SMALL-SCALE WATER PUMPING IN BOTSWANA

VOLUME II: DIESEL SYSTEMS

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ABBREVIATIONS AND ACRONYMS

AID	Agency for International Development, Washington, DC
BRET	Botswana Renewable Energy Technology Project
BRS	Borehole Repair Service
BTC	Botswana Technology Centre
CTO	Central Transportation Office
CWPP	Comparative Water Pumping Project
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)
kW	kilowatt
m^3	cubic meters
MHA	Ministry of Home Affairs
MLGL	Ministry of Local Government and Lands
mm	millimeter(s)
MMRWA	Ministry of Mineral Resources and Water Affairs
MOA	Ministry of Agriculture
MOE	Ministry of Education
NGO	nongovernmental organization
ODA	Overseas Development Administration
O&M	operation and maintenance
P	pula
PV	photovoltaic
RET	renewable energy technology
RIIC	Rural Industries Innovation Centre
SACU	Southern Africa Customs Union
SACU	Southern Africa Customs Union Agreement
SIDA	Swedish International Development Authority
TGLP	Tribal Grazing Land Program
USAID	U.S. Agency for International Development
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. 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 two consultants--Mr. Richard McGowan, engineer; and Mr. Ron White, economist. This report covers the work of the project from February 1986 through June 1987.

CWPP was a continuation of one component 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 assistance 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 (RIIC), and the water engineer at the Ministry of Local Government and Lands (MLGL) were very useful and gratefully accepted. The support and assistance provided by the REDSO energy advisor, Mr. C. Anthony Pryor, in initial support of the activity and its ongoing evaluation were also invaluable.

I. EXECUTIVE SUMMARY

The Comparative Water Pumping Project (CWPP), a pump testing and evaluation program in Botswana, was jointly funded for the past three years by the U.S. Agency for International Development (USAID) and the Ministry of Mineral Resources and Water Affairs (MMRWA) of the Government of Botswana (GOB). The pump testing and evaluation program began under the auspices of the Botswana Renewable Energy Technology (BRET) Project, managed by Associates in Rural Development, Inc. (ARD). It focused on the installation, testing and evaluation of a wide variety of diesel, wind, solar photovoltaic (PV), grid-electric, and human- and animal-powered pumping systems throughout rural Botswana. This earlier phase field-tested diesel pumps at five sites, and the results were included in the BRET report, WATER PUMP FIELD TESTS IN BOTSWANA (McGowan and Hodgkin, 1985).

Because of a perceived need to maximize the benefits from the work completed under the BRET project by gathering longer term data on the recurrent costs of the systems evaluated, CWPP was funded through the Water and Sanitation for Health (WASH) Project of USAID's Bureau for Science and Technology (Office of Health) and MMRWA. This additional data collection and evaluation effort revised the research focus to include not only tests of additional systems in each of the technology categories, but a detailed review of available secondary data on the cost and performance of conventional diesel pumps in Botswana. The results of CWPP are contained in the five-volume report, SMALL-SCALE WATER PUMPS IN BOTSWANA (Hodgkin, White and McGowan, 1987).

This report on diesel pump use in Botswana focuses on the detailed results of the diesel evaluation. The major objective of CWPP's diesel analysis component was to provide a basis on which to judge potential opportunities for using renewable energy technologies for water pumping. The work evolved to include three major tasks:

- development of a combined technical and economic model with which to evaluate the costs and performance of existing engines, and use of the model's sensitivity analysis capability to develop a series of recommended cost reduction strategies;

- evaluation of secondary data on existing pump sets, including review of the operation, maintenance and repair records of the Department of Water Affairs (DWA) and the District Councils, as well as extensive interviews with Water Maintenance Unit technicians, private-sector users and entrepreneurs; and

- continued field-testing of 10 diesel pumping systems currently used in situations typically encountered in rural Botswana.

The latter two tasks were used to generate data for verification of the technical/economic model. The review of existing secondary data, complemented by interviews with a wide range of individuals in the public- and private-sector maintenance and sales organizations, was used to quantify capital and long-term recurrent costs of diesel pump use. The goal of the field-testing was to quantify performance, e.g., fuel consumption and water output, for particular models of engines and pumps. The measured values were then used to confirm similar calculations made from operational records kept by pump operators. This gave confidence in using the processed data from logbook records to estimate performance and costs of diesels over the expected lifetime of the systems.

Major conclusions from the testing and evaluation program include the following:

First, in Botswana, well-coordinated donor and GOB policies have resulted in an unusually well conceived and supported diesel pumping program. However, the capacity of District Water Units to provide operation and maintenance (O&M) support is being taxed as the number of village water supply schemes increases.

Second, equipment standardization has contributed substantially to the success of this program, giving Botswana an institutional and private-sector base from which to expand its water resources development efforts that is stronger than that in much of Africa.

Third, equipment choice and O&M practices vary significantly among different pump users. For purposes of this analysis, users were divided into four major groups: major villages, rural villages, other government agencies and private users. Pumping costs were found to vary significantly across these user groups.

Fourth, DWA's stated policy, to provide potable water to all villages in Botswana, is an important goal. However, as water is supplied to smaller and smaller villages, unit pumping costs increase dramatically.

Fifth, typically, engine loading (hence operating efficiency) is considerably less than optimum. This increases specific fuel consumption (liters of fuel consumed per unit of water pumped) as well as maintenance and repair requirements, thereby increasing the unit cost of pumping water.

Sixth, low borehole yields are a major problem in developing water sources in Botswana. This problem is frequently compounded

by poorly defined characterization of borehole yields, often leading to inappropriate choice of equipment.

Finally, the heavy reliance on diesel systems for water supply will compound problems that may surface should fuel, spare parts and related equipment suddenly become difficult to obtain because of possible regional instability.

Existing pumping practices have served the people of Botswana well in the development of their water resources. To help insure that they will have access to the quantity and quality of water supplies to which they have become accustomed, there is a growing need for cost reduction measures, an increasing focus on equipment reliability, diversification of system types, and continuing analysis of changing conditions that affect cost and performance. Based on these conclusions, the following recommendations are made:

First, design procedures should be modified to improve engine loading, efficiency and cost. More appropriate engine choice and a wider range of engine operating speeds hold the potential for significant cost savings (as much as 31 percent in some cases). In addition, the use of smaller engines (non-Lister) should be considered as service is extended to smaller villages with lower demands.

Second, the GOB should review current policy, which stipulates the use of a full-time pumper. In many instances, a part-time pumper could more than adequately perform all necessary operator duties required, at a considerable savings in operating costs.

Third, proper test pumping of boreholes to more precisely determine long-term borehole yield should be encouraged. This would help to reduce pumping costs, insure improved load-matching of systems and avoid over-pumping of boreholes.

Fourth, to reduce the nearly exclusive reliability on diesel pumping systems, the GOB should consider the use of pumping equipment alternatives in situations where they show the most potential for being cost-effective.

Fifth, increased emphasis should be placed on the implementation of operator training and preventive maintenance programs. This should include implementation of more extensive training program to instruct pump operators in O&M procedures that they can perform on-site without skilled technical assistance, adoption of a preventive maintenance program to reduce recurrent costs, and better planning of transportation needs to reduce the number of trips required to support a given system.

Sixth, the institutional capability to perform technical performance and cost analysis of diesel (and other) pumping systems should be developed, allowing better-informed planning and equipment choices. Water Unit technicians' familiarity with the method of analysis should be developed through training programs at the Botswana Polytechnic.

Finally, it is clear that an awareness and public information campaign to inform private-sector users of the cost implications of improved maintenance would result in improved reliability and cost savings. Studies to better determine the range of private-sector pumping practices and costs would serve to more accurately define the most cost-effective focus of the campaign, as well as to better understand the largest diesel-pump user group in the country.

II. INTRODUCTION

CWPP was an outgrowth of the pump testing and evaluation component of the BRET project. As the BRET project approached completion in September 1985, it became apparent that while many pumps had been installed and tested, the data base of long-term operation, maintenance and repair information necessary for accurate characterization of system recurrent costs was not yet adequate. Fortunately, additional funding for continuation of the pumping work was provided by the GOB and through USAID's WASH project. This report focuses on the diesel pump component of CWPP.

