SMALL SCALE DRINKING WATER SUPPLY SYSTEMS FOR DEEP WELLS

Two desk studies of aspects of deepwell handpumps and alternative small scale mechanical drinking water supply systems

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1 INTRODUCTION

1.1 AIM OF THE STUDY

The aim of this study is to provide an inventory of the problems concerning pump systems for drinking water supply for rural communities in developing countries. The study concentrates on villages with 300 to 2,000 inhabitants where water has to be pumped from deeper water levels (20 to 100 meters in depth).

The following systems will be compared: hand or foot operated pumps and pump systems with a 'prime mover', based on a diesel engine, solar-energy, windmills or animal traction. For details, see the project proposal in appendix I.

The Netherlands Ministry for Development Cooperation, section DST/SO (late DPO/OT), sponsored this study. It consists of a desk study with data compiled from a mission to Burkina Faso and Niger. InterAction Design (IAD) and the Netherlands Economic Institute (NEI) carried out this study.

Both groups report in separate documents:
* Part I : the technical and the management aspects (by IAD) and
* Part II: the financial and socio-economic aspects (by NEI).

This is Part I.

Alas, the study yielded scarcely any new (field) data; the time invested was too short. Furthermore:
* Most projects and services working on such systems hardly have any analysis ready to hand. Very little has been published on this matter.
* Most of the mentioned systems are in an experimental phase and disappointing results are not shown. Many problems and costs are not mentioned. Not being viewed as structural, they are judged to be the consequence of 'growing pains' such as the costs of renovations, supporting missions, et cetera.
* Projects, closed some years ago, are hardly ever studied. Therefore long-term results are scarcely known (they often appear to be disappointing).

For these reasons the results of this study are mainly of qualitative value.

N.B.: From now on hand and foot operated pumps will be called 'handpumps' in this report, unless a foot operated pump is specifically meant.

1.2 RELEVANCE OF THIS STUDY

Numbers of people with access to safe water in developing countries[1] (in millions):

	1980		1985		1990	
	served	unserved	served	unserved	served	unserved
urban	614	376	800	400	983	463
rural	735	1645	1000	1500	1100	1514
Total	1349	2021	1800	1900	2083	1977

1 The table is taken from the WASH Progress Report No. 13, which used material from Carlo Rietveld, "Water Supply and Sanitation in Fast-Growing Cities", paper presented in the inaugural session of the Collaborative Council, The Hague, Netherlands, November 1988.

The number of people with access to safe drinking water has increased in the past 'United Nations International Drinking Water Supply and Sanitation Decade' from 1.349 to 2.083 million, thus by three-quarters of a billion people. However, the number of people without access remained practically the same: almost 2 billion! The main cause is the enormous growth of the population. This situation will not change in the near future.

Most of these people obtain their water from open wells and surface water, which is biologically and very often chemically polluted. This water supply requires hardly any tools or organization and most often management is non-existent.

In recent years particularly these pump systems that could be realized relatively simply were constructed. The remaining supplies are located in more distant and more difficult to access areas, with scattered population, lower ground water tables and tables with limited output. In the years to come we will be confronted with the problems concerning the replacement of the systems installed in the past decennium, which have become too small, obsolete or worn-out.

Purchasing-power in the poor countries in Africa has decreased with an average of 30% over the past decennium. This limits the prospect for an autonomous dissemination of these systems, of village-level management and replacement at the expense of the consumer(-groups) themselves.

The technology of water supply systems has advanced considerably over the past decennium. Yet even the costs of maintenance often turn out to be too high for the users. Local authorities as well as the users still underestimate the importance of maintenance. It is questionable whether more complex water supply systems will ever be affordable for the users, especially once they must pay the costs themselves, which is the trend. Even with the costs of the installation of the well or the borehole excluded. This is reason enough to keep the costs (initial, recurrent and running costs) as low as possible and to realize real sustainable systems for this price.

Together with the (prospective) users a choice must be made either to purchase a new system, resp. how to enlarge or reconstruct the existing one. The (future) consequences must be estimated correctly. This report gives a summary of the present pump systems, offering a better choice. The technical bottle necks, on which further research is desirable, are also described.

2 DEEPWELL HANDPUMPS: STATE OF THE ART

2.1 INTRODUCTION

2.1.1 NEED OF WATER

Most modern drinking water supplies for rural communities in developing countries are calculated on the basis of 15 to 25 liters/person/day. This is considerably less than for urban communities, where average consumptions of up to 50 liters/person/day are reached.
Occasionally the water consumption of the system is even lower, with high-flyers down to 5 liters/person/day. This is caused by:
- cultural habits (accustomed to survival in dry surroundings),
- availability of traditional water sources (depth of water table and walking distance) and
- seasonal influences (especially when during the rainy season surface water becomes available in/near the village).

Many villages can hardly handle larger quantities of water than they are accustomed to. Using water for instance in horticulture demands a great cultural adjustment and often a sensitization[2] support.

When planning a system an increase of consumption must be taken into account, caused by population growth (often >3% a year, i.e. >34% in 10 years) and by an increasing livestock (in rural communities one of the few ways to invest and to save). Assuming the well or borehole has sufficient capacity to meet the increasing needs, the pump will remain the crucial factor.

2.1.2 DISCHARGE RATE AND NECESSARY POWER

The discharge rate of the pump largely depends on the type of pump, its suitability for the present head, the head itself and the input by the 'prime mover' (hand or mechanical). Apart from the constructive properties of the pump, its suitability for a specified head is especially shown by its user friendliness and the mechanical efficiency at that depth. Diagram 2.1 shows a summary of the different relations.

The input by the prime mover (wo)man, the gross power produced by one or more persons, is influenced by the user friendliness of the pump. That is defined by the driving system, the handle stroke and the forces applied on to the handle. For instance: A stroke length too short or too large, or a handle position too low or too high, has a negative effect on the bio-mechanical efficiency of the person while pumping. On the other hand, a pump easily handled cannot absorb much power, so its maximum discharge rate will be limited. Larger strokes and/or faster pumping increases the discharge rate. But a pumping frequency of (much) more than 1 stroke/sec. combined with a large pump stroke is almost physically impossible, even when the pump is easily handled. Because the bio-mechanical efficiency of (wo)men decreases considerably and so limits the maximum power.

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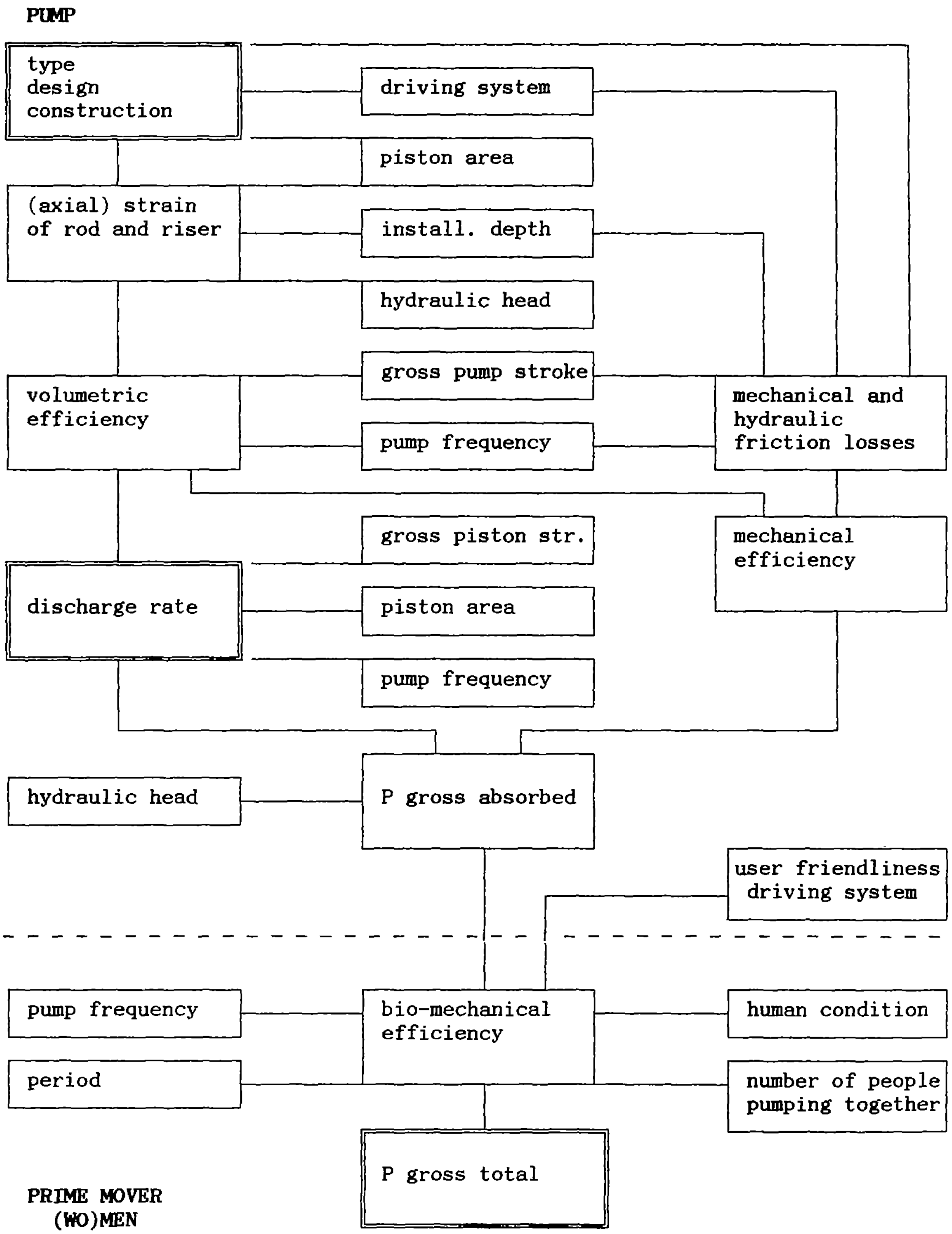
[2] Problems concern a.o. proprietary rights with relation to the ground in the direct neighbourhood of the water source as well as to the water (appropriation of common property), but also the unfamiliarity with the cultivation, its consumption and commercialization.

Diagram 2.1 MAIN RELATIONS BETWEEN Pgross-total, THE DISCHARGE RATE AND THE TYPE OF PISTON PUMP.



The mechanical efficiency of the pump depends on the type of pump, the total pressure head, the volumetric efficiency (especially for pumps with elastic rising mains) and mechanical and hydraulic (friction) losses. The mechanical efficiency of the different handpump diverges from less than 15% up to more than 70%. In short, the power necessary for a certain discharge rate (at identical heads) can differ more than a factor 4, depending on the type of (piston) pump' Especially at large heads, asking for much power, it is important to select a suitable pump because the discharge rate is already limited. This interrelation can diverge strongly for various pump systems. For details see Section 2.2.

The friction losses are defined by the construction of the pump, type of piston seal, etc. They increase more or less proportionately with head. They increase as well with power but less than proportional. Therefore the mechanical efficiency of piston pumps (with stiff rising mains) increases with power [1].

The axial deformation of the piston rod and the rising main influences directly the effective piston stroke and so the volumetric efficiency. The effective piston stroke is equal to the gross piston stroke minus these axial deformations. Particularly the piston pump with a plastic rising main (PVC or especially PE) has to do with this phenomenon. At larger depths the deformation can become equal to the gross piston stroke and so the pump will give no water (volumetric efficiency = 0) [2].

The overall efficiency of the combination (wo)man - pump is: bio-mechanical times mechanical efficiency.

The gross power (effectively put into the pump) is calculated as follows:

$$P_{gross} = P_{net}/\eta_{mech} = q.\rho.g.H/\eta_{mech} \text{ [Watt]}$$

in which:

P_{net}	= net power	[W]
η_{mech}	= mechanical efficiency	[-]
q	= discharge rate	[m3/s]
ρ	= specific mass of water = 1000	[kg/m3]
g	= gravitational acceleration = 9,81	[m/s2]
H	= total head (including hydraulic friction)	[m]

N.B. 1. Power = discharge rate * head * efficiency (* constant), so at a given power the discharge rate will decrease when the head increases.
2. The energy supplied to a pump during a day is expressed in kWh or MJ. The comparison with daily volume [m3] times head [m] (= [m4]), gives an indication of the efficiency of the pump system.

For non-piston pumps similar interrelations exist between gross power, mechanical efficiency and head. In diaphragm pumps and water oscillation pumps the deformation of the rising main appears to have a similar influence as in piston pumps.

When pumping strongly, an adult can produce about 75 Watt (=Pgross) for 10 to 20 minutes. If practical, two persons together can produce about 150 Watt during a similar interval. Figure 2.1 shows what might be the output of a pump per hour, when pumping continuously with a gross power of respectively 75 and 150 W.

In practice it appears that a pump is used effectively for only about half of the time. Much pumping time is lost in changing of persons, to lift the filled bucket, cleansing and placement of the empty bucket, to start pumping, etc. (N.B. Repeatedly starting the pump from standstill asks for extra energy.) In other words: the discharge is not reached in practice; half of this is more realistic.

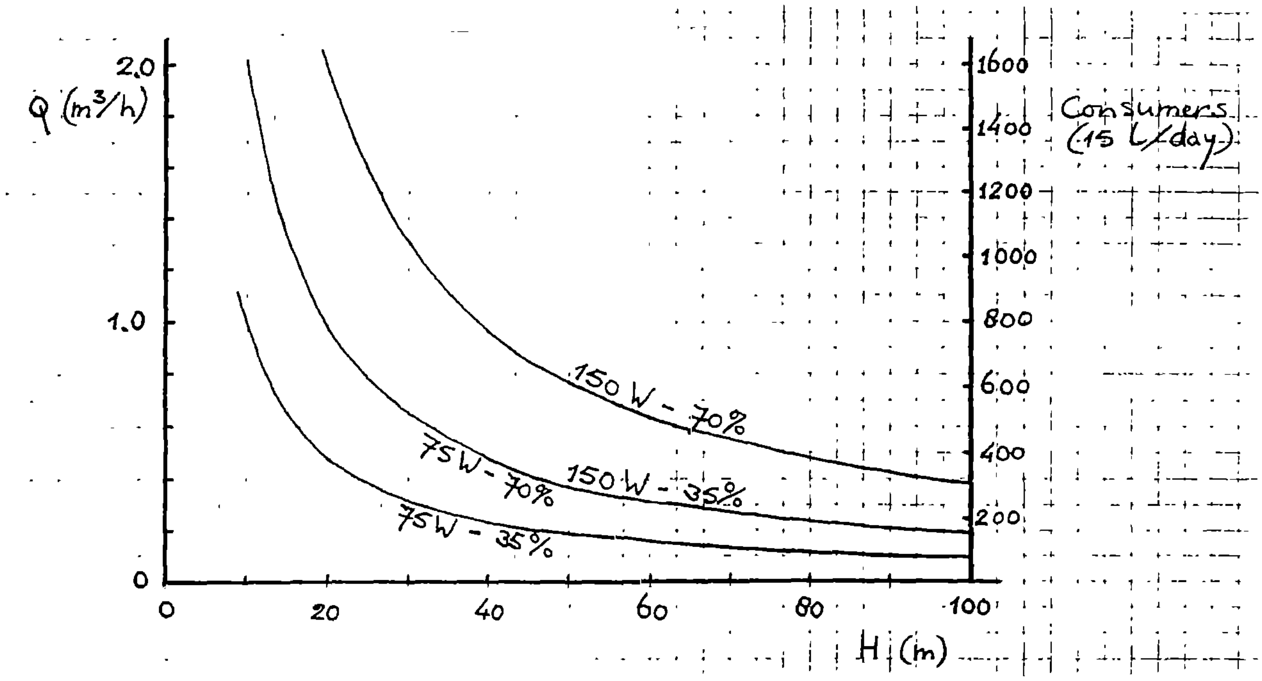


Figure 2.1 The discharge as a function of head, gross power and mechanical efficiency.
Pgross1 = 75 W Pgross2 = 150 W ηmech1 = 70% ηmech2 = 35%
Along the second y-axis the number of consumers, that can be supplied with 15 liters/day, assuming 12 hours/day with an effective pump time of 100 %.

What can be done if one pump cannot meet the needs? How can discharge be increased? More pumps (and more boreholes)? 'Supercharged' pumps? Or a mechanized system? For further details see Section 4.6.

2.2 MAIN PUMP CONFIGURATIONS

2.2.1 DESCRIPTION OF COMMON HAND AND FOOT OPERATED PUMPS

In the past decennium many different pump systems have been (further) developed, but only a few models 'really made it'. The most important pumps, related to numbers sold, are (dated 1990):
- India MkII, more than one million, particularly in India;
- Vergnet, roughly 30,000(?);
- ABI ASM en MN, together roughly 15,000;
- Kardia, roughly 6,000;
- Inkar, roughly 6,000; an improved copy of the India MkII with pvc rising main instead of galvanized steel, just like
- Pumpenboese, roughly 3,500; an improved copy of the India MkII with stainless steel rising main.

Of the other 'generally known' pumps a few thousands are installed: Volanta, SWN, Mono, Pulsa (1,500) and Afridev.

Direct action pumps don't enter into this list; the present models are only suitable for depths up to 20 meters.

The selection of the pumps was based on a combination of reliability and multilateral and bilateral political/financial concerns. In India the India MkII surpassed all its competitors, because this pump was one of the first modern designs and was inexpensive, especially in consequence of local manufacture and

a decent quality control. Meanwhile the India MkII has become slightly outdated. The great number of installed pumps interferes with further development: the dialectics of progress.
In Africa the standard India MkII gives no real satisfaction, a.o. by the intensive use, the large heads and the often corrosive water.

New models hardly have a chance to penetrate the market, because the present pump models have a reasonably to very good record (most of the growing pains are solved). Meanwhile the main point of research is focused on implementation. Furthermore, many developing countries standardized on a few models (per country or per region).
Only reliable, cheaper (in purchase and maintenance) and new pumps entirely manufactured in developing countries for medium or large depths can stand a chance. Motive: mainly to support real sustainability, including the purchase and replacement of pumps at the expense of and by its users.

Principles of operation[3]:

India MkII:	deepwell reciprocating piston pump, lever operated, galvanized riser and rod;
Vergnet:	diaphragm pump, foot operated, two flexible PE hoses between the stand and the cylinder;
ABI MN:	deepwell reciprocating piston pump, lever operated, galvanized riser and rod;
ABI ASM:	ABI ASM superstructure with Vergnet below-ground components;
Kardia:	deepwell reciprocating piston pump, lever operated, threaded PVC riser;
Pulsa:	water oscillation or spring rebound inertia pumping system;
SWN:	deepwell reciprocating piston pump, lever operated, threaded PVC riser;
Volanta:	deepwell reciprocating piston pump, flywheel operated, cemented PVC riser, cylinder extractable through the riser;
Mono:	progressing cavity pump (helical steel rotor in an elastomeric stator), two rotary crank handles, threaded steel riser.

The Vergnet and the Pulsa can be installed in bent boreholes. Because of their flexible risers with small diameter these models lend themselves to plural installation per borehole. Piston pumps can wear excessively in bent boreholes: riser against the borehole casing and piston rod against the riser. Installing more than one (piston) pump in a borehole increases the risk of damage (to each other). More piston pumps per borehole asks for a larger diameter borehole.

2.2.2 DISCHARGE RATE AND LIMITS; Q-H CURVES, MECHANICAL EFFICIENCY

Figure 2.2 indicates the discharge rates of some important pump systems at a gross power of 100 Watt. This figure is not very reliable, because the data is gathered from manufacturer's data at sometimes up to 250 W gross power[4] and data from CRL-tests. Those tests were restricted to a simulated depth of 45 meters (the riser was only 8 meters), in which the important dynamical effects did not occur as in practice. The values in the figure are adjusted for these elastic deformations of PVC risers.

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3 For a more detailed description, see [1].

4 The values given by the manufacturer are sometimes much higher and concern the maximum feasible (calculated and never measured!) discharges, sometimes at a gross power of 250 W (calculations sometimes based on a mechanical efficiency of 100 %!), so discharges for very short intervals.

