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SMALL - SCALE WATER PUMPING IN BOTSWANA

VOLUME I : COMPARISONS

WASH FIELD REPORT NO. 235

DECEMBER 1987

Prepared for
the USAID Bureau for Africa,
Office of Technical Resources,
USAID Mission to Botswana
and the Government of Botswana
WASH Activity No. 328

WASH
WATER AND SANITATION FOR HEALTH PROJECT

Operated by
CDM and Associates

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Prepared for the USAID Bureau for Africa,
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under WASH Activity No. 328

by

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December 1987

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FOREWORD

The results and conclusions of the Comparative Water Pumping Project have been reported in a five-volume set entitled SMALL-SCALE WATER PUMPING IN BOTSWANA. This report consists of only the first volume:

I COMPARISONS

Contained herein is a comparative analysis of seven technologies used for water pumping in Botswana. Volume I draws upon and summarizes the work reported in Volumes II through V.

The remaining volumes are entitled:

II DIESELS

III WINDMILLS

IV SOLAR PUMPS

V ANIMAL-DRAWN PUMPS, BIOGAS, ELECTRIC, AND HANDPUMPS.

Copies of the latter volumes are available upon request from WASH. Specific information regarding all volumes of this report may be requested from Associates in Rural Development, Inc., 110 Main Street, Burlington, Vermont 05402 U.S.A.

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ABBREVIATIONS AND ACRONYMS

AC	alternating current
ADP	animal-drawn pump
AID	Agency for International Development, Washington, DC
ALC	annual life-cycle costs
BCL	Bamangwato Concessions Limited
BDF	Botswana Defense Force
BPC	Botswana Power Corporation
BRET	Botswana Renewable Energy Technology project
BRS	Borehole Repair Service
BTC	Botswana Technology Centre
CWPP	Comparative Water Pumping Project
DC	direct current
DEE	Department of Electrical Engineering
DWA	Department of Water Affairs
EEC	European Economic Community
GOB	government of Botswana
GS	Geological Survey
GTZ	Gemeinschaft fur Technische Zusammenarbeit
km	kilometer(s)
kV	kilovolt
kW	kilowatt
m^2	square meters
m^3	cubic meters
m/sec	meters per second
MLGL	Ministry of Local Government and Lands
mm	millimeter(s)
MMRWA	Ministry of Mineral Resources and Water Affairs
MoA	Ministry of Agriculture
NDB	National Development Bank
NGO	nongovernmental organization
ODA	Overseas Development Administration
P	pula
PV	photovoltaic
RET	renewable energy technology
RIIC	Rural Industries Innovation Centre
RTC	Rural Training Center
SIDA	Swedish International Development Authority
SWL	standing water level
USAID	U.S. Agency for International Development
Wp	peak watts
WTGS	Wind Technology Group Serowe
WUC	Water Utilities Corporation

PREFACE

The Comparative Water Pumping Project (CWPP) was jointly funded by the Government of Botswana and the the U.S. Agency for International Development. Technical assistance was provided by Associates in Rural Development Inc. (ARD) of Burlington Vermont, USA. The project was implemented under the auspices of the Ministry of Mineral Resources and Water Affairs (MMRWA). Project field staff included Mr. Jonathan Hodgkin, engineer and field team leader; Mr. Lucas Motsisi, Chief Technical Officer - Renewable Energy at the Department of Water Affairs; Mr Modise Motshoge and Mr Peter Modimoofile, technicians and a seconded crew led by Mr. Keberang Goitsemang. Project support was provided by consultants Mr. Rick McGowan, engineer; and Mr. Ron White, economist. This report covers the work of the project from February 1986 through June 1987.

The CWPP was a continuation activity of the Botswana Renewable Energy Technology (BRET) Project. Continuing work will be carried out with assistance from the Swedish International Development Authority (SIDA).

The project team wishes to acknowledge the assistence and guidance provided by Mr. F.O. Motlhatlhedi, the Senior Energy Officer at MMRWA. In addition the help and cooperation of the Botswana Technology Centre, the Rural Industries Innovation Centre, the Water Engineer at the Ministry of Local Government and Lands was very useful and greatfully accepted. The support and assistance provided by the REDSO Energy advisor, Mr C.Anthony Pryor in initial support of the activity and ongoing evaluation has also been invaluable.

I. EXECUTIVE SUMMARY

The Comparative Water Pumping Project (CWPP) was jointly funded by the U.S. Agency for International Development's (AID) Water and Sanitation for Health (WASH) project and Government of Botswana's (GOB) Ministry of Mineral Resources and Water Affairs (MMRWA). For the past three years, this project has been involved in a testing and evaluation program for small-scale pumping systems, less than 10 kilowatts (kW). The first part of the program was conducted under the auspices of the Botswana Renewable Energy Technology (BRET) project, and focused on the installation, testing and evaluation of a wide variety of wind, photovoltaic (PV), diesel, grid-electric, and human- and animal-powered pumping systems. It included both mature pumping technologies and development prototypes. The results of this work have been reported in WATER PUMP FIELD TESTS IN BOTSWANA (McGowan and Hodgkin, 15 April 1986).

As a result of the clear benefits to be gained by continuing the program to complete the technical evaluation and collect longer-term data on service requirements and recurrent costs, a second phase for the project was approved, CWPP. The results of the full scope of CWPP are presented in a series of five volumes, SMALL-SCALE WATER PUMPS IN BOTSWANA (Hodgkin, McGowan and White, 1987 and 1988). VOLUME I: COMPARISONS focuses on the seven pumping technologies included in the evaluation program and draws on the work reported in Volumes II to V.

CWPP's major objective was to examine the potential for using renewable energy technologies (RETs) to displace diesel systems for pumping water. Interest in this topic developed as a result of Botswana's goal to reduce the importation of oil and oil products, and a growing perception that renewable pumping technologies were technically viable and could be used in a cost-effective manner in the local context. The work performed to validate these perceptions led to further testing and evaluation of a series of pumps that were already in place, as well as the installation and testing of other system types and configurations. During the course of the project, the following types of pumps were tested and evaluated:

- diesel pump sets--10;
- alternating current (AC) electric pumps--six in two different configurations;
- PV (solar) pumps--12 in five configurations;
- windmills--15, six models;

- animal-drawn pump (ADP)--one, tested by the Botswana Technology Centre (BTC);

- bio-gas substitution pump--one tested by BTC; and

- handpumps--17, three models.

In addition, an extensive examination of existing records and interviews with pump owners, technicians and suppliers added to the information base, and permitted a comprehensive technical and economic analysis of small-scale pumping technologies. The result has been this analysis of small-scale pumping systems as well as a methodology and model for repeating the analysis as a continuing process of reevaluation as conditions change over time.

The goals of the GOB's NATIONAL DEVELOPMENT PLAN VI, 1985-91, include planning for and increasing the availability of safe drinking water supplies, with consideration given to equity, efficiency and affordability. Energy-sector goals include maximizing the use of indigenous energy sources and reducing the country's dependence on imported oil and oil products. In this analysis, it is important to remember that economic parity of unit costs is not a sufficient condition for the adoption of new and possibly unfamiliar technologies. There must be significant economic and/or other advantages to justify their introduction and use. In the context of these policy objectives, and with reference to the technical and economic analysis of CWPP, the following general conclusions have been reached concerning the use of small-scale pumping systems:

- Diesel pumps will continue to supply most of the water needs for Botswana's rural population and livestock. No substantial fuel import reductions should be anticipated unless economic and political conditions change significantly. However, there are opportunities to reduce the cost and increase the reliability of diesel pumping systems.

- Electric pumps have the potential to reduce dependence on imported fuel sources because the coal-fired power plant at Morupula produces electricity with indigenous resources. However, realization of this potential is limited by the extent of the mains network, and lack of information on the long-term variability of aquifers. In addition, the unit cost to pump water with electric pumps is high for small-scale pumping systems because of interconnection costs and relatively high electricity tariffs.

- Windmill use is limited by the generally low prevailing average wind speeds and typical depths from which water must be lifted. Because of low wind speeds in most locations, it is anticiapted that windmills could be used economically in only 10 percent of Botswana's rural areas, and in most of these areas, windmills are already in use. The market is saturated in several areas, but there may be some opportunity to utilize windmills in northern parts of the Central District.

- Given current economic conditions, PV pumps appear to be cost-effective in only a few circumstances. However, they are the only system considered for which prices can be expected to fall. In addition, they provide the best opportunity for diversification of energy sources and reductions in the use of oil products for most rural water pumping applications.

- ADPs have the potential to be cost-effective systems for some private-sector applications. In addition, this type of pump does not require petrochemical fuel for operation. However, the long-term costs and reliability are not yet well documented, and there appear to be some social and organizational constraints on cost-effective use.

- Bio-gas substitution pumps have the potential to displace 80 percent of the fuel used in a diesel engine. However, fuel use is a small proportion of the operating costs for small-scale bio-gas systems. They appear to be only marginally cost-effective in the ranges of this study. Larger-scale use may be more attractive. As with ADPs, system costs are not well documented, and social and organizational constraints may have to be overcome if bio-gas systems are to operate up to their potential.

- Handpumps are clearly cost-effective and offer the opportunity to avoid fuel use at low-demand sites, but the use of handpumps is limited to supplying needs of only about five cubic meters (m^3) a day. In addition, the present policy of locating boreholes well outside of villages further limits appeal to potential users.

In addition to a series of recommendations that relate specifically to each pumping technology considered, several transcend the type of technology. These general recommendations are as follows:

- A water pumping unit should be established as part of the Department of Water Affair's (DWA) Design and Construction Division. This unit would continue to analyze pumping systems to document costs, identify possible improvements in the current use of diesel systems, and monitor the potential of other pumping technologies in a changing economic and technical environment.

- A direct outgrowth of project activities has been a series of computer-based models for the analysis of technical and economic factors rel[illegible]ing to pumping system selection. These models sho[illegible] be used to assist in choosing pumping systems fo[illegible] [illegible]ecific sites and conditions as well as future p[illegible] development.

- More attention should be given to test-pumping of boreholes, including efforts to determine long-term yields and improve the execution of the current test procedure. This work will improve DWA's capacity to specify the most cost-effective diesel systems, assess the potential for electric pumps and design all types of pumping systems properly.

The specific recommendations for each pumping technology include:

Diesel Pumps

- Design procedures and engine choices should be modified to allow increased engine loading and efficiency.

- The current policy that mandates full-time pumpers for village water supply systems should be reviewed because it has a significant impact on the operating costs of diesel pumps.

- Support should be provided to DWA so that the scheduling and organization of construction can be improved.

- The emphasis on pumper training should be increased.

- Current pumping practices and costs in the private sector should be surveyed.

- An awareness campaign should be instituted to inform users of the costs of improper engine maintenance and servicing.

AC-Electric Pumps

- Present pump electrification should be limited to major village systems where electricity is available and aquifer performance is well understood.

- Attempts should be made to resolve jurisdictional difficulties that arise between DWA and the Department of Electrical Engineering (DEE) over the maintenance and installation of electrical equipment. The seconding of DEE electricians to DWA is suggested to simplify the installation, maintenance and repair of electric pumps.

- Well fields should be carefully test-pumped before making any commitment to an electrification project.

PV Pumps

- DWA should make an effort to remain informed of developments in the PV pumping industry, including advances in reliability and efficiency as well as reductions in module costs. This will allow the GOB to take maximum advantage of PV pumping as opportunities for cost-effective applications arise.

- New installations should be limited to boreholes with a low head (less than 30 meters), where demand is less than 30 m^3/day. Initially, new systems should be limited to those that can be installed using DWA's stock of about 50 modules that are already available. Further solar pump installations should be located at sites where they can be shown to be cost-effective, after a training program for technicians and mechanics is underway.

- Monitoring of installed systems should continue, including daily water delivery and system operation and maintenance requirements, at a minimum.

- A PV training program for District Council and Borehole Repair Service (BRS) mechanics and technicians should be instituted to begin infrastructural development for the maintenance and repair of PV pumps.

Windmills

- The installation and use of windmills should continue in the private sector and at selected government posts only where they are clearly appropriate pumping choices. It is anticipated that the installation rate for wind systems will be from three to five per year.

- Indigenous windmill development and promotion activities should be temporarily suspended. Given the anticipated purchase and installation rate, development efforts are best focused elsewhere. If the planned market survey by the Rural Industries Innovation Centre (RIIC) indicates substantially larger private-sector demand than has been found to date, further windmill development activities should be reconsidered.

Animal-Drawn Pumps

- For now, development activity should continue, focusing on cost and social issues surrounding the use, potential and acceptance of other draft animals by ADP users.

- With RIIC, clear project objectives should be developed and continued activity reevaluated one year hence.

Bio-Gas Substitution Pumps

- The GOB's increased emphasis on the use of bio-gas for small-scale pumping applications should be carefully considered. There appears to be some opportunity for cost-effective use of bio-gas substitution if costs for the digester and additional labor can be kept down. However, the organizational constraints involved in these systems need further study, and the market size must be determined. The use of bio-gas for purposes besides water pumping were not considered here.

Handpumps

- Expanded use of handpumps should be planned at low-demand sites. This will include smaller settlements and government posts. Handpumps should also be considered as backups for diesel systems, where feasible.

- A working group should be formed within the Ministry of Local Government and Lands (MLGL) to coordinate and guide this work.

II. INTRODUCTION

CWPP has sought to compare water pumping technologies on technical and economic grounds. It was an outgrowth of the pump testing and evaluation component of the BRET project. As the BRET project was approaching completion in September 1985, it became apparent that while many pumps had been installed and tested, the data base on long-term operation, maintenance and repair was still inadequate to accurately characterize system reliability and recurrent costs. Additional funding to continue the pumping work was provided by AID and GOB. This is the first volume in a series, titled SMALL-SCALE WATER PUMPING IN BOTSWANA, which focuses on the results of this work. The other four volumes on diesel, wind, solar and other pumping systems analyze seven different small-scale water-pumping technologies. This volume seeks to compare those technologies, draw conclusions and provide guidance for future choices.

A. Purpose

The overall goal of this comparison of seven water-lifting technologies is to provide a consistent set of information about the use of these devices so that their relative technical and economic performance can be evaluated. The seven technologies are:

- diesel pumps,
- electric pumps connected to mains,
- wind pumps,
- solar PV pumps,
- animal-drawn pumps,
- bio-gas substitution (for diesel) pumps, and
- handpumps.

The system designs and configurations for each technology reflect the typical or potential use of that technology in Botswana. The choice of configuration was dictated by availability and technical considerations--it was not intended to be exhaustive.

The objective of this comparison is to gain information about the role of each technology within the spectrum of water pumping equipment. This information will be used for four purposes:

- to provide insight into the potential role of each technology for water delivery,
- to provide information on the technical limitations of each pumping system,
- to examine the potential of each device to displace the use of diesel fuel as an energy source for pumping water, and
- to indicate under what conditions each is likely to be economically attractive.

Analysis of the technical and economic information was done using a series of computer-based models, and the results will guide policy decisions concerning water pumping choices. It will also provide the framework for continuing assessment so that policies can be modified as prices, availability of equipment and fuel, technological advances, and other parameters change.

The purpose of this volume is not to provide a detailed technical analysis of each type of pumping system, which is provided in the other four volumes of the series. This volume synthesizes that work and provides information to direct policy, rather than addressing the more technical issues concerning system designers and users. However, an introduction to those issues is also important for policymakers and has been included.

B. Scope of the Analysis

This volume addresses technical considerations and costs for the four user groups that commonly utilize small-scale (up to 10 kW) water pumping equipment in Botswana. They are:

- major village water supply systems, which provide water for domestic use and include about 100 pumps in Botswana--17 major village systems have been designed, installed, operated and maintained by DWA, and are located mostly in larger villages or villages where special water treatment is required;
- rural village water systems, which supply water for domestic use from approximately 525 pumps--these are operated and maintained by District Councils, usually one pump per village, and tend to be further from service facilities than major villages;
- other government posts and camps, which supply water from about 300 pumps for a variety of purposes depending on the situation--many of these sites are

very remote, but they are operated by government agencies or departments and maintained by BRS; and

- private water supply systems, which provide water primarily for livestock--it is estimated that 4,000 to 5,000 pumps are used by private individuals or syndicates (collectives) throughout the country, and are operated by the owners or their agent and repaired by BRS or informal-sector technicians.

For major villages, the range of applications considered by CWPP was 20 to 100 m^3 per day through pumping heads of 30 to 120 meters. For the other three user groups, the range was limited to water delivery of five to 30 m^3 a day for heads of 15 to 60 meters. Although this does not include all of the conditions encountered for the four user groups, it does cover the range where it is most likely that other technologies will be substituted for diesel pump sets.

Other water uses in Botswana include industry, irrigation, domestic supplies for Gaborone and other towns, and mining. For the most part, these applications require pumping systems that are much larger than 10 kW. Some small-scale irrigation activities may fall within the scope of this analysis, but they are few and will not be discussed further. Botswana is increasing its emphasis on irrigated agriculture, and the results of this study should provide valuable insight into the water-lifting aspects of small-scale irrigation.

C. Approach

This analysis is based on testing of and primary data collection for 63 pumping systems of seven types with 15 different configurations of pump and driver. In addition, an extensive analysis of existing secondary data was undertaken to provide parameter estimates for a much greater number of pumps than could be tested. A series of technical and economic computer models were developed to characterize all of the important technical and economic interactions of relevant variables. The technical models were verified using measured data. A discounted cash-flow approach was used in the economic models. These models were then applied using secondary data to calculate the present value of installed capital and recurrent costs. Finally, the present value was divided by total life-cycle water delivery to arrive at a unit cost in pula (P) per cubic meter of water. This approach to comparative analysis of pumping systems is that described in the HANDBOOK FOR COMPARATIVE EVALUATION OF TECHNICAL AND ECONOMIC PERFORMANCE OF WATER-PUMPING SYSTEMS (CWD, 1987).

In a country the size and diversity of Botswana, there are a wide range of pumping applications from small village water supplies to micro-irrigation to water for industry and mining. This study could not investigate all of these applications in detail--its scope was limited to major users of small-scale pumping equipment (up to 10 kW). Even within these user groups (major villages, rural villages, government posts and camps, and private-sector use for livestock watering), applications and operating conditions vary widely. Some major variations include:

- pumping head,
- water requirements,
- distance to installation and service centers,
- level and quality of servicing and repair, and
- availability of funds.

Technical and economic considerations favor the selection of certain pumping systems for each group. The economic analysis presented here takes into account a range of water requirements and pumping heads for each user group as well as possible pump choices. The discounted cash-flow approach that was used permits an overall comparison of pumping options for a range of conditions. The presentation is based on a set of assumptions that is considered typical for each group.

Given the scope of this report, the technical and economic analyses cannot consider all of the possible pumping situations for each user group, and they do not provide a clear indication of the conditions where each type of pump will be most attractive. To identify the conditions where each technology is likely to be the least-cost option, a sensitivity analysis was used. The parameter changes fall into two categories:

- factors that are controlled beyond Botswana's borders, such as the costs of diesel fuel and PV modules, and
- factors in Botswana, such as distance to a service center and the electricity rate structure.

Tables showing unit water costs in economic terms are included to provide an overview of trends that should be helpful in guiding policymakers.

D. Limitations

The analysis presented herein shows that the choice of an appropriate pumping system depends on a number of factors. It is impossible to give a simple, general answer to the question of which pump type is best. The methodology developed for this analysis can be applied to any specific site and application to define the financial and economic costs of pumping water in that instance. However, the final criteria for selecting a pumping system may include other factors that are not easily defined, such as elasticity of water demand. In the end, each application must be considered in terms of its own constraints and requirements. A useful procedure for site-specific pump selection, which includes all relevant considerations--economic, technical, social and institutional, is described in another WASH report, PUMP SELECTION: A FIELD GUIDE FOR DEVELOPING COUNTRIES (McGowan and Hodgkin, 1987).

In addition to the limitations inherent in characterizing each user group by a typical case in terms of service level and costs, the information available for some types of pumping systems is limited. Experience with ADPs and bio-gas substitution systems is not yet sufficient to provide good technical and economic information concerning costs, performance and reliability. There are currently less than 10 each of these pumps installed, and none have been in service for more than five years. When possible, measured data were used, and interviews were conducted with users and fabricators (RIIC personnel) to arrive at likely long-term performance and cost information.

The base of information on private-sector patterns of service and use of pumping systems is also limited due to the large size and diversity of this group as well as a dearth of recorded data on pump use. A limited user survey, examination of service records (where available) and interviews with technicians that service private-sector engines provided an overview of the sector.

The collective experience with handpumps and electric pumps is not extensive partly due to the limited number and age of these installations. Interviews and tests were conducted, and this infomation was shown to be representative by comparing it with reported results from other countries. Most of the locally available wind-pump makes and models were tested as part of CWPP (15 units altogether). However, an exhaustive survey of current windmill use was not possible within the project's framework. Still, interviews with some private-sector users confirmed that practices and costs compare with applications elsewhere. Finally, for solar PV pumps, longer term operation and maintenance data (more than one to three years) is needed to accurately determine the true magnitude of recurrent costs.

Of course, the assumptions made about future conditions are the most uncertain part of this analysis. Although the assumption is that costs for all items included in the analysis will inflate at a similar rate, this not definite. Fuel and spare-parts costs may rise faster than the general rate of inflation, and the cost for PV modules will undoubtedly decrease somewhat, as it has over the past several years. The stability of the southern Africa region may also affect the availability and costs of system components and fuel. These future conditions are difficult to gauge and cannot be fully incorporated in the analysis, which implies that the current study cannot be a onetime effort. Ongoing analysis of changing conditions may reveal options that seem inappropriate at present.

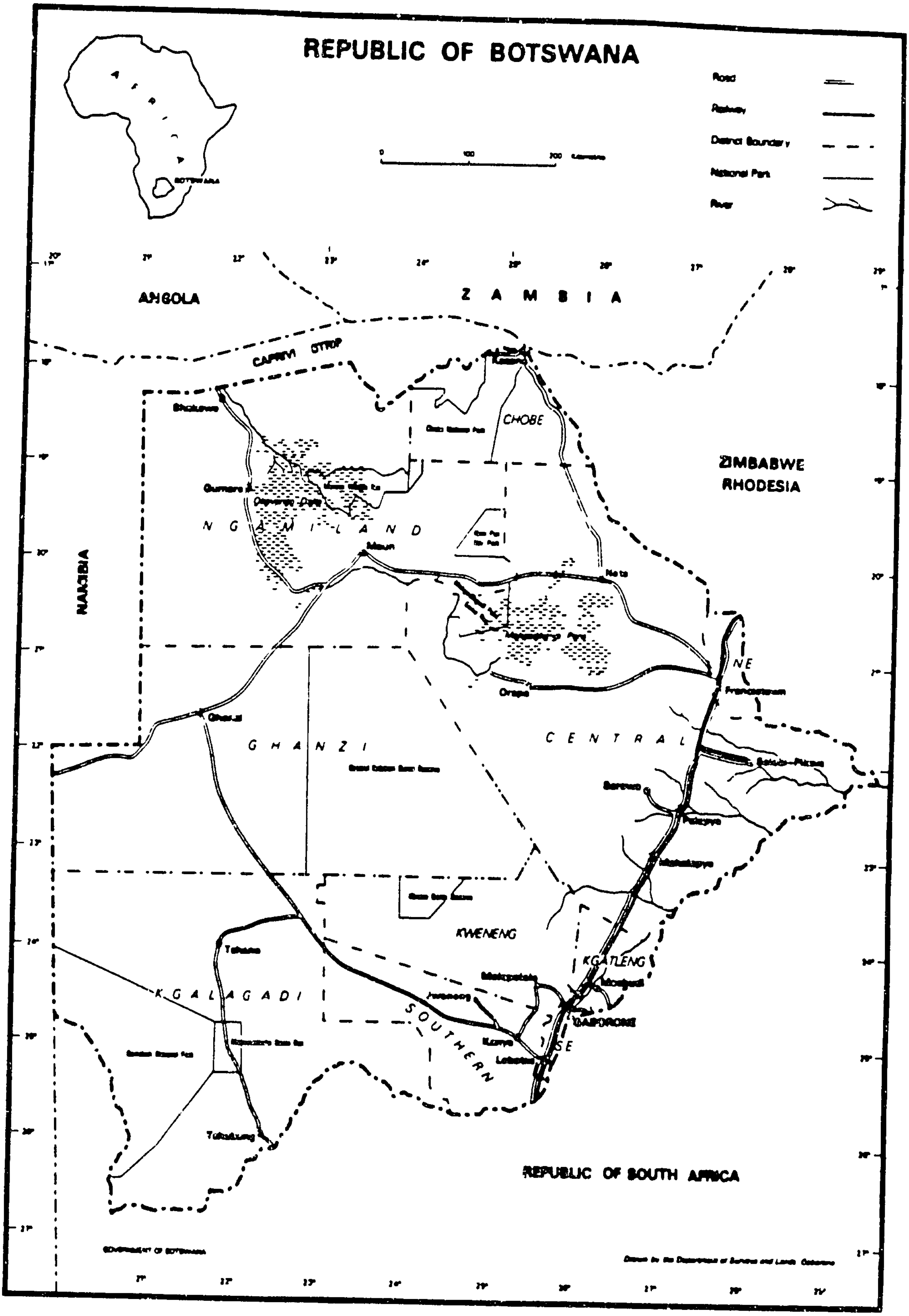
III. BACKGROUND

A. General Information

Botswana has just over one million inhabitants and is situated in the central part of the southern Africa plateau. It is a landlocked country of 582,000 square kilometers (km^2), just north and west of the Republic of South Africa, and shares borders with Namibia, Zambia and Zimbabwe as well (see the map on the following page). The eastern region is more populous, more fertile and receives more rainfall than the western part of the country. The Okavango River and its delta, along with the border rivers (the Chobe and Limpopo), comprise the only naturally occurring surface water in Botswana. The climate is arid to semiarid with annual rainfall ranging from 250 millimeters (mm) in the southwest to 650 mm in the extreme northeast. Most of the rainfall occurs during the summer months of October to April and tends to be localized and variable in terms of both time and space. The region is now in the fifth year of a drought cycle.

The country derives more than half its export earnings from its share in the diamond mines located at Orapa and Jwaneng. Significant contributions are also realized from beef exports beef and tourism. Botswana is currently running a budget surplus, projected to be as high as P219 million in 1987/88. Average inflation for the period from 1979 to 1984 was 11.4 percent, with rates in the range of five to six percent over the last several years. Transportation facilities include the Botswana Railway, which is a single track between Ramatlabama in the south to Ramokgwabena between Francistown and Bulawayo in Zimbabwe. The road network includes two-lane tarmac from Ramatlabama along the eastern part of the country through Lobatse, Gaborone and Francistown to Kasane in the north. There are tarmac feeder roads from Kanye, Lethlakeng, Serowe, Selebi-Phikwe and Ramokgwabena to the main north-south artery. All-weather roads link other major villages and district headquarters, but many secondary roads are passable only in four-wheel-drive or heavier vehicles.

For demographic purposes, the GOB divides the areas where people live into urban, rural and other. Just over 18 percent of the population live in urban areas, defined as the city of Gaborone and towns of Lobatse, Francistown, Selebi-Phikwe, Orapa and Jwaneng. Forty-seven percent live rurally in traditional villages. The rural areas include all villages, which range in size from under 500 to Serowe at over 45,000. The distinction between town and village is made on the basis of whether their layout and design are traditional or western. The remaining 35 percent live in smaller settlements, rural agricultural areas (lands areas) or where cattle are kept (cattle posts).


REPUBLIC OF BOTSWANA
ANGOLA
ZAMBIA
CAPRIVI STRIP
CHOBE
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RHODESIA
NAMIBIA
NGAMILAND
Maun
Nata
Orapa
NE
Francistown
CENTRAL
GHANZI
Ghanzi
Palapye
KWENENG
KGATLENG
Mochudi
GABORONE
SOUTHERN
SE
Kanye
Lobatse
KGALAGADI
Tshane
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REPUBLIC OF SOUTH AFRICA

B. Water Pumping

In the first NATIONAL DEVELOPMENT PLAN, 1969-73, the importance of water resources, their rational use and the careful conservation of water were defined as critical for Botswana's development. From the outset, water supplies (particularly for domestic use) were definitely intended to be the government's responsibility. However, the government's original goal was to place public water supplies to a cost-recovery basis and phase out subsidies. As time has passed, it has become clear that this is unlikely and the government will continue to bear the burden of ensuring an adequate, reliable, public water supply. Unlike many other countries, Botswana has been able to fulfill this responsibility for the most part. Some of the factors that have made this possible include:

- public-sector agencies with sufficient funds (due to government cash surpluses), skills and enthusiasm to address problems and issues related to water supply;
- the long-term support of a single donor in the water supply sector which has provided continuity and allowed both donor and government to develop an effective management and support infrastructure;
- standardization of equipment using Lister diesel engines and Mono pumps for almost all water-pumping tasks, thus minimizing the requirements for training and spare-parts inventories; and
- a currency that is freely traded and participation in the Southern Africa Customs Union (SACU), which allows for the easy importation of needed equipment and spare parts.

It is currently estimated that between 5,000 and 6,000 boreholes are equipped with diesel pumping systems. This excludes Water Utilities Corporation (WUC) installations since they do not use diesel pump sets (see Section III.C.1). Of the diesel engines in the field, more than 90 percent are single-cylinder models. Approximately 85 to 90 percent are Listers or Lister copies, such as the Indian Metex and Induna. The rest are higher speed Japanese and European engines. Total fuel consumption for these engines is estimated to be between eight and 10 million liters per year.

C. Current Government Activity

The GOB's general objectives in the water sector are to:

- continue the development of new village water supply schemes;

- focus on the health aspects of providing clean water;

- provide the water necessary for development in all sectors of the economy; and

- plan for the medium- and long-term water needs of the country.

It should be noted that the first objective is to expand rural water supplies, which agrees with the country's general development objectives of the country, including "a basic concern that social justice, in the form of secure livelihood and access to services, be extended to all Batswana" (NATIONAL DEVELOPMENT PLAN VI, page 60). While the economic viability of these programs is not the primary consideration, the government is increasingly interested in providing public water supplies as cost-effectively as possible. The government agencies that are involved in water-sector activities and concerned about reasonable costs are described in the following subsections.

1. Ministry of Mineral Resources and Water Affairs

MMRWA is responsible for the planning and oversight of public-sector water resources and development activities. Two departments and a para-statal organization under its jurisdiction are involved in water resources development:

- DWA;

- the Geological Survey (GS), and

- WUC, the para-statal organization.

DWA is responsible for water supplies outside the six main urban and mining areas, surface-water investigations, the protection of water sources from pollution and aquatic weeds, and overall water resources planning. This mandate includes borehole siting and drilling, the design of water supply systems, water law (through its Water Apportionment Board), and the operation and maintenance of major village water supplies. Currently, DWA is involved in implementing the Village Water Supply program; rehabilitating village water supplies; water supply schemes funded under drought relief; planning, upgrading and expanding major village water supplies; hydrological studies of the Okavango Delta and other surface water; and national water resources planning.

GS has three main responsibilities--mineral exploration, examination of groundwater sources and regional geological mapping. Its mandate includes regional and local searches for groundwater, regional hydrological mapping and compiling basic data on boreholes in the borehole registry. Although these functions are not directly related to the use of diesel pumping equipment, they are an important part of the mosaic of water-sector activities.

WUC is responsible for all urban water supplies except in the closed diamond-mining town of Orapa, where the mine is responsible for the water supply. In 1984/85, the total water consumption in Botswana's other five urban centers--Gaborone, Lobatse, Francistown, Jwaneng and Selebi-Phikwe--was 23.6 million m^3 or a little less than 18 percent of the country's total water use. All significant water pumps and booster stations for the urban centers are large-scale and electrically driven. Thus, no further consideration need be given to WUC activities as they fall outside the scope of this study.

2. <u>Ministry of Local Government and Lands</u>

MLGL is the central government body that oversees the District Councils, which are largely autonomous and responsible for rural water supplies intended for human consumption. Occasionally, councils operate cattle boreholes as well and charge fees for watering livestock. Larger scale programs that benefit all of the councils are administered by MLGL. These programs currently include:

- drought relief, with funds from the Ministry of Agriculture (MoA);
- rehabilitation of village water supplies, with much of the work being done by DWA; and
- district development support funds for upgrading water units and departments.

District Councils are responsible for the operation and maintenance of rural village water supplies. To fulfill this responsibility, each one operates a Water Department or Water Unit under its Works Department. Budgets earmarked for this work are made available from council revenues and central government recurrent budgets. These budgets have been substantially increased in the last several years as part of an effort to increase the reliability of rural water supplies. At this time, the councils derive only limited revenue from user fees. Fees of P0.30/m^3 are assessed for users with private connections, and the average fee for livestock watering at council-operated boreholes is P6 per head per year.

3. Other Government Agencies

Other government agencies are also involved in water-sector activities. They typically require water for specific purposes, such as animal research or domestic use at rural government camps. Other than the ministries and departments discussed above, the agency most involved in water development for specific uses is the MoA, specifically the following groups:

- Department of Veterinary Service--Animal Health Unit, Trek Routes Unit and Tsetse Fly Control Unit;
- Department of Agricultural Field Services--Artificial Insemination Unit, Communal Areas Management Unit, Ranch Extension Unit, Irrigation Unit and Dam Building Unit;
- Department of Agricultural Research--Animal Production Research Unit; and
- Botswana Agricultural College

All of these agencies operate boreholes for their own purposes. MoA also operates a Small Dams Unit, which is responsible for the siting and development of small dams to be used for livestock watering.

In addition, several other ministries have agencies that require water for special purposes, including the police, Botswana Defense Force, customs and immigration posts, prisons, Department of Wildlife and Parks, secondary schools and Department of Roads. Village water supplies are utilized by these agencies where possible, but in some cases, separate systems are designed and installed.

D. Donor Activity

Swedish International Development Authority (SIDA) has been the largest single donor operating in the water supply sector over the past decade. This long-term commitment by one donor has allowed a comprehensive, integrated approach to water supply problems. Several important results of this approach are that it has encouraged a considerable degree of standardization on pumping equipment, as well as an understanding of operation and maintenance issues, which has led to the provision of support to District Councils. SIDA is currently involved in activities in the Village Water Supply Program, Rehabilitation Program, support to District Councils, water quality, training, planning and technical assistance.

There have been and are other water-sector donors working in Botswana, including the European Economic Community (EEC), Overseas Development Administration (ODA), AID and others involved primarily with research, training and equipment procurement. Gemeinschaft fur Technische Zusammenarbeit (GTZ) is involved in design work at several major villages to support the effort to upgrade their water supplies. These activities are fairly easily integrated with ongoing activities, and there is little of the management coordination difficulties that often plague multi-donor projects.

In many countries, foreign aid is often tied to the purchase of equipment in the donor's country. This is true in Botswana as well. For example, a certain portion of SIDA funds must be spent in Sweden, and EEC funds must be spent in EEC countries. This situation, in combination with deadlines for the expenditure of funds, has encouraged the purchase of capital items (e.g., trucks, pipes, water storage tanks) with aid funds that might appear to be less than optimum choices under other conditions. Botswana is also finding that certain donors do not permit the purchase of South African products, which artificially constrains the available choices for use of funds, especially since Botswana has historically depended heavily on South African products. Although it is clear that these donors are trying to wean Botswana from such heavy dependence on South Africa, it considerably complicates activities in the water supply sector.

Several nongovernmental organizations (NGOs) operate outside the government structure in the water sector. The most active is the Lutheran World Federation, which assists with the financing of equipping specific boreholes and village reticulation (distribution) projects.

2. Private-Sector Activity

An estimated 4,000 to 5,000 privately owned diesel pumps are used in Botswana almost exclusively for watering livestock in cattle-raising areas. These private engine and pump owners can be characterized as individual owner/operators, individual absentee owners or collective owners (syndicates). The maintenance and service conditions for these pumping systems vary greatly. While it is difficult to generalize, owner/operators tend to treat their equipment more carefully than the other two groups. This seems reasonable since private-sector pump operators who work for absentee owners are unlikely to be as careful with the equipment as the owner. Concerns about cash availability often plague syndicates. Average conditions were assumed for the purposes of this report, but it should be remembered that there is wide variability in practices and costs for private-sector cases.

Private-sector engine owners and users must rely largely on private-sector firms for drilling, equipment sales and to equip boreholes. BRS is available for engine and pump servicing and engine overhauls for paid subscribers, which number less than 1,000. There are a few private businesses engaged in engine overhauls, but none provide extensive field service. Other private-sector activity in water pumping includes hydro-geology and engineering consulting, primarily for DWA.

There are 12 Lister engine dealers in Botswana as well as pump or engine dealers for Petter, Hatz, Kubota, Mitsubishi, Lombardini and several others. There are also a number of dealers handling Mono, National and other makes of pumps. Most carry a limited number of engines and a supply of spare parts. Almost all of the equipment originates in South Africa, so procurement is easy and straightforward. Botswana belongs to SACU, which allows a free flow of goods from South African suppliers and access to foreign currency. In most cases, equipment can be ordered from South African wholesalers by telephone and delivered within several days. In this manner, Botswana-based suppliers can avoid the added expense of large inventories.