A. Purpose

During the initial stages of CWPP, the purpose of the field-testing and analysis of diesel pumping systems was primarily to provide baseline data so that the technical and economic aspects of renewable energy pumping systems could be compared to existing diesel technologies. An extensive secondary data collection effort focusing on diesel pumps was not included in the initial work plan. As the work progressed, however, several things became clear. First, although diesel engine technology is relatively mature, factors affecting its use and cost in Botswana are in a constant state of flux as equipment and labor prices, local technical and management skill levels, and effectiveness of the support infrastructure (for installation and service) evolve. Second, the costs and reliability of diesel pump systems are particularly sensitive to human factors, such as following proper installation and O&M procedures. With these considerations in mind, the initial work plan was revised to include a considerably more extensive analysis of diesel pumping systems than was originally anticipated. Fortunately, it was possible to expand the diesel pump effort within the framework of the existing project. The scope of the work thus became threefold:

- to characterize as fully as possible the use of diesel pumps in Botswana, with the goal of determining typical system reliability and costs for different user groups in both the public and private sector;

- to identify suggested strategies that could be used to increase water availability, improve system reliability and decrease the costs of water pumping with diesel engines; and

- to provide baseline data for comparison of water pumping technologies.

B. Scope of the Work

Botswana's water resources development program is fairly rare in that there is an unusually high level of equipment standardization. In the public sector, this is the result of de facto policy decisions. In the private sector, it is due largely to standardization in the public sector and to the wide availability of Lister engines and Mono pumps. Although definitive numbers are not available, it is estimated that about 90 percent of the diesel engines currently used for water pumping are Listers. Most of these are the small-scale, water-cooled S, L and HR series engines rated at less than 10 kilowatts (kW) output. While the present report focuses on these particular engines, there is also some discussion of other less common engine makes and models. This was not originally intended to be a detailed technical report on the performance of diesel engines, but rather a descriptive overview and analysis of the current diesel pumping situation, to be used to make cost and performance comparisons with other pumping system alternatives.

This report examines use of these engines within the specific context of the major user groups in the country. In the public sector, this includes DWA, which is responsible for major village water supplies, the District Councils which are responsible for rural village water supplies, and other ministries, primarily the Ministry of Agriculture (MOA) but also the Ministry of Education (MOE), the Ministry of Home Affairs (MHA) and others. This last group is referred to collectively as other GOB agencies. In the private sector, major user groups include privately owned equipment in the freehold farm areas, Tribal Grazing Land Program (TGLP) ranches, the communal lands areas and collectively owned equipment, although these are lumped together for the detailed analysis due to the limitations of available data.

C. Approach

In order to characterize diesel pump use in as inclusive a way as possible, a variety of primary and secondary data sources were examined. An initial review of existing pumping records made it apparent that these records were often incomplete. In cases where the records were complete, they were probably not representative of the particular user categories. If one assumes that individuals who keep good records are much more apt to carefully maintain their equipment as well, reliance on this information could skew the results of the study. Therefore, numerous site visits and specific tests were conducted to complement the secondary data. In addition, interviews were conducted with diesel pump users, equipment suppliers and government officials, and survey instruments were developed and

used to assist in the characterization of private-sector engine use.

Although it was impossible to gather all of the information one might hope for in a study of this sort, the data base assembled during CWPP begins to define a consistent whole from which useful conclusions can be drawn. However, the reader should bear in mind that the diesel pumping situation in Botswana will likely evolve over time as changes continue to occur in the:

- level of donor activity in the public sector;
- willingness and ability of the GOB to support water-sector programs;
- skill levels of available technicians and supervisory personnel; and
- political and economic situation in southern Africa.

D. Organization of this Report

This volume of the overall report is intended to provide a basis for understanding current small-scale (primarily diesel) water pumping practices. Sections III and IV of this volume cover the historical background, infrastructural aspects, and a description of current water-sector activities in Botswana. These sections contain a detailed examination of the existing maintenance and repair support infrastructure, including relationships among the major players in the water supply sector and their specific responsibilities. These initial sections provide the context for the technical and economic sections that follow.

The main technical presentation comes next. Section V contains a description of the testing and evaluation methodology, its goals and limitations. This section also describes the secondary data collection methods used, and the means of verifying the validity of this information. Section VI provides detailed descriptions of the most common types of systems used, the reasons they are used, and site selection procedures and design considerations. Section VII focuses on operation and maintenance, describing the results of both the equipment testing and secondary data analysis, and describes typical O&M requirements and procedures by engine type and major user group. The financial and economic analysis in Section VIII explores the implications of the current procurement and O&M practices on the life-cycle costs of diesel pumping. This section includes the methodological approach and assumptions used in the analysis, then develops a detailed base case, which is used in the sensitivity analysis. The analysis is then extended to cover

other types of engines and other major user groups. Section IX gives the overall conclusions and recommendations, which focus on a series of specific intervention strategies for reducing the costs of diesel pumping, as well as suggestions for further data collection and analysis that would be useful in refining these strategies.

III. HISTORICAL AND INSTITUTIONAL BACKGROUND

The current state of water pumping in Botswana is the product of a sequence of past decisions and circumstances. A brief look at this sequence of events provides a context for better understanding existing pump-related policies and practices.

A. Early Activities (1920-75)

The British Protectorate of Bechuanaland was governed by the colonial administration, based in Mafeking, South Africa, prior to independence in 1966. The colonial administration began purchasing drilling rigs with colonial development funds shortly after the first boreholes were drilled in Botswana in the 1920s. From the outset, the colonial administration's goal was to lease out the equipment to recover the operating costs of the rigs. However, the tribal authorities and white freehold (landowner) farmers exerted pressure on the colonial administration to subsidize both the drilling and equipping of boreholes for domestic water supplies and cattle watering.

Over time, this pressure led to evolution of the policy that the colonial administration (the British) would pay for most of the capital costs of borehole drilling and equipping, as well as the repair costs for domestic water supply for the Batswana (people of Botswana). The tribal administration (the Batswana) paid the operating costs to cover fuel and employment of a pumper. The policy's objective was to pass on the financial responsibility for supplying water for cattle and irrigation needs to the user. This led to the interpretation that the tribal administration would operate boreholes for cattle watering, and users would pay fees for the water they consumed. This situation continues today at some boreholes operated by the District Councils. Although the colonial administration agreed to organize and pay the repair costs for systems serving domestic needs, it remained unclear whether villagers should pay fees or whether this water should be free.

After independence in 1966, a national development plan was written. In this plan, the importance of water resources, their rational use, and the careful conservation of water were clearly defined as critical to the country's development. At this stage, it was stated that "wherever possible the Government will press for water supplies to be placed on an economic basis and subsidies will be progressively eliminated." At the same time, it was recognized that water supplies would continue to be subsidized for the foreseeable future, and that "the Government is determined that users of water meet the cost or if there is a

subsidy, that the size of the subsidy is clearly identified and made known."

From the beginning, then, it has been clear that water supplies, particularly for domestic use, would be subsidized by the GOB. However, the goal has been to eventually eliminate or at least to reduce the subsidy as much as possible. To this end, the Water Utilities Corporation (WUC) was chartered to provide water where it was felt that costs could be covered by the collection of user fees (i.e., in urban areas). In smaller villages, initially, a levy was assessed to try to help cover the costs of providing water where water was available from centrally located standpipes. However, this levy was abandoned, and while the subsidies (partially covered by donor activities) still exist, the exact levels are difficult to determine. Thus, the GOB has become inextricably involved in the provision of domestic water for a large portion of the population.

There are more than 10,000 boreholes in Botswana today. However, many of these are not equipped due to low yield or poor water quality. It is estimated that there are between 4,500 and 5,500 boreholes equipped with diesel pumps. Of these, about 100 provide water for the major villages (administered under the DWA), 525 are operated by District Councils, 300 are operated by other GOB agencies, and the remainder (between 75 and 80 percent) are operated by the private sector. This listing excludes WUC installations, since they do not use diesel pump sets. Of the engines in the field, more than 90 percent are single-cylinder models. Approximately 85 to 90 percent of the engines are Listers or Lister copies such as the Indian Metex and Induna. The total fuel consumption of these engines is estimated to be between eight and 10 million liters per year.