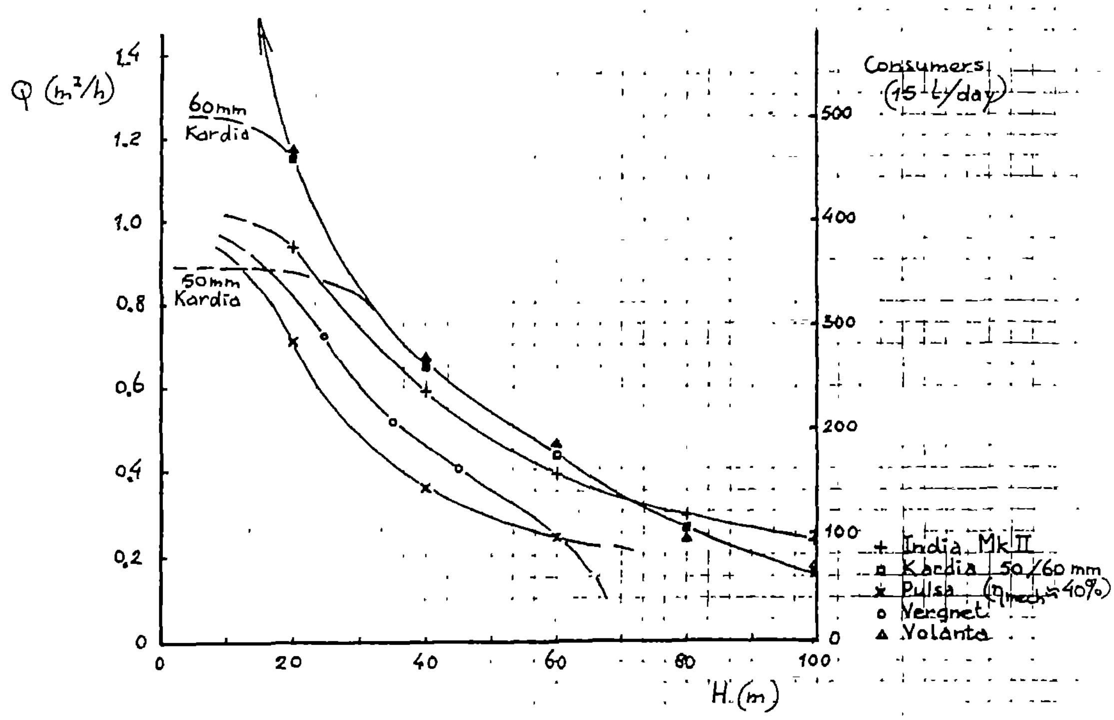

Figure 2.2 Estimated discharge rates of several hand/foot operated pumps at a gross power of 100 Watt (pumping continuously), as a function of the pressure head. (This implies the elastic deformations of the PVC risers.)
Along the second y-axis the number of consumers, that can be supplied with 15 liters/day, assuming 12 hours/day with an effective pump time of 50 %.

Figure 2.2 shows a decreasing discharge rate at increasing pressure heads. This decrease of discharge can be caused by (and/or):

* The forces on the handle/lever/pedal increase at larger heads. That is why (wo)men pump at a lower frequency and/or use a shorter pump stroke;
* A mechanical adaptation of the pump stroke and crank length, like Volanta employs;
* Adaptation of the piston diameter to the pressure head: from 100 mm at small heads up to 40 mm at heads of 50 m and more;
* Increased elastic deformations of the plastic risers, hysteresis, more friction losses and thus lower mechanical efficiencies.

N.B. Adaptation of the (counter-)weight of the lever mainly compensates for the increased weight of the rod at larger depths.

In consequence of the elastic deformations of the PVC risers the discharge rate of e.g. a SWN with a piston of 50 mm at depths of 80 m and more is about nil. A piston of 40 mm would still give an acceptable output.
Besides deformations of the riser of the Pulsa and the Vergnet hysteresis of the riser material and hydraulic absorbing is also important. This causes a more than proportional reduction of discharge rate. For this reason the number of elastic elements in the cylinder of the Pulsa is reduced at large heads. The Vergnet is not adapted 'mechanically' to larger depths. For both types of pumps the users themselves adapt the pump movement (stroke and frequency) to the power and frequency (a function of the head), 'asked' for by the pump, and the available power (by one or more persons, child or adult).

Within its entire range the Pulsa has a lower discharge rate than the other pumps mentioned. Generally, users put more power in the Pulsa and the Vergnet for a short time, because of the disappointing discharge. It is easy for two persons to pump with the Pulsa, in contrast with the Vergnet, which is not equipped for this. Occasionally, the driving systems of both pumps evoke cultural and practical objections. Especially pregnant women don't appreciate the exertion required.

The physical maximum feasible pump frequency with piston pumps limits the discharge of the pump. This is of special consequence for small depths and easy pumping pumps, when the pump stroke and/or the piston diameter is/cannot be increased (or not enough); see the horizontal part of the lines in figure 2.2.

Although the Kardıa has not yet proved itself at larger depths, it could be an excellent competitor of the Volanta as far as the mechanical efficiency is concerned. Both pumps are practically the only suitable pumps in situations of large heads and aggressive water (pH<6), whereby galvanized risers are not expected to live long. (Stainless steel has not yet proven itself under these circumstances.)

Progressing cavity pumps are applied only on a limited scale by a.o. their low mechanical efficiency. Moreover, simple plastic risers are no solution for this type of pump (in corrosive circumstances) on account of their elasticity.

2.2.3 LOCAL MANUFACTURE

A clear distinction between local manufacture and assembly of handpumps is hard to make. Even by local manufacture there usually exists a direct relation between the 'parent factory' and the local manufacturer. The parent factory supplies the materials, parts, the specific production knowledge and -materials (moulds for welding, etc.). Dependent on the situation and the license rights the local manufacturer makes a limited or larger portion of the parts; mostly those parts, which are work intensive or give high transport costs because of their dimensions. The parent factory usually continues to supply the expensive parts, specific to her pump and carrying design rights. Examples are: the elastic balls of the Pulsa and the diaphragm of the Vergnet.

Rights and duties with regard to the pump design and responsibilities (e.g. guarantee) are not always clearly defined for both parties.

The India MkII is produced in several places around the world. A detailed document specifies the materials, the parts and the manufacturing of the pump. For the Afridev such a document exists as well [12]. A parent factory does not exist for these pumps, because they have been developed by the UNICEF-India and the WB-Kenya successively.

2.2.4 COSTS OF PURCHASE AND INSTALLATION

The costs of constructing a pump site can be divided into:

* costs of preparation and management;
* costs of drilling the borehole;
* manufacture and installation of the surface infrastructure: the pump basement, the pavement, the spillway and spillwater settling hole, fence;
* purchase, transport and installation of the pump;
* supervision and inspection;
* import duties, assurances, delivery costs;
* costs for guarantee and loss of interest on postponed payments;
* costs for the training and equipment of local mechanics;

* costs for installing the spare part distribution network;
* costs for sensitization and support of the users.

Table 2.1 EX FACTORY PRICES OF SEVERAL PUMP MAKES WITH STAINLESS STEEL RODS, AT DIFFERENT INSTALLATION DEPTHS (in american dollars):

Mark	Source/year Depth:	20m	30m	40m	60m	80m	100m
ABI/ASM	[5] '87		1260			---	---
ABI/MN	[5] '87		924				
Bourga	[5] '87		1470				
India MkII	[5] '87		750				
Kardia	Preussag '90 pvc	1498		1907		---	---
Mono	[5] '87		1225				
Moyno	[5] '87		1575				
PB	PB '90 ssr	1027		1600	1996	---	---
Pulsa	Fluxinos '89 pe	1297		1374	1451	1528	
SWN	DHV '90 ***,pvc	803		1066	1329	1592	---
Vergnet	[5] '87 pe		945			---	---
Volanta	[5] '87 pvc		1605				

*	without taxes	ssr	stainless steel riser
**	reduction for large quantities	pvc	pvc riser
***	per hundred	pe	pe riser, no rod
---	not applied, c.q. not reasonably applicable without extra provisions.		

Donors and local authorities bear the main part of the costs. The costs for the users are mostly limited to:
* a contribution in the purchase and the realization of the infrastructure (in cash and in kind, such as meals and accommodation for the teams and practical help);
* time to deliberate about the system and its management.

Frequently local mechanics install the pumps; since it is they who will maintain the pumps in the future.

2.2.5 MAINTENANCE AND COSTS

Over the past decennium the reliability of the pumps has grown considerably. On the one side this is due to improvements of details of the pumps, on the other by selection: pumps of lesser quality are no longer installed nor repaired. This sometimes reduced the costs of maintenance dramatically. Unfortunately the reliability of most pumps still decreases strongly at larger depths.

The percentage of broken down pumps and the duration of the breakdown mainly depend on:
* the quality of the pump, its age, the head and the intensity of use;
* the provision of spare parts and the maintenance structure;
* the management structure for the pump; village level if any?
* the involvement, degree of organization and motivation of the users;
* the existence and qualities of alternative water sources;
* the support of development projects (repairs, renovation, sensitization, training, reinforcing the sense of responsibility of the users).

N.B. 1. The financial situation of the village has no clear influence.
2. The percentage of pumps broken down at a given moment and the costs of repairs largely depend on recent interventions of project repair-teams. A.o. therefore it is difficult to recover the real costs of maintenance of a handpump.

Costs given by manufacturers and those produced by field studies, mostly distort the picture:

* In some regions a large number of the pumps is broken down since; it is self-evident that when not in use nor repaired the costs will be low!
* When the users themselves must bear the costs, particularly the expensive repairs are postponed; for example when it concerns the diaphragm of the Vergnet.
* If more pumps are around repairs often are postponed until all pumps have broken down. (Repeatedly they strip one pump to repair another one; those costs are not mentioned.)
* Many costs of maintenance and repairs are excluded like the intervention of mobile teams (projects, expatriates), the replacement at no charge of the expensive parts that should not break down but still 'worn out' much faster than expected (f.e. diaphragm and cemented pvc-risers).

It appears too often that, even years after installation of the pumps, an effective system for distribution of spare parts does not exist. That is why many pumps stay out of action for a long time unnecessarily. (A vicious circle: because of scarcity of spare parts at the distribution point or a great distance and/or excessive costs of repairs, only few parts are sold. Therefore the distribution is not rewarding and the system will collapse.)

Some costs of maintenance, as indicated by the respective manufacturers, c.q. as results of field studies:

* Kardia: mean depth 37m: $3.50; mean depth 27m: $7.00/pump/year [Preussag]
* Pulsa: mean depth 25m: $46/pump/year [Fluxinos]
* Vergnet: $10/pump/year [3]

The various data cannot be compared, mainly because it was not mentioned which costs were charged and how the maintenance is organized (village level maintenance?). Also, the circumstances in which the pumps are used differ strongly, like: heads, intensity of use, acidity of water, etc. In some publications the results of field studies of maintenance costs were clearly manipulated.

Each type of pump has its own specific maintenance problems. These depend on the working principle, the pump design and the materials used for its manufacture. But too often they simply originate from lack of quality control.

<u>SPECIFIC MAINTENANCE PROBLEMS</u>:

INDIA MKII:	corrosion of the galvanized parts, problems with/after replacement of the crank bearings;
KARDIA :	cracked threaded joints of the PVC-riser, occurs at larger depths;
PULSA :	fractures in the joint of the elastic riser;
VERGNET :	diaphragms (costs about 1/3 of the whole pump)[5];
VOLANTA :	cracked cemented joints of the PVC-riser, occurs at larger depths.

5 Meanwhile the Vergnet manufacturer alleges to have developed a diaphragm with a lifetime of many years. They dare to guarantee the actual diaphragm for three years (once per pump).

Wear and tear of parts for these pumps is reduced to acceptable proportions. The manufacturers work at a limited scale on the improvement of details.

2.3 CONCLUSIONS AND SUMMARY

The reliability of handpumps has increased considerably over the last decade. Most pumps are now corrosion resistant and wear and tear is reduced to acceptable proportions. However, at a large installation depth the reliability decreases strongly, mainly due to fatigue. Therefore most manufacturers only guarantee their pumps for heads up to about 50 meters.

Most handpumps are/have only been monitored for just a few years and therefore offer a rosy picture of costs of maintenance. But the long term costs frequently appear higher then anticipated.

The mechanical efficiency decreases strongly with depth for handpumps with plastic rising mains. This further reduces, sometimes dramatically, the already limited discharge rate for large heads. Therefore only few of these handpumps are suitable for very large heads.

The actual technical development of handpumps is mainly aimed at the improvement of details.

Because of the improved reliability of modern handpumps, especially for heads up to 50 meter, the availability is now mainly limited by the quality of the management and spare parts supply.

The potential to increase the discharge rate of handpumps is limited.

3 PROBLEMS WITH DEEPWELL HANDPUMPS

3.1 INTRODUCTION

The users describe the main problems they experience with drinking water supply based on handpumps as follows:

1 the pump does not give water; it is broken down (again);
2 the pump is giving less water than normal;
3 only after pumping for a while the pump gives water;
4 the pump does not give enough water for everyone;
5 pumping costs too much effort;
6 they dislike the water (the taste, the color, ...);
7 its operation encounters cultural and/or physical objections;
8 the costs are too high.

In technical terms its causes can be formulated as follows:

* The system doesn't work (optimally) because of a technical defect: 1+2+3;
* The system doesn't work optimally because of a defective construction or installation, c.q. adaptation of the system to the circumstances: problems (4)+(5)+(6)+(7)+(8)[6];
* The system is unsuited: problems (4)+(5)+(6)+(7)+(8);

Apart from the discomfort for the users, a temporary breakdown of the pump is nothing special. Each pump system needs maintenance and repairs. If, however, the pump is frequently out of use and/or for long periods, there may be a serious problem. There may be divergent causes, like:

* the pump is unsuited for the application: mechanically too weak, ergonomically or culturally maladjusted, a poor discharge, ...;
* the pump is abused, sabotaged or not properly maintained;
* the pump contains design and/or manufacturing defects;
* the pump is not properly installed;
* the borehole does not satisfy the demands;
* deficient management of the system;
* the absence of spare parts for repairs and/or a mechanic;
* the absence of the necessary funds or
* the costs are seen as exorbitant.

The frequent breakdown, however, may also indicate that the users are not convinced of the advantages of the system and thus let it decay! See Section 3.8 'Management of the pump system' for further details.

The difficulties may arise from technical causes on to:

* a defective preparatory study and execution of the project;
* a failing management of the pump system, and
* unwillingness, shortsightedness, naivety, (political) interests,...

Most of these causes (c.q. background problems) are beyond the scope of this report. In the first instance this study focuses on the technical problems, especially those related to the pump system. However some items were found so important that a brief elaboration is given in the next sections.

3.2 IMPLEMENTATION PROJECTS

To realize a simple but well functioning drinking water supply very different

6 () dependent on the nature and the cause under this denominator or not

matters have to be integrated. They vary from politics to culture, religion, history, (hydro-)geology, drilling technology, pump technology, social-economics, management, interhuman problems, ...

These problems are mostly underestimated. This is shown (after all) by a defective setting of the preparatory studies and the implementation (concerning a.o. co-operation, boarding out and its control, sensitization and monitoring). This is mostly caused by a lack of knowledge, naivety and pressure for time. This may lead to the unfitness of the implemented system for the application requested or only a short time of operation.
A flexible setting of implementation projects is necessary to adapt to unexpected situations and problems. Monitoring is indispensable in order to be timely informed of bottle-necks.

The co-ordination between various implementation projects in the same or nearby regions leaves much to be desired. Often knowledge is not spread and faults are repeated, villages are not equally treated and donors and projects are played off against one another.

SENSITIZATION

The aim of sensitization is: to inform those concerned, to convince them of the importance of defined activities and in this way to encourage their contribution. All this in an effort to create lasting pump systems.

Parts of the task:
* to study the socio-economical situation in the region and to gather detailed information concerning the villages;
* to co-define the strategy of project interventions in villages;
* to create and maintain the communication between project and village, as a well informed intermediary;
* to inform the villagers about project interventions: aim, working method, conditions, consequences (management of the pump, financial consequences, maintenance, etc.);
* to stimulate discussions on these matters, to apply to their sense of responsibility, to promote the involvement of women in the management of the system, etc;
* to assist in the realization of village level maintenance: a management system in which the users are responsible for the management of the pump, its maintenance, repairs and the related costs[7];
* monitoring and auto-evaluation.

Furthermore, sensitization is an important factor in:
* training, motivation and, if necessary, correction of mechanics;
* guidance of project people towards villagers and mechanics;
* maintaining contacts with local authorities.

Problems concerning sensitization:
* Frequently only <u>after</u> the installation of the pumps a sensitizing team is formed. By that time pump management problems have become a general phenomenon. The team has to find a way out: trying to involve the users.
* The sensitizing team has an ungrateful task once the qualities of the pumping

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7 The sensitizing team must underline the importance of a continuing maintenance of the present water sources. These are important as back-up in the case of a (longtime) breakdown of the pump, which is not just imaginative!

system are disappointing (discharge, reliability, lifetime, costs of maintenance, etc.).

* The competition between project technicians (hard) and (wo)men of the sensitizing team (soft): men's versus women's business.

Possible consequences of an inadequate sensitization:

* deficient management of the pump resulting in neither maintenance nor repairs;
* badly informed villagers resulting in incomprehension, opposition and refusal;
* ignorance within the project of the problems in the village and their causes;
* lack of progress of the project: problems with villages and authorities.

3.3 THE BOREHOLE

The yield of the borehole may be insufficient, for example due to geological circumstances or by a badly executed job (insufficiently deep, wrong layer, wrong filter, not well developed, etc.). Or the borehole may silt up due to a coarse filter or a fractured casing. That may result in a jammed pump and extra wear, apart from the pollution of the pumped water.
A not-aligned borehole or a partly collapsed casing, may not only lead to extra wear of the riser and piston rod (guides) but also of the casing itself. (N.B. No borehole is completely straight and vertical!)

A wrongly chosen installation depth of the cylinder may cause problems as well:

* the pump may fall dry because of insufficient depth; apart from miscalculation this may be due to:
    * un underestimation of seasonal effects to the water level and of the dynamic drawdown;
    * a borehole filter too small or too fine, resulting in a large drop of the water level in the borehole, worsened in the end by a clogged filter;
* polluted water and a jammed piston due to insufficient depth of the borehole respectively a pump cylinder hanging in the sand catcher below the borehole filter.

The water quality depends on the site (implantation) and the depth of the borehole, in other words the tapped aquifer. The users notice the difference by a.o. taste, color and acidity: the consequence of biological and chemical pollution. The choices are generally limited, especially with chemical pollution.

Furthermore an incomplete or a wrongly situated (e.g. too low) superstructure may cause problems: for example by the lack of a pump slab, a spillwater drain and catchment facility or a fence. In such cases cleaning (preventing a mud bath) is very frustrating, especially with intensive use. The polluted water may even flow back into the borehole.

Most of these problems have to do with a defective preparatory study, the absence of clear instructions, ignorance of important conditions (particularly the site of the borehole), a defective execution of the borehole, a faulty installation of the pump, c.q. a deficient supervision. Another reason is the lack of simple means to check the alignment and condition of the borehole casing.

TECHNICAL RESEARCH ITEM:
Develop a simple means to check the alignment and condition of borehole casings.

3.4 THE MECHANICAL PRINCIPLE AND THE CONSTRUCTION OF THE PUMP

PROBLEMS RELATED TO THE MECHANICAL PRINCIPLE OF THE PUMP:

* Piston as well as diaphragm pumps have an intermittent pumping action, resulting in pressure waves in the water column and resonance. These intensify not only the load fluctuation in the rising main (and the pump rod) but also the so-called fatigue of the material. The consequences appear mainly in the joints of the (plastic) tubes (threaded/cemented). This is the principal cause of technical problems with handpumps, especially at larger heads. Consequences: excessive repairs including fishing up the broken pump parts from the borehole bottom. For this reason most manufacturers don't recommend the installation of their pumps at depths of more than 40 to 50 meters.
* A decreasing mechanical efficiency and discharge rate because of the axial elasticity of the (plastic) rising main, probably worsened by buckling. Especially at large installation depths, problems may arise if the piston stroke and diameter are not adapted to the rising main diameters.
* Diaphragm and water oscillation pumps have a low mechanical efficiency. This can hardly be improved. Especially at larger depths the discharge rate is low, often causing a problem.
* Wear of rod and riser guides, particularly with piston pumps in not-aligned boreholes.

PROBLEMS RELATED TO THE CONSTRUCTION OF THE PUMP:

* The high initial costs due to the application of corrosion-resistant materials like stainless steel. (Of particular importance when replacing the pump on the account of the consumer.)
* The necessity to adapt the piston diameter to the head (if the crank length cannot be adjusted). Either to keep the handle forces within reasonable limits or to attain a proper discharge rate.
* In the case of a piston pump with a plastic riser: the desirability to adapt the piston stroke and the piston and riser diameters, to optimize the volumetric and mechanical efficiency.
* In piston pumps: the limited buckling strength of plastic rising mains[8]. In progressing cavity pumps: its limited torsion stiffness.
* Fractures in/near the joints of PVC-rising mains, especially at large heads with cemented as well as threaded joints. (These problems arise from lack of experience with using PVC under these circumstances.)
* The high costs of stainless steel rising mains and its high specific mass. This forces manufacturers to limit the use of material (thin-walled tubes) and to apply exceptional constructions, like threads directly rolled onto the tube (Atlas Copco) or threaded parts or sockets welded onto the tube.
* High pressure fluctuations in stiff risers (fluctuations of 4* the static pressure each pump stroke!) and high resonance frequencies, which will, even in steel tubes, accelerate fatigue (especially in the welds).
* 'Open-top cylinder' cannot be combined with leather piston cups (India MkIII experiments).
* The swelling of plastic by absorption of water (a volume increase of up to a few percent, causing fitting problems). Also: a growing strain under a fixed load. (E.g.: a PVC rising main of 80 m length may extend 25 cm in 10 years, which may cause the piston to hit the cylinder top.)

