuel supply may be irregular, creating the need for an on-site fuel storage. In such cases the system description should include relevant details.

DATA SHEET 3.5.2. System description Fuel Engine Pump
(to be completed by technician)

IC Engine	
Year of manufacture : ____________	Manufacturer
Make, type : ____________	Name : ____________
Nominal shaft power : ____ [kW]	Address : ____________
Nominal rotational speed: ____ [revs/min]	Serial no.: ____________
Nominal fuel consumption: ____ [l/h]	
Type of fuel : diesel/petrol/kerosene/ ______ *)	
Volume of fuel tank : [l]	
Transmission	Manufacturer
Type : ____________	Name : ____________
Transmission ratio : ____ [engine revs / pump rev]	Address : ____________
Pump	
Year of manufacture : ____________	
Make : ____________ *)	Manufacturer
Type :Centrifugal/Mono/ ____________	Name : ____________
Position : ____ [meters below ground level]	Address : ____________
Nominal rotational speed: ____ [revs/min]	Serial no.: ____________
Nominal capacity : ____ [kW]	
Nominal efficiency : ____ [%] at ______ [revs/min]	
Storage tank (if any)	
Date of installation : ____	Manufacturer
Type, structure : ____________	Name : ____________
Length, Width, Height : ... * ... * ... = ... [m^3]	Address : ____________
or: Diameter, Height : 0.7854 * (...)^2 * ... = ... [m^3]	Serial no.: ____________
or: Capacity : ____ [m^3]	
Minimum water level : ____ [meters above ground level]	
Back-up system (if any)	Manufacturer
Date of installation : ____	Name : ____________
Make, type : ____________	Address : ____________
Capacity : ____________	Serial no.: ____________

*) circle the correct answer

(continued on next page)

DATA SHEET 3.5.2. System description Fuel Engine Pump
(to be completed by technician)

(continued)

Initial investments (specify currencies: _______________)

ITEM	(a) Cost, insurance, freight (CIF) OR: off-works	(b) Import duties, taxes	(c) Handling, storage, overheads, etc.	(d) Subsidies	(a+b+c-d) TOTAL
Engine					
Pump					
Downhole piping					
Site preparation					
Pumphouse and works					
Storage tank					
Above ground piping					
Installation					
* skilled labour					
* unskilled labour					
* transport					
Other ________					
TOTAL INSTALLED COST					

*NOTE: In case of local manufacture of pump, motor, etc. one may distinguish where possible between: material, low skilled labour, high skilled labour and overhead cost to enable the different economic calculations as mentioned in chapter 6.

*NOTE: If changes of the well construction were needed, because of the choice of a particular technology, the additional costs for well adaptation need to be included. Common costs for the well construction that would be needed for all technologies are not to be included (see also chapter 6).

- Add photographs showing details of the components of the system as mentioned in the previous paragraph.

- Describe the measurement equipment applied during the tests. Give relevant parameters like make and type, (maximum and minimum) capacity, resolution (smallest unit indicated), accuracy (%) and address of supplier. Indicate the position of the instruments in the drawing of the pumping system mentioned above.

- Describe the reliability of the fuel supply. Is the use of alternative fuels allowed?

- Give a listing and the location of available documentation, describing the system, e.g. assembly drawings, instruction books, performance test results, etc..

3.5.3. System Description Solar Pumps

Data Sheet 3.5.3. serves to describe the pumping and storage system.
The capacity of the storage tank may be calculated by L * W * H for rectangular tanks or by $\pi/4 * D^2 * H$ for cylindrical tanks. Use the line "Capacity" for deviating shapes.

DATA SHEET 3.5.3. System description Solar Pump (to be completed by technician)

Solar array	
Year of manufacture : ____	Manufacturer
Make, type : ____	Name : ____
Effective area : ____ $[m^2]$	Address : ____
Orientation : see drawing asked for in 5.3.2.2	Serial no.: ____
Rated power : ____ [W] at irradiance ____ $[W/m^2]$	
Rated voltage : ____ [Volt] at irrad. ____ $[W/m^2]$	
Power control system	Manufacturer
Make, type : ____	Name : ____
Battery storage (if any): ____ [kWh]	Address : ____
Electric pump	
Year of manufacture : ____	
Make : ____	Manufacturer
Type : ____	Name : ____
Position : ____ [meters below ground level]	Address : ____
Nominal rotational speed: ____ [rev/min]	Serial no.: ____
Nominal capacity : ____ [kW]	
Voltage : ____ [Volt] AC/DC *	
Storage tank (if any)	
Year of manufacture : ____	Manufacturer
Type, structure : ____	Name : ____
Length, Width, Height : ... * ... * ... = ... $[m^3]$	Address : ____
or: Diameter, Height : $0.7854 * (...)^2 * ... = ...$ $[m^3]$	Serial no.: ____
or: Capacity : ____ $[m^3]$	
Minimum water level : ____ [meters above ground level]	
Back-up system (if any)	Manufacturer
Date of installation : ____	Name : ____
Make, type : ____	Address : ____
Capacity : ____	Serial no.: ____
*) circle the correct answer	

(continued on next page)

DATA SHEET 3.5.3. System description Solar Pump
(continued) (to be completed by technician)

Initial investments (specify currencies: ______________)

ITEM	(a) Cost, insurance, freight (CIF) OR: off-works	(b) Import duties, taxes	(c) Handling, storage, overheads, etc.	(d) Subsidies	(a+b+c-d) TOTAL
Pump & motor					
Solar modules					
Related solar hardware					
Below ground piping					
Above ground piping					
Pumphouse and works					
Storage tank					
Other______					
Installation/site preparation:					
* skilled labour					
* unskilled labour					
* transport					
TOTAL INSTALLED COST					

*)NOTE: in case of local manufacture of pump, motor, etc. one may distinguish where possible between: material, low skilled labour, high skilled labour and overhead cost to enable the different economic calculations as mentioned in Chapter 6.

*)NOTE: if changes of the well construction were needed, because of the choice of a particular technology, the additional costs for well adaptation need to be included. Common costs for the well construction that would be needed for all technologies are not to be included (see also Chapter 6).

In addition to Data Sheet 3.5.3. supply the following information:

- Make a sketch or drawing of the pumping system. The sketches should indicate the distance above or below a reference ground level of the water intake, the solar photovoltaic array (also indicate its orientation!), the power conditioning equipment, the electric motor, the pump, the water storage tank (if used) and the water discharge pipe. The sketches should show the dimensions (lengths and diameters) and locations of piping fittings, including valves, tees, elbows etc..

- Add photographs showing details of the components of the system as mentioned in the previous paragraph.

- Describe the measurement equipment applied during the tests. Give relevant parameters like make and type, (maximum and minimum) capacity, resolution (smallest unit indicated), accuracy (%) and address of supplier. Indicate the position of the instruments in the drawing of the pumping system mentioned above.

- Give a listing and the location of available documentation, describing the system, e.g. assembly drawings, instruction books, performance test results, etc..

3.5.4. System Description Wind Pumps

Data Sheet 3.5.4. serves to describe the pumping and storage system.
The capacity of the storage tank may be calculated by $L * W * H$ for rectangular tanks or by $\pi/4 * D^2 * H$ for cylindrical tanks. Use the line "Capacity" for deviating shapes.

In addition to Data Sheet 3.5.4. supply the following information:

- Make a sketch or drawing of the pumping system. The sketches should indicate the distance above or below a reference ground level of the water intake, the windmill, the mechanical transmission, the pump, the water storage tank (if used) and the water discharge pipe. The sketches should show the dimensions (lengths and diameters) and locations of piping fittings, including valves, tees, elbows etc..

- Add photographs showing details of the components of the system as mentioned in the previous paragraph.

- Describe the measurement equipment applied during the tests. Give relevant parameters like make and type, (maximum and minimum) capacity, resolution (smallest unit indicated), accuracy (%) and address of supplier. Indicate the position of the instruments in the drawing of the pumping system mentioned above.

- Give a listing and the location of available documentation, describing the system, e.g. assembly drawings, instruction books, performance test results, etc..

DATA SHEET 3.5.4. System description Windpump
(to be completed by technician)

Windmill	
Year of manufacture : ____	Manufacturer
Make, type : ____________	Name : ____________
Rotor diameter : ____ [meters]	Address : ____________
Tower height : ____ [meters]	Serial no.: ____________
Control/safety system : automatic/manual *	
on-off/continuous *	
Transmission	Manufacturer
Type : ____________	Name : ____________
Gear ratio : ____ [rotor revs per pump stroke]	Address : ____________
Stroke of pump rod : ____ [meters]	Serial no.: ____________
Pump	
Year of manufacture : ____	
Make : ____________ *	Manufacturer
Type : Piston/Centrifugal/Mono/ ____	Name : ____________
Position : ____ [meters below ground level]	Address : ____________
(Only for piston pumps)	Serial no.: ____________
Pump diameter : ____ [mm]	
(Only for centrifugal pumps)	
Nominal rotational speed: ____ [rev/min]	
Nominal capacity : ____ [kW]	
Storage tank (if any)	
Year of manufacture : ____	Manufacturer
Type, structure : ____________	Name : ____________
Length, Width, Height : ... * ... * ... = ... [m^3]	Address : ____________
or: Diameter, Height : 0.7854 * $(...)^2$ * ... = ... [m^3]	Serial no.: ____________
or: Capacity : ____ [m^3]	
Minimum water level : ____ [meters above ground level]	
Back-up system (if any)	Manufacturer
Year of manufacture : ____	Name : ____________
Make, type : ____________	Address : ____________
Capacity : ____ [kW]	Serial no.: ____________
*) circle the correct answer	

(continued on next page)

DATA SHEET 3.5.4. System description Windpump
(continued) (to be completed by technician)

Initial investments (specify currencies: ________________)

ITEM	(a) Cost, insurance, freight (CIF) OR: off-works	(b) Import duties, taxes	(c) Handling, storage, overheads, etc.	(d) Subsidies	(a+b+c-d) TOTAL
Pump					
Windmill & tower					
Piping/rising main					
Above ground piping					
Pumphouse and works					
Storage tank					
Other ________					
Installation/site preparation:					
* skilled labour					
* unskilled labour					
* transport					
TOTAL INSTALLED COST					

*NOTE: in case of local manufacture of pump, windmill, etc. one may distinguish where possible between: material, low skilled labour, high skilled labour and overhead cost to enable the different economic calculations as mentioned in Chapter 6.

*NOTE: if changes of the well construction were needed, because of the choice of a particular technology, the additional costs for well adaptation need to be included. Common costs for the well construction that would be needed for all technologies are not to be included (see also Chapter 6).

3.5.5. System Description Hand Pumps

Data Sheet 3.5.5. serves to describe the pumping and storage system.
The capacity of the storage tank may be calculated by L * W * H for rectangular tanks or by $\pi/4 * D^2 * H$ for cylindrical tanks. Use the line "Capacity" for deviating shapes.

In addition to Data Sheet 3.5.5. supply the following information:

- Make a sketch or drawing of the pumping system. The sketches should indicate the distance above or below a reference ground level of the water intake, the pump assembly, the water storage tank (if used) and the water discharge pipe. The sketches should show the dimensions (lengths and diameters) and locations of piping fittings, including valves, tees, elbows etc..

- Add photographs showing details of the components of the system as mentioned in the previous paragraph.

- Describe the measurement equipment applied during the tests. Give relevant parameters like make and type, (maximum and minimum) capacity, resolution (smallest unit indicated), accuracy (%) and address of supplier. Indicate the position of the instruments in the drawing of the pumping system mentioned above.

- Give a listing and the location of available documentation, describing the system, e.g. assembly drawings, instruction books, performance test results, etc..

- Because there is a large variety in hand pumps it is

DATA SHEET 3.5.5. System description Hand Pump
(to be completed by technician)

Hand pump		
Year of manufacture	: ____	
Make	: ______________________	Manufacturer
Type	: Piston/Centrifugal/Mono/______ *	Name : ______________
Position	: ____ [meters below ground level]	Address : ______________
(Only for piston pumps)		Serial no.: ______________
Pump diameter	: ____ [mm]	
Maximum pump stroke	: ____ [mm]	
(Only for screw pumps)		
Nominal flow rate	: ____ [l/min] at ____ [revs/min]	
(other pumps)		
Nominal flow rate	: ____ [l/min]	
Nominal condition	: ______________________	
Capacity of bucket	: ____ [l]	
Number of buckets	: ____ [-]	
______________	: ______________________	
______________	: ______________________	
Storage tank (if any)		
Year of manufacture	: ____	Manufacturer
Type, structure	: ______________________	Name : ______________
Length, Width, Height	: ... * ... * ... = ... [m^3]	Address : ______________
or: Diameter, Height	: 0.7854 * (...)^2 * ... = ... [m^3]	Serial no.: ______________
or: Capacity	: ____ [m^3]	
Minimum water level	: ____ [meters above ground level]	
*) circle the correct answer		

(continued on next page)

DATA SHEET 3.5.5. System description Hand Pump
(continued) (to be completed by technician)

Initial investments (specify currencies: ________________)

ITEM	(a) Cost, insurance, freight (CIF) OR: off-works	(b) Import duties, taxes	(c) Handling, storage, overheads, etc.	(d) Subsidies	(a+b+c-d) TOTAL
Pump					
Pump head					
Piping/rising main					
Above ground piping					
Works, foundation, fencing, etc.					
Storage tank					
Installation/site preparation:					
* skilled labour					
* unskilled labour					
* transport					
Other________					
TOTAL INSTALLED COST					

*NOTE: in case of local manufacture of the hand pump, one may distinguish where possible between: material, low skilled labour, high skilled labour and overhead cost to enable the different economic calculations as mentioned in Chapter 6.

*NOTE: if changes of the well construction were needed, because of the choice of a particular technology, the additional costs for well adaptation need to be included. Common costs for the well construction that wtould be needed for all technologies are not to be included (see also Chapter 6).

recommended to add a number of photographs of the pumping system to the logbook.

3.5.6. System Description Animal Traction Pumps

Data Sheet 3.5.6. serves to describe the pumping and storage system.
The capacity of the storage tank may be calculated by L * W * H for rectangular tanks or by $\pi/4 * D^2 * H$ for cylindrical tanks. Use the line "Capacity" for deviating shapes.

In addition to Data Sheet 3.5.6. supply the following information:

- Make a sketch or drawing of the pumping system. The sketches should indicate the distance above or below a reference ground level of the water intake, the pump assembly, the water storage tank (if used) and the water discharge pipe. The sketches should show the dimensions (lengths and diameters) and locations of piping fittings, including valves, tees, elbows etc..

- Add photographs showing details of the components of the system as mentioned in the previous paragraph.

- Describe the measurement equipment applied during the tests. Give relevant parameters like make and type, (maximum and minimum) capacity, resolution (smallest unit indicated), accuracy (%) and address of supplier. Indicate the position of the instruments in the drawing of the pumping system mentioned above.

DATA SHEET 3.5.6. System description Animal Traction Pump (to be completed by technician)

Pump assembly	
Year of manufacture : ____	
Make : ______________________ *	Manufacturer
Type : Piston/Centrifugal/Mono/ ______	Name : ______________
Position : ____ [meters below ground level]	Address : ______________
(Only for piston pumps)	Serial no.: ______________
Pump diameter : ____ [mm]	
Maximum pump stroke : ____ [mm]	
(Only for screw pumps)	
Nominal flow rate ** : ____ [l/min] at ____ [revs/min]	
(other pumps)	
Nominal flow rate : ____ [l/min]	
Capacity of bucket : ____ [l]	
Number of buckets : ____ [-]	
Transmission :	Manufacturer
Type of harness : ______________________ **)	Name : ______________
Transmission ratio : _____[______________]	Address : ______________
Storage tank (if any)	
Year of manufacture : ____	Manufacturer
Type, structure : ______________________	Name : ______________
Length, Width, Height : ... * ... * ... = ... [m^3]	Address : ______________
or: Diameter, Height : 0.7854 * $(...)^2$ * ... = ... [m^3]	Serial no.: ______________
or: Capacity : ____ [m^3]	
Minimum water level : ____ [meters above ground level]	
*) circle the correct answer **) adapt units to system, e.g. pump revs. per beam rev.	

(continued on next page)

DATA SHEET 3.5.6. System description Animal Traction Pump (to be completed by technician)

(continued)

<u>Initial investments</u> (specify currencies: ______________)

ITEM	(a) Cost, insurance, freight (CIF) OR: off-works	(b) Import duties, taxes	(c) Handling, storage, overheads, etc.	(d) Subsidies	(a+b+c-d) TOTAL
Pump					
Pumping system					
Animals					
Harnesses, etc.					
Piping/rising main					
Above ground piping					
Pumphouse and works					
Storage tank					
Installation/site preparation:					
* unskilled labour					
* skilled labour					
* transport					
Other ______					
TOTAL INSTALLED COST					

*NOTE: in case of local manufacture of the animal pump, one may distinguish where possible between: material, low skilled labour, high skilled labour and overhead cost to enable the different economic calculations as mentioned in Chapter 6.

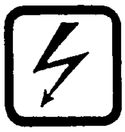
*NOTE: if changes of the well construction were needed, because of the choice of a particular technology, the additional costs for well adaptation need to be included. Common costs for the well construction that would be needed for all technologies are not to be included (see also Chapter 6).

- Give a listing and the location of available documentation, describing the system, e.g. assembly drawings, instruction books, performance test results, etc..

- Because there is a large variety in animal traction pumps it is recommended to add a number of photographs of the pumping system, including the animals, to the logbook.

3.6. DESCRIPTION OF THE SITE

3.6.1. Site Description Grid Connected Electric Pumps



Specify the end-use of the electric pump system:
- =Number of people using the system for drinking water.
- =Area of land irrigated by the system.
- =Number of cattle watered by the system.

3.6.2. Site Description Fuel Engine Pumps

Specify the end-use of the fuel pump system:
- =Number of people using the system for drinking water.
- =Area of land irrigated by the system.
- =Number of cattle watered by the system.

3.6.3. Site Description Solar Pumps

Give information on the solar irradiation conditions prevailing over the year at the test site, if available. Both data on seasonal and daily fluctuations from either a meteo station or another source are of interest. Because the form of the data

DATA SHEET 3.6.3. Summary of solar irradiation data (to be completed by technician)

Source of solar data: O Meteo Station in: ____________
O Other source : ____________
O References : ____________
____

Type, make of equipment : ____________
Reliability of data : ____________
____

(Units: [W/m^2])

Year	J	F	M	A	M	J	J	A	S	O	N	D	Average
19..													
19..													
19..													
19..													
19..													
1988													
Average													

available may vary strongly for different sites, Data Sheet 3.6.3. serves only as an example on how to summarize available information.

Specify the end-use of the solar pump system:
- =Number of people using the system for drinking water.
- =Area of land irrigated by the system.
- =Number of cattle watered by the system.

3.6.4. Site Description Wind Pumps

A detailed map of the surroundings of the wind pump system shall be provided, including location, size and height of any major obstacles like hills, valleys, trees, forests, houses or buildings.
Add a series of 8 to 10 photographs taken at the windpump site in various directions (panoramic view).

DATA SHEET 3.6.4. Summary of wind data
(to be completed by technician)

Source of wind data	O Meteo Station in: ______
	O Other source : ______
	O References : ______
Height of measurements	: ______ [m]
Type, make of equipment	: ______
Exposure	O Good
	O Remarks ______
Units: [m/s]	______

Year	J	F	M	A	M	J	J	A	S	O	N	D	Average
19..	___	___	___	___	___	___	___	___	___	___	___	___	___
19..	___	___	___	___	___	___	___	___	___	___	___	___	___
19..	___	___	___	___	___	___	___	___	___	___	___	___	___
19..	___	___	___	___	___	___	___	___	___	___	___	___	___
19..	___	___	___	___	___	___	___	___	___	___	___	___	___
1988	___	___	___	___	___	___	___	___	___	___	___	___	___
Average	___	___	___	___	___	___	___	___	___	___	___	___	___

Give information on wind and climate conditions including a description of the wind conditions prevailing over the year at the test site. This can be in the form of seasonal probability distributions of wind velocities and directions obtained from

meteorological stations, if present. Also data on daily fluctuations are of interest.
If wind data are available from a nearby site with similar terrain, these should be added to the logbook, along with the name and location of that site.
Because the form of the data available may vary strongly for different sites, Data Sheet 3.6.4. serves only as an example on how to summarize available information.

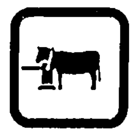
Specify the end-use of the windpump system:

=Number of people using the system for drinking water.
=Area of land irrigated by the system.
=Number of cattle watered by the system.

3.6.5. Site Description Hand Pumps

Specify the end-use of the Hand pump system:

=Number of people using the system for drinking water.
=Area of land irrigated by the system.
=Number of cattle watered by the system.



3.6.6. Site Description Animal Traction Pumps

Specify the end-use of the Animal traction Pump:

=Number of people using the system for drinking water.
=Area of land irrigated by the system.
=Number of cattle watered by the system.

4. SHORT TERM TESTING

4.0 OBJECTIVES OF SHORT TERM TESTING

The objective of this chapter is to describe procedures for carrying out short term field tests needed to characterize the technical performance of existing small scale water pumping systems. The tests focus on measuring the performance of the entire water system rather than of individual components. In some cases optional procedures will also be provided which will permit the calculation of the performance of individual components.

Performance parameters to be obtained from the short term field tests include water pumping rates and system (or component) energy inputs and outputs, both obtained under well defined and (to the extent possible) uniform test conditions and covering the range of expected operation. Based on this, system capacity and overall efficiency are calculated over the range of expected operating conditions.

The results of the Short Term Tests are intended to be used, along with the results of the Long Term Tests, for the same systems as described in Chapter 5, for several purposes:

1. to provide a technical performance data base covering many water pumping system types to be used for the techno-economic evaluation of each system type as described in Chapter 6.

2. to provide technical performance information to the owners or operators of the systems tested which can be used to improve the design, operation or maintenance of their own system.

3. to provide field technical performance information of value to the owners or operators of similar systems, vendors of components for such systems, and governmental and private donor agencies who support the use of such systems.

This chapter is intended to provide directions as to what technical information is needed and how the information should be obtained and presented. It is divided into sections, as with chapters 2, 3 and 5, in accordance with the technical system to be tested.

Test procedures

Because of the many differences among water pumping systems even of the same type, the description of the test procedures will be limited to the information needed to prepare for and carry out the Short Term Tests on a typical system. Examples will be provided of the data sheets for collection of the information.

The following format will be used in describing the test procedures:

Objectives
The specific objectives in carrying out the tests of a particular system.

Test Protocol
Pretest inspections and preparation of test procedures including equipment calibration as applicable, test conditions, number and/or sequence of measurements, instructions for taking measurements, and instructions for carrying out preliminary calculations at the test site.

Data Reduction
Data reduction is carried out in two steps. At the test site (see above), preliminary calculations convert the measured quantities into standard forms such as flow rates and velocities. These standardized quantities can be plotted against each other to determine whether any of the measurements were read or recorded in error. Erroneous data would appear as "outliers" on such plots. Where outliers are identified in the field, additional corrected data can be taken.

Subsequently, at an office where calculators are available, other calculations and plots will be made, generally by trained engineers or technicians using the additional formulas shown in each section, to convert the measured quantities and standard forms into the performance parameters used to evaluate each water system type. These include energy input rate, energy output rate, and overall energy efficiency. The performance parameters are plotted on graphs to generate curves showing the effect of the operating conditions on the system performance.

4.1. GRID-CONNECTED ELECTRIC PUMPS

This section covers water pumping systems in which the prime mover is an electric motor. The motor is coupled mechanically, generally through a transmission, to the pump, which may be a rotating screw (Mono) or centrifugal type. A local or regional electric grid supplies the power for the motor.

4.1.1. Objectives

The objective of the short term tests of grid connected electric pumps is to obtain performance data showing overall system efficiency and water pumping rate as a function of total head and pump speed.

4.1.2. Test protocol

4.1.2.1 Data collection at the start of the tests

Before the short term tests are begun, the data collection described in Chapter 3 should be completed.

4.1.2.2 Pretest inspection and preparations

The following inspections should be carried out prior to field tests. The results should be included as comments in narrative form in the logbook, with notations as to which component or part was inspected and the results of the inspection. If a component listed below is not inspected, that fact should be noted. However, unless the system is not in operating order, do not carry out any maintenance at this time based on the pretest inspections.

Visually inspect the electric motor, electric power cables, meters, cable junctions and splices, and control switches. Comment on the condition of the insulation and electrical contacts, looking particularly for evidence of overheating, arcing at contacts, bare wires, frayed insulation and exposed junctions. Note condition of lubrication of motor bearings, transmission or pump.

Listen to the pump during normal operation. Note if the system does not appear to be in satisfactory physical condition (e.g., look for excessive corrosion, lack of lubrication, lubricant leaks, worn seals) or if the system performance during operation appears to be clearly unsatisfactory (e.g., very low water flow rate, excessive leaks, excessive pump vibrations or noise etc.).

Inspect system piping and valves visually. Open and close all valves (<u>not</u> during operation of the pump!). Note valves which do not operate. Note on a sketch the location and severity of leaks in valves and piping, if any. Also where possible, note the physical condition of the interior surfaces of piping and valves. Determine whether a buildup of scale or other deposits has formed that reduces the effective diameter of the pipe or that causes the interior surface to be extremely rough. Note where the wall thickness has been reduced significantly by corrosion.

<u>Note:</u> Following inspection of the valves, it should be determined that all of the valves leading to and from the pump are set in their open position prior to beginning the tests.

Inspect the storage tank if included in the system. Note any leaks. Clean the sight glass if present.

Inspect the water intake. Examine screens if they are accessible and note their condition, i.e., whether they are intact or have visible holes, whether they are clogged, etc.

Install test equipment as described in sections 2.5.1 and 2.5.2.1, and ensure that the equipment is calibrated and functioning properly. Enter in the logbook a description of the test equipment used (see Section 3.5.1).

For bore hole wells, measure the static suction head (vertical distance from the water level in the borehole to the pump inlet when no water is being pumped and the pump has been off for at least two hours).

4.1.2.3 System maximum pumping rate

The pumping performance tests will consist of sets of measurements taken during ten minute time intervals.
It is recommended to take the sets of measurements as a continuous series. The measurements then just reduce to recording every 10 minutes the readings of the various instruments. Accuracy will greatly improve when the integrating instruments (time, electric energy and flow) are read <u>in the same order</u> every time.

Data Sheet 4.1.1. (column <u>"MEASUREMENTS"</u>) gives a lay-out to be used for noting down the results of the measurements and an example as how to fill in the sheet.
When the ten minute measurements are consecutive, the end of a measurement coincides with the beginning of the next one (see lines 0 to 10). Single measurements need two lines in the sheet. After every interruption a new measurement or block of measurements requires a new "0"-line (see lines 0 and 14).

For this test, if there are any valves in the discharge line from the pump, they should be fully opened. If there is a variable speed transmission between the motor and pump, it should be set for maximum speed. If there is a storage tank as part of the system, it should be at as low a level as possible at the beginning of the test.

DATA SHEET 4.1.1. Measurements and Calculations Short Term Tests

(to be completed by technician)

Location: ______		Date : ______	[YY/MM/DD]
District: ______		Start time : ______	[HH/MM/SS]
Owner : ______		End time : ______	[HH/MM/SS]

	MEASUREMENTS					CALCULATIONS				
No	Time t [HH:MM:SS]	Energy meter reading E_{el} [kWh]	Water meter reading Q_P [m^3]	Suction head H_{in} [m]	Discharge head H_{dis} [m]	Length of period T [s]	Electric power input $P_{el,T}$ [kW]	Water flow rate q_{PT} [l/s]	Hydraulic power output $P_{h,T}$ [kW]	Overall sstem eff. η_{tot} [-]
0	8:51:20	345.214	711.46	X	X					
1	9:01:01	345.299	712.81	-2.5	10.4	581	0.527	2.32	0.180	0.34
2	9:11:14	345.399	714.22	-2.5	10.3	613	0.587	2.30	0.176	0.30
3	9:21:33	345.481	715.46	-2.5	10.3	619	0.477	2.00	0.153	0.32
4	9:31:24	345.566	716.79	-2.4	10.4	591	0.518	2.25	0.177	0.34
5	9:41:05	345.648	718.09	-2.4	10.5	581	0.508	2.24	0.178	0.35
6	9:51:10	345.730	719.37	-2.4	10.4	605	0.488	2.12	0.166	0.34
7	10:01:26	345.815	720.59	-2.4	10.6	616	0.497	1.98	0.159	0.32
8	10:11:17	345.898	721.83	-2.4	10.3	591	0.506	2.10	0.163	0.32
9	10:21:07	345.983	723.19	-2.4	10.2	590	0.519	2.31	0.176	0.34
10	10:31:01	346.067	724.42	-2.4	10.4	594	0.509	2.07	0.163	0.32
11										
12										
13										
14	11:31:47	346.591	732.09	X	X	X	X	X	X	X
15	11:41:37	346.676	733.42	-2.3	10.5	590	0.519	2.25	0.181	0.35
16	11:51:38	346.757	734.53	-2.3	10.4	601	0.485	1.85	0.147	0.30
17	12:01:28	346.835	735.68	-2.3	10.3	590	0.476	1.95	0.153	0.32
18										
19										

Start motor and pump. Allow the system to operate for at least 30 minutes or as long as is required so that the intake head (drawdown) has stabilized.

Take ten sets of ten-minute measurements (as listed below). Allow the system to continue pumping water for one hour. Take three additional sets of measurements. Data Sheet 4.1.1 gives a hypothetical example of these blocks of ten and three sets of measurements.

SET OF TEN-MINUTE MEASUREMENTS:

The following constitutes a set of measurements:

<u>Time</u>

Record the time t (hour, minute, second) of the beginning and end of each ten minute measurement period.

<u>Electric energy</u>

Record the readings (kWh) of the integrating power meter E_{el} at the beginning and the end of each ten minute measuring period.

<u>Water volume pumped</u>

Record the readings (cubic meters) of the integrating flowmeter Q_p at the beginning and at the end of each ten minute measuring period.

<u>Suction head</u>

Record the suction head reading (meters) of the measuring stick, well dipper or other suction head measuring equipment H_{in} once during each ten minute period.

<u>Note:</u> In Data Sheet 4.1.1. the suction head recordings are negative because in the example the pump is below the water surface in the well. See Figure 5.1.1. and the discussion on head measurements on page 5 - 6.

<u>Discharge head</u>

Record the reading (meters) of the pressure gauge at the pump discharge H_{dis} once during each ten minute period.

<u>Note:</u> Not all pressure gauges read in meters. Other possibilities are bar, At (atmosphere), psi (pound per square inch) and kPa (kiloPascal). The following conversion factors should be used:

Pressure		equivalent head	
1 bar	->	10	[m]
1 at	->	10	[m]
1 psi	->	0.69	[m]
1 kPa	->	0.1	[m]

Pump Speed (optional)

If a variable speed transmission is used and measurements are made at different speeds, then measure the pump speed n_S (rpm) using a tachometer at the beginning of each ten minute period.

Preliminary calculations

Length of period T

Calculate the exact length of the "ten minute period" T. T simply equals the difference in time [seconds] between the start and the end of the measuring period.

Example: If the first measurement starts at 08:51:20 and ends at 09:01:01, the length of the period T equals 581 seconds (see lines 0 and 1 of Data Sheet 4.1.1.).

Average electric power input

Calculate the average power input for each ten minute period:

$$P_{el,T} = \frac{3600 * (E_{el,e} - E_{el,b})}{T} \quad [kW]$$

where:

$E_{el,b}$ = the electric energy meter reading [kWh] at the beginning of period T
$E_{el,e}$ = the electric energy meter reading [kWh] at the end of period T
T = the length of the measuring period [s]
3600 = conversion factor (seconds per hour)

Example: At 09:41:05 the energy meter reading was 345.648 kWh. At 09:51:10 the energy meter reading was 345.730 kWh. Because the length of the measuring period was 605 s, the average power input according to the formula is:

$$P_{el,T} = \frac{3600 * (345.730 - 345.648)}{605} = 0.488 \ [kW]$$

(see lines 5 and 6 of Data Sheet 4.1.1.)

Average water flow rate

Calculate the average water flow rate for each ten minute period:

$$q_{PT} = \frac{1000 * (Q_{P,e} - Q_{P,b})}{T} \quad [l/s]$$

where: $Q_{P,b}$ = the integrating flowmeter reading [cubic meters] at the beginning of each ten minute period.
$Q_{P,e}$ = the integrating flowmeter reading at the end of each ten minute period.
T = the length of the measuring period [s]
1000 = conversion factor (liters per cubic meter)

<u>Example</u>: If $Q_{P,b}$ = 723.19 [m^3] and $Q_{p,e}$ = 724.42 [m^3], then the average flow rate is q_{PT} = 2.07 [l/s] (see lines 9 and 10 in Data Sheet 4.1.1.).

Total effective head

Calculate the total effective head H for each ten minute period:

$$H = H_{in} + H_{dis} \quad [m]$$

where: H_{in} = suction head [m]
H_{dis} = discharge head [m]

<u>Example</u>: During the fourth ten minute period the suction and discharge head were -2.4 m and 10.4 m, respectively. (see line 4 of Data Sheet 4.1.1 and Figure 5.1.1 b, page 5 - 5). As a result the total effective head is 8.0 m. The result is not recorded in the Sheet.

Hydraulic power output

Calculate the hydraulic power output for each 10 minute period:

$$P_{h,T} = \frac{9.81 * q_{PT} * H}{1000} \quad [kW]$$

where: q_{PT} = the average water flow rate in [l/s]

H = the total effective head (m)
9.81 = the acceleration due to gravity
1000 = conversion factor (liters per cubic meter)

Example: For the ten minute period in the previous example q_{PT} = 2.25 [l/s]. Then the hydraulic power output is:

$$P_{h,T} = \frac{9.81 * 2.25 * 8.0}{1000} = 0.177 \text{ kW}$$

(line 4 of Data Sheet 4.1.1)

4.1.2.4 Effect of head and pump speed (optional)

For this test, the effect of changing the discharge head and/or the pump speed on the pumping rate and the system efficiency will be determined.

Discharge head effect:

The discharge head can be changed in several ways. The most effective way is if there is one or more valves located in the line between the pump discharge and the system boundary. In this case, the discharge head can be increased by partially closing one valve. The pressure gauge should be located between the valve and the pump. At no time should the valve be closed completely during this test.

Start the pump and motor. Set the transmission to the maximum speed. All valves in the discharge line should be fully open. Operate for about thirty minutes or as long is necessary to allow the motor to reach normal operating temperature and the water intake condition (drawdown) to stabilize.

Close a valve in the discharge line such that the discharge flowrate is reduced by approximately 25-50%. After 10 minutes, take ten complete sets of measurements as described in the previous section. Re-adjust the valve position so that the flow rate is further reduced by about 50%-75%. Take ten complete sets of data. Re-adjust the valve position to be fully open and take ten complete sets of data.

If there are no valves between the pump discharge and the system boundary it may still be possible to vary the discharge head. If there is a storage tank as part of the system and the intake to the storage tank is into the tank bottom, then varying the height of water in the storage tank is another way to change the discharge pressure. Alternatively the water inlet of the tank can be moved upwards temporarily by adding a vertical piece of piping to the system, thus increasing the discharge head.

Pump speed effect:

If the system uses a variable speed transmission, adjust the transmission to provide the lowest speed setting. Open the discharge valve(s) fully. After 10 minutes, take five complete sets of data as indicated below. Re-adjust the transmission to provide a speed setting intermediate between the fastest and slowest and take three complete sets of data.

4.1.3. Data Reduction

Data reduction will make use of the results of the preliminary calculations to arrive at estimates of the overall performance of the grid connected electric system which can be compared to what would be expected based on the manufacturers information or to earlier or later data.

The data reduction will consist of the calculations and preparation of curves based on the experimental measurements and the preliminary calculations.

System Efficiency

For each of the 10 minute measurement sets, calculate the overall system efficiency η_{tot} using the following equation:

$$\eta_{tot} = \frac{P_{h,T}}{P_{el,T}} \quad [-]$$

where: $P_{h,T}$ = Hydraulic power output and
$P_{el,T}$ = Average electric power input, both as calculated above.

Water Output Curves (optional)

If measurements were made at different discharge heads, for each of the measurements plot the average water flow rate q_{PT} along the vertical axis versus the total effective head along the horizontal axis.

If measurements were made at different transmission speeds, plot the average water flow rate along the vertical axis versus the pump speed along the horizontal axis.

Overall system efficiency curve (optional)

If measurements were made at different discharge heads, plot the overall system efficiency η_{tot} along the vertical axis versus the power output $P_{h,T}$ along the horizontal axis.

If measurements were made at different transmission speed settings, plot the system efficiency along the vertical axis versus the power output along the horizontal axis.

4.2. FUEL ENGINE PUMP SYSTEMS

This section covers water pumping systems in which the prime mover is a fuel engine pump. The fuel engine may be either a compression ignition (diesel) or spark ignition (gasoline) engine. The engine is coupled mechanically, generally through a transmission, to the pump, which may be a rotating screw (Mono) or centrifugal type.

4.2.1. Objectives

The objective of the short term tests of fuel engine pumps is to obtain performance data showing overall system efficiency and water pumping rate as a function of engine speed, pump speed, and total effective head.

4.2.2. Test Protocol

4.2.2.1 Data collection at the start of the tests

Before the short term tests are begun, the data collection described in Chapter 3 should be completed.

4.2.2.2 Pretest inspection and preparations

The following inspections should be carried out prior to field tests. The results should be included as comments in narrative form in the logbook, with notations as to which component or part was inspected and the results of the inspection. If a component listed below is not inspected, that fact should be noted. However, unless the system is not in operating order, do not carry out any maintenance at this time based on the pretest inspections.

Visually inspect the engine block, fuel storage tank and fuel lines, fan and fan belt, coolant water reservoir and radiator, internal engine lubricating oil reservoir, and associated gauges and instruments. Comment on the overall condition of the engine, particularly observing the adequacy of engine internal and external lubricating oil and grease, the presence of oil or water leaks, and the presence of dirt or other solid particulates in the cooling water, lubricating oil or grease. Comment on the condition of the spark plugs and/or carburetor or fuel injectors, fan and fan belt and radiator fins.

Listen to and inspect the engine during normal operation. Note difficulties in starting the engine from a cold or from a hot condition. Comment on the observed vibration of the engine block, fuel reservoir and piping, and other associated equipment. Note abnormal noises from the fan and fan belt.

Listen to and inspect the pump during normal operation. Note if the system does not appear to be in satisfactory physical condition (e.g., look for excessive corrosion, lack of lubrication, lubricant leaks, worn seals) or if the system performance during operation appears to be clearly unsatisfactory (e.g., very low water flow rate, excessive leaks, excessive pump vibrations or noise etc.).

Inspect system piping and valves visually. Open and close all valves (not during operation of the pump!). Note valves which do not operate. Note on a sketch the location and severity of leaks in valves and piping, if any. Also where possible, note the physical condition of the interior surfaces of piping and valves. Determine whether a buildup of scale or other deposits has formed that reduces the effective diameter of the pipe or that causes the interior surface to be extremely rough. Note where the wall thickness has been reduced significantly by corrosion.

Note: Following inspection of the valves, it should be determined that all of the valves leading to and from the pump are in their open position prior to the beginning of the tests.

Inspect the storage tank if included in the system. Note any leaks. Clean the sight glass if present.

Inspect the water intake. Examine screens if they are accessible and note their condition, i.e., whether they are intact or have visible holes, whether they are clogged, etc.

Install test equipment as described in sections 2.5.1 and 2.5.2.2, and ensure that the equipment is calibrated and functioning properly. Enter in the logbook a description of the test equipment used (see Section 3.5.2).

For bore hole wells, measure the static suction head (vertical distance from the water level in the borehole to the pump inlet when no water is being pumped and the pump has been off for at least two hours).

4.2.2.3 Pumping performance

The pumping performance tests will consist of sets of measurements taken during ten minute time intervals. The tests will be run at different pump speeds if possible.
It is recommended to take the sets of measurements as a continuous series. The measurements then just reduce to recording every 10 minutes the readings of the various instruments. Accuracy will greatly improve when the integrating instruments (time, fuel consumption and flow) are read in the same order every time.