B. Current Government Activity

The GOB's current general objectives for the water sector are:

- continue development of new village water supply schemes;
- focus on the health issues 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. This is in agreement with the general

development objectives of the country, which include "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, p. 60). While the economic viability of these programs is not the major issue, the GOB is not interested in spending more than is necessary to meet these objectives. Government agencies involved in water-sector activities are described in the subsections below.

1. Ministry of Mineral Resources and Water Affairs

MMRWA has overall responsibility for much of the public-sector water resources and development activity. Two of its departments as well as a parastatal organization under its jurisdiction are involved with water resources development--the Department of Water Affairs (DWA), the Geological Survey (GS), and the Water Utilities Corporation (WUC, the parastatal).

DWA is responsible for water supplies outside the six main urban and mining areas, surface water investigations, protection of water sources from pollution and aquatic weeds, and overall water resources planning. Within this mandate falls borehole siting and drilling, system design, water law (the Water Apportionment Board), and the operation and maintenance of 17 major village water supplies. Operation and maintenance of rural village supplies falls to the District Councils. Currently, DWA is involved in implementing the Village Water Supply program; village water supplies rehabilitation; water supply schemes funded under drought relief; planning, upgrading and expansion of 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 covers the regional and local search for groundwater sources, regional hydrological mapping, and the compilation of basic data on boreholes in the borehole registry. The borehole registry is intended to be the information base on all boreholes in the country, providing drilling details and yield characteristics. All boreholes should be registered by number with the GS. These functions, although not directly related to use of diesel pumping equipment, form an important part of the mosaic of water sector activities.

WUC is responsible for all urban water supplies, except for the closed diamond-mining town of Orapa where the mine is responsible for water supplies. The urban centers are Gaborone, Lobatse, Francistown, Jwaneng and Selebe-Pikwe. The total water consumption in these four centers in 1984-85 was 23.6×10^9 m^3, or a bit less than 18 percent of the total water use country-

wide. All significant water pumps and booster stations are large-scale and electrically driven. No further consideration need be given to WUC activities, as they fall outside the scope of this study.

2. Ministry of Local Government and Lands (MLGL)

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

- drought relief program (with funds sub-warranted from 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).

The District Councils are responsible for the operation and maintenance of rural village water supplies. To fulfill this responsibility, the councils all operate water departments or water units (under the Works Department). For a listing of these departments and units, see Appendix A. Budgets earmarked for this work are made available through council revenues and from 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 (P1.00 equaled US$0.595 as of April 1987) are assessed for users with private connections, and the fee for stock watering (at council-operated boreholes) averages P6/head/year.

3. Other Government Agencies

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

- Department of Veterinary Service--Animal Health Unit, Trek Routes Unit, Tsetse Fly Control Unit;

- Department of Agricultural Field Services--Artificial Insemination Unit, Communal Areas Management Unit, Ranch Extension Unit, Irrigation Unit, 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. In addition, most other ministries have agencies that require water for special purposes. A full list of these and the number of boreholes are is given in Appendix C.

C. Donor Activity

The Swedish International Development Authority (SIDA) has been the largest single donor in the water supply sector over the last decade. This long-term commitment by one donor has allowed a comprehensive, integrated approach to water supply problems. Several important results are that this approach has encouraged a considerable degree of standardization of pumping equipment as well as an in-depth understanding of O&M issues, which has led to provision of substantive support to District Councils. SIDA is currently involved in the Village Water Supply program, the rehabilitation program, support to District Councils, water quality, training, planning and technical assistance.

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

As is the case in many other countries, donor 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, as well as deadlines for expenditure of funds, has encouraged the purchase of capital items such as trucks, pipes, and water storage tanks with these "tied aid" funds, leading to what might appear to be less than optimum choices. Botswana is also finding that certain donors

are not allowing purchase of South African products. This artificially constrains the choices open for use of the funds, especially as Botswana has depended heavily on South African products historically. Although these donors are clearly trying to wean Botswana from such heavy dependence on South Africa, it considerably complicates activities in the water supply sector.

There are several nongovernmental organizations (NGOs) operating in the water sector. Lutheran World Federation is the most active, assisting with the financing of specific borehole-equipping and village reticulation (distribution) projects.

D. Private-Sector Activity

Formal private-sector activity is confined to hydro-geology and engineering consultants, drilling, sales of equipment, borehole equipping, and engine overhaul.

There are 12 Lister 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 supply of engines and a supply of spare parts. Almost all of the equipment originates in South Africa, and procurement is easy and straightforward. Botswana belongs to the Southern Africa Customs Union (SACU). This allows a free flow of goods from South African suppliers as well as access to foreign currency. In most cases, equipment can be ordered from the South African wholesaler by telephone and delivered within several days. Thus, Botswana-based suppliers can avoid the added expense of large inventories.

There is, at present, no private-sector fabrication of pumping equipment, although the Rural Industries Innovation Centre (RIIC) is pressing for local manufacture of several of its pumps. There has also been some interest recently in the manufacture of handpumps, and 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 (a design whose development was supported by the World Bank) by the Serowe Metalworking Brigade.

Private engine-rebuilding shops do exist to overhaul Lister engines, as well as to serve the automotive trade. There are fewer than 10 of these shops in Botswana, performing roughly 200 engine overhauls per year. Some overhaul work appears to be done outside Botswana in South Africa, Zimbabwe and Namibia. DWA, through its Borehole Repair Service (BRS, which also serves the private sector) performs about 100 to 150 overhauls a year for private-sector engine owners.

While there are no formal-sector companies (duly registered Botswana companies) performing field servicing of engines and pumps, there are strong indications that a large informal sector is at work in this area. Technicians performing these field services (including engine overhauling in the field) vary considerably in their skill levels. Some are undoubtedly trained technicians, performing services on their own time while holding down a job with the government or in the private sector. Others are self-taught individuals who have demonstrated the ability to keep equipment operating. Some of the servicing is also performed by the engine owner in an effort to save the cost of hiring others.

IV. SUPPORT INFRASTRUCTURE

The support infrastructure for diesel pumping systems is divided in several important ways. First, there is a division between the private and public sectors, with some aspects of public-sector activity overlapping into the private sector. Second, several different ministries in the public sector are involved heavily in water pumping activities, primarily MMRWA and MLGL. This section examines the diesel-pumping support infrastructure in Botswana, and discusses the respective O&M strategies, responsibilities and capabilities of each of the groups involved.

A. Department of Water Affairs

DWA has four operational divisions (Hydrology, Groundwater, Design and Construction, and Operation and Maintenance) and four support divisions (Administration, Supplies, Accounts and Training). An abbreviated organization chart is given in Figure 1. All divisions of the organization are under considerable pressure from many sides due to the recent drought conditions and need for more water sources, lack of adequately trained staff (particularly at the senior technical and professional levels), and chronic transportation shortages. A brief summary of the activities of the operational and support divisions and a description of their technical training programs are given in this section.

1. Hydrology

The Hydrology Division is responsible for water resources on a macro level (i.e., in terms of well fields, not specific boreholes), planning and water allocation. The major activities that fall within this division include studies of water development possibilities, control of aquatic vegetation and water law. The Water Apportionment Board, which is responsible for the regulation of water usage, is located in the Hydrology Division.

2. Groundwater

The Groundwater Division is responsible for borehole siting and drilling. The goal of the division is to site all boreholes to maximize the drilling success rate. Due to pressure on the drilling program, technical siting methods are probably computed for fewer than three quarters of the boreholes drilled. Most of the government drilling work is also done by this division, although some work is contracted to private-sector contractors.