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8 The Kardia pump is installed with riser guides to prevent buckling, installed at 1 m intervals. They fit into the borehole. This provision limits the deformation of the riser and as such the stress fluctuations and fatigue.

* Corrosion with pH<6 if materials sensitive to corrosion are applied. Under these circumstances galvanized steel is no longer a durable solution for risers and rods.
* The limitations to increase the discharge, if there is a need to. E.g.: the pump is pumping too easy (cannot absorb more power) or the driving mechanism imposes restraints: for example no facility for people to pump together, etc.
* The user unfriendliness of several pumps: the motions (of arms and/or legs) necessary to drive the pump, may encounter ergonomical and cultural objections, particularly for children and (pregnant) women.

For most above mentioned problems solutions exist.

TECHNICAL RESEARCH ITEMS:
* The realization of a price break-through, even for large depths, while maintaining its qualities (e.g. a suitable mechanical efficiency!) by new pump designs.
* The joining of pvc-tubes with sufficient fatigue strength for use at large heads. (CRL is looking into this.)

3.5 (LOCAL) MANUFACTURE[9]

A pump is not entirely assembled and tested before leaving the factory, as with almost all other industrial products. To be sure of its well-functioning, an accurate inspection of the separate parts is therefore extra important before it leaves the factory.

Handpumps still suffer serious problems, even pumps manufactured in so-called 'developed countries'. Many of these are due to a faulty manufacture and a failing quality control. If the manufacture of a handpump requires technical tours de force, even for 'developed countries', then the product is not appropriate. Such products should not be applied for drinking water supply in developing countries.

Problems, which may be the consequence of inferior (local) manufacture, e.g.:
* fitting problems when installing the pump; the tolerances were overlooked;
* deviations of the 'standard pump' in consequence of adaptations to local or changed circumstances, by which the interchangeability may be lost or obstructed;
* a relatively short life of the pump parts caused by:
  - inferior quality materials or defective manufacture (e.g. weak welding);
  - not properly considered nor fieldtested design changes;
* delivery delay.

Problems that appear with (local) manufacture of the pump can be subdivided in:
* <u>General problems</u>: underestimation of the importance of proper management, of personnel management, consultation, self-criticism, quality control, motivation and discipline.
* <u>Production problems</u>, leading to undesirable size, shape and/or quality deviations:
  - underestimation of the importance of production in accordance with the standards;
  - missing or failure of quality control;
  - a limited knowledge of production and control techniques;
  - limited means of production or its defective condition;

9 'Local' manufacture: in the country or in a neighbour country where the pumps are applied.

- non-optimal use of the 'means', personnel as well as tools;
- limited local availability of raw materials and tools, resulting in long delays, particularly in the case of importation;
- difficulty to find a supplier of spare parts to repair imported machines (years after purchase);
- unreliable electricity supply.

* Organizational problems, mostly a consequence of weak management, characterized by (among others):
  - a limited involvement of the management in the production;
  - the low value, attached to the 'capital value' of e.g. production personnel and controllers (their knowledge and experience, the importance of the transmission of knowledge) and the lack of a personnel policy;
  - the great distance between management and personnel, the lack of stimulation and even too many discouraging incentives; resulting in a limited dedication, productivity and involvement of the personnel and high turnover (if there are alternatives like the 'big town');
  - a faulty insight into the costs of manufacture and production losses (whether caused by bad management or not) and the costs of failing quality control (e.g. consequences for costs of guarantee-repairs and the loss of a good name and customers);
  - the absence of preventative maintenance of the means of production, resulting in breakdowns at undesirable moments and often for relatively long periods (caused by delay of delivery of parts, to be imported);
  - investment of limited financial means in unremunerative or not exactly productive matters, like the house and the car of the manager, etc.
* Logistic problems:
  - large transport distances, several frontiers and different means of transport (delay caused by transshipment);
  - few reliable (local) suppliers;
  - adaptation problems and indistinctness about responsibilities, etc.;
  - communication problems: bad/no telephone connection, delays by sending messages by post.
* Financial problems:
  - limited means for down payment;
  - delay with payments of foreign shipments and orders, causing extra delays in shipment and production and also loss of interest;
  - high costs of transport, transfer and import duties;
  - heavily bearing overhead costs because of limited sales; unremunerative investments and improper use of the facilities (e.g. cars);
  - too many 'debtors' (friends, family, authorities, etc.).
* Political problems, at local, national and international level:
  - competition falsifying tax rules (selective immunity);
  - preferential treatment or opposition, with relation to the type of pump, the degree of local production, due to powerful patrons.
* Relation with or dependence of the 'western parent factory':
  - design and license rights;
  - monopoly on the supply of materials and means of production (in practice).
* 'Far from my bed' effects, like:
  - lacking involvement of the parent company in solving problems with 'their pumps', manufactured and supplied by the local manufacturer, for which they are jointly responsible (mostly presupposed on the basis of the relationship between both manufacturers and the donor);
  - deficient involvement in problems with local manufacture;
  - problems related to the guarantee of the pump: sheltering behind the local manufacture/supplier;
  - incomprehension/unwillingness of the local manufacturer in relation to the terms of delivery.

Table 3.1 CUSTOMS RIGHTS AND DUTIES IMPOSED ON THE IMPORT OF PUMPS (expressed in % of the value at importation[10])

Country:	BENIN	BURKINA	IVORY COAST	TOGO	NIGER
Handpumps	24,27	3,93	45,6	10	40,8
Spare parts	15,95	10,29	55,6	10	53,6

Problems, that may play a role on the background:

* Limited knowledge of the manufacturers of problems with the pump in the field;
* In the relationship between the parent company and the local manufacturer:
  - conflicting interests (e.g. protection of its own market) may result in retained support and transmission of knowledge (e.g. who will pay for that?);
  - dependence for the supply of materials, tools and knowledge; important (mostly expensive) spare parts, which are specific to the pump, have to be purchased from the parent company, due to design rights on the pump(parts) (e.g. the diaphragm of Vergnet);
  - limited validity of design and license rights in the country concerned;
  - autonomy of both manufacturers, e.g.: can they each carry out design adaptations? What are their duties and rights?
* Design and production technical aspects:
  - A handpump is a simple product but with high demands made upon fatigue strength. It must function under rather extreme circumstances: high temperature, acidity, sand and clay, non-aligned boreholes, under inexpert use, defective maintenance, vandalism;
  - Maintenance of quality and interchangeability, when the pump is under development, manufactured at several places with different tools and manufactured and applied under divergent circumstances;
  - Lack of knowledge of the effect of manufacturing technologies for the quality of the final product e.g. for the fatigue strength, the resistance for wear, the shape and measures;
  - The application of advanced manufacturing technologies for non-standard parts, which will interfere with local manufacture, e.g.: fibre reinforced synthetics, moulded synthetic parts;
  - Unnecessary tight tolerances, mainly because of using antiquated constructions, or constructions which are relatively difficult to keep under control (e.g. leather cups); especially at local production;
  - A different division of machine and labour costs than the production circumstances to which the pump design is made, resulting in unnecessary high investments for the developing country.
  - An incomplete exploitation of, c.q. adaptation to local circumstances, like low labour costs and limited or other production tools.
* Commercial aspects:
  - The product is too expensive to be sold directly to users(groups); so the market is limited and strongly dependant on foreign donors;
* Opposition from (semi) authorities.

TECHNICAL RESEARCH ITEMS:
Unable to assess. Support, instruction and sensitizing are far more important.

[10] Extract of the report SGI 1986, Projet régional de fabrication de pompes à main, UMOA/CEAO, BOAD.

3.6 INSTALLATION

Technically spoken, the installation of the pump hardly causes problems. Of course its complexity differs with the type of pump (weight, size, complexity), with the installation depth (possibly the need for a pulley-block) and the quality of the preliminary work: the borehole (collapsed, not straight, out of plumb, etc.) and the pump foundation (position of the concrete slab, position of the anchor bolts).

The main practical problems during the installation (campaign) are:
* organizational aspects: co-ordination of people, transport and pump parts, to delegate and to co-operate, control and registrate;
* limited accessibility of villages, depending on the season;
* dealing with and reaching agreements with local authorities.

Most of the problems will arise afterwards! Such as:
* the users don't feel themselves responsible for and owners of the pump; they had no real choice (system, site), they were hardly prepared for the later consequences, their involvement is limited to using the 'pump of the Dutch', for the time the pump is functioning;
* (this results in) problems with managing the system;
* the lack of spare parts and mechanics, because agreements have not been fulfilled and (long term) problems have been underestimated;
* problems concerning the guarantee of the pump.

These problems mainly arise in consequence of a solistic, purely technical intervention. Thereby the installation campaign is not an integrated part of a broad sensitization campaign.

Generally the authorities want a guarantee on the pump for a period of one to two years. During this time the users don't contribute to the (costs of) maintenance, making it impossible to judge their management. Also no real picture can be obtained of the functioning of the local mechanics and the distribution of spare parts[11]. Consequently the prospects for sustainability of the water supply cannot be judged. So only after conclusion of the external intervention the problems will emerge. Who will then backup?

Often the contribution of the national/local authority is 'double' and conflicting. They want a (permanent) involvement in the system, to reinforce the structure, although they cannot fulfil the required efforts, like e.g. maintenance of the pumps, training of mechanics, management of the initial stock. Meanwhile they are an obstructing factor, because they hamper better alternatives[12].

TECHNICAL RESEARCH ITEMS: None.

3.7 OPERATION

Both the pump and its surroundings are of importance for the functioning of the system.

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11 The custom to leave a large stock of spare parts behind (sometimes up to 10% of the total number installed), makes it impossible to judge the functioning (commercially) of the distribution network and stimulates corruption for years.

12 Local authorities must initiate and control; they should not act as a link in a maintenance structure.

Problems originating from the pump:
* A deficient efficiency (mostly at large heads), asking much effort and time to pump even a modest quantity of water;
* Ergonomically spoken, the operation of the pump is too heavy and/or inconvenient to children, pregnant women and weakened people;
* The pump motion encounters cultural or religious objections, like e.g. pumping with the foot;
* Risks of injuries e.g. where parts of the body can be jammed;
* A pump operated with too much ease, will give a limited output and permits the pump to operate much too fast, at the expense of its life;
* In case of leakage much time is lost, because one first has to fill the pump and/or a part of the pumped water is lost;
* A limited output may result in waiting times, if e.g. pumping with more peoples is impracticable.

Problems related to the superstructure and the other facilities:
* The set up is experienced as improper, for example when the pump is placed far above the surroundings so that everyone pumping will be on show to passers-by;
* The pollution, mostly due to the lack of a spillwater run-off channel and catchment facility, a below level installation of the pump and/or the free admission of the cattle to the direct surroundings of the pump. This may cause the spread of diseases and infections by direct contact of the users with the filthy water (e.g. a contaminated container on the head, or by approaching the pump after fording a quagmire);
* An obstructed entrance to the pump, due to lack of space to walk around with more than one person (in- and outcoming) or because of a large quagmire around the pump;
* Obstruction of the water transport from the pump to the water cart or the watering place (costing extra time and effort)[13].

Most users prefer a pump that is heavy to operate (more power at a lower pump frequency). This permits the user to transmit more power onto the pump by increasing the pump stroke and/or by pumping faster (e.g. with more persons) to realize a larger discharge rate[14].

TECHNICAL RESEARCH ITEMS: None.

3.8 MANAGEMENT OF THE PUMP SYSTEM

This section discusses the problems that appear with 'village level management of maintenance' (VLOM).

Management tasks of the committee:
* Stimulate a proper use of the facility;
* Supervision to prevent misuse;
* Organize a regular inspection and cleaning of the pump and its surroundings;
* Make sure that the necessary repairs and replacements are executed;

13 Transport of the water to the home is an important problem, particularly regarding long distances, but this falls outside of the scope of this study.

14 That children cannot operate the pump is seen as positive, since this limits vandalism to the pump.

* Organize the cost recovery and its administration[15]; for maintenance, repairs and future replacement;
* Management of the fund.

Management problems that may occur:
* The villagers don't understand the importance of the system;
* The villagers don't accept the system, because:
  - it doesn't meet their expectations or earlier promises, and/or
  - the system was palmed on or forced upon them; so why should it concern them or why should they pay for it;
* Indistinctness with the villagers about who owns the system: the government, the project, the village or the committee. So it's not theirs and they feel no collective responsibility;
* The people responsible are not taken seriously: their instructions are not obeyed;
* The villagers don't trust the people responsible, particularly concerning the management of the maintenance funds;
* The villagers won't assist them, but on the contrary oppose and impute them.

Consequences of management problems:
* The system doesn't work optimally (e.g., it's a mess, defectively functioning, regularly broken down and/or for a long time);
* The necessity to use alternative water sources more intensively (unclean and sometimes further away);
* The lack of funds for repairs and future replacement (the villagers refuse to pay their contribution any longer, because of bad management of the funds, like ostensibly 'borrowing').

The causes of these problems could be:

A An insufficient preparation and support of the villagers by the implementing project. Therefore they chose the wrong people as committee-members: people without or with a faulty motivation and capacities. This may be a result of:
  * the lack of proper sensitization;
  * the absence of capable and motivated people at village level;
  * the target group was inaccessible because of balances of power in the village (resulting in the exclusion of women, e.g.);

B The problems exceed the capacities of the committee, either because:
  * the committee was insufficiently prepared and supported, or
  * the problems are excessive, like:
    * too many breakdowns occur: due to a bad pump or borehole;
    * the village is too poor or is not motivated;
    * there are too many problems at village level: between families or quarters, ethnics, religious groups, or because of external (political) influences;
    * there are no mechanics and/or spare parts;
    * a large maintenance fund causing distrust, jealousy, 'borrowing', or leading to an abuse of power by the committee while investing the surplus;

C The system doesn't offer any real profit (like a greater discharge, cleaner water, more comfort) but instead causes more problems (e.g., excessive costs, repeated breakdowns and/or for a long time, difficulties to get the system repaired).

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15 To overcome problems, separate accounts and cashboxes can be maintained; i.e. apart for (wo)men, per area, etc.

N.B. When the users experience no real advantages, the members of the committee have an almost impossible task trying to motivate them to maintain the system and to contribute financially.

A new drinking water supply system is often an alien element in the village. The initiative and the choice which system to install nearly always comes from outside the village. At most the villagers can refuse. Formerly it was everyone's own problem to obtain drinking water (apart from digging and maintaining the well). Now the people must become organized. The necessary level of organization and management often exceeds the level of earlier communal activities.
When a number of villagers refuse to contribute financially, extra social tensions may arise. This may lead to further refusal to contribute and so to a complete stop of the system[16].
Guarantee on the pump can work counterproductively. The users are not persuaded from the beginning that the maintenance is their responsibility. In the case of future technical problems they will just wait quietly and expect 'them' to come to solve the problem.

Reasons for the lack of a serious preparation of the users:
* underestimation by the project and the village of the necessity of an effective management of the new system;
* underestimation by the project and donors of the problematic nature of village level management.

Therefore the necessary actions were omitted like sensitization, training and involving the villagers in the preparations and the realization of the system.

N.B.1 During and after the implementation, many village level management problems arise from indistinctness: concerning the responsibilities and tasks of donors, of local authorities, projects, suppliers, mechanics, the management committee and of the users.

2 To evaluate the sustainability of the 'village level management of maintenance' is impossible, as long as the implementing project is involved (directly or indirectly, whether or not structured). Such an implementing project often contributes (more or less hidden) in the sense of motivating the users, of preventive maintenance and serves as a safety net for excessive costs. Without such a support many pump systems will never be sustainable.

TECHNICAL RESEARCH ITEMS: None.

3.9 MAINTENANCE

THE CAUSES OF BREAKDOWNS

Possible causes of breakdowns:
* In intensive use:
    * the extreme fatigue load of parts causing fractures;
    * the rubbing of pump parts against one another and the pump against the borehole casing, causing excessive wear;
* maladjustment of the pump design to:
    * the high acidity of the water;
    * the large head;
* inferior materials, faults in the material, faulty manufacture of parts,

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16 For that reason those responsible for the management of the system urge for a (pad)lock on the pump: not only to disallow use to the defaulters, but also to prevent misuse of the pump.

insufficient quality control;
* accumulated sediment in parts of the pump;
* not straight or partly collapsed boreholes;
* more than one pump in one borehole;
* postponed or bad maintenance and repairs.

Unfortunately at larger heads handpumps still cause different problems, although steady progress has been made over the past decade.

There is a great difference between the real and the apparent maintenance costs of handpump systems. Most reports only give a rough and concealing indication. These differences are due to, among others:
* no mention of the costs of project interventions like free repairs, subsidized transport and renovations;
* repairs not executed (the pump remains broken down);
* stripping one pump to repair the other.

The maintenance costs in the long term (after the conclusion of the project) are not mentioned. For example those due to rusting of the risers and rods, worn through risers and diaphragms.

Generally the maintenance of the borehole exceeds the financial capacity of the villagers.

THE MAINTENANCE STRUCTURE

There are several different systems for the maintenance of handpumps:
* centrally organized maintenance, executed by a (semi-)governmental enterprise;
* a system with a division of tasks between national, regional and local levels, based upon the level of complexity of the technical problems: the so-called 'three-tiers system';
* a division of tasks on two levels: 'two-tiers system';
* no division of tasks: a regional mechanic executes all repairs and installations; if necessary he calls upon a specialized enterpriser like a welder.

(In Niger the distributor of Vergnet pumps has proposed that the authorities conclude a maintenance contract for these pumps, on a fixed rate, to be paid for by the village.)

In general, direct involvement of the government in the maintenance of pumps proves to be unsuccessful. Furthermore, the costs of functioning are excessive. The experiences with the two- and three-tiers systems were reported elsewhere and will therefore not be further discussed here [1].
This section briefly discusses the latter set-up, based on a regional mechanic[17], usually a small entrepreneur. The contribution of the (local) authority is limited to initiator and controller (e.g., to prevent forcing-up of prices) and mediator (in a global sense) in conflicts between villagers, mechanics and the distributor. Generally the authorities will be involved in the necessary maintenance of the borehole (initiation and supervision).

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17 The contribution of a village mechanic is undesirable for most deepwell handpumps. A regional mechanic is better trained and has more experience and tools. This reduces the risk of inadequate repairs. Frequent inspections often cause more problems than they prevent, especially when they are executed by a village mechanic who has to prove himself.

In principle, maintenance is only executed at the request of the management committee. Without their permission no one should have the right to adjust the pump. Maintenance of the direct surroundings of the pump, like the pavement, the spillwater runoff channel and the fence is the task of the village.

PROBLEMS WITH THE REPAIRS

Problems for the village:

* There is no mechanic in the region, never installed or introduced, or he is gone (e.g. exodus);
* The villagers have a conflict with the mechanic, they don't trust him and accuse him of unwillingness, malevolence, etc.;
* There are no spare parts available in the region or only of inferior quality;
* Excessive costs of labour, spare parts, travelling and transport;
* The pump is out of order too often or for too long as repairs take much time.

Problem for the mechanics:

* The weight of pump parts asks for a tripod arrangement;
* The risks of accidents and mistakes, mostly at his expenses;
* Not enough (paid) work to make a living; if sidelines don't produce enough, migration is sometimes the only answer[18];
* The villagers (and the local authorities) hold them responsible for the numerous breakdowns, even when due to design faults;
* They are accused of being only focused on their profit;
* Often they are not paid (in time) for the job and their transport costs;
* They lack the means to replace tools;
* The transport of tools and materials;
* A parasitical (local) authority, threatening to recall the license, tools and the means of transport placed at the disposal of the mechanic.

It is of great importance to make watertight agreements (contracts!) in relation to the proprietary rights of the tools and the eventual means of transport. That should prevent the threat of undeserved recall by local public servers with the excuse that the mechanic doesn't work properly. Otherwise these tools may disappear provoking an erosion of the maintenance infrastructure.

THE DISTRIBUTION OF SPARE PARTS

Via a commercial distribution network spare parts are to be sold in the region. Too often the spare part supply is very unprofessional or non-existent. Sometimes an implementing project or a departmental authority has the task to distribute the spare parts (a value of up to 10% of the total investment in pumps is sometimes simply dumped into their stock). But often their earnings vanish (embezzlement of funds) and the stock of spare parts is not replenished.