At present, there is no private-sector fabrication of pumping equipment, although RIIC is pressing for local manufacture of several of their pumps. There has also been some recent interest in manufacturing handpumps, and it is possible that a joint venture to manufacture parts of the Grundfos handpump may reach fruition in the near future. DWA is also investigating the manufacture of India Mark II handpumps by the Serowe Metalworking Brigade (development of this design was supported by the World Bank).

Private engine-rebuilding shops do exist to overhaul Lister engines and serve the automotive trade, but there are less than 10 in Botswana, which perform roughly 200 overhauls a year. Some overhaul work appears to be done outside Botswana in South Africa, Zimbabwe and Namibia. DWA, through BRS (which also serves the private sector), performs about 100 to 150 overhauls annually for private-sector engine owners.

While no private-sector companies handle the field servicing of engines and pumps, there are strong indications that a large informal sector is at work in this area. The informal sector includes "bush mechanics" as well as other mechanics who are formally employed, but do additional work for cash or in-kind payments. The technicians performing these field services (including engine overhauls in the field) vary considerably in their skill level. Some are undoubtedly trained technicians who provide services on their own time, while also holding down a job with the government or private sector. Others are self-taught individuals who have demonstrated an ability to keep equipment operating. Some servicing is also performed by engine owners in an effort to save the cost of hiring others.

F. Renewable Energy

Although the major portion of water lifting has been and is accomplished with diesel engines and, to a very limited extent, small gasoline (petrol) engines, there has been some use of alternative RETs. Minor use of windmills (200 to 250) and handpumps (about 50) has been going on for several decades. Solar PV pump systems, bio-gas substitution for diesel fuel and animal-drawn technologies are recent innovations with histories of less than five years.

Windmills were first introduced in the farming areas near Ghanzi in the west and south of Lobatse in the east by farmers from South Africa, well before independence (1966). Although standard windmill designs have seen some scattered use in other parts of the country, there has been no widespread use outside these areas to date. Over the past several years, RIIC and Wind Technology Group Serowe (WTGS) have developed horizontal-axis windmills to drive the widely used Mono pump. The goal of these programs was to introduce a locally fabricated windmill that is suitable for the wind conditions found in Botswana. Although there is interest in the RIIC windmill, it has not yet found a wide market.

Handpumps of several designs have been used over the years. Most common were the Godwin and an indigenous human-traction design (Shields and McGowan, 1985), but as diesel pumps became more commonplace these systems fell into disrepair. Recently, interest in handpumps has revived, particularly at the district level with over 40 handpumps installed during the past several years. The India Mark II and Mono direct-drive handpumps are most widely used, and are being supported by District Water Units and Departments. Other designs, including a modern variation of the indigenous human-traction design (Thebe pump), are being installed and tried.

Solar water pumping utilizing PV modules is a new technology arising from the development of lower cost commercially available PV modules. The first PV pump was installed in Botswana in 1982. Since then, over 10 more pumps have been installed and tested, most of them as part of the BRET project and several as a result of BTC's efforts.

Bio-gas technology is well-known and reliable, and bio-gas can be substituted for fuel in diesel engines. RIIC has been involved in efforts to demonstrate and promote this technology in Botswana. To date, more than five bio-gas substitution pumping systems have been built, and there appears to be some interest in the technology.

ADPs have been in use in various forms in many countries for some time, but only recently have efforts been made to introduce this technology to Botswana. RIIC's ADP was designed to drive a Mono pump, and more than 10 of these pumps are in operation. As with bio-gas substitution, there seems to be growing interest in this technology.

IV. PUMP SELECTION ISSUES

Proper selection of a technology for a pumping system involves a complex series of evaluations and decisions. Often, the process is shortcut by the unilateral decision of a designer, user or donor who may not have evaluated all of the possible choices. This may be due to the seemingly overwhelming task of making sense of the available information, a bias toward one type of system or the requirements of aid funds. Frequently, the approach in decision-making regarding pumps is to consider only what is well-known and available, ignoring other possibilities.

The purpose of the present work is to broaden this range of consideration and examine the implications of making other choices. However, within the broader range of equipment choices, technical, economic and infrastructural constraints limit choices in specific situations. These limits immediately narrow the selection to pumping systems that can reasonably be expected to meet the demands of a particular situation. In addition, the capacity to maintain and repair systems must exist, if long-term reliability goals are to be met. In examining the issue of comparing technologies more closely, it becomes clear that a number of issues, both apparent and subtle, must be considered and somehow factored into the selection process.

The normal technical procedure for designing a pumping system is to select the pump first and then choose a driver. Usually, the type of pump is chosen, based on the head and required flow rate. A manufacturer is then selected, based on local availability of the pump, the manufacturer's reputation and price. Only then is a specific pump chosen to meet the site's actual water requirements for a given total pumping head. In certain cases, such as submersible pumps, the job of designing the system is now complete, as the power source is an integral part of the pump selected. More often, a driver must also be chosen. Again, a driver type (e.g., electric motor or diesel engine) is selected based partly on power output, repair and maintenance capabilities, and expectations regarding cost and reliability. A specific manufacturer is chosen based on local availability and reputation. Then, a specific model or configuration is selected based on the pump's power requirements.

This report discusses pumping technologies in a general way, considering typical situations found in Botswana. However, it should be remembered that for each case, the pumping system must be matched to a set of site-specific conditions, including the borehole's technical limitations, water requirement at the site and equipment limitations. Before any water pumping technology can be chosen for a specific site, a number of factors that affect the performance characteristics demanded of a pumping system must be known. These include borehole characteristics and water users' requirements.

A. Borehole Characteristics

Boreholes are drilled by private-sector operators and DWA. The total drilling capacity of DWA is in the range of 300 boreholes per year, with private-sector drillers adding between 200 to 250. DWA's success rate (defined as boreholes yielding from 1.5 to 2.0 m^3/hour) is only a little over 50 percent, which attests to the difficult hydro-geological conditions. This rate has risen in recent years, most probably due to better siting work. The cost for drilling a 200-meter, eight-inch borehole (typical in Botswana) with half of it cased and including test pumping, but not transportation, is around P20,000. As a single-cylinder Lister engine costs less than P5,000, the importance of improving drilling success rates and utilizing lower yielding boreholes, where possible, is readily apparent.

Once boreholes are drilled, the water level is recorded, and they are tested for drawdown, yield and water quality. Resting water levels vary up to about 100 meters. The levels for boreholes in the eastern, most heavily populated areas of the country are often 40 meters or less and sometimes as little as 15 meters in the Tuli Block area. Shallow water tables are also found in the north around the Makgadikgadi pans, and near the northern river systems and Okavango delta. The water table tends to be deeper in the west and southwest (the western Kweneng, Southern, Ghanzi and Kalagadi districts) with resting levels often in the range of 100 meters. However, even in these areas, water can be found in some places at depths of less than 30 meters. With deeper water levels, the use of windmills and handpumps will be limited as they cannot pump much water from these depths. Commercially available solar pumps may be prohibitively expensive for higher heads and greater water demands compared to diesel pumps that are designed to meet similar requirements.

The goal of test pumping is to establish the borehole's yield and drawdown characteristics. DWA's policy is to test-pump a borehole for 48 hours with an eight-hour recovery period that is also monitored. These tests serve to establish a criterion for pumping system design, but are inadequate to determine the aquifer's long-term performance or the borehole's sustainable yield. However, it does establish a design pumping rate, usually 60 to 65 percent of the test yield. These tests are an improvement over earlier procedures that sometimes called for 12-hour tests--in some cases, only eight-hour tests were conducted.

Drawdown measures the lowered water level in a borehole as a result of pumping. It tends to be highly variable, from nearly zero up to 75 to 100 meters, depending on the aquifer's characteristics and pumping rate, but generally, the higher the pumping rate, the greater the drawdown. However, due to the flexible, robust nature of equipment installed on most boreholes (Lister/Mono pump sets), it not as critical to know the precise drawdown since Mono pumps are not as sensitive to head fluctuations, compared to submersible pumps, and are usually installed near the bottom of the borehole regardless of the resting water level. In combination with the cost of test-pumping, this has led to poor test-pumping practices.

Given test results, it is often impossible to use the data collected to predict drawdown at different pumping rates, but the proper figures for pumping water level are important for determining the total head and, hence, the appropriate design of all pumping systems. The sizing of solar pumping systems is particularly sensitive to head and thus to the proper calculation of drawdown during pumping. Submersible pumps are also sensitive to this factor, as the efficiency of this type of pump is sensitive to head.

If the borehole depends on seasonal recharge from rainfall and runoff, as opposed to longer term rainfall patterns, the resting water level and drawdown may vary both seasonally and over drought cycles. The result of such fluctuations is often the discovery that the pumping equipment is no longer delivering the necessary volume of water and is pumping some percentage of air. In this regard, the Mono pump is reasonably forgiving in the short run, but a submersible pump will be severely damaged if this occurs. Longer term monitoring could assist in a fuller understanding of borehole characteristics, thus allowing cost-saving design refinements at the site and the use of a wider range of equipment.

A borehole's maximum yield is also determined from the pump test results. Yields can range from nothing to more than 50 m^3/hour, with average yields (depending on the geological formation) of two to six m^3/hour. These relatively low yields lead to diesel pump sets that operate at low efficiencies (i.e., are under-loaded), as the smallest diesel is still usually overpowered for these applications. Unfortunately, 48-hour test pumping, as performed by DWA, is insufficient to reliably determine a borehole's long-term performance. The understanding of hydro-geological conditions over much of the country is inadequate, and such short pumping tests are insufficient to determine long-term aquifer characteristics.

All of these factors taken together help explain the popular belief that boreholes are drying up. First, appropriate design of a pumping system depends on accurate characterization of the borehole's yield and drawdown characteristics. Since these may not be accurately measured, the equipment that is eventually installed may overpump the borehole, causing it to "dry up." Second, if the borehole is drilled into an aquifer that depends on seasonal recharge, water level and yield may decline during the dry season. With even less recharge during the current drought cycle, this decline may well be more pronounced. Third, many boreholes in Botswana are drilled into difficult formations where water reaches the borehole through cracks and fissures in the rock formation. Over a period of time, with water movement always toward the borehole, these cracks and fissures may become blocked with particulate matter that migrates with the water, thus causing a more permanent decline in well performance.

With the high cost of drilling boreholes, it seems reasonable to consider utilizing low-yield boreholes (less than 1.5 m^3 per hour) that would have been abandoned in the past. Unfortunately, many so-called low-yield boreholes have never been test-pumped, and with current test-pumping practices, it is uncertain that the results would be accurate even if the tests were performed. Minor errors in estimated maximum yield or slight decreases may well make a difference in whether these boreholes can meet water needs. As a result, once a borehole has been identified as low-yield, it is usually abandoned. These factors limit the scope of use for low-yield boreholes. However, in some cases of extreme need, low-yield boreholes have been equipped with diesel pump sets. In most cases, these diesel engines are severely under-loaded, which would argue for use of a different pumping technology in these uncommon instances.

B. End Uses

In Botswana, the major end uses for water are industry, human consumption, livestock watering and irrigation. At Orapa, the mine maintains its own water supply. Human consumption, livestock watering and irrigation are more dispersed than larger industrial uses. These water needs are usually met by small-scale pumping systems in rural areas. These three end uses are characterized by different seasonal patterns and requirements that can easily have an impact on the selection of a pumping technology.

1. Domestic Use in Villages

Village water supplies are currently designed so that six to eight hours of pump operation a day will provide 30 liters per capita per day, allowing for 10 years of estimated population growth. This means that at the current daily consumption rate of 15 to 20 liters per capita, many village systems equipped with diesel pumps are operating only a few hours each day. Future increases in total consumption can easily be accommodated by increasing the number of pumping hours per day, which may not be so easy to accomplish with some other pumping technologies.

In rural villages, the average daily water requirement is about 30 m^3, but varies considerably for smaller villages (many of which are now being constructed) from 10 to as little as five m^3. There are monthly variations as well with highest and lowest months being in the range of 30 percent higher or lower than the annual average. These variations do not appear to follow any clear pattern other than the fact that the early months of the year seem to show lower water delivery figures than later months. These months coincide roughly with the agricultural season when people are more likely to be at their agricultural lands areas.

Elevated water storage tanks are in common use in rural villages and serve several purposes. First, they provide the pressure for piped delivery of water to standpipes. Second, they give the capacity to deliver water to standpipes at a rate that exceeds the pumping rate for short periods. Third, they provide a stored volume of water for periods when the system breaks down. When RETs are considered, they have a fourth purpose--to meet demand when there is no energy source, either wind or solar. At present, village water storage tanks are designed to supply at least one day of water under design-year conditions. In most cases, this appears to be insufficient to perform the functions of meeting demand during breakdowns, as these typically last from two to five or six days (depending on the distance to the borehole and transportation availability), or windless or cloudy periods if renewable energy is being used.

2. Livestock Watering

Livestock watering from boreholes is common practice throughout Botswana during at least part of the year. In the eastern part of the country, naturally occurring water sources and rainwater runoff collected by dams are used as much as possible during the rainy season until they dry up. In the western part of Botswana, where rainfall is less and the collection of water in rivers and dams less concentrated, there is heavier reliance on borehole water sources. MoA policy states that boreholes for livestock watering should not be closer than eight kilometers and should serve no more than 400 cattle. The Water Apportionment Board specifies that a maximum of 18.2 m^3/day can be drawn from boreholes used for this purpose, but in practice, there is little way to enforce this limit and greater amounts of water are often pumped for larger numbers of cattle.

Seasonal variation in borehole use for livestock watering is high, particularly in the eastern part of Botswana. It is greatest from May to October, the dry season when dams and pans are empty. During the rainy season, a large number of boreholes are not used at all for several months. Average use over the year appears to be five to six hours per day.

Water storage is not found at every livestock-watering borehole, but it is always in the form of ground tanks, usually in the range of 10 to 75 m^3. They are often constructed of cement block or galvanized iron. The cost for water storage of this sort is 10 to 25 percent of that for elevated tanks.

A very high priority is given to the reliability of village water supplies--the government and donors have provided funds and technical assistance to this end. This is particularly important since many villages have only one equipped borehole with no back-up system in the event of an outage. While livestock watering is no less important from the perspective of stock owners, it suffers from a lack of organization and funding difficulties. Livestock owners do have secondary sources of water for their animals that may involve the payment of fees or inconvenience of moving cattle. As such, water demand can be spread to other sources in cases of emergency.

3. Irrigation

Roughly 2,000 hectares are cultivated as irrigated agricultural plots, with plots of over 50 hectares accounting for over half of this total. Larger irrigated areas are found in privately owned freehold land in the Tuli Block, located in the extreme eastern corner of the country. In addition, some flood-recession irrigation is practiced in the Okavango area. It is estimated that 30 million cubic meters of water are needed annually for irrigation, almost two-thirds of this by the larger freehold farms. Much of this water is lifted directly from the river or shallow boreholes nearby.

Partly as a result of successive years of drought, Botswana has chosen to promote irrigation in the western Chobe and eastern Okavango areas in northern Botswana, and continued to support private-sector development in the Tuli Block. The projected total for irrigated land by the end of the development plan period (1992) is 6,000 hectares. This will lead to a significant increase in water and energy requirements, particularly if water must be pumped from deeper aquifers as irrigation is expanded. The increased need will be on the order of 20 percent, while water and energy use in other sectors is projected to rise only from zero to five percent.

The design of CWPP did not allow for an investigation of irrigated agriculture, due to the relatively small amount of irrigated area and predominance of bigger plots that use larger scale pumping equipment. However, it is clear that a closer examination of the water and energy requirements of this end use will be needed as irrigation becomes more extensive. This needs to be done not only in the context of renewable energy use, but also to determine aquifer potential and examine the broader economic implications of irrigation costs on the profitability of irrigated crop production.

C. Equipment

Installation considerations include system design, capital costs, labor (time and skills required) and transportation (distance and vehicle needed). All vary with borehole location and user group.

1. System Design

DWA designs almost all public-sector borehole installations. In most cases, Lister engines with Mono pumps are specified, except for an occasional windmill or electric submersible pump. Standard engine frames and concrete bases are used, and pump houses are constructed. The pump choice is based on borehole yield and drawdown as well as any delivery head and pipe friction. Engines are oversized to meet the start-up torque requirement of the Mono pump. Increased water requirements, due to population growth, are met by increasing the number of pumping hours.

In the private sector, system design is usually completed at the point of purchase. Often, Lister 8/1 engines are requested by buyers although they are almost universally overpowered for the pumping application. Recently, some engines besides Listers are starting to be purchased because they cost less. The available options in Botswana include Hatz, Kubota, Mitsubishi, Lombardini and several others. Private-sector users are turning increasingly to Mono pumps due to their wide availability and sturdy construction. The National reciprocating pump is still sold, and many remain in use.

2. Capital Costs

The capital cost of a pumping system depends partly on what it includes and the source of the equipment. When DWA equips a borehole, it includes the engine, pump, pump head, rising main, Mono drive shafts, engine frame, mounting block, pump house, water meter, 20-mm brass tap and non-return valve. Often, a pressure-relief valve is also installed. All of these are purchased at government tender prices, which may reflect a 20 to 30 percent savings over retail prices. Water-distribution systems and tanks may be part of the system design, but their costs are not included in this analysis.

In the private sector, installed equipment also includes the engine, pump, pump head and related components, but only rarely water meters, taps, non-return or pressure relief valves. In many cases, pump houses are not included. Often, the engine frames and mounting blocks are smaller and, in a few cases, altogether lacking (these are usually owner installations).

3. Labor

DWA maintains six borehole installation crews, each consisting of nine to 10 men and a driver. At least one (sometimes more) is trained as a borehole mechanic with the remainder of the crew being laborers. The installation is not complicated as all the parts are specified and the work straightforward and familiar. An installation takes roughly 20 working days.

Interviews with several private-sector contractors indicated that, in most cases, a borehole installation can be completed in less than a week by three to four skilled installers and several days of unskilled labor. Differences between private and government installation crews are the result of scheduling problems, lack of oversight due to limited supervisory personnel, transportation difficulties and the logistics of government payrolls.

Windmills installed by the BRET/CWPP crew required 10 days to two weeks, and solar installations took four days to a week. However, special skills are required for this work, particularly solar pumps, and special guidance was provided. These times may not be typical for a standard DWA installation crew, even if it is trained for the task.

4. Transportation

DWA crews operate with 10-ton trucks because they have to carry all of the borehole equipment, the crew and their camping equipment to the job site. In addition, numerous local trips are necessary to collect supplies that are available locally, such as beer, firewood and gravel. Usually, one or more return trips must be made to the point of departure to collect forgotten items or take pay sheets to the supervisor. In all, the equivalent of three-and-a-half round-trips are typically made from the crew's point of origin to the borehole.

Transportation for private installation crews is usually by Land Cruiser or three- to five-ton truck. In most cases, the crew does not return to their home base until the job is complete.

D. Borehole Operation

Borehole operation includes labor considerations, when an pump operator or operators are required, and consumables, notably diesel fuel and oil for diesel engines.

1. Pump Operators

Government boreholes that supply water for public consumption are operated by a pumper. In larger villages with more than one borehole, a pumper may be responsible for several boreholes, but in smaller villages, they will have only one borehole to look after. The pumper is responsible for starting and stopping the engine, keeping the engine and pump house clean, and caring for the rest of the village reticulation system, performing such tasks as replacing broken taps, reporting leakage at the tank or in the pipe network and preventing water wastage. Pumpers employed by the government are paid according to government scales and receive about P2,400 annually.

At boreholes operated by other government agencies, such as those at Department of Wildlife camps or MoA agriculture research centers, the pumper may have a broader job description that includes operating the radio or being a driver or maintenance person. This reduces the effective labor cost for operating the borehole.

In the private sector, labor is inexpensive with pumpers making only P400 to P500 annually. These pumpers are not well trained and do not have the same responsibilities as government pumpers. However, this greatly reduced labor cost helps make private-sector engines less expensive to operate than the public-sector systems, though at a generally reduced lvel of overall reliability.

When considering alternatives to diesel engines, it must be remembered that in the public sector, pumpers will still likely be required as long as a reticulation system is in place--starting and stopping the engine is only one of the pumper's tasks. In the private sector, the reduction in labor costs when utilizing wind or solar energy is small. If animal-power or bio-gas pumping systems are used, labor costs are likely to increase, if labor is indeed a financial cost. However, users may collectively share operating responsibilities with no cash transaction. ADP and bio-gas systems cannot realistically be considered for public-sector use as the increased labor requirement would have to be paid for at government wage scales. Analysis indicates that the cost of hiring a pumper for public-sector use of windmills and solar pumps represents the largest component of recurrent costs. In some cases, such as remote

Department of Wildlife game-watering boreholes, pumpers may not be needed to operate wind and solar pumps, which makes them more attractive for these applications. Section VI provides a detailed discussion of these issues.

2. Consumables

Diesel fuel consumption per unit of water delivered depends on engine loading and the pumping head. In Botswana, the range of fuel costs for a majority of systems is from P0.10 to P0.20 per cubic meter of water delivered. This means that annual fuel consumption for most engines used to supply water for rural villages and livestock watering is in the range of 2,000 liters or less for delivering up to 30 m^3 of water per day. Fuel costs are on the order of P.54 to P.67, depending on the use and location. Oil consumption, including oil changes, comprises about four percent of fuel consumption. (For more detail on these figures, see VOLUME II: DIESEL SYSTEMS).

There are other considerations as well--availability and transportation. Near urban areas, the availability of consumables is currently not a problem, although it may be at sometime in the future. However, for more remote sites (both rural villages and livestock watering points), the availability of fuel and oil is more problematic. No widespread shortages exist, but this is critically dependent on adequate transportation facilities which, being engine-driven, are prey to the same problems as diesel pump sets, including breakdowns, spare parts and fuel availability, and a lack of skilled mechanics. For the most part, District Council Water Units have adequate transportation, but it remains a problem for BRS as roughly sixty percent of the vehicle time for its fleet is unavailable at any given moment due to mechanical problems and delays in repairs or replacements. Private-sector transportation may also be problematic, but it appears that flexibility and an ability to make other arrangements allow owners of diesel engines to meet their transportation needs when emergencies arise.

The use of renewable energy sources may overcome the need for consumables (fuel and oil) and, hence, the cost, availability and transportation problems associated with them. However, they cannot overcome transportation problems entirely as breakdowns will occur and periodic trips to check these systems will still be necessary.

E. Reliability

Reliability can refer to the installed equipment or the water supply. Although the two are inextricably bound together, there is a crucial difference in storage and/or back-up pumping equipment.

The function of a water supply system is to deliver water to an end-user when it is needed and in the desired quantity and quality. In most cases, this requires a combination of pumping equipment and a storage system. Water storage is critical for most pumping technologies. Diesel pump sets are designed to take advantage of the engine's power and well yield to pump the necessary water during a few hours of the day. This water can be consumed at other times from storage. The engine can be started whenever the stored water is exhausted, provided the engine is in good condition and the water resource is sufficient. For renewable energy pumping systems, particularly wind and solar systems, water storage serves the additional function of providing water when the energy source is unavailable, which includes calm periods for windmills, and nighttime and cloudy days for solar pumps (except solar pumps with battery storage that can pump during cloudy conditions or at night, if necessary).

The size of the storage tank required will depend on reliability of the energy source, flexibility of demand, peak demand, and availability of back-up pumping systems. Proper sizing of storage tanks is a complicated combination of water demand and energy resource assessments, tank costs and anticipated duration of breakdowns. In general, it appears that one day of storage is insufficient for wind and solar systems because of energy resource constraints. It is insufficient for diesel systems, too, given the typical duration of breakdowns. Four days of water storage appears to be sufficient to address all of these situations.

The reliability of water supplies is also (and perhaps more often) associated with equipment reliability. Equipment reliability effects the reliability of water delivery in two major ways--breakdown frequency and duration.

The frequency of breakdowns is a function of system fragility and complexity, maintenance, availability and cost of spare parts, and skill levels of the operator and repair personnel. The Lister/Mono pump combination that is generally used in Botswana is simple and straightforward, and widespread standardization on this equipment has contributed significantly to system reliability. In the public sector, spare parts are currently available, and although the cost for them is rising, it is not perceived as a major problem. Private owners of diesel pump sets find spare parts a greater obstacle due to the typical remoteness of their operations and continual cash-flow problems. In these cases, spare parts are not always installed when needed (or used parts are fitted) because they are not immediately available and/or there is no cash to purchase them.

Preventive maintenance reduces the frequency of breakdowns. In Botswana, most private-sector users (except perhaps freehold farmers) perform little or no preventive maintenance. This is also true for some council boreholes and those operated by government agencies. It appears that for major village supply systems and some council boreholes, preventive maintenance is carried out intermittently, as time and the availability of transportation permit. A few district councils are following strict preventive maintenance schedules. In these cases, the frequency of breakdowns drops noticeably (from two or three a year to less than one annually). In instances of heavy pump use and no maintenance, the breakdown rate averages five to seven per year.

The breakdown frequency for windmills appears to be about the same as for diesel pump sets, and all indications are that this could be reduced with proper training and reasonable local servicing. To date, solar pumps have had a lower breakdown frequency than windmills and diesel systems. AC-electric pumps and handpumps also have low breakdown rates compared to diesel and wind systems, which may be partly due to their limited use.

The frequency of breakdowns also is a function of how well repair work is done. The recurrence of a problem is likely if repairs are not done properly the first time, and the ability of repair crews to fix and maintain equipment is directly related to their skill level, training they have received and supervision. DWA conducts three levels of training course for borehole mechanics on the servicing and repair of Lister engines and Mono pumps. These mechanics find positions with DWA and council repair crews. As a result, they should have the capability to repair and maintain these pump sets properly.

At present, no formal courses are offered for mechanics who want to learn to repair and maintain renewable energy pumping technologies. Windmill technology is straightforward and mechanical in nature, so training in its repair and maintenance should not be costly or time-consuming. However, the repair and maintenance of solar equipment requires new skills that the current population of borehole mechanics does not possess--some knowledge of electrical theory and electrical troubleshooting.

Although the duration of a breakdown is affected by the availability of funds and spare parts, it is more commonly determined by logistic considerations and infrastructure responsiveness. These include communications, organizational ability of the agency or individual responding to the breakdown, and availability of transportation to the site and trained staff. When a breakdown occurs, it is first necessary to communicate this to the proper authorities. Often, especially for rural villages) this is not easy as there is usually no radio contact, the roads are not well traveled and distances are great. The process of notifying authorities of a breakdown frequently takes a day or two, and full details of the problem are often not transmitted. Sometimes, the only message is that there is no water.

Once the proper authorities have been notified, the repair unit must be in a position to respond with appropriate personnel, transportation, tools and spare parts. To be able to send appropriate personnel, staffing levels must be such that someone with proper training is available to go to the breakdown on short notice. Proper transportation means that a vehicle appropriate for the road conditions and required equipment is available and ready to go. Determining the necessary tools and spare parts is often a bit of a guessing game, which can result in return trips and longer breakdowns.

The concern for water in Botswana is such that the normal duration of a breakdown is significantly less than a week. Some councils claim that once they are notified of a problem, they can usually limit the duration of breakdowns to one day for nearby boreholes and two days for distant ones. However, the average duration is more likely to be three to four days, and durations of up to a week are not uncommon for distant boreholes. During breakdowns, users rely on the water stored in the tank until it is exhausted. Then, they obtain water from other nearby villages or traditional sources.

As noted above, preventive servicing is largely lacking in the private sector, which contributes to both minor and major service requirements. Although the data is very sketchy, all indications are that minor repairs cause few problems as local resourcefulness often compensates for a lack of spare parts. Unfortunately, this sometimes contributes to more serious problems later on that cause longer periods of borehole outage. Loaner engines are available for owners who are BRS subscribers, (i.e., have engine repairs done by BRS). It is not uncommon to find that some repairs go unattended for a month or more, usually due to cash-flow constraints. Freehold farmers often own spare engines for emergency use, thus minimizing the duration of their breakdowns. This does not appear to be common practice among Batswana who operate engines in communal lands areas.

For new technologies that are not yet fully integrated into the spectrum of pumping systems, the availability of spare parts and training will be the largest contributing factors in the length of pumping system outages. Upon notification, the response to and repair of windmills has taken several days, but solar pump repairs often takes longer as more sophisticated troubleshooting is required. Sometimes, repairs have taken longer because of the prototype nature of some of the equipment used and the need to replace components or redesign the system.

F. Acceptance

Batswana tend to be cautious. Their environment and living conditions are such that mistakes are difficult to accommodate. Most people in both the public and private sectors typically take a "wait-and-see" approach. New technologies are not accepted at face value--they must prove themselves not only initially, but also in the long run. A number of factors seem to enter into the decision to embrace new ways of doing things, including initial cost, reliability, ease of use, labor requirements and perception of appropriateness. Once the benefits have been clearly demonstrated, new technologies are accepted, which can be seen in the acceptance of bicycles, diesel pump sets and tractors, among others.

Cost remains a barrier for private individuals, even for the purchase of a diesel engine. Although credit is readily available for diesel pumping systems because these are well-known and understood, lenders have expressed concerns about making larger loans for types of pumps that are less familiar. Cost is not usually a problem in the public sector, but the size of the budget can (and certainly has) dictated the choice of technology. This obstacle is certainly more problematic for the more expensive systems, such as solar pumps, regardless of their potential for long-term cost savings.

In addition, reliability is a major concern. If a chosen technology does not perform a task adequately, it will not be accepted. Also, if it is argued that the long-term savings justify the cost, there must be some degree of certainty and evidence that the system will operate properly in the long run.

Although diesel pump sets do break down, the mechanism for repairing them is known and the costs relatively well understood. Solar pumps are not yet proven in this regard. While the modules are straightforward and reliable, the pumps and controllers are not proven. In addition, the repair infrastructure for these systems is not yet well developed, which leads to some reluctance on the part of potential users. Windmills are known and in use in certain parts of the country, and their mechanical reliability is on a par with diesel systems, although the cost of repairs is much less. However, reliability of the water supply during calm periods is a factor that weighs against their use. Although the bio-gas substitution pump and ADP are proven technically, their long-term reliability and cost factors have yet to be demonstrated conclusively. The fact that some potentially attractive pumping technologies do not yet have a clear operation-and-maintenance history and are not supported by a responsive repair-and-spare-parts infrastructure is as important in choosing a system as the technical performance and cost of the equipment.

Acceptance of a pumping technology also depends on ease of use. As long as they are operating, diesel pumps are easy to use--when water is needed, the pump is started and water delivered. For solar and wind pumps, no starting and stopping is required (unless the storage tank is full), but water cannot be pumped on demand. This requires a sensitivity to solar or wind conditions and some care in adjusting water-consumption patterns, which makes these technologies a little more difficult to use. The more labor-intensive pumping systems, such as handpumps, ADPs and bio-gas substitution pumps, are more difficult because their operation requires physical labor and, sometimes, the participation of several people.

Whether a pumping system is perceived as appropriate also plays a role in its acceptance for certain applications. As the Village Water Supply Program moves toward providing water supplies in smaller villages, other technologies such as handpumps may be suitable to meet their water needs. However, villagers often do not want to accept this technology because they feel the government is committed to provide diesel-driven reticulated water systems. Appropriate-use factors may also play a role in the acceptability of oxen to drive ADPs. Oxen are more powerful than donkeys and can be used to advantage with the ADP, but they have not been used at any field installation thus far.

Borehole characteristics, end uses, installation and operation requirements, reliability and acceptance must all be considered when selecting a pumping system. These factors are discussed for each type of system in Section V.

V. TECHNOLOGY CHOICE

This report compares seven different pumping technologies that range from prototypes to mature, widely used systems and wholly imported to locally fabricated equipment. This broad range makes comparing the equipment difficult and, to some degree, subjective. This section provides a brief description of each technology and issues relating to its use. The advantages and disadvantages of each type of pumping system are also discussed.

A. Diesel Pump Sets

1. Description and Use

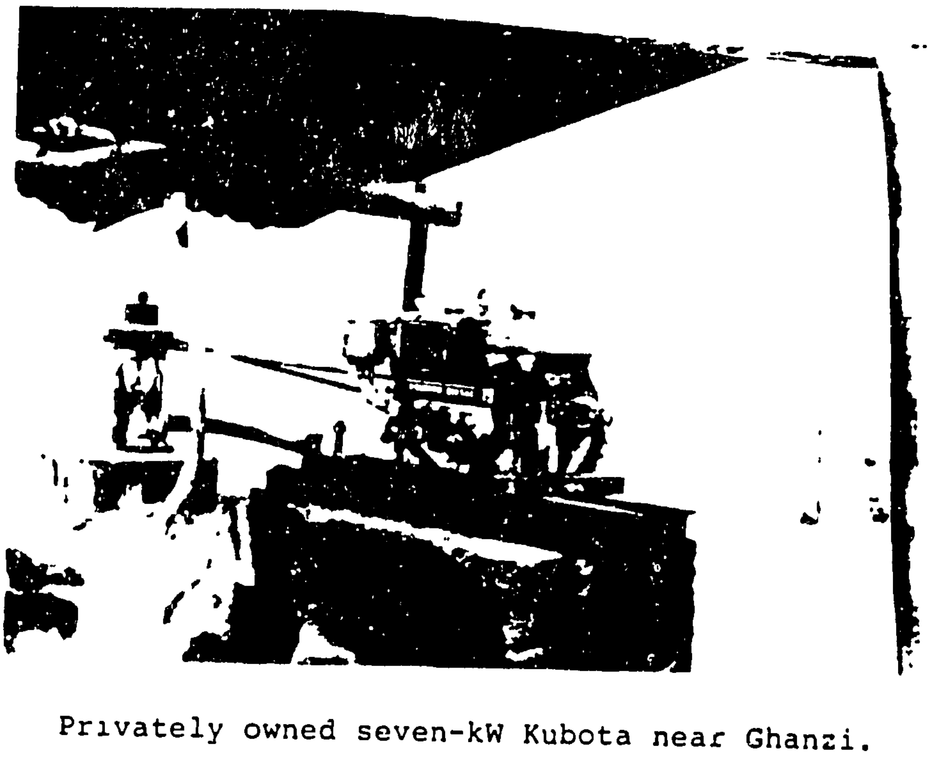
The most commonly used diesel pump set is a Lister engine coupled with a progressive-cavity, positive-displacement, Mono pump. The government has standardized on this configuration for all of its diesel pump installations. The Lister engine is robust and the Mono pump flexible because output is relatively independent of head over a wide range and it is reasonably resistant to pumping some percentage of air or sand. The private sector has also largely standardized on Lister engines, but significant numbers of installations use reciprocating pumps instead of the Mono because many predate the successful introduction of the Mono pump in the late 1970s. There has always been some use of non-Lister engines, but it is estimated that 90 percent of the diesel pump sets in Botswana are still driven by Lister engines.

Diesel fuel accounts for 80 to 85 percent of the energy used to pump water. The remaining energy for water pumping is consumed by larger scale electric systems used to supply towns and mining needs. The Lister engines in use are largely the L and S series and water-cooled, single-cylinder models. Multi-cylinder S and H series engines are often used for major village water supplies and a few in larger rural villages.

2. Issues

A number of issues are associated with the use of each pumping technology. They vary with the system and can be affected by policy decisions that may ultimately influence the selection of pumping equipment. Several of the issues mentioned here are common themes that apply to the examination of other pumping choices as well. For diesel systems, the most important issues include:

Lister ST-3 and Mono pump at Otse. Note the brick pump house; normally, sheet metal is used.



Privately owned seven-kW Kubota near Ghanzi.

- equipment standardization and its effects;

- dependence not only on imported equipment, but also fuel and spare parts;

- BRS subsidies to the private sector;

- the GOB's commitment to provide water to increasingly smaller villages and settlements; and

- an existing widespread installation, maintenance and repair infrastructure.

The development of a standard design procedure for diesel pumping systems in the public sector has simplified system design, reduced the need for spare parts inventories, and eased the burden of training requirements for installation, maintenance and repair. To a certain extent, these standards have also been adopted by the private sector partly due to the BRS policy of servicing only Lister and Lister copies. The choice of Lister as the standard, a model built in South Africa and part of the SACU, has meant that these engines are readily available and spare parts are easy to obtain, which has contributed to the relative reliability of diesel pumping systems in Botswana. This standardization has also led to broad experience with these engines and a well developed formal and informal service network.

While standardization has its benefits, the use of any diesel system implies dependence on foreign sources for equipment, spare parts and fuel. The widespread use of diesel pumping systems means that most water pumping is dependent on factors that are beyond national control. These include price and, because Botswana is landlocked, the willingness and/or ability of her neighbors to allow the purchase or transshipment of critical supplies of fuel and spare parts.

BRS operates to service engines operated by government agencies other than DWA and District Councils, as requested. It also provides services to the private sector for a fee. An examination of the fee structure clearly shows that the service is not self-sustaining and is heavily subsidized by government revenues. However, the extent of this subsidy is not fully understood as few efforts have been made to analyze it. An initial examination of the records indicates that it may be on the order of 50 percent, but a significant effort would be required to determine the subsidy level accurately. This subsidy represents a significant incentive for the use of Lister engines over alternatives and, indeed, promotes continued dependence on diesel pumping systems in the private sector at the expense of other technologies. It also contributes to the lack of formal-sector field-service activity, although such capability exists.