DATA SHEET 4.2.1. Measurements and Calculations Short Term Tests

(to be completed by technician)

Location: ______________________ Date : ____________ [YY/MM/DD]
District: ______________________ Start time : ____________ [HH/MM/SS]
Owner : ______________________ End time : ____________ [HH/MM/SS]

	MEASUREMENTS					CALCULATIONS					
No	Time t [HH:MM:SS]	Fuel cylinder reading C_{fuel} [cm^3]	Water meter reading Q_P [m^3]	Suction head H_{in} [m]	Discharge head H_{dis} [m]	Length of period T [s]	Fuel con-sumpt. V_{fuel} [cm^3]	Water flow rate q_{PT} [l/s]	Fossil power input P_{fossil} [kW]	Hydraulic power output $P_{h,T}$ [kW]	Overall system eff. η_{tot} [-]
0	8:51:20	321.5	711.46								
1	9:01:01	393.5	715.50	-2.5	10.4	581	72.0	7.0	4.91	0.54	0.11
2	9:11:14	475.2	719.72	-2.5	10.3	613	81.7	6.9	5.28	0.53	0.10
3	9:21:33	530.5	723.44	-2.5	10.3	619	55.3	6.0	3.54	0.46	0.13
4	9:31:24	596.4	727.43	-2.4	10.4	591	65.9	6.8	4.42	0.53	0.12
5	9:41:05	656.5	731.32	-2.4	10.5	581	60.2	6.7	4.10	0.53	0.13
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											
16											

Data Sheet 4.2.1. (column "MEASUREMENTS") gives a lay-out to be used for noting down the results of the measurements and an example as how to fill in the sheet.
When the ten minute measurements are consecutive, the end of a measurement coincides with the beginning of the next one (see lines 0 to 6). Single measurements need two lines in the sheet. After every interruption a new measurement or block of measurements requires a new "0"-line.

If there are any valves in the discharge line from the pump, they should be fully opened. If there is a storage tank as part of the system, it should be at as low a level as possible at the beginning of the test.

Fill the fuel measuring cylinder with fuel up to the highest level mark. Set the transmission at maximum pump speed. Start the engine and pump. Set the engine throttle for maximum speed. Allow the engine to run for at least 30 minutes or as long as is required so that the engine has reached its normal operating temperature and the water intake conditions (drawdown) have stabilized. Take five sets of measurements as listed below. Data Sheet 4.2.1. gives a hypothetical example of this block of measurements.

SET OF TEN-MINUTE MEASUREMENTS:

The following constitutes a set of measurements:

<u>Time</u>

Record the time t (hour, minute, second) of the beginning and end of each ten minute measurement period.

<u>Fuel consumption</u>

Record the readings (cubic centimeters) of the measuring cylinder at the beginning and at the end of each ten minute measuring period (C_{fuel}).

If the measuring cylinder only has one mark on it, then fill the cylinder with a calibrated measuring jug to the mark at the beginning of the measuring period, and again at the end of the measuring period. In that case record the amount added at the end of the measuring period as read from the measuring jug in column 8 of Data Sheet 4.2.1. (V_{fuel}).

<u>Water volume pumped</u>

Record the readings (cubic meters) of the integrating flowmeter Q_p at the beginning and at the end of each ten minute measuring period.

<u>Suction head</u>

Record the suction head reading (meters) of the measuring stick, well dipper or other suction head measuring equipment H_{in} once during each ten minute period.

<u>Note:</u> In Data Sheet 4.2.1. the suction head recordings are negative because in the example the pump is below the water surface in the well. See Figure 5.2.1. and the discussion on head measurements on page 5 - 18.

Discharge head

Record the reading (meters) of the pressure gauge at the pump discharge H_{dis} once during each ten minute period.

Note: Not all pressure gauges read in meters. Other possibilities are bar, At (atmosphere), psi (pound per square inch) and kPa (kiloPascal). The following conversion factors should be used:

Pressure		equivalent head	
1 bar	->	10	[m]
1 at	->	10	[m]
1 psi	->	0.69	[m]
1 kPa	->	0.1	[m]

Pump Speed (optional)

If a variable speed transmission is used and measurements are made at different speeds, then measure the pump speed n_s (rpm) using a tachometer at the beginning of each ten minute period.

Preliminary Calculations:

Length of period T

Calculate the exact length of the "ten minute period" T. T simply equals the difference in time [seconds] between the start and the end of the measuring period.

Example: If the first measurement starts at 08:51:20 and ends at 09:01:01, the length of the period T equals 581 seconds (see lines 0 and 1 of Data Sheet 4.2.1.).

Fuel consumption

Calculate the fuel consumption for each ten minute period:

$$V_{fuel} = C_{fuel,e} - C_{fuel,b} \quad [cm^3]$$

where: $C_{fuel,b}$ = fuel measuring cylinder reading at the beginning of period T

$c_{fuel,e}$ = fuel measuring cylinder reading at the end of period T

If alternatively the fuel consumption is measured by recording the amount of fuel to be added at the end of period T to fill the fuel tank to the mark as described above, V_{fuel} simply equals this amount.

Example: At 09:11:14 the level in the fuel cylinder was 475.2 cm^3. At 09:21:33 the level was 530.5 cm^3. V_{fuel} equals the difference between these numbers:

$$V_{fuel} = 530.5 - 475.2 = 55.3 \ cm^3$$

(see lines 2 and 3 of Data Sheet 4.2.1)

Average water flow rate

Calculate the average water flow rate for each ten minute period:

$$q_{PT} = \frac{1000 * (Q_{P,e} - Q_{P,b})}{T} \quad [l/s]$$

where: $Q_{P,b}$ = the integrating flowmeter reading [cubic meters] at the beginning of each ten minute period.
$Q_{P,e}$ = the integrating flowmeter reading at the end of each ten minute period.
T = the length of the measuring period [s]
1000 = conversion factor (liters per cubic meter)

Example: If $Q_{P,b}$ = 727.43 [m^3] and $Q_{p,e}$ = 731.32 [m^3], then the average flow rate is q_{PT} = 6.7 [l/s] (see lines 4 and 5 in Data Sheet 4.2.1.).

Total effective head

Calculate the total effective head H for each ten minute period:

$$H = H_{in} + H_{dis} \quad [m]$$

where: H_{in} = suction head [m]
H_{dis} = discharge head [m]

4.2.2.4 Tests at varying pump speed (optional)

Turn off engine and reset transmission for a slower pump speed, preferably at the slowest speed that the transmission will permit. Restart the engine and pump, allow the engine to run for 30 minutes, and take five sets of measurements as listed above.
Reset the transmission to maximum pump speed. Adjust the engine throttle to obtain measurements at about five different engine speeds ranging from the maximum to the slowest speed that the engine runs in a stable manner without stalling.

4.2.3. Data reduction

Data reduction will make use of the results of the preliminary calculations to arrive at estimates of the overall performance of the fuel engine pumping system which can be compared to what would be expected based on the manufacturers information or to earlier or later data.

The data reduction will consist of the calculations and preparation of curves based on the experimental measurements and the preliminary calculations.

<u>Fossil power input</u>

For each ten-minute period calculate the average fossil power input P_{fossil} using the following equation:

$$P_{fossil} = \frac{3.6 * V_{fuel} * B}{T} \quad [kW]$$

where:
- V_{fuel} = fuel consumption during period T in [cm^3]
- T = length of period T in [s]
- B = the caloric value of the fuel in [kWh/l]
- 3.6 = conversion factor (seconds per hour, liters per cubic meter)

The caloric values of various fuels are as follows:

Type of fuel	Nett Caloric Value B [kWh/l]
Diesel oil / gasoil	11
Petrol / gasoline	9
Kerosene / parrafin	10

<u>Example:</u> From 09:31:24 to 09:41:05 the fuel consumption $V_{fuel} = 60.2\ cm^3$. Assuming for the example that the fuel is diesel oil gives B = 11 kWh/l. Then the fossil power input is:

$$P_{fossil} = \frac{3.6 * 60.2 * 11}{581} = 4.1\ kW$$

(see lines 4 and 5 of Data Sheet 4.2.1)

Hydraulic power output

Calculate the hydraulic power output for each 10 minute period:

$$P_{h,T} = \frac{9.81 * q_{PT} * H}{1000} \quad [kW]$$

where: q_{PT} = the average water flow rate in [l/s]

H = the total effective head (m)
9.81 = the acceleration due to gravity
1000 = conversion factor (liters per cubic meter)

<u>Example:</u> For the ten minute period in the previous example q_{PT} = 6.7 [l/s]. Then the hydraulic power output is:

$$P_{h,T} = \frac{9.81 * 6.7 * 8.1}{1000} = 0.53\ kW$$

(line 5 of Data Sheet 4.2.1)

System Efficiency

For each of the 10 minute measurement sets, calculate the overall system efficiency η_{tot} using the following equation:

$$\eta_{tot} = \frac{P_{h,T}}{P_{fossil}} \quad [-]$$

where: $P_{h,T}$ = Hydraulic power output and
P_{fossil} = Average fossil power input, both as calculated above.

Water Output Curves (optional)

If measurements were made at different pump speeds (resulting from either different engine or different transmission speeds), plot the average water flow rate q_{PT} along the vertical axis versus the pump speed n_S along the horizontal axis.

Overall system efficiency curve (optional)

If measurements were made at different engine or transmission speeds, plot the overall system efficiency η_{tot} along the vertical axis versus the power output $P_{h,T}$ along the horizontal axis.

4.3. SOLAR PUMPS

This section covers water pumping systems in which the prime mover is a solar photovoltaic electric pump. The systems may use AC or DC motors which drive centrifugal or screw type pumps. The systems may make use of power conditioning equipment to adjust the voltage level generated under various irradiance conditions in order to result in higher pump and motor efficiencies.

4.3.1. Objectives

The objectives of the short term tests of solar pumps is to obtain performance data showing overall system efficiency and water pumping rate as a function of irradiance and total effective head and covering the normal range of irradiance expected at the site.

4.3.2. Test Protocol

4.3.2.1 Data collection at the start of the tests

Before the short term tests are begun, the data collection described in Chapter 3 should be completed.

4.3.2.2 Pretest inspection and preparations

The following inspections should be carried out prior to field tests. The results should be included as comments in narrative form in the logbook, with notations as to which component or part was inspected and the results of the inspection. If a component listed below is not inspected, that fact should be noted. However, unless the system is not in operating order, do not carry out any maintenance at this time based on the pretest inspections.

Visually inspect the array assembly. Note in the logbook the relative cleanliness (transparency) of the array glass covers, and the number and location of modules or cells that are known to be defective. Examine the instruments and controllers and note in the logbook signs of insulation deterioration or moisture intrusion which may cause shorting.

Listen to and inspect the pump during normal operation. Note if the system does not appear to be in satisfactory physical condition (e.g., look for excessive corrosion, lack of lubrication, lubricant leaks, worn seals) or if the system performance during operation appears to be clearly unsatisfactory (e.g., very low water flow rate, excessive leaks, excessive pump vibrations or noise etc.).

Inspect system piping and valves visually. Open and close all valves (not during operation of the pump!). Note valves which do not operate. Note on a sketch the location and severity of leaks in valves and piping, if any. Also where possible, note the physical condition of the interior surfaces of piping and valves. Determine whether a buildup of scale or other deposits has formed that reduces the effective diameter of the pipe or that causes the interior surface to be extremely rough. Note where the wall thickness has been reduced significantly by corrosion.

Note: Following inspection of the valves, it should be determined that all of the valves leading to and from the pump are in their open position prior to the beginning of the tests.

Inspect the storage tank if included in the system. Note any leaks. Clean the sight glass if present.

Inspect the water intake. Examine screens if they are accessible and note their condition, i.e., whether they are intact or have visible holes, whether they are clogged, etc.

Install test equipment as described in sections 2.5.1 and 2.5.2.3, and ensure that the equipment is calibrated and functioning properly. Enter in the logbook a description of the test equipment used (see Section 3.5.3).

For bore hole wells, measure the static suction head (vertical distance from the water level in the borehole to the pump inlet when no water is being pumped and the pump has been off for at least two hours).

4.3.2.3 Pumping Performance

The pumping performance tests will consist of sets of measurements taken during ten minute time intervals under conditions where the solar panels are receiving full sun.

The ten minute measurement intervals should be distributed equally throughout the day starting at approximately 09:00 local time and ending at approximately 16:00 local time. A total of 50 sets of ten minute measurements should be taken over a period of several days.

It is recommended to take the sets of measurements in a number of blocks of consecutive measurements. Within these blocks the measurements then just reduce to recording every 10 minutes the readings of the various instruments. Accuracy will greatly improve when the integrating instruments (time, irradiation, array energy output, flow and stroke/revolution counter) are read in the same order every time.

Data Sheet 4.3.1. (column "MEASUREMENTS") gives a lay-out to be used for noting down the results of the measurements and an example as how to fill in the sheet.
When the ten minute measurements are consecutive, the end of a measurement coincides with the beginning of the next one (see lines 0 to 3, 5 to 8, etc.). Single measurements need two lines in the sheet (see lines 10 and 11). After every interruption a new measurement or block of measurements requires a new "0"-line (see lines 0, 5, 10, 13, 17 and 21).

It is not necessary that there be no clouds as long as the clouds do not obscure the sun during measurement periods. If the sun is obscured during any portion of a measurement period, then data taken during that period should be omitted and that fact noted in the logbook.

If there are any valves in the discharge line from the pump, they should be fully opened. If there is a storage tank as part of the system, it should be at as low a level as possible at the beginning of the test.

Start the motor and pump in the morning of a clear day as soon after sunrise as the solar radiation will permit. Allow the system to operate continuously throughout the test. Take a first block of 3 - 5 ten-minute measurements starting at approximately 09:00 local time and following that, at approximately one hour intervals until approximately 16:00 local time.

SET OF TEN-MINUTE MEASUREMENTS:

The following constitutes a set of measurements:

Time

Record the time t (hour, minute, second) of the beginning and end of each ten minute measurements period.

Irradiation

Record the integrated irradiance (Wh/m2) reading from the pyranometer E_{sol} at the beginning and at the end of each ten minute period.

Water volume pumped

Record the readings Q_P (cubic meters) of the integrating flow meter at the beginning and at the end of each ten minute measuring period.

DATA SHEET 4.3.1. Measurements and calculations Short Term Tests

(to be completed by technician)

Location: ______________________ Date : ________ [YY/MM/DD]

District: ______________________ Start time : ________ [HH,MM,SS]

Owner : ______________________ End time : ________ [HH,MM,SS]

Array area A_{array} : 3.4 [m^2]

	MEASUREMENTS						CALCULATIONS			
No	Time	Solar irrad.	Array energy output	Water meter reading	Suction head	Discharge head	Length of period	Average irradi-ance	Average flow rate	Overall system eff.
	t	E_{sol}	E_{el}	Q_P	H_{in}	H_{dis}	T	$P_{sol,T}$	q_{PT}	η_{tot}
	[HH:MM:SS]	[Wh/m^2]	[Wh]	[m^3]	[m]	[m]	[s]	[W/m^2]	[l/s]	[-]
0	8:51:20	4256	4563	2548.37						
1	9:01:01	4399	4603	2548.94	3.5	7.7	581	886	0.98	0.036
2	9:11:14	4549	4647	2549.60	3.5	7.7	613	881	1.08	0.039
3	9:21:33	4704	4691	2550.30	3.5	7.8	619	901	1.13	0.041
4										
5	10:31:01	5798	5004	2554.85						
6	10:40:51	5961	5053	2555.52	3.6	7.9	590	995	1.14	0.038
7	10:51:09	6135	5102	2556.28	3.6	8.0	618	1014	1.23	0.041
8	11:01:24	6307	5152	2557.03	3.6	8.0	615	1007	1.22	0.041
9										
10	12:11:35	7491	5492	2561.83						
11	12:21:32	7660	5543	2562.55	3.7	8.0	597	1019	1.21	0.040
12										
13	13:11:48	8495	5782	2565.84						
14	13:21:43	8660	5830	2566.47	3.7	8.0	595	998	1.06	0.036
15	13:31:40	8825	5879	2567.14	3.7	7.9	597	995	1.12	0.038
16										
17	14:21:38	9616	6107	2570.35						
18	14:31:41	9767	6150	2570.93	3.8	7.8	603	901	0.96	0.036
19	14:41:33	9916	6191	2571.58	3.8	7.8	592	906	1.10	0.041
20										
21	15:31:24	10618	6395	2574.53						
22	15:41:15	10749	6432	2575.10	3.8	7.6	591	798	0.96	0.040
23	15:50:55	10873	6469	2575.59	3.8	7.5	580	770	0.84	0.036
24	16:00:46	10997	6507	2576.15	3.8	7.5	591	755	0.95	0.041
25										
26										
27										

Suction head

Record the reading (meters) of the suction head H_{in} once during each ten minute measurement.

<u>Note:</u> If the pump is below the water surface in the well the suction head should be recorded as a negative number. See Figure 5.3.1. and the discussion on head measurements on page 5 - 33.

<u>Discharge head</u>

Record the reading (meters) of the pressure gauge at the pump discharge H_{dis} once during each ten minute period.

<u>Note:</u> Not all pressure gauges read in meters. Other possibilities are bar, At (atmosphere), psi (pound per square inch) and kPa (kiloPascal). The following conversion factors should be used:

Pressure		equivalent head	
1 bar	->	10	[m]
1 at	->	10	[m]
1 psi	->	0.69	[m]
1 kPa	->	0.1	[m]

<u>Temperature (optional)</u>

Record the module internal temperature (deg C) beneath the glass cover of one or more solar cell modules at the beginning of each ten minute period. If the temperature of the module cannot be obtained, record the ambient temperature of the air on the outside of the solar panels.

<u>Array energy output (optional)</u>

Record the array electric energy output E_{el} (Watthours) at the beginning and the end of each ten minute measurement period.

<u>Pump Speed (optional)</u>

Measure the pump speed n_s (rpm) using a tachometer at the beginning of each ten minute period.

Preliminary calculations:

Length of period T

Calculate the exact length of the "ten minute period" T. T simply equals the difference in time [seconds] between the start and the end of the measuring period.

Example: If the first measurement starts at 8:51:20 and ends at 9:01:01, the length of the period T equals 581 seconds (see lines 0 and 1 of Data Sheet 4.3.1.).

Average water flow rate

Calculate the average water flow rate for each ten minute period:

$$q_{PT} = \frac{1000 * (Q_{P,e} - Q_{P,b})}{T} \quad [l/s]$$

where: $Q_{P,b}$ = the integrating flowmeter reading [cubic meters] at the beginning of each ten minute period.
$Q_{P,e}$ = the integrating flowmeter reading at the end of each ten minute period.
T = the length of the measuring period [s]
1000 = conversion factor (liters per cubic meter)

Example: If $Q_{P,b}$ = 2556.28 [m^3] and $Q_{P,e}$ = 2557.03 [m^3], then the average flow rate is q_{PT} = 1.22 [l/s] (see lines 7 and 8 in Data Sheet 4.3.1.).

Total effective head

Calculate the total effective head H for each ten minute period:

$$H = H_{in} + H_{dis} \quad [m]$$

where: H_{in} = suction head [m]
H_{dis} = discharge head [m]

Average solar irradiance

Calculate the average irradiance $P_{sol,T}$ for each ten minute period:

$$P_{sol,T} = \frac{3600 * (E_{sol,e} - E_{sol,b})}{T} \quad [W/m^2]$$

where: $E_{sol,b}$ = the integrating pyranometer reading at the beginning of period T (Wh/m^2).
$E_{sol,e}$ = the integrating pyranometer reading at the end of period T
T = length of measuring period T (s)
3600 = conversion factor (seconds per hour)

Example: If $E_{sol,b}$ = 8660 [Wh/m^2] and $E_{sol,e}$ = 8825 [Wh/m^2], the average solar irradiance is:

$$P_{sol,T} = \frac{3600 * (8825 - 8660)}{597} = 995 \ W/m^2$$

(see lines 14 and 15 in Data Sheet 4.3.1.)

4.3.2.4 Discharge head effect (optional)

The following day or the next clear day, close a discharge valve such that the discharge flow rate is reduced by about 25-50%. Start the motor and pump as in the preceding paragraph and repeat the measurements.

4.3.3. Data Reduction

Data reduction will make use of the results of the preliminary calculations to arrive at estimates of the overall performance of the solar pump system which can be compared to what would be expected based on the manufacturers information or to earlier or later data.

The data reduction will consist of calculations and preparation of curves based on the experimental measurements and the preliminary calculations.

Power Input

Calculate the average solar power input $P_{sol,i}$ for each ten minute period using the following equation:

$$P_{sol,i} = P_{sol,T} * A_{array} \quad [W]$$

where: $P_{sol,T}$ = the average irradiance (W/m^2)
A_{array} = the gross solar panel surface area (m2)

Example: Between 14:21:38 and 14:31:41 the average solar power input was:

$$P_{sol,i} = 901 * 3.4 = 3063.4 \ [W]$$

See lines 17 and 18 in Data Sheet 4.3.1. The number 3.4 is the array area as given in the top lines of the data sheet. The result is not recorded.

Hydraulic power output

For each of the ten minute measurements sets, calculate the hydraulic power output $P_{h,T}$ using the following equation:

$$P_{h,T} = 9.81 * q_{PT} * H \quad [watt]$$

where: q_{PT} = the average flow rate (l/s)
H = the total effective head (m)
9.81 = the acceleration due to gravity.

Example: If q_{PT} = 0.96 [l/s] and H_{in} and H_{dis} are 3.8 [m] and 7.8 [m] respectively, then $P_{h,T}$ = 109.2 [Watt] (see line 18 of Data Sheet 4.3.1.; result not recorded).

Overall system efficiency

For each of the 10 minute measurement sets, calculate the overall system efficiency η_{tot} using the following equation:

$$\eta_{tot} = \frac{P_{h,T}}{P_{sol,i}} \quad [-]$$

where: $P_{h,T}$ = Hydraulic power output and
$P_{sol,i}$ = Average solar power input, both as calculated above.

Example: For the ten minute measurement that started at 14:21:38 the results of the previous examples lead to:

$$\eta_{tot} = \frac{109.2}{3063.4} \approx 0.036$$

(see line 18 of Data Sheet 4.3.1)

Water Output Curve

For the data taken with all discharge valves fully open, plot the average water flow rate q_{PT} along the vertical axis versus the time of day along the horizontal axis.

Electric power output curve (optional)

Calculate for each ten minute period the electric power output $P_{el,sol}$ of the solar array:

$$P_{el,sol} = \frac{3600 * (E_{el,e} - E_{el,b})}{T} \quad [W]$$

where: $E_{el,b}$ = the electric energy meter reading at the beginning of period T (Wh)
$E_{el,e}$ = the electric energy meter reading at the end of period T
T = length of period T (s)
3600 = conversion factor (seconds per hour)

Plot the array output power $P_{el,sol}$ along the vertical axis versus the irradiance $P_{sol,T}$ along the horizontal axis.

Figure 4.3.1. gives an example of such a graph.

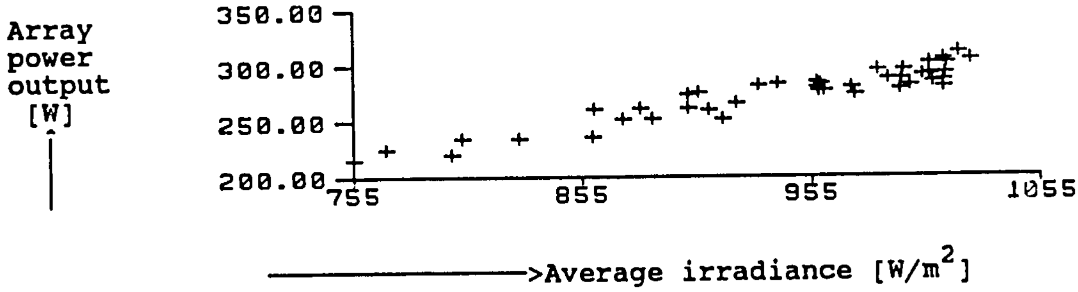


Figure 4.3.1. Example of electric power output curve

4.4. MECHANICAL WIND PUMPS

This section covers water pumping systems in which the prime mover is a windmill. The windmill is coupled mechanically, generally through a transmission, to the pump, which may be a reciprocating, rotating screw (Mono), or centrifugal type.

4.4.1. Objectives

The objective of the Short Term Tests of windmill direct drive systems is to obtain curves showing system water pumping rates, energy inputs and outputs, and efficiencies as a function of ten-minute average windspeeds covering the normal range of windspeeds expected at the site.

Additional data will be obtained on the performance of the windmill and of the pump. These include rotor speed characteristics as a function of windspeed and load, and water pumping rate as a function of rotor speed.

4.4.2. Test Protocol

4.4.2.1 Data collection at the start of the tests

Before the short term tests are begun, the data collection described in Chapter 3 should be completed.

4.4.2.2 Pretest inspection and preparations:

The following inspections should be carried out prior to field tests. The results should be included as comments in narrative form in the logbook, with notations as to which component or part was inspected and the results of the inspection. If a component listed below is not inspected, that fact should be noted. However, unless the system is not in operating order, do not carry out any maintenance at this time based on the pretest inspections.

Inspect the windmill rotor, the transmission and the pump assembly visually. Determine the condition of the blades, shaft and bearings, both those used for transmitting power and for yawing. Note changes from the original form or spacing of the blades. Comment on the visible wear of all the moving parts including bearings and transmission gears. Note whether lubrication appears adequate.

Observe the windmill during operation. Note whether the rotor turns freely in its bearings and whether it turns easily with the changes in the wind direction. Note excessive vibration of windmill shaft or transmission, if any, while the rotor is rotating.

Listen to the pump during operation. Note if the system does not appear to be in satisfactory physical condition (e.g. look for excessive corrosion, lack of lubrication, lubricant leaks, worn seals) or if the system performance during operation appears to be clearly unsatisfactory (e.g. very low water flow rate, excessive leaks, excessive pump vibrations, noises).

Inspect system piping and valves visually. With the windpump furled, open and close all valves. Note valves which do not operate. Note on a sketch the location and severity of leaks in valves and piping, if any. Also where possible, note the physical condition of the interior surfaces of piping and valves. Determine whether a build-up of scale or other deposits has formed that reduces the effective diameter of the pipe or that causes the interior surface to be extremely rough. Note where the wall thickness has been reduced significantly by corrosion.

Note: Following inspection of the valves, it should be determined that all of the valves leading to and from the pump are set in their open position prior to beginning the tests.

Inspect the storage tank if included in the system. Note any leak. Clean the sight glass if present.

Inspect the water intake. Examine screens if they are accessible and note their condition, i.e. whether they are intact or have visible holes, whether they are clogged, etc.

Install test equipment as described in sections 2.5.1. and 2.5.2.4., and ensure that the equipment is calibrated and functioning properly. Enter in the logbook a description of the test equipment used (see section 3.5.4).

For bore hole wells, measure the static suction head (vertical distance from the water level in the borehole to the pump inlet when no water is being pumped and the pump has been off for at least two hours).

4.4.2.3 Pumping performance.

The pumping performance tests will consist of sets of measurements taken during ten minute time intervals.
It is recommended to take the sets of measurements as a continuous series. The measurements then just reduce to recording every 10 minutes the readings of the various instruments. Accuracy will greatly improve when the integrating instruments (time, wind speed, flow and stroke/revolution counter) are read in the same order every time.

Data Sheet 4.4.1. (column "MEASUREMENTS") gives a lay-out to be used for noting down the results of the measurements and an example as how to fill in the sheet.
When the ten minute measurements are consecutive, the end of a measurement coincides with the beginning of the next one (see lines 0 to 6). Single measurements need two lines in the sheet (see lines 10 and 11). After every interruption a new measurement or block of measurements requires a new "0"-line (see lines 0, 10 and 13).

A total of 100 sets of ten minute measurements should be taken over a period of several days. If wind conditions warrant, the sets of measurements should cover periods when the windspeed is high as well as periods when the windspeed is low.
If the rotor does not rotate at all during a 10 minute period, that period should be omitted.

Engage the rotor and pump early in the morning (just after sunrise) of a day with expected normal windspeed. After the windspeed has become so high that the rotor is turning steadily, take a series of ten-minute measurements as follows:

SET OF TEN-MINUTE MEASUREMENTS:

The following constitutes a set of measurements:

Time

Record the time t (hour, minute, second) of the beginning and end of each ten minute measurements period.

Windrun

Record the readings (kilometers) of the integrating anemometer (windrun meter) R_W at the beginning and at the end of each ten minute measuring period.

Water volume pumped

Record the readings (cubic meters) Q_P of the integrating flow meter at the beginning and at the end of each ten minute measuring period.

Rotor rotations

Record the readings (revolutions) of the integrating rotation counter attached to the rotor N_R at the beginning and the end of each ten minute measuring period.

DATA SHEET 4.4.1. Measurements and Calculations Short Term Tests

(to be completed by technician)

Location:		Date :	[YY/MM/DD]
District:		Start time :	[HH:MM:SS]
Owner :		End time :	[HH:MM:SS]
Pressure head H_p : / [m]		Rotor Diameter: 8 [m]	

	MEASUREMENTS (see section 4.4.2.)						CALCULATIONS (see section 4.4.2. and 4.4.3.)				
No	Time	Wind run	Water meter reading	Rotor rotations *)	Suction Head	Discharge Head	Length of period	Average Wind	Flow rate	Rotational speed **)	Perform. factor
	t	R_W	Q_P	N_R or N_S	H_{in}	H_{dis}	T	speed V_T	q_{PT}	n_{RT} or n_{ST}	C_p.eta
	[HH:MM:SS]	[km]	[m^3]	[-]	[m]	[m]	[seconds]	[m/s]	[l/s]	[rev/s]	[-]
0	7:30:30	156.23	762.31	1829	X	X					
1	7:41:25	158.69	762.57	2165	4.4	31.5	655	3.68	0.40	0.51	0.091
2	7:51:05	160.56	762.77	2424	4.3	31.5	580	3.31	0.34	0.45	0.108
3	8:00:40	162.53	762.99	2703	4.2	31.5	575	3.43	0.38	0.49	0.108
4	8:10:20	164.69	763.24	3017	4.1	31.5	580	3.72	0.43	0.54	0.095
5	8:20:40	167.14	763.52	3366	4.0	31.5	620	3.95	0.45	0.56	0.083
6	8:31:20	169.58	763.80	3717	3.9	31.5	640	3.81	0.44	0.55	0.089
7											
8											
9											
10	9:20:45	180.22	764.98	5207	X	X	X	X	X	X	X
11	9:31:05	182.34	765.20	5495	3.7	31.5	620	3.42	0.35	0.46	0.099
12											
13	9:50:25	187.39	765.75	6168	X	X	X	X	X	X	X
14	10:00:40	189.72	766.00	6482	3.7	31.5	615	3.79	0.41	0.51	0.084
15	10:11:00	191.95	766.22	6773	3.7	31.5	620	3.60	0.35	0.47	0.085
16	10:20:40	193.74	766.39	6999	3.6	31.5	580	3.09	0.29	0.39	0.111
17	10:31:00	195.92	766.62	7288	3.6	31.5	620	3.52	0.37	0.47	0.095
18	10:40:50	197.81	766.81	7541	3.6	31.5	590	3.20	0.32	0.43	0.109
19	10:51:00	199.70	767.01	7797	3.6	31.5	610	3.10	0.33	0.42	0.123
20	11:00:40	201.39	767.18	8022	3.6	31.5	580	2.91	0.29	0.39	0.132
21	11:10:40	203.00	767.35	8247	3.6	31.5	600	2.68	0.28	0.38	0.164
22	11:20:30	204.70	767.52	8472	3.6	31.5	590	2.88	0.29	0.38	0.135
23	11:30:05	206.41	767.71	8714	3.6	31.5	575	2.97	0.33	0.42	0.140
24	11:40:10	207.33	767.84	8908	3.6	31.5	605	2.43	0.21	0.32	0.167

*) Change into Pump strokes if applicable. **) Change into pump stroke rate if applicable.

Pump strokes

(Only as an alternative for rotor rotations; Pump strokes and rotor rotations are related by the transmission ratio).
For reciprocating pumps, record the readings (number of strokes) of the integrating stroke counter N_S at the beginning and the end of each ten minute measuring period.

Suction head

Record the reading (mèters) of the suction head H_{in} at the beginning of each ten minute period.

Note: If the pump is below the water surface in the well the suction head should be recorded as a negative number. See Figure 5.4.1. and the discussion on head measurements on page 5 - 49.

Discharge head

Record the reading (meters) of the pressure gauge at the pump discharge H_{dis} at the beginning of each ten minute period. During Short Term Tests the discharge head is defined as the head the pump "sees", including pipeline friction losses (see Annex 2.2).

Note: Not all pressure gauges read in meters. Other possibilities are bar, At (atmosphere), psi (pound per square inch) and kPa (kiloPascal). The following conversion factors should be used:

Pressure		equivalent head	
1 bar	->	10	[m]
1 at	->	10	[m]
1 psi	->	0.69	[m]
1 kPa	->	0.1	[m]

Preliminary calculations:

Length of period T

Calculate the exact length of the "ten minute period" T. T simply equals the difference in time [seconds] between the start and the end of the measuring period.

Example: If the first measurement starts at 7:30:30 and ends at 7:41:25, the length of the period T equals 655 seconds (see lines 0 and 1 of Data Sheet 4.4.1.).

Average windspeed

Calculate the average windspeed for each ten minute period:

$$V_T = \frac{1000 * (R_{w,e} - R_{w,b})}{T} \quad [m/s]$$

where: $R_{w,b}$ = the integrating anemometer reading (kilometers) at the beginning of the measuring period.
$R_{w,e}$ = the integrating anemometer reading at the end of measuring period.
T = the length of measuring period.

Example: If $R_{w,b}$ = 162.53 [km] and $R_{w,e}$ = 164.69 [km], the average windspeed is V_T = 3.72 [m/s] (see lines 3 and 4 in Data Sheet 4.4.1.).

Average water flow rate

Calculate the average water flow rate for each ten minute period:

$$q_{PT} = \frac{1000 * (Q_{P,e} - Q_{P,b})}{T} \quad [l/s]$$

where: $Q_{P,b}$ = the integrating flowmeter reading [cubic meters] at the beginning of each ten minute period.
$Q_{P,e}$ = the integrating flowmeter reading at the end of each ten minute period.
T = the length of the measuring period.
1000 = conversion factor (liters per cubic meter)

Example: If $Q_{P,b}$ = 764.98 [m^3] and $Q_{p,e}$ = 765.20 [m^3], then the average flow rate is q_{PT} = 0.35 [l/s] (see lines 10 and 11 in Data Sheet 4.4.1.).

Average rotational rotor speed

Calculate the average rotational speed of the windmill rotor for each ten minute period:

$$n_{RT} = \frac{N_{R,e} - N_{R,b}}{T} \quad \text{[revs/s]}$$

where: $N_{R,b}$ = the integrating rotation counter reading at the beginning of the measuring period.
$N_{R,e}$ = the integrating rotation counter reading at the end of the measuring period.
T = the length of the measuring period.

Example: If $N_{R,b}$ = 6773 [-] and $N_{R,e}$ = 6999 [-], then the average rotational speed n_{RT} = 0.39 [rev/s] (see lines 15 and 16 in Data Sheet 4.4.1.).

Average stroke rate (optional)

Calculate the average stroke rate n_{ST} of the reciprocating pump for each ten minute period:

$$n_{ST} = \frac{N_{S,e} - N_{S,b}}{T} \quad \text{[strokes/s]}$$

where: $N_{S,b}$ = the integrating stroke counter reading at the beginning of the measuring period.
$N_{S,e}$ = the integrating stroke counter reading at the end of the measuring period.
T = the length of the measuring period.

Average effective plunger capacity (optional)

Calculate the average effective plunger capacity of the reciprocating pump:

$$PC = \frac{q_{PT}}{n_{ST}} \quad \text{[liter/stroke]}$$

4.4.3. Data Reduction.

Data reduction will make use of the results of the preliminary calculations to arrive at estimates of the overall performance of the windmill system which can be compared to what would be expected based on the manufacturers information or to earlier or later data.
The data reduction will consist of the preparation of the following curves based on the experimental measurements:

Water Output Curve

For each of the ten minute measurement sets, plot the average water flow rate q_{PT} along the vertical axis versus the average windspeed V_T along the horizontal axis. Figure 4.1. gives an example.

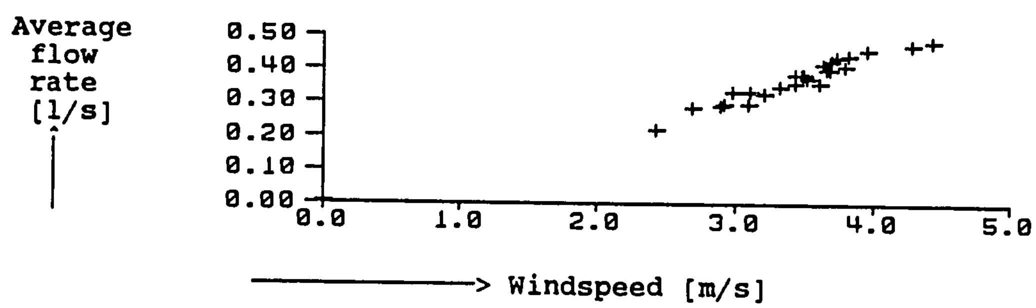


Figure 4.1. Example of water output curve

Rotor Rotational Speed Curve.

For each of the 10 minute measurement sets taken with the rotor engaged, plot the average rotational speed n_{RT} of the windmill rotor along the vertical axis versus the average windspeed V_T along the horizontal axis. Figure 4.2. gives an example.

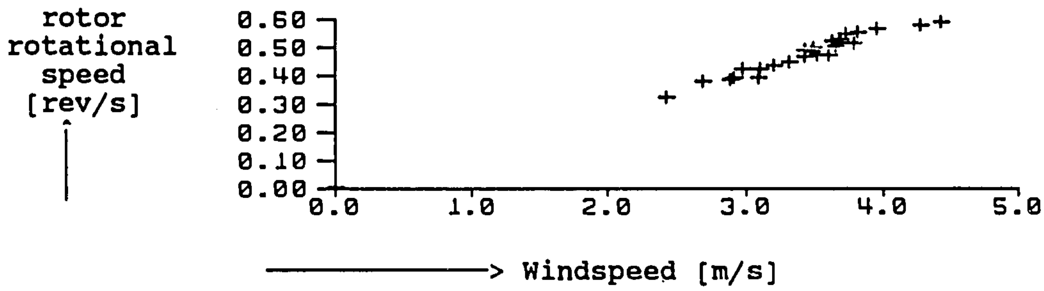


Figure 4.2. Example of rotor rotational speed curve

Hydraulic power output curve

For each of the ten minute measurements sets, calculate the hydraulic power output $P_{h,T}$ from q_{PT}, H_{in} and H_{dis} using the following equation:

$$P_{h,T} = 9.81 * q_{PT} * (H_{in} + H_{dis}) \quad [watt]$$

where: 9.81 = the acceleration due to gravity.

Example: If q_{PT} = 0.29 [l/s] and H_{in} and H_{dis} are 3.6 [m] and 31.5 [m] respectively, then $P_{h,T}$ = 99.9 [Watt] (see line 20 of Data Sheet 4.4.1.; result not recorded).

Plot the hydraulic power output $P_{h,T}$ as calculated for each ten minute measurement along the vertical axis versus the average windspeed V_T along the horizontal axis.

Power input

For each of the ten minute measurements sets, calculate the power input $P_{i,T}$ using the following equation:

$$P_{i,T} = 0.393 * rho_a * D^2 * V_T^3 \qquad [watt]$$

where: 0.393 = conversion factor equalling $\pi/8$,
D = rotor diameter [m],
V_T = average windspeed [m/s],
rho_a = density of air, obtained from the table below.

Example: If $D = 8$ [m], $V_T = 2.91$ [m/s] and $rho_a = 1.23$ [m^3/kg],

then $P_{i,T} = 762$ [Watt] (see line 20 of Data Sheet

4.4.1. ; result not recorded)

Altitude above sea level [m]	Air density rho_a [kg/m^3]		
	15°C	25°C	30°C
0	1.23	1.18	1.15
1000	1.09	1.05	1.02
2000	0.96	0.93	0.90
3000	0.85	0.82	0.79
4000	0.75	0.72	0.70
5000	0.65	0.63	0.61

Overall windpump performance factor curve

For each of the ten minute measurement sets, calculate the overall windpump performance factor C_p.eta from the following equation:

$$C_p.eta = \frac{P_{h,T}}{P_{i,T}} \qquad [-]$$

where: $P_{h,T}$ = hydraulic power output,
$P_{i,T}$ = power input, both as calculated above.

Example: If $P_{h,T}$ = 99.9 [Watt] and $P_{i,T}$ = 762 [Watt], then

C_p.eta = 0.13 (see line 20 of Data Sheet 4.4.1.).

Plot the windpump performance factor C_p.eta for each ten minute measurement set along the vertical axis versus the average windspeed V_T along the horizontal axis. Figure 4.3. gives an example. The large scatter in the region with average windspeeds between 1.2 and 2.8 [m/s] is caused by the so-called hysteresis effect; Within this range of windspeeds a running windpump will continue to run and a not-running windpump will not start.

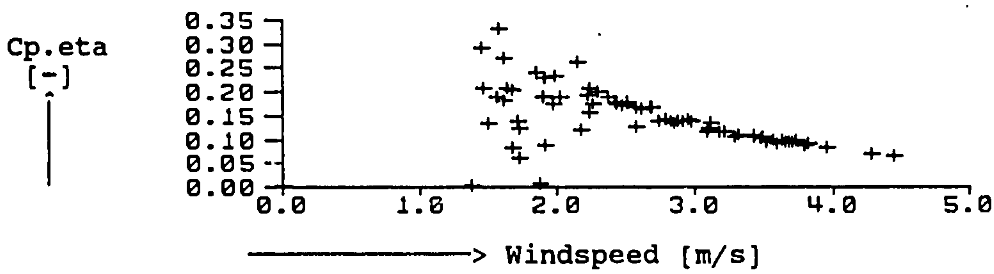


Figure 4.3. Example of overall windpump performance factor curve.