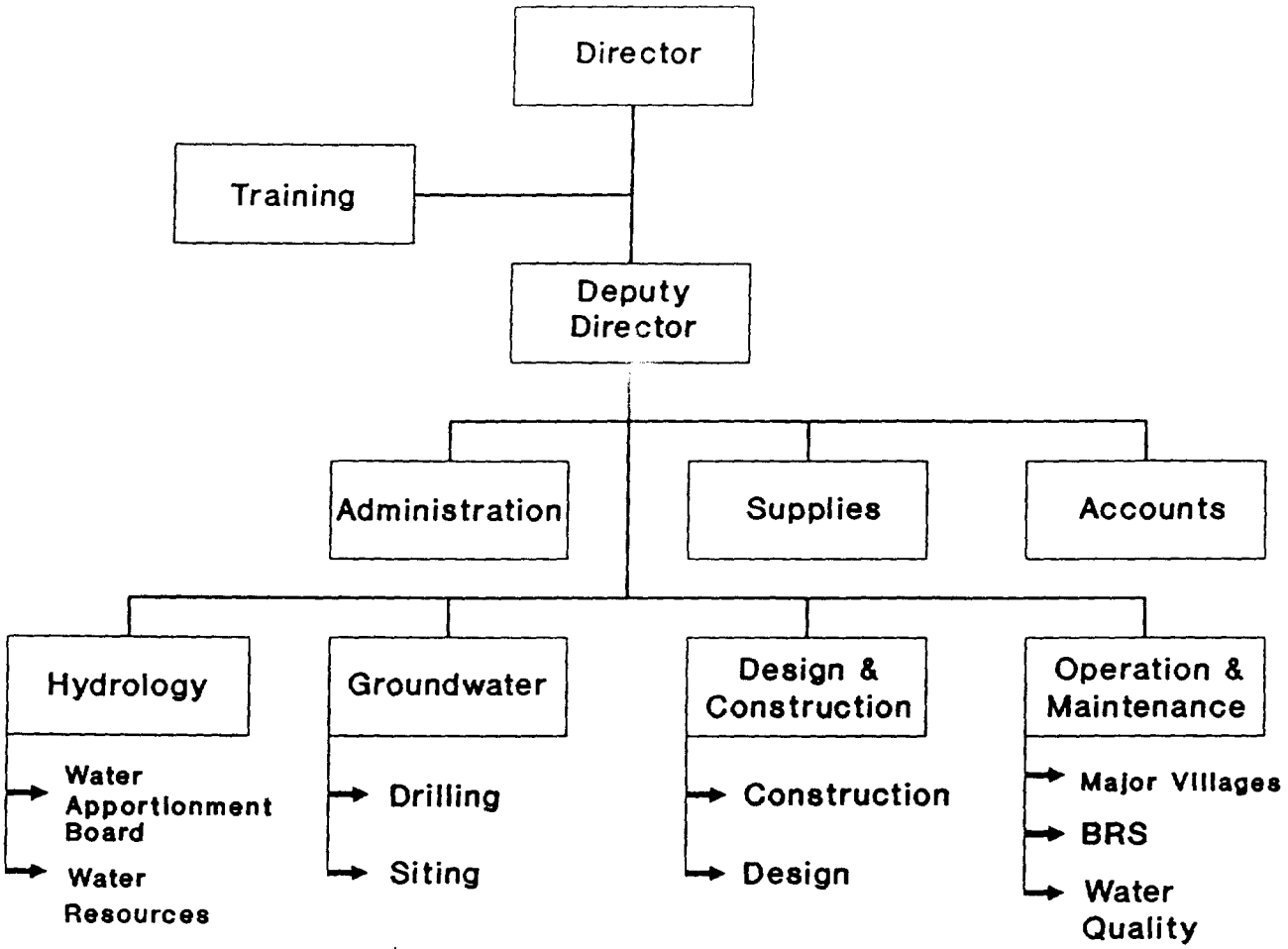

Figure 1. Department of Water Affairs

There are six rotary borehole drilling rigs, seven percussion rigs and three new cleaning rigs. The capacity of the drilling section is about 200 boreholes per year, with a success rate of about 50 percent (which varies with local geological conditions). This success rate is considered good when hydro-geological conditions are taken into account. The drilling section is also responsible for test-pumping of boreholes to determine yield and recharge rates, and for collection of water samples for laboratory analysis of water quality. In the past, test-pumping of boreholes was minimal, with tests often lasting only 12 to 24 hours or not performed at all. Current policy is to complete a 48-hour pump test and 24-hour recovery. Unfortunately, these tests are often not performed carefully, and results are of questionable value for determining drawdown at different pumping rates. As discussed in later sections, this can have significant adverse effects on pump selection.

3. Design and Construction

The design section is responsible for selecting the equipment to be used for all government boreholes. This includes major villages and government agency users, such as the Department of Wildlife, police camps, Botswana Defense Force camps, customs and immigration posts, and MOA departments. A list of these agencies is given in Appendix C. At this point, a large portion of the section's work is for MLGL in support of rural village water supplies. This work is divided into three main parts. First, the Village Water Supply Program seeks to establish new water supply schemes in rural villages, including reticulation systems, storage tanks and public standpipes. The goal of this program, underway for more than 10 years, is to establish 354 village schemes by 1991. More than 285 village systems are now complete.

The second focus of MLGL's water development activities is the rehabilitation of village systems built in the early part of the program. Villages which had systems rehabilitated later in the program have benefited from the lessons learned in design and construction techniques. Also, many villages have grown faster than initially anticipated. This has led to the need for rehabilitation of many previously installed village systems. Local consultants have been involved in some of this work.

The third MLGL support activity is part of the Drought Relief Program. Under this program, villages considered to be in extreme need as a result of the current drought conditions are considered for borehole drilling and equipping.

The construction section is responsible for engine installation, laying pipelines, erecting storage tanks and installing public standpipes. This section has 30 crews based in

Gaborone, Francistown and Maun. These are divided into borehole-equipping, tank erection and general crews. There are seven borehole-equipping crews with a capacity of about 70 boreholes per year (10 boreholes per year per crew). The common mode of transport for the section is 10-ton Scania or Toyota trucks. A few seven-ton Toyota and five-ton Bedfords are also available to the construction section.

4. Operation and Maintenance

Operation and maintenance of water supplies for the 17 major villages is the responsibility of this division. These 17 villages tend to be those with larger populations or special water treatment requirements. A listing of these villages can be found in Appendix B. Although rural villages are designed and built by DWA, the O&M function is performed by the District Councils. At present, this includes about 90 diesel engines for boreholes and booster pumps (about a third are single-cylinder engines), and fewer than 10 electric pumps. There is a DWA office in each of the major villages to perform or oversee repairs and collect revenue from those with private connections. The current tariff for water is P0.30 per cubic meter. The rate is currently under review and will most certainly be revised upwards. Repair and maintenance for the major village diesel sets are performed by the DWA office or the nearest BRS outstation and paid for out of DWA's current funds. Transportation is usually provided by Land Cruiser or by five-or seven-ton trucks.

The borehole and pumping situation is in a constant state of flux in many villages as conditions and needs change. In many cases, these major village systems are pushing the limits of borehole yields, requiring engines to be run for long hours. In several villages there are active programs to identify new well fields to meet increasing demand. The broader aspects of the well field hydraulics are only now being understood more fully. Only recently has it been possible for longer term management to replace the crisis management approach that had existed in the past. This will allow the section to concentrate less on the search for water sources and more on cost-effective management of existing systems.

BRS is also administered under this section. Originally established as the Borehole Preventive Maintenance Service (BPMS) in the 1970s, BRS was not able to fulfill its original mandate (to provide maintenance service to government agencies and private subscribers) and was therefore redesignated as BRS. The responsibility of BRS is twofold: to service boreholes for other government agencies, and to service private subscribers to BRS. BRS currently services all boreholes for other government agencies (about 300) and has about 1,200 private subscribers

(about 50 percent are in arrears and no longer receive service). Originally, an annual subscriber fee was charged to each private subscriber, but several years ago the system was changed. Now a flat fee of P80 is charged for service calls. The average number of service trips is about one per year per borehole (when non-payers are accounted for).