Since 1978, SIDA has supported the Village Water Supply Program. This program's goal has been the installation of water supply systems in 354 villages. It is scheduled to complete this task in the early part of the next decade. As the program enters its closing stages, smaller villages and settlements are being equipped with diesel pumping systems. In 1981, 13 of these villages had populations of less than 100, and it is estimated that the average population for villages where pumping schemes remain to be built is under 300. It is clear that in many of these cases, the pumping requirements are small in terms of both power requirement and water delivery. Most diesel engines already appear to be under-loaded (i.e., overpowered for the application), which contributes to system inefficiencies and increased maintenance requirements. The limited availability of small diesel engines (sizes smaller than two kW are difficult to find) compounds this problem. Hence, with low water requirements, it is reasonable to consider other pumping technologies.

The following listing shows the major advantages and disadvantages of diesel pumping systems in the context of their use in Botswana.

Advantages

- Equipment is readily available from agents and dealers in Gaborone and a number of towns.
- A repair infrastructure is available through BRS, private companies and the informal sector.
- Pumps can be used to meet demand by adjusting the number of hours of operation.
- The labor required to operate a diesel system is moderate as only one operator is necessary to start and stop the engine, so the operator may have other duties.
- The capital cost is relatively low, with single-cylinder engines costing P2,000 to P2,500.
- There is no practical size limit on the equipment.

Disadvantages

- A supply of diesel fuel is required, which includes its cost and transportation for delivery.

- Fuel and spare parts are imported, which implies dependence on foreign sources and transportation to Botswana.

- Diesel pumps cannot be operated without an attendant, so a pumper must be hired.

- Units smaller than two kW are difficult to find. For cases requiring smaller engines this contributes to low loading, inefficient operation and increased maintenance demands.

- Diesel engines require regular maintenance and periodic overhauls, which contribute to high recurrent costs.

- Diesel systems are noisy, which is a particular problem with older boreholes that are in or near villages.

- These systems contribute to pollution through the spillage of oil and fuel and engine exhaust.

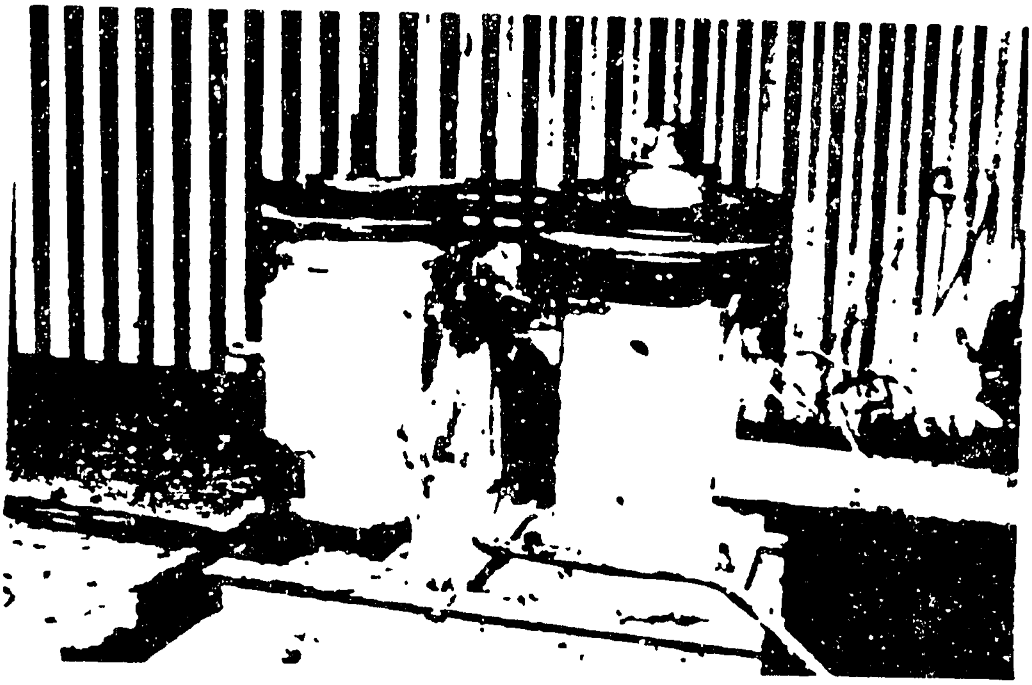
CWPP performed careful tests on 10 small-scale diesel engines and examined the field-service records for about 20 percent of the engines used in major villages and 10 percent in rural villages. In addition, overhaul records for 500 engines were examined, and extensive interviews conducted with pump owners, technicians and private entrepreneurs. This work is reported in VOLUME II: DIESEL SYSTEMS, which is the basis for understanding their use, characteristics and costs.

B. Mains-Connected Electric Pumps

1. Description and Use

These pumping systems utilize electric motors to drive pumps, which requires an electrical energy source of the proper voltage that capable of delivering the required amperage. In general, 380-volt three-phase motors are used with 11- or 33-kilovolt (KV) feeders from the utility grid. Unless 380-volt power is already available very nearby, a step-down transformer is required. It is possible to use diesel-driven generators as the electrical energy source, but this is not common. AC-induction motors are used to drive Mono pumps (or in a few booster-pump applications, surface-mounted centrifugal pumps), or the motors are specifically designed for use with submersible pumps. The latter systems are usually purchased as a unit.

Electrically driven Mono pumps and submersible pumps (e.g., Grundfos, Jacuzzi) are both used. The former have certain advantages in that the motor can be serviced without pulling the pump. In addition, the Mono is familiar, flexible and robust. The standard induction motors used with these systems can be serviced and rewound, if necessary, in Botswana. Submersible pumps also appear to have some advantages--if chosen carefully, they can be significantly more efficient (up to 70 percent, as opposed to about 40 percent for electrically driven Mono pumps), installation is easy and the service requirements have been low. The disadvantage is that they do not operate well at other than design pumping conditions and can be destroyed if they pump dry.



Grid-electric motor driving a Mono pump at Mochudi.

Probably less than 100 electric pumps are currently in use in Botswana. They are used somewhat in several areas in the eastern part of the country and where rural power stations exist (notably Maun). Electric pump use is severely limited by the extent of the mains distribution network and high cost of interconnection if overhead lines must be included. Further, the current electrical energy tariff structure is high, approximately P0.19 per kilowatt-hour (kWh), which does not favor electric pump use strictly on a cost basis.

2. Issues

Issues that positively affect the potential use of electrical pumps include a local energy source, as the Morupula coal-fired power station is now in operation, and low maintenance and pumper training requirements. On the negative side are the cost and implications of mains extension, lack of understanding of local aquifer performance (and subsequent variations in head and drawdown), current tariff structure and resulting rate for water pumping, and service and repair infrastructure.

A major attraction of the increased use of electrical power for water pumping is the use of local coal to generate electricity. The coal-fired power plant at Morupula decreases the country's dependence on foreign energy sources. The resulting displacement of disel fuel by the use of electricity has the potential to reduce Botswana's dependence on its neighbors. Movement in this direction has already begun in towns and major villages where it is practical.

One apparent advantage in using electric pumps is the low service requirements and frequency of breakdowns. This is especially true of submersible systems. The reduced service requirement eases the burden of logistic support, particularly in terms of scheduling and transportation. As already noted however, submersible pumps are vulnerable in other ways--reduced efficiency if the pump is improperly specified and susceptibility to damage if the water level in the borehole is too low.

A potential advantage of electrical pumping systems is that much of the equipment's operation can be controlled electronically. In instances where the use of electronic controls is practical (i.e., the borehole is not too far from the village), they reduce the need for pumpers. Although these sites would still have to be checked periodically, and pumpers have other duties, any reduction in pumper costs (especially for systems satisfying small demands) will reduce unit pumping costs.

Included in the cost to install and use electrically driven pumps is the cost of extending the mains. The cost for overhead lines is P10,000 to P12,0 per kilometer. If boreholes proposed for electrification are an, significant distance from existing mains, this cost can be very high. Further, if the long-term yield of a borehole is unknown, this expense is difficult to justify as it is not easily recovered if the borehole cannot be used for a long period of time. This supports the argument for an improved program of borehole test-pumping. When long-term aquifer performance is better understood, electrification can reasonably be considered, if the distance to the utility mains is no more than a kilometer or two (the exact distance will be determined by other factors on a case-by-case basis). If donors are willing to support the cost of mains extension, electrical pumping systems appear more attractive. Further, multiple uses of electrical energy in a village can help justify mains extension. However, most of the electricity demand to date is for public-sector use--private connections are common only in urban areas.

The current electricity tariff is one reason for the limited number of private connections. The water-pumping tariff of P0.19 does not favor the use of electricity for this purpose. The tariff structure has two categories. The first is for all users except the Bamangwato Concessions Limited (BCL) mine at Selebi-Phikwe. A special agreement was made with BCL with under which the Selebi-Phikwe power station was built. This agreement gives the mine a substantial subsidy. To meet the financial objectives laid out in the Botswana Power Corporation (BPC) Act and supply power to the BCL mine at the agreed-on rates, the tariff level to other consumers is inevitably high to support the mine's subsidy.

The cost of electricity is such that diesel pumping systems still appear to less expensive to purchase, operate and maintain from a financial perspective. Recently, a study has been conducted on the electricity tariff structure. Any reduction in the tariff for water pumping will help electric pumps to be financially competitive with the alternatives. The economic cost for electric pump use depends on the economic cost to provide electricity. It has proved difficult to determine this figure, but it is clear that the economic cost is significantly less than the metered cost.

As the only field maintenance infrastructure for electrical pumping equipment is in the public sector, all components must be serviced and repaired by DEE. This can create administrative difficulties and substantial delays as interdepartmental procedures must be followed. It will be necessary for DWA and DEE to come to an agreement to simplify many of these procedures. This may result in the incorporation of electrical maintenance and service capability within DWA or the seconding of DEE personnel to DWA for this purpose. The private-sector service infrastructure for electrical equipment does include contractors who are capable of replacing equipment and one firm that can repair electric motors. There does not appear to be any work in this area in the informal sector.

The following list indicates the major advantages and disadvantages of electric pump use in Botswana's local context.

<u>Advantages</u>

- For power generated at Morupula, the energy source is local.

- Equipment and installation costs are relatively low, apart from electrical hook-up costs.

- Electric pumps can provide on-demand water delivery.

- Recurrent costs for maintenance are low.

- There is no practical size limit on the equipment.

- With electronic controls, it is possible to operate these systems automatically, thereby reducing pumper costs.

- Electric pumps operate quietly.

Disadvantages

- The cost of grid extension and switch-gear is high, which adds to the cost of many installations, and this expense is not easily recovered if the pumps must be moved.

- High electricity tariffs contribute to high pumping costs.

- Access to power in most of the country is very limited.

- The repair and maintenance capability for submersible pumps is currently limited.

- New troubleshooting skills and electrical training are needed for operators and technicians.

CWPP tested six electrical pumping systems, with both Mono pump configurations and submersible pumps. Interviews with equipment suppliers and repair shops were also conducted.

C. Windmills

1. Description and Use

Windmills are pumping systems that utilize energy in the wind to pump water, which is accomplished by capturing this energy through rotation of the windmill rotor. With reciprocating pumps, wind energy is translated into a reciprocating vertical motion that is used to drive a piston pump. In the case of Mono pumps, the rotation of the windmill rotor is translated via a right-angle drive to a Mono pump through a system of gears and belts. Reciprocating windmills are well-known worldwide as farm-type windmills. The designs that drive Mono pumps were developed in Botswana.

Windmills have been used in several areas of Botswana for many years--an estimated 200 to 250 windmills are found largely on the Ghanzi Farms and south of Lobatse. These areas are characterized by average annual wind speeds that are in excess of three meters per second (m/sec) and pumping heads of under 40 meters. In nearly all cases, windmills are used to water livestock.

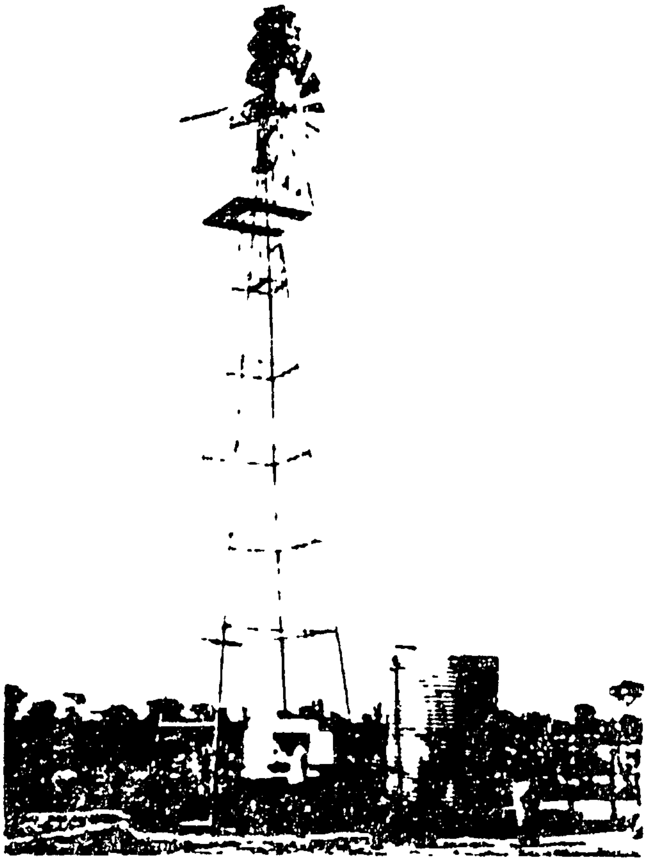
The variation in winds over the course of the year and seasonal needs for livestock watering dictate the design conditions for these pumps. Unfortunately, the season with the highest water demand (the winter dry season) coincides with the period of lowest wind speed. In roughly half the country, the average wind in the month with the lowest wind-speeds is less than 2.5 m/sec. This, and the fact that the water table depth is over 40 meters for large sections of Botswana, limit the use of windmills. They are not suitable for providing significant additions to major village water supplies, and the variation in water delivery due to variable wind speeds makes them unsuitable for use with rural village water supplies where the demand is relatively constant. Windmills may have some application at certain government posts where small amounts of water are needed.

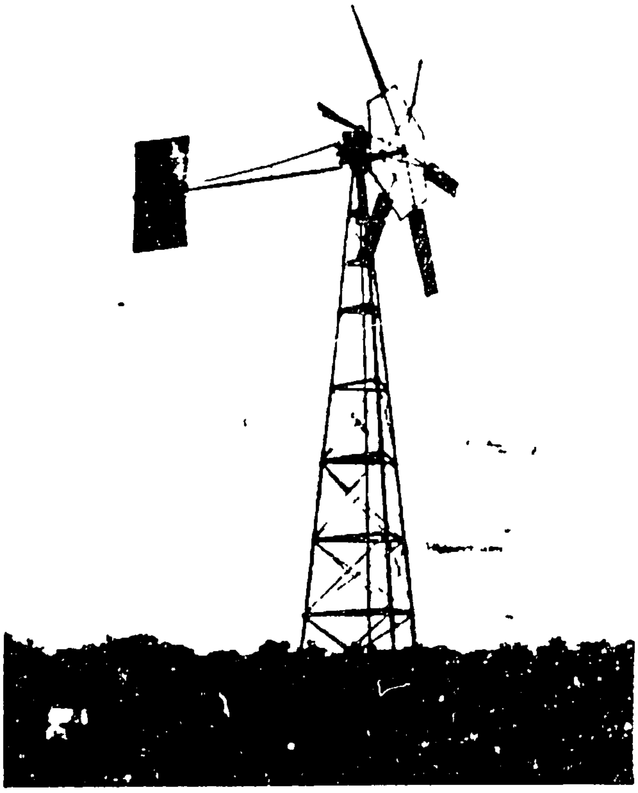
2. Issues

Considerable efforts have been made over the past several years to develop and promote the use of windmills. An extensive study of Botswana's wind regime has been completed, and major issues concerning the possible use of windmills have been defined. These include the performance of windmills under local wind regimes and their potential to displace diesel fuel. RIIC's work in developing a windmill for local fabrication has raised other issues relating to the use of products designed and built in Botswana, as opposed to imports, and the probable windmill market. Further, as a result of the intermittent nature of wind energy, the issue of water storage must be addressed.

As outlined in VOLUME III: WINDMILLS, performance is closely tied to the prevailing winds and total pumping head. Most manufacturers' wind-system design procedures do not adequately predict the performance at the wind speeds found in Botswana. The average annual wind speed for much of the country is less than three m/sec, with the low wind-speed months in the range of 2.5 m/sec. Testing indicates that these wind speeds in combination with water levels of 40 meters or more (typical in much of the country) effectively limit water delivery from windmills to less than 10 m^3/day for roughly 90 percent of

Standard-design Climax 12
at Sedibeng.





RIIC Motswedi at Malau.
This windmill drives a Mono pump.

Botswana. Windmills do have some potential for use in the remaining 10 percent of the country. In some of these areas, windmills are already being used.

There are important questions about the potential market for windmills in the country and level of effort that should be expended by public-sector agencies to support or promote windmill use in these areas. Currently, Stewarts and Lloyds, who distribute the Climax windmill, say their sales in Botswana are fewer than five per year. RIIC is planning an extensive market study for various water-pumping technologies. The results of this study should indicate whether this figure can be increased.

In the past, RIIC's development of the Motswedi windmill, which was designed to drive a Mono pump, has been supported by the public sector. Continued support has been based on the need to promote local industry, provide training and reduce the country's dependence on foreign imports, particularly diesel fuel. Given the recent wind-resource survey and economic analysis of locally designed windmills, these arguments are now being questioned. Although proper market surveys have yet to be completed, it appears that the potential market for windmills will be limited, which constrains the industrial development aspect of public-sector support for windmills. While the training being provided is valuable in terms of improving general technical skills, it could be accomplished more directly in other ways. Finally, because all the materials needed for windmill fabrication must be imported, not much savings in imports are actually realized.

The use of windmills does reduce dependence on imported spare parts and fuel, both in displaced engines and transportation of fuel to the site, which should not be overlooked for sites where water demand can be met by a wind system. However, from a national perspective, the potential diesel fuel savings as a result of windmill use are well under one percent of the total amount used to pump water.

Windmills are likely to require more water storage than on-demand pumping systems, such as diesel engines, due to daily variation in anticipated water delivery and the need to supply water during calm periods. Although an extensive analysis of this topic was not part of CWPP, it appears that three to four days of water storage is sufficient. Since most windmills are used to water livestock from tanks at ground level, the incremental cost of this storage is not as high as if elevated storage were required.

The major advantages and disadvantages of windmill use in Botswana are presented below.

Advantages

- Windmills have no fuel requirements.
- Recurrent costs are low, largely due to the predominance of inexpensive repairs.
- Mechanical controls permit unattended operation.
- Wind systems are relatively quiet and nonpolluting.
- The use of pumping equipment fabricated in Botswana contributes to employment in the country.

Disadvantages

- Water delivery depends on the prevailing wind speeds, and the relatively low average wind speeds will limit windmill applications in Botswana.
- The capital cost for wind-system equipment is relatively high--P7,000 to P10,000.
- There are size limitations on the equipment that is currently available--a windmill with 7.6-m diameter is the largest commercially available size and can produce an output of about two kW at a wind speed of three m/sec.
- Larger storage tanks are needed to provide water during calm periods.
- The support infrastructure for wind-system design, installation and maintenance is limited.

In an effort to more fully understand the potential for windmill use, the BRET and CWPP projects installed eight windmills and monitored 14 for different periods of time. A DWA crew handled most of the repairs and servicing. Records were kept to quantify the costs of this support.

D. Solar Pumps

1. Description and Use

In recent years, interest in the use of solar PV pumps has grown. PV modules are assembled into an array that converts the sun's rays into direct-current (DC) electrical power. The power is then used directly or indirectly, through power conditioning equipment or batteries, to drive electric pumps that are specifically designed for this purpose. A number of configurations are possible (see VOLUME IV: SOLAR PUMPS). Those tested in Botswana included submersible pumps (direct-coupled and AC with an inverter) and Mono systems (with batteries and controllers of several types). The solar pumps tested included configurations utilizing up to 32 modules, with a peak power output of 1.4 kW. Some pumped 15 to 20 m^3/day at heads of up to 40 meters which makes it clear that, from a technical perspective, they can produce usable amounts of water. Actual water delivery depends on total pumping head, efficiency of the pumping system, number of modules and solar radiation level. System cost is strongly dependent on the number of modules required, each of which can typically produce 40 to 55 watts during the middle part of a clear day and cost P650 to P800.

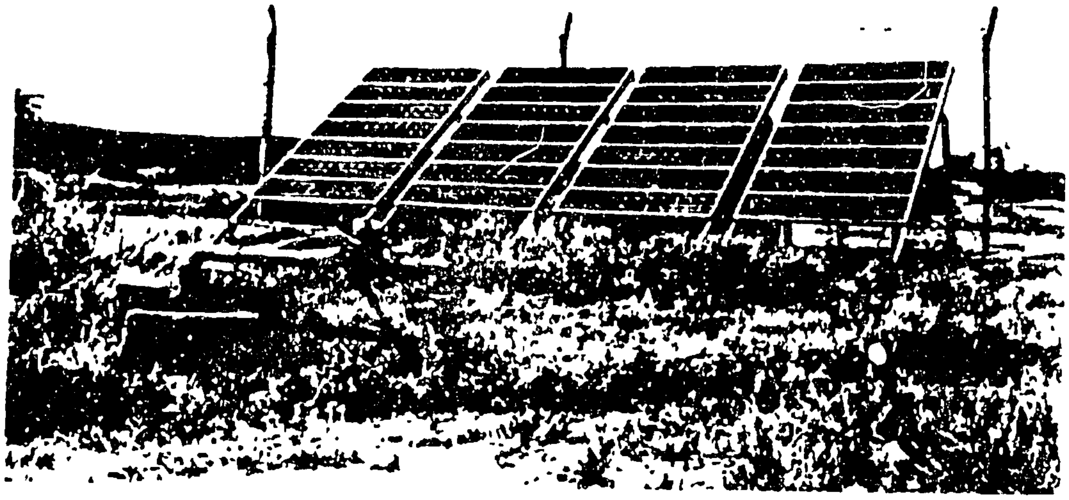
The solar radiation levels in Botswana are favorable for the use of PV equipment--there is an average of over 3,000 hours of sunshine per year and the average solar radiation levels throughout the year are 5.5 to 6.5 kWh/m^2 per day on a 30° tilt. This high and fairly even insolation level favors the use of PV pumps for relatively constant demand situations.

As of mid-1987, 12 solar pumps had been installed in Botswana. Further, four are planned as part of the SIDA-funded Village Water Supply Program (two each in Boteti and Mahalapye, subdistricts of Central District). Several smaller solar pumps are also planned by the Department of Wildlife for low-head applications in the Moremi and Savuti areas east of the Okavango Delta.

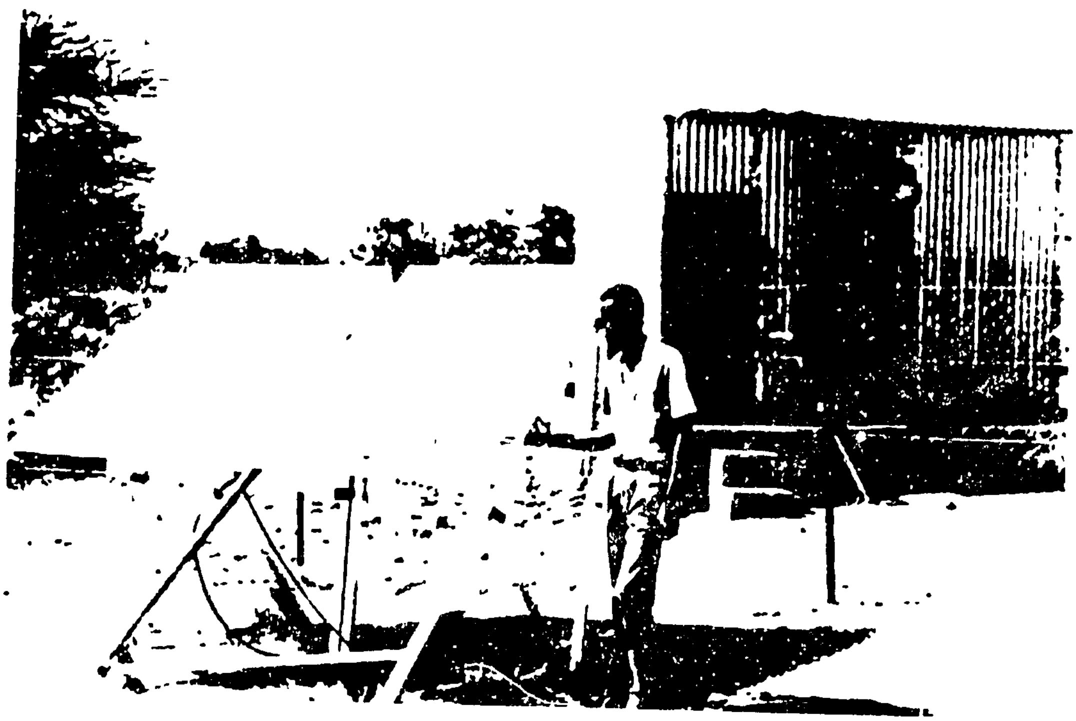
2. Issues

A number of issues are associated with more widespread use of solar pumps. While the capital costs are high, they also have the potential for lower long-term costs due to their low recurrent service requirements to date and lack of fuel needs. However, the need to provide training and develop a support infrastructure, current lack of reliable system design procedures and dearth of information on long-term service requirements are problems. The potential to operate without a pumper and displace diesel fuel are also important issues when considering the use of solar pumps.

The largest single component of the installed capital cost is the PV array, which amounts to 60 to 80 percent of that cost. However, module costs have been steadily declining. Over the past three years, the international price has declined from US$8.00 to US$4.50 per peak watt (Wp), although not all of that decrease has been evident in Botswana because of currency exchange rates. Still, the trend seems clear. A decrease in the



Solar PV pump at Molapowabajang--
ARCO Solar modules and Grundfos pump.



Solar PV pump at Mmathubudukwane--
ARCO Solar modules and Mono pump with controller.

local price to P10 per Wp (from the current level of P12.5/W_p) over the next several years seems very likely and longer term decreases are possible.

The installation and servicing of solar pumps require new skills. Widespread use of solar pumps will necessitate training courses to familiarize installation crews, mechanics and technicians with the characteristics of PV modules, arrays and controllers as well as safety procedures. Borehole mechanics at the district level and from DWA do not currently possess these skills, so preliminary training courses are being planned to train the mechanics and technicians who will need to understand PV pumps to service the currently installed systems. However, a larger, more comprehensive training program will be needed if more extensive use of solar pumps is to be contemplated.

An additional concern about the use of solar pumps is the need for a replicable design procedure. The submersible pumps tested by CWPP performed at levels that were consistently below manufacturers' predictions. This appears to be due to the fact that field conditions are neither ideal nor equivalent to laboratory conditions. Using the project's test results, reasonable performance predictions can now be made for Grundfos pumps. However, this is not the case for the Mono pump systems. When using the Mono pump controller, the choice of pulleys, adjustment of belt tension and Mono gland packing need to be more fully understood before a reliable design procedure can be developed. For battery-controlled systems, it is easier to determine some of the design details since the motor and pump will operate at a constant speed, but exact design procedures that can be depended on to provide reliable water delivery are not yet available to DWA.

One major argument that has been made in favor of solar pumps is the reduced need for operator participation. Since the pump can be controlled electronically, it need not be switched on and off. However, pumpers do have other duties, and for public-sector applications in rural areas, it is not easy to hire part-time pumpers since central government regulations do not allow this at present. District Councils are not bound by these regulations, but pending approval of their proposed service scheme, most have been following the government's lead. From a financial perspective, it would be advantageous if district regulations allowed the use of part-time operators not only for solar pump installations, but also diesel systems installed in smaller villages where pumping is only done a few days a week.

Like windmills, ADPs and hand pumps, PV systems are free of the need for fuel for pumping and can consistently deliver water in excess of 10 m^3/day without a high labor input. As such, they have the best potential to displace fuel in rural villages and at some government agency installations. However, CWPP analysis (see Section VI) indicates that the unit cost for water delivered by these systems is currently high for most pumping applications. Still, the strategic importance of energy diversification and reduced dependence on diesel pumping also play a role in decisions concerning this technology.

The following list outlines the major advantages and disadvantages of using PV pumping equipment in Botswana.

Advantages

- The high reliability of PV modules is indicated by the willingness of manufacturers to guarantee performance for 10 years.
- PV systems have lower service requirements than diesel pumps, and the reduced breakdown rates of several configurations contribute to low recurrent costs.
- The potential for unattended operation can reduce unit water costs and favor special applications where it is difficult or expensive to provide pump attendants.
- PV pumps do not require imported fuel either for their operation or transportation of fuel to the site, thus reducing costs and dependence on imported supplies.
- Due to relatively uniform radiation levels in Botswana throughout the year, water delivery is fairly constant. In addition, the months with the highest radiation levels coincide with the driest part of the year.
- Because of its modular nature, PV systems can be matched quite closely to the amount of water needed and, within the limits of the pump and motor, modules can be added as water requirements increase.
- PV pumps operate quietly and are nonpolluting.

Disadvantages

- PV pumping systems are expensive, largely due to the cost of solar modules.
- The design procedures for several configurations are not yet adequate to accurately predict pump

performance, which necessitates oversizing the system to ensure the design level of water delivery.

- Solar pumps cannot supply water on-demand since they rely on adequate insolation. As a result, larger storage tanks are needed.

- An adequate cadre of trained technicians is not yet in place to service, troubleshoot and repair the electronic equipment, if necessary.

- The GOB's current policy requires that pumpers be used even when they may not be necessary, which unavoidably increases the cost of solar pumping.

Fourteen PV pumps of different configurations have been installed and tested at 10 different sites. These configurations include submersible pumps (direct-coupled, direct-coupled with a voltage tracker and AC with an inverter) and Mono pump systems (with batteries, a Mono power tracker and a voltage tracker). The results of the short- and long-term testing and records of necessary repairs form the basis for understanding the use of this technology in Botswana, its potential, limits and costs.

E. Animal-Drawn Pumps

1. Description and Use

The ADP is a product of RIIC research and development. It is essentially a transmission arrangement that allows draft animals to operate a Mono pump by pulling draw-bars in a circular path. The step-up of the transmission is on the order of 1:1,000, depending on the final ratios chosen. It allows the slow working pace of draft animals (approximately one revolution of a six-meter radius path per minute) to be translated into the high speeds required for efficient operation of the Mono pump. The Mono pump was chosen because it is commonly used in Botswana and the pump's rotation lends itself to the input of draft animals working on a circular path.

Five ADPs have been installed in the country to date, but are not the latest configuration, which is still being tested at RIIC. The device is intended for dissemination in the private sector as it is labor-intensive, compared to diesel engines--draft animals must be collected, harnessed and then driven to ensure that water is delivered. The labor requirements will likely preclude its use in the public sector because of government wage scales. The ADP's major advantages are that it does not require fuel or any support from the diesel service and repair infrastructure.

2. Issues

Issues of concern about the ADP relate to its cost, reliability and user considerations. The projected cost is P6,700, which is more than three times the cost of a small Lister engine. However, it should be noted that for all systems besides handpumps (and electric pumps in a few cases), the initial cost exceeds that of a diesel engine. Still, a high initial cost is likely to be a barrier to purchasing a system, particularly for private individuals, unless loan or grant arrangements can be made on favorable terms.

No significant indication of the ADP's long-term reliability is currently available. Ultimately, if it is to be accepted, it must not require significant servicing, particularly if that requires trained technicians or service trips.

In addition to these concerns, the ADP requires a coordinated effort on the part of users, including the care, feeding and training of draft animals as well as harnessing and driving them when the pump is used. These efforts must be made by pump users if the system is to gain acceptance. It is important that users understand these requirements and make arrangements to ensure they are met. The cost of supplemental feed, purchase of draft animals and/or labor must also be fully understood.

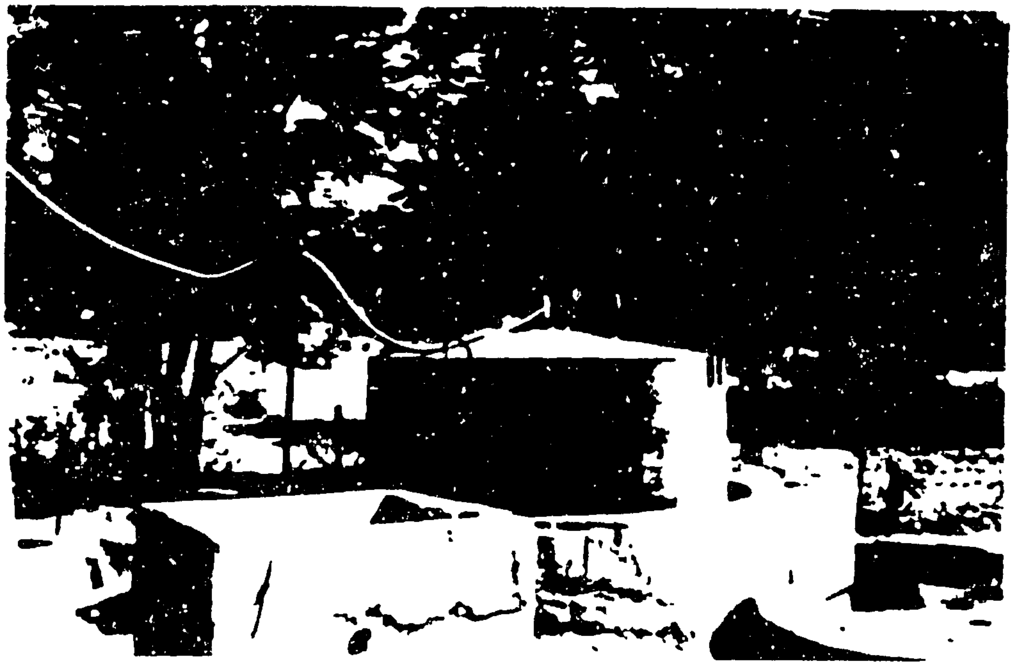
There has been some discussion of the use of oxen insted of donkeys as draft animals. It is clear that they would provide more power and, hence, deliver water at a higher rate or through higher heads. Further examination of the acceptance of oxen for this purpose should be encouraged.

At present, RIIC is providing service for ADPs (except for the Mono pump) and has the expertise to do so. However, if the device is to be installed any distance from Kanye, where RIIC is located, it will be necessary to train others to service and repair the machine so that these costs can be minimized and the response to difficulties is prompt.

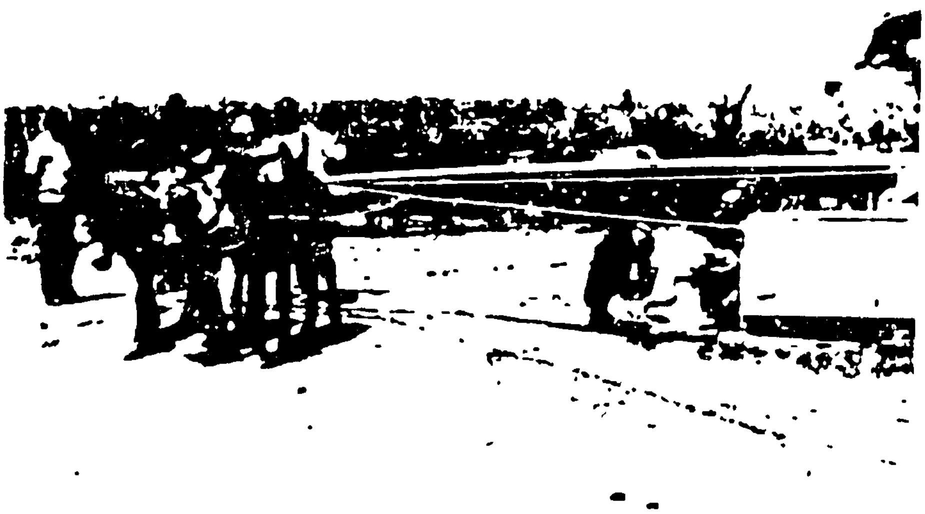
The advantages and disadvantages of use of the ADP in Botswana are summarized below.

Advantages

- The ADP is completely free of diesel fuel requirements.



Experimental bio-gas digester at RIIC. A larger digester of similar design is installed at Diphawana.



ADP at Gamorotswana.

- Within limits, water can be pumped on-demand by operating the ADP for longer or shorter periods of time.

- Operation of the ADP is nonpolluting.

Disadvantages

- If donkeys are the power source, water delivery is limited depending on the pumping head, due to the power that can be generated by a donkey and the number that can be used at one time.

- ADP use requires a strong organizational structure to support its continued operation because of the participatory nature of the device.

- For public-sector applications, labor costs would be high, which will likely preclude its use for such applications under current conditions.

CWPP performed short-term tests on one ADP, and the BRET project funded testing of another by BTC. However, the major contributions to understanding this device have come from tests performed by RIIC, and interviews and discussions with users and developers of the technology.

F. Bio-Gas Substitution

1. Description and Use

Bio-gas is a mixture of methane, carbon dioxide and trace gases, the product of the anaerobic decomposition of organic matter in a "digester." There are two major types of digesters--fixed-dome (or Chinese) and floating-dome (or Indian). RIIC experimented with both designs before deciding to concentrate its efforts on the floating-dome type because it is easier to build properly and the gas is provided at pressure (as a result of the floating dome). Successful tests have led to dissemination efforts. The bio-gas that forms can be used for lighting, cooking and heating. It can also be substituted for gas to operate refrigeration systems or displace fuel in diesel engines. It is this last use that relates to water pumping.