4.5 HAND PUMPS

This section covers water pumping systems in which the prime mover is a human operating a one-person hand pump. The pump may be a reciprocating type, a rotating screw type, or a counterpoise or swing basket system.

4.5.1 Objectives

The objectives of the short term tests of hand pumps is to obtain performance data showing the distribution of water pumping rates for different types of hand pumps as a function of the age and sex of the pumper and the suction head (drawdown).

4.5.2 Test Protocol

4.5.2.1 Data collection at the start of the tests

Before the short term tests are begun, the data collection described in Chapter 3 should be completed.

4.5.2.2 Pretest inspection and preparations

The following inspections should be carried out prior to field tests. The results should be included as comments in narrative form in the logbook, with notations as to which component or part was inspected and the results of the inspection. If a component listed below is not inspected, that fact should be noted. However, unless the system is not in operating order, do not carry out any maintenance at this time based on the pretest inspections.

Visually inspect the pump assembly. If possible, disassemble the pump assembly and inspect individual parts. Note in the logbook worn or corroded parts: for reciprocating pumps, cylinder, piston, and packing; for rotating screw pumps, screw and liner; for counterpoise or swing basket systems, inadequate counterweight or leaking baskets, etc.

Listen to and inspect the pump during normal operation. Note if the system performance during operation appears to be clearly unsatisfactory (e.g. very high force needed to operate pump, very low water flow rate, excessive leaks, excessive pump noise etc.).

Inspect system piping and valves visually. Open and close all valves. Note valves which do not operate. Note on a sketch the location and severity of leaks in valves and piping, if any. Also where possible, note the physical condition of the interior surfaces of piping and valves, where present. Determine whether a buildup of scale or other deposits has formed that reduces the effective diameter of the pipe or that causes the interior surface to be extremely rough. Note where the wall thickness has been reduced significantly by corrosion.

<u>Note:</u> Following inspection of the valves, it should be determined that all of the valves leading to and from the pump are in their open position prior to the beginning of the tests.

Inspect the storage tank if included in the system. Note any leaks. Clean the sight glass if present.

Inspect the water intake. Examine screens if they are accessible and note their condition, i.e. whether they are intact or have visible holes, whether they are clogged, etc.

Install test equipment as described in section 2.5.1. and ensure that the equipment is calibrated and functioning properly. Enter in the logbook a description of the test equipment used (see Section 3.5.5).

For borehole wells, measure the static suction head (vertical distance from the water level in the borehole to the pump inlet when no water is being pumped and the pump has been off for at least two hours).

4.5.2.3 Normal Pumping Test

With the cooperation of the normal users of the pump, observe and record the pump use characteristics over a period of 24 hours. All individuals using the pump should use the containers they normally use, and should be encouraged to fill them only to the amount that they normally do.

Data Sheet 4.5.1. gives a lay-out to be used for noting down the information required and an example as how to fill in the sheet. During a measuring period the following information about persons using the pump is to be recorded:

<u>Pumping time, water volume pumped and characterization of users</u>

For each usage proceed as follows:

1. By means of the stop-watch measure the time T_P a person needs to fill her/his tin or bucket.
2. By means of the calibrated container measure the volume of the water pumped Q_{PP} by each user.
3. Determine her/his sex and age. In many cases it is not necessary to ask after the age; the class (7-11, 12-17, »17) can be determined by guessing.

Put the results in Data Sheet 4.5.1.; Sex and age are recorded by noting down the pumping time and the water volume pumped in the applicable column. Put the pumping time in seconds before the semi-colon and the water volume pumped in liters behind it.

DATA SHEET 4.5.1. Measurements and Calculations Short Term Tests

(to be completed by technician)

Location: ______ Date : [YY,MM,DD]
District: ______ Begin time: [HH,MM]
Owner : ______ End time : [HH,MM]

Discharge head H_{dis} : 7.30 [m]

No	Time t	Pumping time T_p [s]; Water volume pumped per user Q_{pp} [l]						Suction head	Number of strokes	Average pumping rate	Average effective pl. cap.
		female			male			H_{in}	N_S	q_{PT}	PC
		7-11	12-17	> 17	7-11	12-17	> 17				
	HH;MM	[s];[l]	[s];[l]	[s];[l]	[s];[l]	[s];[l]	[s];[l]	[m]	[-]	[l/s]	[l/stroke]
1		80;9						-1.80	26	0.11	0.35
2			95;19					-1.80	30	0.20	0.63
3					75;11			-1.90	22	0.15	0.50
4				85;20				-1.80	48	0.24	0.42
5			75;16					-1.80	31	0.20	0.48
6						65;18		-1.80	32	0.28	0.56
7					60;12			-1.70	20	0.20	0.60
8				75;16				-1.70	35	0.21	0.46
9			60;11					-1.70	23	0.18	0.48
10		75;10						-1.70	24	0.13	0.42
11					95;18			-1.70	42	0.19	0.42
12					80;15			-1.70	32	0.19	0.47
13				80;17				-1.70	40	0.21	0.43
14		60;11						-1.70	20	0.18	0.55
15				75;19				-1.70	35	0.25	0.54
16							75;21	-1.70	40	0.28	0.53
17			65;14					-1.60	25	0.22	0.56
18			80;17					-1.60	28	0.21	0.61
19				110;20				-1.60	50	0.18	0.40
20											

Example: On line 13 in Data Sheet 5.5.1. it can be seen that a woman older than 17 years pumped 17 liters of water. It costs her 80 seconds to fill her container.

Number of strokes

For reciprocating hand pumps or swinging baskets, count and record the number of strokes N_S for each usage.

Suction head

Every hour during the day, measure and record the time (hours, minutes) and the suction head H_{in} (meters).

Note: If the pump is below the water surface in the well the suction head should be recorded as a negative number. See Figure 5.5.1. and the discussion on head measurements on page 5 - 63.

Discharge head

Measure the discharge head at the beginning of the day. For handpumps it can be considered constant. Record its value in the heading of Data Sheet 4.5.1. It is the vertical distance between the pump body and the water outlet level. See also the note under suction head.

Preliminary Calculations:

Average pumping rate

Calculate the average pumping rate q_{PT} for each pumper:

$$q_{PT} = \frac{Q_{PP}}{T_P} \quad [l/s]$$

where: Q_{PP} = the water volume pumped by the user in [l]

T_P = the pumping time in [s]

Example: The 16th user pumped 21 l water in 75 seconds. As a result his average pumping rate is:

$$q_{PT} = \frac{21}{75} = 0.28 \quad [l/s]$$

Average effective plunger capacity

Calculate the average effective plunger capacity PC (only for reciprocating pumps):

$$PC = \frac{Q_{PP}}{N_S} \quad [1/\text{stroke}]$$

where: Q_{PP} = the volume of water pumped by the user in [l]

N_S = the number of strokes of the pump handle

Example: The first user pumped 9 liters of water in 26 strokes. According to the formula the average effective plunger capacity is:

$$CP = \frac{9}{26} = 0.35 \quad [1/\text{stroke}]$$

This low value (when compared with the other results in Data Sheet 4.5.1. could be explained by the fact that a little girl is not able to use the full stroke length of the handpump.

4.5.2.4 Continuous Pumping Test

Arrange for the participation of a representative group of local water pumpers. The group should consist of 5-15 individuals. Each participant should use the same water container that they normally use and pump the same quantity of water as they normally remove. The water pumped during this test can be stored for later use.

The users should be asked to operate the pump one at a time in the same sequence such that the pump is being continuously operated. This should continue for a total time period of between one and two hours during which a set of measurements should be taken as described below.

The above sequence should be repeated on the next day.

Also for these tests a data sheet with a lay out as given in Data Sheet 4.5.1. can be used.

The following constitutes a set of measurements:

Time

Record the time (hour, minute) of the beginning t_b and end t_e of this continuous pumping test. Put the results in the heading of Data Sheet 4.5.1. (right hand side).

Water volume pumped and characterization of users

For each usage proceed as follows:

1. By means of the calibrated container measure the volume of the water pumped Q_{PP} by each user.
2. Determine her/his sex and age. In many cases it is not necessary to ask after the age; the class (7-11, 12-17, »17) can be determined by guessing.

Put the results in Data Sheet 4.5.1.; Sex and age are recorded by noting down the water volume pumped in the applicable column. Leave the space for the pumping time (as used in the previous test) open and put the water volume pumped in liters behind the semi-colon.

Alternatively, if two larger containers (as described in section 2.5.1., sub water volume pumped, sub b. page 2 - 9) are available, the total volume pumped should be measured directly: Count the number of large containers that can be filled by the tins, buckets, etc. of the pumpers during the measuring period.

Number of strokes

For reciprocating hand pumps or swinging baskets, count and record the number of strokes N_S for each usage.

Suction head

Measure and record the suction head H_{in} (meters) regularly. In many cases it is not necessary to measure at the beginning of each usage. For wells of sufficient capacity the results will vary only slightly (see Data Sheet 4.5.1.). Measurements should be performed that often that differences between subsequent measurements are smaller than 10%.

Note: If the pump is below the water surface in the well the suction head should be recorded as a negative number. See Figure 5.5.1. and the discussion on head measurements on page 5 - 63.

Discharge head

Determine the discharge head H_{dis}. For hand pumps it can be considered constant. Record its value in the heading of Data Sheet 5.5.1. It is the vertical distance between the pump body and the water outlet level. See also the note under suction head.

Preliminary calculations:

Length of test period T

Calculate the length of the test period T. T simply equals the difference in time between the start and the end of the test period.

Average pumping rate during test period

Calculate the average pumping rate during the test period q_{PT}

$$q_{PT} = \frac{SUM(Q_{PP})}{T} \qquad [l/s]$$

where:

$SUM(Q_{PP})$ = the sum of the water volume pumped by all users during the test in [l]

T = the length of the test period T in seconds

4.5.3 Data Reduction

Data reduction will make use of the results of the preliminary calculations to arrive at estimates of the overall performance of the hand pump system which can be compared to what would be expected based on the manufacturers information or to earlier or later data.

The data reduction will consist of calculations and preparation of curves based on the experimental measurements and the preliminary calculations.

<u>Water Pump Usage Distribution</u>

For the data taken during the Normal Pumping Test, prepare diagrams of pump usage. These will consist of plots of time intervals (one half hour per interval) along the horizontal axis and the number of pumpers using the pump during each time interval along the vertical axis.

<u>Normal Pumping Rate Distribution</u>

For the data taken during the Normal Pumping Test, prepare diagrams of pumping rates. These will consist of plots of pumping rate intervals along the horizontal axis and the number of measurements of pumping rate which fell within that range along the vertical axis.

<u>Note:</u> The pumping rate intervals should be selected such that the full range of pumping rates observed is divided up into 5-10 intervals.)

Separate diagrams should be prepared for male pumpers, for female pumpers and for each age category.

4.6 ANIMAL TRACTION PUMPS

This section covers water pumping systems in which the prime mover is one or more animals operating a pump. The pump may be a reciprocating or rotating screw type.

4.6.1 Objectives

The objectives of the short term tests of animal traction pumps is to obtain performance data showing the distribution of normal water pumping rates as a function of the characteristics of the animals used and of the drawdown.

4.6.2 Test Protocol

4.6.2.1 Data collection at the start of the tests

Before the short term tests are begun, the data collection described in Chapter 3 should be completed.

4.6.2.2 Pretest inspection and preparations

The following inspections should be carried out prior to field tests. The results should be included as comments in narrative form in the logbook, with notations as to which component or part was inspected and the results of the inspection. If a component listed below is not inspected, that fact should be noted. However, unless the system is not in operating order, do not carry out any maintenance at this time based on the pretest inspections.

Visually inspect the pump assembly. If possible, disassemble the pump assembly and inspect individual parts. Note in the logbook worn or corroded parts: for reciprocating pumps, cylinder, piston, and packing; for rotating screw pumps, screw and liner etc. Listen to and inspect the pump during normal operation. Note if the system performance during operation appears to be clearly unsatisfactory (e.g. very high force needed to operate pump, very low water flow rate, excessive leaks, excessive pump noise etc.).

Inspect system piping and valves visually. Open and close all valves. Note valves which do not operate. Note on a sketch the location and severity of leaks in valves and piping, if any. Also where possible, note the physical condition of the interior surfaces of piping and valves, where present. Determine whether a buildup of scale or other deposits has formed that reduces the effective diameter of the pipe or that causes the interior surface to be extremely rough. Note where the wall thickness has been reduced significantly by corrosion.

Note: Following inspection of the valves, it should be determined that all of the valves leading to and from the pump are in their open position prior to the beginning of the tests.

Inspect the storage tank if included in the system. Note any leaks. Clean the sight glass if present.

Inspect the water intake. Examine screens if they are accessible and note their condition, i.e. whether they are intact or have visible holes, whether they are clogged, etc.

Install test equipment as described in section 2.5.1. and ensure that the equipment is calibrated and functioning properly. Enter in the logbook a description of the test equipment used (see Section 3.5.6).

For borehole wells, measure the static suction head (vertical distance from the water level in the borehole to the pump inlet when no water is being pumped and the pump has been off for at least two hours).

4.6.2.3 Performance tests

Arrange for the use over a period of one to two days of two or more representative teams of draft animals normally used for water pumping. If there is more than one species that is used for water pumping at the site, attempt to assemble teams of each type. Each team of animals used should be only of one type. Record in the logbook the number and type of animals which comprise each team.

Inspect the animals just prior to use to be sure that they can perform the water pumping normally expected of them. Be sure that the animals have been fed and watered properly and at their usual times and that they are rested.

If there are valves downstream of the pump discharge, they should be fully opened. If there is a storage tank as part of the system, the level of water should be as low as possible.

Assemble and attach a team of animals to the pump assembly and initiate pumping. The animals should walk at their normal speed and should continue for the same period as their normal shift or until their speed noticeably decreases. Take during this period a set of measurements as indicated below. Repeat the test with the additional teams as available. Repeat the same tests on a second day.

Data Sheet 4.6.1. gives a lay-out to be used for noting down the information required and an example as how to fill in the sheet. For each team (or shift or period) two lines are available marked by B(egin) and E(nd).

DATA SHEET 4.6.1. Measurements and Calculations Short Term Tests

(to be completed by technician)

Location: ____________ Date : ________ [YY,MM,DD]

District: ____________ Begin time : ________ [HH,MM]

Owner : ____________ End time : ________ [HH,MM]

Discharge head H_{dis} : 12.7 [m]

No	Time t [HH,MM]	Water meter reading Q_P [m^3]	Suction Head H_{in} [m]	Kind, number & condition of animals [xx,n,qq]*	Number of revolutions N_R [-]	Length of the shift T [HH;MM]	Water flow rate q_{PT} [l/s]	Average volume pumped per rev. PC [l/rev]
B	06:25	1345.5	-1.7	mu, 2, +/-				
E	07:45	1362.1	-1.6		121 **)	1:20	3.5	137
	Type of break: ~~rest~~ / change of animals/							
B	07:58	1362.1	-1.6	mu, 2, -				
E	09:46	1375.9	-1.6	mu, 2, --	95 **)	1:48	2.1	145
	Type of break: ~~rest~~ / change of animals/							
B	11:03	1375.9	-1.6	mu, 2, +				
E	12:36	1400.1	-1.5		174 **)	1:33	4.3	139
	Type of break: rest / ~~change of animals~~/							
B	13:40	1400.1	-1.7	mu, 2, +				
E	15:45	1428.3	-1.6		200 **)	2:05	3.8	141
	Type of break: rest / ~~change of animals~~/							
B	16:05	1428.3	-1.6	mu, 2, +				
E	17:45	1453.7	-1.6		182 **)	1:40	4.2	140
	Type of break: ~~rest~~ / change of animals/							
B	1							
E					**)			
	Type of break: rest / change of animals/							

*) For kind of animals xx use the following codes:

- hh: heavy horse
- lh: light horse
- mu: mule
- do: donkey
- co: cow
- bl: bullock
- ox: ox
- ca: camel
- bf: buffalo
- __: ______

For condition qq use the following codes:

- ++ : excellent
- \+ : good
- +/-: medium
- \- : poor
- --: bad

**) Choose the relevant alternative

SET OF MEASUREMENTS

Time

By means of a watch determine the clock time t (hours, minutes) at the beginning and the end of the pumping period for each team of animals.

Water volume pumped

Record the readings (cubic meters) Q_p of the integrating flowmeter at the beginning and at the end of the pumping period for each team of animals.

Suction head

Record the suction head (meters) H_{in} at the beginning and at the end of each pumping period.

Note: If the pump is below the water surface in the well the suction head should be recorded as a negative number. See Figure 5.6.1. and the discussion on head measurements on page 5 - 74.

Discharge head

Determine the discharge head at the beginning of the day. For animal pumps it can be considered constant. Record its value in the heading of Data Sheet 4.6.1. It is the vertical distance between the pump body and the water outlet level. See also the note under suction head.

General Description of the Animals

Record in the logbook the condition of the animals at the start of the test i.e. do they appear healthy and do they appear rested. If the animals do not appear to be all in the same condition, i.e. some animals appear to have considerably less ability to pull their share than the rest, this should be described in the logbook. In data sheet 4.6.1. this information can be summarized in the column "Kind, number and condition of animals".

where: $R_{w,b}$ = wind run meter reading at the beginning of period T,
$R_{w,e}$ = wind run meter reading at the end of period T,
T = length of observation period in hours,
3.6 = conversion factor 3600/1000.

Example: On 7 February 1987 the wind run meter indicated 35153 km ($R_{w,b}$); a week later the reading was 37123 km ($R_{w,e}$). Then the formula leads to V_T = 3.2 [m/s] (see example in lines 5 and 6 in Data Sheet 5.4.1.).

Water volume pumped

When the flow meter readings Q_P are registered in m^3, the water volume pumped over a period T is:

$$Q_{PT} = Q_{P,e} - Q_{P,b} \qquad [m^3]$$

where: $Q_{P,b}$ = the reading of the integrating flow meter at the beginning of period T,
$Q_{P,e}$ = the reading of the integrating flow meter at the end of period T.

Example: On 21 March 1987 the flow meter at the pump outlet indicated 4184 m^3 ($Q_{P,b}$). A week later the reading was 4249 m^3 ($Q_{P,e}$). Application of the formula leads to $Q_{P,T}$ = 65 m^3 (see lines 11 and 12 in Data Sheet 5.4.1.).

Water volume actually used

When the flow meter readings Q_U are registered in m^3, the water volume actually used over a period T is:

$$Q_{UT} = Q_{U,e} - Q_{U,b} \qquad [m^3]$$

where: $Q_{U,b}$ = the reading of the integrating flow meter at the beginning of period T,
$Q_{U,e}$ = the reading of the integrating flow meter at the end of period T.

<u>Average volume pumped per revolution</u>

Calculate the average volume pumped per revolution of the pumping team PC (liters):

$$PC = \frac{1000 * (Q_{P,e} - Q_{P,b})}{N_R} \quad [l/rev]$$

where: $Q_{P,b}$ = the integrating flowmeter reading [cubic meters] at the beginning of the pumping period.
$Q_{P,e}$ = the integrating flowmeter reading at the end of the pumping period.
N_R = the number of revolutions made by the pumping team.

<u>Example:</u> The second team made 95 revolutions. Then PC becomes:

$$PC = \frac{1000 * (1375.9 - 1362.1)}{95} = 145 \quad [l/rev]$$

5. LONG TERM TESTING

5.0 OBJECTIVES OF LONG TERM TESTING

During Long Term Testing three different types of information have to be collected over a longer period of time:

1. Performance of the system,
2. Reliability of the system,
3. Costs of operation and maintenance of the system (recurrent costs).

Information on the performance of the system is obtained by periodic reading of instruments, that measure parameters of interest such as the water volume pumped.

Information on the reliability of the system is obtained by carefully recording in the logbook all events and incidents that do not belong to the normal operation of the pumping system.

Information on recurrent costs of the system is obtained by punctually keeping an administration of all costs occurring during the period of evaluation of the system.

In the following six sections each pumping technique is treated in detail.

Please note that the Long Term Test does not focus on sub-system efficiencies; "internal" quantities like the number of pump strokes are not measured. If an indication is wanted on the possible deterioration of components after some years, another Short Term Test may be executed as a diagnostic tool (see Chapter 4 of this Handbook) after a certain period of time.

In order not to burden the owner/operator too much, it is recommended that he only collects the information that needs to be collected continuously during the Long Term Test: all information to be gathered at the start of the tests as well as the data handling after the tests should preferably be looked after by professional staff. In section 2.4. a recommended division of tasks is given and commented upon.

5.1. GRID-CONNECTED ELECTRIC PUMPS

5.1.1. The "System" during Long Term Tests

During the Long Term Tests the system under observation consists of the following parts:

1. Electric motor ┐ Technical system as considered during
2. Pump ┘ [Short Term Test.
3. Storage tank, if any
4. Back-up system, if any
5. Resources: =Manpower
   =Water
   =Electricity from grid
   =Money
6. Output : =(Useful) water.

In most cases a back-up system, if any, consists of a diesel pump or a hand pump. According to the considerations at the end of Section 2.1. it might be subjected to a Long Term Test simultaneously (see Sections 5.2. and 5.5. respectively).

5.1.2. Measurements and data collection during Long Term Tests

5.1.2.1 Measurements

Measurement equipment required and recommendations with respect to its installation have been described in sections 2.5.1. and 2.5.2.1.

Within the framework of Long Term Testing measurements shall be performed on a weekly basis.
It is recommended to choose a fixed time in the week (e.g. every Monday morning) to carry out the measurements; by doing so their regular performance is guaranteed and the chance of forgetting measurements is minimized.

Data Sheet 5.1.1. (column "MEASUREMENTS") gives a lay-out to be used for noting down the numerical information required and an example as how to fill in the sheet. For every measurement one line on the data sheet is available. At the start of the Long Term Test the start reading of the various instruments is recorded on the first line (marked by "0"). When during Long Term Tests a new Data Sheet is opened, the first line is used for copying the last measurement of the previous Data Sheet.

The two bottom lines of Data Sheet 5.1.1. are used for average and cumulative values over a longer period of time.

DATA SHEET 5.1.1. Measurements and Calculations Long Term Tests

(to be completed by owner (MEASUREMENTS) and technician (CALCULATIONS))

Location: Start Date : [YY/MM/DD;HH]

District: End Date : [YY/MM/DD;HH]

Owner :

Discharge head H_{dis} : 37 [m] Horizontal Distance L : / [m] Pressure head H_p : / [m]

No	Date and time t [YY/MM/DD;HH]	Energy meter reading E_{el} [kWh]	Water meter reading Q_P [m^3]	Suction Head H_{in} [m]	Length of period T [hours]	Electric energy consumption $E_{el,T}$ [kWh]	Water volume pumped Q_{PT} [m^3]	Hydraulic system output $E_{h,T}$ [kWh]	Overall system efficiency η_{tot} [-]
	MEASUREMENTS (see section 5.1.2.1)				CALCULATIONS (see section 5.1.3)				
0	87/01/03:11	0.973	472.8	2.00					
1	10:08	30.320	567.4	2.50	165	29.347	94.6	10.03	0.34
2	17:14	58.613	654.0	1.75	174	28.293	86.6	9.15	0.32
3	24:10	90.636	753.8	3.25	164	32.023	99.8	10.64	0.33
4	31:18	118.103	841.4	2.25	176	27.467	87.6	9.40	0.34
5	87/02/07:12	148.780	943.2	2.00	162	30.677	101.8	10.75	0.35
6	14:15	180.452	1050.0	3.00	171	31.672	106.8	11.39	0.36
7	21:10	215.033	1161.8	3.25	163	34.581	111.8	12.11	0.35
8	28:10	247.677	1268.8	2.00	168	32.644	107.0	11.45	0.35
9	87/03/07:12	283.673	1385.2	2.25	170	35.996	116.4	12.30	0.34
10	14:13	318.340	1499.0	3.00	169	34.667	113.8	12.18	0.35
11	21:11	355.940	1613.4	4.00	166	37.600	114.4	12.51	0.33
12	28:09	396.125	1733.4	4.50	166	40.185	120.0	13.37	0.33
13	87/04/04:12	433.174	1846.4	4.50	171	37.049	113.0	12.66	0.34
14	11:14	471.694	1966.8	4.50	170	38.520	120.4	13.49	0.35
15	18:16	506.373	2078.4	4.25	170	34.679	111.6	12.47	0.36
16	25:12	547.355	2214.6	4.00	164	40.982	136.2	15.12	0.37
17	87/05/02:11	587.562	2345.2	4.00	167	40.207	130.6	14.46	0.36
18	09:10	626.274	2471.0	4.00	167	38.712	125.8	13.93	0.36
19	16:11	661.613	2580.6	3.50	169	35.339	109.6	12.06	0.34
20	23:11	698.742	2693.6	3.50	168	37.129	113.0	12.36	0.33
21	30:11	733.785	2797.4	3.50	168	35.043	103.8	11.35	0.32
22	87/06/06:14	766.664	2894.0	4.00	171	32.879	96.6	10.63	0.32
23	13:10	800.871	2996.8	4.00	164	34.207	102.8	11.38	0.33
24	20:11	834.370	3097.8	3.75	169	33.499	101.0	11.15	0.33
25	27:10	868.503	3204.2	3.50	167	34.133	106.4	11.67	0.34
26	87/07/04:11	903.915	3317.8	3.50	169	35.412	113.6	12.42	0.35
	Half-yearly cumulative values:				4368	902.942	2845.0	310.41	
	Half-yearly average value:								0.34

Date and Time

Write Date and Time in the format YY/MM/DD;HH.
E.g. 87/01/03;11 is equivalent to 3 January 1987 at 11 a.m.. Recording the time in whole hours is sufficiently accurate for the present purpose.

Electric energy consumption

For Long Term Tests the integrating electric power meter (kWh-meter) shall be used. Write the results in kWh (kiloWatt-hours).

Water volume pumped

Measure the volume pumped using the integrating flow meter. Check the flow meter regularly in order to detect malfunctioning e.g. due to contamination as soon as possible (see 2.5.1.). Care should be taken to record whether and when the flow meter passed its maximum number of digits and started at the zero reading, especially if for any reason readings are taken over longer intervals than prescribed.
During Short Term Testing the flow meter was installed at the pump outlet. Do not forget to move it to the storage tank outlet (if any) at the start of the Long Term Tests.

Head

Suction Head

If the level of the water source showed large variations during the Short Term Tests, the accuracy of the tests may be improved by taking an additional measurement of the suction head H_{in} e.g. half-way the measuring period T. Put all values in the logbook and record the average value (in metres [m]) in Data Sheet 5.1.1..

Discharge Head

In many cases the discharge head H_{dis} is constant. It is simply the vertical distance between the pump and the discharge pipe outlet at the top of the storage tank.
If the discharge pipe enters at the bottom of the storage tank, the discharge head should be measured up to the average water level in the tank (e.g. half-way between top and bottom). Write the results in metres [m].

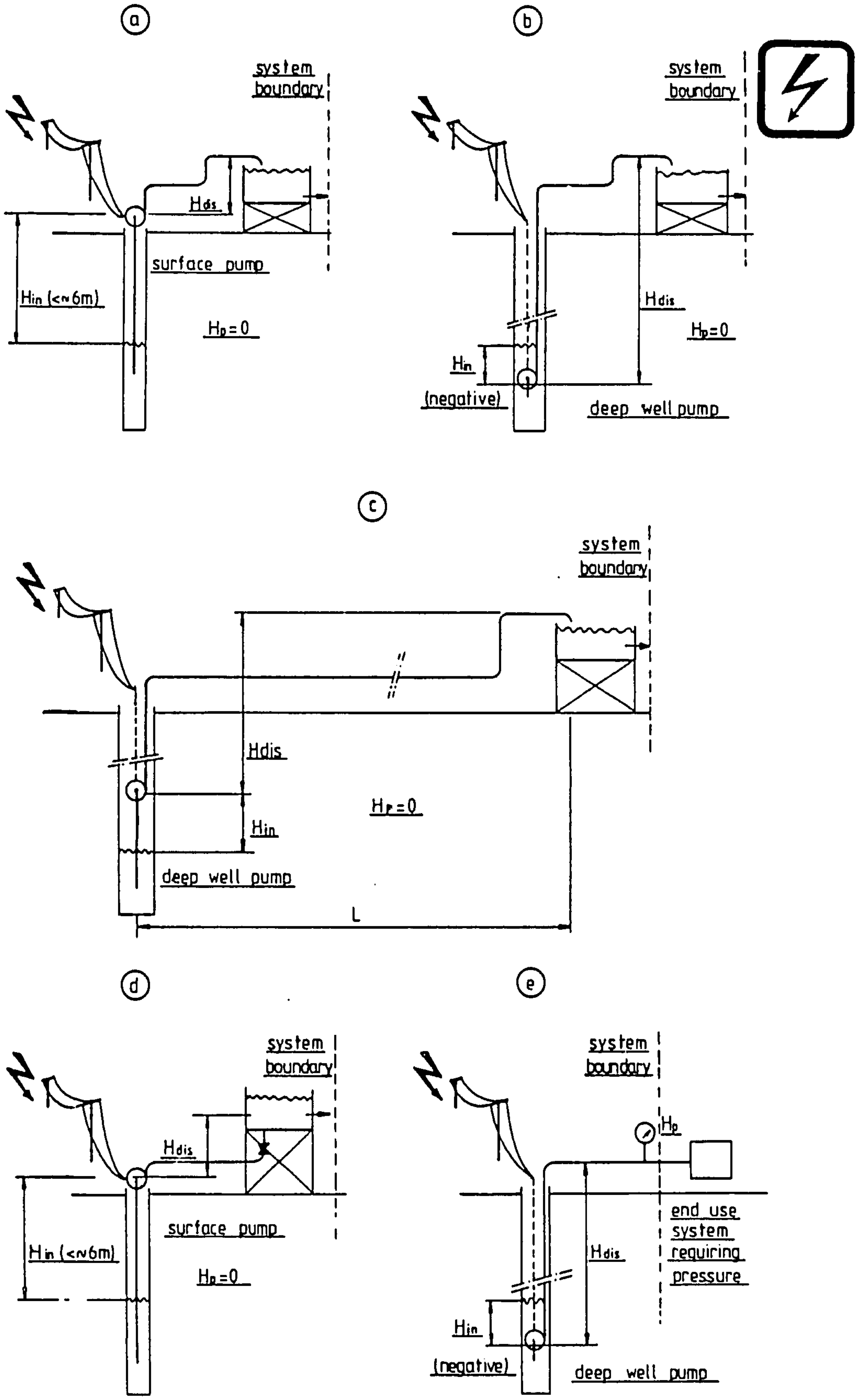


Figure 5.1.1. Examples of head measurements

<u>Pressure Head</u>

In most electric pump applications a storage tank functions as a water tower to generate a pressure head as required for the end use system. Then this pressure simply forms part of the discharge head from pump level to storage tank water level and must not be measured separately. If alternatively for example an electric pump directly feeds a system requiring a pressure at its intake, e.g. a sprinkler system, the discharge pressure H_p should be measured at the sprinkler system intake by means of a bourdon type manometer. Write the results in metres [m].

In Figure 5.1.1. some examples are given to illustrate the measurement of the different types of head for a number of situations:

<u>Case a.</u>

A shallow well is equipped with a surface pump and a storage tank. The suction head H_{in} is measured from the water level to the centre of the pump, the discharge head H_{dis} from the centre of the pump to the end of the pipe above the storage tank. In this case there is no pressure head.

<u>Case b.</u>

A tube well is equipped with a deepwell pump and a storage tank. Because the pump is below the water level, H_{in} is negative. It should be calculated by the difference between the water level (meters below ground level) and the position of the pump (meters below ground level).

<u>Case c.</u>

A tube well feeds a storage tank at a long distance L. Note L down in the heading of Data Sheet 5.1.1.. The suction head is calculated as in case b.. Because the pump is situated above the water level, H_{in} is now positive.

<u>Case d.</u>

The storage tank is fed through its bottom. Therefore H_{dis} is measured between pump level and the average water level in the tank.

<u>Case e.</u>

The pumping system feeds an end use system requiring a pressure. The corresponding pressure head is measured by means of a manometer at the system boundary.

5.1.2.2 Additional data collection

The logbook should describe in sufficient detail all events occurred e.g. the activities carried out with regard to servicing, maintenance (i.e. preventive action), repair (i.e. corrective action) and overhaul. It should specify the date of the event, the amount of time spent and the costs (distinguish between skilled and unskilled labour, parts, materials, lubricants and transportation). It is recommended to make this description by systematically treating the following issues:

-Maintenance
    =Actions performed (by whom?). If standard, refer to users manual.
    =Replaced parts
    =Lubricants used
-Break downs of the system (including shut-downs of the grid)
    =Description of system failure
    =When was it discovered?
    =Who was warned, how?
    =(Possible) causes
    =When repair started?
    =Actions performed (by whom, time spent?)
    =When was the system ready for operation again?
-Operation of the system
    =Payments of electricity bills
    =Periods of water shortage, reasons
-Water source
    =Occurrence of abnormal water levels in water source.
    =Running dry of the well.

Data sheet 5.1.2. gives a lay-out and a hypothetical example as how to complete this sheet. It can be used as a summary of all events and simultaneously serve as a table of contents to refer to logbook pages with detailed information. The first lines of Data Sheet 5.1.2. give information on the people contributing to the logbook. The subsequent columns of the data sheet contain the date of the event, the initials of the reporter (it is very important that any person putting down information in the logbook is identified by his initials; he is an important source of additional information when needed), a short description, the time during which the system was out of order (down time), the time spent to maintenance or other activities, the costs and the page number of the logbook where detailed information, if any, is recorded. The example shows how the different kinds of costs can be distinguished by using more lines for a single event.

DATA SHEET 5.1.2. Chronological survey of all relevant events (to be completed by various people)

Initials	Function	Name
AB	Owner	Butsi, A
FA	Technician	Abebe, F
PS	Operator	Sanford, P

Date	Init	Description	Down time [hours]	Time spent [hours]	Costs [..$..]	logbook page
87/04/28	FA	Maintenance	30			26
		Skilled labour		12	60	
		Grease			1	
87/04/29	FA	System ready for operation again				
87/04/30	AB	Operators salary			35	
87/05/02	AB	Electricity Bill			20	

5.1.3. <u>Data reduction Long Term Tests</u>

Data analysis should be initiated as soon as possible after data collection to quickly indicate possible problems with either the pumping system or the data collection instruments.
Early detection of any anomalies in the data will not only lead to more reliable data, but will also eliminate potential problems resulting from incorrect installations of equipment or oversights in the design. Also deterioration of performance in time will be detected by doing so.

If during the Long Term Tests large deviations from expected values are found, it is recommended to perform (part of) a Short

Term Test in order to identify possible causes of these deviations.

5.1.3.1 Performance

The results of reduction of data on system performance are recorded in Data Sheet 5.1.1. in the column indicated by "CALCULATIONS".
Two steps of data reduction are performed, both using the same type of calculations and formulas.

1. After every measurement cumulative and average values are calculated over the period of time between that measurement and the previous one. The length of the period of observation T equals the time between two successive measurements (about 1 week). The calculations are performed using pairs of two successive measurements. The results are noted down in Data Sheet 5.1.1. behind the corresponding measurements.

2. After a certain period of time (half a year, a year), when a data sheet is fully completed, cumulative and average values over that longer period are calculated. Now the length of the period of observation T equals the time between the two measurements at the beginning and at the end of that period. For the calculations the latter two measurements are used. The results are noted down on the two bottom lines of Data Sheet 5.1.1.. and in Data Sheet 5.1.3. under the heading "Performance".

Length of period T

The length of the period of observation T simply equals length of time between two measurements.

Example: The first measurement took place on 3 January 1987 at 11.00 A.M. (87/01/03;11), the second one on 10 January at 08.00 A.M. (87/01/10;08). The length of the time period T is 7 days minus 3 hours equalling 165 hours (see lines 0 and 1 of Data Sheet 5.1.1.).

Electric energy consumption

When the electric energy meter readings E_{el} are registered in kWh, the electric energy consumption $E_{el,T}$ over the period T simply equals:

$$E_{el,T} = E_{el,e} - E_{el,b} \quad [kWh]$$

where: $E_{el,b}$ = the Electric energy meter reading at the beginning of the period T.
$E_{el,e}$ = the Electric energy meter reading at the end of period T.

<u>Example:</u> If $E_{el,b}$ = 247.677 [kWh] and $E_{el,e}$ = 283.673 [kWh] then the electric energy consumption during period T

$E_{el,T}$ = 35.996 [kWh].

See lines 8 and 9 of Data Sheet 5.1.1.

<u>Water volume pumped</u>

When the flow meter readings Q_P are registered in m^3, the water volume pumped over a period T is:

$$Q_{PT} = Q_{P,e} - Q_{P,b} \quad [m^3]$$

where: $Q_{P,b}$ = the reading of the integrating flow meter at the beginning of period T
$Q_{P,e}$ = the reading of the integrating flow meter at the end of period T

<u>Example:</u> On 21 March 1987 the flow meter at the pump outlet indicated 1613.4 m^3 ($Q_{P,b}$). A week later the reading was 1733.4 m^3 ($Q_{P,e}$). Application of the formula leads to $Q_{P,T}$ = 120 m^3 (Lines 11 and 12, Data Sheet)

<u>Hydraulic system output</u>

The hydraulic system output $E_{h,T}$ over a period T can be calculated from Q_{PT} by:

$$E_{h,T} = 0.0027 * Q_{PT} * \frac{H_b + H_e}{2} \quad [kWh]$$

where: H_b = total effective head (see Annex 2.2) at the beginning of period T
H_e = total effective head at the end of period T
0.0027 = conversion factor (9.81/3600).

<u>Example:</u> During the week from 9 to 16 May 1987 the hydraulic system output was:

$$E_{h,T} = 0.0027 * 109.6 *(\frac{4 + 3.5}{2} +37) = 12.06 \text{ [kWh]}$$

See lines 18 and 19 of Data Sheet 5.1.1.. (The number 37 stands for the discharge head H_{dis}, see heading of the Data Sheet).

Overall system efficiency

The overall system efficiency η_{tot} for a period T is obtained by:

$$\eta_{tot} = \frac{E_{h,T}}{E_{el,T}} \quad [-]$$

Example: During the period of the previous example $E_{el,T}$ = 35.339 [kWh]. As a result η_{tot} = 12.06/35.339 = 0.34. (Line 19, Data Sheet 5.1.1).

Average and cumulative values over a longer period of time

The bottom lines of Data Sheet 5.1.1. are used for noting down average and cumulative values over a longer period of time. In the example this period has a length of 26 weeks.

The Total length of period T (being 4368 hours in the example) can be obtained by summing all calculated T-values or alternatively by the difference between the first and the last "Date and Time" (lines 0 and 26).

For the Total electric energy consumption and the Total water volume pumped the formulas explained in the beginning of this section are applied using the integrating meter readings on line 0 and line 26. The result is:

Half-yearly electric energy consumption =
903.915 - 0.973 = 902.942 [kWh]

Half-yearly water volume pumped = 3317.8 - 472.8 = 2845.0 [m^3]

The Half-yearly hydraulic energy output is obtained by summing all 26 values.

For the Half-yearly overall system efficiency simply the cumulative values of $E_{h,T}$ and $E_{el,T}$ are used:

$$\eta_{tot,\frac{1}{2}y} = 310.41 / 902.942 = 0.34$$

NOTE:

The overall system efficiency η_{tot} relates the hydraulic output of the electric pumping system to the amount of

DATA SHEET 5.1.3. Summary for Electric Pumping System
(to be completed by technician)

SUMMARY OVER 19___

Location: ____________________
District: ____________________
Owner : ____________________

Performance

Yearly electric energy consumption	:	________	[kWh]
Yearly water volume pumped	:	________	[m^3]
Overall system efficiency	:	________	[-]

Operation

Operating time of the system	:	________	[hours]
Total time needed for maintenance	:	________	[hours]
Total time needed for repairs	:	________	[hours]
Total down-time	:	________	[hours]
Number of break-downs	:	________	[-]
Mean down time	:	________	[hours]
Mean time between failures	:	________	[hours]
Availability	:	________	[-]
Other uses of system	:	________	[hours]
(pls. give details in log or below		________	________
________ ________	:	________	________

Recurrent Costs [________]*

	operation	maintenance	repair	total
Skilled labour	____	____	____	____
Unskilled labour	____	____	____	____
Electricity	____	____	____	____
Materials	____	____	____	____
Parts	____	____	____	____
Transportation	____	____	____	____
Replacements	____	____	____	____

*) Indicate currency; note details on replacements (types and time), repairs, etc. in the log.

electric energy consumed. Its value normally is in the range from 0.20 to 0.40. Much lower values might be caused by:
- a bad matching of the pump to the pumping head,
- losses in the piping system,
- a worn pump or worn electric motor.

The average and cumulative data over the period of a year (to be calculated as described above) should be put in Data Sheet 5.1.3. under the heading "Performance".