BRS also maintains workshops in Gaborone and Maun that perform major service to both government and private subscribers. These services are primarily engine overhauls, but also include repair of pump heads and Mono pumps. The capacity of these workshops is about 450 engines per year. The charges for rebuilding include labor at a flat P80, plus machine shop charges (if any) and parts (at the government tender price). BRS also operates a program through which engines are loaned to subscribers while theirs are being overhauled. The charge is P3/day, to a maximum of 90 days. It is assumed that any delay in return of the overhauled engine beyond 90 days is the fault of BRS. The services of BRS are provided at no cost to other government agencies. Although there are charges for service to private subscribers, the service is subsidized.

The third section in the division is the water quality section, which has responsibility for both chemical and biological analyses of water samples from all boreholes. Water quality standards are based on World Health Organization (WHO) recommendations. Water that does not meet these standards is not used for human consumption--new boreholes are sited and drilled. High salinity is the most prevalent water quality problem, with large areas around the Makgadikgadi pans and the far western regions affected. It is in these areas that siting work is important, as successful boreholes (from a quality standpoint) are hard to find.

5. Training

The activities of the training section fall into three main categories: overseas professional training, technical training both in Botswana and in the region, and mechanics' training. Professional training takes place at the university level, largely in Europe and the United States. This level of training is supported by donors, and candidates are often chosen from the ranks of DWA staff. Returning graduates are placed in the departments which best suit their skills, but the immediate needs of the various departments are also considered. The terms of the overseas study agreement require that the returning graduates work for the GOB for a specified time. It is, however, possible to repay the government and remove this obligation, and this is sometimes done. As a result, DWA has some difficulty in retaining professional staff, as the salaries in private business are often higher.

Technician training often takes place at the Botswana Polytechnic. The Polytechnic has a water technicians' training program that is usually fully enrolled with DWA and District Council candidates. DWA supports the program by providing instructors for various courses over the three-year period of study. There are other regional programs (in Zimbabwe, Zambia and Swaziland) that accept students from Botswana for courses of varying length. Funds to cover these students are usually provided by donors, and candidates are selected from current DWA personnel. Returning graduates often return to their old positions at DWA.

Training for borehole mechanics, pipe fitters, drillers and other tradespeople takes place at DWA thorough periodic courses. The Department of Public Service Management's Trade Test Centre administers certification tests at three levels for most trades. Certification allows movement up the scales of responsibility and salary. These training courses are open to candidates from other ministries as well, with MLGL taking greatest advantage on behalf of the District Councils. There is less job stability in this group, as only the most highly qualified receive "permanent and pensionable" posts. As a result, graduates move relatively easily among government, council and private posts.

B. District Councils

District Councils are responsible for maintaining the engines and pumps that service rural villages. These villages are spread throughout the country, and are often several hundred kilometers from the District Council headquarters (where service centers are located). In recent years, the number of these village water supply schemes has increased dramatically--nearly doubling, to more than 500 boreholes, in the last 10 years. This is largely the result of the Village Water Supply Program. There are water departments in two districts (Ghanzi and North West); in the rest, there are water maintenance units that fall under the Council Works Department. In Central District there are five subdistricts that maintain their own water units. There are 13 water units or departments country-wide. The difference between water units and water departments appears minor, but has significant implications in terms of authority, budget and priority within the District Councils. These departments and units are responsible for anywhere from fewer than 20 to more than 75 boreholes each. In several districts, sub-depots are being established to more effectively respond to breakdowns and maintenance needs. A full listing of the water units, departments and sub-depot locations can be found in Appendix A.

The Swedish donor organization SIDA has been closely involved with developments in the public water sector. As a result of a study completed in 1979 (Ashford and Miller), a major

effort to upgrade the councils' capacity has been undertaken. This has had a major impact on the District Councils' effectiveness. The effort included placing an expatriate water engineer at MLGL to assist in disbursing funds and help water technicians with technical and logistical problems. Expatriate technicians headed most of the water units and water departments in the recent past, while an extensive water technicians' training program was undertaken at the Polytechnic. High levels of funding were provided to purchase tools, upgrade equipment and acquire vehicles. This effort is now drawing to a close, as the posts of water technician were localized in all districts by the end of 1987, and the upgrading funds were expended. Abnormally high levels of funding can be anticipated over the next several years due to other donor activity in this area and to the availability of drought relief funds.

The effort to upgrade District Council effectiveness in water supply program implementation is a good example of how infrastructure and logistical advances can affect the reliability and cost of diesel pump systems. During the last several years, funds have been used to purchase new vehicles, making the transportation system more reliable. Furthermore, most districts have replaced worn-out or marginally serviceable diesel engines with newer models. This will reduce maintenance requirements for the next several years. In most cases the technicians are now able to implement (or at least plan) preventive maintenance programs, rather than devote of their time to breakdowns. Unfortunately, even with recent donor assistance, it has not yet been possible to institute preventive maintenance programs in the larger districts (measured in numbers of boreholes or in geographical area), as the time and energy demanded by breakdowns has been too great.

All of this has had a large impact on the cost and reliability of the water supplies. Ninety percent of all rural water supplies are estimated to be operational at any given time. It remains to be seen whether the recent Polytechnic graduates will gain experience fast enough to maintain the current level of service. It also remains to be seen whether sufficient funding will continue so that this level of service can be maintained.

C. Private Sector

Private-sector use of small diesel-engine pump sets easily exceeds the total of all government installations. Almost all private pump sets are used for stock watering. In order for private citizens to drill a borehole or install a pump set, they must follow a a series of steps, which depend in part on the land tenure situation at the proposed site.

There are several blocks of freehold farms (Ghanzi Farms, Tuli Block, Molopo Farms and several others). Most land is either tribal land or leasehold land administered by the GOB. For boreholes to be located on tribal land, permission to drill the borehole must be obtained from the District Land Board. This is not necessary in freehold land cases. The main purpose of the Land Board in this matter is to ascertain that there are no other boreholes within eight kilometers of the proposed site. This requirement is intended to decrease the risk of stock overgrazing by precluding the drilling of boreholes too close together.

Once permission is granted by the Land Board and before drilling starts, the borehole must be registered with the Geological Survey, which assigns a borehole number. After completion of the borehole, the Water Apportionment Board (situated at DWA) must grant permission to extract water from the borehole. For stock watering purposes, the maximum amount approved is 18.2 m^3/day--the estimated water requirement for a herd of 400 livestock units. (Individual livestock are classified for feeding and watering purposes as 0.6 to 1.2 livestock units each depending on age, sex and size). Recently, approvals by the Water Apportionment Board have averaged about 100 to 150 boreholes per year.

Private individuals have a number of different options for financing well drilling and borehole equipping. In a very few cases, individuals will be able or willing to pay for the capital costs by spending cash reserves or through the sale of cattle. However, a much more common approach is to secure a loan from the National Development Bank for the all of the initial borehole costs, including equipping of the completed borehole. The current interest rate on this type of loan is 12 percent. There are also several programs available through the MOA that can help with financing through grants (e.g., Services to Livestock Owners in Communal Areas [SLOCA] and drought and water relief programs). In most cases, the lending organization examines a package proposal for drilling and equipping a borehole at a specific site, prepared by one of the six private-sector firms that do the latter work and often subcontract the drilling. There are about 15 private drilling rigs at work in Botswana, with several contractors coming into the country occasionally (primarily from South Africa) for specific jobs.

Lister diesel engines and spares are readily available from a wide range of dealers in the urban centers, as well as in several of the major villages. All of these are imported from SALister in South Africa. Other diesel equipment is available from dealers scattered throughout the country. For example, Petter engines are handled by Tarr and Turk in Mahalapye, Hatz is handled by the Motor Centre in Gaborone, and Kubota by the Oasis Store in Ghanzi. However, Lister remains the engine of choice

for most users, with annual sales (for both new installations and replacements) of about 400 units per year.

The quality of private-sector servicing, both field servicing and in-shop engine overhaul, varies widely. Most of the freehold farmers are capable of doing their own field servicing and usually have spare engines on hand for occasions when major servicing is necessary. These farmers can often accomplish major servicing, such as engine overhaul. However, there are a number of private companies that do this work and engines are often taken to them. Since some of the freehold farm areas are close to South Africa, major overhaul jobs are often sent across the border, as many farmers feel that the price and quality of work justify the additional difficulties of this approach.