Experiments have shown that 80 percent of the diesel fuel used in a small-scale diesel engine can be displaced by bio-gas. It is impossible to displace all of the fuel in the diesel engines that are currently available in Botswana, so the use of bio-gas for pumping is still tied to petrochemical supplies and the service infrastructure for diesel engines. Since a bio-gas system can only act as a fuel replacer, costs for the system must be recoverable in fuel savings.

2. Issues

Issues involved in the potential use of a bio-gas substitution pumping system include the cost of the additional labor requirement to collect and feed processed manure into the digester, organization of that labor, and capital and recurrent costs of ownership and operation. From a national perspective, the potential for fuel savings and local employment from digester fabrication also need to be considered.

Although the service and repair requirements of operating a bio-gas pumping system are not significantly greater than those of a diesel system, less fuel is needed, but the labor requirements are greater. For users who are willing to spend the time satisfying these labor requirements, the financial advantage of reduced operating costs may make a bio-gas system attractive. This labor includes collecting cattle dung (the fuel source), mixing it with water to create a slurry and feeding it into the digester. In addition, the effluent, which can be used as a fertilizer, must be removed. As a result, it is important that users understand these requirements and are willing to commit to them. Of course, it is always possible to operate the pump using diesel fuel alone, but if users are not committed to full utilization of the system, the cost savings are diminished. In the public sector, use of this technology is limited by the additional labor requirement, which must currently be paid for at government wage rates.

Costs for the construction and maintenance of bio-gas systems are not well documented. RIIC suggests that digesters cost from P50 to P100 per m^3, and any analysis based on this degree of variation in cost can only be indicative. The repair and maintenance costs of the digester alone are not likely to be great, but it must be remembered that all of the service costs for the diesel engine are still incurred when bio-gas is substituted for diesel fuel. A thorough analysis of capital costs for fabricating parts and system installation as well as documentation of recurrent costs should be undertaken to permit a more accurate assessment of the potential of these systems. This is necessary because, as mentioned above, these costs must be recoverable from the fuel savings.

The advantages and disadvantages of using a bio-gas substitution pumping system in Botswana are listed below.

Advantages

- The use of bio-gas in diesel engines is proven in a technological sense and has demonstrated the capability to displace up to 80 percent of the fuel used in a diesel engine, thus saving 80 percent of the fuel cost.

- Bio-gas substitution pumping systems can be operated on-demand and can continue to be used with diesel fuel alone if the bio-gas system is not operational.

- Effluent from the digester can be used as fertilizer.

- Excess bio-gas can be used for other purposes, including lighting, heating and cooking.

Disadvantages

- The use of a bio-gas substitution system still involves the provision of diesel fuel and dependence on the service and maintenance infrastructure for diesel engines.

- The operation of a bio-gas system is slightly more complicated than a diesel engine alone, and additional labor is required to collect dung, mix it with water, feed the digester and remove the effluent.

CWPP did not test any bio-gas substitution systems. The information contained in this report and VOLUME V: (title?) comes from interviews with users and an examination of tests performed by RIIC and BTC, as part of the BRET project.

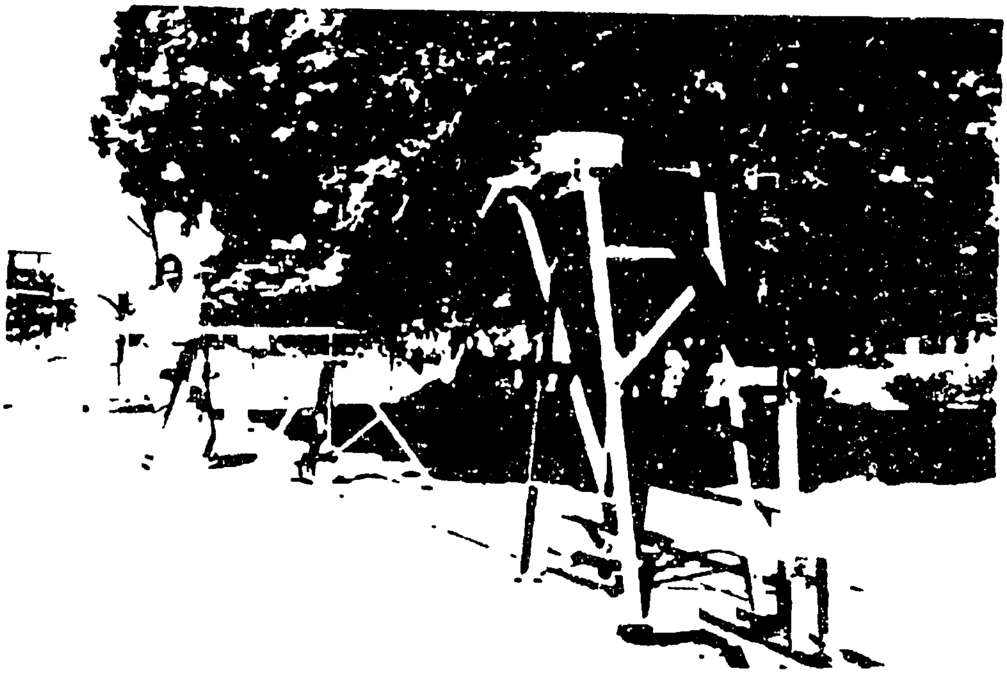
G. Handpumps

1. Description and Use

Handpumps are devices that are designed for human-powered water delivery. The most common configuration is a piston pump, where the pump is operated by a handle that gives the user some mechanical advantage. The India Mark II handpump is an example of this type of design. Another increasingly common system is the Mono handpump which, in its most recent configuration, drives a Mono pump by direct, horizontal, circular motion of the pump handle. Currently, fewer than 30 of the former and 15 of the latter are installed in Botswana. In addition, there is renewed interest in the Thebe pump. This is a human-traction system that is operated by walking in a circle and pushing a lever arm, which is connected to a mechanism designed to operate a piston pump. This pump design, refined by RIIC, is capable of lifting water from up to 100 meters.

Indıa Mark II handpump at Thlareseleele.

Mono direct-drıve handpump.



Thebe pump.

2. Issues

Handpumps are the only technology considered by CWPP that require the active participation of each water user. It is also the only one that would not be connected to a storage and reticulation system. These two factors place handpumps in a slightly different category of pumping equipment. Several handpumps were installed and monitored by the project and, in response to growing interest, as many as 10 different models will be in use by the end of 1987.

There are limitations on handpump use. For Botswana, five m^3/day appears to be a reasonable upper limit on water delivery for handpumps. This restricts their use to smaller settlements and lands areas where water demand is low. Some handpump designs have the capacity to pump water from more than 30 to 35 meters, including the Thebe pump and several models with counterbalanced handles. However, none have yet been used in Botswana at depths in excess of 50 meters.

Recent drilling programs have concentrated on locating water sources well outside village limits to minimize the possibility of borehole pollution. Although a number of boreholes could support handpump use, in many cases, they are more than several kilometers from potential users.

If handpumps are to be used extensively in the future, some effort must be made to provide the resources to repair and maintain them. It seems clear that these needs will not be large relative to the current requirements of diesel systems. However, current District Water Units are already pressed to service diesel pumping schemes, and it is likely that handpumps would receive low priority in terms of repair and maintenance.

The major advantages and disadvantages of handpump use in Botswana are listed below.

Advantages

- Handpumps have low capital and recurrent costs relative to the alternatives.
- They do not need expensive reticulation systems as users must come to the pump.
- They can be simply designed, and if a suitable pump is selected, it would be possible to manufacture the pump-head and spare parts in Botswana.
- Low, controllable water delivery rates make handpumps suitable for use with low-yield boreholes.
- Handpumps do not require fuel for operation.

Disadvantages

- The practical limit on water delivery is less than five m^3/day from heads of 30 to 35 meters or less for the handpump models that are widely available in Botswana, although this may change with introduction of the Thebe pump, which is designed to pump from up to 100 meters.
- The location of most boreholes at a distance from villages will limit handpump use unless new boreholes are provided.

As part of the BRET project, 14 handpumps were installed and tested. A number of these were retested during CWPP, most of which were India Mark II models. In addition, several Mono direct-drive handpumps were also tested. The results of the BRET project's earlier work with handpumps are presented in TWO TYPES

OF HAND PUMPS -- RESULTS OF FIELD TESTS IN BOTSWANA (Hodgkin and McGowan, 1985).

VI. ECONOMIC ANALYSIS BY MAJOR WATER-USER GROUP

Water use can be divided into four categories:

- irrigation;
- human consumption, including urban domestic use, major villages, rural villages and smaller settlements;
- livestock watering in freehold areas and on communal lands; and
- industry, including urban light industrial and mining uses.

Systems that meet urban domestic, industrial and mining needs are large, with water provided from dams and/or groundwater sources using pumps with large electric motors or diesel engines. In general, irrigation is characterized by low pumping heads, but large volumes which also require larger motors or engines.

The remaining categories of water use are largely supported by small diesel engines and other technologies that use less than 10 kW. Major and rural villages are subdivided because their infrastructural arrangements and water requirements differ. Livestock watering represents the largest use of water--roughly 41 percent of the total for Botswana (Kenna, May 1987), and almost all of it is met by privately owned, single-cylinder diesel engines. Scattered settlements and lands areas are not currently included in any formal water-supply activities. A few water users have been provided with handpumps, but planning for the provision of water to these areas is part of the NATIONAL DEVELOPMENT PLAN VI, 1985-1991. Smaller settlements and lands areas will not be discussed separately. Rather, they will be included in the analysis of rural villages since the same service network will most probably apply.

A. Economic Analysis Approach

A separate economic analysis is presented for each of the four major user groups as their infrastructural arrangements, pump locations and costs differ. These differences have implications for economic costs and, hence, the appropriateness of possible pumping system choices. The results of the economic analysis are presented in three tables. The first defines the existing conditions for each major user group. The two other tables are given to highlight the effect of changes in existing conditions, which include:

- internal factors that can be controlled by the government, such as improved maintenance procedures or reductions in pumper costs; and

- additional external factors over which the government has no control, e.g., increases in fuel prices or decreases in the case of PV modules.

Both sets of factors have an impact on pumping policy and pump selection. The major difference is that the first set can be affected by the actions of pump installers and users. For the second set, Botswana can only react.

In presenting the results, the second table includes the existing average conditions for each major user group as well as the set of internal conditions, which can be controlled and changed by the government. The third table presents the results when both sets of changes (internal and external) are incorporated into the analysis. While a wide variety of sensitivity analyses were conducted, only those factors that had a significant effect on the results are included here. This approach was taken to try and identify cases where RETs are or will likely become the most cost-effective option in comparison with conventional technologies. The third table for each major user group identifies the cases that are most likely to fall into this category.

It should be noted that two of the more important conditions included in the first table for each user group were greater than average installation and service distances, and somewhat less than average head cond tions. This economic analysis does not include building the support infrastructure that may be needed for new technologies. However, based on sensitivity analysis, the range of heads and flow rates give an indication of the extent to which these factors are conditions for considering renewable energy system use. The companion volumes in this series provide more detailed sensitivity analyses on the effects of remoteness and head on pumping costs.

The economic analysis here was done in a slightly different fashion than in the companion volumes--it is not strictly a presentation of the results for the more than 60 pumping systems tested and evaluated by CWPP, but rather, an extension of this work that permits a comparison of similar systems. For this comparison, all of the analyses are based on a given water demand and head which represent typical conditions for each major user group.

The analysis is based on a net present value (NPV) approach-no effort was made determine the economic benefit of the water delivered. Instead, the volume of water was used directly, with future delivery discounted, as is appropriate when using the NPV approach. Economic benefits were not calculated for several reasons, including the difficulty of determining an economic value and the fact that the purpose of this work is to compare similar pumping systems, not various types of projects. It was assumed that the decision to provide water has already been made. The purpose of this analysis was to assist in determining which system is likely to be the least expensive in economic terms. The results are presented in terms of economic (not financial) unit costs, in Pula per cubic meter of water delivered.

The technologies that are capable of providing water on-demand (e.g., diesel and grid-electric pumps) are simply operated whenever water is required. The unit-cost analysis for these systems is thus based directly on the amount of water pumped. Variable costs for these systems will be proportional to the amount of water pumped. For several other systems, such as wind and solar PV pumps, the situation is somewhat different. They can operate whenever the renewable energy resource is available, pumping water that essentially has no incremental variable costs. In this analysis, it was assumed that they pump only enough water to satisfy the specified demand. For properly sized systems, there will be periods when the pump's capacity is greater than current demand. This additional unused capacity has not been factored into the analysis.

The results presented in this report include a range of small-scale pumping situations that are commonly found in Botswana. Of course, it cannot include every possible case, and for any specific water pumping situation, the results may be significantly different than those presented here. However, this analysis method allows the evaluation of any particular case. The computer models used for these analyses are available at DWA and can be employed to assist in making pumping choices for specific situations. In addition, if any of the basic assumptions of this analysis change over the next several years, it is possible to use the models to recreate this broader analysis to help policymakers redirect government efforts in the water-pumping sector.

B. Major Villages

There are 17 major villages, and their water systems are operated by DWA, which has offices in those villages to collect user fees from those with private connections and oversee system operation, servicing and repair. The major villages include those with District Council offices, some where water treatment is required and several others with high water demand. About 100 boreholes were pumped to supply the water requirements of these 17 villages in 1985. Their total requirement was 13,000 m^3/day, and the village with the smallest demand was Tsabong at 150 m^3/day. All of the major villages operate multiple boreholes to meet demand, allow flexibility in the operation of the water supply system and provide a reliable supply.

1. Technology Choice

Given the major villages' high water demands and the fact that these systems are operated by a government agency, a number of pumping technologies need not even be considered for this user group, including windmills, solar pumps, ADPs and bio-gas substitution. With Botswana's wind regime and the limitations of head and rotor size, windmills cannot be expected to produce much more than 15 m^3/day under the most favorable conditions. This conclusion had already been reached by DWA after experimenting with windmills in the late 1970s. Although solar pumps could be made large enough to meet the demands of major villages, they are currently too expensive to use for pumping large amounts of water through the typical heads for major villages. Both the ADP and bio-gas substitution must be considered in a developmental stage at this time. However, if they were market-ready, the labor costs would be high since government pay scales would apply. In addition, the output expected from an ADP could not contribute significantly to meeting the level of demand for most major villages. For bio-gas technology to be useful, provision must be made for the labor involved in dung collection and effluent disposal.

Handpumps are limited in pumping rate and the head through which they can pump, which constrains opportunities for their use in major villages to serving as a back-up system for other technologies. While this role helps provide greater assurance of water availability, handpumps are not likely to be necessary in major villages due to the reliability afforded by multip pumping plants. This is a more important consideration for rural villages. Thus, of the spectrum of pumping choices considered by CWPP, the remaining possibilities are:

- diesel pump sets, and
- grid-connected electric pumps.

Therefore, the comparison of technologies for major villages was restricted to these two options. A decision to use electrical pumps must consider aquifer performance if any significant mains extension will be required. Since mains extension is expensive, the borehole must be usable over a long period for the investment in overhead lines to be worthwhile. Submersible pumps are most efficient when pumping heads are constant. If this is the case and submersible pumps can be used, the number of service and repair trips are likely to be fewer.

In the following analysis, electric submersible pumps were assumed. They are slightly less expensive than electrically driven Mono pumps and their recurrent requirements are less both economically and logistically. Lister engines and Mono pumps were assumed for diesel systems, with the engine model depending on the head being considered. The population of major villages is growing at annual rate of roughly five percent. This analysis assumes that the water demand on boreholes will increase by a similar amount. A seven m^3/hour pumping rate was assumed because this is near the average pumping rate for single-cylinder engines that pump water in major villages. Given this pumping rate, growth in demand from 100 m^3/day cannot be met without increasing the pumping rate. In these cases, it was assumed that the water output levels off at the maximum possible amount. Other major assumptions are noted in the tables.

2. Economics

Table 1 contains seven matrices (one for each technology) of daily water requirements (ranging from 20 to 100 m^3/day) and heads (from 30 to 120 meters), which are typical for boreholes used in the major villages. The blank matrices for windmills, solar pumps, handpumps, bio-gas and ADPs indicate that these technologies were not considered for this particular user group for the reasons just given in Section VI.B.1. The major assumptions for each technology in the analysis are shown below the set of matrices. Assumptions that are common to all technologies are given at the top of the list of assumptions. Those which are specific to a particular technology are listed only under that technology heading.

The matrices in Table 1 for diesel and electric pumps show several apparent trends:

- unit costs (in Pula per cubic meter of water) increase with decreasing water delivery and increasing head, from the upper right figure for 100 m^3/day at 30 meters of head to the lower left, 20 m^3/day at 120 meters of head; and
- electric pumping is more expensive than diesel for all of the cases considered here.

Unit costs increase with increasing head because the energy requirement for pumping increases, assuming constant demand. This means that although fixed equipment costs remain nearly the same despite changes in head and water output, the variable pumping costs increase as the energy demand increases. Unit costs increase with decreasing demand because there are fewer units (cubic meters of water) over which to spread the fixed cost of the system.

MAJOR VILLAGE

All values are economic unit costs in Pula per cubic meter
Discount rate is 6%
Output is stated cubic meters per day discounted
at 6% over 20 years.

STANDARD ASSUMPTIONS

m3/day	Diesel Output 20	30	50	100	Windmill Output 20	30	50	100	Solar Output 20	30	50	100	Grid Electric Output 20	30	50	100
Head 30m	.36	.28	.21	.15	Not Considered				Not Considered				.48	.34	.23	.15
Head 60m	.39	.31	.24	.18									.52	.38	.27	.19
Head 90m	.42	.33	.26	.20									.56	.42	.30	.23
Head 120m	.51	.41	.34	.28									.60	.46	.34	.27

m3/day	Handpump Output 20	30	50	100	Biogas Pump Output 20	30	50	100	Animal Traction Pump Output 20	30	50	100
Head 30m	Not Considered				Not Considered				Not Considered			
Head 60m												
Head 90m												
Head 120m												

Standard Assumptions: (included 5% growth in demand)
Installation Distance at 150 km, service from 50 km
7m3/hr pumping rate
Government tender prices for equipment
Full time pump operator

Diesel:
1. Use of LT-1 at 30,60 meter head, ST-1 at 90 m, and 8/1 at 120 m
2. Installation labor and transportation average for DWA
3. 17.5 thebe/hr for spares for maintenance and repair
4. Engine efficiency dependent on loading

Electric:
1. 2km of 11kv overhead line included
2. Electricity tariff of 10.7 thebe per unit (current tariff)
3. Equivalent installation costs as for diesel
4. 40% motor/pump efficiency

Table 1. Major Village Applications -- Standard Assumptions

The unit costs for electric pumps are more expensive than diesel largely due to the cost for grid interconnect of two kilometers of overhead line and the step-down transformer. If electrical power is available at the borehole and no overhead line costs are incurred (i.e., only a transformer to step down the voltage to the required level was needed), the use of electric pumps is considerably more cost-effective (see Table 3). As might be expected, the recurrent costs for electric pumps are less than for diesels, while the capital costs are greater. It is not the cost of the electric pump itself that is so high, but rather the cost of submersible cable, the three-phase starter, low-water safety disconnect switch and related hardware.

Table 2 shows unit water costs if certain changes in operating conditions (over which the Government has some control) could be put into effect. These factors could include changes in improved installation practices and subsequent cost savings, better maintenance of diesel engines, lower economic costs for electricity, use of a half-time pumper for electric pumps, and no mains extension or transformer costs. By far, the most significant of these factors that can be controlled internally is reducing the pumper labor cost by half, and it is only this change that is included in Table 2. This could occur for a number of reasons, the most obvious being that the pumper is responsible for operating more than one pump, so the salary can be split between two systems, for example.

The net effect of halving the pumper cost for diesel and electric pumps in major villages is to reduce the unit cost of diesel pumping by seven to 14 percent (across the range of head/demand conditions) and of grid-electric pumping by one and 10 percent. These results show that assumptions about variable costs, such as the cost of power, have a much greater effect on high head/demand situations, and those about fixed costs (e.g., a half- or full-time pumper) have a much larger impact on low-head/demand situations. Comparatively, reducing the amount of pumper labor lowers the unit costs of both systems, but diesels remain slightly more cost-effective than grid-electric pumps for all head/demand conditions.

Table 3 shows unit costs for both systems when the reduction in pumping labor is coupled with two other externally imposed conditions:

- a 10 percent annual increase in the price of diesel fuel, and

- eliminating the cost to the GOB of additional overhead lines to connect electric pumps.

While a 10 percent annual increase in fuel prices may seem extreme, this is essentially equivalent to doubling the price of

m3/day	Diesel Output 20	30	50	100	Windmill Output 20	30	50	100	Solar Output 20	30	50	100	Grid Electric Output 20	30	50	100
Head 30m	.31	.24	.19	.14	Not Considered				Not Considered				.43	.31	.20	.14
Head 60m	.34	.27	.22	.17									.47	.35	.24	.18
Head 90m	.37	.30	.24	.19									.51	.39	.28	.22
Head 120m	.45	.38	.32	.26									.55	.43	.32	.26

m3/day	Handpump Output 20	30	50	100	Biogas Pump Output 20	30	50	100	Animal Traction Pump Output 20	30	50	100
Head 30m	Not Considered				Not Considered				Not Considered			
Head 60m												
Head 90m												
Head 120m												

Notes: Changes in Standard Assumptions
Diesel: 1. Pumper labor cost reduced by 50%
Electric: 1. Pumper labor cost reduced by 50%

Table 2. Major Village Applications -- Cost Variations due to Internal Factors

fuel over seven-and-a-half years. This situation might well occur if there were a serious disruption of normal diesel delivery due to increasing instability in the region. Such a situation might require the procurement of fuel supplies through other channels, which could greatly increase costs to the government. However, Botswana has the capacity to generate its own electricity, so the cost of operating electric pumps is less vulnerable to this type of uncontrollable cost increase and no changes were assumed for this series of cases.

For diesel pumps, Table 3 shows that the escalation in fuel prices combined with the decrease in pumper costs has a net effect of increasing unit costs between six and 68 percent. The greatest change occurs at the highest head and demand (120 meters and 100 m^3/day) since that is the case where the energy and, hence, fuel requirements are the greatest.

The basis for the second change in the external assumptions is that through donor support of pump electrification programs, the government may not h' e to directly incur expenses for electrifying certain boreholes, except for the purchase of step-down transformers). If this is the case, Table 3 shows that the unit costs for grid-electric pumps drop dramatically relative to diesel systems. (If the decreased pumper labor charges are also included, there is a 19 to 50 percent decrease from the unit costs given in Table 1.) The greatest decrease in unit costs occurs for the lowest head/demand case, since the fixed costs that are being avoided (the pumper and two km of overhead lines) are amortized over the least amount of water.

3. Infrastructure

DWA is responsible for the maintenance and repair of the diesel pumping equipment used in major villages. Each major village has a DWA office with full or limited maintenance capacity. In several villages, service is provided by nearby major village shops or BRS. Major engine problems are addressed by replacement and then subsequent repair, which is done in Gaborone or Maun workshops. This system appears to be responsive to service needs. The operation of multiple boreholes and/or existence of back-up boreholes also helps provide water system reliability. The primary difficulty for major villages appears to be locating and developing new water sources quickly enough to meet rising demand and replace boreholes with declining yields.

The use of electric pumps offers some benefits and introduces several difficulties. The benefits are eliminating the service and repair requirements of diesel engines, which includes service at the site and engine rebuilding. This reduces problems that stem from difficulties with transportation facilities. The current disadvantages include a lack of full

m3/day	Diesel Output 20	30	50	100	Windmill Output 20	30	50	100	Solar Output 20	30	50	100	Grid Electric Output 20	30	50	100
Head 30m	.38	.31	.25	.20	Not Considered				Not Considered				.24	.18	.13	.10
Head 60m	.44	.38	.32	.26									.28	.22	.17	.14
Head 90m	.50	.43	.37	.30									.32	.26	.21	.18
Head 120m	.69	.61	.55	.47									.36	.30	.25	.22

m3/day	Handpump Output 20	30	50	100	Biogas Pump Output 20	30	50	100	Animal Traction Pump Output 20	30	50	100
Head 30m	Not Considered				Not Considered				Not Considered			
Head 60m												
Head 90m												
Head 120m												

Notes. Additional changes in Standard Assumptions
Diesel: 1. 10% annual escalation in fuel cost
Electric 1. No overhead line extension cost

Table 3. Major Village Applications -- Cost Variations due to Internal and External Factors

control over electric pumping systems. Power outages must be resolved by BPC or the proper authority and problems with electric motors by DEE. The present arrangement for the maintenance and repair of electric pumps is that the pump is the responsibility of DWA, but the motor is DEE's responsibility. If DWA is going to use electric pumps in any substantial way, it should develop the capacity to maintain the electrical pump components. In addition, the effective use of electric pumps, especially submersibles, is limited by the current level of understanding regarding aquifer performance and sustainable borehole yields. In these cases, diesel engines that drive Mono pumps are more flexible.

4. Conclusions and Recommendations

It is clear that most water pumping for major villages will continue to done with diesel pump sets. Given the present situation, this is likely to be the least-cost alternative except for cases where electrical interconnection costs are negligible and aquifer performance is understood well enough so that submersible pumps can be used. When electrical pumping appears feasible, submersible pumps offer some advantages in terms of potential efficiency and reliability, if the groundwater resource is well understood. Otherwise, electrically driven Mono pumps will be the most reasonable solution because of their robustness and insensitivity to head fluctuations. Surface-mounted motors and Mono pumps also have some advantages as component replacement is somewhat easier and the motor is accessible. In either case, complete test-pumping of the borehole is required to determine its longer term sustainable yield.

Expanded use of electrical pumps is also advantageous in that the power source is in the country and, hence, not subject to disruption. The long-term advantages of national control over the energy source are especially attractive to Botswana, given regional instability and the fact that it is landlocked. However, pump electrification projects should be examined carefully before they are implemented. DWA is already using electric pumps in several locations and has a number of electric pumps that it uses for test-pumping. Any consideration of increased use of electric pumping systems should include provisions for DWA to develop the internal capacity to service and repair the electrical equipment used for pumping.

C. Rural Villages

Rural village water supplies are defined as those that are the responsibility of District Councils. Although most are installed by DWA, District Water Units and Departments oversee all aspects of their operation and servicing. In most cases, one borehole serves each village. A borehole must pump 20 to 30 m^3/day to satisfy an average village's water needs, although the requirements of some villages are as low as 5 m^3/day for between 200 and 250 people. The Village Water Supply Program started many of these schemes over the past 10 years, and as it enters its later stages, smaller villages are being provided with diesel engines and standpipe water supplies. Recently, it was estimated that the average size of the villages remaining in the program is in the range of 200 to 250 people. These rural village systems are operated and maintained by District Council Water Units and Departments that are located at 13 sites in Botswana. The boreholes they are responsible for may be several hundred kilometers from the Water Units or their sub-depots.

1. Technology Choice

As previously noted, single-cylinder Lister engines coupled with Mono pumps are almost universally used at present, and it is anticipated that this will continue to be the case for the foreseeable future. However, there appear to be opportunities for the use of other pumping devices, including electric systems, solar pumps and handpumps, in some cases. Windmills do not appear to be suitable choices because of low average wind speeds and rural villages' pumping head requirements, which include a substantial friction head for the long pipelines from the borehole to the village. Also, the water requirements for the domestic needs of villages are quite inelastic, and the goal of the village program is to provide water reliably. The probability of water shortages due to calm periods, particularly during the winter months with low winds, is unacceptable.

Bio-gas substitution and ADPs are "participatory" technologies that require large labor inputs relative to diesel engines. The expectation of continued government involvement in rural water supplies makes it unlikely that community participation could be organized on the scale necessary for successful use of these technologies. If labor to operate these systems must be purchased, its cost become an effective barrier to their use. Thus, of the spectrum of pumping choices originally considered, the remaining possibilities for rural villages are:

- diesel pump sets,
- grid-connected electric pumps,
- solar pumps, and
- handpumps.

Technical limitations will also affect the potential of several of these technologies. In cases where technical limitations that preclude the use of a particular technology are reached, no economic analysis is given.

On average, the sustainable yield of boreholes in rural villages is less than for major villages because lower pumping rates can be accepted if the demand can be met--the average pumping rate for rural villages is 3.5 m^3/hour. For diesel systems, LT-1 engines and Mono pumps are specified. Submersible pumps were assumed for both grid-electric and solar pumps. For handpumps, a labor cost for pumping was assumed for this economic analysis. The wage rate used is the government rate for casual (unskilled) labor of P0.64/hour. The population and, hence, water requirement in each rural village is growing at a different rate, but an average growth factor of three percent was assumed. Since borehole yield is fixed, additional water is delivered by longer pumping hours. This does not present a major problem except for solar pumps, which must be designed to "pump at night" in later years of the analysis. Battery storage will have to be provided to accomplish this and was included when the number of pumping hours exceeded six per day on an annual basis.

2. Economics

Table 4 gives a cost comparison of these four technologies under current average rural village conditions, with the exception of distances for installation and servicing. The major assumptions are shown on the table, and as before, the systems that are not applicable are so indicated. The major conclusions are that:

- for the majority of cases, diesel pump sets provide water at the lowest unit cost;

- as with the major villages, grid-electric pumps become more attractive relative to diesel systems as the water requirement increases, but there are currently no instances where grid power is available at remote rural sites;

- solar pumps appear to be most competitive under low-head conditions, but even in these cases, they are more expensive than diesel systems at current tender costs; and

- in cases where handpumps can meet the demand (five m^3/day), they provide water at a lower unit cost than any other technology.

RURAL VILLAGE

All values are economic unit costs Pula per cubic meter
Discount rate is 6%
Output is stated cubic meters per day discounted
at 6% over 20 years

STANDARD ASSUMPTIONS

m3/day	Diesel Output 5	10	20	30	Windmill Output 5	10	20	30	Solar Output 5	10	20	30	Grid Electric Output 5	10	20	30
Head 15m	1.02	1.01	.61	.47					2.14	1.11	.62	.46	2.28	1.17	.61	.43
Head 30m	1.04	1.02	.62	.48	Not Considered				2.24	1.21	.74	.60	2.31	1.19	.63	.45
Head 45m	1.06	1.04	.63	.49					2.34	1.32	.87	.73	2.33	1.21	.65	.47
Head 60m	1.08	1.06	.65	.50					2.45	1.42	.99	.86	2.35	1.23	.67	.49

m3/day	Handpump Output 5	10	20	30	Biogas Pump Output 5	10	20	30	Animal Traction Pump Output 5	10	20	30
Head 15m	1.09											
		Out										
Head 30m	1.10				Not Considered				Not Considered			
			Of									
Head 45m	1.15											
				Range								
Head 60m	1.16											

Basic Assumptions: (includes 3% growth in demand)
Installation Distance at 400 km, service from 300 km
3.5 m3/hr pumping rate
Full time salaried operator (exc handpump)
Government tender prices for equipment

Diesel:
1. Use of LT-1 all cases (efficiency dependent on loading)
2. Installation transportation and labor average for DWA
3. 17.5 thebe/hr for spares for maintenance and repair

Electric:
1. 2km of 11kv overhead line included
2. Electricity tariff of 10.7 thebe per unit (current tariff)
3. Equivalent installation costs as for diesel
4. 40% motor/pump efficiency

Solar:
1. Solar array sized to meet demand
2. Battery systems quoted for 20m3/day at 45 and 60 meters head and 30m3/day at 30, 45, and 60 meters head (4 yr batt life)
3. Solar pump/motor overall efficiency is 32%
4. Equivalent installation costs as for diesel
5. Module cost at P670 each for Arco Solar M-55 (P12.6/Wp)
6. Module replacement due to damage, one per year

Handpump:
1. India Mk II priced for 15 and 30 meters
2. Mono direct drive Handpump priced for 45 and 60 meters
3. Pumping rate is 450 liter per hour
4. Labor to pump included at P0.64/hr (actual pumping time)

Table 4. Rural Village Applications -- Standard Assumptions

Table 5 shows the unit costs when the most significant internally controllable conditions (noted under the table) are changed. While changes in some of the other assumptions (e.g., reducing installation costs for diesel pumps or reasonable reductions in the electricity tariff for electric pumps) will have some effect on unit costs, they are not significant compared to those given in the table. The conditions that have the greatest effect on unit costs are:

- reducing the cost for the pump operator to half-time for diesel and electric systems and one-quarter time for solar pumps, which reflects the decreased amount of time a pumper would actually have to spend operating these systems;
- reducing module damage from vandalism or theft through village education programs; and
- for handpumps, halving the pumping labor cost to P0.32 to reflect the lower opportunity cost of labor in remote areas.

Reducing the pumper labor charge and module replacement frequency for solar pumps has the obvious effect of reducing the unit costs for all solar systems. Diesel costs drop by eight to 14 percent, solar by 10 to 28 percent, grid-electric by 10 to 11 percent and handpumps by 30 to 33 percent. The greatest decreases in unit costs occur at the lowest head/demand for each system, which shows how dependent unit pumping costs are on the pumper labor charge. A comparison of unit costs across the range of systems leads to the following conclusions:

- the range of conditions where diesel is the least-cost option decreases considerably;
- solar pumps become cost-competitive with the diesel costs given in Table 4 for all heads less than 30 meters and several low-demand/high-head cases.
- grid-electric pumps retain their slight competitive edge over diesels only in the 30 m^3/day range (as in Table 4), but as already noted, there are few, if any, remote sites where power is now available; and
- handpumps remain the system of choice for the lowest demand sites.

Table 6 presents the unit costs for the various system options when changes in external factors (i.e., costs that are beyond the government's direct control) accompany the changes in the assumptions shown in Table 5. External factors that have the greatest effect on unit costs include:

m3/day	Diesel Output 5	10	20	30	Windmill Output 5	10	20	30	Solar Output 5	10	20	30	Grid Electric Output 5	10	20	30
Head 15m	1.56	.88	.54	.42	Not Considered				1.55	.82	.47	.36	2.02	1.04	.55	.38
Head 30m	1.58	.89	.55	.44					1.65	.92	.60	.50	2.05	1.06	.57	.40
Head 45m	1.60	.91	.56	.45					1.76	1.02	.72	.63	2.07	1.08	.59	.42
Head 60m	1.63	.93	.58	.46					1.86	1.12	.84	.77	2.10	1.10	.61	.44

m3/day	Handpump Output 5	10	20	30	Biogas Pump Output 5	10	20	30	Animal Traction Pump Output 5	10	20	30
Head 15m	.73	Out Of Range			Not Considered				Not Considered			
Head 30m	.74											
Head 45m	.79											
Head 60m	.81											

Notes: Changes in Standard Assumptions

- Diesel. 1. Half time pump operator
- Electric: 1. Half time pump operator
- Solar: 1. Quarter time pump operator
  2. Module replacement due to damage 1 every 3 years
- Handpump: 1. Labor to pump included at P0.32 per hour

Table 5. Rural Village Applications -- Cost Variations due to Internal Factors

- a 10 percent annual escalation rate in fuel costs, which might represent a sudden dramatic decrease in the availability and, hence, increased cost of petroleum fuels due to regional unrest;

- a 13 percent reduction in solar PV module costs to P500 for an ARCO M-55--this is equivalent to P9.4/Wp or US$5.60/Wp, which represents more typical international costs for PV modules; and

- no line-extension cost for grid-electric pumps--for example, in donor-funded borehole electrification programs.

The results in Table 6 for each technology should be compared to those in Table 4, which uses the standard assumptions. The effects of incorporating both sets of changed conditions (internal and external) are:

- while diesel pumping costs drop 10 percent for the lowest head/demand situation because of the half-time pumper, unit costs rise 16 percent for the highest head/demand (60 meters and 30 m^3/day);

- solar pumping is less expensive than the diesel costs from Table 4 for all cases except the two highest demand cases at 60 meters of head;

- grid-electric pumping becomes the least-cost option in all cases where power is available at the site, but there are currently few, if any, sites where this actually applies, as already noted; and

- handpumps remain the least-cost option for low-demand sites (five m^3/day).

3. Infrastructure

The 13 District Council Water Units and Departments are responsible for maintaining rural village water supplies and any public supplies that exist in smaller settlements and lands areas. At present, these organizations are adequately funded and have acceptable levels of transportation available to service these widely distributed sites. The skills and organizational ability of each unit's staff vary considerably. Except for several of the largest geographical districts and those with the greatest number of boreholes, the level of service is quite good.