5.1.3.2 Reliability of the electric pumping system

As stated, Data Sheet 5.1.2. shows information on reliability e.g. the number of system failures, their type and duration, repair types and times, maintenance problems, climatological, natural or other phenomena affecting delivery reliability, any inherent design faults, etc.
In Data Sheet 5.1.3. this information will be summarized for a period of a year under the heading "Operation". Some items are already suggested in the sheet.

The various total times asked for might require some explanation. Operating time is the time during which the system was running during the length of period T. It can be estimated by dividing the yearly electric energy consumption by the average power input of the electric motor as measured during Short Term Tests (See Chapter 4.1.1.)
Total time needed for maintenance and total time needed for repair equal the number of man hours spent to maintenance and repair respectively.
Total down-time is the total time the system was not in operating order due to system failures.

The reliability of the system can be expressed by three different indicators, viz. the mean down time (MDT), the mean time between failures (MTBF) and the availability. They are calculated as follows:

$$MDT = \frac{\text{Total down-time}}{\text{number of break-downs}} \quad \text{[hours per break-down]}$$

$$MTBF = \frac{\text{Length of period} - \text{Total down-time}}{\text{number of break-downs}} \quad \text{[hours]}$$

$$\text{Availability} = \frac{\text{Length of period} - \text{Total down-time}}{\text{Length of period}} \quad [-]$$

These indicators all refer to different aspects of reliability. E.g. if a short MTBF is caused by many break-downs of short duration (due to quick repair service), the MDT is low and the availability of the system is high.

In addition, other events could be summarized, for instance those having occurred strikingly often (e.g. pumping dry of the well). Careful consideration of Data Sheet 5.1.2. should result in meaningful summaries of events.

5.1.3.3 Recurrent costs

The data on recurrent costs collected during the Long Term Test, recorded in Data Sheet 5.1.2. will be summarized in Data Sheet 5.1.3. under the heading "Recurrent costs".
Details on types and times of repairs will be noted down in the log.

5.2. FUEL ENGINE PUMPS

5.2.1. The "System" during Long Term Tests

During the Long Term Tests the system under observation consists of the following parts:

1. Fuel storage tank ┐
2. I.C. engine ├ Technical system as considered during [Short Term Test.
3. Transmission │
4. Pump ┘
5. Storage tank, if any
6. Back-up system, if any
7. Resources: =Manpower
   =Water
   =Fuel
   =Money
8. Output : =(Useful) water.

In most cases a back-up system, if any, consists of a hand pump. According to the considerations at the end of Section 2.1. it might be subjected to a Long Term Test simultaneously (see Section 5.5.).

5.2.2. Measurements and data collection during Long Term Tests

5.2.2.1 Measurements

Measurement equipment required and recommendations with respect to its installation have been described in sections 2.5.1. and 2.5.2.2.

Within the framework of Long Term Testing measurements shall be performed on a weekly basis.
It is recommended to chose a fixed time in the week (e.g. every Monday morning) to carry out the measurements; by doing so their regular performance is guaranteed and the chance of forgetting measurements is minimized.

Data Sheet 5.2.1. (column "MEASUREMENTS") gives a lay-out to be used for noting down the numerical information required and an example as how to fill in the sheet. For every measurement one line on the data sheet is available. At the start of the Long Term Test the start reading of the various instruments is recorded on the first line (marked by "0"). When during Long Term Tests a new Data Sheet is opened, the first line is used for copying the last measurement of the previous Data Sheet.

DATA SHEET 5.2.1. Measurements and Calculations Long Term Tests

(to be completed by owner (MEASUREMENTS) and technician (CALCULATIONS))

Location: ______________________ Start Date : __________ [YY/MM/DD;HH]

District: ______________________ End Date : __________ [YY/MM/DD;HH]

Owner : ______________________

Discharge head H_{dis} : 27 [m] Horizontal Distance L : 100 [m] Pressure head H_p : ——— [m]

	MEASUREMENTS (see section 5.2.2.1)				CALCULATIONS (see section 5.2.3.)					
No	Date and time t [YY/MM/DD;HH]	Filled up fuel V_{fuel} [l]	Water meter reading Q_P [m^3]	Suction Head H_{in} [m]	Length of period T [hours]	Cumulative fuel consumption VC_{fuel} [l]	Fossil Energy input E_{fossil} [kWh]	Water volume pumped Q_{PT} [m^3]	Hydraulic energy output $E_{h,T}$ [kWh]	Overall system efficiency η_{tot} [-]
0	87/01/03:11		472.8	2.00						
1	10:08	8.28	576.4	2.50	165	8.28	91.08	94.6	10.03	0.11
2	17:14	8.31	654.0	1.75	174	16.59	91.41	86.6	9.15	0.10
3	24:10	9.67	753.8	3.25	164	26.26	106.37	99.8	10.64	0.10
4	31:18	8.54	841.4	2.25	176	34.80	93.94	87.6	9.40	0.10
5	87/02/07:12	10.86	943.2	2.00	162	45.66	119.46	101.8	10.75	0.09
6	14:15	11.50	1050.0	3.00	171	57.16	126.50	106.8	11.39	0.09
7	21:10	11.01	1161.8	3.25	163	68.17	121.11	111.8	12.11	0.10
8	28:10	9.46	1268.8	2.00	168	77.63	104.06	107.0	11.45	0.11
9	87/03/07:12	10.16	1385.2	2.25	170	87.79	111.76	116.4	12.30	0.11
10	14:13	11.06	1499.0	3.00	169	98.85	121.66	113.8	12.18	0.10
11	21:11	11.37	1613.4	4.00	166	110.22	125.07	114.4	12.51	0.10
12	28:09	11.04	1733.4	4.50	166	121.26	121.44	120.0	13.37	0.11
13	87/04/04:12	10.46	1846.4	4.50	171	131.72	115.06	113.0	12.66	0.11
14	11:14	12.26	1966.8	4.50	170	143.98	134.86	120.4	13.49	0.10
15	18:16	11.33	2078.4	4.25	170	155.31	124.63	111.6	12.47	0.10
16	25:12	15.27	2214.6	4.00	164	170.58	167.97	136.2	15.12	0.09
17	87/05/02:11	14.60	2345.2	4.00	167	185.18	160.60	130.6	14.46	0.09
18	09:10	14.06	2471.0	4.00	167	199.24	154.66	125.8	13.93	0.09
19	16:11	10.96	2580.6	3.50	169	210.20	120.56	109.6	12.06	0.10
20	23:11	11.23	2693.6	3.50	168	221.43	123.53	113.0	12.36	0.10
21	30:11	10.31	2797.4	3.50	168	231.74	113.41	103.8	11.35	0.10
22	87/06/06:14	10.73	2894.0	4.00	171	242.47	118.03	96.6	10.63	0.09
23	13:10	11.49	2996.8	4.00	164	253.96	126.39	102.8	11.38	0.09
24	20:11	10.13	3097.8	3.75	169	264.09	111.47	101.0	11.15	0.10
25	27:10	11.78	3204.2	3.50	167	275.87	129.58	106.4	11.67	0.09
26	87/07/04:11	10.26	3317.8	3.50	169	286.13	112.86	113.6	12.42	0.11
	Half-yearly cumulative values:				4368	286.133	3147.47	2845.0	310.41	
	Half-yearly average value:									0.10

The two bottom lines of Data Sheet 5.2.1. are used for average and cumulative values over a longer period of time.

Date and Time

Write Date and Time in the format YY/MM/DD;HH.
E.g. 88/09/08;16 is equivalent to 8 September 1988 at 4 p.m..
Recording the time in whole hours is sufficiently accurate for the present purpose.

Fuel consumption

Measurement of fuel consumption is done by means of a measuring jug. Fill the fuel tank of the engine up, to a level well determined by a mark at the start of the Long Term Tests. The amount of fuel consumed in a certain period is determined by measuring the amount of fuel required to top up the tank to the mark.
Do not forget to include the fuel filled up in between two measurements!
The latter pitfall can be by-passed by using a fuel tank with a capacity larger than the maximum weekly consumption.
Write the results of the measurements in litres [l].

Water volume pumped

Measure the volume pumped using the integrating flow meter.
Check the flow meter regularly in order to detect malfunctioning e.g. due to contamination as soon as possible (see 2.5.1.).
Care should be taken to record whether and when the flow meter passed its maximum number of digits and started at the zero reading, especially if for any reason readings are taken over longer intervals than prescribed.
During Short Term Testing the flow meter was installed at the pump outlet. Do not forget to move it to the storage tank outlet (if any) at the start of the Long Term Tests.

Head

Suction Head
If the level of the water source showed large variations during the Short Term Tests, the accuracy of the tests may be improved by taking an additional measurement of the suction head H_{in}, e.g. half-way the measuring period T. Put all values in the logbook

and record the average value (in metres [m]) in Data Sheet 5.2.1..

<u>Discharge Head</u>

In many cases the discharge head H_{dis} is constant. It is simply the vertical distance between the pump and the discharge pipe outlet at the <u>top</u> of the storage tank.
If the discharge pipe enters at the <u>bottom</u> of the storage tank, the discharge head should be measured up to the average water level in the tank (e.g. half-way between top and bottom). Write the results in metres [m].

<u>Pressure Head</u>

In most fuel engine pump applications a storage tank functions as a water tower to generate a pressure head as required for the end use system. Then this pressure simply forms part of the discharge head from pump level to storage tank water level and must not be measured separately. If alternatively for example a diesel pump directly feeds a system requiring a pressure at its intake, e.g. a sprinkler system, the discharge pressure H_p should be measured at the sprinkler system intake by means of a bourdon type manometer. Write the results in metres [m].

In Figure 5.2.1. some examples are given to illustrate the measurement of the different types of head for a number of situations:

<u>Case a.</u>

A shallow well is equipped with a surface pump and a storage tank. The suction head H_{in} is measured from the water level to the centre of the pump, the discharge head H_{dis} from the centre of the pump to the end of the pipe above the storage tank. In this case there is no pressure head.

<u>Case b.</u>

A tube well is equipped with a deepwell pump and a storage tank. Because the pump is below the water level, H_{in} is negative. It should be calculated by the difference between the water level (meters below ground level) and the position of the pump (meters below ground level).

<u>Case c.</u>

A tube well feeds a storage tank at a long distance L. Note L down in the heading of Data Sheet 5.2.1.. The suction head is calculated as in case b.. Because the pump is situated above the water level, H_{in} is now positive.

<u>Case d.</u>

The storage tank is fed through its bottom. Therefore H_{dis} is measured between pump level and the average water level in the tank.

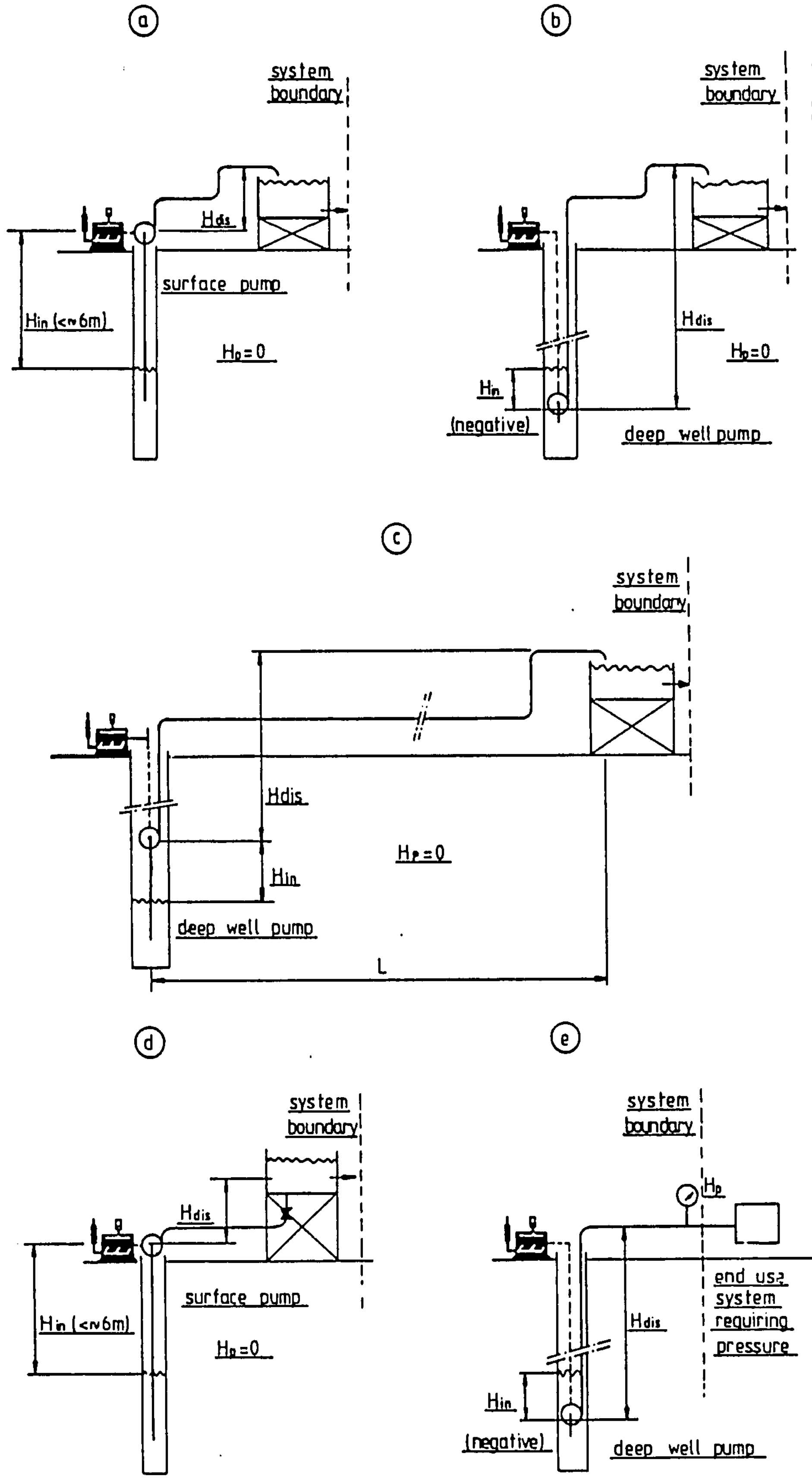


Figure 5.2.1. Examples of head measurements

Case e.
The pumping system feeds an end use system requiring a pressure. The corresponding pressure head is measured by means of a manometer at the system boundary.

5.2.2.2 Additional data collection

The logbook should describe in sufficient detail all events occurred e.g. the activities carried out with regard to servicing, maintenance (i.e. preventive action), repair (i.e. corrective action) and overhaul. It should specify the date of the event, the amount of time spent and the costs (distinguish between skilled and unskilled labour, parts, materials, lubricants and transportation). It is recommended to make this description by systematically treating the following issues:
-Maintenance
  =Actions performed (by whom?). If standard, refer to users manual.
  =Replaced parts
  =Lubricants used
-Break downs of the system (including fuel shortages, if any)
  =Description of system failure
  =When was it discovered?
  =Who was warned, how?
  =(Possible) causes
  =When repair started?
  =Actions performed (by whom, time spent?)
  =When was the system ready for operation again?
-Operation of the system
  =Payments fuel
  =Periods of water shortage, reasons
-Water source
  =Occurrence of abnormal water levels in water source.
  =Running dry of the well.

Data sheet 5.2.2. gives a lay-out and a hypothetical example as how to complete this sheet. It can be used as a summary of all events and simultaneously serve as a table of contents to refer to logbook pages with detailed information. The first lines of Data Sheet 5.2.2. give information on the people contributing to the logbook. The subsequent columns of the data sheet contain the date of the event, the initials of the reporter (it is very important that any person putting down information in the logbook is identified by his initials; he is an important source of additional information when needed), a short description, the time during which the system was out of order (down time), the time spent to maintenance or other activities, the costs and the page number of the logbook where detailed information, if any, is recorded. The example shows how the different kinds of costs can be distinguished by using more lines for a single event.

DATA SHEET 5.2.2. Chronological survey of all relevant events (to be completed by various people)

Initials	Function	Name
AB	Owner	Butsi, A
FA	Technician	Abebe, F
PS	Operator	Sanford, P

Date	Init	Description	Down time [hours]	Time spent [hours]	Costs [.ƒ..]	Logbook page
13/04/28	FA	Maintenance	20			26
		Skilled labour		12	60	
		Oil			5	
		Unskilled labour		24	50	
03/04/19	FA	System ready for operation again				
03/04/30	[illegible]	Operators salary			40	

5.2.3. <u>Data reduction Long Term Tests</u>

Data analysis should be initiated as soon as possible after data collection to quickly indicate possible problems with either the pumping system or the data collection instruments.
Early detection of any anomalies in the data will not only lead to more reliable data, but will also eliminate potential problems resulting from incorrect installations of equipment or oversights in the design. Also deterioration of performance in time will be detected by doing so.

If during the Long Term Tests large deviations from expected values are found, it is recommended to perform (part of) a Short Term Test in order to identify possible causes of these deviations.

5.2.3.1 Performance

The results of reduction of data on system performance are recorded in Data Sheet 5.2.1. in the column indicated by "CALCULATIONS".
Two steps of data reduction are performed, both using the same type of calculations and formulas.

1. After every measurement cumulative and average values are calculated over the period of time between that measurement and the previous one. The length of the period of observation T equals the time between two successive measurements (about 1 week). The calculations are performed using pairs of two successive measurements. The results are noted down in Data sheet 5.2.1. behind the corresponding measurements.

2. After a certain period of time (half a year, a year), when a data sheet is fully completed, cumulative and average values over that longer period are calculated. Now the length of the period of observation T equals the time between the two

   measurements at the beginning and at the end of that period. For the calculations the latter two measurements are used. The results are noted down on the two bottom lines of Data Sheet 5.2.1. and in Data Sheet 5.2.3. under the heading "Performance".

Length of period T

The length of the period of observation T simply equals length of time between two measurements.

Example: The first measurement took place on 3 January 1987 at 11.00 A.M. (87/01/03;11), the second one on 10 January at 08.00 A.M. (87/01/10;08). The length of the time period T is 7 days minus 3 hours equalling 165 hours (see lines 0 and 1 of Data Sheet 5.2.1.).

Cumulative Fuel consumption

After a new measurement has been performed, the new value of the cumulative fuel consumption is obtained by adding the filled up fuel to the previous value of the cumulative fuel consumption:

$$VC_{fuel,new} = VC_{fuel,previous} + V_{fuel} \qquad [1]$$

Example: On February 7th, 1987 the cumulative fuel consumption $VC_{fuel,previous}$ = 45.66 l. The amount of fuel used from February 7th to 14th V_{fuel} = 11.5 l. According to the formula the cumulative fuel consumption on February 14th $VC_{fuel,new}$ = 45.66 + 11.5 = 57.16 l. (see lines 5 and 6 of Data Sheet 5.2.1.).

Water volume pumped

When the flow meter readings Q_P are registered in m^3, the water volume pumped over a period T is:

$$Q_{PT} = Q_{P,e} - Q_{P,b} \qquad [m^3]$$

where: $Q_{P,b}$ = the reading of the integrating flow meter at the beginning of period T

$Q_{P,e}$ = the reading of the integrating flow meter at the end of period T

Example: On 21 March 1987 the flow meter at the pump outlet indicated 1613.4 m^3 ($Q_{P,b}$). A week later the reading was 1733.4 m^3 ($Q_{P,e}$). Application of the formula leads to $Q_{P,T}$ = 120 m^3 (see lines 11 and 12 in Data Sheet 5.2.1.).

Hydraulic system output

The hydraulic system output $E_{h,T}$ over a period T can be calculated from Q_{PT} by:

$$E_{h,T} = 0.0027 * Q_{PT} * \frac{H_b + H_e}{2} \qquad [kWh]$$

where: H_b = total effective head (see Annex 2.2) at the beginning of period T

H_e = total effective head at the end of period T

0.0027 = conversion factor (9.81/3600).

Example: During the week from 9 to 16 May 1987 the hydraulic system output was:

$$E_{h,T} = 0.0027 * 109.6 * (\frac{4 + 3.5}{2} + 27 + 10) = 12.06 \ [kWh]$$

See lines 18 and 19 of Data Sheet 5.2.1.. (The number 27 stands for the discharge head H_{dis}, the number 10 stands for the equivalent head for horizontal transport H_{hor}, see heading of the Data Sheet and Annex 2.2).

Fossil energy input to the system

The fossil energy input to the system is calculated by:

$$E_{fossil} = V_{fuel} * B \qquad [kWh]$$

where: B = the caloric value of the fuel in [kWh/l]

The caloric values of various fuels are as follows:

Type of fuel	Nett Caloric Value B [kWh/l]
Diesel oil / gasoil	11
Petrol / gasoline	9
Kerosene / parrafin	10

Example: From March 14th to 21st the fuel consumption V_{fuel} = 11.37 l. Assuming for the example that the fuel is diesel oil gives B = 11 kWh/l. Then the fossil energy input E_{fossil} = 11.37 * 11 = 125.07 kWh. (see line 11 of Data Sheet 5.2.1.)

Overall system efficiency

The overall system efficiency η_{tot} for a period T is obtained by:

$$\eta_{tot} = \frac{E_{h,T}}{E_{fossil}} \qquad [-]$$

<u>Example:</u> During the period of the previous example E_{fossil} = 125.07 [kWh]. As a result η_{tot} = 12.51/125.07 = 0.10. See line 11 of Data Sheet 5.2.1.

<u>Average and cumulative values over a longer period of time</u>

The bottom lines of Data Sheet 5.2.1. are used for noting down average and cumulative values over a longer period of time. In the example this period has a length of 26 weeks.

The <u>Total length of period T</u> (being 4368 hours in the example) can be obtained by summing all calculated T-values or alternatively by the difference between the first and the last "Date and Time" (lines 0 and 26).

For the <u>Cumulative fuel consumption</u>, simply the calculated result from line 26 can be copied: 286.133 l.

The <u>Cumulative fossil energy input</u> can be calculated by multiplying the Cumulative fuel consumption by the caloric value of the fuel:

Half-yearly fossil energy input = 286.133 * 11 = 3147.47 kWh.

For the <u>Total water volume pumped</u> the formulas explained in the beginning of this section are applied using the integrating meter readings on line 0 and line 26. The result is:

Half-yearly water volume pumped = 3317.8 - 472.8 = 2845.0 [m^3]

<u>The Half-yearly hydraulic energy output</u> is obtained by summing all 26 values: 10.03 + 9.15 + 10.64 + ... + 12.42 = 310.41 kWh.

For the <u>Half-yearly overall system efficiency</u> simply the cumulative values of $E_{h,T}$ and E_{fossil} are used:

$$\eta_{tot,\frac{1}{2}y} = 310.41 \;/\; 3147.47 = 0.10$$

<u>NOTE:</u>

The overall system efficiency η_{tot} relates the hydraulic output of the fuel engine system pumping system to the amount of fuel consumed. Its value normally is in the range from 0.05 to 0.15. Much lower values might be caused by:
- bad adjustment of the engine,
- a worn pump.

The average and cumulative data over the period of a year (to be calculated as described above) should be put in Data Sheet 5.2.3. under the heading "Performance".

DATA SHEET 5.2.3. Summary of information of ICE Pumping System
(to be completed by technician)

SUMMARY OVER 19___

Location: ______________________
District: ______________________
Owner : ______________________

Performance

Yearly fuel consumption	:	________	[l]
Yearly water volume pumped	:	________	[m^3]
Overall system efficiency	:	________	[-]

Operation

Operating time of the system	:	________	[hours]
Total time needed for maintenance	:	________	[hours]
Total time needed for repairs	:	________	[hours]
Total down-time	:	________	[hours]
Number of break-downs	:	________	[-]
Mean down time	:	________	[hours]
Mean time between failures	:	________	[hours]
Availability	:	________	[-]
Other uses of system	:	________	[hours]
(pls.give details in log or below)		________	________
________________	:	________	________

Recurrent Costs [________]*

	operation	maintenance	repair	total
Skilled labour				
Unskilled labour				
Fuel and lubricants				
Materials				
Parts				
Transportation				
Replacements				

*) Indicate currency; note details on repairs, replacements (types, time), etc. in the log.

5.2.3.2 Reliability of the fuel pump system

As stated, Data Sheet 5.2.2. shows information on reliability e.g. the number of system failures, their type and duration, repair types and times, maintenance problems, climatological, natural or other phenomena affecting delivery reliability, any inherent design faults, etc.
In Data Sheet 5.2.3. this information will be summarized for a period of a year under the heading "<u>Operation</u>". Some items are already suggested in the sheet.

The various total times asked for might require some explanation. <u>Operating time</u> is the time during which the system was running during the length of period T. It can be estimated by dividing the yearly fossil energy consumption by the average power input of the engine as measured during Short Term Tests (See Chapter 4.2.1.)
<u>Total time needed for maintenance</u> and <u>total time needed for repair</u> equal the number of man hours spent to maintenance and repair respectively.
<u>Total down-time</u> is the total time the system was not in operating order <u>due to system failures.</u>

The reliability of the system can be expressed by three different indicators, viz. the mean down time (MDT), the mean time between failures (MTBF) and the availability. They are calculated as follows:

$$MDT = \frac{\text{Total down-time}}{\text{number of break-downs}} \quad \text{[hours per break-down]}$$

$$MTBF = \frac{\text{Length of period} - \text{Total down-time}}{\text{number of break-downs}} \quad \text{[hours]}$$

$$\text{Availability} = \frac{\text{Length of period} - \text{Total down-time}}{\text{Length of period}} \quad [-]$$

These indicators all refer to different aspects of reliability. E.g. if a short MTBF is caused by many break-downs of short duration (due to quick repair service), the MDT is low and the availability of the system is high.

In addition other events could be summarized, for instance those having occurred strikingly often (e.g. pumping dry of the well). Careful consideration of Data Sheet 5.2.2. should result in meaningful combinations of events.

5.2.3.3 Recurrent costs

The data on recurrent costs collected during the Long Term Test are recorded in Data Sheet 5.2.2. and will be summarized in Data Sheet 5.2.3. under the heading "Recurrent Costs".
Details on types and times of repairs will be noted down in the log.

5.3. SOLAR PUMPS

5.3.1. The "System" during Long Term Tests

During the Long Term Tests the system under observation consists of the following parts:

1. Photo voltaic array ┐
2. Power control system ├─ Technical system as considered [during Short Term Test.
3. Electric pump ┘
4. Storage tank, if any
5. Back-up system, if any
6. Resources: =Manpower
   =Water
   =Solar energy
   =Money
7. Output : =(Useful) water.

In most cases a back-up system, if any, consists of a diesel pump or a hand pump. According to the considerations at the end of Section 2.1. it might be subjected to a Long Term Test simultaneously (see Sections 5.2. and 5.5. respectively).

5.3.2. Measurements and data collection during Long Term Tests

5.3.2.1 Measurements

Measurement equipment required and recommendations with respect to its installation have been described in sections 2.5.1. and 2.5.2.3.

Within the framework of Long Term Testing measurements shall be performed on a regular basis. The maximum period of time allowed between two measurements depends on the capacity of the storage tank that usually is part of a solar pump system. The time between two successive measurements should be about equal to the time during which the end-use system can function without major problems when it starts with a storage tank full of water, while no further water is being pumped during that period. Given the most common storage tank sizes for the various applications for irrigation purposes usually a period of one week between the measurements is sufficient. For drinking water systems this period will vary between one day and half a week. It is recommended to choose fixed times in the week to carry out the measurements; by doing so their regular performance is guaranteed and the chance of forgetting measurements is minimized. Possible schemes could be for an irrigation system every Monday morning, for a drinking water system every Tuesday and Friday at noon, etc.

Data Sheet 5.3.1. (column "MEASUREMENTS") gives a lay-out to be used for noting down the numerical information required and an example as how to fill in the sheet. For every measurement one line on the data sheet is available. At the start of the Long Term Test the start reading of the various instruments is recorded on the first line (marked by "0"). When during Long Term Tests a new Data Sheet is opened, the first line is used for copying the last measurement of the previous Data Sheet.

The two bottom lines of Data Sheet 5.3.1. are used for average and cumulative values over a longer period of time. It is recommended to chose the number of lines in Data Sheet 5.3.1. in such a way that averages and cumulative values are calculated over a proper period of time i.e. a month, a quarter or half a year. Dependent on the chosen period of time between two successive measurements (see above) the following lengths of Data Sheet 5.3.1. should be applied:

Time between two successive observations	Number of lines in Data Sheet 5.3.6.	Length of averaging period
1 day	31	month
half a week	26	quarter
1 week	26	half a year

Date and Time

Write Date and Time in the format YY/MM/DD;HH.
E.g. 87/01/03;11 is equivalent to 3 January 1987 at 11 a.m..
Recording the time in whole hours is sufficiently accurate for the present purpose.

Solar irradiation

For Long Term Tests the integrating pyranometer shall be used. Write the results in $[Wh/m^2]$. The pyranometer should be set at the same angle to the sun as the solar array. Calibrate (and recalibrate) the instrument according to the manufacturer's instructions.

DATA SHEET 5.3.1. Measurements and Calculations Long Term Tests

(to be completed by owner (MEASUREMENTS) and technician (CALCULATIONS))

Location: ____________________ Start Date : __________ [YY/MM/DD;HH]

District: ____________________ End Date : __________ [YY/MM/DD;HH]

Owner : ____________________

Discharge head H_{dis} : 37 [m] Area of photo voltaic array A_{array} 3.4 [m^2]

	MEASUREMENTS (see section 5.3.2.1)					CALCULATIONS (see section 5.3.3.)					
No	Date and time t [YY/MM/DD;HH]	Pyrano meter reading E_{sol} [Wh/m^2]	Water meter reading Q_P [m^3]	Water meter reading Q_U [m^3]	Suction Head H_{in} [m]	Length of period T [hours]	Solar irradiation $E_{sol,T}$ [Wh]	Water volume pumped Q_{PT} [m^3]	Water volume used Q_{UT} [m^3]	Expl. factor f_{se} [-]	Overall system eff. η_{tot} [-]
0	87/01/03:11	1,302	236.4	1345.4	2.00						
1	10:08	40,536	283.7	1387.5	2.50	165	133,396	47.3	42.1	0.89	0.038
2	17:14	78,360	327.0	1426.9	1.75	174	128,602	43.3	39.4	0.91	0.036
3	24:10	121,172	376.9	1478.5	3.25	164	145,561	49.9	51.6	1.03	0.037
4	31:18	157,893	420.7	1513.9	2.25	176	124,851	43.8	35.4	0.81	0.038
5	87/02/07:12	198,905	471.6	1566.9	2.00	162	139,441	50.9	53.0	1.04	0.039
6	14:15	241,247	525.0	1632.7	3.00	171	143,963	53.4	65.8	1.23	0.040
7	21:10	287,478	580.9	1681.9	3.25	163	157,186	55.9	49.2	0.88	0.039
8	28:10	331,119	634.4	1731.8	2.00	168	148,379	53.5	49.9	0.93	0.039
9	87/03/07:12	379,242	692.6	1785.4	2.25	170	163,618	58.2	53.6	0.92	0.038
10	14:13	425,589	749.5	1840.6	3.00	169	157,580	56.9	55.2	0.97	0.039
11	21:11	475,856	806.7	1894.0	4.00	166	170,908	57.2	53.4	0.93	0.037
12	28:09	529,579	866.7	1896.8	4.50	166	182,658	60.0	2.8	0.05	0.037
13	87/04/04:12	579,110	923.2	1898.6	4.50	171	168,405	56.5	1.8	0.03	0.038
14	11:14	630,608	983.4	1945.9	4.50	170	175,093	60.2	47.3	0.79	0.039
15	18:16	676,970	1039.2	1996.5	4.25	170	157,631	55.8	50.6	0.91	0.040
16	25:12	731,759	1107.3	2057.7	4.00	164	186,283	68.1	61.2	0.90	0.041
17	87/05/02:11	785,512	1172.6	2125.0	4.00	167	182,760	65.3	67.3	1.03	0.040
18	09:10	837,265	1235.5	2155.1	4.00	167	175,960	62.9	30.1	0.48	0.040
19	16:11	884,510	1290.3	2197.0	3.50	169	160,633	54.8	41.9	0.76	0.038
20	23:11	934,148	1346.8	2239.7	3.50	168	168,769	56.5	42.7	0.76	0.037
21	30:11	980,997	1398.7	2290.2	3.50	168	159,287	51.9	50.5	0.97	0.036
22	87/06/06:14	1,024,953	1447.0	2380.7	4.00	171	149,450	48.3	90.5	1.87	0.036
23	13:10	1,070,684	1498.4	2428.6	4.00	164	155,485	51.4	47.9	0.93	0.037
24	20:11	1,115,469	1548.9	2472.8	3.75	169	152,269	50.5	44.2	0.88	0.037
25	27:10	1,161,101	1602.1	2523.6	3.50	167	155,149	53.2	50.8	0.95	0.038
26	87/07/04:11	1,208,443	1658.8	2574.5	3.50	169	160,963	56.8	50.9	0.90	0.039
	Monthly/Quarterly/Half-yearly cumulative values:					4368	4104279	1422.5	1229.1		
	Monthly/Quarterly/Half-yearly average values:									0.86	0.038

Water volume pumped and water volume actually used

During Short Term Tests for solar pump systems with a storage tank the flow meter was installed at the pump outlet. During Long Term Tests a second meter (same type) shall be placed at the discharge of the storage tank.

In order to obtain information on the effect of the storage tank, during Long Term Testing the owner should preferably not switch off the pump when the tank is full. To avoid spillage of water the system should be equipped with an overflow pipe to a place where excess water can be utilized. Do not feed back the excess water to the well; it might contaminate the water source!
By doing so the flow meter between the pump and the tank measures the potential water volume pumped at the given circumstances. The second flow meter measures the water volume actually consumed by the end-user or the end-use system.
Under certain conditions it might be difficult to require the owner to operate his pumping system continuously, e.g. when the water is scarce. A compromise might be to operate the system continuously during a shorter period of time. Also an indemnification might be offered to the owner to compensate for the extra running hours.

If for any reason only one flow meter is available, it should be installed at the storage tank outlet.

Check the flow meters regularly in order to detect malfunctioning e.g. due to contamination as soon as possible (see section 2.5.1.). Care should be taken to record whether and when the flow meters passed their maximum number of digits and started at the zero reading again, especially if for any reason readings are taken over longer intervals than prescribed.

The water volume pumped is read from the flow meter between pump and storage tank, the water volume actually used is read from the flow meter at the storage tank outlet.
Note the results down in cubic metres [m^3].

Head

Suction Head

If the level of the water source showed large variations during the Short Term Tests, the accuracy of the tests may be improved by taking an additional measurement of the suction head H_{in} e.g. half-way the measuring period T. Put all values in the logbook and record the average value (in metres [m]) in Data Sheet 5.4.1..

Discharge Head
In many cases the discharge head H_{dis} is constant. It is simply the vertical distance between the pump and the discharge pipe outlet at the top of the storage tank.
If the discharge pipe enters at the bottom of the storage tank, the discharge head should be measured up to the average water level in the tank (e.g. half-way between top and bottom). Write the results in metres [m].

Pressure Head
In most solar pump applications a storage tank functions as a water tower to generate a pressure head as required for the end use system. Then this pressure simply forms part of the discharge head from pump level to storage tank water level and must not be measured separately. If alternatively for example a solar pump directly feeds a system requiring a pressure at its intake, e.g. a sprinkler system (which is not common practice), the discharge pressure H_p should be measured at the sprinkler system intake by means of a bourdon type manometer. Write the results in metres [m].

In Figure 5.3.1. some examples are given to illustrate the measurement of the different types of head for a number of situations:

Case a.
A shallow well is equipped with a surface pump and a storage tank. The suction head H_{in} is measured from the water level to the centre of the pump, the discharge head H_{dis} from the centre of the pump to the end of the pipe above the storage tank. In this case there is no pressure head.

Case b.
A tube well is equipped with a deepwell pump and a storage tank. Because the pump is below the water level, H_{in} is negative. It should be calculated by the difference between the water level (meters below ground level) and the position of the pump (meters below ground level).

Case c.
A tube well feeds a storage tank at a long distance L. Note L down in the heading of Data Sheet 5.4.1.. The suction head is calculated as in case b.. Because the pump is situated above the water level, H_{in} is now positive.

Case d.
The storage tank is fed through its bottom. Therefore H_{dis} is measured between pump level and the average water level in the tank.

Case e.
The pumping system feeds an end use system requiring a pressure. The corresponding pressure head is measured by means of a manometer at the system boundary.

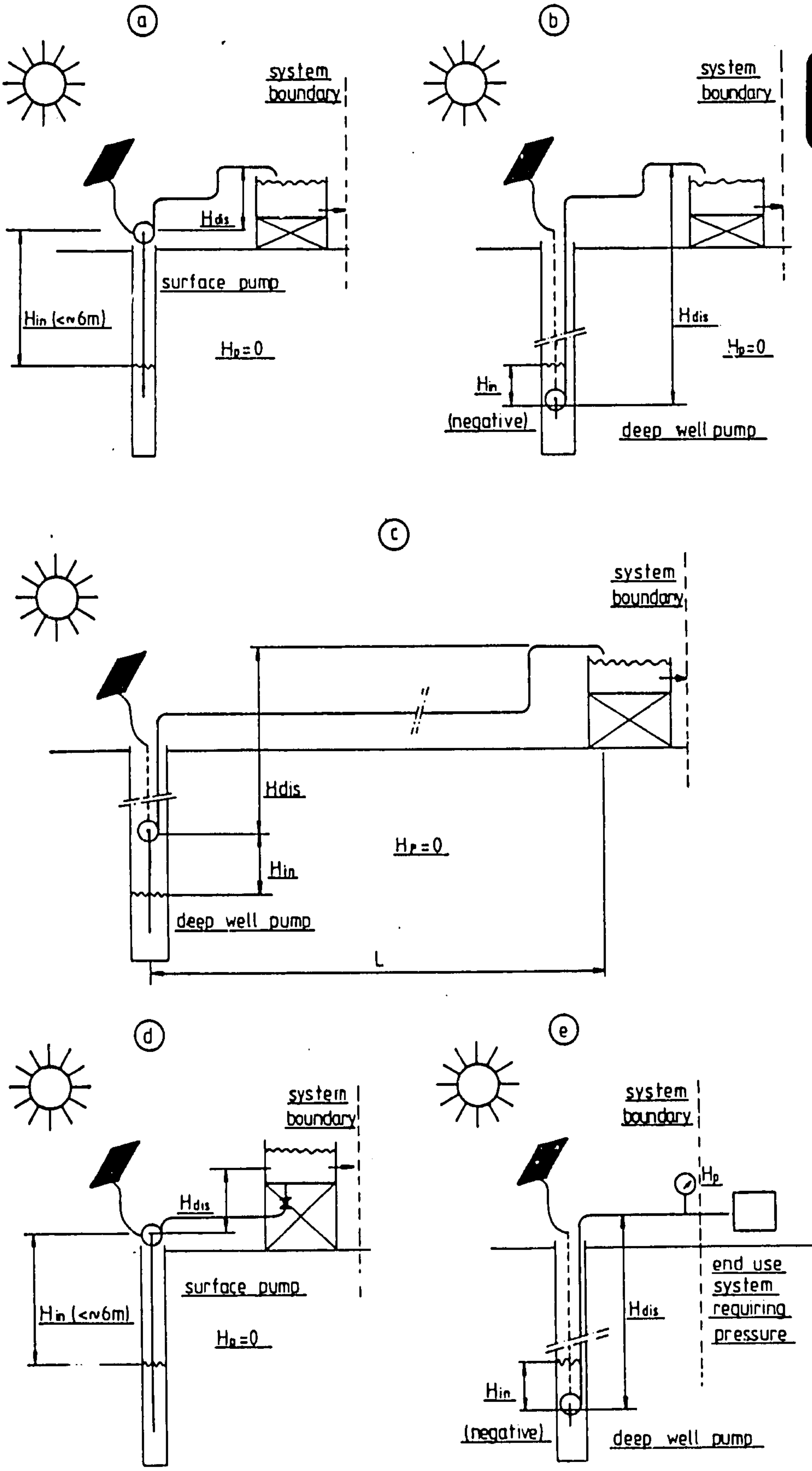


Figure 5.3.1. Examples of head measurements

5.3.2.2 Additional data collection

The logbook should describe in sufficient detail all events occurred e.g. the activities carried out with regard to servicing, maintenance (i.e. preventive action), repair (i.e. corrective action) and overhaul. It should specify the date of the event, the amount of time spent and the costs (distinguish between skilled and unskilled labour, parts, materials, lubricants and transportation). It is recommended to make this description by systematically treating the following issues:

-Maintenance
  - =Actions performed (by whom?). If standard, refer to users manual.
  - =Replaced parts
  - =Lubricants used

-Break downs of the system
  - =Description of system failure
  - =When was it discovered?
  - =Who was warned, how?
  - =(Possible) causes
  - =When repair started?
  - =Actions performed (by whom, time spent?)
  - =Period during which the system was out of order

-Operation of the system
  - =Periods of water shortage, reasons

-Water source
  - =Occurrence of abnormal water levels in water source.
  - =Running dry of the well.