The single largest repair and maintenance service organization is BRS. Private (and public) BRS subscribers can obtain service and repair for their engines and pumps at highly subsidized rates. However, for a number of reasons, it appears that many subscribers are dissatisfied with the service they receive. As subsidized as the service is, it is still considered expensive by some users, and complaints of slow response are common. The expense complaint stems from the fixed job fee of P80, regardless of the problem. In truth, this is rarely adequate to cover even the transportation costs to the borehole, but is seen as an exorbitant cost for minor repairs.

It appears that part of the slow-response problem stems from both inadequate transportation facilities at the BRS outstations and an inadequate stock of spare parts. This has given rise to a large informal service sector which is, unfortunately, difficult to characterize properly. Service costs can be minimized by cash or in-kind payments to government mechanics who are willing to work during their free time, or to any other so-called "bush mechanic" who has demonstrated an ability to get an engine operating again.

The phenomenon of the informal service sector has two major implications. First, the skill levels of mechanics available in this sector vary widely; hence, there is a wide range in reliability and cost of engine maintenance and overhaul, which directly affects engine lifetime. Second, while there is little doubt about the ability of these mechanics to keep minor problems under control, this is often done at the expense of the long-term cost effectiveness of the pumping system. This O&M strategy is not necessarily a counterproductive approach to operating a borehole, however, since an individual's entire personal wealth in cattle may be at stake, and ultimately there remains the safety net of BRS to overhaul the engine and loan the user another one while repairs are being done.

D. Record-Keeping

DWA, the District Councils and BRS all have record-keeping systems. These records vary in form, content and completeness. Private pump-set owners are not required to keep records and often do not. The following section summarizes the record-keeping practices of the different engine user groups.

1. Department of Water Affairs

DWA records are quite extensive, and represent the largest single body of information on O&M costs. At the borehole, the pumper must keep a detailed logbook containing a daily record of engine operation hours, water delivered, a notation for a service visit, and fuel and lubricant use for each engine in service. The log does not contain entries for pumping water level or delivery pressure. These logs are submitted monthly as part of field office reports to DWA headquarters, where the information is processed to determine pumping rate, fuel consumption rate, and specific fuel consumption per cubic meter of water delivered.

While the information so collected and processed generally appears to be fairly accurate, a close examination of several records has revealed some inconsistencies. These are sometimes related to important technical parameters (increased fuel consumption or reduced pumping rate). However, they are occasionally due to broken water meters or inaccuracies introduced through improper recording procedures by the pumper.

In addition to logbooks, DWA maintenance and repairs are recorded using a system of job and time sheets. This system requires that a record be kept for each repair or maintenance trip to the borehole. These records indicate the nature of the trip, any spares used (including their price), vehicle driven, number of mechanics or laborers involved, and length of time to complete the work. Travel time of maintenance crews is not included. These records are only maintained for service visits made by DWA crews assigned to the major village water supplies and are submitted to DWA headquarters monthly. These records appear to be reasonably complete. It is possible that there are some discrepancies in the time recorded for the service trips and that some trips have not been recorded, but by cross-checking the records, it appears that these oversights are minimal.

DWA field offices also collect revenue from the sale of water in cases where individuals have private connections. A survey of four major villages reveal that 70 to 80 percent of the billed revenues are collected.

2. Borehole Repair Service

BRS charges for its services to the private sector and must, therefore, keep accurate records of the services it performs. Since BRS does not actually operate boreholes, it does not maintain logbooks on pumping plants. However, it does use a system of job and time sheets for recording time and materials spent on service calls. These job and time sheets contain the same information as DWA field-office reports and appear to be fairly accurate. BRS also serves the public sector by performing service (not billable) on pump sets operated by other ministries and government agencies, as well as occasional services for DWA. Records are kept and costs calculated in the same manner as for the private subscribers. In addition, BRS workshops keep accurate records of all of the services performed in engine and pump overhaul. They also maintain an engine registry where all the repairs to an engine are recorded by engine number.

The records for BRS services can be misleading because of the subsidies to BRS. Neither transportation nor repair-crew mobilization costs are charged to BRS subscribers (except insofar as the P80 fee covers them). The Central Transport Office (CTO) maintains the vehicle fleet and provides fuel. The charges also do not cover the overhead of operations at headquarters or at the outstations themselves. Given the nature of the financial records that are kept, it is very difficult to compute the level of subsidy provided to BRS. From the 1984-85 report on Borehole Repair Service Activities, it is estimated to be about 75 percent of actual costs. This would fall to about 60 percent if services to other government agencies were billable.

3. District Councils

The nine administrative districts are largely autonomous. As such, there is little uniformity in record-keeping practices within the different water units and departments. The only uniformity is the pumper's logbook. The pumper is to fill this log out daily, including fuel used, hours operated, and water pumped. The logbook also has a space for remarks about the general state of the equipment. An example of a logbook page is included as Figure 2.

Unfortunately, these logbooks were introduced only recently (on the suggestion of MLGL). In some districts they have yet to be used widely. It is estimated that the logbooks are in use at half of the council boreholes. Part of the difficulty is that many of the older pumpers are illiterate and cannot complete the forms. In other cases, the logbooks have not been introduced because they are considered a low-priority task. In some cases no water meter is installed, so water delivery is not recorded.

DISTRICT COUNCIL WATER MAINTENANCE UNIT

LOG OF PUMPING PLANTS

Place _____ Borehole No. _____

Month _____ 19 Type of engine _____

Operator _____ Engine No. _____

Date	OPERATION OF ENGINE							Received quantity		Consumption		Delivery of water			Remarks, work carried out, breakdowns etc
	Start	Stop	Start	Stop	Start	Stop	Hours of operation	Diesel l	Oil l	Diesel l	Oil l	Water meter before start	Water meter after stop	Pumped Quantity	
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															
11															
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22															
23															
24															
25															
26															
27															
28															
29															
30															
31															
GRAND TOTAL															

CONSUMPTION OF DIESEL & OIL	DIESEL	OIL
Balance from previous month		
Received during the month		
Total		
Total used during the month		
Balance		

OPERATION AND YIELD	
Delivery of water m³	
No. of hours operated this month	
Yield (m³ water — hours operated)	
Consumption of fuel (ml ÷ m³ water)	
Consumption of oil (ml ÷ hours operated)	

WATER LEVEL		
Date	During Operation	After stop (3 hours)

Remarks by Sen. Operator		Remarks by Off. in charge	
Sign	Date	Sign	Date

Figure 2.

As with the major village cases, no water-level readings are recorded. This may change in the future, as there is a plan to equip rural boreholes with electronic depth sensors that would allow quick determination of the water level.

An examination of a sample of these logbooks reveals that in many cases, the pumper does not fully understand how to complete the forms properly. This is to be expected during initial introduction of the logbooks. If attention is paid to this problem and accuracy improves, much useful information will be available in several years.

All districts except Mahalapye Subdistrict have a time and job sheet system for recording work completed at boreholes. However, there is no standard form and no approved manner of handling the sheets once they are completed. All forms include the basic information regarding site, borehole number, type of repair or service performed, and list of spares used. Also included is the vehicle used, mechanic's name, and time spent at the borehole. Some versions include other information as well. These completed forms are sometimes kept in a village file or in a borehole file at the water unit offices. The accuracy of these records depends on the district--more attention is paid to these record-keeping details in some districts than in others. These records were examined but no in-depth analysis has been completed.

In some cases, district water maintenance units also have additional records of equipment breakdowns or crew work assignments that can be checked against the completed job and time sheets. Examination of this information reveals that in some water units the job and time sheet records are not complete, and in some districts they are almost nonexistent. This indicates a wide variety of skill and literacy levels and varying degrees of concern about record-keeping issues at the District Council level.