To date, these service centers have only been responsible for diesel systems and an occasional handpump. If technologies that are new to unit technicians and mechanics are to be

m3/day	Diesel Output 5	10	20	30	Windmill Output 5	10	20	30	Solar Output 5	10	20	30	Grid Electric Output 5	10	20	30
Head 15m	1.64	.95	.62	.50	Not Considered				1.50	.78	.45	.34	1.12	.59	.32	.23
Head 30m	1.67	.98	.64	.53					1.58	.86	.54	.45	1.14	.61	.34	.25
Head 45m	1.70	1.01	.66	.53					1.66	.94	.64	.56	1.17	.63	.36	.27
Head 60m	1.75	1.05	.70	.58					1.74	1.02	.74	.66	1.19	.65	.38	.29

m3/day	Handpump Output 5	10	20	30	Biogas Pump Output 5	10	20	30	Animal Traction Pump Output 5	10	20	30
Head 15m	.73	Out			Not Considered				Not Considered			
Head 30m	.74		Of									
Head 45m	.79			Range								
Head 60m	.81											

Notes: Additional changes in Standard Assumptions
Diesel: 1. 10% annual escalation in fuel cost
Electric 1. No overhead lines extension costs
Solar: 1. Module cost reduced to P500 (P9.4/Wp)
Handpumps: No Changes

Table 6. Rural Village Applications -- Cost Variations due to Internal and External Factors

introduced, a substantial training effort will be required. Electrical systems, whether mains-connected or solar-operated, are unfamiliar to technicians at the District Council Level, so training efforts must include a basic understanding of electricity and troubleshooting skills. To the extent possible, component replacement as a strategy for ensuring system reliability must be encouraged. Component repair will have to be handled by private companies.

DWA is beginning to be more active in efforts to explore the use of handpumps for smaller settlements and lands areas. In addition, District Council Water Units have been showing increased interest in handpump use. If they do enjoy much wider use, this will press the capacity of Water Units. These units have the required skills and tools to support handpump use, but manpower constraints will make it difficult to install and support any great number without additional personnel.

District Councils have been enthusiastic about the potential for solar pump use from the outset. Since they are responsible for the recurrent cost (not the capital cost) of pumps and the service requirement for some solar pump systems seems to be less than for diesel engines, this interest is not surprising. However, the current lack of skilled technician is a barrier to the effective use of solar pumps. Still, it does appear that solar pumps could be used cost effectively in remote areas if the policy regarding full-time pumpers is changed.

4. Conclusions and Recommendations

As for the major villages, rural villages will continue to depend heavily on diesel pumping systems, which can deliver water for the lowest unit cost in all but a few cases. A responsive infrastructure is already in place in most districts to service the Lister-Mono pump combination. In districts where the maintenance and service facilities are not so well organized, efforts should be made to strengthen them. The districts with the greatest need in this respect are those with the most boreholes (Kweneng and Southern) and largest geographical areas (Kgalagadi and Northwest).

Since it is clear that diesel pumping systems will continue to be widely used, additional support should be provided to upgrade technical and management skills at the district level. This support will allow continuing improvement of water system reliability and reduce costs by improving logistic capability and the quality of work performed. Specific efforts should be made to improve the skills of pumpers in diagnosing and reporting problems, which would help reduce the number of service and repair trips to diesel sites.

Plans are already in place to provide the MLGL Water Engineer with an assistant who can help District Water Unit Technicians with specific problems. DWA has been asked to contribute to pumper training through their training section. These are positive steps that should be followed through to their conclusion. Further efforts should be made to support several of the largest districts, which should include helping to establish Water Unit sub-depots in the districts to subdivide the work and the provision of expatriate technicians in several cases until Botswana Polytechnic can train additional Batswana to fill these posts. DWA should seek to organize the crews that equip boreholes and their transportation so as to increase productivity, although this recommendation may prove difficult to implement given DWA's current staffing level.

Clearly, handpumps represent a way to reduce costs and Botswana's dependence on diesel fuel, but the opportunities for handpump use are currently limited by the fact that most boreholes are located well outside the villages. In cases where a borehole is available near a village or settlement that can meet the demand, handpumps are definitely the best choice. They have a further advantage in that they can be used effectively with low-yield boreholes. Another benefit is that handpumps require no storage tank and distribution system, which further bolsters arguments in favor of their use.

Support should be provided for expanding the use of handpumps in appropriate situations, which include providing water supply for smaller settlements and in lands areas as well as serving as a backup for diesel systems in smaller rural villages. At present, the work with handpumps is somewhat disorganized, with District Councils, MoA and, to some degree, DWA all being involved. In addition, RIIC is interested in playing a role in the continued testing and evaluation of handpumps in the field. Coordinating these efforts should be the responsibility of the MLGL Water Engineer, and a handpump coordinating group should be formed. The work with handpumps may require a separate unit within MLGL to locate or arrange for the drilling of boreholes, equip them and arrange for service. Eventually, these tasks should be handled by the District Water Departments as efforts to supply water to small settlements continue.

Electric pumps are not likely to be the least cost-effective method of pumping water for rural village water supplies unless the interconnection costs are near zero, which will be true for only very few rural villages along existing overhead lines or where lines may already be in place for other reasons (e.g., a connection to a school or hospital). As indicated in the preceding section on major villages, the lack of a clear picture on long-term aquifer potential also limits the consideration of AC-electric pumps. The UNDP/World Bank's PUMP ELECTRIFICATION

PREFEASIBILITY STUDY (1986) suggests that there are only 13 such villages (2.5 percent of the total) where electric pumping systems appear to be an appropriate choice. The potential of electric pumps for rural village water supplies is likely to be very small because of the limited extent of the mains network and current low level of understanding of long-term aquifer performance in rural areas. In addition, District Water Units currently have no capability to service or repair electric motors or troubleshoot electric systems.

At current costs, solar PV pumps cannot be considered cost-effective pumping choices in most cases. However, solar pump costs are likely to decrease due to improvements in the technology and reductions in module costs. The most recent tender price of P12.6/Wp exceeds the current international delivered price of about P9/Wp. The unit cost for solar pumping could be significantly decreased by reducing the pumper requirement. PV pumps offer the best long-term possibility for the diversification of energy sources for larger rural village water supplies, which should be taken into consideration for strategic purposes. The cases that are closest to being cost-effective today are those with low heads, under 30 meters, but rural village water supply schemes with such heads are rare. The areas where they are most frequently found are the Boteti Subdistrict and near the Okavango Delta in the Northwest District. The results of the analysis shown in Table 6 indicate that under certain conditions, solar pumping may become even more attractive.

In the future, as prices fall further or more remote water supply schemes are contemplated, the scope for solar pump use will increase. Given this--and because there are already solar pumps in the field and solar pumping represents the best alternative to diesel fuel use for rural villages--certain solar pumping activities should proceed, including continued monitoring of systems in the field, efforts to refine design procedures and training, which is most important for rural villages. A curriculum for a solar pump training course should be developed and training provided to DWA and District Council personnel who must service and repair existing solar pumps. This training should include DC electrical circuit theory and the characteristics of PV modules, array alignment, wiring and fault diagnosis.

D. Other Government Agencies

In addition to domestic water supplies for major and rural villages, the government operates and maintain water supplies for its own agencies, including border posts, police camps, road construction sites, Department of Wildlife camps and an extensive network for the MoA's rural activities. An accounting of these more than 300 boreholes is provided in Appendix C of VOLUME II: DIESEL SYSTEMS. The variation in water requirements at these sites is large from less than one m^3/day up to 30 to 40 m^3/day, with seasonal usage at some locations. In most cases, the government agency that uses the water is responsible for the day-to-day borehole operation, with the BRS branch of DWA performing service and repair functions. In general, these engines do not receive as good care and thorough servicing as those in major and rural villages.

1. Technology Choice

Almost all the new water supplies designed for government agencies use Lister engines and Mono pumps. Some installations predate the introduction of the Mono pump and utilize National pump-heads to drive reciprocating pumps. Fewer than 10 windmills have been installed in support of MoA activities at research stations and along the cattle trek route. To date, no solar pumps have been installed for government agencies, although several are planned for the Department of Wildlife. In most cases, mains-connected electric pumps are not feasible due to the remote nature of many camps--only a few are relatively close to overhead lines. Two are in use with diesel generators (gen-sets) at border posts along the Limpopo River. These gen-sets have multiple uses as they also provide electricity for lighting.

Bio-gas substitution and ADPs are probably not feasible for government use because of their labor costs. However, it is likely and reasonable that the MoA will install several of these pumps at such locations as Rural Training Centers (RTCs) with the aim of demonstrating these technologies to farmers. The technologies considered here for use by government agencies are:

- diesel pump sets,
- windmills,
- solar pumps,
- mains-connected electric pumps, and
- handpumps.

The basic assumptions for government agency cases include no growth in demand and borehole yields of 3.5 m^3/hour. The heads under consideration ranged from 15 to 60 m, which reflects installations that do not generally include long pipe runs and higher heads due to friction losses. The other major difference relative to major and rural villages is that a full-time salaried pumper was not included for any of the pumping technologies, which reflects the reality that tending these pumping systems is just one of a broader set of job responsibilities at most government agency locations. These differences have a pronounced effect on the unit cost of the water delivered.

Windmills will have limitations related to head, wind speeds at the site and available systems. Although the average wind speeds for the country are in the range of three m/sec, this analysis assumes that only windier sites will be chosen for windmills, an average wind speed of 3.5 m/sec was assumed. For water requirements of more than 20 m^3/day and 15 meters head, windmills be unable to meet demand at these speeds. As for village systems, handpumps were not considered for water requirements above five cubic meters per day.

2. Economics

Table 7 shows the unit costs of delivering water, given typical present economic and service conditions for other government installations. These include average repair and maintenance costs for diesel engines, representative distances for servicing, and typical pumping conditions, pumper costs and responsibilities. A summary of the major assumptions used in the analysis is given at the bottom of the table. The major conclusions are:

- handpumps are the least-cost option when five m^3/day or less are required;
- windmills are the least-cost option only for a very small niche--demand of between 10 and 20 m^3/day for heads of less than about 20 meters in areas with adequate wind speeds, approximately 3.5 m/sec.
- solar pumps are not cost-competitive with diesel systems under the base-case assumptions, but they are more attractive as head decreases and water demand increases; and
- as was the case for major and rural villages, grid-connected pumps are most cost-competitive for higher water demands--at 30 m^3/day, the unit costs for grid-electric pumps are still significantly higher than for diesel systems, largely due to interconnection costs (as noted previously, very few sites are within two kilometers of a power line).

Due to the relatively low wind speeds in most of Botswana, wind pumps have only limited application for other Government agencies. The required average design-month wind speed to ensure water delivery of 20 m^3/day at a 15-m head is 3.5 m/sec. To pump 10 m^3/day, between 2.5 and nearly 3.5 m/sec are required as the

OTHER GOVERNMENT AGENCIES AND POSTS

All values are economic unit costs in Pula per cubic meter
Discount rate is 6%
Output is stated cubic meters per day discounted
at 6% over 20 years.

STANDARD ASSUMPTIONS

m3/day	Diesel Output 5	10	20	30	Windmill Output 5	10	20	30	Solar Output 5	10	20	30	Grid Electric Output 5	10	20	30
Head 15m	1.49	.84	.52	.41	1.95	.98	.49	--	2.58	1.34	.73	.54	2.44	1.25	.66	.46
Head 30m	1.51	.85	.53	.42	1.97	.98	--	--	2.71	1.48	.87	.78	2.46	1.27	.68	.48
Head 45m	1.54	.87	.54	.43	1.98	.99	--	--	2.85	1.61	1.10	.85	2.49	1.29	.70	.50
Head 60m	1.56	.89	.56	.45	1.99	.99	--	--	2.99	1.75	1.15	1.00	2.51	1.32	.72	.52

m3/day	Handpump Output 5	10	20	30	Biogas Pump Output 5	10	20	30	Animal Traction Pump Output 5	10	20	30
Head 15m	1.15	Out			Not Considered				Not Considered			
Head 30m	1.17		Of									
Head 45m	1.20			Range								
Head 60m	1.22											

Standard Assumptions:

Installation distance at 400 km, service from 400 km
3.5 m3/hr pumping rate
Government tender prices for equipment
Half time pump operator exc. windmill and handpump

Diesel:
1. Use of LT-1 in all cases (efficiency dependent on loading)
2. Installation Labor and transport average for DWA
3. 17.5 thebe/hr for spares for maintenance and repair

Electric:
1. 2km of 11kv overhead line included
2. Electricity tariff of 18.7 thebe per unit (current tariff)
3. Equivalent installation costs as for diesel
4. 40% motor/pump efficiency

Windmills:
1. Assumes Climax 18 with pumper 1/4 time
2. Assumes windspeed sufficient to provide water up to 3.5 m/s

Solar:
1. Module price at 670 Pula for Arco-Solar M-55
2. Systems sized to provide requirement
3. Battery systems quoted for 20m3/day at 45 and 60 meter heads
4. Equivalent installation costs as for diesel
5. Module replacement due to damage, one per year
6. Solar pump/motor overall efficiency is 32%

Handpump:
1. India Mk II handpump priced for 15 and 30 meters
2. Mono direct drive priced for 45 and 60 meters
3. Pumping rate is 450 liters per hour (with labor at P0.64/hr included)

Table 7. Government Agency Applications -- Standard Assumptions

head increases from 15 to 60 m. The rarity of average wind speeds in the higher ranges during the yearly period of low wind speeds makes it clear that opportunities for windmill use will be limited. In the wind matrix, dashes indicate cases where wind pumps tested during CWPP were incapable of delivering the required amount of water through the head indicated.

As might be expected, solar pumps are not as cost-competitive in this analysis largely due to the fact that the government tender prices for solar modules which were used as the basis for system costs are considerably higher than current international prices. It is highly likely that another bid solicitation for solar modules by the government would result in significantly reduced module costs. Table 9 gives an example of how reduced module costs would affect the unit costs for solar pumping.

Table 8 shows the effects of changing certain assumptions about internal factors that can be controlled by government policy decisions to some extent. The more significant changes include:

- reducing pumper labor to quarter-time for diesel and grid-electric systems, and zero for wind and solar pumps;
- reducing the solar module replacement frequency from one module every year to one every three years; and
- halving the economic cost of labor for handpump operation.

Reductions in labor costs for other government installations could easily be achieved because pump operators for these systems normally have a variety of other responsibilities that are not directly related to water pumping. Wind and solar pumps do not necessarily require any day-to-day operation by an attendant and, thus, would only require occasional semiskilled or skilled labor for routine maintenance or repairs. Solar module breakage could probably be significantly reduced by education programs. The labor charges for handpumps vary depending on assumptions made about the marginal opportunity costs of labor in remote areas.

The major conclusions to be drawn from the changes in the analytical assumptions shown in Table 8 are:

- the cost-effectiveness of handpumps is not dependent on variations in assumptions about labor costs--for low-demand cases, they will always be the least-cost option for all of the heads considered here;

	Diesel				Windmill				Solar				Grid Electric			
	Output				Output				Output				Output			
m3/day	5	10	20	30	5	10	20	30	5	10	20	30	5	10	20	30
Head 15m	1.33	.76	.48	.38	1.79	.90	.45	--	1.97	1.04	.58	.44	2.27	1.17	.62	.43
Head 30m	1.35	.77	.49	.39	1.80	.90	--	--	2.11	1.18	.72	.59	2.30	1.19	.64	.45
Head 45m	1.37	.79	.50	.40	1.81	.91	--	--	2.25	1.31	.85	.75	2.32	1.21	.66	.47
Head 60m	1.40	.81	.52	.42	1.82	.91	--	--	2.39	1.44	.99	.90	2.35	1.23	.68	.49

	Handpump				Biogas Pump				Animal Traction Pump			
	Output				Output				Output			
m3/day	5	10	20	30	5	10	20	30	5	10	20	30
Head 15m	.79	Out			Not Considered				Not Considered			
Head 30m	.80		Of									
Head 45m	.84			Range								
Head 60m	.85											

Notes: Changes in Standard Assumptions

Diesel: 1. Pumper Labor reduced to quarter time
Solar: 1. Pumper labor reduced to zero
2. Module replacement due to damage 1 every 3 years
Electric: 1. Pumper Labor reduced to quarter time
Windmills: 1. Pumper labor reduced to zero
Handpumps: 1. Labor to pump included at P.32/hr

Table 8. Government Agency Applications -- Cost Variations due to Internal Factors

- windmills have the same small application niche as discussed above for rural villages;

- the unit cost of solar pumps is reduced by 10 to 24 percent compared to Table 7, but these systems are still not cost-competitive with diesel pumps under the standard assumptions;

- while the unit costs for grid-electric pumps drop by six to seven percent compared to the standard assumptions, they too are still not competitive with the diesel costs shown in Table 7; and

- diesel pumps remain the system of choice for the majority of cases considered here.

Finally, a second set of changes was made in the assumptions about external conditions, over which Botswana has no direct influence including:

- diesel fuel costs, which may inflate by as much as 10 percent per year due to international problems and regional instability;

- solar modules could easily decrease in price from P670 to P500 each--for the modules considered here, this is equivalent to P9.4 or US$5.60/Wp; and

- no connection costs were assumed for grid-electric pumps, for reasons discussed previously in Section VI.B.3.

For windmills and handpumps, no changes in unit costs are anticipated due to outside influences. It is unlikely that any significant reductions in capital equipment costs for commercially available wind systems or handpumps will be realized in the near future due to the relative maturity of these technologies. The cost of the RIIC Motswedi must be reduced just to meet cost assumptions made in this analysis. Thus, the major conclusions to be drawn from the combination of this set of changed assumptions and those in Table 8 are:

- handpumps are still the system of choice for low-demand sites (five m^3/day or less);

- windmills remain the least-cost option for only a very small set of cases--outputs of 20 m^3/day for heads of about 20 meters in areas with wind speeds that are adequate (approximately 3.5 m/sec) to pump this volume of water;

m3/day	Diesel Output 5	10	20	30	Windmill Output 5	10	20	30	Solar Output 5	10	20	30	Grid Electric Output 5	10	20	30
Head 15m	1.39	.82	.54	.45	1.56	.78	.39	--	1.92	1.00	.55	.41	1.12	.59	.33	.24
Head 30m	1.43	.85	.57	.47	1.58	.79	--	--	2.02	1.10	.65	.53	1.15	.62	.35	.26
Head 45m	1.46	.87	.59	.49	1.59	.79	--	--	2.12	1.20	.76	.65	1.18	.64	.37	.28
Head 60m	1.50	.91	.62	.52	1.90	.80	--	--	2.23	1.30	.86	.77	1.20	.66	.39	.30

m3/day	Handpump Output 5	10	20	30	Biogas Pump Output 5	10	20	30	Animal Traction Pump Output 5	10	20	30
Head 15m	.79	Out Of Range			Not Considered				Not Considered			
Head 30m	.80											
Head 45m	.84											
Head 60m	.85											

Notes: Additional Changes in Standard Assumptions

Diesel: 1. 10% annual escalation in fuel costs
Electric 1. No overhead line extension cost
Solar: 1. Module cost reduced to P500 (P9.4 Wp)
Windmill: No Changes
Handpump: No Changes

Table 9. Government Agency Applications -- Cost Variations due to Internal and External Factors

- solar pumps are marginally cost-competitive with diesel systems, given the data in Table 7, and only in the demand range of 20 to 30 m^3/day at the lowest head considered; and

- grid-electric pumps become cost-competitive with diesel systems across the range of heads and demand level considered when no interconnection costs are incurred, but this seldom occurs, if ever.

3. Infrastructure

In all but a few cases, government agencies using pumping equipment are responsible for its operation. In some instances, full-time pump operators are employed, but mostly, the operator's duties fall to individuals show have other responsibilities as well. Generally, individuals with pumper duties do not appear to have received much training for the role and limit their work to starting and stopping the engine, as required.

Although it appears that government agencies can contract for service in the private sector, there is little incentive to do so, as the BRS section of DWA provides all of these services free through their outstation and workshop network. Transportation difficulties, largely related to availability of functioning vehicles, hinder the responsiveness of BRS personnel to normal service requirements, but in most cases, breakdowns are attended to reasonably quickly if spare parts are available and the repair can be made in the field. Loaner engines are available if the situation warrants.

The BRS network is familiar with Lister engines, Mono pumps and reciprocating pumps driven through pump-heads, but the responsible technicians have only limited knowledge about windmills and have had no exposure to solar or electrical pumping systems. As for District Council Technicians, training is necessary if these new technologies are to be used successfully. The jurisdictional issues between DEE and DWA (mentioned in the discussion of major village systems) when electric pumps are used must also be considered and resolved. Since windmills are already in use, training in proper maintenance and repair is already necessary for the technicians at outstations who are responsible for them.

4. Conclusions and Recommendations

As is true for the other user groups, diesel pumps will continue to perform most of the water lifting for government agencies, and BRS will continue to provide service for these installations. The lack of trained pumpers and logistic support from BRS will maintain breakdown rates for this group that are higher than for rural villages and water reliability at slightly lower levels. Regardless, from an economic perspective, it does not appear that other technologies (besides handpumps) have a significant role to play. However, the range of pumping applications for this group make it one of the most diverse. Unattended and/or quiet operation are important at a number of Department of Wildlife boreholes, demand is low at some customs and immigration camps, water requirements are seasonal along cattle trek routes, and water use is temporary at many of the boreholes used while building roads. These situations provide a reasonable scope for the application of other pumping systems, as special needs help drive pump selection.

Since it is clear that diesel pumping will continue to play a major role in meeting the needs of government agencies, it is important to improve services and reliability for this sector. At this stage, major efforts should be made to improve the transportation situation for BRS and provide pumper training for operators employed by other ministries. The former needs to be coordinated through the Central Transport Organization. For the latter, funds and staff should be made available to the DWA training section to permit the inclusion of other government pumpers in training programs organized by DWA.

Handpumps are clearly the most cost effective pumping choice for very low demand situations (less than five m^3/day). These cases will include many government camps where no wildlife or livestock are watered, except Botswana Defense Force (BDF) and refugee camps. The Department of Wildlife has been interested in the use of windmills and solar pumps for watering wildlife in remote areas where the potential for unattended operation is an important consideration. Two windmills are already installed in Nxai Pan National Park, and several solar pumps are being considered for boreholes in the Moremi and Savuti areas. Quiet operation, for both the enjoyment of tourists and minimal disruption of animal habits, as well as the remoteness of the application are factors in the choice. Unfortunately, many of the Department of Wildlife's boreholes are remote and high-head/demand cases. However, there may be as many as 25 or 30 cases where alternatives to a diesel system can be considered.

DWA and BRS should be made aware of the conditions here handpumps are suitable and use them in those instances. Solar pumps and windmills should be employed when they can produce water at the lowest unit cost or when special situations favor their use. It is not anticipated that there will be many such instances, given the renewable energy resource, pumping heads and water demand. At current levels, solar pumps are not cost-competitive for most rural village applications. As costs continue to decrease, their range of applications will increase. However, the location of several suitable solar pump sites will permit utilization of the remaining stock of solar modules. It will also give DWA and BRS the opportunity to gain valuable experience with this technology. A clearly defined PV pump training program should be provided for DWA personnel. Initially, back-up pumping systems should be included to ensure a more reliable supply for cases where renewable technologies are being used.

MoA operates trek-route boreholes where there would appear to be a need for unattended pump operation. Unfortunately, the characteristics of trek-route use make this difficult for either solar or wind pumps. For trek-route boreholes, a lot of water must be available on-demand for cattle herds passing to the abattoir. There may be applications for solar pumps along the Ramokwabena River where MoA operates seven low-head, river-extraction boreholes for livestock watering.

E. Private Sector

The most extensive and least understood network of pumping equipment is in the hands of private owners--an estimated 4,000 equipped boreholes are operated by this group. The sector includes privately owned equipment that is used in communal areas, pumps owned by syndicates (collectives), and equipment in freehold and leasehold areas.

The only clear similarity among the various private equipment operators is the predominance of cattle-watering applications. In many cases, particularly in eastern Botswana, boreholes and the accompanying equipment are used on a seasonal basis, as the rains and available surface water provide less expensive cattle watering. Year-round, there is greater dependence on boreholes in the western part of the country. Although Water Apportionment Board policy allows the abstraction of enough water for 400 cattle (18.2 m^3/day), the water pumped varies from a small portion of this figure to several times it, depending on the location, cattle density and time of year.

Engine operation and servicing practices vary considerably. In some instances, the quality of service is excellent, but more typically, pump operators are not well trained and service is only provided in response to a pump or engine breakdown. The BRS service network is available to individual engine owners on a fee-for-services basis, provided they have registered with BRS and their accounts are clear. Roughly 25 percent of all private engine owners are enrolled in this program. The remainder perform repairs themselves or contract with informal-sector mechanics. Other than workshop engine overhauls, there is little formal-sector engine or borehole servicing.

1. <u>Technology Choice</u>

Lister engines and copies dominate the private sector, but other equipment is being used increasingly, particularly by freehold farmers. Windmills are used in some areas, especially by freehold farmers on the Ghanzi farms and south of Lobatse--it is estimated that 200 to 250 are installed in these areas. Mains-connected electric pumps are used by a very small number of private individuals who live near the utility grid. These cases are a very small minority and will not likely increase in number until the grid is extended considerably. Several solar pumps have been installed by donors for cooperatives, but to date, no solar pumps are being used by private individuals. Some people have inquired about them, but lose interest when price of the equipment is mentioned. PV pumping systems are not likely to find applications in the private sector until their costs change significantly.

Besides traditional winch-operated systems, handpumps will not produce water in volumes that are large enough for extensive cattle watering. Bio-gas substitution and ADPs are most likely to be considered by the private sector when the additional labor cost is either negligible or provided at the normal rate for private-sector pump operators. In sum, the equipment considered in this analysis for use by the private sector includes:

- diesel pump sets,
- windmills,
- bio-gas substitution, and
- ADPs.

As with rural villages and government posts, a borehole yield of 3.5 m^3/hour was assumed. The major differences between this user group and the public-sector are in the discount rate, equipment costs and labor costs for pump operation. The discount rate used for this analysis was raised to 12 percent from the six percent used in public-sector analysis to reflect the prevailing cost of borrowing money in Botswana. Private individuals cannot take advantage of government tender prices, which raises the price of some equipment by as much as 60 percent. Finally, the cost of employing a pump operator is less in the private sector, which has a profound impact on the cost of water delivery for the cases considered here.

2. Economics

A comparison of the four technologies listed above, when installed and used by private individuals, is given in Table 10. Although it is extremely difficult to generalize about needs and use conditions in the private sector, the factors used to produce these figures are considered typical except for the installation and service distances. The installation distance of 400 km and service distance of 300 km will only be appropriate for five percent or less of the private-sector pumping cases. In addition, it was assumed that pumping equipment will be used all year, which may not be true in many instances. Because naturally occurring surface water is used when it is available, seasonal equipment use will increase the unit costs for pumped water. The assumptions included in the analysis for diesel and wind systems are essentially the same in the previous sections, but it should be noted that for bio-gas substitution, the economic value of the additional labor to collect and mix the dung and remove effluent has been included at P50 annually. The economic cost of labor for ADP operation was included at P0.50/hour of equipment operation. The major conclusions to be drawn from Table 10 are:

- diesel pumping systems are the most cost-effective choice for all of the cases considered;

- for the lowest head cases, windmills may be cost-effective if 20 m^3/day can be pumped, which will require an average wind speed in the range of 3.5 m/sec--these average wind speed and head conditions are not common in Botswana;

- bio-gas substitution provides water at a higher cost than diesel engines in all cases--as the energy cost increases with higher heads and water requirements, the unit costs for bio-gas systems converge with standard diesel systems; and

- ADPs are most attractive for cases with higher water demand, but are not competitive with diesel pumps for any of the cases considered.

In examining this table, it should noted that the unit cost for diesel pumping is considerably less than for rural villages and government agencies (see Tables 4 and 7), which is largely due to lower pump operator costs for the private sector (P450 instead of P2,400 annually). Bio-gas pumping becomes more attractive with higher heads and water requirements because there are greater fuel savings in these cases. The savings range from just over P100 to P1,250 annually, depending on the head and amount of water pumped. It is difficult to say if the assumptions made here represent typical cases as the base of experience with bio-gas pumping in Botswana is limited.

PRIVATE SECTOR

Values are economic unit costs in Pula per cubic meter
Discount rate is 12%
Output is stated cubic meters per day discounted
at 12% over 20 years

STANDARD ASSUMPTIONS

	Diesel				Windmill				Solar				Grid Electric			
	Output				Output				Output				Output			
m3/day	5	10	20	30	5	10	20	30	5	10	20	30	5	10	20	30
Head 15m	.95	.55	.36	.30	1.49	.75	.37	--	Not Considered				Not Considered			
Head 30m	.99	.58	.38	.31	1.51	.75	--	--								
Head 45m	1.03	.60	.40	.33	1.52	.76	--	--								
Head 60m	1.08	.64	.42	.35	1.54	.77	--	--								

	Handpump				Biogas Pump				Animal Traction Pump			
	Output				Output				Output			
m3/day	5	10	20	30	5	10	20	30	5	10	20	30
Head 15m	Not Considered				1.27	.70	.42	.33	1.81	.98	.56	.42
Head 30m					1.30	.71	.43	.34	1.90	1.05	.62	.48
Head 45m					1.34	.73	.44	.35	1.91	1.03	.59	.44
Head 60m					1.37	.77	.46	.36	1.96	1.05	.60	.45

Basic Assumptions:
Installation Distance at 400 km, service from 300 km
3.5 m3/hr pumping rate
Retail prices for equipment

Diesel:
1. Use of LT-1 in all cases (efficiency depends on loading)
2. Pump operator (P450)
3. Installation transportation and labor typical for the private sector
4. 17.5 thebe/hr for spares for maintenance and repair

Windmill:
1. Assumes use of Climax 10
2. Assumes windspeeds (up to 3.5 m/s) necessary to provide water
3. No pumper cost

Biogas:
1. Use of LT-1 engine
2. 80% displacement of diesel fuel for engine operation
3. Digester size 3.6x gas requirement, built for P75/m3
4. Installation at 20 days, and 4 trips with 7 ton truck
5. Additional cost above full time pumper has an economic value of P50 annually

ADP:
1. Equipment lifetime of 10 years
2. Use of donkeys as draft animals
3. Economic value of labor valued at P0.50 per hour of pump operation
4. Sufficient pumping time to deliver required water with 1 or 2 teams of up to 8 animals

Table 10. Private-Sector Applications -- Standard Assumptions

Similarly, for the ADP, the assumptions may not be average as the extent of test results and experience with this technology are also limited. The ADP's major advantage is that it does not depend on any petrochemical fuel.

Up to this point, only economic unit costs have been considered. However, private users are not likely to be convinced to purchase pumping equipment based on an economic analysis as their concerns are more likely to be cash-flow oriented. The capital costs for all of the alternatives to diesel considered for the private sector are higher. A privately purchased Lister LT-1 costs less than P2,500. An ADP is P6,700, a windmill over P9,000, and a bio-gas system includes both a diesel engine and the additional cost of the digester. If recurrent costs are reduced sufficiently by use of these systems, the unit cost in a financial analysis may encourage their use over diesel. However, for the cases considered here, a windmill must be capable of pumping 20 m^3/day to be a more cost-effective choice. The ADP should be chosen over a diesel system only if there is no labor cost for pump operation and the water requirement is over 25 m^3/day. The financial unit cost for bio-gas pumping is higher than for diesel for the entire pumping range considered.

Table 11 shows the unit costs when the following internally controllable conditions are changed:

- more efficient ADP fabrication with a reduction in materials costs from P4,900 to P1,000 and a reduction in fabrication labor of 20 percent;
- more efficient manufacture of bio-gas digesters, which is reflected in a cost reduction from P75 to P50 per cubic meter of digester; and
- training of sufficient crews so that the installation and servicing distances ADPs and bio-gas systems can be reduced by 50 percent.

These changes reflect the ultimate design goals of RIIC, which has developed ADP and bio-gas pumping systems for Botswana, to reduce costs through more efficient fabrication and train technicians throughout the country to build and maintain these systems. Of course, other changes may affect unit costs, such as use of other diesel engines or, for the ADP, the use of the pump owner's donkeys, which eliminate the cost of purchasing animals. The overall effect of these changes is to reduce ADP and bio-gas unit costs, specifically:

- the unit cost of bio-gas pumping is reduced by about 15 percent, almost all of which is due to reduced installation and service distances--this makes

m3/day	Diesel Output 5	10	20	30	Windmill Output 5	10	20	30	Solar Output 5	10	20	30	Grid Electric Output 5	10	20	:
Head 15m	.95	.55	.36	.30	1.49	.75	.37	--	Not Considered				Not Considered			
Head 30m	.99	.58	.38	.31	1.51	.75	--	--								
Head 45m	1.03	.60	.40	.33	1.52	.76	--	--								
Head 60m	1.08	.64	.42	.35	1.54	.77	--	--								

m3/day	Handpump Output 5	10	20	30	Biogas Pump Output 5	10	20	30	Animal Traction Pump Output 5	10	20	3
Head 15m	Not Considered				1.06	.59	.36	.28	1.31	.69	.38	.2
Head 30m					1.10	.61	.37	.29	1.38	.84	.42	.3
Head 45m					1.13	.63	.38	.30	1.41	.74	.41	.3
Head 60m					1.17	.65	.40	.31	1.46	.77	.42	.3

Notes: Changes in Standard Assumptions

ADP: 1. Material cost for fabrication reduced by P1000 (from P4900)
2. Labor in fabrication reduced by 20%
3. Installation and service distance reduced 50%

Biogas. 1. Price of digester is reduced to P50/cubic meter
2. Installation and service distance reduced 50%

Diesel: No changes

Windmill: No changes

Table 11. Private-Sector Applications -- Cost Variations due to Internal Factors

bio-gas cost-competitive for water demands in excess of 20 m^3/day for all of the heads considered; and

- ADP pumping becomes cost-competitive for all cases that demand 30 m^3/day--in a financial accounting, the ADP is cost-effective for all cases requiring 20 m^3/day.

The unit costs for windmills and diesel pumping do not change as all the assumptions stay the same as in Table 10. It is not surprising that the highest head/demand case is the first to become cost-effective for bio-gas pumping, as it requires the greatest amount of energy and fuel, and with 80 percent fuel displacement offers the greatest fuel savings. The ADP also becomes more cost-effective for higher demand levels. Water demand in the range of 20 to 30 m^3/day is not uncommon at boreholes used for watering cattle. The analysis indicates that if the target cost reductions assumed here can be achieved, these technologies can be cost-effective.

One of the largest concerns of private-sector pump users is fuel costs. If the cost increases by 10 percent annually above the rate of inflation, both diesel and bio-gas pumping technologies will be affected. The results of such a change are shown in Table 12 and may be summarized as follows:

- the increase in unit costs for diesel pumping ranges from eight to 17 percent; and

- the unit cost for bio-gas systems changes less than two percent.

The insignificant change in bio-gas pumping costs reflects the low volume of diesel fuel that is required when 80 percent of it is displaced by bio-gas.

If diesel fuel costs increase at a rate that is greater than inflation, clearly, the opportunity for cost-effective use of renewable energy pumping systems increases, such that:

- windmills are cost-competitive with diesels when 20 m^3/day is required and the wind speeds are sufficient to pump that amount;

- bio-gas systems are cost-competitive with diesel pumping when over 10 m^3/day is required; and

- the ADP is cost-competitive with diesel systems at demands of more than 30 m^3/day and similar in cost at more than 20 m^3/day.

m3/day	Diesel Output 5	10	20	30	Windmill Output 5	10	20	30	Solar Output 5	10	20	30	Grid Electric Output 5	10	20	30
Head 15m	1.01	.61	.41	.35	1.49	.75	.37	--	Not Considered				Not Considered			
Head 30m	1.06	.65	.44	.38	1.51	.75	--	--								
Head 45m	1.11	.68	.47	.40	1.52	.76	--	--								
Head 60m	1.17	.72	.51	.43	1.54	.77	--	--								

m3/day	Handpump 5	10	20	30	Biogas Pump Output 5	10	20	30	Animal Traction Pump Output 5	10	20	30
Head 15m	Not Considered				1.06	.59	.36	.28	1.31	.69	.38	.28
Head 30m					1.10	.61	.37	.29	1.38	.84	.42	.31
Head 45m					1.13	.63	.38	.30	1.41	.74	.41	.31
Head 60m					1.17	.65	.40	.31	1.46	.77	.42	.30

Notes: Additional changes in Standard Assumptions

Diesel: 1. 10% annual escalation in fuel cost
Biogas: 1. 10% annual escalation in fuel cost
ADP: No changes
Windmill: No changes

Table 12. Private-Sector Applications -- Cost Variations due to Internal and External Factors

It should be remembered that the conditions specified in these cases are extreme and there is some question about whether these cost reductions can be realized and how many cases there are where the assumed site distances exist. However, the analysis does point out the extent to which the basic assumptions for system capital and operating costs must change for any significant displacement of diesel systems to occur. Social, infrastructural and/or initial cost considerations are just as likely to affect pump choice as long-term economics.

3. Infrastructure

The large numbers of privately owned water-pumping systems and wide variation in service and repair practices make generalizations about the private sector difficult. Infrastructural arrangements in the private sector are quite complex. The equipment owners are sometimes also the pump operators. In many cases, owners are absent and hire operators to start and stop the engines. In most of these instances, it appears that the pump operators have little or no training in proper care of the equipment.

Engine servicing work is done by four major groups--BRS, formal private businesses, informal-sector mechanics and owners. In a few cases, equipment owners operate the engines and are fully capable of performing all maintenance, including engine overhauls. Some even maintain spare engines for emergency use. BRS is used by roughly a quarter of individual engine owners. Even though it is subsidized quite heavily, many consider it to be an expensive service option, which is at least partly due to a P80 standard charge for each service trip, not including parts. Many choose to perform service and repairs themselves or hire mechanics that operate in the informal sector. Mechanics who operate in this way are usually available on short notice and provide service at competitive rates. Very little field servicing is done by formal-sector entrepreneurs, as their prices cannot compete with either informal-sector mechanics or BRS. The formal private sector does perform workshop overhauls of equipment.