Data sheet 5.3.2. gives a lay-out and a hypothetical example as how to complete this sheet. It can be used as a summary of all events and simultaneously serve as a table of contents to refer to logbook pages with detailed information. The first lines of Data Sheet 5.3.2. give information on the people contributing to the logbook. The subsequent columns of the data sheet contain the date of the event, the initials of the reporter (it is very important that any person putting down information in the logbook is identified by his initials; he is an important source of additional information when needed), a short description, the time during which the system was out of order (down time), the time spent to maintenance or other activities, the costs and the page number of the logbook where detailed information, if any, is recorded. The example shows how the different kinds of costs can be distinguished by using more lines for a single event.

DATA SHEET 5.3.2. Chronological survey of all relevant events (to be completed by various people)

Initials	Function	Name
AB	Owner	Butsi, A
FA	Techn	Abebe, F
PS	Operator	Sanford, P

Date	Init	Description	Down time [hours]	Time spent [hours]	Costs [..B..]	logbook page
87/04/28	FA	Maintenance	30			26
		Skilled labour		12	60	
		Grease			1	
		Unskilled labour		12	30	
87/04/29	FA	System ready for operation again				
87/04/30	AB	Operators salary			35	

5.3.3. <u>Data reduction Long Term Tests</u>

Data analysis should be initiated as soon as possible after data collection to quickly indicate possible problems with either the pumping system or the data collection instruments.
Early detection of any anomalies in the data will not only lead to more reliable data, but will also eliminate potential problems resulting from incorrect installations of equipment or oversights in the design. Also deterioration of performance in time may be detected by doing so.

If during the Long Term Tests large deviations from expected values are found, it is recommended to perform (part of) a Short Term Test in order to identify possible causes of these deviations.

5.3.3.1 Performance

The results of reduction of data on system performance are recorded in Data Sheet 5.3.1. in the column indicated by "CALCULATIONS".
Two steps of data reduction are performed, both using the same type of calculations and formulas.

1. After every measurement cumulative and average values are calculated over the period of time between that measurement and the previous one. The length of the period of observation T equals the time between two successive measurements (about 1 day, half a week, 1 week). The calculations are performed using pairs of two successive measurements. The results are noted down in Data sheet 5.3.1. behind the corresponding measurements.

2. After a certain period of time (month, quarter, half a year, a year), when a data sheet is fully completed, cumulative and average values over that longer period are calculated. Now the length of the period of observation T equals the time between the two measurements at the beginning and at the end of that period. For the calculations the latter two measurements are used. The results are noted down on the two bottom lines of Data Sheet 5.3.1. and in Data Sheet 5.3.3. under the heading "Performance".

Length of period T

The length of the period of observation T simply equals length of time between two measurements.

Example: The first measurement took place on 3 January 1987 at 11.00 A.M. (87/01/03;11), the second one on 10 January at 08.00 A.M. (87/01/10;08). The length of the time period T is 7 days minus 3 hours equalling 165 hours (see lines 0 and 1 of Data Sheet 5.3.1.).

Solar irradiation

When the pyranometer readings E_{sol} are registered in [Wh/m^2], the solar irradiation received by the solar array over the period T is:

$$E_{sol,T} = (E_{sol,e} - E_{sol,b}) * A_{array} \qquad [Wh]$$

where: $E_{sol,b}$ = the pyrano meter reading at the beginning of period T,
$E_{sol,e}$ = the pyrano meter reading at the end of period T,
A_{array} = Area of photo voltaic array (solar array) in [m^2]

<u>Example:</u> If $E_{sol,e}$ = 379,242 Wh/m^2 and $E_{sol,b}$ = 331,119 Wh/m^2, then $E_{sol,T}$ = 163,618 Wh, because the Array area equals 3.4 m^2 (see lines 8 and 9 in Data Sheet 5.3.1)

<u>Water volume pumped</u>

When the flow meter readings Q_P are registered in m^3, the water volume pumped over a period T is:

$$Q_{PT} = Q_{P,e} - Q_{P,b} \qquad [m^3]$$

where: $Q_{P,b}$ = the reading of the integrating flow meter at the beginning of period T
$Q_{P,e}$ = the reading of the integrating flow meter at the end of period T

<u>Example:</u> On 21 March 1987 the flow meter at the pump outlet indicated 806.7 m^3 ($Q_{P,b}$). A week later the reading was 866.7 m^3 ($Q_{P,e}$). Application of the formula leads to $Q_{P,T}$ = 60.0 m^3 (Lines 11 and 12, Data Sheet 5.3.1.)

<u>Water volume actually used</u>

When the flow meter readings Q_U are registered in m^3, the water volume actually used over a period T is:

$$Q_{UT} = Q_{U,e} - Q_{U,b} \qquad [m^3]$$

where: $Q_{U,b}$ = the reading of the integrating flow meter at the beginning of period T
$Q_{U,e}$ = the reading of the integrating flow meter at the end of period T

Hydraulic system output

The hydraulic system output $E_{h,T}$ over a period T can be calculated from Q_{PT} by:

$$E_{h,T} = 2.73 * Q_{PT} * \frac{H_b + H_e}{2} \quad [Wh]$$

where:
H_b = total effective head (see Annex 2.2) at the beginning of period T
H_e = total effective head at the end of period T
2.73 = conversion factor (9.81/3.6).

Example: During the week from 9 to 16 May 1987 the hydraulic system output was:

$$E_{h,T} = 2.73*54.8*(\frac{4 + 3.5}{2} +37) = 6096 \ [Wh]$$

See lines 18 and 19 of Data Sheet 5.4.1.. (The number 37 stands for the discharge head H_{dis}, see heading of the Data Sheet).
The result is not recorded in the Data Sheet. It is used in the next calculation:

Overall system efficiency

The overall system efficiency η_{tot} is obtained from the quantities above by:

$$\eta_{tot} = \frac{E_{h,T}}{E_{sol,T}} \quad [-]$$

Example: During the week from 9 to 16 May $E_{sol,T}$ was 160,633 Wh.

Using the value for $E_{h,T}$ for the same period as calculated in the previous example results in

η_{tot} = 0.038 (see lines 18 and 19 of Data Sheet 5.3.1).

Solar pump exploitation factor

The solar pump exploitation factor f_{se} over a period T is calculated by :

$$f_{se} = \frac{Q_{UT}}{Q_{PT}} \qquad [-]$$

Example: During the week from 7 to 14 February 1987 the water volume pumped was Q_{PT} = 53.4 m^3. The water volume actually used was Q_{UT} = 65.8 m^3. As a result f_{se} equals 1.23. See line 6 of Data Sheet 5.3.1..

Average and cumulative values over a longer period of time

The bottom lines of Data Sheet 5.3.1. are used for noting down average and cumulative values over a longer period of time. In the example this period has a length of 26 weeks.

The Total length of period T (being 4368 hours in the example) can be obtained by summing all calculated T-values or alternatively by the difference between the first and the last "Date and Time" (lines 0 and 26).

For the Solar Irradiation, the Total water volume pumped and the Total water volume used the formulas explained in the beginning of this section are applied using the integrating meter readings on line 0 and line 26. The result is:

Half-yearly solar irradiation = (1,208,443 - 1,302)*3.4
= 4,104,279 Wh

Half-yearly water volume pumped = 1658.9 - 236.4 = 1422.5 [m^3]

Half-yearly water volume used = 2574.5 - 1345.4 = 1229.1 [m^3]

The Half-yearly average solar pump exploitation factor (in the example being 0.86) results from the quotient of the half-yearly water volume pumped and half-yearly water volume used.

For the Half-yearly overall system efficiency the half-yearly hydraulic system output $E_{h,T=\frac{1}{2}y}$ has to be determined:

$$E_{h,T=½y} = 2.73 * Q_{P,T=½y} * H_{average} \quad [Wh]$$

Where:

$Q_{P,T=½y}$ = half-yearly water volume pumped (1422.5 [m^3]),
$H_{average}$ = half-yearly average total effective head.

The last quantity is most accurately calculated when all 27 suction head measurements available in Data Sheet 5.4.1. are used. The result is:

$$H_{in,average} = (2.0 + 2.5 + 1.75 + ... + 3.5)/27 = 3.34 \text{ m.}$$

Because the discharge head is constant (37 m), the average total effective head becomes:

$$H_{average} = 37 + 3.34 = 40.34 \text{ m.}$$

Using these results the half-yearly hydraulic solar pump output is:

$$E_{h,T=½y} = 2.73 * 1422.5 * 40.34 = 156,657 \text{ Wh.}$$

Finally the Half-yearly overall system efficiency is calculated using the formula presented earlier in this section:

$$\eta_{tot,½y} = \frac{E_{h,T=½y}}{E_{sol,T}}$$

Inserting the average and cumulative values from above the result is:

$$\eta_{tot,½y} = \frac{156,657}{4,104,279} = 0.038$$

NOTES:

1. The overall system efficiency of the solar pump relates the hydraulic output of the solar pump to the energy content of the solar irradiance received by the solar array surface area. According to "Water Pumping Devices" (Peter Fraenkel, IT Publications 1986) its value normally is in the range from 0.02 to 0.03. The best systems available achieve overall system efficiencies of 0.05.
   Much lower values might be caused by:
   -a worn pump
   -a filthy solar array
   -a malfunctioning power control system

-a dry well.
-a sub-optimal matching of the system (too small or too large a pump).

2. The solar pump exploitation factor f_{se} relates the water volume pumped to the water volume actually used. Its maximum value is 1.00[1], which means that all water pumped is useful applied. A high value of f_{se} is important; when it is halved, the costs of the water is doubled. Low values of f_{se} might be caused by:
   -too large a solar pump
   -too small a storage tank
   -low water requirements during periods with high solar irradiance
   -a leak in the storage tank.

The average and cumulative data over the period of a year (to be calculated as described above) should be put in Data Sheet 5.3.3. under the heading "Performance".

5.3.3.2 Reliability of the solar pump

As stated, Data Sheet 5.3.2. shows information on reliability e.g. the number of system failures, their type and duration, repair types and times, maintenance problems, climatological, natural or other phenomena affecting delivery reliability, any inherent design faults, etc.
In Data Sheet 5.3.3. this information will be summarized for a period of a year under the heading "Operation". Some items are already suggested in the sheet.

The various total times asked for might require some explanation. Operating time is the time during which the system was running during the length of period T. Total time needed for maintenance and total time needed for repair equal the number of man hours spent to maintenance and repair respectively. Total down-time is the total time the system was not in operating order due to system failures.

The reliability of the system can be expressed by three different indicators, viz. the mean down time (MDT), the mean time between failures (MTBF) and the availability. They are calculated as follows:

$$MDT = \frac{\text{Total down-time}}{\text{number of break-downs}} \quad \text{[hours per break-down]}$$

1 As shown in the example (line 6 of Data Sheet 5.3.1), the value of f_{se} might be higher than 1 over shorter periods of time. The effect is caused by the storage tank that can "produce" water even if there is no new water input at all.

$$MTBF = \frac{\text{Length of period} - \text{Total down-time}}{\text{number of break-downs}} \quad [hours]$$

$$Availability = \frac{\text{Length of period} - \text{Total down-time}}{\text{Length of period}} \quad [-]$$

DATA SHEET 5.3.3. Summary of information of Solar Pump System
(to be completed by technician)

SUMMARY OVER 19___

Location: ______________________________
District: ______________________________
Owner : ______________________________

Performance

Yearly solar irradiation	:	________	[Wh]
Yearly water volume actually used	:	________	[m^3]
Yearly water volume pumped	:	________	[m^3]
Overall system efficiency	:	________	[-]
Solar pump exploitation factor	:	________	[-]

Operation

Operating time of the system	:	________	[hours]
Total time needed for maintenance	:	________	[hours]
Total time needed for repairs	:	________	[hours]
Total down-time	:	________	[hours]
Number of break-downs	:	________	[-]
Mean down time	:	________	[hours]
Mean time between failures	:	________	[hours]
Availability	:	________	[-]
________________	:	________	______
________________	:	________	______
________________	:	________	______

Recurrent Costs [________]*

	operation	maintenance	repair	total
Skilled labour	______	______	______	______
Unskilled labour	______	______	______	______
Materials	______	______	______	______
Parts	______	______	______	______
Transportation	______	______	______	______
Replacements pump	______	______	______	______
Replacements PV	______	______	______	______

*) Indicate currency; note replacement types & time in log

These indicators all refer to different aspects of reliability. E.g. if a short MTBF is caused by many break-downs of short duration (due to quick repair service), the MDT is low and the availability of the system is high.

In addition other events could be summarized, for instance those having occurred strikingly often (e.g. pumping dry of the well). Careful consideration of Data Sheet 5.3.2. should result in meaningful summaries of events.

5.3.3.3 Recurrent costs

The data on recurrent costs collected during the Long Term Test, recorded in Data Sheet 5.3.2. will be summarized in Data Sheet 5.3.3. under the heading "Recurrent Costs".
Details on the various repairs, maintenance items, replacements etc. will be noted down in the log.

5.4. MECHANICAL WIND PUMPS

5.4.1. The "System" during Long Term Tests

During the Long Term Tests the system under observation includes the following parts:

1. Windmill
2. Transmission — Technical system as considered during [Short Term Test. (items 1–3)
3. Pump
4. Storage tank, if any
5. Back-up system, if any
6. Resources: =Manpower
=Water
=Wind
=Money
7. Output : =(Useful) water.

In most cases a back-up system, if any, consists of a diesel pump pump. According to the considerations at the end of Section 2.1. it might be subjected to a Long Term Test simultaneously. It is recommended to use Section 5.2. for that purpose.

5.4.2. Measurements and data collection during Long Term Tests

5.4.2.1 Measurements

Measurement equipment required and recommendations with respect to its installation have been described in sections 2.5.1. and 2.5.2.4.

Within the framework of Long Term Testing measurements shall be performed on a regular basis. The maximum period of time allowed between two measurements depends on the capacity of the storage tank that usually is part of a windpump system. The time between two successive measurements should be about equal to the time during which the end-use system can function without major problems when it starts with a storage tank full of water, while no further water is being pumped during that period. Given the most common storage tank sizes for the various applications for irrigation purposes usually a period of one week between the measurements is sufficient. For drinking water systems this period will vary between one day and half a week. It is recommended to choose fixed times in the week to carry out the measurements; by doing so their regular performance is guaranteed and the chance of forgetting measurements is minimized. Possible schemes could be for an irrigation system every Monday morning, for a drinking water system every Tuesday and Friday at noon, etc.

Data Sheet 5.4.1. (column "MEASUREMENTS") gives a lay-out for noting down the numerical information required and an example as how to fill in the sheet. For every measurement one line on the data sheet is available. At the start of the Long Term Test the start reading of the various instruments is recorded on the first line (marked by "0"). When during Long Term Tests a new Data Sheet is opened, the first line is used for copying the last measurement of the previous Data Sheet.

The two bottom lines of Data Sheet 5.4.1. are used for average and cumulative values over a longer period of time. It is recommended to choose the number of lines in Data Sheet 5.4.1. in such a way that averages and cumulative values are calculated over a proper period of time i.e. a month, a quarter or half a year. Dependent on the chosen period of time between two successive measurements (see above) the following lengths of Data Sheet 5.4.1. could be applied:

Time between two successive measurements	Number of lines in Data Sheet 5.4.1.	Length of averaging period
1 day	31	month
half a week	26	quarter
1 week	26	half a year

Date and Time

Write Date and Time in the format YY/MM/DD;HH.
E.g. 87/01/03;11 is equivalent to 3 January 1987 at 11 a.m.. Recording the time in whole hours is sufficiently accurate for the present purpose.

Wind speed (Wind run)

For Long Term Tests the integrating cup anemometer (wind run meter) shall be used. Write the results in km (kilometers).

Water volume pumped and water volume actually used

During Short Term Tests for wind pump systems with a storage tank the flow meter was installed at the pump outlet. During Long Term Tests a second meter (same type) shall be placed at the discharge of the storage tank.

DATA SHEET 5.4.1. Measurements and Calculations Long Term Tests

(to be completed by owner (MEASUREMENTS) and technician (CALCULATIONS))

Location: ______ Start Date : 87/01/03 [YY/MM/DD]

District: ______ End Date : 87/07/04 [YY/MM/DD]

Owner : ______

Discharge head H_{dis}: 37 [m] | Pressure head H_p: / [m] | Horizontal distance L: / [m] | Rotor Diameter: 5.18 [m]

	MEASUREMENTS (see section 5.4.2.1)					CALCULATIONS (see section 5.4.3.)					
No	Date and time t [YY/MM/DD;HH]	Wind run R_W [km]	Volume pumped Q_P [m^3]	Volume used Q_U [m^3]	Suction Head H_{in} [m]	Length of period T [hours]	Average Wind speed V_T [m/s]	Volume pumped Q_{PT} [m^3]	Volume used Q_{UT} [m^3]	Exploitation factor f_{we} [-]	Quality factor e [-]
0	87/01/03:11	20836	1680	93753	2.00						
1	10:08	23925	2018	94054	2.50	165	5.2	338	301	0.89	0.07
2	17:14	26932	2326	94334	1.75	174	4.8	308	280	0.91	0.08
3	24:10	29647	2616	94634	3.25	164	4.6	290	300	1.03	0.09
4	31:18	32879	2956	94909	2.25	176	5.1	340	275	0.81	0.07
5	87/02/07:12	35153	3148	95109	2.00	162	3.9	192	200	1.04	0.10
6	14:15	37123	3282	95274	3.00	171	3.2	134	165	1.23	0.12
7	21:10	39236	3464	95434	3.25	163	3.6	182	160	0.88	0.12
8	28:10	41836	3714	95667	2.00	168	4.3	250	233	0.93	0.10
9	87/03/07:12	44345	3944	95879	2.25	170	4.1	230	212	0.92	0.10
10	14:13	46597	4124	96054	3.00	168	3.7	180	175	0.97	0.11
11	21:11	48091	4184	96110	4.00	166	2.5	60	56	0.93	0.12
12	28:09	49644	4249	96113	4.50	166	2.6	65	3	0.05	0.12
13	87/04/04:12	51553	4376	96117	4.50	171	3.1	127	4	0.03	0.13
14	11:14	52960	4418	96150	4.50	170	2.3	42	33	0.79	0.11
15	18:16	54613	4482	96208	4.25	170	2.7	64	58	0.91	0.10
16	25:12	56089	4542	96262	4.00	164	2.5	60	54	0.90	0.12
17	87/05/02:11	57712	4610	96332	4.00	167	2.7	68	70	1.03	0.11
18	09:10	59636	4750	96399	4.00	167	3.2	140	67	0.48	0.14
19	16:11	62191	4992	86504	3.50	169	4.2	242	186	0.76	0.10
20	23:11	64610	5213	96751	3.50	168	4.0	221	167	0.76	0.11
21	30:11	66908	5405	96938	3.50	168	3.8	192	187	0.97	0.11
22	87/06/06:14	68140	5436	96996	4.00	171	2.0	31	58	1.87	0.12
23	13:10	69675	5509	97064	4.00	164	2.6	73	68	0.93	0.13
24	20:11	71561	5630	97170	3.75	169	3.1	121	106	0.88	0.12
25	27:10	73665	5790	97323	3.50	167	3.5	160	153	0.96	0.12
26	87/07/04:11	76099	5982	97495	3.50	169	4.0	192	172	0.90	0.09
	~~Monthly~~/~~Quarterly~~/Half-yearly cumulative values:					4368		4302	3742		
	~~Monthly~~/~~Quarterly~~/Half-yearly average values:						3.51			0.87	0.12

In order to obtain information on the effect of the storage tank, during Long Term Testing the owner should preferably not switch off the pump when the tank is full. To avoid spillage of water the system should be equipped with an overflow pipe to a place where excess water can be utilized. Do not feed back the excess water to the well; it might contaminate the water source!
By doing so the flow meter between the pump and the tank measures the potential water volume pumped at the given circumstances. The second flow meter measures the water volume actually consumed by the end-user or the end-use system.
Under certain conditions it might be difficult to require the owner to operate his pumping system continuously, e.g. when the water is scarce. A compromise might be to operate the system continuously during a shorter period of time. Also an indemnification might be offered to the owner to compensate for the extra running hours.

If for any reason only one flow meter is available, it should be installed at the storage tank outlet.

Check the flow meters regularly in order to detect malfunctioning e.g. due to contamination as soon as possible (see section 2.5.1.). Care should be taken to record whether and when the flow meters passed their maximum number of digits and started at the zero reading again, especially if for any reason readings are taken over longer intervals than prescribed.

The water volume pumped is read from the flow meter between pump and storage tank, the water volume actually used is read from the flow meter at the storage tank outlet.
Note the results down in cubic metres [m^3].

Head

Suction Head

If the level of the water source showed large variations during the Short Term Tests, the accuracy of the tests may be improved by taking an additional measurement of the suction head H_{in} e.g. half-way the measuring period T. Put all values in the logbook and record the average value (in metres [m]) in Data Sheet 5.4.1..

Discharge Head

In many cases the discharge head H_{dis} is constant. It is simply the vertical distance between the pump and the discharge pipe outlet at the top of the storage tank.
If the discharge pipe enters at the bottom of the storage tank, the discharge head should be measured up to the average water level in the tank (e.g. half-way between top and bottom). Write the results in metres [m].

Pressure Head
In most wind pump applications a storage tank functions as a water tower to generate a pressure head as required for the end use system. Then this pressure simply forms part of the discharge head from pump level to storage tank water level and must not be measured separately. If alternatively for example a wind pump directly feeds a system requiring a pressure at its intake, e.g. a sprinkler system (which is not common practice), the discharge pressure H_p should be measured at the sprinkler system intake by means of a bourdon type manometer. Write the results in metres [m].

In Figure 5.4.1. some examples are given to illustrate the measurement of the different types of head for a number of situations:

Case a.
A shallow well is equipped with a surface pump and a storage tank. The suction head H_{in} is measured from the water level to the centre of the pump, the discharge head H_{dis} from the centre of the pump to the end of the pipe above the storage tank. In this case there is no pressure head.

Case b.
A tube well is equipped with a deepwell pump and a storage tank. Because the pump is below the water level, H_{in} is negative. It should be calculated by the difference between the water level (meters below ground level) and the position of the pump (meters below ground level).

Case c.
A tube well feeds a storage tank at a long distance L. Note L down in the heading of Data Sheet 5.4.1.. The suction head is calculated as in case b.. Because the pump is situated above the water level, H_{in} is now positive.

Case d.
The storage tank is fed through its bottom. Therefore H_{dis} is measured between pump level and the average water level in the tank.

Case e.
The pumping system feeds an end use system requiring a pressure. The corresponding pressure head is measured by means of a manometer at the system boundary.

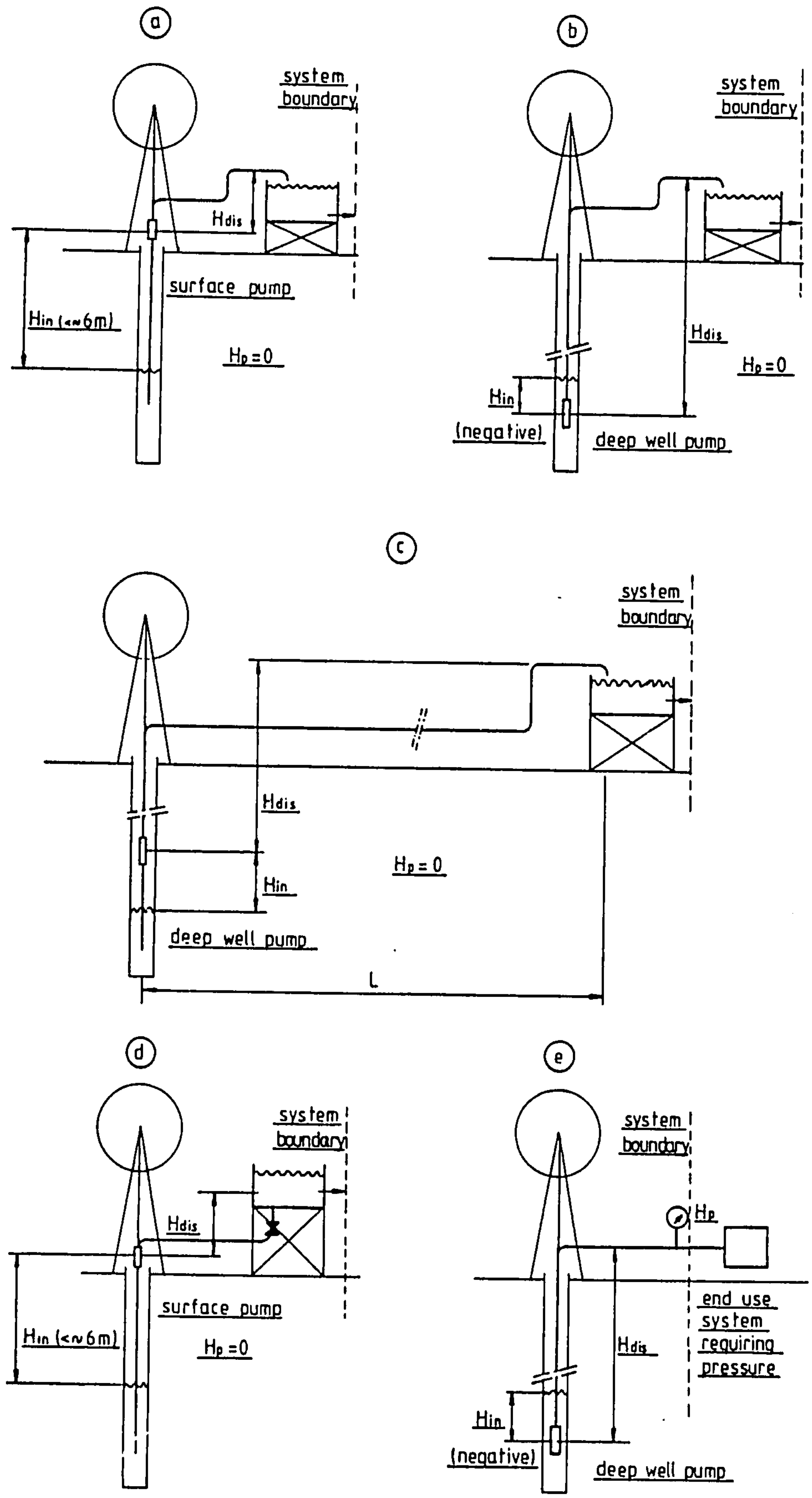


Figure 5.4.1. Examples of head measurements

5.4.2.2. Additional data collection.

The logbook should describe in sufficient detail all events occurred e.g. the activities carried out with regard to servicing, maintenance (i.e. preventive action), repair (i.e. corrective action) and overhaul. It should specify the date of the event, the amount of time spent and the costs (distinguish between skilled and unskilled labour, parts, materials, lubricants and transportation). It is recommended to make this description by systematically treating e.g. the following issues:

-Maintenance
- =Actions performed (by whom?). If standard, refer to users manual.
- =Replaced parts
- =Lubricants used

-Break downs of the system
- =Description of system failure
- =When was it discovered?
- =Who was warned, how?
- =(Possible) causes
- =When repair started?
- =Actions performed (by whom, time spent?)
- =When was the system ready for operation again?

-Operation of the system
- =Periods of intentionally furling of the windpump, reasons
- =Periods of water shortage, reasons

-Water source
- =Occurrence of abnormal water levels in water source.
- =Running dry of the well.

Data sheet 5.4.2. gives a lay-out and a hypothetical example as how to complete this sheet. It can be used as a summary of all events and simultaneously serve as a table of contents to refer to logbook pages with detailed information. The first lines of Data Sheet 5.4.2. give information on the people contributing to the logbook. The subsequent columns of the data sheet contain the date of the event, the initials of the reporter (it is very important that any person putting down information in the logbook is identified by his initials; he is an important source of additional information when needed), a short description, the time during which the system was out of order (down time), the time spent to maintenance or other activities, the costs and the page number of the logbook where detailed information, if any, is recorded. The example shows how the different kind of costs can be distinguished by using more lines for a single event.

DATA SHEET 5.4.2. Chronological survey of all relevant events
(to be completed by various people)

Initials	Function	Name
AB	Owner	Butsi, A
FA	Technician	Abebe, F
PS	Operator	Sanford, P

Date	Init	Description	Down time [hours]	Time spent [hours]	Costs [.Ø..]	logbook page
87/04/28	FA	Maintenance	30			26
		Skilled labour		12	60	
		Grease			1	
		Leather cup			2	
		Unskilled labour		24	50	
87/04/30	AB	Operators salary			40	
87/05/02	PS	Windpump furled				27
87/05/03	PS	Windpump in operation again	18			

5.4.3. Data reduction of Long Term Tests

Data analysis should be initiated as soon as possible after data collection to quickly indicate possible problems with either the pumping system or the data collection instruments.
Early detection of any anomalies in the data will not only lead to more reliable data, but will also eliminate potential problems resulting from incorrect installations of equipment or oversights in the design. Also deterioration of performance in time may be detected by doing so.

If during the Long Term Tests large deviations from expected values are found, it is recommended to perform (part of) a Short Term Test in order to identify possible causes of these deviations.

5.4.3.1 Performance

The results of reduction of data on system performance are recorded in Data Sheet 5.4.1. in the column indicated by "CALCULATIONS".
Two steps of data reduction are performed both using essentially the same types of calculations and formulas.

1. After each measurement cumulative and average values are calculated over the period of time between that measurement and the previous one. The length of the period of observation T equals the time between two successive measurements (e.g. 1 day, half a week, 1 week). The calculations are performed using pairs of two successive measurements. The results are noted down in Data sheet 5.4.1. behind the corresponding measurements.

2. After a certain period of time e.g. a month, a quarter, half a year, a year), when a data sheet is fully completed, cumulative and average values over that longer period are calculated. Now the length of the period of observation T equals the time between the two measurements at the beginning and the end of that period. For the calculations the latter two measurements are used. The results are noted down on the two bottom lines of Data Sheet 5.4.1. and in Data Sheet 5.4.3. under the heading "Performance".

Length of period T

The length of the period of observation T simply equals the length of time between two measurements.

Example: The first measurement took place on 3 January 1987 at 11.00 A.M. (87/01/03;11), the second one on 10 January at 08.00 A.M. (87/01/10;08). The length of the time period T is 7 days minus 3 hours equalling 165 hours (see lines 0 and 1 of Data Sheet 5.4.1.).

Average wind speed

When the wind run meter readings R_w are registered in km, the average wind speed over a period T is:

$$V_T = \frac{R_{w,e} - R_{w,b}}{3.6 * T} \quad [m/s]$$

where: $R_{w,b}$ = wind run meter reading at the beginning of period T,
$F_{w,e}$ = wind run meter reading at the end of period T,
T = length of observation period in hours,
3.6 = conversion factor 3600/1000.

<u>Example:</u> On 7 February 1987 the wind run meter indicated 35153 km ($R_{w,b}$); a week later the reading was 37123 km ($R_{w,e}$). Then the formula leads to V_T = 3.2 [m/s] (see example in lines 5 and 6 in Data Sheet 5.4.1.).

<u>Water volume pumped</u>

When the flow meter readings Q_P are registered in m^3, the water volume pumped over a period T is:

$$Q_{PT} = Q_{P,e} - Q_{P,b} \qquad [m^3]$$

where: $Q_{P,b}$ = the reading of the integrating flow meter at the beginning of period T,
$Q_{P,e}$ = the reading of the integrating flow meter at the end of period T.

<u>Example:</u> On 21 March 1987 the flow meter at the pump outlet indicated 4184 m^3 ($Q_{P,b}$). A week later the reading was 4249 m^3 ($Q_{P,e}$). Application of the formula leads to $Q_{P,T}$ = 65 m^3 (see lines 11 and 12 in Data Sheet 5.4.1.).

<u>Water volume actually used</u>

When the flow meter readings Q_U are registered in m^3, the water volume actually used over a period T is:

$$Q_{UT} = Q_{U,e} - Q_{U,b} \qquad [m^3]$$

where: $Q_{U,b}$ = the reading of the integrating flow meter at the beginning of period T,
$Q_{U,e}$ = the reading of the integrating flow meter at the end of period T.

Hydraulic windpump output

The hydraulic system output $E_{h,T}$ over a period T can be calculated from Q_{PT} by:

$$E_{h,T} = 2.73 * Q_{PT} * \frac{H_b + H_e}{2} \quad [Wh]$$

where:
H_b = total effective head (see Annex 2.2) at the beginning of period T,
H_e = total effective head at the end of period T,
2.73 = conversion factor (9.81*1000/3600).

Example: During the week from 9 to 16 May 1987 the hydraulic system output was:

$$E_{h,T} = 2.73*242*(\frac{4 + 3.5}{2} +37) = 26922 \ [Wh]$$

See lines 18 and 19 of Data Sheet 5.4.1.. (The number 37 stands for the discharge head H_{dis}, see heading of the Data Sheet).
The result is not recorded in the Data Sheet. It is used in the next calculation:

Quality factor

The quality factor e is obtained from the quantities above by:

$$e = \frac{E_{h,T}}{A * V_T^3 * T}$$

where:
A = rotor area calculated from the rotor diameter D by:
A = $0.785 * D^2 \quad [m^2]$
P_T = hydraulic windpump output
V_T = average windspeed.

Example: During the week from 9 to 16 May 1987 the hydraulic output was 26922 Wh. (see previous example). In this period the quality factor equals:

$$e = \frac{26922}{0.785*(5.18)^2*4.2^3*169} = 0.1$$

See lines 18 and 19 in Data Sheet 5.4.1.

Windpump exploitation factor

The windpump exploitation factor f_{we} over a period T is calculated by :

$$f_{we} = \frac{Q_{UT}}{Q_{PT}} \qquad [-]$$

Example: During the week from 7 to 14 February 1987 the water volume pumped was Q_{PT} = 134 m^3. The water volume actually used was Q_{UT} = 165 m^3. As a result f_{we} equals 1.23. See line 6 of Data Sheet 5.4.1..

Average and cumulative values over a longer period of time

The bottom lines of Data Sheet 5.4.1. are used for noting down average and cumulative values over a longer period of time. In the example this period has a length of 26 weeks.

The Total length of period T (being 4368 hours in the example) can be obtained by summing all calculated T-values or alternatively by the difference between the first and the last "Date and Time" (lines 0 and 26).

For the Long term average wind speed, the Total water volume pumped and the Total water volume used the formulas explained in the beginning of this section are applied using the integrating meter readings on line 0 and line 26. The result is:

$$\text{Half-yearly average windspeed} = \frac{76099 - 20836}{3.6 * 4368} = 3.51 \text{ [m/s]}$$

Half-yearly water volume pumped = 5982 - 1680 = 4302 [m^3]

Half-yearly water volume used = 97495 - 93753 = 3742 [m^3]

The Half-yearly average windpump exploitation factor (in the example being 0.87) results from the quotient of the half-yearly water volume pumped and half-yearly water volume used.

For the Half-yearly average quality factor the half-yearly hydraulic windpump output $E_{h,T=\frac{1}{2}y}$ has to be determined:

$$E_{h,T=\frac{1}{2}y} = 2.73 * Q_{P,T=\frac{1}{2}y} * H_{average} \qquad \text{[Wh]}$$

Where:

$Q_{P,T=\frac{1}{2}y}$ = half-yearly water volume pumped (4302 [m^3]),
$H_{average}$ = half-yearly average total effective head.

The last quantity is most accurately calculated when all 27 suction head measurements available in Data Sheet 5.4.1. are used. The result is:

$$H_{in,average} = (2.0 + 2.5 + 1.75 + \ldots\ldots + 3.5)/27 = 3.34 \text{ m.}$$

Because the discharge head is constant (37 m), the average total effective head becomes:

$$H_{average} = 37 + 3.34 = 40.34 \text{ m.}$$

Using these results the half-yearly hydraulic windpump output is:

$$E_{h,T=\frac{1}{2}y} = 2.73 * 4302 * 40.34 = 473{,}772 \text{ Wh.}$$

Finally the <u>Half-yearly average quality factor</u> is calculated using the formula presented earlier in this section:

$$e_{\frac{1}{2}y} = \frac{E_{h,T=\frac{1}{2}y}}{A * V_T^3 * T}$$

Inserting the average and cumulative values from above the result is:

$$e_{\frac{1}{2}y} = \frac{473{,}772}{0.785 * (5.18)^2 * 3.51^3 * 4368} = 0.12$$

<u>NOTES:</u>

1. The quality factor e of the windpump system relates the hydraulic output of the windpump to the energy content of the air flowing through the rotor area over a longer period of time. For "classical design" windpumps the quality factor varies between 0.08 and 0.11. For modern design windpumps its value lies between 0.10 and 0.15. A measured quality factor of a windpump system much lower than previously measured or lower than expected based on information supplied by the windpump builder or vendor might be caused by:
   -a low volumetric efficiency of the pump
      =a worn leather cup,
      =worn valves,

-a problem in the windmill
  =deformation of blades,
  =defect in control mechanism,
-a dry well.
-a sub-optimal matching of the system (too small or too large a pump).

DATA SHEET 5.4.3. Summary of information of Windpump System
(to be completed by technician)

SUMMARY OVER 19___

Location: ______________________
District: ______________________
Owner : ______________________

Performance

Average wind speed	:	______	[m/s]
Yearly water volume actually used	:	______	[m^3]
Yearly water volume pumped	:	______	[m^3]
Quality factor	:	______	[-]
Wind pump exploitation factor	:	______	[-]

Operation

Operating time of the system	:	______	[hours]
Total time needed for maintenance	:	______	[hours]
Total time needed for repairs	:	______	[hours]
Total down-time	:	______	[hours]
Total time "put out of the wind"	:	______	[hours]
Number of break-downs	:	______	[-]
Mean down time	:	______	[hours]
Mean time between failures	:	______	[hours]
Availability	:	______	[-]
______	:	______	______
______	:	______	______
______	:	______	______

Recurrent Costs [______]*

	operation	maintenance	repair	total
Skilled labour	______	______	______	______
Unskilled labour	______	______	______	______
Materials	______	______	______	______
Parts	______	______	______	______
Transportation	______	______	______	______
Replacements	______	______	______	______

*) Indicate currency; note replacement types & time in log

2. The windpump exploitation factor f_{we} relates the water volume pumped to the water volume actually used. Its maximum value is 1.00[1], which means that all water pumped is useful applied. A high value of f_{we} is important; when it is halved, the cost of the water is doubled. Low values of f_{we} might be caused by e.g.:

- too large a windpump
- too small a storage tank
- low water requirements in a windy period
- a leak in the storage tank.

The average and cumulative data over the period of a year (to be calculated as described above) should be put in Data Sheet 5.4.3. under the heading "<u>Performance</u>".

5.4.3.2 Reliability of the windpump system

As stated, Data Sheet 5.4.2. shows information on reliability e.g. the number of system failures, their type and duration, repair types and times, maintenance problems, climatological, natural or other phenomena affecting delivery reliability, any inherent design faults, etc.
In Data Sheet 5.4.3. this information will be summarized for a period of a year under the heading "<u>Operation</u>". Some items are already suggested in the sheet.

The various total times asked for might require some explanation. <u>Operating time</u> is the time during which the system was running during the length of period T. <u>Total time needed for maintenance</u> and <u>total time needed for repair</u> equal the number of man hours spent to maintenance and repair respectively. <u>Total down-time</u> is the total time the system was not in operating order <u>due to system failures</u>. <u>Total time "put out of the wind"</u> is the total time during which the windpump has been intentionally put out of operation.

The reliability of the system can be expressed by three different indicators, viz. the mean down time (MDT), the mean time between failures (MTBF) and the availability. They are calculated as follows:

$$MDT = \frac{\text{Total down-time}}{\text{number of break-downs}} \quad \text{[hours per break-down]}$$

---

1 As shown in the example (line 6 of Data Sheet 5.4.1., the value of f_{we} might be higher than 1 over shorter periods of time. The effect is caused by the storage tank that can "produce" water even if there is no new water input at all.

$$\text{MTBF} = \frac{\text{Length of period} - \text{Total down-time}}{\text{number of break-downs}} \text{ [hours]}$$

$$\text{Availability} = \frac{\text{Length of period} - \text{Total down-time}}{\text{Length of period}} \text{ [-]}$$

These indicators all refer to different aspects of reliability. E.g. if a short MTBF is caused by many break-downs of short duration (due to quick repair service), the MDT is low and the availability of the system is high.

In addition other events could be summarized, for instance those having occurred strikingly often (e.g. pumping dry of the well). Careful consideration of Data Sheet 5.4.2. should result in meaningful summaries of events.

5.4.3.3 Recurrent costs

The data on recurrent costs collected during the Long Term Test, recorded in Data Sheet 5.4.2., will be summarized in Data Sheet 5.4.3. under the heading "Recurrent Costs". Details on types and times of repairs will be noted down in the log.

5.5. HAND PUMPS

5.5.1. <u>The "System" during Long Term Tests</u>

During the Long Term Tests the system under observation consists of the following parts:

1. Hand pump ├ Technical system as considered during [Short Term Test.
2. Storage tank, if any
3. Resources: =Manpower
   =Water
   =Money
4. Output : =(Useful) water.