Problems for the local distributor(/importer):

* A limited turnover and a low profit;
* The difficulty to find a supplier of spare parts (of older models);

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18 Preferably a mechanic is selected from several already independent operating entrepreneurs. They must receive an appropriate training and moral support during the preliminary stage. They must be involved in the installation and possible renovation programs, even of other types of (hand) pumps in their region, on a commercial basis. In this way they gain experience and they increase their consideration and their income. These may keep them in their regions.

* The long delivery times;
* Paying in advance;
* Import restrictions.

Problems for the manufacturer:
* Delivery of the right spare parts, years after installation of the pump.
* Small margins due to insignificant numbers.

The high import duties on pumps and especially on spare parts are an extra handicap. This problem is mostly discovered after the withdrawal of the donor projects and the expiry of their import facilities (exemption from taxation)! Local manufacture is often discouraged by import impediments and duties on tools and raw materials.

TECHNICAL RESEARCH ITEMS: None.

3.10 REPLACEMENT

Replacement of the old or worn pump may be necessary once repairing is more costly than buying a new pump, when obtaining spare parts has become an insoluble problem, or because of its limited discharge rate replacement by an other type of (mechanical) pump may be necessary.

Replacement at the initiative and expense of the villagers, will hardly ever happen. Therefore, most implementation projects don't succeed in realizing a sustainable pump system in the villages. It serves only temporarily: a few years.

A village, attached to its old pump, will try to keep it working for years by repairing it. Only a few villages can afford to replace the pump. Those who didn't take the trouble to maintain their old pump, will not exert themselves to replace it (in due time).

When preparing for replacing the old pump the village will face the following difficulties:
* Invest an excessive sum at once (instead of gradually, as with repair);
* Managing a large fund and making it profitable before investing it;
* The lack of a credit system or investment facilities;
* Other investments/expenses have priority and offer better results in the short term;
* The villagers prefer to wait for a generous 'brother' or the next rehabilitation project, to avoid 'unnecessary' investments;
* And last but not least: care killed the cat...

When making a choice for a new pump, the following considerations are important to the villagers:
* What is better: to renovate the old pump or to replace it?
* Which pump to chose, taking into account the directives of the authorities (standardization), of technical developments and the (future) demand of the village?
* Where to buy it and under what conditions (e.g. is it sensible to pay in advance)?
* Who is going to maintain the pump and where can we get spare parts?

Problems for a rehabilitating project:
* Is replacement by the project justifiable when the villagers are not motivated, have no money, have not saved, have embezzled the maintenance fund, have no management committee? In short: what is the sense of just

replacing?
* Which pumps to replace? Also in villages where the old pump was not maintained?
* Replacement by which model of pump?
* Does the village have to pay an advance; do they have to pay (off) the whole pump?

N.B. If the villagers don't have to pay at this time for the replacement of their old pump, will 'replacement at their expense' be taken serious next time? Logical reaction of the villagers: 'tomorrow is another day'.

In practice the rehabilitating project steamrolls the existing situation. Replacement alone will not lead to a sustainable solution. So a rehabilitating project will have to pay attention to: sensitizing of the villagers, training and equipment of the mechanics, installing and/or reinforcing of spare part distribution, ...

The problem that the position of the foundation bolts may not correspond with the new pump is minor compared to other problems.

TECHNICAL RESEARCH ITEMS:
How to decrease the purchase costs of handpumps.

3.11 CONCLUSIONS + SUMMARY

The causes for malfunctioning of a handpump, or being or staying out of order, strongly diverge. Up to heads of about 40 meter design technical problems should no longer be relevant. Alas, many villages have to contend with very high maintenance costs, because their handpump is not 'up-to-date'.
At large heads technical problems are still significant: mainly because of fatigue and strongly reduced mechanical efficiencies. Therefore only few manufacturers dare to guarantee their pump for such heads.

Because handpumps have become much more reliable in the past decade, other problems have gained importance over technical problems. Important problems are:
* inadequate management and quality control at the (local) manufacture;
* deficient preparation and execution of the implementation;
* villagers, unprepared to manage and maintain the pump, due to lack of proper sensitization;
* no spare parts supply and no mechanics;
* problems with the borehole;
* lack of means to replace the handpump (in due time).

These problems sometimes dramatically reduce the sustainability and availability of the handpump. For most of these problems solutions are available. Serious execution of the various tasks will generally comply with the needs.

Problems, asking for extra attention:
* the limited profits for mechanics and for the distributor, threatening the sustainability of the maintenance structure;
* reliable and appropriate saving and credit facilities for the villagers, in behalf of the future replacement of the pump;
* monitoring.

Problems requiring technical investigations:
* how to reduce the cost price of handpumps drastically;
* the development of lasting joints in pvc rising mains (fatigue resistant);
* the development of a simple means to examine boreholes.

4 ALTERNATIVES FOR DEEPWELL HANDPUMPS: POTENTIALS AND CONSTRAINTS

4.1 INTRODUCTION

By 'alternatives' are meant:
* Pump systems, mainly intended for the drinking water supply for 300 to 2000 people (about 6 to 50 m3/day), and for dynamic water levels between 30 and 100 meters, without a distribution system (just taps near the pump system);
* Stand-alone systems ('where there is no grid'), with a prime mover based on solar energy, wind, diesel or animal traction, or a combination of these.

N.B. The systems concerned have a 'daily volume times head' from 180 to 5000 m4, and form an important part of the non-piped mechanized drinking water supplies. The systems with large discharge rates are frequently equipped with a distribution network.

Systems based on a combination of prime movers, to be called 'hybrids', will be discussed in section 4.6. This includes muscle-powered systems; in support of the other prime mover (mixed) or (temporary) substitution (standby).

The systems consist of: a borehole, a pump with rising main, a drive, a prime mover with control and protection systems, a water tap system and usually a water reservoir. They should also be equipped with a water runoff channel and a fence.

The potentials and constraints of these alternative systems depend on:
* the circumstances: head, discharge rate, availability of sun, wind and diesel oil, ...;
* the technology of the system: stage of development, suitability for and adaptation to the circumstances, technical construction;
* the quality and availability of mechanics and spare parts;
* the village: motivation, socio-economic situation, management capacities;
* the quality of implementation: sensitization, instruction and support by the project, involvement of the village;
* financial aspects: amplitude and partition of the costs: initial costs, running costs, repairs, replacement--see NEI-report;
* the policy and interference of (local) authorities.

Whether the villagers will use the modern pump system depends on:
* the water quality of the system, like hardness, taste;
* the walking distance to the tap, accessibility, opening hours and availability of the system[19];
* the old situation: the accessibility, depth, distance and water quality of the old sources (wells, c.q. handpumps and/or surface water);
* the price of the water and the system of payment.

[19] Availability = (length of period - total down-time) / length of period.

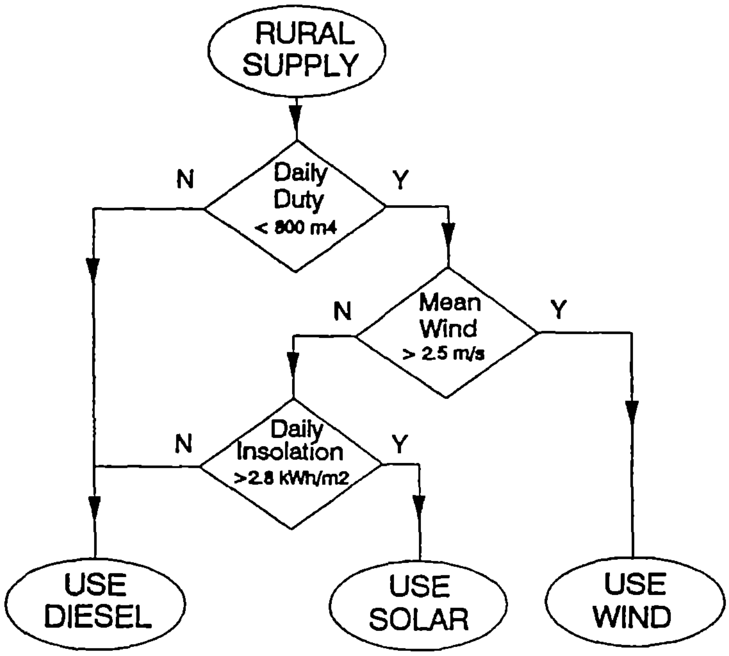

Figure 4.1 Decision chart for an appraisal of solar, wind and diesel pump appropriateness
(Source: 'Solar photovoltaic products', '91 [7])

N.B. When compared with the 1988 edition of 'Solar photovoltaic products' the appraisal margins for appropriateness have shifted remarkably: for PV-systems from 500 m4 up to 800 m4 and for solar irradiation from 5 down to 3 kWh/m2! All in spite of recent considerable increases in price for PV-systems for large heads.

Relevant cost items:
* research costs (several systems are still under development);
* material and manufacturing costs, guarantee costs;
* margins for the manufacturer, distributors, installer, ...;
* transport and transhipment costs, import duties, insurances;
* construction and installation costs;
* running costs, like: fuel, operator, maintenance, sale of water, administration, travelling expenses to the bank, ...;
* management costs;
* costs of repairs: travelling expenses of informant, mechanic and tools, spare parts, fetching the spare parts, labour costs;
* costs of replacement (see above);
* project costs, like: preparatory study, execution or boarding out, supervision, instruction and sensitizing, backstopping;
* financing costs.

Because of all these expenses the ultimate costs of the system will exceed the 'ex factory prices' several times. Not only the costs, but also the interests of various parties concerned may be decisive in choosing a system. Whether that choice will also be the best for the users is questionable. Does the village really have a say in the matter, apart from 'yes' or 'no'?

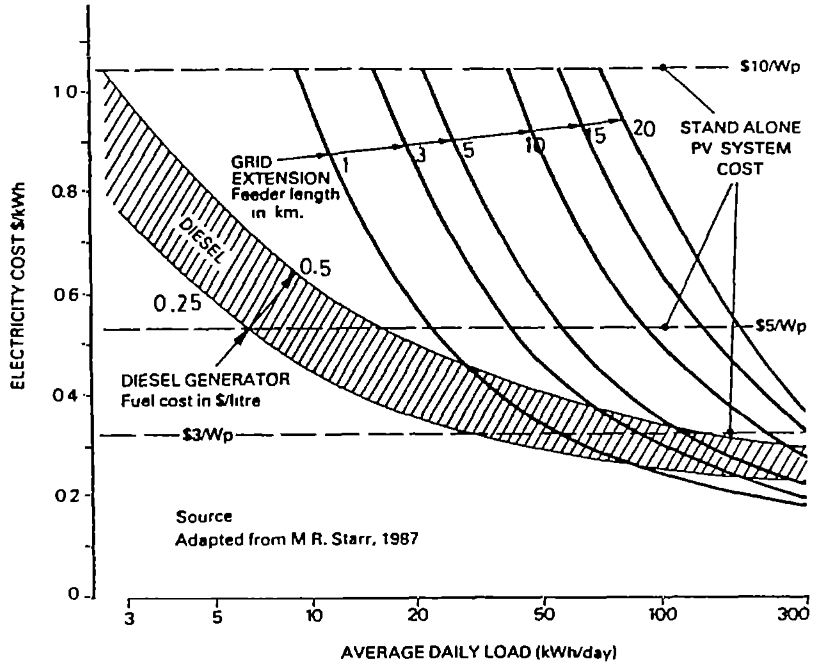

Figure 4.2 Comparative costs of PV, diesel power and grid extension (1987)[20] (Source: 'Solar photovoltaic products','91 [7])

N.B. Which costs are included in this comparison? The running costs for the village in case of total village-level management of maintenance? Also the costs of the implementing project? Based on monitoring or on estimations? To what extent has the situation changed since 1987? Unfortunately, this publication will hardly answer these questions.

The sustainability of the various systems remains a weak point. A number of methods to boost sustainability have been tried. For example:

* technical measures, aimed at:
  - increasing receipts from the system, e.g. by stimulating water consumption by extending the system with laundry slabs, watering place, water tower and distribution system and a large ground level water storage (design Mali Aqua Viva); or
  - decreasing the costs:
    - reduction of the system to its very essence, e.g.: no taps nor reservoir and/or
    - limiting the need for regular maintenance and inspections (unfortunately leading to more advanced and complex systems);
* extra support of the village: sensitization, instruction, credits, subsidies, insurance, maintenance contract, ...

It is questionable whether large and complex systems will ever be profitable and sustainable for small villages, apart from rich and fast growing communities. Usually the villagers continue to use the old springs for a major part of their water consumption, making it more difficult to make the new system profitable.

A mechanized pump system is much more expensive (purchase, maintenance, replacement) than e.g. handpumps (for similar discharges). The question is whether such systems are in the interest of poor communities. The extra time

20 Peak Watts (Wp) = the output of a PV module or array under reference conditions, a.o. a solar irradiation of 1000 W/m2.

gained in comparison with the use of a handpump is limited and can only partly be converted into productive work. Besides, the water quality does not improve. The mechanized system only offers more luxury to the users. The fact that a mechanized pump realizes a larger discharge rate from a borehole than is possible with a simple handpump is mainly in the interest of the donor, possibly saving an extra borehole. Also, for the villagers it will be hard to make a surplus of water profitable.

Mechanized pump systems usually increase dependence on foreign countries and make use of scarce foreign exchange (for oil, spare parts, ...).

Good management is a major factor for the sustainability of the system. See for further details Section 4.7 and for socio-economic aspects the NEI report.

For larger heads the following pumps are mainly used:
* multi-stage centrifugal pumps;
* rotary positive displacement pumps: like 'Mono';
* piston displacement pumps: for small discharges.

As hybrid diaphragm pumps (Vergnet) and water oscillation pumps (Pulsa) are also used on a limited scale.

For large heads and for small discharges piston pumps and rotary positive displacement pumps can be used. For large discharge rates centrifugal pumps are the only real solution. The efficiency of multi-stage centrifugal pumps decreases with the diameter of the pump.
The life span of the pumps strongly depends on the sediment in the water (type, concentration) and accidentally running dry. (Preventive) maintenance is usually limited to replacing bearings, seals and the pumping element, when done timely. Corrosion is hardly of account for these pumps, as most of them are made of corrosion resistant materials. Piston pumps may suffer from fatigue. Because of the specialized character of these pumps, one fully depends on the manufacturer, c.q. (local) distributor. The potential for local manufacture is limited, except for piston pumps.
The overall efficiency (pump plus drive), the discharge rate and the head determine the size of the prime mover.

Important types of water reservoirs and some constraints:
* steel tanks, bolted or welded: leakage due to incompetent manufacture or installation, corrosion due to a poor protective layer;
* concrete, poured on the spot or bricklayed with blocks: cracks, decay of concrete, if the work is not done professionally (e.g. faulty foundation and/or reinforcement) or by lack of a protective synthetic layer as protection against aggressive water (p.e. pH<6).

The choice of the type of reservoir usually depends on the local availability of raw materials and manufacture and transport facilities. Depending on the site and the needs the reservoir is either built directly on the ground, on a small platform or on a tower. Usually the big reservoirs are made out of concrete.

The reservoir (eventually with tower) may have an important effect on the total initial costs. Therefore most reservoirs are relatively small. The capacity is often less than the water consumption of one day. It is therefore primarily meant to set off peaks in the water intake and to permit water tapping while the pump is not working (temporarily). As a backup for days without enough wind or sun, or during a breakdown, these reservoirs have no significance. In these cases an alternative spring or an extra prime mover is indispensable.

The small systems are frequently experimental in relation to the technology used, the economics or the management. Generally the impulse for such experiments comes from outside the developing country itself.

4.2 SOLAR ENERGY SYSTEMS: PHOTOVOLTAIC SYSTEMS

SITUATION

Only photovoltaic systems are still relevant. Other systems based on solar energy have been pushed out of the market due to: the plummeted prices for PV panels, their mechanical simplicity and the great reliability of electric systems.
Three types of PV cells are generally in use: mono-crystalline and multi-crystalline wavers (around 16% respectively 13% efficiency) and thin film amorphous silicon modules (5-9%). The potential for cost reduction is greatest for the latest type. The power output (especially of the latest type) diminishes slightly with time.
The maximum power output increases with the level of irradiance, but decreases with temperature rises.

The average total daily solar irradiation varies roughly between 1 and 8 kW/m2/day (tilted array surface). This value varies with latitude, with climate, season and weather. The captured radiation is a combination of direct and diffuse radiation.

Two types of array settings are used:
* in most cases: fixed flat plate arrays, tilted at an angle approximately equal to the angle of latitude for the site;
* for some small units: tracking arrays, to follow the path of the sun and to capture more irradiance.

The modular set up of the PV-arrays makes it possible to adapt to a particular situation and in the future modules can be added as water requirements increase.

Old PV pump systems (+/-1980) consisted of an above ground direct current (DC) electric motor, driving a rotary positive displacement pump via a mechanical drive. This system appears less reliable, is more expensive and, compared with systems based on a submersible pump, its efficiency is lower.
A submersible pump is a compact unit of a pump (usually a centrifugal pump) and an electric motor hanging in the water in the borehole. Commonly DC submersible pumps are used for small capacities (<400 m4) and alternating current (AC) motors for the larger capacities. The AC motor pump unit is more compact and needs less maintenance. DC has to be converted by use of a DC/AC invertor to 3-phase AC. Most systems are smaller than 1500 Wp (about 1000 m4 for the Sahel).

Several handpump manufacturers (among others: Pulsa, Vergnet, SWN) experiment with handpumps 'with extension': an above ground DC motor and a mechanical drive for the handpump (see Hybrids, Section 4.6). This set up is chosen because of its electronic simplicity, highest efficiency and lowest costs.

N.B. A high efficiency piston pump with an efficient PV-drive turns out to be an efficient solution for large heads and limited discharges.
A PV-drive may increase the discharge rate of a handpump, especially at larger depths, by 2 to 3 times (with a maximum of 300 to 400 W absorbed power).

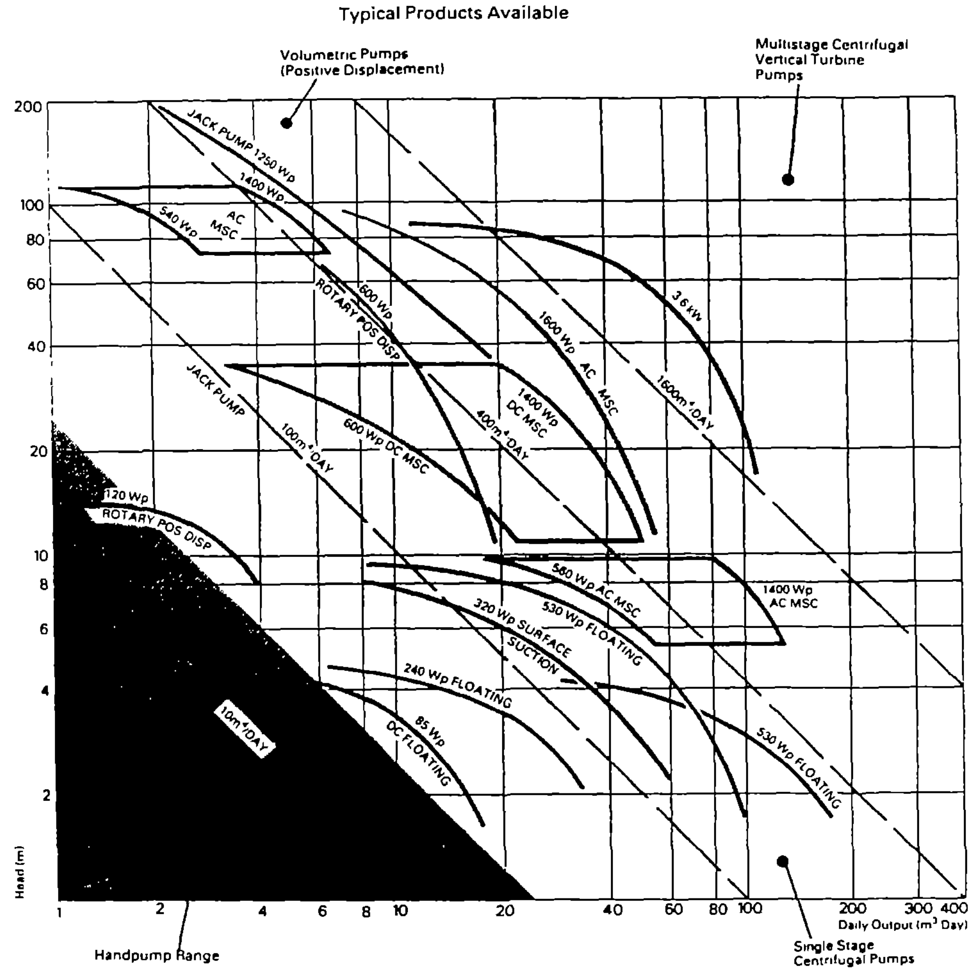

Figure 4.3 Performance of commercially available solar pumping systems (Source: 'Solar photovoltaic products' '91 [7])

The efficiency of a submersible pump with invertor is about 30-40%, giving an overall efficiency of 4 to 5% for an efficient PV-system. The life span of a centrifugal pump is about 6 years, depending on the intensity of use and the water quality (sediment, acidity). The life span of the DC/AC-invertor is sometimes very disappointing; not even a year. This technology is in full development and probably these problems will soon be solved.