Although there is no definitive information, it seems clear that private-sector water-pumping equipment is generally less reliable than that operated by the government. The cost and intervals for engine overhauls performed by both BRS workshops and the private sector confirm that these engines are not well cared for. In addition, the expectation for diesel engine lifetimes in the private sector is considerably less. All this indicates there is significant room for improvement in the care and servicing of private-sector diesel engines.

Windmills are used in several areas in Botswana. Most of these cases are freehold farmers in the Ghanzi District and area south of Lobatse. Informal surveys of owners indicated that many are pleased with windmill performance, though there appears to be slow, but steady movement toward diesel pumps. When asked, all the owners indicated that they perform all their own servicing and routinely check their systems to be sure they are operating smoothly. All indicated that they had back-up diesel engines or could move their cattle to ensure that their livestock would be watered during extended calm periods.

Currently, all RIIC windmill, ADP and bio-gas pump servicing has been done from RIIC in Kanye, which results in long transportation distances to some parts of Botswana. If local technicians are trained to fabricate, install and service this equipment, these costs will be reduced and the response to system problems will likely be improved.

4. Conclusions and Recommendations

The characteristics of private-sector pump owners and operators, who are the largest users of small-scale pumping equipment, are neither as well understood nor well documented as they should be. In spite of the limited information that is currently available, it appears that diesel pumps are cost-effective for most pumping applications. In such a large and diverse group, there are bound to be some cost-effective applications for wind, bio-gas and ADP systems. The analysis given here is not sufficiently exhaustive to categorically eliminate the use of any pumping technology, but the difficulty at this stage is determining the scope for application of each type of pumping system.

However, it appears that windmills will have a limited role due largely to limited wind speeds, particularly during the dryer winter period. Both bio-gas and ADP systems depend on extensive user participation and careful control of fabrication costs to minimize the unit cost of water delivery. All are affected by the distance to service centers and number of service trips required. The longer term role that for ADPs and bio-gas substitution has not yet been fully determined. Clearly, as fuel costs increase, RETs become more attractive.

Diesel pumps will undoubtedly continue to meet the largest portion of the private sector's need for cattle watering. In the interests of reducing the costs of operating these systems and improving their reliability, a campaign should be undertaken to more fully inform users of the benefits of careful service and need for preventive maintenance. This could result in reductions in diesel fuel use and disruptions due to breakdowns. BTC has begun to put together such a campaign, and this work should be encouraged. This effort could include radio messages and handouts for each engine buyer concerning proper maintenance procedures and the possible financial costs of carelessness and breakdowns.

The lack of information about water-pumping practices for such a large user group needs to be addressed. Information about private-sector water users is vital to a fuller understanding of the potential for wind, ADP and bio-gas substitution pumping systems. MoA should conduct a survey as part of this efforts in its Division of Animal Production. This would more clearly characterize current private-sector use of diesel engines, and will enable effective efforts to address the needs of this sector and more accurately determine the potential for using alternative technologies. Since RIIC is most active in the development and promotion of water-pumping technologies that could have impact for this user group, it should conduct a comprehensive survey and assessment of the market for the technologies it is developing.

VII. CONSTRAINTS AND INCENTIVES

The constraints and incentives to the successful use of alternatives to diesel pumps include the obvious technical and economic issues detailed in the preceding sections. However, there are other concerns that will affect the choice of an alternative system, including local availability of equipment, infrastructure support capability for each alternative, credit arrangements, and perceived national interest. These are detailed in the subsections below.

A. Technical Limitations

The most obvious of the technical limitations are apparent from the tables included in Section VI. Among these is the practical limit of water delivery with handpumps. Handpumps can pump well over five m^3/day if in continuous use from morning until night. However, it is not likely that handpumps will be installed at sites in Botswana where the requirement is greater than this. Conventional handpumps utilizing piston pumps are also limited to pumping from depths of less than about 30 meters. Beyond this head, users complain of difficult pumping due to the cylinders used. The Mono handpump, and the Thebe pump currently being refined by RIIC, have the capacity to pump from deeper water levels. With these technologies, the limit appears to be 75 to 100 meters for almost all boreholes in Botswana. ADPs are also limited by the pumping rate that can be achieved by the maximum number of animals that can be used. ADPs can pump at high rates from shallower boreholes, and yield limitations are likely to be the limiting factor in these cases. The pumping rate and the practical limit of the number of operating hours determine the limit on the daily output of handpumps and ADPs.

For windmills, the maximum rotor diameter available, pumping head and wind speed limit the ability of the technology to pump water. The largest locally available windmill is just over six meters. Average wind speeds range up to just over four m/s at a few selected locations, with the national average closer to three m/s. Seasonal fluctuations in wind speed may also contribute to limited usage. The winter dry season is normally the period with the lowest wind speeds. Rest-water levels are commonly in the range of 30 to 80 meters. In addition, well yields become an issue because windmills pump the most water during high winds. However, the pumping rate during these periods may exceed the borehole yield. Care must be taken so that the pumping rate does not exceed the borehole yield and damage the pump. If a borehole is found that can handle the peak pumping rate of a windmill, there is likely to be pressure to increase the average water delivery by selection of another technology such as diesel. When windmills are used, additional water storage may also be required to ensure availability of water.

The technical limitations of solar pumping systems include equipment capacity. Currently available submersible PV pumping systems are limited to less than 1.5 kW. Larger Mono pumping systems are possible when batteries are included. However, this adds to system complexity and cost. Fortunately, Botswana's solar resource is good, in the range of 20 MJ/m^2/day, and consistent throughout the year. However, the need for short-term water storage at some sites may be a limitation due to the additional cost of storage.

A less obvious technical limitation is the inability to precisely predict day-to-day performance. This is more true of solar and wind pumps than other systems. For windmills, it is necessary to know the average wind speed at the proposed site. A wind resource study has been completed (Larsson, 1986) and there is a generalized understanding of average wind speeds. However, the fact that the water delivered is so sensitive to wind speed means that accurate prediction is difficult. Even if site wind speeds are well documented in a statistical sense, prediction of day-to-day windmill output is not possible due to daily wind variation. It is possible to predict, if site wind speeds are accurately known, the average performance of windmills using reciprocating pumps for average wind speeds above two m/s. For the Motswedi driving a Mono pump, the predictive tools are just now being developed.

For solar photovoltaic pumps, the major problem has been that manufacturers' predictions have been overly optimistic. The Grundfos solar pump, the most reliable of the submersible solar pumps tested, requires an adjustment to the pump curves provided by the manufacturer to allow reasonable output prediction and system sizing. The manufacturer appears to overestimate performance by about 10 percent. The sizing algorithm for Mono systems with Mono controllers is not well defined. The manufacturer has not provided a consistent, easily used algorithm for system choice. Mono pumps with batteries depend on an accurate estimation of the subsystem efficiency. Due to their constant motor and pump speed, this is easier than for systems that use the Mono controller.

It is not possible to confidently predict the daily performance of solar and wind pumping systems due to

- uncertainty of the energy source on a day-to-day basis;

- lack of data on long-term average energy availability at the site in question (for windmills, particularly because the variability is high);

- incomplete and/or inaccurate data on borehole yields and drawdowns; and

- lack of easily used, accurate, manufacturer-produced system-sizing algorithms.

This means that systems must be oversized to allow for errors in assumptions and design procedures. Such oversizing has been common for diesel pumping systems due largely to the conservative treatment of borehole data. This increases the cost of pumping systems. For diesel engines, cost per additional kW is not high (from P400 to P1,500 per kW). However, the increase is particularly high for solar pumps (P12,000 per kW) because of the high cost of solar modules.

When daily water demand increases over time, due to growth in a village, for example, diesel engines can, in most cases, be operated additional hours to satisfy the demand. This flexibility is a major advantage of diesel pumping systems (and other systems with this characteristic as well). Windmills have no capacity to increase performance to match increasing need. To increase the average daily water output, a larger windmill is required. Solar pumps have some flexibility in that the array can be enlarged to provide additional energy. In some cases this may require system redesign and additional expense. Flexible response to growth in demand is an important selection criterion in such situations.

The lack of knowledge about the long-term performance of aquifers limits the effective use of all pumping technologies. This is particularly true for electrical pumping systems. If overhead lines are to be brought to a borehole, there must be some assurance that long-term sustainable yields are sufficient to justify their expense. Power-matching factors are very important for accurate sizing of solar and wind systems. Proper yield and drawdown information is important for accurately determining pumping head to keep costs to a minimum. In addition, for these systems, the peak pumping rate is likely to be significantly greater than the average rate (except for Mono pumps with batteries). It is important to be certain that the boreholes will yield water at peak rates.

Although the Lister-Mono pump configuration is flexible, current design practices dictate that systems be over-designed to ensure that demand can be met. This over-design takes place because the designer must assume the maximum possible pumping head condition. This assumption often results in larger engines than required, lower loading conditions, and inefficient systems. These will be more expensive than necessary to purchase and operate. DWA is currently engaged in a program to improve test pumping, which will allow improvement in design and operation of all pumping technologies.

B. Market Size and Availability

There are currently about 5,000 equipped boreholes in Botswana. New boreholes are being equipped at the rate of 100 to 150 per year (including both public- and private-sector cases). At present, diesel engines are being installed on almost all of these. Windmills have been in use for some time, and it is estimated that between 200 and 250 have been installed. Fewer than 20 solar pumps and fewer than 50 handpumps are in use. Only five ADPs and three bio-gas plants are being used for pumping applications. Windmills represent less than five percent of all installed pumping systems, and all other alternative pumping technologies an additional two percent. Clearly, the past market for alternatives to diesel pump sets has been small.

For a pumping system to be a candidate for purchase, it must be locally available and readily serviceable. The willingness of pumping equipment distributors and dealers to support products is a function of the market. The market for Lister engines and Mono pumps in Botswana is well established. It appears that the market for higher speed diesel engines is growing, as a result of the lower initial cost and growing availability. For other technologies to receive adequate support from local dealers, there must be a demonstrated market for the equipment. Efforts to establish the Motswedi as a privately manufactured windmill have met some resistance because future sales are uncertain. Government intervention in the form of demonstrations and information dissemination regarding appropriate technologies may help in establishing a market for technologies unknown to the private sector. The proposed RIIC pump market study should assist in identifying potential markets, if they exist, for bio-gas pumps, ADPs and windmills.

Intervention in the form of government tenders for equipment and support of local companies can help convince suppliers that markets exist within the public sector. However, such efforts must be considered carefully as market limitations are often indicators of resistance to a technology for valid technical, economic or social reasons. If this is true, the intervention will not substantially contribute to the continued use of the targeted technology.

C. Training

Successful use of any technical equipment requires a variety of skills, including design, installation, operation and servicing. For currently used technologies, appropriate training programs are in place.

DWA already has offers a curriculum and series of courses that provide skilled individuals for the department, District Councils and private sector. The latter is not so much by design, but because some individuals choose to leave government service. DWA runs three levels of trade tests for borehole mechanics and engine technicians, each lasting from five to 15 weeks. SALister and Mono pumps (Africa), who provide much of the pumping equipment, assist by providing training materials and teaching some short courses. Testing and certification follow each of the courses. Promotions and increased salaries generally accompany successful completion of the courses.

Many professional-level Batswana receive degrees abroad as a result of donor programs financed by USAID, SIDA and ODA. With donor assistance, out-of-country short-term training is available for technicians and professional staff in a variety of locations from Italy and France to Malawi and the Republic of South Africa. This training covers all aspects of DWA activities from hydrology and remote sensing to water system design and pollution control.

As new technologies are introduced, it is important that training programs be developed and implemented. Teaching of the requisite skills must be included in the existing curriculum or separate courses must be available. If separate courses are offered, they must be formally accepted as qualification for advancement as is the case for diesel systems. The duration and cost of training will depend on the technology and on manufacturer and/or donor willingness to participate in course development and instruction. The remainder of this section discusses in general terms the training needs that will exist if new technologies are introduced.

Windmills, handpumps and ADPs are mechanical systems that should require a minimum of training. Training for use of these technologies can build easily on existing mechanical knowledge. The Climax division of Stewart and Lloyds has informally agreed to assist by offering a one- to two-week course in windmill installation and repair. RIIC should provide training to private-sector service personnel so that ADPs can be serviced at the local level. This would decrease the duration of breakdowns, should they occur, and reduce overall costs by lowering transportation costs. DWA or the District Councils should organize training sessions on the installation and maintenance of handpumps. However, if the Mono handpump is to be used extensively, Mono Pumps (Africa) should be approached to assist with training courses.

The skills required for successful use of bio-gas substitution pumping will include basic mechanical skills and some understanding of the chemical processes of anaerobic digestion. RIIC should organize training to build on existing knowledge and teach the necessary additional skills to service crews and operators. In addition, bio-gas construction techniques should be taught to others so that the high labor and transportation costs of handling construction from the RIIC base at Kanye can be avoided.

Both solar pumps and AC-interconnected electrical pumps require some knowledge of electrical theory and motors. DEE conducts training courses in electrical equipment installation and servicing. However, at present, these do not include courses specifically directed to the need for technicians familiar with photovoltaic systems. For solar PV pumping systems, training will need to go beyond the electrical aspects and cover such issues as array orientation, module shading, and the more complex troubleshooting procedures necessitated by the output rates of solar pumps under varying solar conditions.

It is clear, from the present state of diesel engine care and servicing, that although training courses are in place, there continues to be a need for upgraded training--particularly in the private sector and for pump operators. Diesel systems have more complex day-to-day maintenance requirements than the others examined. They contain more moving parts and require more frequent servicing. Although DWA has training courses in place and is conducting these courses, additional efforts in the form of refresher courses and/or greater field supervision should be considered, particularly for pumpers. The private sector could also benefit from an information campaign directed at informing engine owners and users of the need for preventive maintenance.

The extent of training offered in the use of new technologies will depend in some measure on the anticipated future use of these systems. The cost of extensive training efforts cannot be justified for the installation and servicing of a handful of systems. The effort required to develop a training course, organize the logistics, and arrange for proper certification for attendees should not be underestimated. Efforts at organizing a training program for solar pump technicians has been underway for over a year, after a formal request was made by the water engineer at MLGL on behalf of the District Councils. There has been little movement to date due largely to the inter-ministerial approvals required. The cost and extent of training required to keep systems operating in the field need careful consideration during the process of technology selection.

D. Transportation

Transportation costs are clearly a part of the overall cost of pumping system use. They have been included in the financial and economic analysis. However, availability of transportation has been mentioned only in passing. This issue, not easily accounted for in an economic analysis, is clearly an important parameter in reliable pumping system operation.

The District Council Water Units currently have adequate transportation facilities. This is due in large part to the funds made available over the past several years through SIDA and EEC support programs. Issues of servicing and repair of vehicles are at least as complex as for diesel pumping systems. The problems in some districts are more acute than in others. It has been suggested that private-sector repair shops be used to help ensure vehicle availability. There has been resistance to this from district officers who feel a need to use district facilities. Standardization of equipment (Toyota) has been an important component in minimizing equipment down time. Recently, due to equipment source constraints, EEC funds have been used to purchase Mercedes and Land Rover vehicles It remains to be seen whether spares and servicing will limit the usefulness of these vehicles.

At DWA, and particularly for BRS, transportation availability remains a problem. All repair and servicing of vehicles is performed by the Central Transportation Organization (part of the Ministry of Works) and its priorities are often different from DWA's. There has also been some difficulty in obtaining spares for the Swedish Scania trucks used extensively by installation crews and the Drilling Section. The Scanias were procured with Swedish "tied aid" funds. The field offices of BRS use Bedford and Toyota trucks for the most part. They have been particularly hard hit by transportation difficulties. During the 1984-85 fiscal year, 97 vehicles were taken out of service and only 56 replaced. Vehicle availability was in the range of 60 percent. This severely constrains the BRS from performing effectively, particularly where servicing and nonessential repairs are involved.

Concerns about transportation availability are a factor in the pumping system selection process. Part of the impetus towards pump electrification is the perception that the number of service and repair trips to boreholes could be reduced. The servicing of diesel engines is transportation-intensive relative to most of the pumping technologies considered. This is due not only to the service and repair requirements, but also the need to deliver fuel. This constraint on diesel engine use favors the alternatives.

E. Financing

Within the public sector, funds for water supply projects are available through the recurrent budget, the development budget, or from donors. These funds must be approved by the Ministry of Finance and Development Planning. Financing for the purchase and installation of equipment tested under CWPP was provided through donor assistance--largely USAID via the BRET project--and through Government of Botswana development funds. SIDA funded the purchase of four additional solar pumps and a number of handpumps. The French Embassy also provided four handpumps.

Donors are heavily involved in funding and providing technical assistance for major government programs in the water supply sector. SIDA has traditionally been the major donor, assisting with the Village Water Supply Program, water supply rehabilitation and extension, the water hygiene campaign, training, and other special studies such as a tariff study, a design manual and development of a national water master plan. Other donors are also involved. An example is the Lutheran World Federation, which has participated in funding and implementing water projects for rural villages. The German Bank for Reconstruction (KFW) is assisting with efforts in the redesign and upgrading of four major-village water supply systems. Execution of the first of these projects (Palapye), funded by EEC, is just beginning and will include electrification of the well field. The activity of such donors in assisting Botswana to move towards reduced dependence on diesel fuel is a factor in the potential for alternatives to diesel pumping.

The willingness of donors to assist in funding water system design and installation is a major determinant of which activities are pursued. Normal donor reluctance to fund recurrent cost items favors the use of technologies that minimize these costs (e.g., diesel). This has hindered the use of more expensive technologies that might offer the advantage of delivering water at lower unit cost.

Private-sector water supply activities are largely in support of cattle watering. The sale of cattle can and does play a significant role in funding these systems. Loans for borehole drilling and installation are available from the National Development Bank (NDB) or normal bank loans. The prevailing NDB interest rate for borehole equipping is 12 percent, and a normal bank loan is somewhat more expensive. Some farmers can take advantage of loan and grant programs administered by MoA. Funds from these programs can assist lower income farmers or organized syndicates to install pumping equipment. Loans and/or grants to replace equipment are harder to obtain.

To date, the NDB, which handles most of the loan activity for pumping equipment, has only funded diesel systems. They appear interested in RETs but remain reluctant to lend funds for technologies that remain unproven over the long term. This is particularly true for equipment that is significantly more expensive than diesel. Heightened awareness and long-term demonstration are valuable in convincing lenders of the viability of alternative pumping systems.

The MoA programs have been more adventurous as they perceive their role to include technology demonstration and increasing user awareness of pumping alternatives. Purchase and demonstration of ADPs and the Thebe handpump have been initiated by the Communal Areas Management Unit of MoA. The longer term technical and economic success of these demonstrations is likely to have a significant impact on future system use.

Direct government intervention by way of subsidies and/or duty on equipment is limited. There is a five percent duty and 15 percent Customs Union surcharge on photovoltaic modules imported into Botswana, which increases the price for the private sector. Diesel fuel is available for off-road use with a duty level of about one percent, and of six percent for road use. Private borehole owners appear to use road-duty fuel as it is easier to obtain. BRS is heavily subsidized and passes some of this subsidy along in the form of low charges to ts subscribers for service calls.

The electricity tariff is high, as the energy-intensive mining processes at the Selibe-Phikwe mine are subsidized through the tariff structure for its remaining customers. The high tariff discourages the use of electric pumps.

F. Strategic Considerations

Botswana is a landlocked country. Its major trading partners are those within the Southern Africa Customs Union. More than 75 percent of all imports come from within the Customs Union, with the Republic of South Africa being far and away Botswana's largest trading partner. The major supply route to the ocean and most other trading partners is via rail to the South African port at Durban. Botswana recognizes the need to reduce its vulnerability to events outside its control. Furthermore, NATIONAL DEVELOPMENT PLAN VI (p. 21) states that the "volatile socio-political conditions in the region pose a constant danger of instability affecting Botswana's economy." Botswana currently enjoys a large budget surplus. This provides a measure of security to the nation and allows the government to undertake development activities. However, foreign exchange earnings are dependent on export of a limited number of commodities whose prices are fixed by forces beyond Botswana's control. For example, diamonds represented more than 70 percent of the country's export earnings in 1984. Botswana is also susceptible to periodic drought conditions. The current drought cycle is in its sixth year. Drought conditions are felt most acutely in the poorer rural areas of the country. Water supply and supplemental feeding programs become major issues under these conditions.

The government's awareness of the vulnerability of water supplies was a major factor in the exploration of alternatives to diesel engines. The day-to-day situation over the past several years appears reasonably stable; availability of fuel and spares has not been a major factor. However, this may not continue to be the case. Botswana's strategic concern is to be as prepared as possible if and when conditions change. This preparedness may require decisions to support activities that do not currently appear economically justified. Already, efforts have included electrification of boreholes in major villages in order to utilize an indigenous coal resource. The country's strategy is also likely to include support for some solar pumping activities, expanded use of handpumps, and continued support for ADP development.

VIII. CONCLUSIONS

The analytical work of CWPP has yielded a number of conclusions about the costs of water pumping with standard diesel systems, as well as the potential for displacing diesels with other conventional and RET-based pumping systems. These conclusions are based on an analysis of both measured and estimated technical performance, cost, institutional and social parameters, and a series of sensitivity analyses to determine the impact of certain necessary assumptions. The conditions and assumptions upon which the analysis is based are not static. Changes in the economic climate worldwide and/or economic alignments in the southern Africa region may change these conditions and assumptions to favor other pumping options for a particular situation. The analysis takes into consideration the stated policy goals of Botswana's NATIONAL DEVELOPMENT PLAN VI. To briefly reiterate, within the water supply sector, these goals include:

> To continue the development of new village water supply schemes and extension of existing schemes.
>
> To plan for the medium and long term water requirements of Botswana, taking into account all potential demands.

The plan further states:

> In determining its resource allocation and pricing policies for the water sector, the Government has to consider equity, efficiency, and affordability. Equity demands that all Batswana should, as soon as possible, have access to safe water. Efficiency demands that users should not be encouraged to waste what is, in Botswana, a scarce and expensive resource; that schemes should be cost effective; and that they should be properly maintained. The criterion of affordability recognizes that resources available to the sector are limited: this has implications for cost recovery, for gearing capital investment to sustainable recurrent costs, for standards of provision, and for the definition of Government's role in the sector.

The plan also states policy guidelines and specific policy objectives for the energy sector:

> The assumption underlying policy and planning in this sector is that although market forces have an important role to play, simply leaving them to

balance supply and demand is inadequate for various reasons. These reasons include:

Both the potential for economic development of indigenous energy resources and strategic considerations must be explicitly considered.

In the cases of certain forms of energy, Botswana is heavily dependent on imported supplies and is vulnerable to disruption of imports.

Specific policy objectives in the energy sector include the following:

To maximize the use of viable indigenous energy resources and, wherever possible, minimize dependence on imported sources of energy.

To minimize dependence on imported oil and oil products, particularly because of the potential for interruption of normal supplies, but also because of the expected long term rising price.

This section discusses the major conclusions of the work by technology and considers each within the framework of the user groups discussed in Section VI. Conclusions and recommendations take into account not only the strictly technical and economic issues examined in detail in these reports, but also the stated water-sector and energy policies indicated above.

A. Diesel Pumps

There is no doubt that diesel pumping systems will continue to dominate water lifting for all user groups. The unit water cost for delivered water is lower than for almost all other system options considered when the water requirement exceeds five m^3/day. When the requirement is five m^3/day or less, handpumps become the least-cost option. In addition, the service infrastructure is much more developed than for any of the other possible equipment choices. Equipment standardization, while contributing greatly to the strength of the existing diesel-pump support infrastructure, does have its drawbacks in terms of appropriate engine choice and promotion of competition. To a large extent, these drawbacks are compensated for by the following advantages: familiarity of design engineers, technicians and users with the equipment; spares availability and minimized inventories; and straightforward system design--all of which have contributed to reasonably reliable water delivery. Both the formal and informal sectors are fairly responsive to the needs of diesel systems.

It is clear, nonetheless, that there remains considerable room for improvement in diesel pump use, including:

- more attention to system design and engine loading, possibly leading to introduction of smaller engines if possible;

- more careful management of installation labor and transportation costs in the public sector and greater attention to preventive maintenance, contributing to cost reduction and system reliability;

- improved capacity of larger District Water Units, with additional training, particularly for pumpers, to help improve reliability; and.

- for the benefit of private-sector engine owners and users, heightened awareness of the service requirements and costs, both financially and in reliability, resulting from poor maintenance.

The economic cost of water delivery with diesel pumps is relatively insensitive to many factors internally controllable in Botswana. However, unit water costs do increase dramatically with decreasing water requirements, making diesel systems relatively expensive pumping choices for small villages and settlements. The use of full-time pump operators and the often long distances from borehole sites to installation service centers magnify these costs. Diesel pumping systems are more vulnerable than any RET-driven pumping system to disruption of fuel supply.

From a strictly economic standpoint, even a significant escalation of diesel fuel cost as a result of shortage does not automatically make other alternative systems attractive. However, the uncertainty associated with future fuel availability strongly suggests that a strategic decision to promote alternative pumping systems is sensible.

There are opportunities to reduce water supply costs, diversify energy sources, and decrease (however slightly) excessive dependence on imported oil products, given current circumstances. For example, one strategy that would help achieve these goals is the encouragement of wider handpump use in rural areas. Where limited amounts of water are required, handpumps are a considerably less expensive technology. There are also limited opportunities to use other renewable-energy pumping technologies. The following sections summarize the conclusions drawn with respect to alternatives to diesel pumping, and describe the circumstances under which each becomes cost-competitive with diesels.

B. Grid-Electric Pumps

It is somewhat surprising that electric pumping systems are not more cost-competitive with diesels. Electric pumping was not economically competitive (for the heads and outputs considered) for any major user group, given the standard assumptions. This is largely due to the magnitude of electricity tariffs and the need (at nearly all potential sites) to purchase overhead lines for connection to the electricity mains. Only where the interconnection costs are negligible does the use of electric pumps become cost-competitive with diesel at the heads and demand levels considered here. The current extent of electricity mains severely limits the potential for using electric pumps in all but a few of the major villages. If two kilometers or more of overhead lines must be installed to connect the borehole to the mains, then electrical pumps become cost-effective only for much larger water demand cases than those considered by this project.

A second major constraint to the widespread use of electric pumps over the near term is the lack of trained technicians to provide technical support in Botswana.

Finally, because electric submersible pumps are very susceptible to variations in the water table, electric pumps should not be considered unless there is some certainty that the long-term borehole yield is sufficient. Currently, knowledge of both seasonal and long-term variations in aquifer performance is fairly limited, particularly for rural areas.

The potential for reducing dependence on imported diesel fuel and substituting local coal resources by using electricity from the Morupula power plant is an attractive incentive for expanded pump electrification. However, in the near term, use of electric pumping systems will be limited to a few major village systems. Extension of the electricity mains network will increase opportunities.

C. Windmills

Due to the relatively limited wind resource, and to the moderate-to-high pumping heads experienced in most of Botswana, water delivery from even the largest windmills is fairly limited. As a result, Botswana is not likely to have widespread applications for windmills. The existence and continued use of windmills in some areas attest to the localized nature of the perceived cost-effectiveness of windmill use. These are generally low-head cases where 10 to 20 m^3 per day can be delivered reliably.

Over the past several years, a considerable sum has been spent on wind resource evaluation, windmill development, and windmill testing and evaluation. There have been benefits beyond the equipment developed and the information gained. However, unless an unmistakable market for windmills can be demonstrated, it is not clear that additional efforts in this field can be justified. When the occasion arises, suitable equipment can be procured from outside Botswana at little cost to the economy. Windmills will be cost-effective compared to diesels only under conditions where:

- pumper labor costs are negligible;
- wind speeds during the design month are greater than 3.5 m/sec;
- heads are moderate (15 to 25 meters) and demands are in the 10 to 20 m^3/day range; and
- at fairly remote sites, reduced maintenance requirements can generate operation and maintenance cost savings relative to diesels.

There are very few sites where these circumstances occur together in Botswana. Pumper costs will be low only where the pumper's salary can be spread over other activities (such as at other government installations), or in the private sector where wages are quite low and there is no formal requirement for full-time pump attendants.

D. Photovoltaic Pumps

There has been more interest in photovoltaic-driven pumps than in any of the other technologies considered. This has been due largely to the belief that these systems hold promise for cost-effectively meeting future pumping needs by displacing fossil fuel use. The performance testing and economic analysis performed during the project indicate that this potential has not yet been realized for most conditions found in Botswana. Unit water costs are higher than initially anticipated due to:

- lower efficiencies than claimed by manufacturers;
- unanticipated problems with module breakage due to vandalism; and
- the strong effect on unit costs of the current public-sector pumper employment policy.

Some manufacturers claimed pump set efficiencies as high as 50 percent. Measured efficiencies for well-matched systems were typically only 32 percent. Module breakage is seldom if ever mentioned in the comparative economics of solar pumps; however, module breakage can easily add 20 percent or more to the recurrent costs of PV pumps. The current government requirement for a full-time pumper at every borehole negates one of the greatest advantages of PV pumps--their capacity for unattended operation. Finally, diesel pumping costs are lower than originally anticipated. These observations currently limit the potential of PV pumps.

PV pumps will be cost-effective compared to diesels in Botswana only under circumstances where:

- pumper labor costs are negligible, or where pumps can or must run unattended (such as wildlife watering boreholes);
- heads are low to moderate heads (10 to 30 meters) and demands are in the 10 to 30 m^3/day range;
- module breakage is kept to a minimum (on the order of one module per system every three years);
- field-proven equipment is used, not merely prototype equipment with the potential for higher performance;
- at fairly remote sites, greatly reduced maintenance requirements can generate operations and maintenance cost savings relative to diesels; and
- PV module prices in Botswana more closely reflect current internationally quoted prices.

Other possible changes that would obviously affect the economic viability of solar pumps include increases in diesel fuel prices and increased pump system efficiency, and policy changes in pumper requirements. The standard module prices (which typically represent about 80 percent of the system cost) used in the economic analysis in this report were P670 per module, or P12.64/Wp (per peak Watt). Recently solicited quotes for large quantities (200) of modules delivered in Gaborone are on the order of P8.75/Wp, a reduction of over 30 percent. This obviously has a significant effect on unit costs.

PV pumps also hold the most promise for diversification of energy source for rural rural villages and government camps where more than five m^3/day of water are required. Although under the present assumptions of this analysis the government policy goal of cost-effectiveness compared to diesels cannot be met in most cases, the energy goal of minimizing dependence on imported fuel can be addressed. For these reasons continued activity in solar pumping is recommended. These activities should include continued monitoring of the currently installed solar pumps, installation of a limited number of pumps at low-head sites, and development of a training curriculum in photovoltaics and photovoltaic use.

E. Animal-Drawn Pumps

ADPs have the potential to pump 20 to 30 m^3/day under conditions controllable at the local level with no reliance on diesel fuel. This alone makes examination of the ADP important. However, it is clear that the applications are limited to private-sector cases due to higher labor costs for this "participatory" technology. Although there are private-sector cases where the ADP appears to be an attractive pumping choice from an economic perspective, the assumptions made for the ADP are not well documented due to limited cost data and limited experience with the few systems installed to date.

The organizational, management and logistical requirements for use of ADPs are also factors in the pumping system's potential. These factors must be understood more completely in order to fully evaluate potential. In addition, it is clear that the fabrication cost of the device must be kept to a minimum. Although the unit delivered cost of water is marginally less than for diesel systems in the 20 to 30 m^3/day range, the incentive for adoption of these units may not be sufficient, especially if the initial cost of the unit remains high (currently several times the cost of a diesel engine). In summary, ADPs will be cost-effective alternatives to diesel only where:

- the pumper charge is negligible (only in the private sector);
- the necessarily participatory nature of the technology is addressed by well-organized management of system operation;
- output is above about 25 m^3/day for the entire range of heads considered; and
- construction costs are reduced to at least 20 percent below the current cost of prototype systems.

A carefully monitored program in ADP development is justified by strategic considerations of potential diesel fuel displacement. A more careful study of the financial, economic and social issues should be included.

F. Bio-Gas Substitution

As with ADPs, the bio-gas substitution system will have its greatest application in private-sector use as a result of the participatory nature of its operation. However, unlike the ADP, the design being promoted in Botswana must still rely on diesel fuel and the service network for diesel engines. The engine burns a combination of diesel fuel and bio-gas, so some percentage of the diesel normally used is displaced by bio-gas. As such, the cost of construction and operation of the bio-gas component of the system must be paid for in reduced fuel consumption over the life of the system. The analysis conducted indicates that this is only likely to be the case where:

- the maximum diesel-fuel displacement occurs 'at high energy requirements);
- the pumper charge is negligible (only in the private sector, usually);
- the participatory nature of the technology is addressed by well-organized management of system operation;
- output is above about 25 m^3/day for the entire range of heads considered; and
- a concentrated, easily accessible source of animal dung is available.

The potential of these systems to displace diesel fuel use is greatest in those cases where fuel consumption is greatest. This is evidenced by the converging unit costs of diesel and bio-gas as the water requirement increases.

As with the ADP, actual cost information and field operating experience with these systems in Botswana is limited. Reduction in construction costs for the digester can have an effect on the economic evaluation of the system. Also, the participatory nature of the device (collection of the dung, etc.) and the logistical and organizational requirements will limit the system's acceptability.

The Botswana Energy Master Plan concludes that support should be provided for bio-gas activities. These conclusions are based on assumptions about optimum digester size and fuel displacement potential. The plan concluded that systems designed to provide water for 900 cattle (roughly 600 livestock units) during the dry season may be economically attractive at heads greater than 30 meters. Six hundred livestock units will require in the range of 30 m^3/day during the dry season. Both the above plan and CWPP's work indicate that the economics of bio-gas use solely for cattle watering is less attractive as water requirements decrease. There is as yet no good estimate of the number of privately owned boreholes that pump more than 30 m^3/day, and thus could be considered reasonable candidates for bio-gas use.

CWPP was restricted to examination of the use of bio-gas for water pumping. Continuation of bio-gas activities may also be justified by petrochemical and wood fuel replacement when uses other than water pumping are considered.

G. Handpumps

The most unequivocal finding of CWPP is that for those situations where handpumps can meet the water requirement (about five m^3/day at less than 50 meters head), they are the least-cost pumping choice by a wide margin. In addition, the use of handpumps alleviates the need for reticulation and water storage. Handpumps also reduce the need for diesel fuel and the transportation of that fuel to the pump site. The cases where handpumps can be used cost-effectively include sites primarily in settlements and small villages with populations of less than 200. In addition, handpumps should also be considered for use in areas with scattered rural dwellings. As a result of their low cost, handpumps also have a potential role to play as back-up units for diesel systems in cases where the borehole is not far from the village.

The typically low water delivery rate (500 l/hr or less) makes handpumps a suitable choice for low-yield boreholes, provided the boreholes are easily accessible by users. Current DWA policy of seeking boreholes well outside the bounds of villages (at least one km) reduces the potential for handpumps on many existing boreholes, as the walking distance would discourage handpump use. Modification of this policy (along with a campaign to educate villagers about the causes and dangers of water source contamination) should be considered for small settlements.

IX. RECOMMENDATIONS

Based on the conclusions summarized in Section VIII, this section makes a series of recommendations about future activities in support of pump technologies. The first subsection covers general recommendations; the others are grouped by technology.

A. General

DWA should establish a water pumping unit within its Design and Construction Division. This unit should have the capability to perform limited field research and evaluation tasks, and to analyze the results of such evaluation from technical and economic perspectives. It is recommended that the computer modeling tools developed under CWPP be the primary instrument for this continuing evaluation. The technical and economic assessment of pumping systems, and determination of the impacts of changes in pumping policy or practices, are complex, yet they are critical to the cost-effective selection and management of water supply systems. Evaluation of possible pumping options should be part of the design process, and suitable evaluation procedures should be both readily available to and well understood by system designers.

The current pump evaluation work should not be regarded as complete with the publication of this series of reports. As technology development continues, long-term operation and maintenance costs become better quantified, and the costs of system components and fuel change over time, new water choices may be appropriate. DWA's water pumping unit should be responsible for continuing to update and upgrade the data to help refine the pumping system design process, allowing the government and private sector to make more cost-effective decisions about equipment choice and operation and maintenance practices. It is important to remember that economic parity of unit costs is not a sufficient condition for adoption of new and possibly unfamiliar technologies. There must be significant economic and/or other advantages to justify their introduction and use.

The initial tasks of the water pumping unit should be to:

- conduct further monitoring and evaluation of the cost and performance data for a wider range of diesel pumps, and promote cost-reduction strategies derived from this report and those examinations;
- monitor international developments in the cost of and technology advances in photovoltaic pumping technology;

- participate in the development of reliable solar pump design procedures (based on the model developed during CWPP); and

- participate in and encourage the introduction and ongoing monitoring and evaluation of handpumps.

This unit should be staffed by three to five individuals. The activities of the unit should be guided by the principal water engineer (Design and Construction Division). Close working relationships should be maintained with other ministries and government organizations that could contribute to or benefit from the activities of the water pumping unit. Periodic reports on the unit's activities should be made available to interested parties.