5.5.2. <u>Measurements and data collection during Long Term Tests</u>

5.5.2.1 Measurements

During Long Term Testing measurements should be performed every 8 days during a whole day. As a result successive measuring days are different days in the week, e.g. Monday 22 February, Tuesday 1 March, Wednesday 9 March, etc.

Data Sheet 5.5.1. gives a lay-out to be used for noting down the <u>numerical</u> information required and an example as how to fill in the sheet. During a measuring day the following information about persons using the pump is to be recorded in Data Sheet 5.5.1 :

<u>Pumping time, water volume pumped and characterization of users</u>

For each user proceed as follows:
1. By means of the stop-watch measure the time a person needs to fill her/his tin or bucket.
2. By means of the calibrated container measure the volume of the water pumped by each user.
3. Determine her/his sex and age. In many cases it is not necessary to ask after the age; the class (7-11, 12-17, »17) can be determined by guessing.

Put the results in Data Sheet 5.5.1.; Sex and age are recorded by noting down the pumping time and the water volume pumped in the applicable column. Put the pumping time in seconds before the semi-colon and the water volume pumped in liters behind it.

<u>Example:</u> On line 13 in Data Sheet 5.5.1. it can be seen that a woman older than 17 years pumped 17 liters of water. It costs her 80 seconds to fill her container.

DATA SHEET 5.5.1. Measurements and Calculations Long Term Tests

(to be completed by technician)

Location: ______________________ Date : __________ [YY,MM,DD]
District: ______________________ Begin time : __________ [HH,MM]
Owner : ______________________ End time : __________ [HH,MM]

Discharge head H_{dis} (or Total effective head H **) : 7.3 [m]

No	Pumping time T_p [s] ; Water volume pumped per user Q_{PP} [l] — female 7-11 [s];[l]	female 12-17 [s];[l]	female » 17 [s];[l]	male 7-11 [s];[l]	male 12-17 [s];[l]	male »17 [s];[l]	Suction head H_{in} [m]	Water volume pumped Q_{PT} [m^3]
B							-1.8	846.658
E							-1.8	846.951
1	80 ; 9	;	;	;	;	;	-1.8	
2	;	95 ; 19	;	;	;	;		
3	;	;	;	75 ; 11	;	;		
4	;	;	85 ; 20	;	;	;		
5	;	75 ; 15	;	;	;	;		
6	;	;	;	;	65 ; 18	;		
7	;	;	;	60 ; 12	;	;	-1.7	
8	;	;	75 ; 16	;	;	;		
9	;	60 ; 11	;	;	;	;		
10	75 ; 10	;	;	;	;	;		
11	;	;	;	95 ; 18	;	;		
12	;	;	;	80 ; 15	;	;		
13	;	;	80 ; 17	;	;	;	-1.7	
14	60 ; 11	;	;	;	;	;		
15	;	;	75 ; 19	;	;	;		
16	;	;	;	;	;	75 ; 21		
17	;	65 ; 14	;	;	;	;		
18	;	80 ; 17	;	;	;	;		
19	;	;	110 ; 20	;	;	;	-1.6	
C	215 ; 30	375 ; 76	425 ; 92	310 ; 56	65 ; 18	75 ; 21		
S	1015 [s] ; 198 [l] *)			450 [s] ; 95 [l] *)				
T	1465 [s] ; 293 [l] *)							0.293 [m^3]

*) Specify units if others than [s];[l] are used

**) Fill in Total effective head if appropriate (see Figure 5.5.1. , case c and explanation)

Water volume pumped (optionally)

Only if the hand pump is equipped with a storage tank, the integrating flow meter (at the outlet of the storage tank, see section 2.5.1.) should be read at the beginning and the end of every measuring day. Use the first lines of Data Sheet 5.5.1., marked by B(egin) and E(nd), and write the results in cubic meters [m^3] (last column).
Check the flow meter regularly in order to detect malfunctioning e.g. due to contamination as soon as possible (see section 2.5.1.). Care should be taken to record whether and when the flow meter passed its maximum number of digits and started at the zero reading.

Head

In order to calculate the total effective head the suction head (including the draw down) and the discharge head should be measured. Generally it is not necessary to repeat the measurement of the suction head for each person using the hand pump. Measure the suction head so often, that differences between successive measurements are not greater than 20 percent. Write the results in [m] in the last but one column of Data Sheet 5.5.1..
Generally the discharge head is constant.
Write the results in metres in the heading (fourth line) of Data Sheet 5.5.1..

In Figure 5.5.1. some examples are given to illustrate the measurement of the different types of head for a number of situations:

Case a.
A shallow well is equipped with a surface pump. The suction head H_{in} is measured from the water level to the centre of the pump, the discharge head H_{dis} from the centre of the pump to the outlet of the pump.

Case b.
A tube well is equipped with a deepwell handpump. Because the pump is below the water level, H_{in} is negative. It should be calculated by the difference between the water level (meters below ground level) and the position of the pump (meters below ground level).

Case c.
A bucket pump lifts water between the water level in the well and the point where the buckets are emptied. In cases like this it is not meaningful to distinguish between different kind of heads. The total effective head simply equals the difference in the two levels.

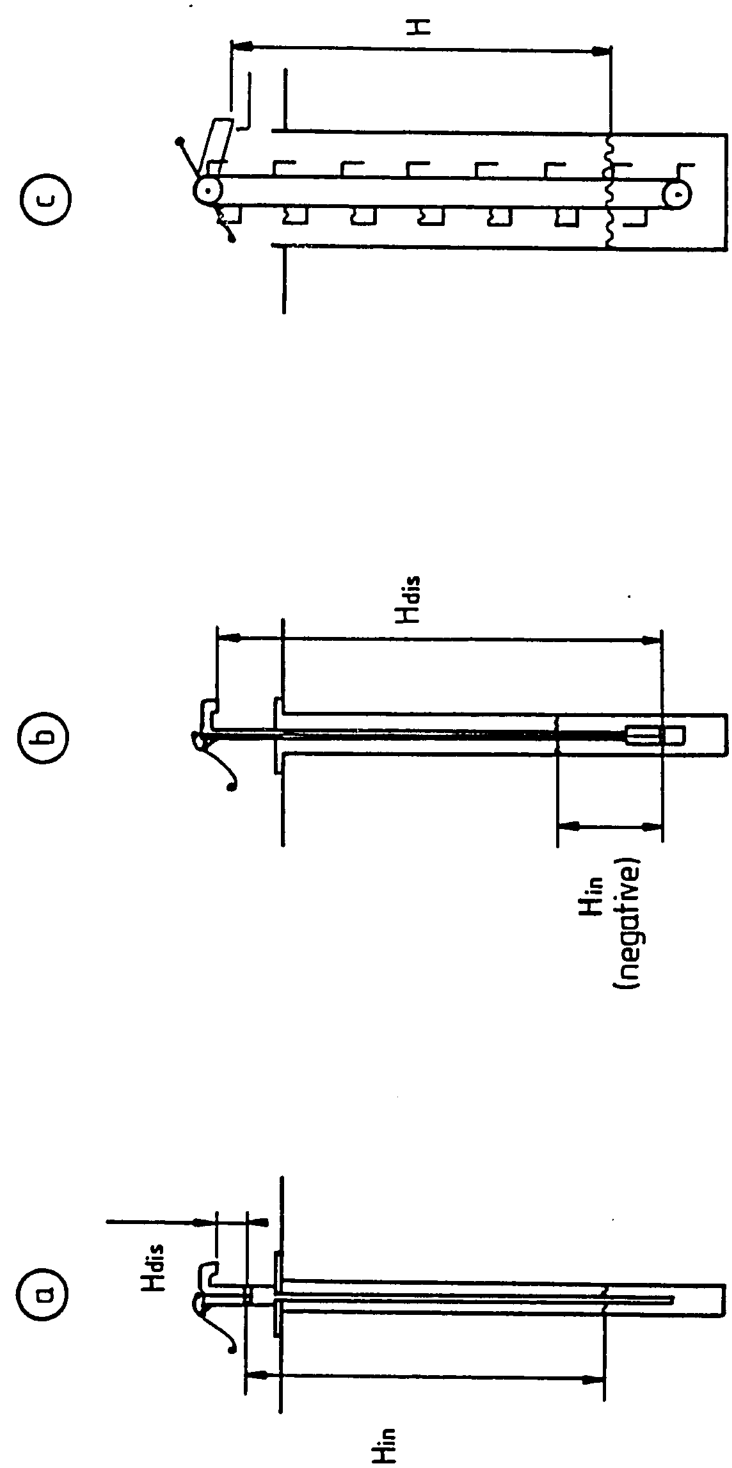


Figure 5.5.1. Examples of head measurements

<u>Example:</u> In Data Sheet 5.5.1. it can be seen that the suction head is rather constant. It has only been measured a few times during the day. The negative sign indicates that the pump is below the water level in the well (see case b. in Figure 5.5.1.).

5.5.2.2 Additional data collection

The logbook should describe in sufficient detail all events occurred e.g. the activities carried out with regard to servicing, maintenance (i.e. preventive action), repair (i.e. corrective action) and overhaul. It should specify the date of the event, the amount of time spent and the costs (distinguish between skilled and unskilled labour, parts, materials, lubricants and transportation). It is recommended to make this description by systematically treating the following issues:

-Maintenance
- =Actions performed (by whom?). If standard, refer to users manual.
- =Replaced parts
- =Lubricants used

-Break downs of the system
- =Description of system failure
- =When was it discovered?
- =Who was warned, how?
- =(Possible) causes
- =When repair started?
- =Actions performed (by whom, time spent?)
- =When was the system ready for operation again?

-Operation of the system
- =Periods of water shortage, reasons

-Water source
- =Occurrence of abnormal water levels in water source.
- =Running dry of the well.

Data sheet 5.5.2. gives a lay-out and a hypothetical example as how to complete this sheet. It can be used as a summary of all events and simultaneously serve as a table of contents to refer to logbook pages with detailed information. The first lines of Data Sheet 5.5.2. give information on the people contributing to the logbook. The subsequent columns of the data sheet contain the date of the event, the initials of the reporter (it is very important that any person putting down information in the logbook is identified by his initials; he is an important source of additional information when needed), a short description, the time during which the system was out of order (down time), the time spent to maintenance or other activities, the costs and the page number of the logbook where detailed information, if any, is recorded. The example shows how the different kinds of costs can be distinguished by using more lines for a single event.

DATA SHEET 5.5.2. Chronological survey of all relevant events (to be completed by various people)

Initials	Function	Name
AB	Owner	Butsi, A
FA	Techn.	Abebe, F
PS	Operator	Sanford, P

Date	Init	Description	Down time [hours]	Time spent [hours]	Costs [.£...]	logbook page
07/04/20	FA	Maintenance	30			26
		Skilled labour		6	30	
		Grease			1	
		Leather cup			2	
		Unskilled labour		24	50	
27/04/20	AB	Operators Salary			20	

5.5.3. Data reduction Long Term Tests

Data analysis should be initiated as soon as possible after data collection to quickly indicate possible problems with either the pumping system or the data collection instruments.
Early detection of any anomalies in the data will not only lead to more reliable data, but will also eliminate potential problems resulting from incorrect installations of equipment or oversights in the design. Also deterioration of performance in time may be detected by doing so.

If during the Long Term Tests large deviations from expected values are found, it is recommended to perform (part of) a Short Term Test in order to identify possible causes of these deviations.

5.5.3.1 Performance

Pumping time and water volume pumped per class of users

Determine the pumping time and the water volume pumped per class of users by totalizing the six columns in Data Sheet 5.5.1.. Write the results on the bottom line marked by "C" (again pumping time [s] before the semi-colon and water volume pumped [l] behind it).

Example: In the column "female, 7-11" of Data Sheet 5.5.1. this summation gives 215 seconds pumping time and 30 liters of water.

Pumping time and water volume pumped for females and males

Determine the pumping time and water volume pumped per sex by totalizing the totals per class three by three. Write the results on the bottom line of Data Sheet 5.5.1. marked by "S". When the use of seconds and liters as units yields too large numbers, switch over to minutes (hours) and cubic meters.

Example: The three classes of males pumped during 310, 65 and 75 seconds and water volumes of 56, 18 and 21 liters respectively. The total values for "male" are 450 seconds and 95 liters.

Total water volume pumped

Determine the total pumping time and the water volume pumped during the measuring day by totalizing all six columns. Write the result on the bottom line marked by "T". When the use of seconds and liters as units yields too large numbers, switch over to minutes (hours) and cubic meters.

Example: Further summing of the numbers of Data Sheet 5.5.1. gives a total pumping time of 1525 seconds and a total water volume pumped of 304 liters.

Water volume pumped (optionally)

Only if the hand pump system is equipped with an integrating flow meter, the water volume pumped can be calculated alternatively. When the flow meter readings Q_P are registered in m^3, the water volume pumped during a measuring day is:

$$Q_{PT} = Q_{P,e} - Q_{P,b} \qquad [m^3]$$

where: $Q_{P,b}$ = the reading of the integrating flow meter at the beginning of the day.
$Q_{P,e}$ = the reading of the integrating flow meter at the end of that day.

If all measurements and calculations have been performed correctly (and if not too much water has been spilled) Q_{PT} will not differ very much from the total water volume pumped as calculated above (bottom line "T" in Data Sheet 5.5.1.). Write the value of Q_{PT} in Data Sheet 5.5.1., bottom right.

Example: In Data Sheet 5.5.1. $Q_{P,b}$ = 846.658 m^3 and $Q_{P,e}$ = 846.951 m^3. As a result Q_{PT} = 846.951 - 846.658 = 0.293 m^3. This result lies within 4 % of the water volume as measured by summing the water volumes pumped per person.

Water volume pumped over a longer period of time (optionally)

If the hand pump system is equipped with an integrating flow meter, the procedure as described above yields periodical flow meter readings, i.e. every 8 days two readings, see lines "B" and "E" in Data Sheet 5.5.1.. The difference between two readings delivers the water volume pumped during the concerning period of time.

Pumping rate per class of users

The pumping rate per class of users can be calculated by dividing the total water volume pumped for any class by the total time that class spent on pumping (i.e. divide the numbers behind the semi-colon by the numbers before it in Data Sheet 5.5.1., bottom line "C"). Please mind the units! Put the results in Data Sheet 5.5.3..

Example: In class "male, 7 -11" 56 liters of water has been pumped in 310 seconds. The pumping rate thus equals 56 / 310 = 0.18 l/s.
The totals per sexe and the overall total can be calculated similarly.

DATA SHEET 5.5.3. Pumping rate per class of users
(to be completed by technician)

Location : ______________ Date: ________[YY/MM/DD]
District : ________________________________
Owner : ________________________________

Units: [l/s]	Age [y]			Total
sex	7-11	12-17	» 17	
female	0.14	0.20	0.22	0.20
male	0.18	0.28	0.28	0.21
Total				0.20

5.5.3.2 Reliability of the handpump system

As stated, Data Sheet 5.5.2. shows information on reliability e.g. the number of system failures, their type and duration, repair types and times, maintenance problems, climatological, natural or other phenomena affecting delivery reliability, any inherent design faults, etc.
In Data Sheet 5.5.4. this information will be summarized for a period of a year under the heading "Operation". Some items are already suggested in the sheet.

The various total times asked for might require some explanation. Operating time is the time during which the system was running during the length of period T. Total time needed for maintenance and total time needed for repair equal the number of man hours spent to maintenance and repair respectively. Total down-time is the total time the system was not in operating order due to system failures.

The reliability of the system can be expressed by three different indicators, viz. the mean down time (MDT), the mean time between failures (MTBF) and the availability. They are calculated as follows:

$$MDT = \frac{\text{Total down-time}}{\text{number of break-downs}} \quad \text{[hours per break-down]}$$

DATA SHEET 5.5.4. Summary of information of Hand pump System (to be completed by technician)

SUMMARY OVER 19___

Location : ______
District : ______
Owner : ______
Pumping head: ______

Performance

Average number of users per day	:	______	[-]
Average water volume pumped per day	:	______	[m^3]
Yearly water volume pumped (opt.)	:	______	[m^3]

Operation

Operating time of the system	:	______	[hours]
Total time needed for maintenance	:	______	[hours]
Total time needed for repairs	:	______	[hours]
Total down-time	:	______	[hours]
Number of break-downs	:	______	[-]
Mean down time	:	______	[hours]
Mean time between failures	:	______	[hours]
Availability	:	______	[-]
....	:	______	______
....	:	______	______
....	:	______	______

Recurrent Costs [________]*

	operation	maintenance	repair	total
Skilled labour	______	______	______	______
Unskilled labour	______	______	______	______
Materials	______	______	______	______
Parts	______	______	______	______
Transportation	______	______	______	______
Replacements pump	______	______	______	______

*) Indicate currency; note replacements type & time in log

$$\text{MTBF} = \frac{\text{Length of period} - \text{Total down-time}}{\text{number of break-downs}} \text{ [hours]}$$

$$\text{Availability} = \frac{\text{Length of period} - \text{Total down-time}}{\text{Length of period}} \text{ [-]}$$

These indicators all refer to different aspects of reliability. E.g. if a short MTBF is caused by many break-downs of short duration (due to quick repair service), the MDT is low and the availability of the system is high.

In addition, other events could be summarized, for instance those having occurred strikingly often (e.g. pumping dry of the well). Careful consideration of Data Sheet 5.5.2. should result in meaningful summaries of events.

5.5.3.3 Recurrent costs

The data on recurrent costs collected during the Long Term Test are recorded in Data Sheet 5.5.2. and will be summarized in Data Sheet 5.5.4. under the heading "Recurrent Costs". Details will be noted down in the log.

5.6 ANIMAL TRACTION PUMPS

5.6.1. The "System" during Long Term Tests

During the Long Term Tests the system under observation consists of the following parts:

1. Animal driven pump ⌐ Technical system as considered during [Short Term Test.
2. Storage tank, if any
3. Resources: =Manpower
   =Animal power
   =Water
   =Money
4. Output : =(Useful) water.

5.6.2. Measurements and data collection during Long Term Tests

5.6.2.1 Measurements

During Long Term Testing measurements should be performed every 8 days during a whole day. As a result successive measuring days are different days in the week, e.g. Monday 22 February, Tuesday 1 March, Wednesday 9 March, etc. During such a day measurements are taken at the beginning and at the end of every shift of animals. It is assumed that animals work on one to three hour shifts. After such a period they get a rest or they are replaced by fresh animals.

Data Sheet 5.3.1. (column "MEASUREMENTS") gives a lay-out to be used for noting down the numerical information required and an example as how to fill in the sheet. For each shift a pair of lines, marked by "B"(begin) and "E"(end) is available.

Time

By means of a watch determine the clock time at the beginning and at the end of the shift. Write the results in hours and minutes [HH,MM].

Water volume pumped

Read the flow meter at the beginning and at the end of the shift. Write the results in [m^3], with one or two digits behind the decimal point.

DATA SHEET 5.6.1. Measurements and Calculations Long Term Tests

(to be completed by technician)

Location: ______________________ Date : __________ [YY,MM,DD]

District: ______________________ Begin time : __________ [HH,MM]

Owner : ______________________ End time : __________ [HH,MM]

Discharge head H_{dis} : 12.7 [m]

MEASUREMENTS (see section 5.6.2.1)					CALCULATIONS (see section 5.6.3.)			
No	Time t [HH,MM]	Water meter reading Q_P [m^3]	Suction Head H_{in} [m]	Kind, number & condition of animals [xx,n,qq]*	Length of the shift T [hours]	Water volume pumped Q_{PT} [m^3]	Hydraulic energy output $E_{h,T}$ [Wh]	Overall system efficiency η_{tot} [-]
B	06:25	1345.5	-1.7	mu, 2, +/-				
E	07:45	1362.1	-1.6	__ __ __**)	1.33	16.6	501	0.42
Type of break: ~~rest~~ / change of animals/								
B	07:58	1362.1	-1.6	mu, 2, -				
E	09:46	1375.9	-1.6	mu, 2, --**)	1.8	13.8	418	0.26
Type of break: ~~rest~~ / change of animals/								
B	11:03	1375.9	-1.6	mu, 2, +				
E	12:36	1400.1	-1.5	__ __ __**)	1.55	24.2	737	0.53
Type of break: rest / ~~change of animals~~/								
B	13:40	1400.1	-1.7	mu, 2, +				
E	15:45	1428.3	-1.6	__ __ __**)	2.08	28.2	851	0.45
Type of break: rest / ~~change of animals~~/								
B	16:05	1428.3	-1.6	mu, 2, +				
E	17:45	1453.7	-1.6	__ __ __**)	1.67	25.4	770	0.51
Type of break: ~~rest~~ / change of animals/								
B	____	____	____	__ __ __				
E	____	____	____	__ __ __**)	____	____	____	____
Type of break: rest / change of animals/								
Cumulative values for the measuring day								
Average values for the measuring day								

*) For kind of animals xx use the following codes:

hh: heavy horse	bl: bullock
lh: light horse	ox: ox
mu: mule	ca: camel
do: donkey	bf: buffalo
co: cow	__: ______

For condition qq use the following codes:

- ++ : excellent
- \+ : good
- +/-: medium
- \- : poor
- --: bad

**) Choose the relevant alternative

Check the flow meter regularly in order to detect malfunctioning e.g. due to contamination as soon as possible (see section 2.5.1.). Care should be taken to record whether and when the flow meter passed its maximum number of digits and started at the zero reading, especially if for any reason readings are taken over longer intervals than prescribed.

There is a large variety of animal traction pumps. For many of them the simple method of measuring the water volume pumped as described here can not be applied directly. See for alternatives Section 2.5.1. sub water volume pumped sub c.

Head

In order to calculate the total effective head the suction head (including the draw down) and the discharge head should be measured.
Values of the suction head are recorded at the beginning and at the end of the shift. Write the results in [m].
Generally the discharge head is constant.
Write the results in [m] in the heading of Data Sheet 5.6.1. (fourth line).

In Figure 5.6.1. some examples are given to illustrate the measurement of the different types of head for a number of situations:

Case a.
A shallow well is equipped with a surface pump. The suction head H_{in} is measured from the water level to the centre of the pump, the discharge head H_{dis} from the centre of the pump to the outlet of the pump.

Case b.
A tube well is equipped with a deepwell handpump. Because the pump is below the water level, H_{in} is negative. It should be calculated by the difference between the water level (meters below ground level) and the position of the pump (meters below ground level).

Case c.
A bucket pump lifts water between the water level in the well and the point where the buckets are emptied. In cases like this it is not meaningful to distinguish between different kind of heads. The total effective head simply equals the difference in the two levels.

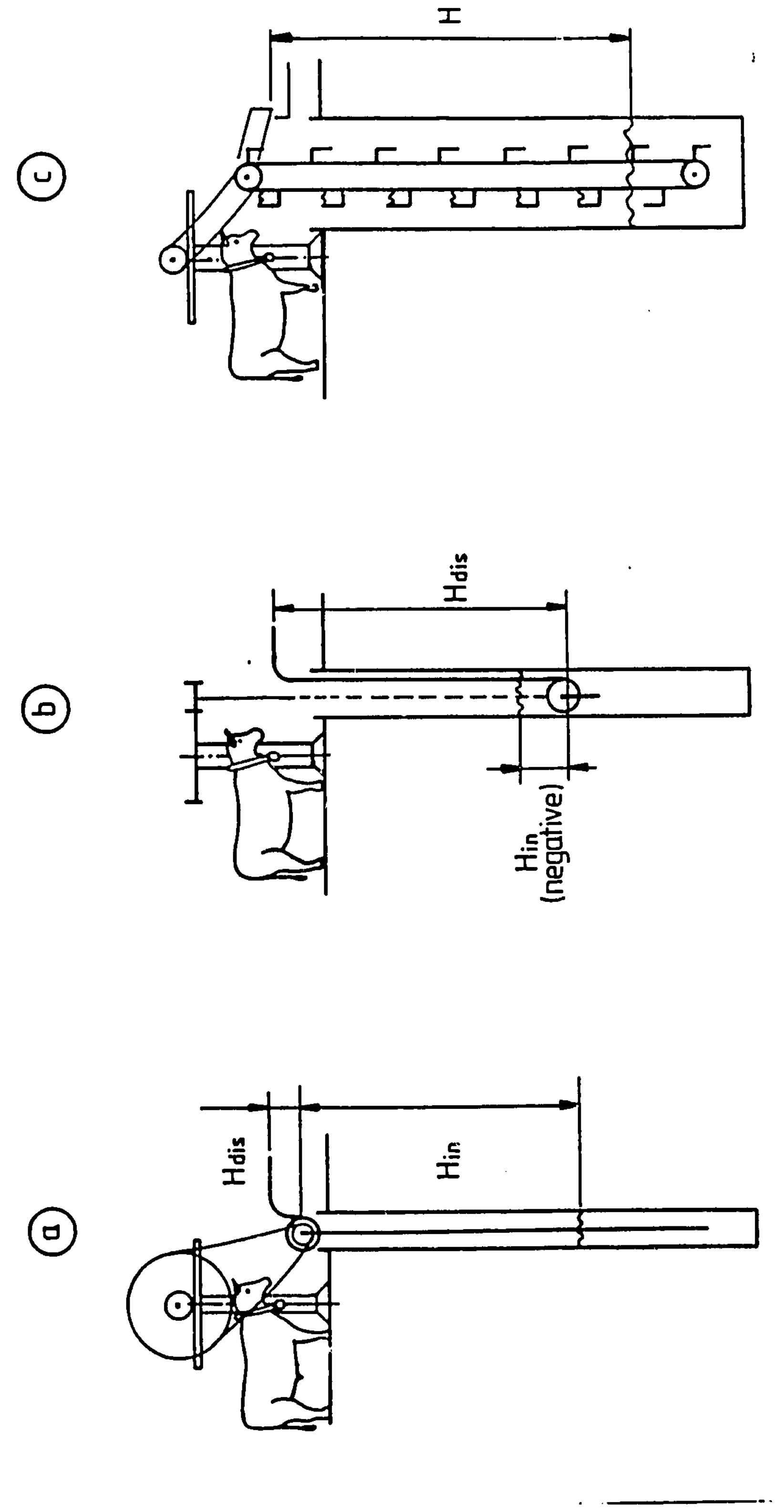


Figure 5.6.1. Examples of head measurements

<u>Example:</u> In Data Sheet 5.6.1. it can be seen that the suction head is rather constant. The negative sign indicates that the pump is below the water level in the well (see case b. in Figure 5.6.1.).

<u>Kind, number and condition of animals</u>

In Data Sheet 5.6.1. the first line of each pair (the one marked by "B") is used to indicate the kind, the number and the condition of the animals. For the kind of animals and their condition use the codes as defined on the bottom lines of the Sheet. If the kind of animals is not in the list, it is to be added on the blanc line under "bf: buffalo". Only if the condition of the animals has changed significantly during the shift, e.g. when they have got extremely tired, use the second line (the one marked by "E") to indicate the situation at the end of the shift. After each shift a line is available in the Sheet to indicate the type of break.

5.6.2.2 Additional data collection

The logbook should describe in sufficient detail all events occurred e.g. the activities carried out with regard to servicing, maintenance (i.e. preventive action), repair (i.e. corrective action) and overhaul. It should specify the date of the event, the amount of time spent and the costs (distinguish between skilled and unskilled labour, parts, materials, lubricants and transportation). It is recommended to make this description by systematically treating the following issues:

-Maintenance
  =Actions performed (by whom?). If standard, refer to users manual.
  =Replaced parts
  =Lubricants used
-Break downs of the system
  =Description of system failure
  =When was it discovered?
  =Who was warned, how?
  =(Possible) causes
  =When repair started?
  =Actions performed (by whom?)
  =When was the system ready for operation again?
-Operation of the system
  =Periods of water shortage, reasons

DATA SHEET 5.6.2. Chronological survey of all relevant events (to be completed by various people)

Initials	Function	Name
AB	Owner	Butsi, A
FA	Techn.	Abebe, F
PS	Operator	Sanford, P

Date	Init	Description	Down time [hours]	Time spent [hours]	Costs [..$..]	logbook page
88/04/28	FA	Maintenance	30			26
		Skilled labour		6	30	
		Grease			1	
		Unskilled labour		12	25	
88/04/29	FA	System ready for operation				
88/04/30	AB	Operators salary			25	

-Water source
=Occurrence of abnormal water levels in water source.
=Running dry of the well.

Data sheet 5.6.2. gives a lay-out and a hypothetical example as how to complete this sheet. It can be used as a summary of all events and simultaneously serve as a table of contents to refer to logbook pages with detailed information. The first lines of Data Sheet 5.6.2. give information on the people contributing to the logbook. The subsequent columns of the data sheet contain the date of the event, the initials of the reporter (it is very important that any person putting down information in the logbook is identified by his initials; he is an important source of additional information when needed), a short description, the time during which the system was out of order (down time), the time spent to maintenance or other activities, the costs and the page number of the logbook were detailed information, if any, is recorded. The example shows how the different kinds of costs can be distinguished by using more lines for a single event.

5.6.3. Data reduction Long Term Tests

Data analysis should be initiated as soon as possible after data collection to quickly indicate possible problems with either the pumping system or the data collection instruments.
Early detection of any anomalies in the data will not only lead to more reliable data, but will also eliminate potential problems resulting from incorrect installations of equipment or oversights in the design. Also deterioration of performance in time may be detected by doing so.

If during the Long Term Tests large deviations from expected values are found, it is recommended to perform (part of) a Short Term Test in order to identify possible causes of these deviations.

5.6.3.1 Performance

The results of reduction of data on system performance are recorded in Data Sheet 5.6.1. in the column indicated by "CALCULATIONS".

Length of the shift T

The length of the shift T simply equals the time in hours between the beginning and the end of the shift.

Example: In Data Sheet 5.6.1. the first shift works from 06:25 to 07:45. So the duration of this shift is 80 minutes, equalling 1.33 hours.

Water volume pumped per shift

When the flow meter readings Q_P are registered in m^3, the water volume pumped during the shift is:

$$Q_{PT} = Q_{P,E} - Q_{P,B} \qquad [m^3]$$

where: $Q_{P,B}$ = the reading of the integrating flow meter at the beginning of the shift.
$Q_{P,E}$ = the reading of the integrating flow meter at the end of the shift.

Example: For the second shift in Data Sheet 5.6.1. $Q_{P,B}$ = 1362.1 m^3 and $Q_{P,E}$ = 1375.9 m^3. Then Q_{PT} = 1375.9 - 1362.1 = 13.8 m^3.

Hydraulic system output

The hydraulic system output $E_{h,T}$ during the shift can be calculated from Q_{PT} by:

$$E_{h,T} = 2.73 * Q_{PT} * \left[\frac{H_{in,B} + H_{in,E}}{2} \right] + H_{dis} \quad \text{[Wh]}$$

where:
- $H_{in,B}$ = suction head at the beginning of the shift.
- $H_{in,E}$ = suction head at the end of the shift.
- H_{dis} = discharge head.
- 2.73 = conversion factor (9.81/3.6).

Example: For the third shift Q_{PT} = 24.2 m^3. $H_{in,B}$ and $H_{in,E}$ being -1.6 and -1.5 m respectively and with H_{dis} = 12.7 m (see top lines of Data Sheet), $E_{h,T}$ = 737 Watt.

Animal energy input

The animal energy input $E_{an,T}$ to the system during the shift can be estimated roughly by:

$$E_{an,T} = T * nn * P_{an} \quad \text{[Wh]}$$

where:
- T = length of shift in hours
- nn = number of animals
- P_{an} = power per animal in Watts (see Table on next page)

Example: For the third shift the animal power input to the system according to the formula above equals:

$E_{an,T}$ = 1.55 * 2 * 450 = 1395 Watt

(This number is not entered into the Data Sheet, it should be put into the logbook)

TABLE 5.6.1. Power of various animals[1]

Animal	Power range [W]	Average P_{an} [W]
heavy horse	500-1000	750
light horse	400-800	600
mule	300-600	450
donkey	75-200	150
cow	200-400	300
bullock/ox	300-500	400
camel	400-700	550
buffalo	600-1000	800

Overall system efficiency

The overall system efficiency η_{tot} is obtained from the quantities above by:

$$\eta_{tot} = \frac{E_{h,T}}{E_{an,T}} \quad [-]$$

Example: Using the result of the previous examples, for the third shift the overall system efficiency becomes:

$$\eta_{tot} = 737 / 1395 = 0.53$$

5.6.3.2 Reliability of the animal pump system

As stated, Data Sheet 5.6.2. shows information on reliability e.g. the number of system failures, their type and duration, repair types and times, maintenance problems, climatological, natural or other phenomena affecting delivery reliability, any inherent design faults, etc.
In Data Sheet 5.6.3. this information will be summarized for a period of a year under the heading "Operation". Some items are already suggested in the sheet.

The various total times asked for might require some explanation. Operating time is the time during which the system was running during the length of period T. Total time needed for maintenance and total time needed for repair equal the number of man hours spent to maintenance and repair

1 Derived from: Peter Fraenkel, Water-Pumping Devices, FAO 1986.

respectively. Total down-time is the total time the system was not in operating order due to system failures.

The reliability of the system can be expressed by three different indicators, viz. the mean down time (MDT), the mean

DATA SHEET 5.6.3. Summary of information on Animal driven Pump (to be completed by technician)

SUMMARY OVER 19___

Location : ____________________
District : ____________________
Owner : ____________________
Pumping head: ____________________

Performance

Average water volume pumped per day	:	________	[m^3]
Number of animals in shift	:	________	[-]
Average operational hours per day	:	________	[hours]
Average overall system efficiency	:	________	[-]

Operation

Operating time of the system	:	________	[hours]
Total time needed for maintenance	:	________	[hours]
Total time needed for repairs	:	________	[hours]
Total down-time	:	________	[hours]
Number of break-downs	:	________	[-]
Mean down time	:	________	[hours]
Mean time between failures	:	________	[hours]
Availability	:	________	[-]
Other uses of system/animals	:		[hours]
(pls.specify in log)		________	________

Recurrent Costs [________]*

	operation	maintenance	repair	total
Skilled labour	____	____	____	____
Unskilled labour	____	____	____	____
Fodder	____	____	____	____
Materials	____	____	____	____
Parts	____	____	____	____
Transportation	____	____	____	____
Replacement pump	____	____	____	____
Replacement harness	____	____	____	____
Replacement animals	____	____	____	____

*) Indicate currency; note replacements types & time in log

time between failures (MTBF) and the availability. They are calculated as follows:

$$\text{MDT} = \frac{\text{Total down-time}}{\text{number of break-downs}} \quad \text{[hours per break-down]}$$

$$\text{MTBF} = \frac{\text{Length of period} - \text{Total down-time}}{\text{number of break-downs}} \quad \text{[hours]}$$

$$\text{Availability} = \frac{\text{Length of period} - \text{Total down-time}}{\text{Length of period}} \quad [-]$$

These indicators all refer to different aspects of reliability. E.g. if a short MTBF is caused by many break-downs of short duration (due to quick repair service), the MDT is low and the availability of the system is high.

In addition, other events could be summarized, for instance those having occurred strikingly often (e.g. pumping dry of the well). Careful consideration of Data Sheet 5.6.2. should result in meaningful summaries of events.

5.6.3.3 Recurrent costs

The data on recurrent costs collected during the Long Term Test are recorded in Data Sheet 5.6.2. and will be summarized in Data Sheet 5.6.3. under the heading "Recurrent Costs". Details are noted down in the log.

6. ECONOMIC ANALYSIS OF WATER PUMPING

6.1. INTRODUCTION

The purpose of this chapter is to provide a guide for obtaining and analyzing cost and performance data on a range of pumping systems. To achieve this purpose, both the data needed and the use of a conventional analytic technique are described. The manipulation of the data to produce the analysis is described in terms of numerical examples, formulae, and the use of spreadsheet software for microcomputers.

6.1.1. Scope of the Chapter

The emphasis here is on the practical use of existing techniques rather than developing new methods or adherence to all the finer points of the theories involved. The literature on cost effectiveness analysis and related techniques (e. g., cost benefit analysis and project analysis) is quite large and no attempt to review it will be made here. Those who wish to delve into the subject are directed to the list of references for this chapter.

The task is to estimate the cost of purchasing, installing, and operating a given system over its useful life in such a way that comparison between systems is facilitated. This chapter addresses the relative feasibility or attractiveness of a variety of technologies and not their absolute feasibility*. The comparisons of pumping systems are between systems which are assumed to produce the same level of direct benefits (i. e. a given quantity of water); consequently direct benefits will be ignored. Other benefits which may result from the investments are also ignored. The focus of this chapter is on comparing costs of different systems. Common costs--those which are a part of every system under consideration, such as conveyance costs--are also omitted on the grounds that to do so (a) simplifies the analysis and (b) does not change the relative position of the systems if ranked on the basis of cost. The emphasis is on how systems differ in terms of cost per cubic meter of pumped water.

The costs which are analyzed are:

=» the costs of the whole system, "total system costing." Total system costs (with the single exception of common costs noted above) are needed because systems differ with respect both to on-site costs and outlays for off-site equipment, fuel, and associated maintenance systems.

* From various sides the editors received critical comments on the assumption of equal benefits in terms of water output of the alternative systems, because this would be unrealistic. Moreover, some reviewers have insisted to discount not only costs but also the water volume pumped, in order to arrive at a price per cubic meter that can be compared between systems different in project length and water delivery pattern. However, changing these methodological issues at this stage would have delayed this publication too long. Their incorporation in the final version of this Handbook will be considered.

=» the costs of a system over its operating lifetime, "life cycle costing." Life cycle costing is needed because systems have service lives of different length and have different proportions of capital and recurrent costs.

These costs will be examined from two related perspectives. First, financial costs are those seen by the farmer or other potential user of the system. Second, economic costs are those seen by the government or society at-large. As will be demonstrated, analysis from both perspectives is essential to a full understanding of the problem.

6.1.2. Structure of the Chapter

In sections 6.1. and 6.2., the concepts and techniques used in the analysis are examined. Conventional project analysis which examines the project from the perspective of both the user and the government is explained. The second part of the chapter (6.3.) focuses on actually developing the two data sets which are to be analyzed --the economic and financial data sets-- as well as the questions which arise when forecasting recurrent costs and other practical issues associated with the analysis. The second part ends with the introduction of the analytic technique to be used, present value analysis. Step-by-step examples which apply both a manual technique and a

TABLE 6.1: Steps in analysis

1. Create Financial Data Set
   a. tabulate total installed costs
   b. list assumptions underlying analysis
   c. tabulate year 1 recurrent costs
   d. project recurrent costs over span of analysis

2. Create Economic Data Set
   a. determine adjustments for price distortions
   b. transform financial data to create economic data

3. Apply Present Value Methods
   a. Calculate Present Value of Recurrent Costs: both financial and economic
   b. Sum Total Installed Cost and Present Value of Recurrent Costs
   c. Calculate Water Output
   d. Calculate Unit Costs of Water: both financial and economic

microcomputer-based approach are presented in 6.4. The third part, as an example, examines sample spreadsheets for each of the six technologies covered by the Handbook (section 6.5).

Table 6.1 is a simple flow chart that serves two closely related purposes. First, it outlines the steps followed in the analysis. Second, it indicates the structure of the chapter itself.

6.2. BASIC CONCEPTS OF ECONOMIC/FINANCIAL ANALYSIS

The analytic problem is to develop both economic and financial estimates of life-cycle costs of pumping systems so that these cost data along with other information can be used to make pumping system related choices. The costs to be evaluated can be simplified into a generalized formula as follows:

$$LCC = TIC + R + U + L + E$$

where: LCC = Life Cycle Cost
TIC = Total Installed Cost
R = Repair and Replacement parts
U = Upkeep (normal maintenance materials)
L = Labor (to maintain and operate)
E = Energy

The method first distinguishes between two types of inputs, "capital" and "recurrent costs." The Total Installed Costs (TIC) including the pumping system components and their installation --the prime mover, pump, well or intake structure and, where necessary, storage-- are all capital costs. Note that labor and transportation, associated with the installation of the system are included in the TIC.

The remaining items in the equation are recurrent costs. These inputs are consumed or must otherwise be continually re-supplied --parts, the labor of the operator and the maintenance mechanic, and energy. In addition, the periodic replacement of pumps, engines, or other major system components are also a part of recurrent costs --even though these usually do not arise on an annual basis. Note that in this analysis there are items which are normally thought of as recurrent costs which are included along with normal capital items in total installed costs. For example, there may be an initial stock of fuel, operating capital to purchase fuel or electricity, or a deposit associated with a power connection. In many situations it may be good practice to include an item for an inventory of spare parts in the capital costs, even though these will be used over time. Where such inventory is needed for year-one operation, it should be treated as capital.

Two Analytic Perspectives: Economic and Financial

As noted above, what is needed is a pair of cost estimates for each system. Conventional analysis, as described by Gittinger (1982, p. 18) for example, distinguishes between financial and economic analyses. Where the financial analysis takes the point of view of the individual farmer or other user, the economic analysis takes the point of view of the society as a whole. The two perspectives are complementary in that they deal with the same components of costs, but evaluate them differently. Very briefly, the two perspectives differ on four dimensions:

First, in financial analysis taxes and subsidies are seen by the user as an integral part of costs and are, indeed, an outflow of funds. In economic analysis, taxes and subsidies are seen as transfer payments or flows of funds which are internal to the nation i.e., they are not outflows. (The government is assumed to represent the society at-large.)