The price of PV-panels is decreasing slowly. Momentarily the prices are about 4 $/Wp (ex factory, without taxes). However, the increasing prices of the other parts (partly) compensate the price reduction of the panels. (N.B. PV pump systems for large heads have even become much more expensive recently.) Complete systems will not become cheaper, unless large quantities are sold (scale effects, cash-and-carry). The ex factory prices for complete systems (PV-arrays with support, invertor and controller, submersible pump set and cables) varies at the moment from 12 to 24 $/Wp. The costs of a complete system (with reservoir), installed by an installer may come to 3 to 4 times this ex factory price!

The technology is complicated, especially for an AC system, but maintenance and repairs are relative simply. This is due to: 1) the limited need for maintenance and repairs; 2) the mechanical simplicity of the system and 3) repairing is mainly a question of replacing, especially the electronic components. With relatively simple means local mechanics can localize the defect. Generally repair will only be successful if new spare parts are available. For the time being the distribution of spare parts is a weak link.

Regular maintenance and inspection of the above ground parts is simple (e.g. cleaning the panels) and women,· generally the only people motivated, can take care of that. Without such interventions the system will continue to work (except if cables are eaten away), be it with less capacity. Maintenance and repairs of the down-borehole parts is a specialized job, which is normally only done in case of a breakdown--when no more water is pumped. This rarely happens because PV-systems (in principle) can last for years without replacement of spare parts (some types of DC-motors do need having the carbon brushes replaced every two years, which is a serious matter for a submersible pump system).

Because of the modular set up of PV-systems (panel, submersible pump, ...) and because industrial standards are met (threads, voltages, etc.), it is relatively simple to find new units even after years: other brands of units can be used.

POTENTIALS

For the time being, this pump technology will not outstrip other ('non grid') systems, although the appraisal margins for appropriateness for PV-pumps shifted remarkably from 500 m4 in '88 up to 800 m4 now. This is particularly due to:

* other systems are less reliable;
* the relatively simple maintenance and repairs (=replacement!);
* the quiet and non-polluting operation of PV-systems, independent of organic fuel.

The scale on which these pump systems will be applied in developing countries momentarily depends on external donors and the <u>eventual</u> reduction in price of complete PV-systems.

CONSTRAINTS

The most important constraints are:

* Fluctuations in solar radiance; to compensate for these fluctuations the system (especially the PV-arrays) can be overdimensioned or a reservoir, an extra prime mover (hybrid) or an alternative source can be added.
* The present high costs of purchase and replacement which largely exceed the carrying capacity of the local population. This further limits the restricted potentials of PV-systems in relation to diesel and wind, even in sunny regions.

Although the reduction of the price of the panels steadily continues, the purchase cost of complete systems seems to have stabilized. For large heads and large discharge rates especially the system can hardly compete. The investment costs are about proportionate to the wanted capacity and thus to the PV-array surface. Besides, precisely the prices of PV-systems for large heads have gone up. (Maybe in the meantime these systems have been enlarged on account of complaints from the field about the capacity, which was less than indicated?)

The panels are susceptible to damage during transport and may become an impediment to the villagers after installation.

The life span of most modern PV-systems appears to be long. But these systems are not free of maintenance: breaking panels, broken invertor, wearing (centrifugal) pump, corrosion, sensitive complex electronics and damaged cables (UV, termites). Besides, there is the risk of a stroke of lightning: one stroke may damage the whole system, including the borehole. (How much chance?) The PV-system is also susceptible to vandalism and theft. This may lead to excessive costs for the users. (Should calamities be covered by insurance, maintenance contracts or leasing contracts???)
The system involves an extra infringement on (foreign) cash reserves. For the time being, manufacture in developing countries will be of limited importance.

The technology is relative new. To prevent a permanent dependence on specialist interventions (high costs, long breakdown periods) a decent system of local mechanics and the distribution of spare parts must be realized. Only with satisfactory returns and enough systems installed, this may become profitable and thus sustainable.

Management by the village is an important condition to attain an effective and efficient management and functioning of the pump system. However, building up and managing a relative large fund for maintenance and future replacement often causes problems!

TECHNICAL RESEARCH ITEMS: specialized research; manufacturers responsability

4.3 WIND ENERGY SYSTEMS

SITUATION

Windmills may be competitive at mean wind speeds of minimally 3 m/s (calculated over periods of months) and limited capacities (up to 800 m4), especially for large heads. At higher mean wind speeds the economic efficiency strongly increases. To bridge windless periods a sizable water reservoir, a standby prime mover or an alternative water source (well, handpump, ..) is indispensable.

For larger heads (>30 m) only piston pumps and progressive cavity pumps are applied. From a technical point of view, the most simple construction is a piston pump driven by a crank drive mechanism. Its discharge rate is limited, due to the low maximum admissible pump frequency because of resonances of the water column in the rising main (just a few strokes per second). The progressive cavity pump needs a more advanced driving system. However, this pump is suitable for larger discharge rates, because much higher numbers of revolutions are admissible (as much as 1000 rpm). In consequence of its higher purchase costs this system is only profitable at higher wind velocities and larger capacities. Systems based on e.g. a wind generator (electric) and a submersible pump are too costly and too complex for this application.

Due to the large torque needed for starting piston pumps and progressive cavity pumps only slow rotating multi-blade mills can be applied.

Using windmills for (drinking) water supply is an old technology, even from great depths. Old multi-blade models are still manufactured and sold. In the past decade research on windmill pump systems has focused on the reduction of costs, simplifying local manufacture and maintenance, improving safety systems and realizing higher overall efficiencies. Higher efficiencies have been realized by (among others) provisions to facilitate the start at lower wind velocities (reduction of starting torque).
The technology of windmills in combination with piston pumps is practically

5.4. General comparison of unit water costs for different small-scale water pumping techniques

An idea of the current and future water costs of wind pumps, when compared to fuel and solar pumps, can be obtained from Figures 5.3.a and 5.3 b The figures have been prepared, using the equations presented in Appendix C, which are basically the same as those used in the cost comparison procedure presented in Section 5 2.

In the figures the unit water cost related to the pumping system (i e. excluding water source, storage, and distribution) is indicated as cost per unit of hydraulic energy, and is shown as a function of the annual average pumping requirement per day On both axes different units are indicated Energy may be expressed either as kWh hydraulic, or as m^4 (i e volume of water in m^3 times head in m, see Section 1.2, Chapter 1)

The graphs are based on the data given in Table 5 5 However, inclusion of the complete ranges of all parameters indicated in the table would tend to fill the graph completely with very wide bands of cost curves, and the distinction between the technologies would be lost. Therefore some assumptions were made for the different technologies. In a situation where these assumptions are not valid, a new set of graphs may be drawn, using the equations in Appendix C and the blank graph paper in Appendix E The assumptions made here are the following·

Engine-driven pumps

Investment	For very small water requirements it was assumed that the smallest available size of engine is used. If, for large water requirements, a larger pump set is needed than the largest available gasoline pump, it was assumed that more pumps will be used. This is realistic for suction pumps. However, if the pump is to be installed on a tubewell, this would imply additional tubewells, which is not realistic.
Lifetime	According to Table 5 5 and number of hours of operation, see below (use and application)
Maintenance and repair.	Both values of Table 5 5 are included in the range indicated in the figure
Operating cost	Fuel US $ 0 35 – 0 70 per liter, the band in the figure covers both values Operator zero (this cost is difficult to assess and in any case similar for different technologies)
Output performance·	According to Table 5 5 with efficiency of pump and lines of 40%.
Use and application	Diesel· 2000 hours per year. For 365 days of operation this means 5 5 hours per day Kerosene/gasoline 1000 hours per year. For 365 days of operation this means 2 75 hours of operation per day For very small water requirements, where the smallest available size is used, the number of hours of operation is reduced according to the requirement

Wind pumps

Investment·	Classical: US $ 400/m^2 (total, including transport, installation) Future US $ 200/m^2 For very small water requirements it was assumed that very small wind pumps are available, down to 1 m diameter. For large water requirements, requiring a wind machine larger than 8 m diameter, it was assumed that electrical systems are used, at the same specific investment cost
Lifetime.	15 years.
Maintenance.	Present 5%, Future. 3%, Fixed annual cost· US $ 50
Operating cost	Zero (this cost is difficult to assess and similar for different technologies).
Output performance·	Quality factor $\beta = \bar{P}/AV^3$· classical: $\beta = 0\ 08$, future. $\beta = 0.15$ (see Table 2.2, Chapter 2).
Use and application:	Ratio of hydraulic power demand in design month to annual average hydraulic power demand: 1.

Note that the wind speed indicated in the figure is the wind speed in the design month.

Solar pumps

Investment·	Present· US $ 18/W_p, Future US $ 9/W_p, Long term· US $ 6/W_p
Lifetime	15 years
Maintenance and repair	See Table 5 5
Operating cost	Zero (this cost is difficult to assess and anyhow similar for different technologies).
Output performance·	Average daily energy subsystem efficiency: $\eta_s = 40\%$.
Use and application:	Ratio of hydraulic power demand in design month ·and annual average hydraulic power demand· 1.

The irradiation in the design month was assumed to be 4 kWh/m^2/day, or 14 MJ/m^2/day.

Source: Wind Pumping Handbook [10]

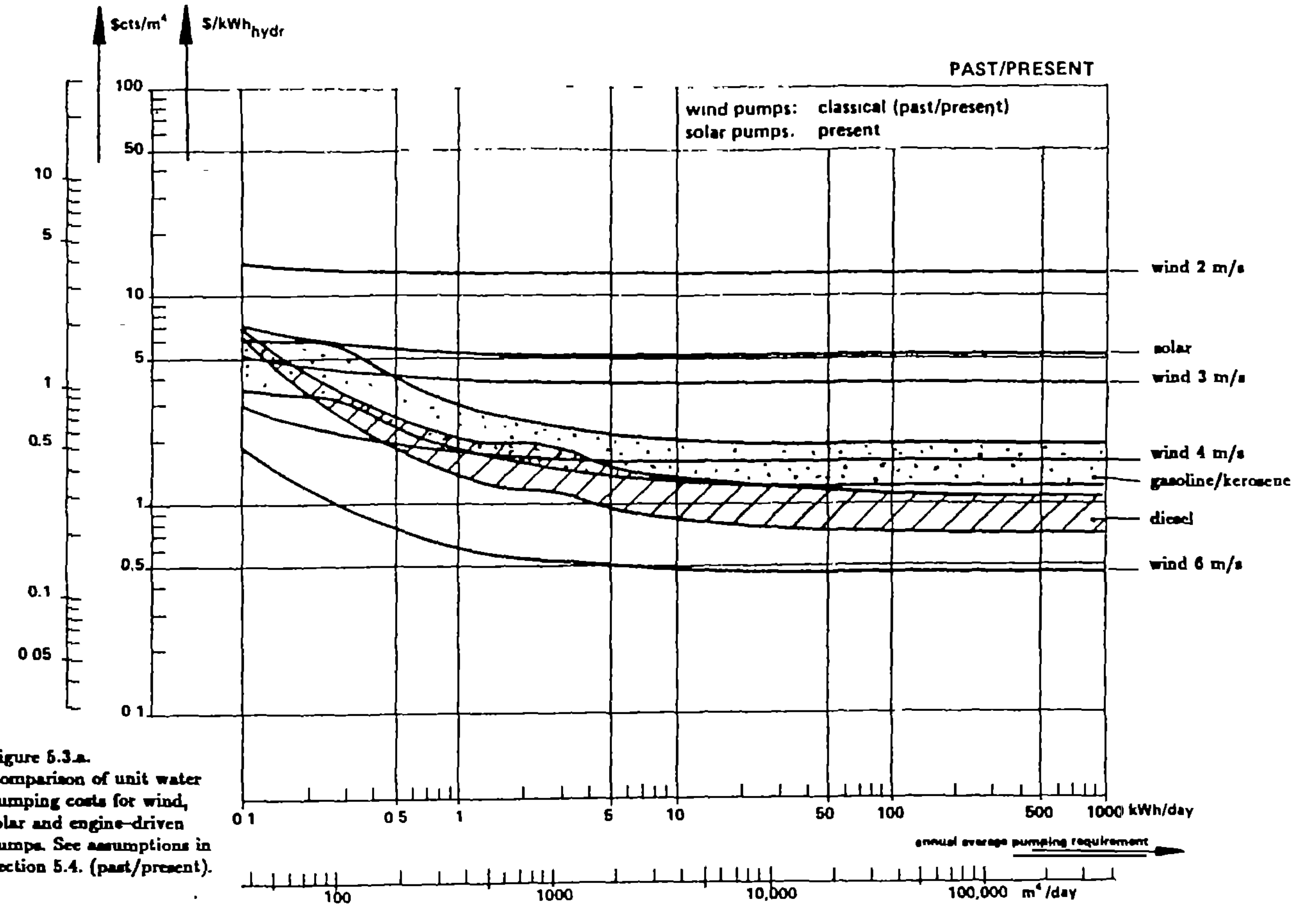

Figure 5.3.a.
Comparison of unit water pumping costs for wind, solar and engine-driven pumps. See assumptions in Section 5.4. (past/present).

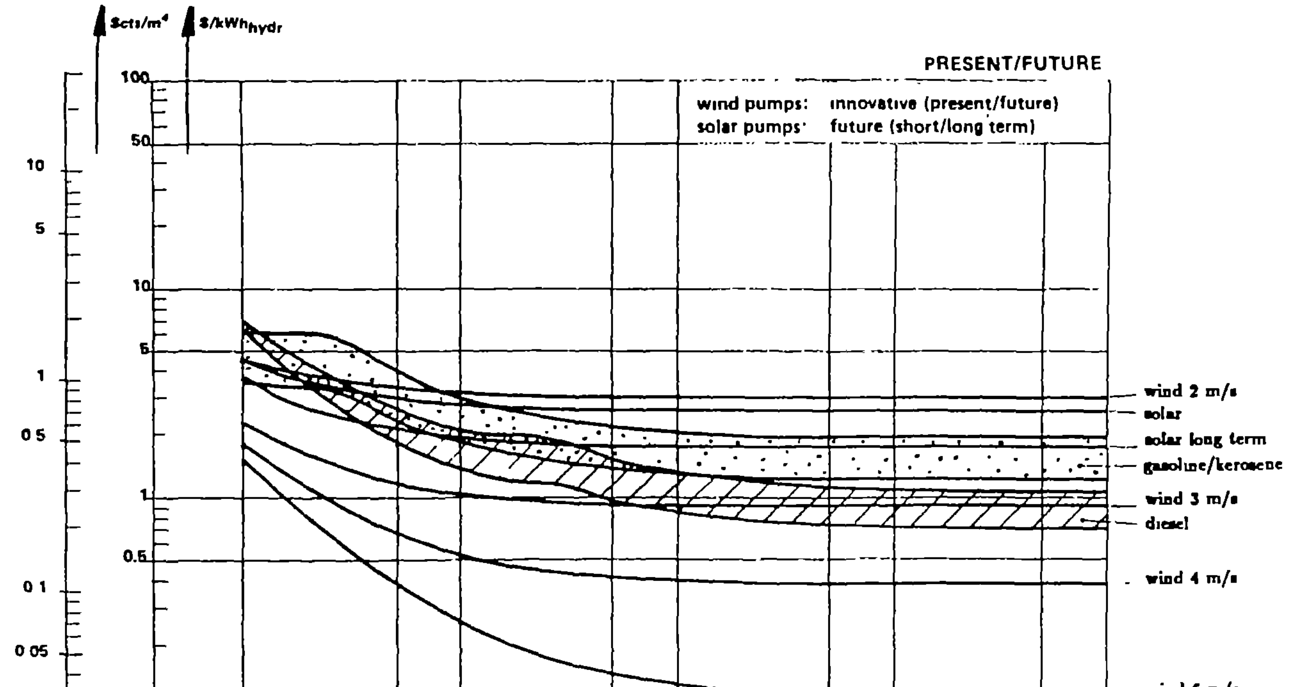

Figure 5.3.b.
Comparison of unit water pumping costs for wind, solar and engine-driven pumps. See assumptions in Section 5.4. (present/future).

Note:
Graphs are based on average values of investment costs, fuel costs, etc. Always make your own calculations based on prevailing costs in your situation

Source: Wind Pumping Handbook [10]

completely worked out. Only for large and more complex systems (hydraulic and electric) new developments can still be expected.

With regard to local manufacture developments are still possible, like: better adapted designs, batch production (at increased demand), improved quality control and lower costs. PV-systems, diesel generators and submersible pumps are high-tech, mass produced and tested in the factory. Windmill manufacture, on the contrary, involves a classic method of metal work (piece-work) in which quality control is generally underdeveloped, though every weld is of great importance because of the high fatigue loads and the enormous forces during storm. Besides, the first complete assemblage and testing only takes place after final installation.

The wind energy systems have become more reliable. However, an essential condition is: qualified and timely maintenance.

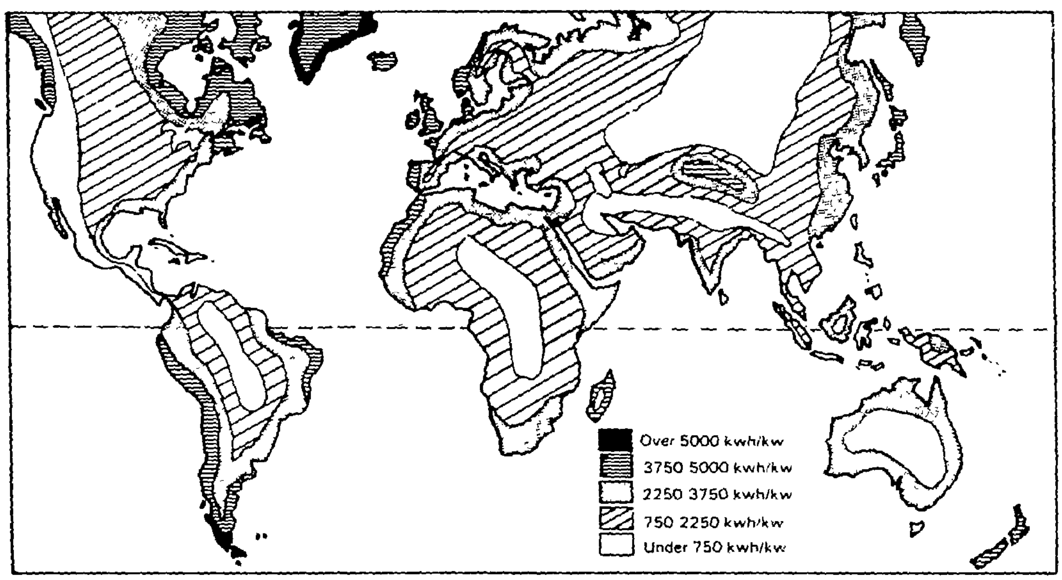

Figure 4.3 Annual mean wind speeds (approximate indication) (Source: 'Water pumping devices' [9])

POTENTIALS

In places with mean wind speeds of more than 3 m/s during the whole year (calculated over periods of a month), a windmill pump system may be the best solution. This is the case in many developing countries situated on the coast.

Yet, although windmill pump systems:
* are clean in application and use a free and clean source of energy;
* consist of simple technology (straight forward mechanical system);
only a limited growth of the installed capacity in developing countries is to be expected for drinking water supply in the short term.

Auto-dissimination is out of the question, except for commercial private use. However, that is only profitable at small heads: irrigation.

Donors and implementation projects could try to alter this situation.

CONSTRAINTS

Wind is an inconstant and limited source of energy and necessitates an extra prime mover (hybrid), a water reservoir or an alternative water source. The wind force strongly varies with the location. Windmills need space and a free air current. Generally the best location for a windmill is not the right place for a borehole.

Where people are not used to windmill pump systems, it will not reach a large scale application. (Even where it used to be the case, windmills are disappearing.) Why?