Since so much depends on the location of suitable boreholes with known characteristics, it is recommended that test pumping procedures be reevaluated. Test pumping practices should more closely follow the procedures that have already been established by DWA (but are not always carried out in practice). Although it is clear that test pumping is expensive, there is little doubt that myriad difficulties arise from inadequate understanding of aquifer performance, borehole yields and drawdown characteristics. Many of these difficulties (e.g., pumping systems incapable of meeting demand, and increased pump maintenance costs) stem from the inability to properly design pumping systems because of inadequate borehole data. Incomplete data also make the design of solar pumps very difficult (since their output is so dependent on head), and the specification of electric pumps in general and submersible pumps in particular, inadvisable.

B. Diesel Pumps

It is recommended that policies be changed and effort made to reduce pumper cost for public sector water supplies. This will have a significant impact on pumping costs. The use of half-time pumpers should be possible in many rural villages where the water demand is low, thus hours of pump operation and servicing of the pipe network and standpipes are relatively limited.

There are additional efforts that can reduce diesel pumping cost. Design procedures should be modified to allow the operation of diesel pumps at a higher loading level. This will result in the selection of more appropriately sized engines in many cases. An examination of the possibility of using smaller engines to improve loading and reduce fuel consumption for some cases should be undertaken. These two initiatives can reduce fuel use and operation and maintenance costs.

It is further recommended that additional support be provided to the Construction Section to allow improvement in the organization and scheduling of borehole installation so that costs can be reduced. With the help of the water pumping unit, installation and operation and maintenance costs should be more carefully monitored and analyzed. Increased emphasis should be placed on pumper training at the District Council level and for other government agencies, particularly as regards proper reporting of faults. This training should be the responsibility of DWA's Training Division, with sponsorship of participants by other ministries.

Efforts to control costs within the private sector should include a survey of current pumping practices and costs for stock watering and irrigation. This survey should be conducted under the auspices of MoA. It is also recommended that the BTC initiative to inform private-sector diesel pump owners/operators of the effects of service practices and costs be supported. These efforts can assist in increasing reliability and reducing long-term costs of pumping within this sector.

C. Grid-Electric Pumps

It is recommended that, due to electricity mains extension costs and unconfirmed aquifer performance, pump electrification projects should proceed with caution. However, the stated policy goal of reducing dependence on diesel fuel for water pumping suggests that continued efforts towards pump electrification should continue since the use of electric pumps in major villages represents the largest potential for diesel fuel displacement at present. Pump electrification should be limited to major villages where aquifer characteristics are generally well known and electrical power is available. Most major villages that fall within this category have already started on this course. A more complete test pumping program is needed before active pump electrification plans are justified. Donor assistance should be sought in support of these programs, particularly to cover electricity mains extension. The mechanism for electrical equipment service and repair must be clearly established. The establishment in DWA of a unit of electricians seconded from DEE should be considered.

Pump electrification for rural villages should not be actively undertaken at this time, as the economics of such programs appear to be marginally viable, unless the utility interconnect distance is very short and interconnect costs are negligible. Such situations are currently rare, but when they occur, electrification should be considered.

D. Solar PV Pumps

There are currently about 20 solar pumps in place, with at least four more to be installed in the near future. At present there are not a sufficient number of trained technicians to service any significant increase in solar pump installations. In addition, the economic analysis does not favor photovoltaic pump use under most conditions at current tender costs. However, solar pumping (along with handpumps) is a promising new technology allowing diversification of energy sources for rural areas, and international PV module prices have dropped well below current tender costs.

It is recommended that the proposed water pumping unit continue to monitor the existing PV pump installations to gain more experience and confidence with the technology and to collect further information on recurrent costs and reliability. The unit should also establish contacts within the industry and with solar pump users to allow evaluation of technology changes and monitoring of price changes for equipment. Further work in system design (specifically for the Mono pump systems) should be completed, particularly as regards pump selection and pulley sizing.

It is recommended that no larger scale PV pump program be implemented at this time. Installation of already planned photovoltaic systems should proceed, and additional systems could be considered which first make use of equipment already in stock. Low-head application for government agencies and rural villages should receive priority. As there are already a number of solar pumps in place and the responsibility for these systems will rest with the District Water Units, a training course is recommended to develop skills in troubleshooting and repair of these systems.

E. Handpumps

Expanded use of handpumps should be encouraged, both to replace proposed diesel installations in smaller villages and in areas with scattered rural dwellings where safe water supplies are lacking. A handpump coordinating group should be established by the MLGL's water engineer. The group should consist of representatives from DWA (Groundwater, and Design and Construction divisions), MoA, Ministry of Commerce and Industry (RIIC), Ministry of Health, and District Councils. Initial considerations should be:

- possible use of handpumps in some of the remaining villages within the Village Water Supply Program;
- evaluation of new handpumps being imported by DWA and MLGL, the District Council Water Units' capacity

to maintain handpumps, and the logistical structure necessary for doing so; and

- location of new boreholes nearer to villages where appropriate, and determination of the health education requirements to avoid possible water source contamination.

F. Windmills

In light of the technical and economic limitations of windmill use, it is recommended that government support of windmill activities be reduced. There will continue to be a a small market for windmills in some areas. This market is being satisfied by the private sector through equipment imported from the Republic of South Africa. Although the Kenyan Kijito has been shown to be a superior machine technically, the anticipated market does not justify the efforts at widespread introduction through fabrication in Botswana. Nor is importation from Kenya reasonable, as the spare parts procurement would be difficult. If these machines become available within the SADCC region, the Kijito should be considered as a pumping choice.

Government involvement in the windmill promotion and development program at RIIC should be reconsidered. It appears doubtful that a large windmill market could or should be generated. Indications of market size from the pumping market study proposed by RIIC will help determine if this is a reasonable strategy. If further windmill development work is anticipated, clear performance and cost goals must be specified during the program planning phase. A timetable for continued development and further refinement of the performance prediction methodology will also be necessary.

As there are a few windmill installations at government camps and posts, and there will continue to be a few new installations, it is recommended that BRS personnel in areas with windmill installations receive some training in maintenance and repair procedures. RIIC and the Climax division of Stewart and Lloyds should be contacted to assist in a short course of about one week's duration.

G. Animal-Drawn Pumps

It is recommended that ADP development activities continue. The potential for cost-competitiveness in some cases, and the fact that diesel fuel is completely displaced, make this a system with promise. However, the RIIC ADP development program should have clearer directives. These include a formal evaluation of user response to the technology, including organization of labor, use of supplemental feed, and use of oxen. In addition, careful monitoring and evaluation of ADP fabrication costs must seek to reduce the cost of the device as much as possible.

The pump market study to be completed by RIIC will help identify the potential sales of the ADP. A reevaluation of the progress of the program and acceptability of the technology should be made after one year, with the specific goal of recommending or not recommending further work on the ADP in light of the progress and results of the efforts to date.

H. Bio-Gas Substitution

The economic analysis of bio-gas pumping does not support widespread use of the technology for the range of applications considered. Bio-gas pumps are more attractive as the pumping system size and hence fuel requirements increase. The number of larger installations where bio-gas could be used effectively should be determined as part of the RIIC pump market study.

Again, bio-gas pumps were not a major focus of CWPP. Pump performance data were only available for a single system (out of the five installed in Botswana). The project did not study the use of bio-gas for other purposes or for combined purposes, and is not prepared to comment on the economics of other uses for bio-gas. Regardless of the application of bio-gas systems, a more careful documentation of fabrication, installation and operation costs should be included in any further work.

I. Summary

In summary, consideration of all aspects of pump selection is complex, involving changing technical, economic, social and political realities. In addition, each set of site-specific conditions varies in head, water requirement, distance to installation and service facilities, etc. It is clear that for the foreseeable future, diesel pumping will play the greatest role in water pumping in Botswana. However, there are likely to be suitable applications for each of the technologies considered, although the number of installations and potential for fuel displacement are limited. Application of the modeling techniques used in this report will allow continued evaluation of pump options on a case-by-case basis, and will contribute to improved pump selection in the future.

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APPENDIX A

Test Sites

Animal-Drawn Pump

Gamorotswana	RIIC Mark I with Mono pump

Bio-Gas Substitution Pump

Diphawana	ST-1 with Mono

Diesel Pumps

Bonwapitse	ST-1 with Mono pump
Kopong	TS-2 with Mono pump
Lotlhokane-East	ST-2 with Mono pump
Mabalane #3	HR-2 with Mono pump
Malotwana	SR-1 with Mono pump
Mmaphashalala	ST-1 with Mono pump
Mmankgodi	LT-1 with Mono pump
Mogobane	ST-1 with Mono pump
Mogojogojwe	ST-1 with Mono pump
Oodi	8/1 with Mono pump

Electric Pumps

Mochudi (850)	surface-mounted motor with Mono pump
Mochudi (3136)	submersible pump
Mochudi (3137)	submersible pump
Moeding College	surface-mounted motor with Mono pump
Molepolole (camp)	submersible pump
Ncojane	submersible pump with generator set

Handpumps

Dikgonnye	Petro
Gootau	India Mark II
Hukuntsi	India Mark II
Kike	Mono
Mahatlane	India Mark II
Malatswae	India Mark II
Malokaganyane	India Mark II
Manyelanong	Mono
Molengwane	India Mark II
Ramogotsi	India Mark II
Sedibeng	India Mark II

Segoditsane	India Mark II
Segorong	India Mark II
Sengwoma	India Mark II
Sorilatholo	India Mark II
Tlhareseleele	India Mark II
Tsietsamotswana	Mono

Solar Pumps

Gulushabe	Mono with Mono Controller
Lepasha	Mono with batteries
Mahalapye	Jacuzzi
Mmadikola	Grundfos
Mmathubudukwane	Mono with Mono controller
Mochudi	Grundfos
Mochudi	Jacuzzi
Molapowabajang	Grundfos
Molapowabajang	Jacuzzi
Mookane-Khumalo	Mono with Mono controller
Otse	Mono with batteries
Nthane	Mono with Mono controller

W.nd Pumps

Dipotsana	Climax 12
Dutlwe	Wind Baron, 21 feet
Kgoro	Climax 10
Malau	RIIC Motswedi
Malesane	Southern Cross 14
Matlolakgang	Climax 18 with diesel backup
Mochudi	Kijito, 20 feet
Mochudi	RIIC Motswedi
Mochudi	Wind Baron, 21 feet
Mochudi	WTGS
Mogojogojwe	RIIC Motswedi/diesel hybrid
Pitsane-Botloko	Kijito, 20 feet
Sedibeng	Climax 12
Shoshong	WTGS
Tlhareseele	Climax 12

APPENDIX B

Description of Economic Models

Diesel

The economic model for diesel pumping analysis utilizes a present-value approach to arrive at a unit water cost. The unit water cost is calculated by dividing the present value of all costs (installed capital and recurrent costs) by the amount of water delivered. The result is given in terms of pula per cubic meter. Recurrent costs are discounted to arrive at a present worth, and the volume of water delivered is similarly discounted. The water is discounted because the volume is seen as a measure of worth. No financial or economic value was assigned to the water, but this could be done. The financial and economic analyses were performed using standard techniques. In addition to the financial and economic components of the diesel pump analysis, the model performs a limited technical analysis, which includes determining engine loading, fuel consumption and fuel efficiency.

Assumptions

All of the model's assumptions are defined by the user, as shown in the figure on the following page. A brief description of these user-defined inputs and the way they are used in the model is presented next.

In terms of site information, the total pumping head is used (in combination with other factors) to determine the amount of energy required to pump water, engine loading and fuel consumption. The annual consumption growth factor allows the model to include a factor for growth in water demand. This growth is accounted for by increasing the engine's operating hours by the growth factor. The pump level, which may well differ from total head, is used in conjunction with the rising-main unit cost to determine the total rising-main cost. Distances to installation and service centers may vary depending on who performs these tasks, but these two figures are used with vehicle cost to calculate transportation costs.

All capital costs associated with the engine and pump installation are included here. Certain information that permits a calculation of the labor and transportation costs for pump installation are also incorporated. The capital cost is used to determine the initial installation cost and also when engine replacement becomes necessary. The pump cost includes the pump itself and components that are at ground level. Piping costs in

Diesel Analysis : Base Case Rural Village

Assumptions

Site Information

90	m Total Pumping Head
3%	Annual consumption growth factor
100	m Pump Level
200	Km one way from installation center
100	Km one way from service center

Capital Cost Information

2109	Cost of the Engine
599	Cost of the Pump and Mono head
18	Cost of the Rising Main per meter
1190	Cost of the Pump House including engine block
450	Cost of the Piping and components above ground
200	Cost of installation crew per day
50%	of installation cost is allowance
20	Number of days to install
10	ton truck installation transport (choose 1,7 or 10)
3.5	Times return trip distance for installation transport

Engine Information

8.57	Hrs of Operation per day	
3.5	Pumping rate (M3/Hr)	
3.37	Derated engine output	
1.29	Liters of fuel per hour at full load	LT-1 = .93, 2.18Kw
0.75	Assumed pump efficiency	ST-1 =1.29, 3.37Kw
5000	Hrs between Overhauls	8/1 =2.16, 4.5Kw
500	Pula per Overhaul (materials)	
100	Pula per Overhaul (labor)	
8	Overhauls per lifetime (no salvage for old engine)	

Transportation Information

0.47	Pula/Km Light 4x4 light truck (1 ton)
0.85	Pula/Km Heavy 7 ton truck
1.05	Pula/Km Heavy 10 ton truck

Recurrent Costs

2400	Pula/year for pumper	
7	Unskilled labor cost (Pula per day)	
12	Skilled labor cost (Pula per day)	
0.54	Pula/liter for diesel fuel	3129 Hrs/yr 1st year
1.00	Fuel escalation rate	5486 Hrs/yr 20th year
0.04	Oil as a fraction of fuel use	
2.00	Pula/liter oil cost	
0.175	For materials per hour of operation	
4	Man days unskilled labor per trip	
1	Man days skilled labor per trip	
1	Trips at 0.47 Pula/Km	
2	Trips at 0.85 Pula/Km	
12	Average allowance per trip (per-diems)/man	
1833	Liters of diesel per year	
3	Trips/year "chargeable" for fuel delivery Heavy vehicle	

Financial Information

20	Years Amortization Period
0.06	Discount Rate

Economic Information

0.5	Shadow price of labor
1.1	Shadow price of imports

30	Cubic meters/day delivered
90	Total head
7351	Kwhr/day hydraulic energy required
34%	Engine loading
0.586	Pred. fuel consumption(l/hr)
0.17	Liter fuel/cubic meter water
14%	Efficiency (fuel to water)

ALC cost (P/m3 F)	0.51
ALC cost (P/m3 E)	0.44
Inst. cap. cost	11618
PW of rec. costs	69886

the borehole are variable depending on the pump level and, thus, are calculated separately. No pump replacement costs were assumed as these costs are covered elsewhere under recurrent costs. The cost of the rising main per meter is used with pump level to calculate the cost of below-ground piping. The cost for the pump house and engine block includes all civil works, and these items are assumed to last for the life of the analysis. Any repair or replacement of them must be included under recurrent materials cost. The cost of piping and above-ground components includes non-return valves, water meters, pressure-relief valves and any other components found in the pump house.

The daily cost for an installation crew includes salaries and allowances, such as per-diem or overnight allowance. It is assumed that the portion of this figure which is not allowances is unskilled labor, and it is shadow-priced accordingly in the economic analysis. Installation time is used in conjunction with the daily cost for the crew to determine the labor and allowance costs for the whole installation. Installation transportation includes considerations for the use of different vehicles for equipment installation. This information is combined with the transportation cost per kilometer for these vehicles and multiples of the round-trip distance to determine installation transportation costs.

Under engine information, the number of hours of engine operation is needed to determine the amount of water pumped per day, fuel cost, materials repair cost, and timing for engine overhaul and replacement. Pumping rate is used to calculate engine loading and thereby fuel consumption. It is also used with hours of operation to determine daily and annual water delivery. De-rated output (not full rated power) is used to determine engine loading and fuel consumption. An algorithm in the model uses full-load fuel consumption along with de-rated engine output, pump efficiency, total head and pumping rate to calculate actual fuel consumption, which will be less than full-load consumption.

Overhaul interval is included in the model, which is used with daily hours of operation to calculate the year for each overhaul. The cost for these overhauls is then divided between materials and labor so each can be shadow-priced accordingly in the economic analysis. The number of overhauls per engine lifetime is used with hours between overhauls and daily hours of operation to determine the year of engine replacement. At the end of the term for the analysis, a salvage value is assigned to the engine by taking 75 percent of the prorated engine value since the last overhaul.

Transportation information gives the cost per kilometer of using three different sizes of vehicles. These figures are used to calculate transportation costs for installing and servicing the pump.

For <u>recurrent costs</u>, the pump operator cost is given in pula per year for the pumper. This cost is assumed to be for unskilled labor and is shadow-priced accordingly in the economic analysis. Unskilled and skilled labor costs are used with the number of person-days per trip and number of trips to calculate annual labor costs for service trips. The pula/liter figure for diesel fuel is the current cost, including duties and adjustments. The economic cost of diesel is shadow-priced as an import with no adjustments for the duty paid. In Botswana, the duty on diesel fuel is a small percentage of the pump price. The escalation of fuel costs allows for increases in fuel prices above the general inflation rate. The figure for oil as a fraction of fuel use permits an estimate of engine oil use (both oil burned and changed). Oil costs are also included to permit financial and economic valuation of this oil. The cost for materials per engine hour of operation is an annual amount for field service and repair divided by annual operating hours, but it does not include overhauls since they can be included separately as described above.

The figure for person-days of labor (skilled and unskilled) per trip defines the makeup of an average repair or service crew that makes field trips. The trips are broken down by vehicle type to facilitate the calculation of transportation costs. The average allowance includes per-diem or overnight expenses, as necessary. This cost is not shadow-priced. In many cases, fuel delivery trips are combined, so the delivery cost should be allocated to more than one engine. The figure for trips that can be charged for fuel delivery permits apportionment of a part of the transportation cost for fuel delivery to the engine site that is being analyzed.

The <u>financial information</u> includes amortization period and discount rate. The amortization period is currently set at 20 years, and changing it on the spread-sheet can produce meaningless results. The discount rate is used to calculate the present worth of future costs and discounted water volume. The <u>economic information</u> is used to make adjustments to unskilled labor and imported materials under financial costs in order to arrive at economic costs.

Results

The results for each analysis are shown in the upper right corner of the analysis sheet. They include a restatement of the site's head and water demand. The daily hydraulic energy requirement is also given to permit rapid assessment of the potential for renewable energy systems.

Several technical parameters are calculated and presented, including engine loading, predicted fuel consumption (in liters per hour), specific fuel consumption (liters per cubic meter of water delivered), and overall engine and pump efficiency. This efficiency is determined by dividing the energy required to lift a volume of water divided by the energy content of the predicted volume of fuel required.

The financial and economic figures include annual life-cycle costs (ALC) in P/m^3 in both financial and economic terms. These are calculated by summing installed capital costs and the present value of the stream of recurrent costs and then dividing by the discounted volume of water delivered over the term of the analysis. Installed capital costs and the present worth of recurrent costs (in financial terms) are also included. Installed capital costs cover equipment, labor and transportation. Recurrent costs refer to all future expenditures, including engine replacement, if necessary. These figures are included to allow their comparison.

In addition, the analysis includes a discrete annual summation of recurrent costs, which is used to calculate the present worth of recurrent costs. The figure on the next page shows costs for the first 10 years for both financial and economic accounting. Labor, transportation and materials have been separated to allow for appropriate shadow-pricing.

Other Technologies

The analyses for other pumping technologies use the same approach. The only changes are due to the differing characteristics of the technologies, which actually forces a consistent analysis approach. It is this consistency that provides the basis for technology comparison. A brief description of how the inputs and results for each technology differ from those for a diesel system is presented in the following subsections. At the end of this appendix, a sample analysis sheet is presented for each technology.

Animal-Drawn Pump

The ADP financial and economic model differs from the diesel in that allowances are made for local manufacture of the device and entries are included for the purchase, care and feeding of draft animals. This model does not include a technical design feature, which must be completed before using the model. Local manufacture of the device implies local labor, which may be shadow-priced in an economic analysis. It requires that equipment costs be divided into materials and skilled and unskilled labor. An allowance is made for the purchase of

SUMMARY OF RECURRENT COSTS FOR EACH SYSTEM BY YEAR

YEAR:	1	2	3	4	5	6	7	8	9	10
Financial										
Ann. fuel & oil cost	721	743	765	788	812	836	861	887	913	941
Pumper Salary	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
Ann. Rec Cost (Mat)	365	376	387	399	411	423	436	449	462	476
Ann. Rec Cost (Labor)	141	141	141	141	141	141	141	141	141	141
Ann. Rec. Cost (Transport	434	434	434	434	434	434	434	434	434	434
Annual rep trip allowance	180	180	180	180	180	180	180	180	180	180
Overhaul Cost (material)	0	0	500	0	500	0	500	0	500	0
Overhaul Cost (labor)	0	0	100	0	100	0	100	0	100	0
Replacement cost	0	0	0	0	0	0	0	0	0	0
Overhaul Field Labor	0	0	35	0	35	0	35	0	35	0
Overhaul Transport	0	0	340	0	340	0	340	0	340	0
Salvage										
Total Recurrent Cost	4241	4274	5282	4342	5352	4414	5427	4491	3506	4572

SUMMARY OF RECURRENT COSTS FOR EACH SYSTEM BY YEAR

Year :	1	2	3	4	5	6	7	8	9	10
Economic										
Ann. fuel & oil cost	793	817	842	867	893	920	947	976	1005	1035
Pumper Salary	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
ARC (M)	402	414	426	439	452	465	479	494	509	524
ARC (L)	89	89	89	89	89	89	[illegible]	89	89	89
Ann. Rec. Cost (Transport	477	477	477	477	477	477	477	477	477	477
Annual rep trip allowance	180	180	180	180	180	180	180	180	180	180
Overhaul Cost (material)	0	0	550	0	550	0	550	0	550	0
Overhaul Cost (labor)	0	0	100	0	100	0	100	0	100	0
Replacement cost	0	0	0	0	0	0	0	0	0	0
Overhaul Field Labor	0	0	18	0	18	0	18	0	18	0
Overhaul Transport	0	0	374	0	374	0	374	0	374	0
Total Recurrent Cost	3141	3176	4255	3251	4332	3331	4414	3415	4501	3505

animals, which requires the number of animals, their cost and useful working life as inputs. In addition, veterinary care and supplemental feeding entries are included, as these may be important items. Harness costs and their lifetimes are also included. The pumping rate will depend on the pump chosen and number of animals per shift, which is a user-defined parameter. Labor costs are not given in annual terms, but rather per hour of pump operation. Allowances can be made for the labor required to collect and harness animals.

As in the diesel analysis model, the results include a unit cost for water pumped in both financial and economic terms, which are calculated in exactly the same way as in the diesel analysis. Capital costs and the present value of recurrent costs are also reported.

Bio-Gas Substitution

The analysis model for bio-gas substitution is very similar to the diesel model. The differences are inclusion of the bio-gas plant and a substitution rate for diesel fuel. One underlying assumption involves a rough sizing algorithm for the bio-gas plant. The assumption is that .6 liters of diesel fuel can be displaced by one cubic meter of bio-gas, and given Botswana's climate, 3.6 cubic meters of digester volume are required to produce one cubic meter of bio-gas. In addition, it is assumed that digesters are be built in increments of five cubic meters. The price per cubic meter of digester volume (with unskilled labor separated out) and fuel displacement rate are user-defined inputs for the analysis. There is also a provision for the increased labor needed to feed and care for the digester.

The results for the bio-gas analysis are similar to those for the diesel analysis. However, the present worth of fuel savings over the life of the analysis and digester cost are also included as well as the present worth of additional labor costs besides the pump operator, if any.

Electric Pumps

The analysis for AC electric pumping systems includes a provision for utility interconnection costs, which reflect the kilometers of overhead line that are required and transformer costs. It is assumed that these costs include labor. The overall efficiency for the pump/motor is a user-defined parameter. The electricity cost is also user-defined, for both financial and economic costs. This permits a financial analysis using the metered rate and an economic cost that may include a local labor component or exclude various subsidies. The life of the electric motor is given in hours, and replacement is included in the analysis. The replacement of all other components must be included under annual materials for servicing.

The results of this analysis include financial and economic unit costs in pula per cubic meter of water. The annual electricity cost (in financial terms) and daily hours of operation are also included. Finally, the installed cost and present worth of recurrent costs are given.

Handpumps

The handpump financial and economic analysis program allows for the use of imported or locally fabricated pumps. The pump-head and skilled and unskilled fabrication labor are also shown separately. If the pump is imported, no fabrication labor is included, but if locally fabricated, materials costs are entered under the cost of the pump-head. The analysis also has separate pump and rising-main costs, so that the analysis can be tailored to different conditions. In addition, the pumping rate (in liters per minute) is user-defined. This along with daily demand permits calculation of the number of hours per day that the pump must operate. It also allows inclusion of the cost for a pumper, if desired. For the economic analysis, a pumper cost should be included since the time taken to pump water does have some value.

The analysis results are similar for the other technologies considered. Financial and economic results are given as a water cost per cubic meter of water delivered over the term of the analysis. Installed capital cost and the present worth of the recurrent costs are also included.

Solar Pumps

The PV solar pump analysis model has considerable flexibility. The financial and economic program does not include a design module because configurations can vary so widely, but it does allow for a wide variety of pump components. The major user-defined inputs include the design parameters of head, daily demand and component costs, including controllers or batteries, as necessary. Also included are replacement intervals for components. Solar modules may need to be replaced due to normal wear or damage/theft--both possibilities are taken into account. The time between module replacements refers to the average time between replacement of a single module due to damage or theft. Module lifetime refers to the life of the array, without considering vandalism or theft. Service is included as the number of trips and average materials costs incurred annually.

The results include an estimate of the hours of operation per day, given a user-defined maximum pumping rate and other calculated solutions, as in the analyses of other pump types.

Wind Pumps

As with the PV pump analysis, the wind system's design and expected output must be known before using the financial/economic package to calculate unit water costs. The analysis program includes user-defined inputs for average pump performance over the year and performance during the months with the lowest wind speeds. There may be a wide variation in performance over the year, which can affect system sizing and water valuation. If the windmill will not be operating during high-wind periods, water will not be delivered and should not be included in the analysis. The average annual performance and low-wind performance figures define the extremes for the analysis and thus permit an estimation of costs, which may be somewhere in between. The other user-defined input parameters are similar to those for the other pumping technologies.

As a result of inputs for average daily water delivery and average water delivery during a month with low wind speeds, there are two sets of financial and economic results. These are unit costs (in pula per cubic meter) based on the two levels of water delivery. The actual value will depend on how much water is really used. During months with higher wind speeds, water can be pumped beyond the amount that can be delivered reliably year-round. However, it that additional water is of no value, the financial and economic figures for the low wind-speed month should be used. If all the water that can be pumped year-round is of value (i.e., is used), the annual figures should be considered.

Animal Drawn Pump

Assumptions

Site Information

60 Total Pumping Head
70 Pump Level
200 Km one way from installation center
100 Km one way from service center
30 Cubic meters per day delivered
8 Number of animals required

Capital Cost Information

4900 Materials cost ADP
1350 Skilled Labor in manufacturing
450 Unskilled labor in manufacturing
1000 Cost of the pump
21 Cost of the Rising Main per meter
50 Cost additional materials
600 Cost of the foundation and civil works
100 Cost of installation crew per day
5 Number of days to install
7 Ton truck installation transport (choose 1,7,or 10)

Transportation Information

0.47 Pula/Km 4x4 light truck (1 ton)
0.85 Pula/Km Heavy 7 ton Truck
1.05 Pula/Km Heavy 10 ton Truck

Recurrent Costs

0 Cost of labor per hour to operate ADP
40 Cost of animals (each)
5 Useful life of animals for pumping (yrs)
30 Cost of harnesses
2 Useful life of harnesses (yrs)
0 Annual supplemental feed
0 Annual veterinary care
50 Annual cost in spare parts (for ADP only)
200 Annual cost in spare parts (pump and other equipment)
7 Unskilled labor cost (Pula per day)
12 Skilled labor cost (Pula per day)
4 Man days unskilled labor per trip
1 Man days skilled labor per trip
1 Trips at 0.47
1 Trips at 0.85 Pula/Km
10 ADP lifetime iPula/Km
Note:replacement labor is half original

Financial Information

20 Years Amortization Period
0.12 Discount Rate

Economic Information

0.5 Shadow price of labor
1.1 shadow price of imports

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60 Meters head
30 m3/day average output
8 Animals
3.4 M3/hr pumping rate
8.8 Hours of operation per day

Annual Life cycle cost (P/m3 F)	0.24
Annual Life cycle cost (P/m3 E)	0.24
Cap cost installed (F)	11390
PW of recurrent cost (E)	8093

Biogas Pump : Private

Assumptions

Site Information

60 Total Pumping Head 30 m3/day output
0% Annual consumption growth factor
70 Pump Level
200 Km one way from installation center
300 Km one way from service center

Capital Cost Information

2439 Cost of the Engine
856 Cost of the Pump and Mono head
26 Cost of the Rising Main per meter
600 Cost of the Pump House including engine block
50 Cost of the Piping and components above ground
75 Cost of Biogas plant (per cubic meter)
20% Cost of biogas plant is labor
150 Cost of installation crew per day
100%of installation cost is allowance
20 Number of days to install
7 ton truck installation transport (choose 1,7 or 10)
4 Times return trip distance for installation transport

Engine Information

8.57 Hrs of Operation per day
3.5 Pumping rate (M3/Hr)
2.18 Derated engine output
0.93 Liters of fuel per hour at full load LT-1 = .93, 2.18Kw
80% diesel fuel displaced ST-1 =1.29, 3.37Kw
0.75 Assumed pump efficiency 8/1 =2.16, 4.5Kw
10000 Hrs between Overhauls
800 Pula per Overhaul (materials)
100 Pula per Overhaul (labor)
4 Overhauls per lifetime (no salvage for old engine)

Transportation Information

0.47 Pula/Km Light 4x4 light truck (1 ton)
0.85 Pula/Km Heavy 7 ton truck
1.05 Pula/Km Heavy 10 ton truck

Recurrent Costs

450 Pula/year for pumper
0 Cost per additional hr for biogas
7 Unskilled labor cost (Pula per day)
12 Skilled labor cost (Pula per day) 3129 Hrs/yr 1st year
0.62 Pula/liter for diesel fuel 3129 Hrs/yr 20th year
1.00 Fuel escalation rate
0.04 Oil as a fraction of fuel use
2.00 Pula/liter oil cost
0.2 For materials per hour of operation
4 Man days unskilled labor per trip
1 Man days skilled labor per trip
1 Trips at 0.47 Pula/Km
0 Trips at 0.85 Pula/Km
1 Average allowance per trip (per-diems)/man
1362 Liters of diesel per year
1 Trips/year "chargeable" for fuel delivery

Financial Information

20 Years Amortization Period
0.12 Discount Rate

Economic Information

0.5 Shadow price of labor
1.1 Shadow price of imports

30.0 Cubic meters/day delivered
60 Total head
4.8 M3 biogas req'd/day
20 M3 digester volume

35% Engine loading
0.435 Pred. fuel consumption(l/hr)
0.12 Liter fuel/cubic meter water
12% Efficiency (fuel to water)

ALC cost (P/m3 F)	0.33
ALC cost (P/m3 E)	0.33
Inst. cap. cost	11625
PW of rec. costs	15339
PW of fuel savings	5046
Cost of digester with labor	1500

Electric Pump

Assumptions

Site Information

2	Distance to electricity grid (km)
90	Total Pumping Head
100	Pump Level
200	Km one way from installation center
100	Km one way from service center

Pumping Information

20	Cubic meters per day delivered
0%	Growth in demand
3.5	m3/hr pumping rate
40%	Overall pump/motor efficiency
0.187	Electricity cost per Kw-hr (Pula)
0.187	Economic cost electricity (pula/kw-hr)

Capital Cost Information

1164	Cost of electric motor (replaced at lifetime)
700	Cost of electric starter
0	Cost of pump
12000	Cost per km overhead line
3600	Cost for transformer
8	Cost of the Rising Main per meter
490	Cost balance of system (mechanical)
1280	Cost balance of system (electrical)
1000	Cost of civil works
200	Cost of installation crew per day
20	Number of days to install
0.5	Of labor cost as allowance
10	Ton truck installation transport choose 1, 7, or 10)

Transportation information

0.47	Pula/km 4X4 light truck (1 ton)
0.85	Pula/km Heavy 7 ton truck
1.05	Pula/km Heavy 10 ton truck

Recurrent Costs

2400	Pula annually for pumper
100	For materials for service annually
12	Skilled labor cost (daily)
7	Unskilled labor cost (daily)
1	man days skilled labor per trip
4	Man days unskilled labor per trip
2	Trips at 0.47 Pula/km
0	Trips at 0.85 Pula/km
15000	Electric motor lifetime (hrs)

Financial Information

20	Years Amortization Period
0.06	Discount Rate

Economic Information

0.5	Shadow price of labor
1.1	Shadow price of imports

90	Meters head
837	Pula/yr electricity cost (financial)
20	m3/day average output
5.7	Hours per day of operation
5.7	Hours in year 20

Annual Life cycle cost (P/m3 F)	0.97
Annual Life cycle cost (P/m3 E)	0.81
Total installed cost (F)	37664
Total installed cost (E)	37630
PW of recurrent cost (F)	43683
PW of recurrent cost (E)	30159

Handpump Analysis: Mark II

Assumptions

Site Information

30	Total Pumping Head
0%	Annual growth in demand
40	Pump Level
200	Km one way from installation center
100	Km one way from service center

Capital Cost Information

420	Cost of the handpump head
0	Fabrication skilled labor
0	Fabrication unskilled labor
142	Cost of the pump
10	Cost of the Rising Main per meter
100	Cost of the foundation and fence
200	Cost of installation crew per day
5	Number of days to install
7	ton truck for installation (choose 1, 7, or 10)

Handpump Information

2.25"	Pump size
3	Cubic meters per day delivered
7.50	Liters per minute average production
10	Pumphead lifetime in years
5	Pump cylinder lifetime in years

Transportation Information

0.47	Pula/Km Light 4x4 Light truck (1 ton)
0.85	Pula/Km Heavy 7 ton Truck
1.05	Pula/Km Heavy 10 ton Truck

Recurrent Costs

0.64	Pula/hr for pumper
7	Unskilled labor cost (Pula per day)
12	Skilled labor cost (Pula per day)
25	For materials for service annually
4	Man days unskilled labor per trip
1	Man days skilled labor per trip
1	Trips at 0.47 Pula/Km
0	Trips at 0.85 Pula/Km

Financial Information

20	Years Amortization Period
0.06	Discount Rate

Economic Information

0.5	Shadow price of labor
1.1	shadow price of imports

30	Meters head
3.0	m3/day average output
6.7	Hours per day of use
6.7	Hours per day of use (in year 20)
0.64	Pula per hour for labor of pumping

Annual Life cycle cost (P/m3 F)	1.85
Annual Life cycle cost (P/m3 E)	1.10
Installed cost (F)	2572
PV of recurrent cost (F)	20690

Solar Pump Analysis: Rural Village

Assumptions

Site Information
30 Total Pumping Head
40 Pump Level
3% Growth in demand
350 Km one way from installation center
500 Km one way from service center

Capital Cost Information
670 Cost of each solar module
14 Number of modules
9380 Total Modules cost
0 Cost of the controller
300 Cost of batteries
1250 Cost of related solar hardware
4700 Cost of the pump/motor
8 Cost of the Rising Main per meter
1500 Cost of the foundation and fence
450 Cost of the Piping and components above ground
200 Cost of installation crew per day
50% of installation cost is allowance
10 Number of days to install
10 ton truck installation transport (choose 1,7,or 10)
1.75 Times return trip distance for installation transport

Solar Pump Information
10 Cubic meters per day average annual
20 Module lifetime in years
36 Months between module replacement due to damage
5 Controller lifetime in years
0 Battery lifetime in years
5 Pump/motor lifetime in years

Transportation Information
0.47 Pula/Km 4x4 light truck (1 ton)
0.85 Pula/Km Heavy 7 ton truck
1.05 Pula/Km Heavy 10 ton truck

Recurrent Costs
1200 Pula/year for pumper
7 Unskilled labor cost (Pula per day)
12 Skilled labor cost (Pula per day)
100 For materials for service annually
4 Man days unskilled labor per trip
1 Man days skilled labor per trip
2 Trips at 0.47 Pula/Km
0 Trips at 0.85 Pula/Km

Financial Information
20 Years Amortization Period
0.06 Discount Rate

Economic Information
0.5 Shadow price of labor
1.1 shadow price of imports

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30 Meters head
10 Meters cubed per day

18.1 Meters cubed in year 20
6.0 Hrs per day at max rate (yr 20)
9380 Capital cost modules
36% Capital cost/Life cycle cost

Annual Life cycle cost (P/m3 F)	1.07
Annual Life cycle cost (P/m3 E)	1.01

		Financial	Economic
Initial Capital Cost	:	17900	19690
PW of Recurrent Costs	:	37606	32679

Windmill Analysis: Government installation

Assumptions

Site Information
- 15 Total Pumping Head
- 25 Pump Level
- 200 Km one way from installation center
- 300 Km one way from service center

Capital Cost Information
- 9634 Cost of the windmill & tower
- 385 Cost of the Pump
- 14 Cost of the Rising Main per meter
- 834 Cost of the foundation and fence
- 67 Cost of the Piping and components above ground
- 200 Cost of installation crew per day
- 100% of installation labor is allowance
- 20 Number of days to install
- 10 Ton truck installation transport (Choose 1,7,or 10)
- 3.5 Times return trip distance for installation transport

Windmill Information
- 5.5 Meters diameter of windmill
- 4 " Cylinder size
- 2.5 m/sec average windspeed
- 8.0 Cubic meters per day in low windspeed month
- 11.8 Cubic meters per day average annual
- 10 Cylinder replacement interval (years)
- 20 Lifetime in years

Transportation Information
- 0.47 Pula/Km Light 4x4 truck (1 ton)
- 0.85 Pula/Km Heavy 7 ton truck
- 1.05 Pula/Km Heavy 10 ton truck

Recurrent Costs
- 600 Pula/year for pumper
- 7 Unskilled labor cost (Pula per day)
- 12 Skilled labor cost (Pula per day)
- 50 For materials for service annually
- 4 Man days unskilled labor per trip
- 1 Man days skilled labor per trip
- 2 Trips at 0.47 Pula/Km
- 0 Trips at 0.85 Pula/Km

Financial Information
- 20 Years Amortization Period
- 0.12 Discount Rate

Economic Information
- 0.5 Shadow price of labor
- 1.1 shadow price of imports

- 11.8 Cubic meters/day (avg annual)
- 8.0 Cubic meters/day (low wind month)
- 15 Total head
- 2.50 Meters/sec average windspeed

- 5.5 Windmill diameter
- 4.00 Cylinder size in inches

ALC cost (P/m3 F) Annual	0.82
ALC cost (P/m3 E)	0.80
ALC cost (P/m3 F) Low Wind Month	1.22
ALC cost (P/m3 E)	1.18
Inst. cap. cost	16740
PW of rec. costs	9789

APPENDIX C

Aquifer Performance and Borehole Costs

Borehole drilling and development costs are not included in the analysis of water-pumping equipment presented in this report, but are issues that may affect technology selection. For instance, borehole yield will affect the choice of pumping equipment. In addition, if lower yield boreholes that are not currently in use can be utilized, the need for additional drilling may be reduced. The goal of this appendix is to introduce issues associated with aquifer performance and borehole characteristics, and discuss the costs and implications of drilling and success rates.