4. Private Sector

Information on private-sector use of diesel pump sets is sparse. Record-keeping is practically unknown, except perhaps in some freehold farm cases. In almost no cases are water meters installed, and very few records are kept of repair and maintenance costs. Information on transportation costs or numbers of required repair trips is simply not available. Furthermore, if the above information were available, it is not likely that it would represent typical cases, since anyone willing to go to the trouble of carefully recording such items would most certainly treat their equipment more carefully than the norm. For this reason, no great effort was made to identify private diesel pump-set owners who maintained good records.

However, anyone identified as having experience servicing private-sector water pumping needs was interviewed. A questionnaire (see Appendix O) was developed and distributed through selected District Agriculture Officers in an attempt to gain some insight into the practices and expectations of private engine owner/operators. Unfortunately, too few users responded to the questionnaire for it to have statistical significance.

Over the past few years, several major reports and minor papers (Hitchcock; Flink; Bailey) have reported on private-sector pumping costs. These reports typically include information on pumper costs, maintenance and repair costs, and, in several cases, reliability estimates. Most of this information was compiled from interviews of private users. Although the records are sparse, all of this information is consistent and, in sum, gives a reasonable overview of the cost of water pumping in the private sector. This information has been factored into the calculations of O&M cost components for the privately owned system case discussed in Section VIII.

V. DATA COLLECTION, TESTING AND MODELING

A. Data Collection (Secondary Sources)

While considerable performance and cost information data are available from a variety of secondary sources, they vary considerably in quality, accuracy and completeness from one user group to another. Virtually every known source of diesel pump-related data in Botswana was examined in varying levels of detail. The following sections discuss this secondary data collection effort, categorized in terms of primary user group.

1. Major Villages

The most complete set of information on engine and pump use for the major villages is available in the form of monthly summaries at the Operation and Maintenance Division of DWA. The raw data from pumpers' logs, job and time sheets, and work orders are available as well. The records for four villages (Mochudi, Palapye, Ghanzi and Thamaga) were examined in considerable detail to determine engine hours, fuel consumption, and water delivery over the most recent completed year (1986). In addition, the records for all repairs and maintenance for the engines and pumps in these villages were analyzed. This sample represents between 20 and 25 percent of the engines in use in the major villages. In addition, a less detailed analysis of the records for the other 13 major villages was conducted to verify that the four villages chosen were indeed representative of major village cases.

2. Rural Villages (District Council Water Units)

Following interviews with the water unit technicians, 12 of the 13 water units were visited (see Appendix D). Before each visit, a cross-section of village water supply systems was chosen for close examination. In several cases, the villages were visited and the pumpers' logbooks were examined. In some of these cases, the records were not available either at the borehole or at water unit offices. In quite a number of instances, the records did not include some important piece of information such as water delivery (if no meter was fitted) or hours of operation (if the pumper was not literate). In all, the records of 60 boreholes, representing about 12 percent of the schemes within the jurisdiction of the councils, were examined. Very few of these were complete records in every way. However, by considering a subset of the sample (22 cases), the average repair and maintenance costs could be calculated per hour of operation. The visits also provided the opportunity to evaluate the technical capabilities and problems of the various water

units, and learn the details of practical, field-level management of pump set repair and servicing.

3. Other Government Agencies

As the repair and servicing of pump sets operated by government agencies other than DWA is not charged to the agency in question, it is reasonable to assume that all servicing of these engines is completed by BRS. The BRS activities report for 1984-85 (the most recent available) was consulted for a broad overview of the costs for servicing these engines. The data, in a less aggregated form, are also available from monthly summaries sent from BRS outstations. This information is then compiled into site histories by O&M crews. In addition to examination of these records, nine of the 12 outstations were visited in order to examine records available there, and to interview the Chief of Station at each location. The results of these visits are compiled in Appendix E. To gain insight on the service provided by BRS, informal interviews were also conducted with several individuals responsible for agency-operated pump sets. These records and interviews (although not complete, particularly in providing hours of operation and water delivery by location) provided a coherent overview of diesel pump use by this group.

4. Private Sector

Reliable information outlining the typical practices and costs for private engine owners/operators is particularly difficult to find, and several parallel avenues of approach were taken. First, BRS maintains records of repairs made, and the costs for all of its subscribers were examined. BRS outstation visits also provided valuable insights into private-sector practices; these formed the base from which other research was conducted. Interviews were conducted at six (of about eight) workshops performing overhaul services for private engine owners. In addition, two (of six) firms specializing in borehole equipping were visited. The MOA was informally approached to ascertain whether it would be able to conduct a survey of engine owners. Interest was expressed, although assistance was not available within the project time frame. Questionnaires were eventually distributed informally to a cross-section of engine users. While there is no pretense that this sample was statistically representative, the information gained from the questionnaire responses did tend to confirm the conclusions drawn from other sources.

5. Other Information

Engine overhaul costs (and intervals in some cases) are available though the records kept at the BRS workshop in Gaborone. A full year of overhaul information (406 engines) has been analyzed (see Appendix F). Although private-sector workshops performing the same tasks were visited, they did not make available complete records. However, interviews with technicians provided considerable insight into overhaul costs and typical engine condition at overhaul in the private sector.

The question of engine lifetimes for public-sector engines was addressed by examining DWA records for scrap engines and engines to be auctioned (boarded). Interviews did not provide much useful information on engine lifetimes for private owners, since their estimates ranged from five or seven years to the anecdotal cases of 50-year-old engines. The most reasonable figures were reached by estimating the engine replacement rate. A survey of sales of all diesel engine distributors over the past two years was conducted. Then the record of the Water Apportionment Board's approvals over the same period was examined so that new installations could be subtracted from replacements. This provided an answer that was consistent with all other reliable data examined.

B. Field-Testing and Evaluation

The diesel performance field-test program complemented the secondary data collection and analysis in several important ways. It helped to confirm the general validity of the fuel consumption and water output records kept by pumpers. It also pointed out the importance of system and component matching (and mismatching) in the design process to the system life-cycle costs. Tests were conducted on 10 different pump sets and consisted of a series of short-term measurements of fuel consumption, pumping rates, head, and pump and motor speed. For a description of the test procedure, see Appendix I.

The major objectives of the tests were to determine the engines' fuel consumption under typical field operating conditions and to calculate the associated engine loading conditions (see Section V.C.2 below and Appendix G for a detailed explanation of loading). The test results were then compared with figures calculated from the partial-load fuel consumption estimates supplied by SALister, the engine manufacturer. The general agreement between the Lister estimates and the field-test results suggests that it is reasonable to use the Lister tables to estimate engine-de-rated, partial-load fuel consumption for the technical and economic analysis of other sites.

A second objective was to determine the overall efficiency of diesel engines under field conditions, and its relation to engine loading conditions. These figures were then used in conjunction with the financial/economic analysis to develop several suggested strategies for reducing the costs of diesel pumping.

1. Site Selection

Ten test sites that were generally representative of the cross-section of single-cylinder, Lister-Mono pump systems were chosen. Each of the commonly used engine models was represented, and a range of typical heads and flow rates for rural village water supply schemes was covered. The specific details of individual test sites are given in Appendix H. At one site (Mmaphashalala), the borehole drawdown was such that the pump was pumping some air, and the test results indicated that the problem existed. At all other test sites, the tests were more successful in terms of quantifying the range of pumping conditions generally encountered in rural villages.

2. Test Procedure

The short-term performance test procedure included the measurement of fuel consumption and water output over a specified time interval. The water level in the borehole, delivery head, and speed of the pump and engine were also measured. Measurement intervals ranged from 10 to 15 minutes, and tests were repeated 10 times. The resulting set of values were used to arrive at an average fuel consumption, total head, water delivery, and engine and pump speeds (in revolutions per minute, or rpm) for each site.

To check the results on-site, calculations of fuel consumption per hour and water delivery per hour were made after each test. These figures were then compared to the logbook figures (where available). The overall efficiency of the system (the ratio of hydraulic energy delivered to fuel energy consumed) was then calculated for at least one of the testing intervals (assuming the energy content of the diesel fuel to be a standard 38 MJ/liter), to be certain that the test results were reasonable. Details of the testing procedure are given in Appendix I.

3. Results

The test results at each site are summarized in the table below.