* The costs are too high for the users, especially of maintenance and repairs (although the initial costs are generally lower, compared with PV-systems, and born by the donors);
* Its disappointing sustainability, due to:
  * lack of the necessary maintenance discipline;
  * the great risk of damage and of protracted out of order due to:
    - storm damage: sensitivity for storms, in spite of safety systems;
    - damage caused by lightning: sensitivity for strokes of lightning because of the large height and the steel construction;
    - sensitivity to inexpert maintenance/interventions (e.g. putting the safety system in disuse);
* The alternatives are too inviting due to their modern image: diesel, solar.

A motivated management committee and/or mature direct parties concerned is an important condition for regularly executed (preventive) maintenance. Without this the windmill system risks being ruined completely. Probably because necessary maintenance is not carried out on time, many windmills break down. Major damage cannot be quickly repaired on the spot, so the system will be out of use for quite some time. Due to the small number of windmills and the lack of standardization the spare part supply remains problematical.

N.B. A windmill is a typical 'male' technology. Women, generally the only party directly concerned, 'don't know anything about it'. They cannot climb into the tower to form a picture of the situation and therefore depend completely on men, who often don't give a damn. Besides, the villagers are dependent on the mechanic, even if they don't trust him or find him incompetent.
Without regular inspection nobody will notice the slow break down of the windmill or the pump (in contrast with e.g. a handpump). Only after the system stops giving water and the damage is already considerable, they call for the mechanic. The importance of preventive maintenance is often underestimated by the management committee as well as the mechanic. But even if the mechanic proposes to replace parts preventively, the committee prefers to wait until the system is really broken down (stopped pumping water). They are afraid the mechanic only wants to line his pockets! Sad to say that repairs are often badly done.

The management of funds for maintenance and future replacement is a difficult task.

The transport of the system is problematic: a lot of materials and a wide three-dimensional construction. This is of extra importance with regard to future replacement by the village.

The intermittent working piston pumps are sensitive to the resonance frequencies of the water column. These intensify the fatigue load, which may result in fractures, especially after inexpert repairs.

TECHNICAL RESEARCH ITEMS: Adapting windmill designs to local manufacture.

4.4 COMBUSTION ENGINES: DIESEL

SITUATION

Diesel engines are available with a capacity from about 3 kW. To prevent premature wear the engine normally is derated to about 2/3 of its maximum power. The smallest diesel engine is powerful enough for pump systems with a daily volume times head of 2000 m4. For smaller capacities a few hours running a day is sufficient. A water reservoir is required to be able to tap water during the whole day. Water output can be adapted to the needs, independent of the weather conditions (sun, wind).

Stationary diesel engines for deepwell pump systems can be divided in:

* low speed engines: heavy, durable (up to 20,000 hours), maximum 1200 rpm (e.g. 'Lister');
* high speed engines: compact, cheap in purchase, less durable (up to 8,000 hours), up to 3000 rpm;
* water cooled or forced air cooled (noisy).

Transporting, installing and replacing a diesel engine is relative simple.

The present efforts are mainly focused on the improvement of production technologies and on the reduction of the need for maintenance. For these small stationary diesel engines developments related to the reduction of noise and pollution of air and ground are minimal (spin-off excepted).

Most mechanized pump systems are 'diesel-electric': a 3-phase AC generator, directly built on to the engine, provides a centrifugal submersible pump with current. In anglophone countries mechanically driven rotary positive displacement pumps are also used. Both systems require little space. For very large depths (and limited discharge rates) mechanically driven piston pumps are also used, because of their high overall efficiency.

Suitability and reliability depend on (apart from the quality of the installation):

* the regular availability of diesel oil and its quality;
* adequate supervision and frequent (preventive) maintenance to prevent running dry of the diesel engine and the pump; this depends on the operator, the mechanics, the spare parts and material supply;
* funds for running costs: this depends on the socio-economic situation and the management by the village.

Compared to a solar or wind energy system the investment costs for a diesel system are generally lower. This is due to the large numbers of diesel engines sold and the limited quantity of relatively cheap parts it consists of. On the contrary the running costs of a diesel system are many times higher, due to the price of fuel, more frequent maintenance and repairs and the necessity of an operator. The expected rise of fuel prices on the world-market as a result of expected scarcity has not occurred. The worldwide stock of fossil fuels isn't at all depleted, so for the time being diesel pump systems will remain competitive.

In the countryside of most developing countries a wide experience with diesel engines exists. Although a diesel engine is a complex piece of technology, maintenance does not have to be problematic if engines of well-known trade-marks and models are applied. Often there is a brisk trade in new and second hand spare parts and a great deal of experience with overhaul. In several developing

countries spare parts for these engines are locally made.
Diesel engines need regular maintenance. But in case of back repair they may also run for a long time--their capacity will gradually decrease while fuel consumption may double. However, back maintenance will generally cause great damage to the engine.

POTENTIALS

The steady growth of the number of diesel pump systems will continue. For the time being in many cases sun and wind pump systems form no real alternative.
For the time being, increasing costs of fuel and more stern environmental regulations will not have a negative influence.

To the village throbbing diesel engines are a clear evidence of progress, which supports the management committee in its task. The frequent call for financial means (a.o. for running costs) stimulates the involvement of the village, which may result in a proper management of the funds (and supervision thereupon).

Future replacement of the system at the expense of the village remains a weak link in sustainability.

CONSTRAINTS

Generally a diesel pump system means:
* high running costs, at the expense of the users and a negative cash flow for the village and the country;
* an increased dependence on import of fuel and spare parts;
* an extra burden for the environment.

The operation of the diesel engine requires a motivated and capable operator. A diesel engine requires a lot of maintenance and is sensitive to back maintenance, possibly resulting in great damage (running dry of the engine, short-circuiting, etc.).

In case of a non standard model diesel generator, there is a large chance of a prolonged breakdown period, due to a faulty spare part supply.

Due to the high running costs the village has less means to save for future replacement of the system.

TECHNICAL RESEARCH ITEMS: non

4.5 ANIMAL TRACTION SYSTEMS

SITUATION

For smaller heads several traditional systems and mechanisms do exist. Most systems for large heads consist of hardly more than a bag, a rope and a pulley. The animals are alternately walked from and to the well in a straight line. The dragging rope sweeps dirt into the well--as a consequence the water in the well no longer deserves the name of drinking water. For a borehole this system is hardly of interest due to its limited discharge rate. (N.B. At an open well several women may lift water simultaneously and/or several animal traction systems may operate.)
The very few modern and advanced systems for large heads have a higher overall

efficiency, but the investments are correspondingly high. The capacity of these systems is limited to 1000 m4 and is usually based on a carousel.

An animal traction system demands a continuously available operator and several teams of animals as relief and standby. The animals need to be tended well the whole year.

The running costs may rise considerably, particularly due to the costs for the operator and the animals, even in case of a system with limited capacity. The economic efficiency of a modern system is not necessarily better than of a traditional system (apart from a more effective use of the borehole). On the other hand, these funds stay in the village!

In places where animals are not traditionally used for water supply, modern animal traction systems also stand little chance, due to cultural barriers and the lack of the 'developed' image. Many existing animal traction systems are replaced by modern fully mechanized systems (diesel, ...).

Animal traction systems are a clean and simple mechanical technology. Usually there are enough standby 'prime movers' available.

Modern communal pump systems probably use privately owned animals to draw water. Otherwise the animals risk getting insufficient rest and care. This may lead to social tensions and closing down of the system.

POTENTIALS

The number of modern animal traction pump systems for communal drinking water supply from deep wells/boreholes will probably not increase much.

CONSTRAINTS

A carousel system monopolizes a great deal of space around the borehole/well and thus limits the discharge rate. The capacity is limited to 1000 m4 by the animal traction system.
The running costs are considerable and can hardly be reduced. The animals need to be well cared for throughout the year--what are the possibilities for that: feed, medical care, water rate, knowledge and motivation.

There are hardly any designs for efficient animal traction pump systems for large depths, which are maintenance poor and suitable for local manufacture.

Animal traction systems lack a modern image. Whether this can be altered is open to doubt.

TECHNICAL RESEARCH ITEMS: ?

4.6 HYBRIDS

SITUATION

Possible reasons to choose a hybrid:
* increasing the availability of the drinking water supply by an extra prime mover as standby;
* increasing the capacity of the pump system and the borehole by pumping for

more hours a day, a week... (in the absence of sun or wind, or to set off a temporary greater need for water);

* reducing the costs of the system:
    * satisfied with a smaller or even no reservoir, a smaller windmill or less PV-panels;
    * limiting the necessity of an alternative water source;
* it has the function of a safety net: if by lack of means (money, spare parts) the main prime mover cannot be repaired or replaced, the system is still serviceable (to avoid losing the whole investment).

N.B. The running costs of a hybrid system may be much higher.
Adding a second prime mover will complicate the system.
When a system choice is made, the consequences for the initial investment costs (for the donor) as well as the running costs (for the users) should be considered.
For large communities and in situations without a decent alternative water source, a hybrid may be indispensable.

Two types of 'hybrids' (hybrid in connection with the drive) appear to be technically viable:

* for large systems (>1000 m4) like a PV-system or a wind generator: a diesel generator as standby;
* for small systems: a (hand)pump system, driven by sun, wind, diesel or animal traction, with the possibility of manpower as substitution or support.

Other combinations hardly occur.

Large hybrid systems with an electric system (PV+diesel) permit a simple coupling of both prime movers (alternately) to one submersible pump. In case of a mechanical drive this is difficult and less inviting.

Three approaches exist for small systems:

* a handpump with a prime mover, or
* a handpump coupled with a mechanically driven pump, or
* a mechanically driven pump system with the possibility of lending a hand or (temporarily) substituting the main prime mover.

A few examples:

* a Volanta-pump, driven by a small diesel engine by means of a flat belt;
* a SWN-pump, to which an electric submersible PV-pump system is coupled;
* a Pulsa-Solar, a flywheel version of the Pulsa hand/foot operated pump, PV-electrically driven;
* a Volanta-pump, in which the superstructure is (temporarily) disconnected, driven by a windmill.

From the point of view of management and maintenance these systems are a simple upgrading of handpump technology. If required, it is easy and not at all dramatic to fall back on manpower. Without too much risk the capacity of a borehole and a handpump can be increased (a more expensive(?) solution is the installation of a second borehole with handpump). Besides, the system offers more comfort. In practice the maximum head is about 40 m, although piston pumps (may) have a deeper reach.
For a hybrid system partly based on manpower, it is probably unrealistic to count on more than 300 Watt gross manpower per system--3 to 4 people pumping together by hand. With 'legpower' (like cycling) two persons might already realize the same power level. These levels can be generated for many hours, when pumping continuously in a relay system.

Concerning the drive, several handpumps are prepared for larger capacities. The

effectively absorbed power of other pumps could be adapted with a few changes to the drive mechanism and the piston stroke or diameter. As a result these pumps can no longer be operated by only one person.
The increase of the capacity of the handpump is probably profitable if the well or borehole has sufficient capacity and the pump is (mechanically) prepared and suited. Hybrids based on handpumps have the same kind of technical problems as normal handpumps, probably even more because they are used more intensively. Maintenance of such a system could also be performed by local mechanics, if they are properly instructed.

POTENTIALS

For many large systems adding a small diesel (generator) as standby may be indispensable.
For small but fast growing communities (<1000 people) upgrading their handpump by adding a mechanical prime mover may be a useful compromise.

CONSTRAINTS

Hybrid systems are more complex and increase the dependence on imported technology. If a broken down prime mover is not repaired immediately, the effect of a greater reliability is annulled to a large extent. This may too often be the case.

Driving a handpump mechanically may only increase the discharge rate 2 to 3 times. Its capacity will not exceed 1000 m4.

Development and fieldtesting of small hybrid systems is backward, so the systems have not yet proven themselves.

TECHNICAL RESEARCH ITEMS: development + fieldtesting of small hybrid pump systems

4.7 MANAGEMENT

Not technology but faulty management is often the cause of the decay of a mechanized drinking water supply. The importance and problematic nature of proper management has been underestimated for a long time.

The tasks and responsibilities for running a mechanized pump system consist of among others:
* organizing and supervising operations, correct use, maintenance and repairs;
* organizing cost recovery and administration, for maintenance, repairs and future replacement;
* management of funds.

These tasks and responsibilities are not necessarily in the hands of one management team. There are several options:
* management by a (semi-)governmental service;
* village level management (VLOM);
* commercial boarding out of the management of the system.

In the first case the (semi-)government owns the system, in the second generally the village. Supervision on boarding out may either be the responsibility of the government or of the village (committee), the respective owner. Especially commercial boarding out is a matter of divided (delegated) responsibilities.
Each variant has its own problems and potentials:

1 Management by a (semi-)governmental service:
* the service may dispose of the necessary capacity and means,
but:
* the distance to the village is long, resulting in communication problems, travelling times and expenses, minimal involvement of the service and thus long breakdown times;
* the village fully depends on the bureaucracy, the people responsible are not approachable or cannot be called to account, the village can easily be blackmailed by maintenance teams;
* this is an expensive solution for the country: highly paid people and high overhead and travelling expenses;
* when the means of the service decreases, a whole range of systems will collapse; 'near is my shirt, but nearer is my skin';
* the limited availability of the system will lead to problems with the village: their refusal to pay, certainly in case of water rate increases, will result in bad maintenance and the system (further) degrades;
* by lack of user involvement there will be no social control in case of misuse, theft, vandalism, ...

The official approach with e.g. a full time operator, paid according to official scales, often leads to a deficit of the system.

2 Management by the village (committee) (VLOM):
* great involvement of the village in their system, there will be dedication and social control;
but also problems, due to:
* a possible lack of manpower: no management capacities, a failing financial management, lack of technical knowledge;
* socio-cultural problems in the village, possibly leading to non-payment, to sabotage and to problems with the nomination of the management committee;
* assistance based on voluntariness: apart from moral pressure hardly any sanctions exist;
* a wait-and-see attitude as well as a lack of financial means: important in case of calamities and replacement of the system;
* external influences like politics, economy and climate.

3 Management boarded out to a commercial enterprise:
* direct financial self-interest is the basis of their involvement (in the short term);
* the responsibilities are clear: two parties, business agreements, no voluntariness, sanction instruments;
* used to take initiatives to improve exploitation;
but also:
* without adequate agreements and control the situation may get out of hand: forcing up of prices, neglecting system maintenance (short-term interest), non-fulfillment of (financial) obligations, abuse, mutual blackmail, etc.

The trend is to hand over more responsibility to the users: VLOM (management on village level, either by a committee, or with a commercial boarding out of, for example, operation, sale of water and/or maintenance). For small, often isolated communities this is generally the only practical solution, and for the village as well as for the country the only affordable one. However, aiming at VLOM including the future replacement of the system at the expense of the village is not always realistic. The two last mentioned management types probably have the highest availability at the lowest costs.

In case of VLOM, the contribution of the government should be:
* to take the initiative, regulate, supervise, but not: manage, repair nor man

the pump system;
* temporary (financial) support in case of major problems (management level, calamities);
* if necessary:
  * take the initiative for the maintenance of the borehole;
  * funding (or fund raising) for the future extension or replacement of the system.

Involvement and the role of women:

In spite of their considerable contribution to the village water supply, women are rarely involved in the management of the water supply system, certainly not when management is exerted by the government. Usually, in the case of VLOM and outboarded management, women may en bloc enforce their contribution, for example by striking. Direct participation of women in the management committee often has to be gained with outside help (by the government, donors, or the implementation project).

Sometimes, in case of a crisis of confidence between the men and the women of the village with regard to the management of the funds, the solution is two separate cash boxes.

Due to socio-cultural discrimination, women usually have insufficient understanding of the technical aspects of the system. That is why their contribution to the operation of the system is generally marginal: sweeping the pavement and possibly selling water at the tap.

There is a good chance that particularly women will foot the bill for their family for water tapped from the system. This is especially the case if water is paid in retail. Women who sold water in the village will partly lose their income, namely for drawing or pumping water from the old water sources.

Exploitation of the system and management of funds:

The running costs of the mechanized system are often much higher than anticipated at the time of installation. Earnings from the sale of water often disappoint, for example because many villagers continue to use the old sources for a sizable part of their water consumption (nearer and cheaper, better tasting, out of habit). Besides, it is difficult to make such an investment really profitable. For horticulture, for example, the water is generally too expensive. Moreover, a limited availability or a too limited discharge rate are extra handicaps.

The price fixing is a delicate question, certainly when good alternatives exist in the village. A price experienced as too high will drive away the customers, resulting in even higher prices: the upward price spiral. Moreover, during the changeover from a handpump or well to a mechanized 'alternative', suitable opening hours and an introduction rate is desirable to attract customers.

Management and saving of considerable public funds often leads to problems. This is caused by, among others, the lack of experience to manage so much money, the social pressure to pay for other urgent needs and the high 'costs' attached to saving or exploiting the funds:
* in case of saving on a bank account: inflation, travelling and accommodation expenses, fees for the bank, bankruptcy of the bank, ...;
* in case of trading/investments in kind: costs of transport, pesticides for storage, storage costs, losses/depreciation/theft;
* in case of loans within the village: the great chance that the borrower cannot or does not want to repay.

Some villages have realized a surplus and a fund for social activities in the village. In most cases a lasting dependency on the government/donor has been created: as safety net in case of calamities and as technical adviser in case of reconstruction and extension. Many management problems originate from a failure in sensitization and training of the village population.

N.B. The management of old water sources remains an important task, as a buffer in case the mechanized system breaks down!

CONCLUSIONS

VLOM is most promising for sustainable drinking water supplies in small villages, especially once women play a larger role. To attain this situation support from outside the village is necessary, especially from implementation projects (sensitization and training).
The extension and future replacement of the system at the expense of the village momentarily has little chance of success due to the relatively high costs and limited means of the village. Technical and credit support may improve this situation.

4.8 CONCLUSIONS + SUMMARY

In the past decade the technology of the differing mechanized water pump systems for larger heads has improved considerably. Further technical improvement of the systems is difficult, except in the case of animal traction systems and small hybrid systems in which development is retarded.

Problems with the management of the system, with spare part supply and with financing are presently the main obstructions for a better availability. VLOM, with/without a commercial boarding out of the (daily) management, offers the best perspectives for the management of these systems.

For the time being future replacement at the initiative and expense of the users will remain an illusion in most cases, except for some handpump and animal traction systems. Multiplication of the systems will only be realized with external financial inputs, as auto-dissemination is not likely.

The main factors that play a role in the choice of a system, are: the local availability of sun, wind and diesel oil, the total head and the discharge rate, the initial and running costs, the experience with and the image of the system concerned. But also national and bilateral political pressure play a role.

Experience indicates that for:
* systems with a daily volume times head of more than 2000 m4: use diesel;
* an average wind speed of less than 3 m/s over the least windy month: a windmill system is not appropriate;
* a minimal average daily solar radiation of less than 3 kWh/m2/day during the darkest month: a PV-system is not appropriate.

No mechanical pump system stands out for several of the abovementioned reasons. It is therefore impossible to make a simple division or selection based on e.g. only the head. In all considered systems variants exist for heads up to 100 m (in principle). For small discharge rates and large heads piston pumps can be applied. For large discharge rates only multi-stage centrifugal pumps (electric submersible pumps) are applicable.

In the future limited reductions of the initial and running costs can only be expected of PV-systems. Gradually PV-systems will monopolize a major part of the market for mechanized pump systems.

In table 4.2 the main factors for the selection and judgement of the systems have been summarized.

#

ASPECTS	HANDPUMPS	SOLAR PV PUMPS	WIND PUMPS	DIESEL PUMPS	ANIMAL DRIVEN PS.	HYBRID SYSTEMS Handpump + ...	Sun/wind + diesel
Initial costs	low	very high	high	medium - low	medium	medium	high
Running costs:							
- operation	low	zero	zero	medium	high	low	low - medium
- fuel	zero	zero	zero	high	zero	zero	medium
- maintenance	low	low - medium	low - medium	high	medium	medium	high
Installation:							
- prime mover	-	complex	complicated	medium	simple, daily	medium - complex	complex
- pump unit	simple	medium - simple	simple	medium	medium	simple	medium
Operation	continuously	unattended	unattended	intermittent	continuously		intermittent
Max output	very limited	medium	medium	unlimited	limited	limited	high
Water storage	no need	essential	essential	essential	limited need	limited need	essential
Heads	< 100 m	< 100 m	> 100 m	> 100 m	> 100 m	< 100 m	> 100 m
Daily vol. times head	< 400 m4	< 1000 m4	< 1000 m4	unlimited	< 1000 m4	< 800 m4	< 2000 m4
Life expectancy:							
- prime mover	-	very long	long	short	short	medium	long and short
- pump unit	short - medium	long	medium - long	medium - long	short - medium	short	medium - long
Maintenance	easy	complicated	medium	complicated	medium	medium - complex	complicated
Sensitivity for:							
- lack of maintenance	limited	limited	high	high	medium	medium	high
- bad maintenance	limited	high	high	high	medium	medium	high
- calamities	low	high	high	low	medium	medium	high
- theft	low	high	low	medium	medium	high	high - medium
Sustainability	high	mediocre	low	mediocre	high	mediocre	low
Constraints	limited output	very costly	wind, maintenance	running costs, fuel	r-costs, image	costly	costly
Potentials	good	mediocre	limited	mediocre	limited	mediocre	limited
VLOM chances	good	mediocre	limited	mediocre	good	mediocre	limited
Pollution	no	no	no	yes	no	no	mediocre
Replacement by village	realistic	illusion	illusion	imaginable	realistic	imaginable	illusion
Women participation.							
- operation	yes	yes	no	no	no	yes	no
- maintenance	yes	yes	no	no	no	yes	no
- repairs	exceptionally	no	no	no	no	no	no
Availability	reasonable	good	reasonable	reasonable	good	reasonable	good
Scale back potential	-	sun -> diesel	wind -> hand	no	animal -> hand	just by hand	abandon one pm
Image of system	neutral	modern	dubious/modern	modern	dubious	modern	modern

5 FINAL CONCLUSIONS

The aim of the desk study was to provide an inventory of the problems concerning pump systems for the drinking water supply for rural communities in developing countries: villages with 300 to 2,000 inhabitants where water has to be pumped from deeper water levels (20 to 100 meters in depth). Handpumps were compared with 'stand-alone' systems with a prime mover based on solar energy, wind, diesel or animal traction or a combination of these ('hybrids').