Aquifer Performance

An aquifer is a rock or soil stratum that holds or has the potential to hold water which can flow through it. This water-bearing capacity may be due to primary or secondary porosity and the aquifer's configuration may be classified as confined or unconfined. The potentiometric surface* may be above (artesian) or below ground level. Primary porosity is found when the aquifer exists where the rock formation is porous. Secondary porosity occurs where the rock has been modified by fracturing or dissolution. Combinations of these two conditions may exist. In unconfined aquifers, the upper level of the water table is under atmospheric pressure only (phreatic). The overburden for such underground water is permeable. These aquifers tend to be affected most quickly by seasonal precipitation patterns. Confined aquifers are overlain with an impervious layer. Water under these conditions is often under some pressure, which is indicated when the water rises above the level where was struck during drilling. Confined aquifers may not be perfectly confined and leakage into or out of them may occur.

In Botswana, unconfined aquifers include the sand river systems in the northeast and Okavango Delta. A large portion of the boreholes where settlement is the greatest are in hard rock areas. There, secondary porosity offers the best prospects for successful boreholes. In the eastern part of the country, these are mostly fracture systems in granite, metamorphic and compact sedimentary rocks.

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*This is the imaginary surface representing the total head in a confined aquifer. It is the level that water will rise in a borehole.

The behavior of an aquifer is characterized by transmissivity and a storage coefficient. Transmissivity is a measure of the rate at which water moves in the aquifer and is normally given in units of m^3/day/meter depth of the aquifer. Transmissivity in the locale of a borehole can be calculated from test-pumping. Along with the aquifer's volume, the storage coefficient (or storativity) is a measure of the total water resource, of which only a portion can be recovered.

Only local transmissivity can readily be determined by simple test-pumping. To know the volume of water that is available, the aquifer's boundaries must be known, both vertical and horizontal. Storativity and specific yield (percentage of water in a saturated body of rock or soil) cannot be estimated from test-pumping a single borehole, but rather requires the use of observation wells. If the volume, specific yield and transmissivity are known, the water resource can be assessed and optimum borehole spacing and design selected.

To determine sustainable yield, an understanding of recharge rates is also necessary. A recharge assessment requires several years of observing water levels in suitably sited observation wells that are not within the draw-down cones of production wells. In most cases in Botswana, the test-pumping done does not include observation wells and only transmissivity can be determined. This means there is little understanding of the sustainable yield available from a given borehole or well field.

Drilling

DWA has six rotary drilling rigs and seven percussion rigs. With this equipment, they are responsible for drilling boreholes for other government agencies, the rural village programs (i.e., Rural Village Water Supply Program, Village Rehabilitation Program and Drought Relief Program) and major village water supplies. DWA's drilling capacity is on the order of 300 boreholes per year. The rotary rigs drill in the range of 6,000 meters per year and the percussion rigs much less. The appropriate rig for drilling depends on the formation. Most of the boreholes in hard rock areas are drilled to 200 to 250 meters, but recent drilling near the Central Kalahari Game Reserve has gone to over 400 meters.

The private sector's drilling capacity is somewhat less with only two companies that have more than one rotary rig currently operating in Botswana. There are eight to 12 privately owned drilling rigs in the country, and none have the capacity to drill beyond 250 meters.

The success of a drilling program depends on the geological and geophysical techniques for siting boreholes in the aquifer being penetrated, drilling technique and proper borehole design and development. Solution cavities in dolomite with high yields are particularly difficult to strike, but geophysical methods are producing good results in fractured rock systems. Sandstone (where primary porosity is the source) is frequently interbedded with shales, etc., which can result in a high proportion of failures. The location of boreholes near demand areas often limits the options to less promising formations.

DWA has a borehole siting section that locates boreholes using such resources as aerial photographs, geological mapping and satellite imagery. Geophysical methods include electrical resistivity and electromagnetic surveys. Although the goal is to site each borehole, actual site visits are not always made. More careful siting is done when boreholes are being drilled in particularly difficult formations. During 1985/86, the success rate (defined as a yield of 1.5 m^3/hour or more) for boreholes drilled by DWA was 53 percent. The success rate for rotary rigs (61 percent) was higher than for percussion rigs. Still, for the whole country, roughly two boreholes must be drilled for every successful one. It does appear that improved borehole siting has made some difference as the success rate today is higher than it was 10 years ago.

Today, 48 hours of test-pumping is normally done on successful boreholes, followed by eight hours of recovery observation. In some instances, longer tests are run. The goal of these tests is to establish criteria to select a design output for the pumping system. Sometimes, the typical test-pumping practice is inadequate to determine the design output. An examination of a sample of test-pump reports found discontinuities that can only be explained as mistakes or poor execution of the test. The results are inadequate to determine the long-term drawdown of production wells or the aquifer's storativity. This means that current test-pumping practices cannot guarantee reliable water sources over the long run.

Drilling Costs

A number of factors affect drilling costs. They are related to the formation being penetrated, drilling method used, rate of progress, depth and diameter of the hole, and borehole completion and development procedure. Other costs are related to the rig's condition, and downtime and logistic arrangements for crews in the field. DWA has calculated an average price for drilling and casing boreholes of various diameters. Figures for the most common diameters are shown in the table below.

DWA Estimated Drilling Costs

Procedure	Cost (pula/meter)
drilling	70
inserting 6-inch casing	33
inserting 6.5-inch casing	38
inserting 8-inch casing	48
inserting 10-inch casing	73
inserting 12-inch casing	88
inserting 6-inch well screen	336
inserting 8-inch well screen	416
pipe driving	140
gravel packing (per borehole)	1,500
test-pumping (per hour)	45

A breakdown of the drilling costs reveals that about 20 percent is for fuel to operate the rig and run the compressor and support vehicles. Drilling tools and circulating media comprise 25 percent, 17 percent is for wages and allowances, rig depreciation takes 12 percent, and the remaining 26 percent goes for rig maintenance, consumables such as gas and welding rods, and other incidentals.

A six-inch borehole drilled to 200 meters with one-third of it cased would cost about P16,000. To put this in perspective, a Lister ST-1 engine costs the government P2,300. The total installed cost for a base-case diesel pump is about P12,000, and the present value of recurrent costs over the 20 years of the analysis is about P70,000 (see VOLUME II: DIESEL SYSTEMS). It is clear that borehole costs are a significant percentage of these expenses. On average, two boreholes must be drilled for each successful one, so the cost per meter of successful borehole is effectively doubled. If a larger percentage of boreholes were successful or lower yield boreholes could be utilized, thus reducing the drilling required to find a useful one, the financial and economic savings could be significant. However, practical problems limit these initiatives.

Efforts are always being made to improve siting techniques for boreholes, and the results already indicate the success of these efforts. However, even with the best siting methods, the yields from boreholes drilled in many of Botswana's formations may be low and dry holes will continue to be quite common.

Further, the use of existing lower yield boreholes is limited. In the past, if the anticipated borehole yield could not meet water demand, it was left uncased, thus increasing the likelihood of a cave-in. In addition, these boreholes are not normally test-pumped. These two factors makes reliance on these boreholes a bit risky.

Borehole Yields

The possible output rates for boreholes depend heavily on the formation's geology and skill with which the borehole was sited, drilled, completed and developed. In areas with dolomites and some sandstones, yields are often above 10 m^3/hour. Unfortunately, in much of Botswana, yields are considerably less than this--in some areas, the best rates may be as low as 1.5 to two m^3/hour. The average yield for many successful boreholes in populated areas is in the range of three to six m^3/hour. If these yields are sustainable, they are sufficient for many rural villages. However, there is no convincing information to indicate that these yields are sustainable. In fact, some evidence shows they are declining.

Declining yields have resulted in the need to drill new boreholes for a number of rural villages. This seems to be recurring with regularity for several possible reasons:

- drought conditions during the past drought cycle have reduced the recharge necessary to sustain yields;
- test-pumping is insufficient to show whether the resource is of limited extent; and
- borehole development is insufficient and completion inadequate to keep fines from clogging the interstices of the aquifer or silting the borehole.

It is quite possible that a combination of these reasons is responsible for observed declining yields. Unconfined aquifers are more likely to be affected by drought conditions and the lack of recharge, and older boreholes that were drilled only as deep as seemed necessary at the time are particularly vulnerable during the current drought. It has already been noted that current test-pumping practices do not measure aquifer potential, but only give an indication of the borehole's design output over a short period. It has been suggested that in some instances, water is being "mined" as the aquifer is not being recharged at all. There is very little way to show this without collecting information over several seasons.

Among the most prevalent borehole problems (excluding difficulties with pumping equipment) is the plugging of fissures with silt and fines. The problem develops as fine material migrates with the water through the aquifer toward the borehole. This material reduces the flow of water to the borehole and, hence, yield. Proper borehole development can reduce this problem. However, under the current heavy program of drilling, the development time for completion of boreholes is not given a high priority.

Issues Relating to Pump Selection

The borehole factors that relate to small-scale pumping choices are similar for any technology, although the magnitude of these factors may favor or mitigate against certain pumping options. These factors include:

- standing water level (SWL),
- draw-down characteristics for a given output,
- borehole yield, and
- sustainability of yield.

Knowledge of all these factors enables pump selection. If the draw-down output characteristics are not well-known, the only approach may be to equip the borehole for a percentage of the test-pumping output. The fact that these borehole characteristics are not well understood results in improper equipment specification. Issues relating to borehole characteristics and proper equipment selection are discussed in many places in this report. DWA's decision to standardize on the Mono pump is one way of handling these problems. The Mono pump exhibits a high efficiency over a range of heads and is reasonably resistant to damage. The worst-case condition of the pumping water level being at the pump intake is allowed as a possibility when designing pumping systems. The significance of these factors is certainly understood, but conditions do not permit all of the necessary data to be obtained.

There is interest in the use of electric pumping systems, where possible. With the capital cost of power lines, switch-gear, etc., care must be taken to be certain that the sustainable yield is sufficient to justify the expense. In addition, the use of submersible pumps should not be considered if the drawdown for the proposed pumping rate is uncertain, as the efficiency of submersible systems is sensitive to head.

Windmills are known to generally produce only limited amounts of water. However, during periods of high wind, the pumping rate may be significant and may cause excessive drawdown and/or overpump the borehole. This problem occurred at Tlhareseleele (see VOLUME III: WINDMILLS). The use of windmills on lower yield boreholes should be approached with caution.

PV modules are currently quite expensive--in the range of P12/Wp, delivered to Botswana. There is a direct relationship between the number of modules and head for a given water demand. This means that it is very important to know the total pumping head when solar PV pumps are being considered. A small incremental increase in the power requirement results in a large cost increase, which is not true for diesel engines. Unfortunately, the accuracy with which some test-pumping is performed makes it difficult to calculate draw-own conditions for solar pumping rates. The current practice is to try to define drawdown at maximum yield, not an intermediate yield.

The use of low-yield boreholes to reduce the drilling requirement has been considered. In most instances, these boreholes yield less than 1.5 m^3/hr. If the resting water level is less than 30 meters, handpumps could be considered, depending to some extent on the borehole's location. Diesel pumping systems can be installed on these boreholes, which has been done in some extreme cases, but the investment is high relative to the amount of water pumped. Windmills exhibit characteristics that make them unsuitable for most low-yield boreholes. The use of solar pumps on such boreholes is technically feasible, as demonstrated by the BTC installation at Mogonye, but the cost may be high depending on the pumping head. Concern about declining yield for boreholes that already have low yields argues against the widespread use of expensive equipment on such boreholes. As mentioned above, most low-yield boreholes are not properly test-pumped, cased or developed--a process that costs on the order of P5,000. This also suggests that care should be used when considering the equipping of low-yield boreholes.

Conclusions

Borehole characteristics vary widely due to the different geological formations being drilled and their individual hydraulic characteristics. It is clear from drilling records that borehole and aquifer potential are not well understood for most of Botswana. More extensive test-pumping is one requirement for gaining a better understanding of prevailing hydro-geologic conditions. This should include greater use of observation boreholes, longer, more careful test-pumping, and long-term monitoring of water levels. Unfortunately, some of these practices are expensive. Observation wells are drilled at a cost of about P70/meter, and test-pumping costs P45/hour. When one borehole is sought for a rural village water supply or government camp, these procedures have not been considered cost-effective. However, more careful adherence to accepted test-pumping procedures and longer term monitoring of borehole water levels by pumpers are inexpensive methods that will help give a better understanding of long-term borehole performance.

Given the high cost of PV power and high incremental cost of oversizing the array to provide the power needed, special care should be taken with boreholes that may be equipped with solar pumps. The results of test-pumping that is properly done will enable prediction of the borehole's draw-down characteristics at the anticipated pumping rate, not just maximum yield. Of course, this level of testing should be performed on all potential production boreholes. Field practices for test-pumping need to be improved to provide this information.

If low-yield boreholes are being considered for production use because of need and poor prospects for locating a higher yielding borehole, every effort should be made to properly develop the borehole (i.e., achieve the highest sustainable yield possible) and test-pump it carefully. Depending on its location, handpumps are probably the most suitable type of pumping equipment. However, diesel and solar pumping systems should be considered in special cases.

APPENDIX D

Water Storage

Water storage is an issue that runs through the literature on pumping water using renewable energy, but despite concerns about storage issues and their effect, very little has been written on the subject. Although the five volumes in this series on SMALL-SCALE WATER PUMPING IN BOTSWANA do not specifically address water storage, it might be argued that this issue has been left out. This concern is justified as reliable water supply was the end goal of CWPP. With wind and solar energy, in particular, this implies water storage for calm or cloudy periods. The difficulty with integrating water storage more completely into the water-pumping analysis presented here and in the other volumes is that the issues are so complex, and a full study would be necessary to address all of the issues relating to water storage. This appendix merely serves to introduce those issues and briefly discuss the major relevant topics.

Purposes of Storage

There are four major purposes for including water storage in a water supply scheme:

- to provide system pressure from elevated tanks,
- to balance pumping and use rates,
- to provide storage during equipment malfunctions, and
- for renewable energy pumping systems, to provide overall reliability during periods when the energy resource is unavailable.

Any or all of these purposes can affect decisions about water storage. For major villages where multiple water sources are used, the size of the storage tank is usually determined by the need to balance the pumping rates from various boreholes with water use patterns. During morning and late afternoon, when water demand is highest, there must be sufficient water available. If the total hourly pumping rate for the village is less than the hourly water requirement during these periods, storage is necessary so that water will be available to meet the additional demand. Further, elevated tanks are used in major villages to provide the pressure needed to overcome losses in providing water to distant standpipes.

Other Issues Affecting Water Storage

Beyond the four major purposes of water storage, other factors affect decisions concerning the selection of a water tank, both model and size. The following subsections discuss several of these factors.

Size Restrictions

Many storage tanks are available only in incremental sizes, though this is not true for cement-brick, ground-level tanks. Rectangular, sectional, steel tanks can be made in different sizes but DWA has standardized on and purchases only 25, 50, 75 and 100 m^3 tanks. Curved, sectional, steel "squatter" tanks are purchased in 20 and 45 m^3 sizes. Corrugated, galvanized-iron tanks are available only in sizes up to nine m^3. Although this does not exhaust the available tank models, it serves to illustrate the situation.

The difficulty arises when the design for a rural village scheme calls for a 27 m^3 tank, for example. In such a case, a 45 or 50 m^3 tank is chosen, and the village may have three or four days of storage at its present consumption rate. In smaller cases, where five to 10 m3/day is required, a 20 or 25 m^3 tank must be specified. This would provide four days of storage, regardless of the pumping technology selected. When ground-level tanks are being considered, storage costs are much less because stands are not needed. Unless brick tanks are considered, the same situation with incremental availability applies.

In addition, the cost per cubic meter of water storage decreases as storage tanks increase in size. For sectional steel tanks, the size can be doubled from 25 to 50 m^3 with only a 40 percent increase in cost. This leads to the reasonable policy of choosing the larger tank when in doubt.

Costs and Lifetimes

Although water storage tanks are passive devices that do not require daily attention, they do not last forever nor are they maintenance-free. The useful lifetime of a steel tank is a function of water quality, the gauge of steel used, quality of the steel coating (usually galvanizing), environment where it is situated, and care with which the tank is manufactured and installed. If the water being stored is aggressive and the galvanized coating has been damaged or is not of high quality, a steel tank will begin to rust. In Botswana, the humidity is low, thus minimizing concern about environmental conditions.

Erecting tanks requires care to ensure that all the joints fit properly and are carefully sealed. This depends not only on the skill of the construction crew, but also the components, including care taken during component fabrication and attention to construction details so that field erection is not too difficult. The quality of cement-brick and ferro-cement tanks is much more a function of the builder's skill and care. There are no manufactured components and little chance of corrosion if they are built properly.

The useful lifetime of a storage tank varies from several years to more than 20 depending on the factors discussed above. Selection of an appropriate tank must weigh the purchase and installation price against its anticipated lifetime.

Maintenance of storage tanks involves periodic cleaning and patching, if necessary. The rusting of steel tanks can be limited, and deterioration of cement and ferro-cement tanks can be checked. In general, it appears that very little such maintenance is ever done. It is limited to repairs when tanks begin to leak, which is often too late to prevent rusting of the tank and stand. Vinyl tank liners are available in several standard sizes and can be made to fit any tank. Extreme care is necessary when installing these liners as they are easily damaged and can stretch and tear if the fit is not good.

Special Renewable Energy Pumping Requirements

When considering pumping systems, such as windmills and solar pumps, that cannot provide water on demand, concerns about the water supply's reliability arise. For these systems, water must be stored for calm or cloudy periods. The amount of storage required depends on the flexibility of water demand. For certain applications, such as domestic use, demand is fairly inflexible, but in others (e.g., livestock watering), there may be some short-term flexibility, particularly if another water point is nearby. Determining the proper amount of water storage for wind and solar applications is difficult and depends on the statistical variation of the energy source and user flexibility. A full analysis of these aspects of sizing storage systems is beyond the scope of CWPP. Indeed, very little work on this subject has been undertaken anywhere. However, a brief summary of current thinking on it is helpful in understanding the issue.

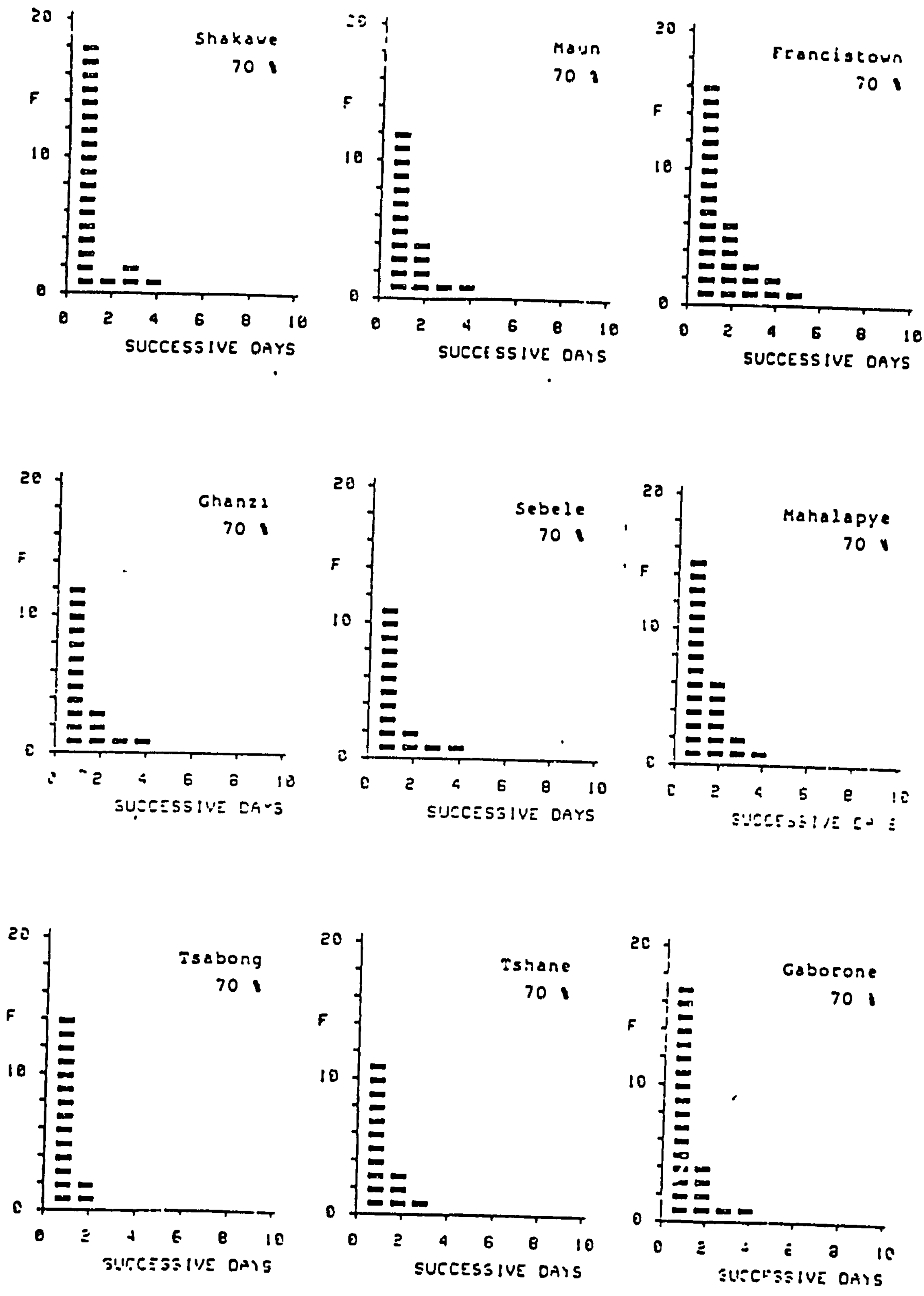
As is discussed in VOLUME IV: SOLAR PUMPS, the water pumped with a solar pumping system is a function of the solar radiation level. For systems without batteries, which provide storage in electrical form rather than as water in a tank, the instantaneous flow rate is also a function of insolation levels. Clearly, daily water delivery will depend on average daily insolation levels. Estimates of a solar pump's average production are based on average insolation levels over a month or longer, which ignores the fact that during shorter overcast periods (measured in days), water delivery may be significantly less than average. The issue is how much storage is necessary to bridge these overcase periods, and this depends on the duration of these periods.

Fortunately, information is available about the duration of cloudy periods in Botswana, a statistical summary of which can be found in "Clear Skies and Cloudy Days in Botswana" (J. Andringa 1987). The average number of days with an overcast of 50, 70 and 90 percent are given for nine stations. These values were determined as the percentage of a day where a trace was not burned in a Cambell-Stokes sunshine recorder. In addition, a summary of the frequency distribution for successive cloudy days is presented. The figure on the next page shows the summary for 70 percent overcast days. It reveals that the longest cloudy period with this level of overcast is four days for every station but Francistown (five days). This level of overcast corresponds to roughly 4.3 to 4.4 $kWh/m^2/day$. Although it would appear that storage in the range of four days would be needed to supply water during overcast periods, considerably more work remains to be done to verify this figure.

Water storage is also necessary to bridge calm periods for windmills. Wide variation in wind speeds and the fact that windmill performance is so sensitive to wind speed means that this subject must be given careful consideration, but again, very little work has been done on this topic. It seems clear that the duration of calm periods will be a function of average wind speed and the wind speed distribution. Given constant demand, the period of most concern will certainly be the lowest wind-speed period of the year when the likelihood of calm is also greatest.

Sizing a storage tank depends on the windmill's water delivery and water demand. A common rule of thumb is that three to four days of storage is sufficient for a windmill pumping system, but this is somewhat simplistic since it does not take into account some of the factors listed above. However, simple modeling techniques indicate that 90 percent of daily demand, fixed at the average daily output of a windmill, can be met by four days of storage, if the average wind speeds are above two m/sec, and three days of storage is adequate if the average wind speed is above three m/sec. It appears to be difficult to ensure that more than 90 percent of demand is met, although if the windmill is slightly oversized, all of the water demand may be met.

This topic needs closer attention and may affect pump selection, depending on water storage costs. It appears that three to four days of storage is a reasonable amount for both solar and wind pumps, but this is more than is now mandated for



Frequency distribution of successive days which were overcast for more than 70 % of the daylength. Nine stations of Botswana are presented.

rural village water supplies and incremental storage costs should be considered when choosing a pumping system.

Donor Involvement

In the water supply sector, the availability of donor funds, specifically those that are tied to purchases from certain countries, has an effect in several areas. Purchases under these restrictions often involve items with high capital costs that can be purchased easily--vehicles, pumping and drilling equipment are typical items. Storage tanks are also easily purchased with donor funds.

Several years ago, DWA received a shipment of Braithwaite tanks from the United Kingdom, and some are still in stock. The delivered price of these tanks several years ago was higher than what similar tanks can be purchased for today. Lipp tanks, which are very expensive, have also been purchased with Swedish "tied" aid. This is not to say that these purchases were imprudent. Decisions must be made in view of restrictions placed on donated funds, and these purchases were perceived to be the best use of those funds at the time. However, they do affect the overall decision-making process, if tanks are made available to the GOB at no cost besides the opportunity to purchase some other item. The availability of donor funds tends to favor more expensive, longer lasting tanks and the choice of larger ones for a given site.

Back-Up Water Sources

In most cases, pumping system users have an alternate source of water. In major villages, this usually takes the form of multiple boreholes. For livestock watering, it may be arrangements with nearby borehole owners for anytime when an engine or pump is out of service. The existence of back-up systems for the eventuality of a pump set being out of service lessens the need for water supplies that are 100 percent secure. In turn, this reduces the need for storage as a supply source during breakdowns. In addition, users often maintain a certain level of informal storage, if they perceive that a pumping system is performing irregularly. This typically takes the form of drums or containers of water that are kept separately from the main storage tank. To some degree, users can adjust their use of water if a temporary shortage exists. While these factors are neither well researched nor well understood, they do offer some flexibility for overall water pumping/storage system.

Types of Storage

Storage tanks fall into two general groups--elevated and ground-level tanks. In a few instances, a ground-level tank can be situated on a hill that is large enough so sufficient pressure can be provided for the water delivery system, but most rural villages must rely on elevated tanks for pressure. As mentioned previously, almost all livestock watering is done from ground-level tanks. The following two subsections discuss available elevated and ground-level tanks and their costs. Unless otherwise noted, those costs do not include tank construction.

Elevated Tanks

Most elevated tanks are made of steel or galvanized-iron on steel stands. Several types are used in Botswana. In addition, the Swedish Lipp tank is an elevated tank that includes its own base. Experiments have been done with elevated ferro-cement tanks as well.

Dorbyl, Braithwaite and View tanks are sectional steel tanks that are assembled by bolting together one m^2 steel panels. Tanks of various sizes and shapes can be fabricated in this manner. This type of tank has a good reputation as a solid long-lasting tank, if properly installed--the useful life of these tanks is estimated at 20 to 30 years. The major complaint about them is the difficulty of obtaining a proper seal along the edges of each section. They are also expensive, ranging in cost from P250 to P400 per cubic meter for tank sizes of 25 to 100 m^3. Sizes of 25, 50, 75 and 100 m^3 are commonly used, with a few special orders for even larger tanks.

"Squatter" tanks are cylindrical, sectional, galvanized sheet-steel tanks that are available through Hanoya Agricultural Engineering, a local firm. They are assembled at the site with bolts along vertical flanges. These tanks are more susceptible to corrosion than sectional steel tanks because the galvanizing is not as good and the quality of steel not as high. Hanoya tanks are available in two sizes, 20 and 45 m^3. Liners are available for them when they begin to leak badly. These tanks are no longer being installed by DWA, but the last tender prices for them (from 1985) were P420 and P250 per m^3 for the 20 and 45 m^3 tanks on six-meter stands with covers, respectively. Liners cost P750 and P1,100 for the two different sizes. Lifetime estimates for these tanks are five to 10 years without liners.

Lipp tanks have only recently been introduced in Botswana as a result of the tied-aid component of Sweden's involvement in the water supply sector. They were originally designed as grain silos, but are equally suitable for water storage as long as the seams are tight. The tank is constructed from the ground up using a continuous spiral of galvanized sheet steel. A special machine is required to bend, crimp and seal the seams during fabrication. The advantage of these tanks is that the top section provides elevated storage, which gives service pressure, while the lower section can hold a reserve supply that is accessed by a tap at the tank's base of the tank. The major complaints about this tank are its high cost, the specialized skills that erection requires and special care needed to ensure a proper seal at the bottom of the tank. No Lipp tank has been in use long enough to know how they will last. Using only on the elevated portion of the tank, the costs are about P2,000/m^3, including installation. However, if all of the water storage in the tank is considered, the price per cubic meter ranges from P300 to P500 depending on size.

Several suppliers offer prefabricated corrugated galvanized-iron tanks. They are available in several small sizes up to nine m^3. These tanks are inexpensive, but prone to leak if they are not handled and transported carefully. They also tend to deteriorate quickly, often lasting only one or two years. Tank liners are available for about P500. The cost of these tanks is in the range of P100/m^3.

The term ferro-cement describes a process of layering light-gauge wire mesh with cement to form a solid finished product. BTC has promoted this process for making water storage tanks. There has been some success with ferro-cement ground-level tanks, and several elevated tanks have also been built. The latter have developed leaks due to the difficulty of building such tanks on stands or because the stands were not stiff enough. These tanks cost P500/m^3, including installation.

Ground-Level Tanks

Ground-level tanks range from the Lipp tank (which is actually a ground-level tank) to locally made cement-brick tanks. All of the elevated tanks described above can be used as ground-level tanks by providing a proper foundation. A brief discussion of each major type of ground-level tank is given below.

Sectional tanks have already been discussed. When built on the ground, they tend to be easier to construct properly. Prices for these tanks decrease when the tank stand is not needed--they range from P150 to P225/m^3 or roughly 60 percent of the cost of elevated tanks. Clearly, there are major cost advantages to using ground-level tanks when possible.

Hydrocon tanks are similar in construction to the "squatter" tanks described above. Major differences are a larger diameter and inclusion of a polyvinyl chloride (PVC) liner at installation. The prices of these tanks range from P100 to

P200/m3 as the size decreases from 100 to 17 m^3. These tanks have only been introduced in Botswana during the last few years, so there is not yet enough experience with them to be able to discuss problems or their lifetime. There is no reason they cannot last 10 years or more if care is taken not to damage the liner.

Large-diameter, corrugated, galvanized-iron tanks are quite popular for livestock watering. They are large-diameter sectional tanks that are sealed and bolted together. They come in diameters of 20 and 30 feet and are six feet high. The cost is P8 to P9/m^3. These tanks have the same problem as the elevated ones in that they will only last several years. The typical local practice is to build a cement-brick tank inside the corrugated, galvanized-iron tank when it begins to leak too badly.

Cement-brick tanks are inexpensive and can be made in any shape or size. Their cost includes a high percentage of local labor compared to steel tanks. The main disadvantage is that they must be built carefully and sealed well. Brick bases can be made to elevate these tanks, and this is done, up to about a half meter. Higher brick stands are not used in Botswana. The cost of brick tanks is in the range of P10 to P25/m^3, including construction costs.

Ferro-cement tanks on stands have been discussed previously, and there has been more success with ground-level tanks than elevated ones. They are now being built in different sizes by several brigades and private contractors. To date, about 80 have been built for rainwater catchment and livestock watering. These tanks are attractive because they have a higher labor requirement with a low materials cost. The only difficulty is that care must taken to build these tanks properly so they do not leak. Ferro-cement tanks cost P75 to P100/m^3, including construction.

Life-Cycle Costs

The life-cycle costs of storage tanks depend on the tank's initial capital cost, repair costs and useful life. The initial capital cost includes the cost of the tank cost plus construction costs. DWA's Design and Construction section has crews who specialize in tank construction. They install "squatter" and sectional steel tanks, which are commonly used for rural village water supply schemes and at government posts. The installation of Lipp tanks is quite specialized, so this work is contracted out to a private firm. The remaining types of water storage tanks are constructed by private contractors or the owners. Costs for tank erection have not been carefully analyzed, and no clear figures are available for the different sizes and types of tanks. Estimates for these and repair costs (which are not zero) have been made to give some idea of the order of magnitude for the life-cycle cost of storage tanks.

Life-cycle costs for elevated storage are considerable higher than ground-level tanks, which is due partly to the cost of the tank stand and partly to the fact that more choices are available for ground-level tanks. The cost of water storage was calculated by summing the costs for tank purchase and installation, and then adding the present value of repairs and necessary tank replacement over a 20-year period. These costs were then normalized by dividing by the 20 years and tank size to give a price per cubic meter per year. For the most commonly used sectional steel tanks, the cost of water storage ranges from 20 to 15 P/year/m^3 as tank size increases from 25 to 50 m^3. "Squatter" tanks give higher values (30 to 50 P/year/m^3) because of their shorter lifetimes. The corrugated galvanized-iron tanks were even more expensive due to their small size and limited useful life.

Ground-level tanks are much less expensive. Sectional steel tanks are 40 to 60 percent cheaper simply from excluding the tank stand, but they are among the more expensive ground-level tanks at 15 to 20 P/year/m^3. Hydrocon lined tanks are almost as expensive at 10 to 15 P/year/m^3 as the tank size decreases from 45 to 20 m^3. Brick and ferro-cement tanks are less expensive at two to 10 P/year/m^3, depending on size. One advantage of brick tanks is that they can be built to any specifications. Corrugated-iron ground-level tanks tend to be more expensive than brick or ferro-cement tanks because of their short useful life.

These figures are only rough calculations of the cost of water storage, which is a significant part of the overall cost of delivering water. It is clear from these figures that water storage costs have less of an impact on overall costs if ground-level tanks can be used and more of an effect if smaller storage tanks are required.

Conclusions

From the foregoing, it is clear that there is a wide range of water storage options. Long-term costs will depend on the tank size and model as well as whether it is on the ground or elevated, as the cost of ground-level storage is considerably less than elevated storage. The more expensive tanks that are currently used in Botswana appear to be worth the additional cost, largely because their anticipated lifetimes are significantly longer. It is too early to tell whether the most expensive Lipp tanks will follow this pattern.

In addition, larger storage tanks are less expensive per cubic meter. The fact that most tanks come in only several sizes simplifies the choice of a tank in some ways, but complicates the analysis of proper selection techniques, particularly for renewable energy water-pumping systems. The size chosen depends on the purpose of storage. For wind and solar systems, it appears that storage of three to four days is sufficient, although more work needs to be done on this topic. In cases where ground-level tanks are used, the incremental cost of additional storage for wind and solar systems will not be large, but this may not be true if elevated storage is needed.

For remote rural villages, the currently available sizes of elevated storage tanks may not be sufficient if they are intended to provide water during equipment breakdowns, considering typical response times. If larger tanks are mandated for rural village water supply systems, this will tend to favor renewable pumping systems, and larger tanks may not be needed to provide for calm or cloudy periods. Further, the smallest elevated tank being used is 25 m^3 (DWA does not install nine m^3 corrugated galvanized-iron tanks), so four days of storage meets water requirements of 61/4 m^3/day and three days for 81/3 m^3/day.