Second, market prices are used in the financial analysis since these are the prices seen by the participants in the project. These values are adjusted for the transfer payment component and other distortions. After adjustment these values are used in economic analyses.

Third, in financial analysis interest on borrowed funds is simply another cost. In the economic analysis, interest is a part of the total return (to society at-large) and is not netted-out.

Fourth, the economic perspective recognizes that market prices (used in financial analysis) tend to under-value some costs to society. That is, markets tend to fail to incorporate (or fully account for) environmental and social dimensions of a project (e.g., job creation).

The important contribution of this dualistic analysis is that it permits analysts to identify projects which may be attractive at one level of analysis (economic or financial) and unattractive from the other. That is, through this method it is possible to evaluate such commonly encountered elements as subsidies, controlled prices, and unrealistic exchange rates in terms of their effect on a particular project or the differential effect these elements may have across a spectrum of technologies. The dualistic analysis better informs decision makers where the investments being considered have quite comparable costs from the individual's point of view but quite different costs from the perspective of the nation, or vice versa.

For the analyst, the economic and financial perspectives amount to two different data sets both of which must be analyzed using the same technique. Actually these analyses can be performed in parallel, a procedure considerably simplified by the use of widely-available spreadsheet software for microcomputers. Part Two, which follows immediately, discusses the development of the data needed for the analysis.

6.3. PREPARING THE DATA SETS

Setting-up the data for the analysis is a three-step process:
(1) obtain the financial prices,
(2) estimate economic prices by adjusting financial prices and
(3) project the recurrent costs (both financial and economic) over the time span of the analysis.

6.3.1. The Financial Data Set

The starting point for preparation of the data sets is obtaining the financial prices. Financial prices are simply the market prices the user faces for any particular input. The data come from several sources: the short and long term testing, pumping system suppliers, and government planning agencies. At the start of a pump testing project, there may be some information that cannot be supplied from these sources. In these cases, data from earlier studies or best available estimates will have to be substituted. The long and short term testing results will provide estimates of systems reliability as well as estimates of the recurrent costs such as operating and maintenance costs, including the necessary inputs of energy, materials, transportation, and labor. Information on capital costs may be obtained by surveying local suppliers or reviewing recent government procurement documents, as appropriate.

It is important to recognize that precise data on costs are seldom readily available. Indeed, an important objective of a testing project is to obtain better estimates of costs and to learn how costs may vary for particular pumping systems under different operating conditions. Thus testing projects will produce a range of cost estimates which are, in turn, likely to be further refined as testing proceeds and experience is gained.

Capital costs will also vary both between suppliers and over-time. Moreover, the installed costs of systems will vary because transportation and labor costs may differ within a nation. It is important to anticipate these differences and document them. Depending on the particular institutional arrangements for pricing and distributing petroleum products, fuel prices may vary within a country to account for transport costs. Such data may be available from planning officers, motor pool officials, or fuel distributors. Be prepared to collect data which reflect (for example) the real regional differences in the cost of installing and operating systems. It is important to perform cost analysis using the high and low values for these inputs in addition to the common practice of performing the analysis using only the averages.

6.3.2. The Economic Data Set

The economic data set is created by making a series of adjustments or transformations to the financial data set. The two data sets are structurally parallel. Information needed to create the economic data set, such as the shadow prices for foreign exchange and labor and the appropriate interest or discount rates, should be available from the government economic planning office. Alternative estimates of these parameters may also be available from economic officers of the various bilateral or multilateral development assistance agencies operating in the country. In the discussion below possible information sources for other necessary cost and economic data are suggested.

Analysts should be cautioned at the outset that while spreadsheet software makes it a fairly simple task to create alternative economic data sets, the creation of such data sets is not the goal of the analysis. What is sought is improved understanding of the costs of pumping and how they differ when seen from the financial or economic perspective. Adjusting the financial data set to account for truly minor differences can create a situation characterized by spurious accuracy. Shadow pricing is not, as a rule, applied unless there is a marked difference in costs between the economic and financial perspectives. One of the benefits of using spreadsheet software for the analysis is the ability to experiment with shadow pricing on a component of costs and determine what (if any) difference it makes to use shadow prices.

The costs most likely to need adjustment are those for imported items and those which contain a substantial amount of unskilled local labor. That is, the cost differences are most likely to result from (a) differences in the valuation of foreign exchange, (b) differences arising out of taxes and duties, and (c) alternative valuations of unskilled domestic labor. Adjustments may be needed in the costs of the equipment, products, or services used in a pumping system if the item is imported --including items which are locally fabricated from largely imported components. The distinction can be taken further in that locally available goods and services (such as a locally fabricated windmill tower) can be analyzed according to its imported and domestic content. The imported component may be raw materials, such as steel, and the domestic component may be the labor.

Each category of data which is likely to need adjustment and which is likely to be encountered is included in the table below. In addition, a more detailed discussion of the rationale for these adjustments is presented in Annex 3.

TABLE 6.2. Summary of adjustments used to create the economic data set

Data	Use	Source
Foreign Exchange Rate Premium	Adjust price of imported products to compensate for over or under-valued local currency	Economic Planning Agency, Regional Development Banks, World Bank, or IMF
Taxes and Duties	Net-out government receipts from financial prices	Revenue Agency or Customs Bureau
Unskilled Labor	Adjust local labor rate to reflect the economic opportunity cost	Planning Agency Development Bank Reports
Fixed and/or Regulated Prices e.g., Electricity and Petroleum Products	Remove price distortions which arise from the regulatory or control system	Regulatory Boards or Commissions

Practical Limits to Adjustments

It should be recalled that the results of the analysis, are expressed as unit costs, i. e., per cubic meter of water pumped over the twenty-year period of analysis. The practical effect of this is that as the amount of water pumped increases many costs actually become minimal. As a consequence, shadow pricing adjustments become less and less of a practical issue as the quantity of water increases. Where the quantity of water is small (e. g., small village water supply systems) the converse is true. Where full-time pumpers are required by custom and water demand is low, the difference between financial and economic costs can be quite large. The shadow pricing of unskilled labor is an important aspect of the analysis in these cases.

It is unrealistic to imagine that as part of an evaluation of pumping costs an original and independent estimate of foreign exchange rates, energy prices, or shadow prices for unskilled labor will be prepared. The development of such reports is a much broader task requiring investigation of details that cannot be probed here. It is simply the case that the best available data should be sought from appropriate agencies, the sources fully documented, and used. In the absence of available estimates, it is desirable to use sensitivity analysis to show the potential gains (in terms of making the analysis of water pumping more accurate) from having better price estimates.

6.3.3. Forecasting

Once both the economic and financial data for year-one are assembled, the recurrent costs must be projected over the life of the project. Forecasting recurrent costs is an instance, like that noted just above, in which the boundaries of water pumping analysis are reached. The analysis requires, for example, a twenty year forecast of petroleum prices. It is unrealistic to expect that original work on petroleum forecasting will be done as part of a waterpumping analysis. There are, however, some practical steps which can be taken to cope with the forecasting problem --for petroleum and other items as well.

For convenience, methods of making forecasts are shown in the table below for each of the major categories of input data. In addition a somewhat more detailed discussion of the issues involved in making these forecasts is included in the Annex 4.

TABLE 6.3. Summary of Approaches to Forecasting

Data Item	Technique
General Inflation	Assume that the costs of all inputs increases at the same rate
Specific Rates of Inflation	Include additional adjustment only if significantly different from general trend
Petroleum Prices (or other major inputs)	Use both high and low values from official estimates and/or use simple assumption such as: real prices will double in 20 years
Imported Goods	World Bank Manufacturing Unit Value Index

6.3.4. Other Analytic Issues

As noted at the beginning of this section, the major analytic tasks are developing the two data sets (economic and financial) and projecting the recurrent costs over the span of the analysis. In addition, there are a number of other issues which arise in the course of conducting the analysis. These issues have been summarized and included in the table below; a more detailed discussion of the issues is included in the Annex 5.

TABLE 6.4. Summary of Other Analytic Issues

Issue	Resolution
Sensitivity Analysis	Confine to inputs which can substantially affect unit prices or those which differ markedly when the economic or financial data sets are compared
Specifying Water Requirements	Determine water requirements prior to performing analysis. It may be necessary to consider growth in demand especially that arising from population growth
Treatment of Renewables	Water output which exceeds specified amount (above) should not be used in the analysis
Discounting Physical Quantities	Physical Quantities (e.g., water output) should not be discounted
Storage	Where clearly a part of all systems being considered, it may be ignored as are other common costs
Maintenance and Repairs	Maintenance costs are those incurred to prevent breakdown; repair costs are those made to fix broken equipment
Reliability	Include costs which are directed toward improving the level of service, such as training, repair facilities, fuel delivery trucks, etc.

Having examined the analytic and technical issues involved in creating the needed data for the analysis, the next step is to examine the technique for analyzing the two sets of data which have been created.

6.3.5. Analytic Techniques: Present Value Analysis

Numerous texts and handbooks exist which explain in some detail the basis for the whole family of discounted cash-flow techniques. These texts generally review the debates regarding the finer points of the methods. Those who wish to learn more about the methods, should review works listed in the References section. To accomplish the purposes of this Handbook, however, it is necessary to explain the application of the chosen technique in such a way that potential users can use it for practical analysis.

The choice of techniques grows out of the nature of the decision maker's problem which is to choose systems that minimize the cost of pumping a given amount of water. First costs, or year-one costs, are an unreliable guide to the life-cycle costs. A decision to choose a certain system carries with it an uneven out-flow of funds (costs) over time. That is, there will be an investment in year-one which is followed by outlays for fuel and operating and maintenance costs over the life of the system. Some systems have a greater proportion of the total costs in the first year of the project than do others--e. g., wind machines as compared to diesel pumpsets. Thus the method chosen for the analysis must adjust these uneven flows and permit comparisons across systems. The principle which underlies such adjustments is called the time value of money: costs which occur in different time periods are not of equal weight. Costs are of less weight, value, or worth the further into future they can be deferred. To reflect these preferences, future costs are adjusted or "discounted" by a factor which is called a discount rate.

Present value analysis is a means of adjusting the stream of (uneven) yearly outlays so they may be expressed and compared as though they were being incurred in year-one. The formula used to calculate the present value (PV) of a twenty year stream of costs is

(equation 6-1): Present value (PV) =

$$\text{SUM}\left[\frac{CF1}{(1+r)} + \frac{CF2}{(1+r)^2} + \ldots + \frac{CF8}{(1+r)^8} + \ldots\ldots + \frac{CF20}{(1+r)^{20}}\right]$$

where: CF = stream of cash flows (annual)
r = the discount rate
$(1 + r)^n$ = the discount factor

To clarify the workings of this equation, it is helpful to substitute numbers for the symbols in the above equation. These numbers are those used in both the manually worked-out example

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and the sample spreadsheet (Table 6.6.) which follow and which are shown for the full twenty years in Table 6.5. below.

$$\text{SUM: } \frac{130}{(1.10)^1} + \frac{130}{(1.10)^2} + \ldots + \frac{1130}{(1.10)^8} + \ldots + \frac{130}{(1.10)^{20}} \text{ or}$$

$$\text{SUM: } \frac{130}{1.10} + \frac{130}{1.21} + \ldots + \frac{1130}{2.14} + \ldots + \frac{130}{6.73} \text{ or}$$

$$\text{SUM: } 118.18 + 107.44 + \ldots + 527.15 + \ldots + 19.32 = 1791$$

The equation shows that each year's cash flow (recurrent costs in this analysis) is discounted by dividing the cash flow by a term which is calculated by adding one to the discount rate and raising that sum (1 + r) to a power which is equal to the number of years into the future that the cash flow occurs. These discounted cash flows are summed to yield the present value (PV) of the recurrent costs. When the PV of recurrent costs and the Total Installed Cost are summed, the result is the Life Cycle Cost.

In practice, the estimated recurrent costs will not be the same for each year for a variety of reasons. The major reason for this difference is the routine replacement or major overhaul of the pump and/or power unit. In the numerical example above, and as can be seen in Table 6.5. and sample spreadsheet Table 6.6., the pump has a life of eight years. Therefore, year 8 and year 16 show an undiscounted cash flow of 1130 (100+10+10+10+1000) while the remaining years show 130 (100+10+10+10).

While it is unlikely that many analysts will use a manual method, it is instructive to work through a problem. To make the most of this exercise, the data used in the manual example are exactly the same as that used a sample spreadsheet (Table 6.6) which follows. The data for the manual example are shown in Table 6.5. To further clarify the linkage between the manual example and the spreadsheet, the corresponding row and column references for the spreadsheet are shown in brackets (for example: [D9]).

Column two (CF in equation 6-1) is a series made up of the sum of each year's recurrent costs which are also shown as row (f) in the Financial Analysis section of the sample spreadsheet, Table 6.6. Column three is the discount factor, $(1 + r)^n$ in Equation 6-1 above. Column four is the present value of the

TABLE 6.5.: An Exercise in Manual Methods: Calculating Present Value

Year	CFn Row (f) from Financial Analysis	$(1 + r)^n$ (r = [M5] = 10%)	PV for Each Year
1	130	1.10	118.18
2	130	1.21	107.44
3	130	1.33	97.67
4	130	1.46	88.79
5	130	1.61	80.72
6	130	1.77	73.38
7	130	1.95	66.71
8	1130	2.14	527.15
9	130	2.36	55.13
10	130	2.59	50.12
11	130	2.85	45.56
12	130	3.14	41.42
13	130	3.45	37.66
14	130	3.80	34.23
15	130	4.18	31.12
16	1130	4.59	245.92
17	130	5.05	25.72
18	130	5.56	23.38
19	130	6.12	21.26
20	130	6.73	19.32

Present value of Recurrent Costs	1791.00	[D9]
Total Installed Costs	3610.00	[D7]
Life Cycle Costs	5401.00	

figure in column two which is calculated (as shown in Equation 6-1) by dividing the nominal costs by the discount factor. (Note: data in Table 6.5 have been rounded for purposes of illustration and are no longer precisely correct.)

The present values for each year (column four) are summed (1791) to total the present value of all recurrent costs, cell D9 in Table 6.6. When this figure is added to the total installed costs (cell D7), the result is commonly known as the life cycle cost. In analysis of water pumping projects, it is standard practice to express the life cycle costs in terms of unit costs.

In this example the total water pumped over the span of the analysis is the product of: 20 (years) x 365 (days per year) x 5 (cubic meters per day) = 36500. Dividing the LCC of 5401 by 36500 yields a quotient of .15. Therefore, for purposes of comparisons the cost of pumping water with this system is estimated to be .15 units of currency per cubic meter, in financial analysis (cell D5). Please note, however, that this figure should not be interpreted as an estimate of the delivered cost of water. Some costs, notably those common to all systems being compared, have been omitted. Therefore, this estimate is valid only when used for purposes of comparison with other estimates which have been derived using the same system boundaries, assumptions, etc.

At this point, it is important to examine two very important assumptions that have been made but not yet discussed: the discount rate and the term of the analysis.

Discount Rates

As can be seen in Equation 6-1, the value chosen for the discount rate is a major determinant of the present value. The effect of discounting can be understood by examining Table 6.5. Since the undiscounted cash flows are identical at 130 (except for years 8 and 16), the result of discounting can easily be seen by examining the series in the right-most column. The recurrent costs in year one are two percent of the Life Cycle Cost (LCC) while the year twenty costs are less than one-half of one percent of the LCC.

The rate used may well vary depending on whether financial or economic analysis is being performed. For financial analysis, the appropriate rate is the market interest rate for loans for investment capital which represents either the cost of money to the private investor or the opportunity cost to the investor if his/her own funds are used in some other way rather than invested in a pumpset. Within a country, the interest rate can vary widely depending on differences in risk and the mobility of capital or local availability of credit. The relevant rate will depend on the specific situation. Information regarding the choice of an appropriate rate is likely to be available from economic planning officers in the appropriate agricultural or water agency. For economic analysis the discount rate should be based on the government's economic planning criteria for project investments. The rate will primarily reflect the opportunity cost or the marginal productivity of capital.

All else equal, the higher discount rates will make technologies with higher year-one costs look less attractive than those with lower year-one costs and higher recurrent costs. This is true simply because in such a case a smaller share of the total costs is subject to deeper discounting (that is, divided by larger discount factors) and the higher rate quickly reduces the value of the recurrent costs in the out-years.

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Planning Period or Term of the Analysis

In principle, for present value calculations the life of the longest lasting system component should be used for the term of the analysis or the planning period. For the problem at hand, comparing the costs of different pumping systems, this principle provides no unambiguous answer. One of the questions being explored, in fact, is the life of the various components. Moreover, one goal of the analysis is to focus attention on the cost reductions which can occur when improved maintenance extends the life of the major components. An informal review of the literature indicates that many analysts have simply chosen to use a twenty-year time span for the analysis. With nearly any discount rate, costs incurred beyond the twenty-year time span will have little effect on the unit costs calculation. Therefore, based on practical considerations rather than theory, twenty years should be used.

6.3.6. Use of Microcomputer Software

It is anticipated that the analyst will be using one of the standard spreadsheet software packages (e. g., Microsoft Excel, Quattro, Multiplan, Lucid, SuperCalc4, ZenCalc, etc.) available for microcomputers. These packages contain the needed financial analysis function which calculates the present value (PV) of a user-specified range of figures. In most software, the function used is called net present value (NPV). An examination of most software documentation, usually somewhat lacking in explanation, will reveal that there is no error in using a function called NPV to calculate PV. The "netness" of NPV is that it can be used to analyze a broad range of problems some of which may include both costs and benefits (e.g., net returns on an investment: the value of the returns minus the cost of the investment).

Use of spreadsheet software makes it possible to quickly and easily evaluate (for example) a range of cost estimates for key variables and thereby produce a sensitivity analysis which shows changes in unit costs associated with different assumptions or cost estimates for crucial components of total cost such as fuel. An added benefit of using spreadsheet software is that most (but not all) of these packages have the ability to produce graphics which can be helpful in illustrating and understanding other matters of interest. For example, pie charts can be used to illustrate and visually compare the components of cost (capital, labor, fuel, etc.) for different systems or for the same system under different sets of assumptions.

In order to reduce the cost of computation and make the analysis more efficient, it is important to give some prior thought to the actual design or layout of the spreadsheet, which both organizes the analysis and serves as the calculating device. Experienced spreadsheet users may have their own approach to this problem, but for those not so experienced a simple example is shown in Table 6.6. Placing different categories of information in different regions of the spreadsheet serves to make the logic of the analysis clear to others --or to yourself should you be called away from the task for a few weeks or months. For this example, the spreadsheet is divided into four parts: (a) Results, (b) Assumptions, (c) Inputs, and (d) Calculations. The rationale for the layout chosen here is that by locating the Results in the upper left corner, it is possible to quickly move to that block by pressing the "home" key. The "navigation" commands of particular programs may lend themselves to somewhat different layouts. The point is that if there is very much analysis to be done, the ease and speed of work can become an issue. In addition, this layout is designed to print on a single sheet of ordinary paper (either A4 or 8.5 x 11) when a smaller printer font is used. This is an advantage for presentation purposes and when preparing reports. Where this is not of concern, it is simpler to let the recurrent costs continue through column Y.

The extent to which the analyst takes advantage of the various features of the available software will not be explored here except in passing. The degree to which the actual analysis is "automated" depends on both the familiarity of the user with the software and the features of the software. The assumptions here are (a) the spreadsheet being used is very basic and (b) the analyst has little or no familiarity with spreadsheet software. The best way to learn to use spreadsheet software is to have a real problem to analyze. Therefore, it is expected that many analysts, will begin with simple spreadsheets and will learn to take advantage of various features of their software at a pace which is comfortable to them.
(Note: Rather than using a manual technique to check results of spreadsheet analysis, it is suggested that data from sample spreadsheets in this chapter be used instead.)

The financial data included in the sample spreadsheet are all in powers of ten to make visual comparison between the economic and the financial data sets easier. To further explain the linkages between the data sets, each section of the spreadsheet will be discussed.

Results Box

The box in the upper left corner of the spreadsheet contains the results of the analysis. As the analysis of the two data sets

TABLE 6.6 Spreadsheet for explanation

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
2	A N S W E R	B O X							A S S U M P T I O N S						
3	==============================								======================						
4				Financial		Economic									
5	PV per m3			0.15		0.16			Real Discount Rate				0.1		
6									Shadow Price Unskilled Labou				0.5		
7	Total Installed Costs			3610		3848			Shadow Foreign Exchange				1.25		
8									Taxes on Equipment				0.1		
9	PV of Recurrent Costs			1791		2109									
10									Life of Pump in years			8			
11	Output: m3/day		5												
12															
13					F I N A N C I A L			A N A L Y S I S							
14					==										
15	RECURRENT COSTS					year1	year2	year3	year4	year5	year6	year7	year8	year9	year10
16	Fuel			100	(a)	100	100	100	100	100	100	100	100	100	100
17	Parts/materials			10	(b)	10	10	10	10	10	10	10	10	10	10
18	Pump replacement				(c)								1000		
19	Skilled Labour			10	(d)	10	10	10	10	10	10	10	10	10	10
20	Transportation			10	(e)	10	10	10	10	10	10	10	10	10	10
21	Total				(f)	130	130	130	130	130	130	130	1130	130	130
22															
23	CAPITAL COSTS														
24	Pump			1000											
25	Engine			1000											
26	Other			100											
27	Site Preparation			100											
28	Pumphouse and Works			100		year11	year12	year13	year14	year15	year16	year17	year18	year19	year20
29	Storage Tank			1000	(a)	100	100	100	100	100	100	100	100	100	100
30	Other			100	(b)	10	10	10	10	10	10	10	10	10	10
31	Installation				(c)						1000				
32	Skilled Labour			100	(d)	10	10	10	10	10	10	10	10	10	10
33	Unskilled Labour			100	(e)	10	10	10	10	10	10	10	10	10	10
34	Transport			10	(f)	130	130	130	130	130	1130	130	130	130	130
35	Total Installed Cost			3610											
36															
37															
38															
39															
40					E C O N O M I C			A N A L Y S I S							
41					==										
42	RECURRENT COSTS					year1	year2	year3	year4	year5	year6	year7	year8	year9	year10
43	Fuel			125	(a)	125	125	125	125	125	125	125	125	125	125
44	Parts/materials			11	(b)	11	11	11	11	11	11	11	11	11	11
45	Pump replacement				(c)								1136		
46	Skilled Labour			10	(d)	10	10	10	10	10	10	10	10	10	10
47	Transportation			10	(e)	10	10	10	10	10	10	10	10	10	10
48	Total				(f)	156	156	156	156	156	156	156	1293	156	156
49															
50	CAPITAL COSTS														
51	Pump			1136											
52	Engine			1136											
53	Other			114											
54	Site Preparation			100											
55	Pumphouse and Works			100		year11	year12	year13	year14	year15	year16	year17	year18	year19	year20
56	Storage Tank			1000	(a)	125	125	125	125	125	125	125	125	125	125
57	Other			100	(b)	11	11	11	11	11	11	11	11	11	11
58	Installation				(c)						1136				
59	Skilled Labour			100	(d)	10	10	10	10	10	10	10	10	10	10
60	Unskilled Labour			50	(e)	10	10	10	10	10	10	10	10	10	10
61	Transport			11	(f)	156	156	156	156	156	1293	156	156	156	156
62	Total Installed Cost			3848											

is wholly parallel, this explanation will be in terms of the financial data set only.

(a) Total installed costs (cell D7) is simply a duplicate of cell D35, which is the sum of the Capital Costs (D24 through D34). This "duplicate" is located in the Results Box simply for convenience.

(b) Cell D9 is the present value of the recurrent costs which is the stream of recurrent costs over the twenty year period of the analysis discounted by the Real Discount Rate. That is, the series made up of the sums of each year's recurrent costs (cells F21 through O21 and F34 through O34) which are discounted at the rate shown in cell M5. These recurrent costs include two replacements of the pump, one each in years 8 and 16, otherwise the yearly outlays are identical. Note that these figures are the same as are reported in the second column of Table 6.5, above.
When actually entering the formula for cell D9, it is useful to enter the discount rate in terms of the location of the cell containing the value that is to be used, rather than the value itself. That is, if the cell reference (M5) is used instead of 0.10, it is quite simple to explore the cost implications of different discount rates by merely substituting one number for another in cell M5 and watching D5 and D9 take on new values. This approach is simpler and less likely to introduce errors than the alternative of editing the actual formulae to change the discount rate.

(c) The daily water output of the system is entered into cell C11 and is multiplied by 7300 (the number of days in 20 years) to obtain total output for the period of the analysis.

(d) Finally, cells D7 and D9 are summed (= 5401) and then divided by the total water pumped (36,500 m3) to arrive at .15 units of currency per cubic meter, [D5].*

Assumptions Box

(a) The real discount rate is entered in cell M5; its only use in the analysis is that discussed in note 2 above. Software differs as to the form in which the discount rate should be entered, but most accept the decimal fraction form shown here. Care should be taken, as this is the most likely place in the analysis to misplace a decimal. If there is a substantial difference between the discount rate faced by the user and the government, a separate Economic Discount Rate can be added here and used for the economic analysis.

(b) The Shadow Price for unskilled labor is entered in cell M6. As with the discount rate, it is recommended that when

* According to the footnote at page 6.1 it should be emphasized that the number in cell D5 cannot be considered as the real cost per cubic meter water pumped. Since common costs have been omitted and the water output has not been discounted, it should rather be considered as a relative cost indicator.

the figure is needed in a formula it be included as a cell reference --as discussed in note (b) above. In this example, cell D60 is calculated by multiplying D33 by cell M6.

(c) The Shadow Foreign Exchange adjustment (cell M7) indicates that the local currency is over-valued by 25 percent. Cell M7 is used to adjust the financial prices of imported items. A second adjustment (cell M8, an ad valorem 10 percent tax) corrects these prices for taxation. For example, cell D17 (parts and material) is first adjusted for this tax component (cell M8) by dividing it by 1.1. After that using cell M7, the result is multiplied by 1.25 to correct the non-tax part of the financial costs for exchange rate.
The full adjustment is: (10/1.1)*1.25 = 11.36. When rounded to the nearest whole unit of currency, the value is 11; cell D44 contains this figure.

(d) The life of the pump is shown to be eight years; this cost is included in the capital costs in year one and as a recurrent cost in years eight and sixteen. While many spreadsheets contain functions which would automate the insertion of replacement of costs at year 8 and year 16, it is most often better done manually by simply entering the cell reference (e. g., D51) in the appropriate blank cell (e. g., M45). Those very familiar with their software may wish to make this automatic, but those not so familiar could invest more time getting it right than by simply doing it manually.

Transforming Financial Costs into Economic Costs

To review, the financial costs are adjusted based on the information shown in the assumptions box to create the economic data set. An example of this was shown in note (c) above concerning the shadow foreign exchange adjustment.

(a) Cells D24, D25, D26, and D34 are adjusted for foreign exchange and taxes to yield the counter-part cells of D51, D52, D53, and D61. Note that the net adjustment is as calculated in note (c) above. The other capital costs were found, in this example, to be local products and were not adjusted. In the case of skilled labor (D32 and D59), the wage rate was judged to reflect the alternative-use costs to society and no adjustment was needed.

(b) For this example, no adjustments were made to the fuel costs. In practice, as will be shown later in the technology-by-technology examples, both liquid fuels and electricity often contain tax and subsidy components which cause the economic costs to differ from the financial. No real price escalation was included.

TABLE 6.7 Spreadsheet Diesel Pump

S A M P L E   S P R E A D S H E E T: D I E S E L

	Financial	Economic		
PV per m3	0.31	0.2A	Real Discount Rate	0.06
			Shadow Price Unskilled Labor	0.5
Total Installed Costs	11150	11338	Shadow Foreign Exchange	1.25
			Taxes on Equipment	0
PV of Recurrent Costs	56540	49038		
			Life of Pump in years	8
Output: m3/day	30			

F I N A N C I A L   A N A L Y S I S

RECURRENT COSTS			year1	year2	year3	year4	year5	year6	year7	year8	year9	year10
Fuel and lubrication	1100	(a)	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100
Maintenance: parts	400	(b)	400	400	400	400	400	400	400	400	400	400
Maintenance: labor	120	(c)	120	120	120	120	120	120	120	120	120	120
Enigine overhaul: parts	500	(d)		500		500	500		500		500	500
Engine overhaul: labor	100	(e)		100		100	100		100		100	100
Pump replacement		(f)								600		
Labor (pumper)	2400	(g)	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
Transportation	510	(h)	510	510	510	510	510	510	510	510	510	510
Total		(i)	4530	5130	4530	5130	5130	4530	5130	5130	5130	5130

CAPITAL COSTS												
Engine	2100											
Pump	600		year11	year12	year13	year14	year15	year16	year17	year18	year19	year20
Downhole piping	200	(a)	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100
Site Preparation	200	(b)	400	400	400	400	400	400	400	400	400	400
Pumphouse and Works	1200	(c)	120	120	120	120	120	120	120	120	120	120
Storage Tank	1000	(d)		500		500	500		500		500	500
Above ground piping	450	(e)		100		100	100		100		100	100
Installation		(f)						600				
Skilled Labour	2000	(g)	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
Unskilled Labour	2000	(h)	510	510	510	510	510	510	510	510	510	510
Transport	1400	(i)	4530	5130	4530	5130	5130	5130	5130	4530	5130	5130
Total Installed Cost	11150											

E C O N O M I C   A N A L Y S I S

RECURRENT COSTS			year1	year2	year3	year4	year5	year6	year7	year8	yeer9	year10
Fuel and lubrication	1375	(a)	1375	1375	1375	1375	1375	1375	1375	1375	1375	1375
Maintenance: parts	500	(b)	500	500	500	500	500	500	500	500	500	500
Maintenance: labor	78	(c)	78	78	78	78	78	78	78	78	78	78
Enigine overhaul: parts	625	(d)		625		625	625		625		625	625
Engine overhaul: labor	100	(e)		100		100	100		100		100	100
Pump replacement		(f)								750		
Labor (pumper)	1200	(g)	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Transportation	638	(h)	638	638	638	638	638	638	638	638	638	638
Total		(i)	3791	4516	3791	4516	4516	3791	4516	4541	4516	4516

CAPITAL COSTS												
Engine	2625											
Pump	750		year11	year12	year13	year14	year15	year16	year17	year18	year19	year20
Downhole piping	250	(a)	1375	1375	1375	1375	1375	1375	1375	1375	1375	1375
Site Preparation	200	(b)	500	500	500	500	500	500	500	500	500	500
Pumphouse and Works	1200	(c)	78	78	78	78	78	78	78	78	78	78
Storage Tank	1000	(d)		625		625	625		625		625	625
Above ground piping	563	(e)		100		100	100		100		100	100
Installation		(f)						750				
Skilled Labour	2000	(g)	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Unskilled Labour	1000	(h)	638	638	638	638	638	638	638	638	638	638
Transport	1750	(i)	3791	4516	3791	4516	4516	4541	4516	3791	4516	4516
Total Installed Cost	11338											

6.4. DISCUSSION OF SAMPLE SPREADSHEETS

A sample spreadsheet has been prepared for each of the technologies covered by the handbook. The financial data used for these analyses should be considered as example only; general conclusions can not be drawn from it. It is based on work done for the Comparative Water Pumping Project, a project jointly funded by the Government of Botswana and the U.S. Agency for International Development. Associates in Rural Development provided technical assistance for the project which was implemented through the Ministry of Mineral Resources and Water Affairs. The specific reports from that project are listed in Chapter 7.

The data in these spreadsheets is somewhat different than that found in the project reports. In Botswana, the difference between economic and financial data sets is often quite small --frequently well within the estimating error. The purpose of this handbook is to explore differences. Therefore, some adjustments are made to better illustrate the analytic approach.

The overall structure of these spreadsheets is the same as that used in Table 6.6 (above). Therefore the general explanation which was provided there will not be repeated here.

Diesel-powered Pumpset

The capital costs are shown individually for the major components of the system (engine, pump, tank, etc.). There are two considerations when establishing categories of costs. First, where tax or subsidies differ by type of material (assembled equipment vs parts, raw material vs manufactured goods, etc.) the analysis is clearer when the categories reflect the characteristics of the tax structure. In some cases it will be sufficient to simply separate imports from domestic products. Second, there may be different suppliers or different brands of (e. g.) pumps being tested and major components should be isolated so that cost and or performance differences can easily be accounted for.

In the specific case at hand, the engine is subject to the shadow exchange adjustment and no other taxes or adjustments are made. All the capital costs are subject to this adjustment, with the exception of items which are locally produced. Local items are the site preparation, pumphouse and works, storage tank, and the labor components. The remaining adjustment is that unskilled labor is reduced from 2000 to 1000 by the shadow price for unskilled labor. Note that after all adjustments, the financial total installed costs are roughly equivalent to the economic; the increases for currency valuation are nearly balanced by the reduction in the value of the labor.

Considering the recurrent costs, the same general rules apply in that shadow prices are applied to unskilled labor and to imported items (foreign exchange adjustment). With the exception of labor, all the recurrent costs are adjusted by the foreign exchange shadow adjustment to reflect the fact that they are imported. Within the labor categories, unskilled labor is adjusted as above.
Particular attention is directed to maintenance labor which is shown to be 120 in the financial analysis and 78 in the economic. This item is included here as an example of how not to do it. The maintenance labor is composed of both skilled and unskilled labor - thirty and seventy percent, respectively. The seventy percent is subject to the .5 shadow price while the thirty percent is included at the full value. In numbers: skilled labor is valued at 36 and unskilled at 84 in the financial analysis; in the economic analysis, skilled labor remains 36 and the unskilled is reduced to 42 for a total of 78. While no arithmetic error has been made, the spreadsheet is not clear on this point --it looks like an error. It is better to keep the categories of labor separate as is done in the capital costs with installation labor, for example. In this case, the actual figure is too small to make any real difference in the analysis. In the installation labor, however, that is not the case.

Where there are records of sufficient length and accuracy, many costs will be found to vary by actual running time of the engine. Fuel consumption is an obvious example. In the spreadsheet, there is an implicit assumption that the engine will be operated the same number of hours each year. Frequently that is not a bad assumption. If enough is known about a given situation, there may be better assumptions however. For example, if the population of a village is growing by three percent per year or if for some other reason (such as the addition of private taps) a trend can be documented, then some explicit adjustment can be made.

A related problem is included in the spreadsheet. Small, low-speed Diesel engines can last a very long time--if they are maintained. The engine in the sample operates 3000 hours per year; engine overhauls are shown separately in the spreadsheet at intervals of 5000 hours. Therefore overhauls are fairly frequent, but not really expensive. It is important to distribute costs over time, especially significant ones, using as much accuracy as possible. Where data permit better characterization of the costs on something more accurate than an annual average, the better estimate should be used and the basis for the estimates should be noted.

Note that transportation (in both capital and recurrent costs) is adjusted by the shadow foreign exchange adjustment. This adjustment is made to reflect the fact that two major components of transport (equipment and fuel) are imported. Transportation can be a significant part of both recurrent and capital costs. Therefore, some analytic awareness must be taken of the differences which exist between the two perspectives: economic and financial.

Photovoltaic Pumps

The equipment used here is an array of twenty-one solar modules driving a submersible pump. The balance of the capital costs is self-explanatory. In terms of the differences between the economic and financial data sets, unskilled labor is adjusted by the .5 shadow price. Note that the adjustments for foreign exchange and taxes are the same (.10). These adjustments off-set one another on the imported items which are assembled or manufactured items. Items which are imported, but which are unfinished products, are only subject to the foreign exchange adjustment, i. e., transportation and above ground piping. The major difference between the two data sets is the adjustment to the unskilled labor.

It is noteworthy that a major component of the recurrent costs for the system is the replacement of the modules. The replacement rate used here, one per year for a twenty-one module system, is based on actual experience in Botswana. The other major item is the pump and motor replacement, this too is based on experience. The replacement rate for submersible pumps is dependent on the quality of water, the quality of the pump, among other things. It is intuitively appealing to add an amount of labor and transportation to the year in which the pump is replaced. If information on such costs exist, it can be included. These costs --especially where submersible pumps are concerned --are comparatively small and are unlikely to change the analysis much.

After the spreadsheet is set up, it is an easy task to modify the appropriate recurrent costs (substituting guesses for missing data) to determine if the costs of acquiring the data are likely to be matched by improvements in the analysis.

TABLE 6.8 Spreadsheet Solar Pump

S A M P L E S P R E A D S H E E T: P H O T O V O L T A I C

	Financial	Economic
PV per m3	0.33	0.33
Total Installed Costs	28295	27418
PV of Recurrent Costs	20230	20207
Output: m3/day	20	

Real Discount Rate	0.06
Shadow Price Unskilled Labor	0.5
Shadow Foreign Exchange	1.1
Taxes on Equipment	0.1
Life of Pump in years	5

F I N A N C I A L A N A L Y S I S

RECURRENT COSTS			year1	year2	year3	year4	year5	year6	year7	year8	year9	year10
Module replacement	670	(a)	670	670	670	670	670	670	670	670	670	670
Parts and materials	100	(b)	100	100	100	100	100	100	100	100	100	100
Pump replacement		(c)					4700					4700
Maintenance: skilled labor	12	(d)	12	12	12	12	12	12	12	12	12	12
unskilled labor	28	(e)	28	28	28	28	28	28	28	28	28	28
Transportation	120	(f)	120	120	120	120	120	120	120	120	120	120
Total		(g)	930	930	930	930	5630	930	930	930	930	5630

CAPITAL COSTS	
Pump & motor	4700
Solar modules	14070
Related solar hardware	1250
Above ground piping	450
Pumphouse and Works	1500
Storage Tank	1000
Other	100
Installation	
Skilled Labour	2000
Unskilled Labour	2000
Transport	1225
Total Installed Cost	28295

	year11	year12	year13	year14	year15	year16	year17	year18	year19	year20
(a)	670	670	670	670	670	670	670	670	670	670
(b)	100	100	100	100	100	100	100	100	100	100
(c)					4700					4700
(d)	12	12	12	12	12	12	12	12	12	12
(e)	28	28	28	28	28	28	28	28	28	28
(f)	120	120	120	120	120	120	120	120	120	120
(g)	930	930	930	930	5630	930	930	930	930	5630

E C O N O M I C A N A L Y S I S

RECURRENT COSTS			year1	year2	year3	year4	year5	year6	year7	year8	year9	year10
Module replacement	670	(a)	670	670	670	670	670	670	670	670	670	670
Parts and materials	100	(b)	100	100	100	100	100	100	100	100	100	100
Pump replacement		(c)					4700					4700
Maintenance: skilled labor	12	(d)	12	12	12	12	12	12	12	12	12	12
unskilled labor	14	(e)	14	14	14	14	14	14	14	14	14	14
Transportation	132	(f)	132	132	132	132	132	132	132	132	132	132
Total		(g)	928	928	928	928	5628	928	928	928	928	5628

CAPITAL COSTS	
Pump and motor	4700
Pump	14070
Related solar hardware	1250
Above ground piping	450
Pumphouse and Works	1500
Storage Tank	1000
Other	100
Installation	
Skilled Labour	2000
Unskilled Labour	1000
Transport	1348
Total Installed Cost	27418

	year11	year12	year13	year14	year15	year16	year17	year18	year19	year20
(a)	670	670	670	670	670	670	670	670	670	670
(b)	100	100	100	100	100	100	100	100	100	100
(c)					4700					4700
(d)	12	12	12	12	12	12	12	12	12	12
(e)	14	14	14	14	14	14	14	14	14	14
(f)	132	132	132	132	132	132	132	132	132	132
(g)	928	928	928	928	5628	928	928	928	928	5628

TABLE 6.9 Spreadsheet Grid Connected Electric Pump

SAMPLE SPREADSHEET: GRID ELECTRIC

	Financial	Economic
PV per m3	0.18	0.19
Total Installed Costs	12200	11680
PV of Recurrent Costs	14687	15415
Output: m3/day	20	

Real Discount Rate	0.06
Shadow Price Unskilled Labor	0.5
Shadow Foreign Exchange	1.1
Taxes on Equipment	0.1
Life of Pump in years	8

FINANCIAL ANALYSIS

RECURRENT COSTS		
Electricity	800	(a)
Parts	10	(b)
Pump replacement		(c)
Skilled labor	50	(d)
Transportation	100	(e)
Total		(f)

	year1	year2	year3	year4	year5	year6	year7	year8	year9	year10
(a)	800	800	800	800	800	800	800	800	800	800
(b)	10	10	10	10	10	10	10	10	10	10
(c)								3600		
(d)	50	50	50	50	50	50	50	50	50	50
(e)	100	100	100	100	100	100	100	100	100	100
(f)	960	960	960	960	960	960	960	4560	960	960

CAPITAL COSTS	
Pump	3600
Motor and starter	1800
Piping and meters	1300
Electric controls	500
Pumphouse and Works	700
Storage Tank	1000
Other	100
Installation	
Skilled Labour	1200
Unskilled Labour	1200
Transport	800
Total Installed Cost	12200

	year11	year12	year13	year14	year15	year16	year17	year18	year19	year20
(a)	800	800	800	800	800	800	800	800	800	800
(b)	10	10	10	10	10	10	10	10	10	10
(c)						3600				
(d)	50	50	50	50	50	50	50	50	50	50
(e)	100	100	100	100	100	100	100	100	100	100
(f)	960	960	960	960	960	4560	960	960	960	960

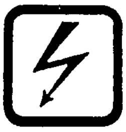
ECONOMIC ANALYSIS

RECURRENT COSTS		
Electricity	880	(a)
Maintenance: parts	11	(b)
Pump replacement		(c)
Skilled labor	33	(d)
Transportation	100	(e)
Total		(f)

	year1	year2	year3	year4	year5	year6	year7	year8	year9	year10
(a)	880	880	880	880	880	880	880	880	880	880
(b)	11	11	11	11	11	11	11	11	11	11
(c)								3600		
(d)	33	33	33	33	33	33	33	33	33	33
(e)	100	100	100	100	100	100	100	100	100	100
(f)	1024	1024	1024	1024	1024	1024	1024	4624	1024	1024

CAPITAL COSTS	
Pump	3600
Motor and starter	1800
Piping and meters	1300
Electric controls	500
Pumphouse and Works	700
Storage Tank	1000
Other	100
Installation	
Skilled Labour	1200
Unskilled Labour	600
Transport	880
Total Installed Cost	11680

	year11	year12	year13	year14	year15	year16	year17	year18	year19	year20
(a)	880	880	880	880	880	880	880	880	880	880
(b)	11	11	11	11	11	11	11	11	11	11
(c)						3600				
(d)	33	33	33	33	33	33	33	33	33	33
(e)	100	100	100	100	100	100	100	100	100	100
(f)	1024	1024	1024	1024	1024	4624	1024	1024	1024	1024



Grid Connected Electric Pumps

This example includes no costs associated with the extension of the grid to the site or any transformer costs. Capital equipment includes a submersible pump, which is priced separately from the motor and starter. This treatment allows pump replacement as a separate transaction. The taxes and the foreign exchange adjustments off-set each other. Therefore, economic and financial total installed costs differ due to the installations costs --transport and unskilled labor. In the economic analysis, electricity is shadow priced using (an example) foreign exchange adjustment, to account for the fact that the equipment and fuel used in the production of electricity are imported. Electricity is actually the energy source which is most likely to exhibit price distortions. It is very important to investigate electricity pricing policies to ensure that proper adjustments are made for subsidies.