1 The study yielded scarcely any new (field) data. A justified evaluation and comparison of the different systems was therefore impossible, in particular with relation to the actual availability of the systems and the costs. Its results are mainly of qualitive value and so its objective was only partially realized.

2 The reliability of handpumps has increased considerably over the past decade. However, at a large installation depth the reliability decreases strongly, mainly due to fatigue. Besides, only few of the handpumps with plastic rising mains are suitable for very large heads, because of the strongly reduced discharge rates. Therefore most manufacturers only guarantee their pumps for heads up to about 50 meters.

3 The availability of modern handpumps is now mainly limited by:
   * inadequate management and quality control at the (local) manufacture of pumps;
   * deficient preparation and execution of implementation;
   * villagers, unprepared to manage and maintain the pump, due to lack of proper sensitization;
   * no spare parts supply and no mechanics;
   * problems with the borehole;
   * lack of means to replace the handpump (in due time).

   For most of these problems solutions are available. Serious execution of the various tasks will generally comply with the needs.

4 The technology of the differing mechanized water pump systems for larger heads has improved considerably. Further technical improvement on the systems is difficult, except in the case of animal traction systems and small hybrids in which development is retarded.
   Problems with the management of the system, with spare part supply and with financing are presently the main obstructions for a better availability.

5 VLOM, with/without a commercial boarding out of the (daily) management, offers the best perspectives for the management of these systems, especially once women play a larger role. To attain this situation, support from outside the village is necessary, especially from implementation projects (sensitization and training).

6 The extension and future replacement of the pump systems at the expense of the village momentarily has little chance of success due to the relatively high costs and limited means of the village, except for some handpump and animal traction systems. Multiplication of the systems will only be realized with external financial inputs, as auto-dissemination is not likely.

7 The main factors that play a role in the choice of a system, are: the local availability of sun, wind and diesel oil, the total head and the discharge rate, the initial and running costs, the experience with and the image of the system concerned. But also national and bilateral political pressure play a

role.

8 Experience with mechanical pump systems indicates that for:
* systems with a daily volume times head of more than 2000 m4: use diesel;
* an average wind speed of less than 3 m/s over the least windy month: a windmill system is not appropriate;
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9 No mechanical pump system stands out for several of the abovementioned reasons. It is therefore impossible to make a simple division or selection based on e.g. only the head. In all considered systems variants exist for heads up to 100 m (in principle). For small discharge rates even with large heads piston pumps can be applied. For large discharge rates only multi-stage centrifugal pumps (electric submersible pumps) are applicable.

10 In the future limited reductions of the initial and running costs can only be expected of PV-systems. Gradually PV-systems will momopolize a major part of the market for mechanized pump systems.

11 Problems requiring technical investigations (eventually with DGIS support):
* the development of a simple means to examine boreholes;
* how to reduce the cost price of handpumps drastically;
* the development of lasting joints in PVC rising mains[21];
* the development of small hybrids.

Most other technical problems are dealt with by the manufacturers of the differing systems and independant research institutes.

12 An important non-technical research item: an evaluation of recent experiences with village level management of these systems.

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21 CRL is looking into this.

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FINANCIAL AND SOCIO-ECONOMIC ANALYSIS OF DRINKING WATER SUPPLY SYSTEMS

A desk-study of financial and socio-economic
aspects of deepwell hand pumps
and alternative small scale
drinking water supply systems.

Ferry van Wilgenburg

August 1991

Human Settlement Economics

NETHERLANDS ECONOMIC INSTITUTE

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1. INTRODUCTION

Next to a technical analysis of drinking water supply systems in developing countries a financial and socio-economic analysis is necessary, in order to consider the impacts for all parties concerned (e.g. users, local/national authorities). Appraisal of water supply projects (both ex ante and ex post) is performed by means of a cost-effectiveness analysis. The analysis described in this section consists of a financial and a socio-economic part.

The financial approach is an analysis from an private point of view (i.e. the project promoter). Financial analysis typically relates cash inflows to cash outflows to see whether a project can meet its annual cash requirements (= liquidity analysis), and whether the various sources of finance involved will yield an acceptable financial return (= profitability analysis). Financial analysis moreover considers aspects like revenues and expenditures, user charges and cost recovery.

Socio-economic analysis takes the point of view of the nation as a whole. It takes into account that revenues and expenditures (as described in the financial analysis) often are an incomplete measure of the project's benefits and costs to society. It differs from financial analysis in types of effect taken into account (external effects, linkage effects etc.) and valuation (pricing, including the rate of discount).

The main subjects of this report are:

a) comparison of deepwell hand pumps and alternative small scale water supply systems (diesel, solar energy, wind energy and animal traction) on financial and economic aspects;
b) evaluation of the organisational, financial and socio-economic impacts of these water supply systems on parties involved like water users, water boards and authorities;

The report focuses on water supply from great depths.

In chapter 2 the financial aspects of deepwell hand pumps and their alternatives are discussed. Chapter 3 reviews possible socio-economic costs and benefits of the water supply systems. Organisational and cost recovery aspects are highlighted in chapter 4. The findings of chapters 2 to 4 are summarized in chapter 5, which makes some concluding remarks on aspects of deepwell hand pumps and alternative small scale water supply systems. Technical economic terms used in this report will be explained in the appendix I. In appendix II an example is given of the outcome of a cost-effectiveness analysis and sensitivity analysis.

Considering a) the wide scope of the water supply systems discussed given their location and project specific character, and b) the limited availability of data on deepwell pumping and their contradictionary character, figures and conclusions presented in the report should only be considered indicative.

2. FINANCIAL ASPECTS

2.1. General remarks

The financial analysis is used in order to be able to make a comparison between different systems. Where financial cost-benefit analysis shows what project is justified from a financial point of view, by comparing discounted cash inflows and outflows, financial cost-effectiveness analysis is used to select the cheapest option by looking at the cost side of the different systems only. Cost-effectiveness analysis is to be applied at sites where a certain production level is needed (e.g. because of consumption per capita). By calculating discounted cost per m^3 of water produced, it is possible to rank systems.

In order to compare costs per m^3 of different water supply systems a distinction must be made between capital (initial investment) costs and operating and maintenance (O&M), or recurrent costs. Table 2.1. gives a general overview of the general components of both capital and O&M costs.

Table 2 1· Capital and O&M costs of a water pumping system

Capital costs	land
	site preparation
	foundations
	pumping equipment
	storage tank
	power supply equipment
	prime mover (e.g. diesel engine, electric motor)
	pipework and appurtenances
	installation and mounting (e g transport, labour)
O&M costs·	consumables (e.g. fuel, lubricants, fodder)
	salaries and wages
	spare parts and replacements

Source: Hofkes, E.H e a. (1986), p p. 31

In order to establish a lifetime approach, operating and maintenance costs will have to be discounted over the economic lifetime of the system, in order to make them comparable to capital costs; since recurrent costs appear in the future they can not be compared to capital costs directly. By discounting the recurrent costs, by means of the discount rate[1], their present value is calculated. In that way they are comparable to capital costs. By combining discounted total and O&M costs and the yield of the system cost per m^3 can be calculated.

In discussing the financial aspects of (deepwell) hand pumps and their small scale alternatives, we assume that the costs for drilling the borehole (either by hand or drilled) will be more or less the same for hand pumps and their alternatives. These costs are therefore not considered in this report.

[1] The prevailing project-specific real (i.e. inflation adjusted) interest rate may be used as the discount rate. Otherwise discount rates between 8 and 15% are considered for developing countries by the World Bank.

Table 2.2: Initial investment and O&M aspects of different water supply systems compared

Energy source	Type of pumping device	Frequency of maintenance attention[2]	Technical skills[3]	Frequency of back-up support required[4]	Level of back-up support required[5]	Capital costs	O&M costs
human energy	deepwell handpump[6]	medium/ high	medium	medium/ high	medium/ high	medium	high
diesel fuel	diesel engine	medium	medium	medium	high	medium	high
solar energy	solar photo-voltaic	low	high	low	high	high	low/ medium
wind energy	commer-cially manufac-tured	low	medium	low	high	high	low
	village level product	high	low	low	low	low	medium
animal energy	animal traction	high	low	medium	medium	low/medium	medium

Source: Hofkes, E.H. (1986)

In table 2.2. the differences between initial investment and O&M aspects of (deepwell) hand pumps and alternative small scale water supply systems are presented. This table may be seen as a rough summary of paragraphs 2.2. - 2.6.

2.2. (Deepwell) hand pumps

The common characteristics of hand pumps are that they are easy to install, operate and that they are cheap. A few decades ago hand pumps used in developing countries were copies from those used in the western world. Because of problems like fatigue (corrosion, extensive use) and high capital and recurrent costs, initiatives were undertaken to develop appropriate hand pumps; low-cost, long

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2 Low, once a month; medium, once a week; high, daily

3 Low, locally trained villagers; medium, trained operators (local mechanics, carpenters, blacksmiths); high, qualified technicians

4 Low, once a year; medium, once every 3-4 months; high, once a month

5 Low, local mechanic; medium, specially trained mechanic; high, qualified technician

6 Given the present state of technology

lasting pumps requiring little maintenance. Several countries (e.g. India, Bangladesh) developed their own hand pumps (India Mark, Tara) in order to offer a low cost alternative for hand pumps designed in western countries. This local production reduced capital costs of hand pumps considerably - because of design, low wages and the prices of local resources - compared to the 'western' pumps, but maintenance still remained a difficult issue. By involving users (e.g. at community or village level) in the actual planning, construction and operation, maintenance costs, often caused by negligence and ignorance, could be reduced.

Problems arise when water has to be pumped up from great depths. This may be needed because of given geographical/ natural circumstances (deserts), or because of a fallen water table (long period of drought, 'over use' of water). Water supply from deep wells will be more costly than water supply from shallow wells. There are several reasons for this cost increase:

A) The yield (m^3/hr) an average person can draw from a well is shown in table 2.3. Yield decreases with increasing depth for equal power input. The water delivery rates in litres per minute (Q^dpm) are influenced by power input W^p (50 Watt), the mechanical efficiency of the hand pump E, (50%) and the pumping lift H:
(Q^dpm = $6W^pE/H$).

Table 2.3: Yield (m^3/hr) drawn from a well by an average person

Dynamic water level (m)	5	10	20	30	40	50
Yield (m^3/hr)	1.8	0.9	0.45	0.3	0.22	0.18

Source: WRAP (1089)

Because the human energy needed to activate the hand pump is limited, the time a person has to spend pumping water increases with depth which is illustrated in table 2.4.:

Table 2.4: Time required for pumping water

Pumping depth (m)	Time required (hours) for pumping			
	$2m^3$	$3m^3$	$4m^3$	$5m^3$
5	0.7	1.1	1.5	1.8
10	1.5	2.2	2.9	3.7
20	2.9	4.5	5.9	7.4
30	4.5	6.7	8.9	
40	5.9	8.6		
50	7.4			

Power output of pump users: 50 W (average)

Efficiency of pumping: 50%

Number of effective hours of operation per day: 8

Source: Hofkes, E.H. (1986)

By combining the data presented in table 2.3. and 2.4. it becomes obvious that the human input (energy, time) increases greatly with growing depth for obtaining a given quantity of water. This means that, in larger communities particularly, that the number of hand pumps will have to be expanded to provide all persons in the community with water. It is obvious that this affects both capital and recurrent costs of water supply.

B) Pumping water from great depths with a hand pump might affect the time a pump is actually functioning negatively. Because of increased wear of parts like bearings, pump rod and rising mains[7] the pump is highly susceptible to break downs. This results in high recurrent costs, since many repairs will have to be undertaken, and possibly in high capital costs in case of an early renewal of the pump. Heavy duty hand pumps, may provide a solution for depths upto 40 meters (e.g. the India Mark II developed in the 1980's), but for greater depths the problems remain the same.

[7] See also: Besselink, J. e.a. (1990)

Both A) and B) indicate that water supply from a deep well with a hand pump can be costly because either several 'normal' pumps have to be installed in order to obtain enough water (which still leaves the problem of the increased wear of the parts), or a mechanized pump has to be installed, capable of pumping from great depth.

2.3. Diesel pumps

Generally, the initial investment for a diesel pump is higher than for a hand pump. For pumping from great depths a diesel plus direct mechanical pump or a diesel powered generator and submersible electric pump (e.g. multi-stage turbine pump) is required. The price of the diesel pump depends on the pump lift and the daily water demand of the users. Given the wide range of imported and locally made diesel pumps an indication of the capital costs is not given.

Recurrent costs include labour for a pump operator, fuel, lubricants and consumables. The fuel and lubricant consumption of a diesel engine accounts for a significant portion of its operating costs. For a given engine, pump, and site conditions, fuel consumption per cubic meter of water pumped will depend on the loading. At a lower loading (= a measure of the power required of an engine relative to the maximum rated power it is capable of delivering), the engine will consume more fuel per unit of water pumped. An alternative is to use a smaller engine (minimal 3 Kw) at a higher loading. In that case, money would be saved on capital equipment costs, but the wear and tear would increase, possibly leading to higher operating, maintenance, and (eventually) engine replacement costs.

The annual energy cost for a diesel pump is a function of the pump lift, the water demand of the community, the efficiency of motor and pump and the cost of diesel fuel.
Estimates of service and maintenance costs, not including fuel and labour, are likely to be in the range of \$ 0.15 to \$ 0.25 per cubic meter of water delivered. This figure may be higher or lower depending on the operator's skill, the quality of the equipment and other factors.
These costs constitute between 25 and 75 percent of the engine's initial cost or 5 to 15 percent of the system's installed capital costs (which includes not only the engine, but also the pump, the

concrete pad, the transmission, and other items).

The normal lifetime range is 2 to 3 years for lower quality, heavily used, and/or poorly maintained engines to 20 years or more for higher quality systems that are reasonably well maintained and overhauled at regular intervals. Lifetime hours of operation vary from under 5,000 to over 50,000 hours. About 20,000 hours is a reasonable approximation for planning and costing purposes.

Since in many developing countries the supply of diesel fuel can be delayed, it is advisable to buy an extra drum, to store extra diesel. It is furthermore advisable to include a storage tank for water with 1 - 2 days capacity in the scheme, to have a reservoir in case of necessary repairs of motor or pump.

Table 2.5: Cost indication of types of storage tanks

Type of storage tank	Cost per m^3 capacity (US $)
Lined earth bound	5 - 10
Compacted soil with cement lining	8 - 20
Brickwork with cement lining	12 - 25
Ferrocement	15 - 30
Concrete	20 - 30
Steel	60 - 80

Source: Hofkes, E.H. (1986)

Table 2.5. presents an indication of the capital cost per m^3 capacity of storage tanks (1986 US $, prices may differ considerably between countries). Given a daily water demand (m^3) and a required number of days storage, an indication of the capital costs of the tank may be calculated.

2.4. Solar energy: photovoltaic

2.4.1. General characteristics

In photovoltaic pumping systems, solar radiation energy is converted into electricity by solar cells which are interconnected in modules placed in an array. If more power is required (for instance because of the pumping lift), the solar array can easily be expanded by adding more modules. The application of photovoltaic pumps can be limited by the average annual solar irridation and a clearness factor; areas between the Tropics of Cancer and Capricorn are most suited for the use of these pumps.

The continuous research and development of solar pumps has resulted in lower prices and has reduced maintenance. This makes solar energy more suitable for use in developing countries. However, repairs still have to be done by technicians. There is scope for local production, which might mean that repairs will be cheaper, since local technicians are available.

2.4.2. Capital and recurrent costs

In table 2.6. an indication is given of the capital costs, which include photovoltaic panels and the motor pump set, for different pump size systems.

Table 2.6: Indication of capital costs for solar photovoltaic pumps

	Size of pumping system, array rating (W_p: peak Watt)	Cost range (US \$ per W_p)
Small	less than 500	20 - 25
Medium	500 - 3,000	15 - 20
Large	more than 3,000	10 - 15

Source: Hofkes, E.H. (1986)

Solar pump costs depend primarily on two components: the array size and the pumping unit. Solar module costs usually make up 60 to 85 % of total system costs. Pump sets (i.e., a pump and motor) designed for use with PV systems range in price from US$ 1,000 to US$ 3,000. Submersible AC pumps are generally the most expensive because in addition to the pump and the motor, they must have an inverter to convert DC power to AC[8]. Often, the higher cost of these units is more than offset by greater reliability and, consequently, lower recurrent costs.

The photovoltaic system, in particular the array, should be as small as possible, in order to be cost-effective. The costs of the array are correlated to the peak power capacity. Since these costs form a large portion of the overall capital costs, peak power capacity should be in line with demand factors.

Photovoltaic systems require little maintenance; regular cleaning of the surface of the arrays and checking the electric controls can be taken care of by members of the community or by an attendant (wage costs!) at low costs.

Since the availability of solar energy is prone to variations (e.g. due to clouds) storage of water is necessary to ensure a continuous supply of water. Given these variations a storage capacity of 2 - 4 days would be required (for capital costs: see table 2.5.). An alternative can be found in solar energy pumps that have an can also be used as hand pump. The choice for either storage or a pump with an optional use as hand pump depends on factors like capital costs of each alternative and the actual and future size of demand for water.

Practical experiences show that the actual lifetime of a solar system may be considerably shortened by corrosion of electric circuits, malfunctioning of the DC-AC converter or reduction of the lifetime of the pump (e.g. because of sand in the water).

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[8] DC: Direct current = electric current of which the direction is constantly the same.
AC: Alternating current = electric current of which the direction is reversed at frequent intervals.

2.5. Wind energy

2.5.1. General remarks

The use of wind energy has been known for centuries (e.g. Dutch windmills). Wind energy is used in many countries for irrigation and drainage. The use of wind energy for water supply is growing, since it is a renewable energy source that is freely available. In a World Bank study[9] 20 developing countries have been identified in which 40% of the land had average annual wind speeds greater than 3.5 m/s. This is an indication of the wind speed at which wind pumps can be cost-effective (see also appendix II).

Since wind is not permanently blowing a system has to be combined with either a hand pump (or diesel pump) or a storage tank - with a capacity of 5 - 7 days.

2.5.2. Capital and recurrent costs

Roughly, wind pumps can be divided in two sorts; imported high-tech wind pumps and locally made wind pumps. The capital costs of imported wind pumps range from \$300 - \$750/m^2 (m^2 is an measure of the rotor swept area), locally made wind pumps range from \$100 - \$250/m^2. Next to the wind pump a storage tank has to be installed.

Recurrent costs of imported wind pumps will generally be lower than those of locally made ones. Recurrent costs typically include the wage of a local attendant (if any), and operating and maintenance costs for the wind pump system (tower, rotors, pump, pipelines etc.) and storage tank. Repairs - which do not occur regularly if the installation is maintained properly - will have to be carried out by technicians at a relatively high price. Generally, the recurrent costs of imported high-tech wind pumps are estimated to be 3% to 6% of capital costs of the wind pump; recurrent costs of storage tank and piping are estimated to be around 2% of capital costs of the tank.
The lifetime of a wind pump is estimated to be 15 years, but field experiences show that this is an optimistic estimation.

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[9] Blake, S. (1978)

2.6. Animal traction

Animal traction pumps are used in small rural communities, where animals are an part of a traditional way of living. Animals are generally used with slow-moving devices (e.g. chain pumps, water wheels, bucket and rope) in order to lift water for irrigation purposes. Animal traction pumps are not often used to provide a community with drinking water, probably because the animals are private property.