Wind Pumps

The most noteworthy element in the analysis of wind machines is the relatively low recurrent costs. The ratio of capital costs to recurrent can be high, especially where a proven wind machine is being analyzed. Unfortunately, some wind machines - and other devices which provide power for pumping - on the market have not (yet) proven to be reliable -- in these cases the above generalization does not hold.

For the spreadsheet labelled Wind-1, adjustments to capital costs follow the pattern established in the previous spreadsheets. The two major analytic issues for wind machines are the choice of level of output (low-wind month, etc.) and the effect of different discount rates both of which are discussed earlier.

The spreadsheet labelled Wind-2 is based on data developed in the Cape Verde islands, again somewhat adapted here as illustration. The wind machine is locally manufactured and operates in sea winds which result in fairly high maintenance costs to cover frequent painting due to the adverse operating environment -salt air.-

In addition, the wind machine itself is replaced in year 15. Note that this results in a 5775 charge (financial data set). Although only the overall result is shown on the spreadsheet, the discounting reduces this amount to a present value of 1413 units of currency. The net effect of replacing the machine in the fifteenth year of operation is one-hundredth of a unit of currency (one cent) per cubic meter of water delivered.

TABLE 6.10 Spreadsheet Wind Pump - 1

S A M P L E   S P R E A D S H E E T: W I N D

	Financial	Economic
PV per m3	0.31	0.33
Total Installed Costs	22560	24493
PV of Recurrent Costs	1974	2282
Output: m3/day	11	

Real Discount Rate	0.1
Shadow Price Unskilled Labor	0.5
Shadow Foreign Exchange	1.25
Taxes on Equipment	0.1
Life of Pump in years	7

F I N A N C I A L   A N A L Y S I S

RECURRENT COSTS			year1	year2	year3	year4	year5	year6	year7	year8	year9	year10
Parts/materials	50	(a)	50	50	50	50	50	50	50	50	50	50
Cylinder replacement		(b)							350			
Skilled labor	50	(c)	50	50	50	50	50	50	50	50	50	50
Transportation	100	(d)	100	100	100	100	100	100	100	100	100	100
Total		(e)	200	200	200	200	200	200	550	200	200	200

CAPITAL COSTS	
Cylinder	350
Windmill & tower	15000
Piping/rising main	500
Above ground piping	60
Pumphouse and Works	750
Storage Tank	1000
Other	100
Installation	
Skilled Labour	3000
Unskilled Labour	1000
Transport	800
Total Installed Cost	22560

	year11	year12	year13	year14	year15	year16	year17	year18	year19	year20
(a)	50	50	50	50	50	50	50	50	50	50
(b)				350						
(c)	50	50	50	50	50	50	50	50	50	50
(d)	100	100	100	100	100	100	100	100	100	100
(e)	200	200	200	550	200	200	200	200	200	200

E C O N O M I C   A N A L Y S I S

RECURRENT COSTS			year1	year2	year3	year4	year5	year6	year7	year8	year9	year10
Parts/material	57	(a)	57	57	57	57	57	57	57	57	57	57
Cylinder replacement		(b)							398			
Skilled labor	50	(c)	50	50	50	50	50	50	50	50	50	50
Transportation	125	(d)	125	125	125	125	125	125	125	125	125	125
Total		(e)	232	232	232	232	232	232	630	232	232	232

CAPITAL COSTS	
Cylinder	398
Windmill & tower	17045
Piping/rising main	625
Above ground piping	75
Pumphouse and Works	750
Storage Tank	1000
Other	100
Installation	
Skilled Labour	3000
Unskilled Labour	500
Transport	1000
Total Installed Cost	24493

	year11	year12	year13	year14	year15	year16	year17	year18	year19	year20
(a)	57	57	57	57	57	57	57	57	57	57
(b)				398						
(c)	50	50	50	50	50	50	50	50	50	50
(d)	125	125	125	125	125	125	125	125	125	125
(e)	232	232	232	630	232	232	232	232	232	232

TABLE 6.11 Spreadsheet Wind Pump - 2

S A M P L E   S P R E A D S H E E T :   W I N D - 2

	Financial	Economic
PV per m3	0.11	0.10
Total Installed Costs	9950	9825
PV of Recurrent Costs	9695	7848
Output: m3/day 25		

Real Discount Rate	0.1
Shadow Price Unskilled Labor	0.5
Shadow Foreign Exchange	1
Taxes on Equipment	0.1
Life of Pump in years	5

F I N A N C I A L   A N A L Y S I S

RECURRENT COSTS			year1	year2	year3	year4	year5	year6	year7	year8	year9	year10
Parts/materials	300	(a)	300	300	300	300	300	300	300	300	300	300
Pump and piping replacement	750	(b)					750					750
Skilled labor	100	(c)	100	100	100	100	100	100	100	100	100	100
Unskilled labor	350	(d)	350	350	350	350	350	350	350	350	350	350
Transportation	100	(e)	100	100	100	100	100	100	100	100	100	100
Replace windpump in year 15		(f)										
Total		(g)	850	850	850	850	1600	850	850	850	850	1600

CAPITAL COSTS		
Cylinder		500
Windmill & tower	5500	
materials		2500
workshop overhead		2500
skilled labor		350
unskilled labor		150
Below groun piping		250
Pumphouse and works		300
Storage tank		3000
Installation	400	
Skilled labor		100
Unskilled labour		100
Transport		200
Total Installed Cost		9950

	year11	year12	year13	year14	year15	year16	year17	year18	year19	year20
(a)	300	300	300	300	300	300	300	300	300	300
(b)					750					750
(c)	100	100	100	100	100	100	100	100	100	100
(d)	350	350	350	350	350	350	350	350	350	350
(e)	100	100	100	100	100	100	100	100	100	100
(f)					5900					
(g)	850	850	850	850	7500	850	850	850	850	1600

E C O N O M I C   A N A L Y S I S

RECURRENT COSTS			year1	year2	year3	year4	year5	year6	year7	year8	year9	year10
Parts/material	273	(a)	273	273	273	273	273	273	273	273	273	273
Pump and piping replacement	682	(b)					682					682
Skilled labor	100	(c)	100	100	100	100	100	100	100	100	100	100
Unskilled labor	175	(d)	175	175	175	175	175	175	175	175	175	175
Transportation	100	(e)	100	100	100	100	100	100	100	100	100	100
Replace windpump in year 15		(f)										
Total		(g)	648	648	648	648	1330	648	648	648	648	1330

CAPITAL COSTS		
Cylinder		500
Windmill & tower	5425	
materials		2500
workshop overhead		2500
skilled labor		350
unskilled labor		75
Below ground piping		250
Pumphouse and Works		300
Storage Tank		3000
Installation	350	-
skilled labour		100
unskilled labour		50
transport		200
Total Installed Cost		9825

	year11	year12	year13	year14	year15	year16	year17	year18	year19	year20
(a)	273	273	273	273	273	273	273	273	273	273
(b)					682					682
(c)	100	100	100	100	100	100	100	100	100	100
(d)	175	175	175	175	175	175	175	175	175	175
(e)	100	100	100	100	100	100	100	100	100	100
(f)					5775					
(g)	648	648	648	648	7105	648	648	648	648	1330

Although the machine is locally assembled, the only adjustment needed is for the small amount of unskilled labor used in the manufacturing process. if this machine were being compared to one which was imported in a fully assembled condition, then the tax would be applied to the total price of 5500. This would result in the total installed cost in the financial data set to diverge from that in the economic data set.

Animal Traction Pumps

Animal-powered pumpsets can be analyzed in the same fashion as any other investment in a pumping technology. In spite of the lengthy history of use, there is not a lot of reasonably reliable data on some of the more thorny analytic issues, however.

The example system described by the sample spreadsheet is a pumpset being developed by the Rural Industries Innovation Center in Botswana. It consists of a system of chain-driven reduction gears and a belt driven Mono pump. What is of interest in terms of the economic/ financial analysis is that the unit is being manufactured in Botswana of imported parts and imported steel using local labor. Most of the labor costs, however, are for skilled labor which is not subject to the shadow pricing.

It must be noted that on costs for feed for the donkeys there was simply too little experience and too little documentation of long-term tests at this point to have reliable data. Donkeys are widely used in Botswana for pulling carts. It is a matter of some conjecture how the greater-than-normal effort required for water pumping will affect feeding requirements and veterinary costs. In the sample spreadsheet fodder cost should be seen as example only. In addition, no labor charge is included here for the animal driver/ pump operator.

In the present case, six donkeys work two shifts per day and pump 7.5 cubic meters per shift. The donkeys do not do other work, hence the question of how to allocate their costs among various tasks does not arise. In cases where other work is performed, an allocation of joint costs (i. e., feed, veterinary expenses, etc.) based on time would seem the best practical answer.

TABLE 6.12 Spreadsheet Animal Traction Pump

S A M P L E   S P R E A D S H E E T :   A N I M A L   D R A W N   P U M P

	Financial	Economic
PV per m3	0.18	0.19
Total Installed Costs	10940	12175
PV of Recurrent Costs	8682	8980
Output: m3/day	15	

Real Discount Rate	0.1
Shadow Price Unskilled Labor	0.5
Shadow Foreign Exchange	1.25
Taxes on Equipment	0.1
Life of Pump in years	7

F I N A N C I A L   A N A L Y S I S

RECURRENT COSTS			year1	year2	year3	year4	year5	year6	year7	year8	year9	year10
Parts/materials	50	(a)	50	50	50	50	50	50	50	50	50	50
Pump replacement		(b)							600			
Skilled labor	300	(c)	300	300	300	300	300	300	300	300	300	300
Transportation	240	(d)	240	240	240	240	240	240	240	240	240	240
Pump repair (materials)	250	(e)	250	250	250	250	250	250	250	250	250	250
Harness replacement		(f)		180		180		180		180		180
Donkey replacement		(g)					240					240
Total		(h)	840	1020	840	1020	1080	1020	1440	1020	840	1260

CAPITAL COSTS	
Pump	600
Materials	4900
Skilled labor	1350
Unskilled labor	450
Donkeys (per 6 animals)	240
Harness (per 6 anomals)	180
Piping/rising main	720
Pumphouse & works	750
Storage tank	1000
Installation	
Skilled Labour	250
Unskilled Labour	150
Transport	350
Total Installed Cost	10940

	year11	year12	year13	year14	year15	year16	year17	year18	year19	year20
(a)	50	50	50	50	50	50	50	50	50	50
(b)				600						
(c)	300	300	300	300	300	300	300	300	300	300
(d)	240	240	240	240	240	240	240	240	240	240
(e)	250	250	250	250	250	250	250	250	250	250
(f)		180		180		180		180		180
(g)					240					240
(h)	840	1020	840	1620	1080	1020	840	1020	840	1260

E C O N O M I C   A N A L Y S I S

RECURRENT COSTS			year1	year2	year3	year4	year5	year6	year7	year8	year9	year10
Parts/materials	57	(a)	57	57	57	57	57	57	57	57	57	57
Pump replacement		(b)							682			
Skilled labor	300	(c)	300	300	300	300	300	300	300	300	300	300
Transportation	273	(d)	273	273	273	273	273	273	273	273	273	273
Pump repair	284	(e)	284	284	284	284	284	284	284	284	284	284
Harness replacement		(f)		180		180		180		180		180
Donkey replocement		(g)					240					240
Total		(h)	914	1094	914	1094	1154	1094	1595	1094	914	1334

CAPITAL COSTS	
Pump	682
Materials	6125
Skilled labor	1350
Unskilled labor	225
Donkeys (per 6 animals)	240
Harness (per 6 anomals)	180
Piping/rising main	900
Pumphouse & works	750
Storage tank	1000
Installation	
Skilled Labour	250
Unskilled Labour	75
Transport	398
Total Installed Cost	12175

	year11	year12	year13	year14	year15	year16	year17	year18	year19	year20
(a)	57	57	57	57	57	57	57	57	57	57
(b)				682						
(c)	300	300	300	300	300	300	300	300	300	300
(d)	273	273	273	273	273	273	273	273	273	273
(e)	284	284	284	284	284	284	284	284	284	284
(f)		180		180		180		180		180
(g)					240					240
(h)	914	1094	914	1775	1154	1094	914	1094	914	1334

TABLE 6.13 Spreadsheet Hand Pump

S A M P L E S P R E A D S H E E T: H A N D P U M P

	Financial	Economic
PV per m3	0.23	0.25
Total Installed Costs	2260	2236
PV of Recurrent Costs	2792	3263
Output: m3/day	3	

Real Discount Rate	0.1
Shadow Price Unskilled Labor	0.5
Shadow Foreign Exchange	1.25
Taxes on Equipment	0.1
Life of Pump in years	5

F I N A N C I A L A N A L Y S I S

RECURRENT COSTS	
Parts/materials	25
Pump replacement	750
Skilled labor	12
Unskilled labor	28
Transportation	240
Total	

CAPITAL COSTS	
Pump	140
Pump head	420
Piping/rising main	400
Foundation & fence	100
Installation-skilled labor	500
unskilled labor	500
Transport	200
Total Installed Cost	2260

	year1	year2	year3	year4	year5	year6	year7	year8	year9	year10
(a)	25	25	25	25	25	25	25	25	25	25
(b)					140					140
(c)	12	12	12	12	12	12	12	12	12	12
(d)	28	28	28	28	28	28	28	28	28	28
(e)	240	240	240	240	240	240	240	240	240	240
(f)	305	305	305	305	445	305	305	305	305	445

	year11	year12	year13	year14	year15	year16	year17	year18	year19	year20
(a)	25	25	25	25	25	25	25	25	25	25
(b)					140					140
(c)	12	12	12	12	12	12	12	12	12	12
(d)	28	28	28	28	28	28	28	28	28	28
(e)	240	240	240	240	240	240	240	240	240	240
(f)	305	305	305	305	445	305	305	305	305	445

E C O N O M I C A N A L Y S I S

RECURRENT COSTS	
Parts/material	31
Pump replacement	
Skilled labor	12
Unskilled labor	14
Transportation	300
Total	

CAPITAL COSTS	
Pump	159
Pump head	477
Piping/rising mains	500
Foundation & fence	100
Installation-skilled labor	500
unskilled labor	250
Transport	250
Total Installed Cost	2236

	year1	year2	year3	year4	year5	year6	year7	year8	year9	year10
(a)	31	31	31	31	31	31	31	31	31	31
(b)					159					159
(c)	12	12	12	12	12	12	12	12	12	12
(d)	14	14	14	14	14	14	14	14	14	14
(e)	300	300	300	300	300	300	300	300	300	300
(f)	357	357	357	357	516	357	357	357	357	516

	year11	year12	year13	year14	year15	year16	year17	year18	year19	year20
(a)	31	31	3	31	31	31	31	31	31	31
(b)					159					159
(c)	12	12	12	12	12	12	12	12	12	12
(d)	14	14	14	14	14	14	14	14	14	14
(e)	300	300	300	300	300	300	300	300	300	300
(f)	357	357	357	357	516	357	357	357	357	516

Hand Pump

The example hand pump described by the spreadsheet is an India Mark II pump which is used to pump three cubic meters per day. The equipment is imported and the labor and foundation and fencing are locally supplied items.

In this case, the reduction to total installed costs (economic) brought about by the shadow pricing of unskilled labor is sufficient to off-set the increases arising from the foreign exchange adjustment. Note that no costs are included for the labor of actually pumping the water.

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ANNEX 1 LIST OF SYMBOLS

Symbol	Units	Description
A_{array}	[m^2]	Array area
B	[kWh/l]	Caloric value of fuel
C_{fuel}	[cm^3]	Fuel measuring cylinder reading
C_p.eta	[-]	Overall windpump performance factor
D	[m]	Rotor diameter
e	[ ][1]	Quality factor
$E_{an,T}$	[Wh]	Animal energy input
E_{el}	[kWh]	Electric energy meter reading
$E_{el,T}$	[kWh]	Electric energy consumption
E_{fossil}	[kWh]	Fossil energy consumption
$E_{h,T}$	[kWh] or [Wh]	Hydraulic energy output
E_i	[kWh] or [Wh]	Energy input to the system
E_{sol}	[Wh/m^2]	Pyranometer reading
$E_{sol,T}$	[Wh]	Solar irradiation
f_{se}	[-]	Solar pump exploitation factor
f_{we}	[-]	Windpump exploitation factor
g	[m/s^2]	Acceleration due to gravity
H	[m]	Total effective head
H_{dis}	[m]	Discharge head
H_{hor}	[m]	Equivalent head for horizontal transport

1 Originating from a "rule of the thumb" the quality factor e is neither dimensionless, nor has it a meaningful dimension:

[Ws^3/m^5]

Symbol	Units	Description
H_{in}	[m]	Suction Head
H_P	[m]	Pressure head
L	[m]	Horizontal distance
n_S	[rpm]	Tacho meter reading
n_{RT}	[rev/s]	Average rotational rotor speed
n_{ST}	[strokes/s]	Average stroke rate
N_R	[revs]	Rotor rotation counter reading
N_S	[strokes]	Pump stroke counter reading
P_{an}	[W]	Animal power
$P_{el,T}$	[kW]	Electric power input
$P_{el,sol}$	[W]	Solar array electric power output
$P_{h,T}$	[W] or [kW]	Hydraulic power output
$P_{i,T}$	[W] or [kW]	Power input
$P_{sol,i}$	[W]	Average solar power input
$P_{sol,T}$	[W/m^2]	Average solar irradiance
PC	[l/stroke]	Average effective plunger capacity
q_{PT}	[l/s] or [m^3/s]	Average water flow rate
Q_P	[m^3]	Water meter reading (pumped water)
Q_{PP}	[l]	Water volume pumped per person
Q_{PT}	[m^3]	Water volume pumped
Q_U	[m^3]	Water meter reading (used water)
Q_{UT}	[m^3]	Water volume used
rho_w	[kg/m^3]	Density of water
R_w	[km]	Wind run meter reading
t	[YY/MM/DD; HH:MM:SS]	Date and time

Symbol	**Units**	**Description**
T	[s] or [h]	Length of period, length of the shift
T_P	[s]	Pumping time
V	[V]	Voltage
VC_{fuel}	[l]	Cumulative fuel consumption
V_{fuel}	[l] or [cm^3]	Filled up fuel
V_T	[m/s]	Average windspeed
η_{tot}	[-]	Overall system efficiency

<u>Note:</u>

All symbols indicating instrument readings can have the additional subscripts "$_{,b}$" and "$_{,e}$" meaning "at the beginning" and "at the end of measuring period" respectively.

7.15

Annex 2 ABBREVIATIONS AND DEFINITIONS

A.2.1. ABBREVIATIONS AND ACRONYMS

CIDA	Canadian International Development Agency
CIF	Cost, Insurance and Freight
CWD	Consultancy Services Wind Energy Developing Countries
DGIS	Directorate General for International Cooperation (The Netherlands)
FAO	Food and Agricultural Organization
GTZ	Organization for Technical Cooperation (Federal Republic of Germany)
GWEP	Global Windpump Evaluation Programme
IEA	International Energy Agency
IMF	International Monetary Fund
IT	Intermediate Technology
NGO	Non Governmental Organization
NPV	Net Present Value
MDT	Mean Down Time
MTBF	Mean Time Between Failures
OECD	Organization for Economic Cooperation and Development
PV	Present Value
UNDP	United Nations Development Programme
USAID	United States Agency for International Development

A-2.2. TOTAL EFFECTIVE HEAD

For the Long Term Tests described in this Handbook the total effective head H is an important notion. It stands for the <u>useful</u> head over which the water volume pumped is transferred by the pump. It is used to calculate the useful hydraulic system output $P_{h,T}$. Basically it consists of four components, some of which may be zero under certain conditions:

$$H = H_{in} + H_{dis} + H_{hor} + H_{p} \qquad [m]$$

where: H_{in} = suction head

H_{dis} = discharge head

H_{hor} = equivalent head for horizontal transport

H_{p} = pressure head required at the boundary of the pumping system.

<u>The suction head</u> is the vertical distance that the water must be lifted in travelling from the water level of the water source to the pump.

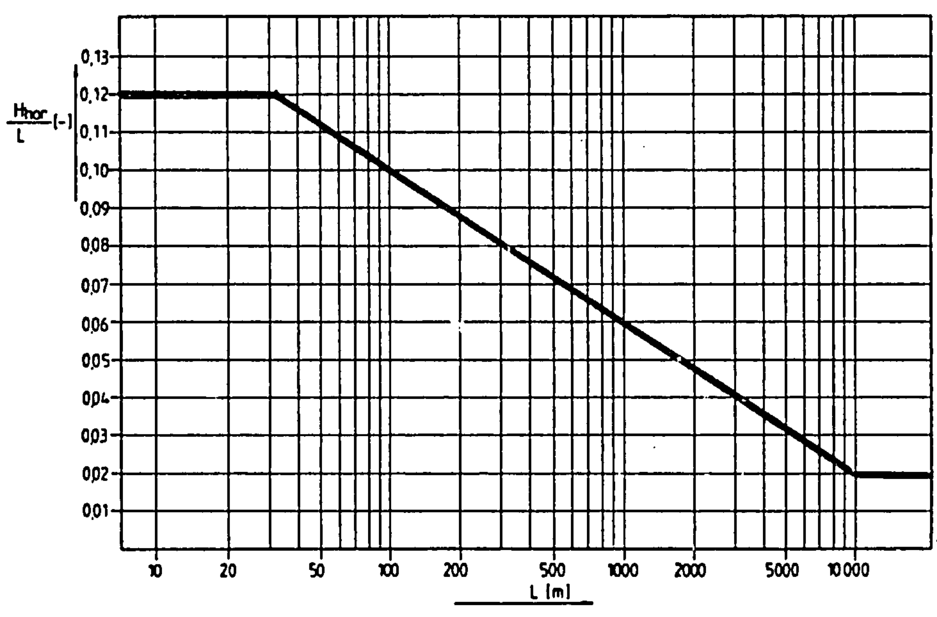

Figure A2.1. Equivalent head for horizontal transport as a function of the distance L.

The discharge head[1] is the vertical distance that the water must be lifted in travelling from the pump to the end of the discharge pipe.

The equivalent head for horizontal transport is a term to reward the function of the system when water is transported over (long) horizontal distances. It is recommended to use Figure A2.1. for determining H_{hor}, starting from L being the distance along which the water is transported horizontally. The curve in Figure A2.1. has been derived as an average of properly designed water pumping systems. It is based on the following assumptions:

- Average flow velocities in pipes between 1 and 2 m/s.
- For long horizontal distances optimal values of the average flow velocity are lower than for short distances.
- The optimal average flow velocity increases with the pipe diameter.

Example: If the horizontal distance L equals 100 m, the factor $H_{hor}/L = 0.1$ (see Figure A2.1.).
As a result, the equivalent head for horizontal transport H_{hor} equals 100 * 0.1 = 10 m.
If the horizontal distance L is longer, e.g. 10,000 m, the factor $H_{hor}/L = 0.02$. Now H_{hor} = 10,000 * 0.02 = 200 meters.

The pressure head required at the boundary of the pumping system is the head required for example to operate a sprinkler installation.

The total effective head H is used to calculate the hydraulic power output of the pumping system $P_{h,T}$:

$$P_{h,T} = Q_{PT} \cdot rho_w \cdot g \cdot H \quad \text{[Wattseconds]}$$

where: Q_{PT} = water volume pumped [m^3]

rho_w = density of water [kg/m^3],

g = acceleration due to gravity [m/s^2].

This hydraulic power output of the system is used to calculate the overall system efficiency η_{tot}:

$$\eta_{tot} = \frac{P_{h,T}}{P_{i,T}} \quad [-]$$

where: P_i = the measured power input to the pumping system.

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1 This definition of discharge head holds for Long Term Testing only. For Short Term Testing, where only the pumping system is considered, the discharge head simply is defined as the head "seen" by the pump.

The function of a pumping system to be rewarded is transport of water to a higher head, to a higher pressure and/or over a certain horizontal distance. This function is quantified by the total effective head as defined above. It rewards a vertical lift (H_{in} and H_{dis}), a horizontal transport in terms of a reasonable friction head (H_{hor}) and a pressure at the pumping system boundary (H_p). If a system is badly designed, e.g. by having high internal friction losses, the measured power input to the system $P_{i,T}$ will be high. As a result the overall system efficiency η_{tot} will be low for such a system.

If a storage tank functions as a water tower to generate the discharge pressure required by the end-use system, this pressure is included in the discharge head from pump level to storage tank water level and must not be measured separately. If alternatively for example a diesel engine pump directly feeds a sprinkler system, the discharge pressure should be measured at the sprinkler system intake by means of a simple manometer.

ANNEX 3. ADJUSTMENTS TO CREATE THE ECONOMIC DATA SET

A3.1 FOREIGN EXCHANGE ADJUSTMENTS

For imported items, the major issue in economic analysis is whether the official foreign exchange rate reflects the relative value of the local and foreign currencies. Often the official exchange rate undervalues the foreign exchange. That is, it sets the value of a U.S. dollar (or other currency) at less than what many people are willing to pay. Such undervaluing is often evidenced by "black markets" where higher exchange rates exist. Black market exchange rates cannot be said to reflect the "correct" exchange rate either, since such usually illegal activity carries with it a variety of risk premia which are impossible to evaluate. The result of over-valued local currency is market prices of imports which are lower than their real or opportunity cost. Where there is a reason to believe that the official exchange rates may not be realistic, shadow foreign exchange adjustments should be made.

It is customary to express these shadow prices in terms of their ratio to the financial price. Where there are exchange rate problems it will usually be that the ratio of the economic or shadow exchange rate of local currency to dollars (or other currency) should be higher. Thus the ratio of the shadow rate to the official rate will be greater than one. It would not be unusual to find a ratio of 1.20 which is interpreted to mean that the official rate underestimates the shadow rate by 20 percent. This is referred to as the shadow premium of foreign exchange. Estimates of this premium should be available from senior government planners or local offices of agencies such as the World Bank.

A3.2 TAXES AND DUTIES

The economic price for a given item may require adjustments for taxes and/or duties in addition to exchange rates. Import duties or other taxes must be netted out from the financial cost to estimate the economic cost. Information about the levels of taxes and duties is usually available from agencies responsible for collecting such revenues. At the same time, firms which actually import the products in question can be a useful source of information about how the taxes and duties are actually applied. If for some reason detailed information is not readily available, an approximation can be made using general information about average duty and tax rates.

A3.3 UNSKILLED LABOR

Economic analysis may also require adjustments to market prices of local inputs when their financial prices do not truly reflect their economic opportunity cost to society. Perhaps the assumption that economists most often leave unstated is that of full employment. That is, that all resources --land, labor, and capital-- are fully employed. As a result, a frequent correction to market prices is for the all too prevalent unemployment of certain categories of labor, in particular unskilled labor. For this input, the economic price of labor is often lower than the financial because the cost to the nation of employing surplus unskilled labor is less than the financial wage rate. Most simply, the economic cost is less because the employment of labor on a water project does not result in reducing any other economic activity. From the societal perspective, using an economic cost which is below the prevailing wage rate accounts for the societal benefits which are derived from the employment of currently unemployed labor.

More formally, the market price for unskilled labor (the pump operator not the pump mechanic) is often higher than the estimated economic price. If such labor is an important part of the pumping costs, some adjustment should be made. As in the case of imported items, what is needed is an estimate of the ratio of the economic (or shadow) price to the market price. In this case the ratio will generally be less than one, figures of 0.5 to 0.8 are common. If shadow prices for such inputs are available from government planners, they should be used.

A3.4 OTHER ADJUSTMENTS

Adjustments to prices are also often needed because of government regulations which either fix prices or constrain price changes. Examples of such regulations are utility rates (tariffs) and some other energy prices which may be set at levels which do not reflect full costs. Differences between the economic cost and the financial cost of petroleum are likely to be greater if the country is an oil producer. There are two approaches which can be used for fuels depending on how the prices are actually set. The first is to determine the economic price by netting out taxes and duties from the financial price and adding in any subsidies. The second is to use a border or C.I.F. price and add in-country costs (depots, transport, and marketing margins). In practice one method will usually be easier than the other, depending on how the price is regulated. Needed information is usually available from private sector fuel distributors, government planning or regulatory officials, or motor pool operators.

Electric power should most often be treated as an imported item, because its cost is frequently based on largely imported components --especially if imported fuels are used for its generation. The financial price can usually be obtained from published tariffs, many of which feature different prices for electricity for different classes of customers. That is, there are frequently subsidized prices for water pumping --especially irrigation. In some few cases, it may be that there are time-of-day tariffs. That is, there may be tariffs which set one price for daytime use and another for night use. Where such tariffs exist, the analysis should be done using each price separately to show the benefits that can be derived from the tariff. It is very important that the economic price used for the analysis be based on the long-run cost of new supplies. What is needed here is what energy economists call the long run marginal cost of electricity. Estimates of this price may be available from the power supply authorities or recent studies sponsored by the World Bank or other lending agency. Where such analysis is not available, an effort should be made to adjust the financial price (or prices) for whatever mixture of duties and subsidies exists.

ANNEX 4. FORECASTING

The first component of the forecasting problem is the factoring out of inflation. Both the relative and absolute costs of inputs change over time due to differing rates of inflation. General price inflation is actually composed of a range of product specific inflation rates for all goods and services. Rather than using each of these rates, it is useful to begin from a simplifying assumption that all costs will change at the same rate over the planning period. While this is a useful and almost necessary initial assumption, it is unlikely to be accurate. Nonetheless, the assumption is useful because it shifts the focus to identifying those components of cost which may rise or fall at rates which are substantially different from the general trend. Whereas the majority of an economy's prices are increasing at roughly similar rates, some prices may have a history of changing at significantly different rates.

For this analysis a common level of inflation is assumed and, therefore, is not explicitly accounted for. Adjustments for inflation are made only for those inputs which are expected to differ from the general trend. This style of analysis is, therefore, said to be in terms of "real" price increases --i. e., net of inflation.

It may also be important to identify and make adjustments to those inputs which are experiencing only slightly higher (or lower) rates of inflation if they are major components of total cost. The prices for which real inflation rates are most often needed are energy commodities (petroleum products, electricity) and other imported goods. The following discussion deals with forecasting energy (petroleum) prices but the suggested approach is generally applicable to estimating the real price increases of other inputs as well.

Since the mid-1970's, it has been extremely hazardous to forecast world energy prices. At present two things are true about forecasting energy prices: (a) anyone can do it and (b) no one has a good record of doing it. In spite of the apparent importance of the issue, there is actually very little good data on how financial (retail) prices have changed in various countries since the run-up in prices began in the 1970's. Forecasts of world prices are plentiful but, based on past performance, are generally unreliable. Forecasts of retail prices are generally done on a country-by-country basis due to the differences in taxes and subsidies and other factors affecting retail prices. Retrospective evaluations of these forecasts are generally unavailable.

For purposes of carrying out an analysis of waterpumping costs, however, there are two general approaches that can be used. First, review existing official or published forecasts to determine their basis and --unless hindsight has proven them quite wrong, use them as one estimate. In many cases, available forecasts will show expected ranges rather than unique numbers. Where a range is available, it is more informative to use the separate values rather than an average. Second, where no credible price forecasts exist, it is best to make simple assumptions about the future. For instance, one simple assumption could be that the real price of energy will double in twenty years. There are two reasons for using such a simple assumption. First, it is just as likely to be as accurate as a more complex assumption or a more complex analysis. Second, the users of the analysis will be much less likely confused and/or distracted since the forecast can be explained without equivocation.

With respect to forecasting the costs of other inputs, the short and long-term testing will provide only very limited information for making these projections. Long-term, as used in this handbook, may mean a period of as little as one year. Information about the life of engines, electric motors, windmills, photovoltaic arrays, among other items will be very limited. Where information is limited and the life of the item can make a significant difference in the present value per unit of water delivered, it is important to use sensitivity analysis to explore the situation. One useful technique is to explore the cost reductions which can be realized from improved maintenance. That is, to estimate the cost reduction that could arise if engine life were extended from (e. g.) three years to seven years.

The World Bank does publish price indices (historical data as well as forecasts) for various commodities, including petroleum. In addition, they produce an index of manufactured items which are imported by developing countries --known as the Manufacturing Unit Value Index. These data can be helpful guides in developing informal forecasts needed for the analysis.

ANNEX 5. OTHER ANALYTIC ISSUES

A5.1 SENSITIVITY ANALYSIS

Once the spreadsheet is set up, it becomes quite easy to run sensitivity analyses. Since it is easy, there is sometimes an unfortunate tendency to give insufficient forethought to the meaning or interpretation of the results. The main reason for performing the analysis is to cope with the uncertainty which surrounds the estimates of future costs. For example, it may be of interest to know what would happen to overall costs if the cost of fuel increases at a rate which is twice as fast as is now projected. Fuel costs are likely to become significant and their rise may look different from the economic perspective than it does from the financial. On the other hand, increases in the costs of unskilled installation labor are not likely to alter the outcome of the analysis by very much if they double or even triple. That is, they are a very small component of total costs and even very large changes will not cause much of a change in the unit costs of water pumped. For these reasons, it is much better to confine sensitivity analyses to those variables which could significantly affect the unit costs --either economic or financial.

A5.2 SPECIFYING WATER REQUIREMENTS

If the larger task is one of estimating the costs of different pumpsets so that they can eventually be compared with each other, then it is important to estimate the water requirements in advance. That is, it is important to estimate the quantity of water that is going to be required (on a daily basis) and to determine whether there are major seasonal patterns in demand which have to be met. Failure to take this step first can bring about two problems (a) it can result in needless work --the development of cost estimates for a pumpset which is incapable of providing the needed water and/or (b) comparisons become meaningless if one pumpset can meet the demand while another cannot. Where pumps are to be used for village water supplies, the question of population growth and its effects on demand must be considered as well. For example, if the equipment sizing procedure is based on a pumpset supplying the needed water in one shift of 8 hours in year-one, then an adjustment should be made for increased running time (fuel consumption, maintenance, etc.) in later years when the engine is running 12 hours per day. There are limits to how many hours an engine can run. While there are 8760 hours in a normal year, there are practical limits. It is possible, but unlikely, that more than 7000 operating hours per year can routinely be obtained.

A5.3 TREATMENT OF RENEWABLES

A related problem arises most often when analyzing renewable-powered pumps. It is the question of "excess water." Especially in analyses involving photovoltaic or wind powered pumps, the unit may for short periods of time actually produce water beyond that demanded. Where wind speed or insolation peaks are not coincident with peaks in demand, then excess water may be pumped. (See the discussion of effective water output in Chapter Five.) There is no justification for crediting this excess volume to the total quantity pumped and, thereby, reducing the unit cost of water. If the pump were diesel or grid electric powered, it would simply be shut off. As a practical matter, there may arise cases where excess water is put to use. In effect, this is simply an example of the demand not being completely evaluated prior to the analysis.

A5.4 DISCOUNTING PHYSICAL QUANTITIES

When using the method described in Chapter 6 for calculating present values, the results are expressed per unit of output. That is, unit costs are the total installed costs plus the out-year recurrent costs discounted back to year-one and expressed per cubic meter of water pumped during the twenty-year span. Note that a portion of the numerator (future recurrent costs) is discounted, the denominator (the quantity of water) is not. Although some of the literature in this field does not adhere to this standard practice, in this handbook the quantity of water is not discounted because of the following reasons:

1. The focus of the analysis is on comparing costs of different systems. By discounting the water output it is suggested that also benefits are considered. However, as put forward in section 6.1.1, the analysis addresses only the <u>relative</u> feasibility or attractiveness of a variety of technologies. To really include the issue of benefits into the analysis would require quite a lot more trouble.
2. It is assumed that the alternative systems produce the same level of direct benefits, i.e. the same pattern of water deliveries during a fixed project period of 20 years length. Discounting the quantity of water would cause an increase of the "cost" of water by the same factor for all systems (at a given discount rate); it would not influence the relative attractiveness of the various technologies.

A5.5 STORAGE

Water storage is one of the more vexing analytic problems to be encountered. In many cases involving village water supplies, storage will be an integral part of the system regardless of the pumpset selected_--wind, diesel, photovoltaic, etc. Moreover, as a practical matter one frequently finds that there are only a few different sizes of storage tanks and as a result storage costs do not vary much. Where storage is clearly a part of all systems to be considered, then it can be safely ignored as a common cost. That is, like other common costs it does no harm to any comparison to ignore the cost of storage. As with other ignored common costs (e. g., the costs of selecting a site, of drilling and casing the well) it does lead to an understatement of the unit cost of pumping water. But the goal of the Handbook is not cost-benefit analysis. Where storage is not a common cost --that is, where it is required for some but not all the technologies being evaluated --then its costs should be included. If it is a distinguishing characteristic (i. e., if in a certain application a given technology requires storage and others do not) then it is appropriate to include the cost.

A5.6 MAINTENANCE AND REPAIR COSTS

For purposes of this analysis it is important to distinguish between maintenance and repairs. Maintenance refers to those expenditures which are intended to prevent breakdowns--e. g., lubricants, engine tuning, etc. Repairs, on the other hand, are expenditures made to correct a problem or to fix broken equipment, engine parts, pump rotors, as well as labor charges needed to install them.

A5.7 RELIABILITY

Reliability is an important characteristic on which to compare pumping systems. Ideally what is needed is the ability to estimate the costs associated with achieving different levels of reliability (however measured). In practice, such data do not exist nor is there any near-term prospect for the development of such information. The practical problem is in recognizing and accounting for the existing costs which are being borne to achieve whatever level of reliability exists. Where back-up systems are present, it is appropriate to perform the same tests and apply the same analysis as for the primary system.

A simple example can make this point. A government water department which has been using diesel-powered pumpsets, may have trained maintenance personnel, repair facilities, and fuel delivery trucks all of which is dedicated to keeping the pumping equipment running. These costs must be accounted for. A common analytic failure is to omit these costs for the existing systems and include such costs for new equipment being considered. For example, if photovoltaic powered equipment is being introduced there is a tendency to include the training and support facility costs but to ignore similar costs for conventional equipment. This would be an error.

There are a variety of costs associated with failure of pumping systems, with preventing their failure, or with minimizing the damage from failure, for example:

(a) the spare parts inventory and support infrastructure costs including skilled repair technicians, etc.

(b) the inventory costs of storing fuel, where fuel availability is an important source of system failure.

(c) the value of lost inputs and other costs if crop yields are routinely diminished due to failure of the pumping system.

(d) the costs of stand-by capacity where users invest in backup equipment in a effort to reduce their costs associated with unreliability.

(e) the costs of any service contract that provides prepaid maintenance, repair, or replacement of pumping equipment. (Note: such contracts are evolving in parts of South Asia where there are areas of intensive pumping, but are not widely available in the developing world.)