Since power input of animals is five to ten times larger than that of man, the amount of water (m^3/hour) lifted from a well may be considerably bigger than by hand pump. Animal traction pumps, however, are often highly inefficient, as much as 80% of the power input is lost. Due to friction inefficiency increases with pumping lift. Still, water supply with an animal traction pump can be feasible when, within a community, agreement can be reached on the use of (privately owned) animals for the provision of drinking water by means of an animal traction pump.

Capital costs: the animal traction pump system consists of animals (power supply) and the pumping installation. The price of an animal (cow, buffalo, donkey) varies from region to region and cannot be universalised. The pumping installation might includes items such as chain pumps, water wheels or bucket and rope which can be purchased locally at low cost. Given the relatively large output (m^3/hour) a storage tank for water which is not (directly) consumed can be considered. The capacity of the tank need not be big.

Recurrent costs: a major component of the O&M costs is the fodder required for animals. Furthermore, the income of the attendant, taking care of installation and animals during the pumping, and materials and manpower, needed for maintenance and repairs, must also be taken into consideration.
In practice the use of animal traction pumps for drinking water purposes is seldom seen, partly because of the (relative) height of recurrent costs.

3. SOCIO-ECONOMIC ASPECTS

Socio-economic appraisal is undertaken to ascertain the overall impact of the project on the country's economy. The linkage of the project with the overall economy is of crucial importance. Socio-economic appraisal narrows down the range of alternative project specifications to the one that contributes most to the country's development objectives. Therefore socio-economic appraisal takes effects into account (both benefits and costs) that are not reflected in the financial analysis.
In the case of water supply projects the following positive effects - benefits - are to be considered:

A) Cost savings: the opportunity costs of the alternative water supply source foregone (e.g. vendors) as a result of the project is considered an economic benefit.
Another source of cost saving can be found in the reduced necessity to boil water before consumption, due to the new water supply.

B) Time savings: if the new water supply system ('with project' situation) enables people, generally women, to spent less time hauling water, compared to the old ('without project') situation, they might spent this 'time-profit' in a productive way. Women may use saved time for extra childcare, activities in the house, or income generating activities. Estimating the size and amount of these income generating activities over the total of the beneficiaries, gives an indication of the total benefits from time savings.

C) Health improvement: the basic goal of water supply projects is to provide people with easily accessible, clean water for consumption. Consequently the general health of users will improve; skin diseases, related to contaminated water use, and stomach/ intestine infections may diminish. As a result, people may be more productive (less 'off days') compared to the old situation. Health improvement depends not only on the quality of the water, but also on the location of the improved water source; if the water source is close to people they are more likely to wash themselves (and their children) more frequently, possibly resulting in a overall health improvement[10].

D) Indirect socio-economic benefits or externalities: certain benefits might accrue to the project, benefits which are 'side-effects' of the project. The new or improved water supply system can be a catalyst for (further) economic development of the area concerned; in urban areas, for instance, it can attract (small) industries. In case of such development employment is created for non-beneficiaries of the water supply system.

Negative effects to society - costs - should also be considered:

E) New or improved water supply may need some time of users. When people are assumed to be involved in assessing the need, in the planning, in the actual construction and in the maintenance of the water supply system, they loose time that might have been spent in a productive, income generating way. This production foregone applies, like time savings, most to women. Furthermore, the users of a water supply system often have to go through some difficulties in order to pay their bills (e.g. long walking distance to a revenue collection post in rural areas).

F) Specifically in large metropolitan areas an increased use of water can lead to a fall of the groundwater level, which has implications for water supply, sanitation and environment.

Socio-economic effects are project- and location specific. It is therefore hard to compare socio-economic effects of projects with (deepwell) hand pumps to projects with alternative small scale water supply systems. However, some general remarks can be made;

- Even if alternative systems are located at some distance of the water users, water can be transported to the beneficiaries by means of a pipeline (ending in a house to house connection of a central yard tap). In that way each of the systems may incorporate time savings for the users.
- Since alternative water supply systems can be bring water (relatively) close to the users an increase of the overall well-being can occur, because of the health improving effect.
- The small scale alternatives possibly allow for an additional

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[10] Source: Black, M. (1990), pp. 113 - 115: "The study concludes that reducing the distance to the water supply is more important than improving its quality for making an impact on (child) health."

use of the water pumped up (next to water for consumption and household use); small scale irrigation. It is impossible to make generally valid remarks on the feasibility of irrigation. Only on site survey can provide an indication. If feasible, irrigation can be the catalyzer of economic development in an area.

4. ORGANISATIONAL AND COST RECOVERY ASPECTS

4.1. Community participation

The community, area or neighbourhood where the water supply system is to be installed may be involved in every stage of the project; assessment of demand and selection of a system in close cooperation with the community can prevent over- or underdesign, and increase their feeling of involvement. Only when the members of the community are convinced of the benefits of the new water scheme, they are likely to make use of it instead of continue to/return to their traditional water source. When they are actively involved in every stage of the project, they will be convinced of the benefits.

Cost recovery aspects are closely related to community participation. First of all the selection of the right system contributes to the ability to recover costs. Secondly, the involvement in the project at every stage is likely to affect their willingness to pay in a positive way. Thirdly, their involvement can reduce the costs considerably, since they supply low-cost resources (such as labour and materials). The community can take care of revenue collection, maintenance and financing, thereby further reducing costs.
Special attention should be paid to the development of local committees to control local participation. Community participation should go hand in hand with training of both committees, water system maintenance personnel and users.

Community participation is nowadays considered a prerequisite for the success of a water supply project.

4.2. Institutional aspects

A move from water supply controlled by central governments agencies towards local authorities, or private enterprises, is visible throughout the developing countries. However, central government agencies are still required to perform a major role in water supply; helping/supporting the initiation of community participation, training/educating and equipping parties concerned (e.g. local authorities, users, maintenance personnel), review of national water supply (where/which projects).

The shift in control over water supply from central government to local authorities or private enterprises quite often face problems, since these institutions are ill equipped, and lack well-trained, capable personnel. A decentralisation should therefore go hand in hand with training and resource supply - both financial and material; a process that can/should be encouraged by donor agencies.

An important issue in the financial aspects of water supply systems is the administrative capacity of the local authorities or private enterprises. Once the scheme is in process, data concerning the actual production and use of water, eventual leakages (both actual and 'administrative'), the kind (household or commercial enterprise) and number of beneficiaries and the revenue to be collected will have to be gathered and updated. The institutions must be capable of collecting revenues and keeping records. When the authorities fail to control the revenue collection, defaulters will not be sanctioned. It is advisable to sanction defaulters by turning off the water supply.
The World Bank policy promotes privatisation of water supply, closely related to community participation.

4.3. Cost recovery

Cost recovery has long been a neglected aspect of water supply systems. Water used to be supplied to beneficiaries free of charge, subsidized by authorities or donors. This policy endangered the replicability of the projects, which should be a primary goal, since the amounts required were too big for funding by government or donor agencies. Therefore, in order to keep the project sustainable from a financial point of view, it is necessary that the users contribute to the recovering of the costs.

The World Bank policy[11] is that both capital and maintenance costs are recovered from the users. If users are allowed to select a

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[11] Churchill, A.A. (1987), pp. 39

system in which they are to contribute in the recovery of only O&M costs, they are likely to opt for a system with (relatively) low recurrent costs - which often means that capital costs are considerable (e.g. solar and wind energy). When however the government or donor is to select a system they are likely to minimize their expenditure and shift as much as possible the recovering of costs - O&M costs - to beneficiaries. In the case of a poor community this may result in the premature breakdown of the system because of the lack of maintenance. In poor villages in Africa and Asia the amount villagers are supposed to pay should be subsidized by authorities until people can fully contribute themselves.

Some remarks on the World Bank policy of total cost recovery can be made.
Firstly, users value the new water supply according to their own criteria, in which time savings, health improvement etc. might be included. Given these user benefits, they are willing to pay a certain amount for the use of water. Only as long as there is a positive difference between what people are willing to pay and what they actually have to pay (consumers' surplus), they will not return to their traditional source.
Secondly, the benefits that flow from the new supply are often not (directly) converted into extra productivity (which means extra income). This means that even if users are willing to pay for the use of water, they might not be able to do so.

A generally accepted policy is the recovery of at least operating and maintenance costs, and where possible of total costs.

4.3.1. Pricing

Given the fact that beneficiaries of a water supply system have to be charged for the use of water different types of pricing have been established.

In systems where water consumption is metered, people are charged according to a tariff per litre consumed. The tariffs vary according to water use (e.g. household and non-household) and amount of water consumed. However, many water supply projects - in particular those in rural areas - have no metered connections. In projects where meters are installed, they often do not function, or are not read

properly.
In those systems where no meters are installed and people have to pay for the amount they consume, users can be charged for the use of water at the yard tap, as they draw water from the tap. A major disadvantage is the necessity of a revenue collector at the tap.

In many cases a lump sum fee, independent of actual water use, will be levied throughout the community. This water charge can vary according to income level and size of household. Where water is provided by a hand pump or a yard tap, excessive water use by an individual is not likely, because of social pressure.
People, in particular the poorest segments of society can contribute in kind, by supplying labour.

Reliance on widespread use of cross-subsidies should be avoided. Often water supply policies are based on financing rural schemes by cross-subsidizing from the proceeds of urban schemes. This is only feasible if the amounts are relatively small, so that urban water charges are well within the paying capacity of the users. Furthermore, the technology applied in rural areas should be in line with the affordability of its users (no over-design), to guarantee maintenance in the long run, independent of other financial sources.

4.3.2. Financing

Several policies concerning financing water supply schemes exist. One policy is to let the community finance the project, by borrowing the necessary funds. This can be done by means of a revolving fund at the local or national level through authorities or (small) financial intermediaries. In reality, however it appears to be hard to interest (small) investment firms in to serve as a financial intermediary, particular in rural areas where they are most needed. Another policy is to promote the use of water supply systems with low O&M costs - in particular in the poorest parts of the world -in order to allow the communities to recover at least O&M costs. As discussed in chapter 2 systems with low recurrent costs generally have considerable capital costs (e.g. photovoltaic systems and wind pumps).These capital costs are (for the greatest part) born by so called extern support agencies - often foreign donor agencies.

There are also programmes, such as the hand pump-well programme in Burkina Faso where the community not only pays for and executes all community-level maintenance but also sets aside reserves for the replacement or extension of the village water supply. Only the construction costs are financed fully by the donors which support the various regional water supply programmes in the country. The actual proportion which the community has to pay back depends on the local economic circumstances. The remainder is a grant from the state and international, bilateral or national donors. Payment of part of the construction costs in labour instead of money makes the system more affordable to a larger number of households than with all payments have to be made in cash.

4.4. Systems compared

In this chapter relevant financial and organizational aspects of water supply systems were discussed. These aspects are used as framework for an indicative comparison between different water supply systems, as presented in table 4.1. and 4.2.

The indicative comparisons presented in table 4.1. and 4.2. are based on the following assumptions:
- Water is lifted from depths of 50 meters or more.
- Costs of geological surveys and drilling (or hand digging) are not included in the comparison.
- Each system is capable of meeting the demand for water.

Since rural water supply differs greatly from supply to urban areas, both types of water supply are reviewed separately; table 4.1. concerns rural water supply, table 4.2. refers to urban water supply.

Deepwell hand pumps and their small scale alternatives are compared in relation to three aspects;

A) Financing: based on 4.3.2. financing alternatives are distinguished;
  - the community is responsible for the financing of the project, either by means of a revolving fund or a loan. The community therefore has to finance both capital and O&M costs.
  - an external support agency bears the capital costs, or a large part of it, thereby promoting the use of systems

with low O&m costs.

B) Organisation: the organisation of the water supply system is either a local level or a national responsibility. Depending on the location of the water supply system, rural or urban[12], this difference in organisation affects the assumed availability and level of technical assistance. It is assumed that in rural circumstances technical skills are low, and technical backup requires some time. In large urban areas technical skill is readily available.

C) Cost recovery: two policies are assumed here;
   - total costs are recovered by the users of the water supply system.
   - O&M costs are recovered by the users.

For each water supply system an indication is given of the feasibility with respect to each of the described fields; financing, organisation and cost recovery.

An indication of the appraisal is given by '+', 'o', and '-':
'+' indicating a positive rating
'o' indicating a neutral rating
'-' indicating a negative rating

Table 4.1: Rural water supply

financing		community				donor agency			
organisation		local		national		local		national	
cost recovery		total	O&M	total	O&M	total	O&M	total	O&M
type of pumping device									
deepwell hand pump		0-0	0--	0+0	0+-	+-0	+-+	++0	+++
diesel fuel pump		0-0	0--	0+0	0+-	+-0	+-+	++0	+++
solar photovoltaic pump		---	--+	-+-	-++	+-0	+-+	+++	+++
wind pump	commercially manufactured	---	--+	-+-	-++	+-0	+-+	+++	+++
	village level product	+++	++0	+++	++0	++0	++0	++0	++0
Animal traction pump		+++	+++	+++	+++	++0	+++	+00	+0+

[12] We assume that cities in rural areas have the same water supply characteristics as far as technical skills available are concerned, as villages in rural areas. Urban areas refer to large metropolitan areas.

Table 4.2: Urban water supply

financing		community				donor agency			
organisation		local		national		local		national	
cost recovery		total	O&M	total	O&M	total	O&M	total	O&M
type of pumping device									
deepwell hand pump		000	00-	0+0	0+-	+00	+0+	++0	+++
diesel fuel pump		000	00-	0+0	0+-	+00	+0+	++0	+++
solar photovoltaic pump		---	--+	-+-	-++	+00	+++	+++	+++
wind pump	commercially manufactured	---	-0+	-+-	-++	++0	+++	+++	+++
	village level product	+++	++0	+-+	+-0	++0	-+0	-+0	++0
Animal traction pump		++0	+++	+-0	+-+	++0	-++	-+0	+++

How to use the table: how is a solar photovoltaic pump appraised in a situation where a rural village is responsible for the financing of the project, the operation and maintenance and where users are assumed to recover total costs? An indication of the appraisal is given in the first column of the row 'solar photovoltaic pump' in table 4.1. (rural water supply): '- - -'. Given the high capital costs of a solar photovoltaic pump a negative relation is assumed with community financing, a negative relation with village level O&M (given the low technical skills) and a negative relation with recovering total costs. In the situation where a donor agency bears the capital costs, an '+ - +' relation is indicated (fifth column in 'solar photovoltaic pump' row); a solar pump is affordable, since only O&M costs have to be financed. Given these circumstances a recovery of total costs by users is more likely.

5. CONCLUDING REMARKS

The comparative study of (deepwell) hand pumps and their alternative small scale water supply systems, on financial, socio-economic and organizational aspects can, given the limited data and the length of the study, only be exploratory and indicative at this stage. The characteristics and costs of any water supply systems are very much determined by location specific variables (e.g. geographical, geological, technical, demographical, financial and socio-economic), and are therefore difficult to compare within the context of a quick desk study.

In spite of the fact that no uniform policies on financing, organisation and cost recovery of water supply systems (and related aspects) are outlined and/or pursued, an indicative relation between each water supply system considered in this report and existing policies is presented in tables 4.1. and 4.2..

A more detailed comparative analysis of (deepwell) hand pumps and alternative small scale water supply systems is only feasible within the scope of a much larger study; preferably an extensive desk study combining e.g. DGIS projects file data with comparative on-site studies, from different parts of the world.

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APPENDIX I: Glossary

Consumers' surplus: the benefits a consumer gets when he/she is provided with a good or service at a lower price than he/she would be willing to pay. It is assumed that aspects like are included in the price consumers are willing to pay.

Cost-benefit analysis: a method of appraising projects that consist of quantifying costs and benefits, expressing them in annual streams over the life of the project, and discounting the resulting net annual flows to obtain a present value.

Cost-effectiveness analysis: an appraisal method that consists of defining the objectives of the project and choosing that solution which minimises total discounted capital and recurrent costs.

Cross-subsidisation: the application of the proceeds from a public service, deriving from its profitable parts, to keep providing that service to users where it would otherwise be unprofitable.

Direct effects: These effects refer to the to the physical inputs and outputs of a project and follow as a rule from the project's technical characteristics. They give rise to receipts and expenditures within the confines of the project and are therefore relevant to the financial analysis.

Discount rate: the rate (analogous to a negative rate of interest) at which future streams of costs and benefits are written down.

Externalities: The net costs and benefits for the economy, which will arise from the execution of the project under consideration but which do not impinge in parties directly involved in the project. These externalities are therefore not reflected in the consumers' willingness to pay for the output of the project.

Internal rate of return: The rate of discount for which the net present value of a project becomes zero.

Net present value: A common decision rule in project appraisal, resulting from summing the discounted difference between costs and benefits for each year of the project's life.

Opportunity cost: The value of a resource in its best alternative use. Costs that defined in terms of benefits foregone (marginal productivity) are therefore opportunity costs.

APPENDIX II: AN EXAMPLE OF COST COMPARISON

In this appendix an example is given of a comparison of three drinking water supply systems. The purpose of this example is not to really compare systems, it merely serves as an illustration of the difficulty of comparing systems in a general desk study.

Table II.1: Cost comparison of wind pump, solar pump and diesel pump for a particular location

Location data:	
Water requirement	27 m^3/d
Pumping head	30 m
Annual average wind speed	4 m/s
Critical length of calm periods	5 days
Monthly average irridation (in critical month)	14 $Mj/m^2/d$ ($4kWh/m^2/d$)
Critical length of cloudy periods	3 days
Smallest size of diesel engine available	3 kW rated power
Cost of 3kW rated diesel pump	$ 4500
Price of diesel fuel	$0.50/liter
Cost of wind pump	$ 350/m^2 of swept rotor area
Cost of solar photovoltaic pumping system	$ 22/Wp installed
Unit cost of water storage tank	$ 30/m^3
Discount rate	8%

Adapted from: Hofkes, E.H. (1986)

The results of the cost comparison are presented in table II.2. Given the conditions in table II.1., a wind pump is the most cost-effective water supply system. By changing some assumptions, different outcomes (rankings) are created:

- if the price of diesel fuel is raised from $ 0.50/litre to $0.85/litre, the cost per m^3 for diesel pumps rises from $0.23 to $0.27, indicating that a major change in the price of diesel fuel has a minor effect on the unit costs.

- if the average annual wind speed is 3 m/s instead of 4 m/s, a larger wind rotor would be required, raising the capital costs to \$ 17.000. The unit cost per m^3 would rise from \$ $0.16/^3$ to \$ $0.27/^3$.

The above mentioned indicates that cost-effectiveness analysis is tied to a particalar place and situation, and that an universal rule or indication is hard to give.

Table II.2

	diesel pump	wind pump	photovoltaic pump
Hydraulic energy output requirement	2.25 kWh/d	2.25 kWh/d = 821 kWh/year	2.25 kWh/d
ᴗize of diesel engine	(smallest available engine) 3 kW rated power		
Swept rotor area E hydr : 0.9 V^3		821 : 0.9 V^3 = 14.25 m^2	
Capital cost (3 kW rated power)	$ 4,500	14.25 x 350 = $ 5,000	
Installed cost of solar pump system			1700 x $ 22/Wp = $15,400
Electrical energy output requirement			5.63 kWh/d
Peak watt rating of system			1700 Wp
Nominal power output	2 kW		
Efficiency of motor and pump			40%
Efficiency of pump	40%		
'ydraulic power output of engine	0.8 kW		
Water output	4.1 l/s		
Hours of operation required per day	1.83 hours		
Efficiency of engine	15%		
Fuel consumption per hour operation	1.34 liters of diesel/hour		
Fuel consumption per year	895 liters of diesel/year		
Capacity of tank required	1 day's supply = 27 m^3	5 + 1 = 6 day's supply = 160 m^3	3 + 1 = 4 day's supply = 110 m^3
Capital cost of tank	$ 810	$ 4,800	$ 3,300
Lifetime of tank	20 years	20 years	20 years
Lifetime of engine	5 years		
Lifetime of diesel pump	10 years		
Lifetime of wind pump		15 years	
Lifetime of solar pump			15 years
Capital cost on annual basis:			
engine and pump	$ 960	$ 650	$ 2,010
tank	$ 95	$ 560	$ 390
Annual fuel costs; 895 liters at $ 0.50 per liter	$ 450		
Annual O&M costs:			
engine and pump (5% of capital cost)	$ 225	$ 250	$ 310
tank (2% of capital cost)	$ 15	$ 100	$ 65
Annual cost of operator	$ 500		
Total annual cost	$ 2,240	$ 1,560	$ 2,775

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Water output per year	9,850 m^3	9,850 m^3	9,850 m^3
Unit cost per m^3	\$ 0.23/m^3	\$ 0.16/m^3	\$ 0.28/m^3