Results of Short-Term Tests

Site:	Engine Model	Head (m)	Flow Rate (m3/hr)	Fuel (l/hr)	Loading (percent)
Bonwapitse	ST-1	58	7.7	.78	48
Kopong	TS-2*	89	7.8	1.23	29
Lotlhokane-E	ST-2	27	7.4	.94	14
Mabalane #3	HR-2	83	14.1	1.76	33
Malotwana	SR-1	48	3.2	.52	15
Mmaphashalala	ST-1	52	5.1	.78	20
Mmankgodi	LT-1	82	2.7	.41	33
Mogobane	ST-1	74	8.7	.82	67
Mogojogojwe	ST-1	99	3.7	.79	44
Oodi	8/1	101	3.9	.74	27

*The Lister TS-2 is a replacement for the older model ST-2.

Loading

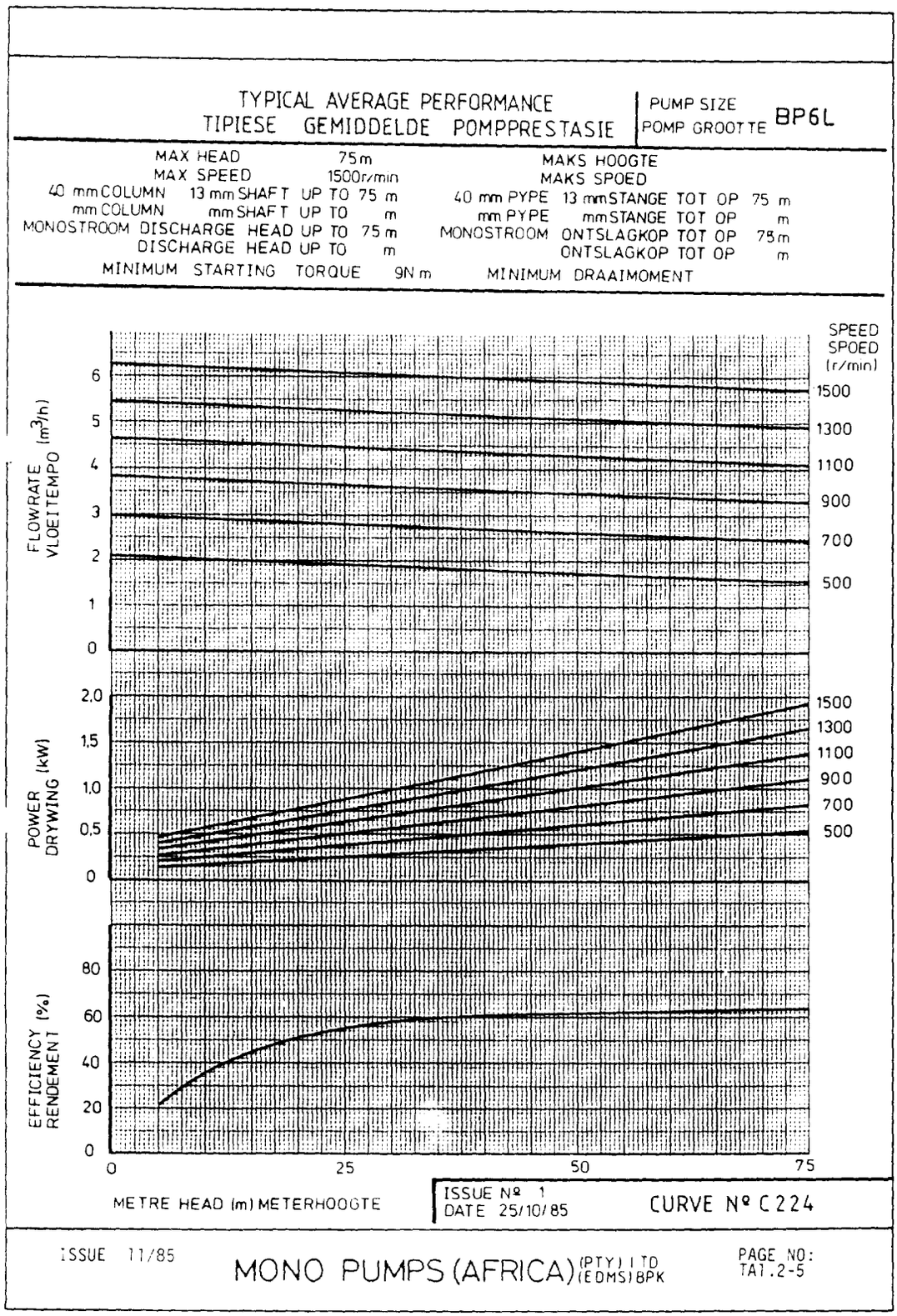
The loading of the engine at each of the test sites was calculated according to the formula given in Appendix G. In each case, the assumption made was that the Mono pump efficiency was as indicated in the manufacturer's specifications of head, flow rate and efficiency, an example of which is shown in Figure 3. The assumption that the manufacturer is accurately representing the pump performance (as opposed to the overly optimistic estimates made by some pump manufacturers) is reinforced by the fact that the measured partial-load fuel consumption figures are so close to those given by Lister. The loading calculation depends on the pump efficiency assumption.

The calculated engine loadings ranged from 14 to 67 percent, with the average being 33 percent. These findings support the widely held view that many engines are not properly loaded (proper loading for maximum engine efficiency is in the 70 to 80 percent range). The test results also support the contention that the design procedures currently in use at DWA result in poorly loaded engines, with consequently higher operating costs.

Fuel Consumption

Fuel consumption is a function of engine loading. For a given engine, the fuel consumption decreases as the loading decreases. However, the decrease in fuel consumption is not

Figure 3.


TYPICAL AVERAGE PERFORMANCE
TIPIESE GEMIDDELDE POMPPRESTASIE
PUMP SIZE
POMP GROOTTE
BP6L
MAX HEAD 75 m
MAX SPEED 1500 r/min
40 mm COLUMN 13 mm SHAFT UP TO 75 m
mm COLUMN mm SHAFT UP TO m
MONOSTROOM DISCHARGE HEAD UP TO 75 m
DISCHARGE HEAD UP TO m
MINIMUM STARTING TORQUE 9N m
MAKS HOOGTE
MAKS SPOED
40 mm PYPE 13 mm STANGE TOT OP 75 m
mm PYPE mm STANGE TOT OP m
MONOSTROOM ONTSLAGKOP TOT OP 75 m
ONTSLAGKOP TOT OP m
MINIMUM DRAAIMOMENT
SPEED
SPOED
(r/min)
FLOWRATE
VLOEITEMPO (m³/h)
POWER
DRYWING (kW)
EFFICIENCY (%)
RENDEMENT
METRE HEAD (m) METERHOOGTE
ISSUE Nº 1
DATE 25/10/85
CURVE Nº C224
ISSUE 11/85
MONO PUMPS (AFRICA) (PTY) LTD (EDMS) BPK
PAGE NO:
TA1.2-5

directly proportional to the decrease in load. Lister provides a series of formulas for calculating the relationship of fuel consumption to load, and this information is graphically represented in Figure 4. In the figure, the line represents the Lister estimates of partial-load fuel consumption, while the data points indicate values measured during the short-term testing. It should be noted that Lister states that fuel consumption predictions at less that 20 percent of full load are less accurate than in the higher loading range, since factors other than loading (such as engine condition) have a greater effect on fuel consumption in the lower loading range.

Under all loading conditions, engine condition (need for decarbonizing, cleanliness of air and fuel filters, etc.) plays a role in fuel consumption, and this explains some of the data scatter in the graph. The results of the test at Mmaphashalala are circled, since the high specific fuel consumption in this case emphasizes the cost penalty for pumping air along with water. The graph indicates that Lister's partial-load fuel consumption formulas predict reasonably well the fuel consumption for these Lister models. While the measured values vary ± 20 percent of the value predicted by Lister, the average percentage difference between the predicted and actual fuel consumption was only three percent (not including the Mmaphashalala case). The Lister partial-load fuel consumption formula is used in financial and economic calculations in Section VIII.

Efficiency

The assumed energy content of the fuel (38,000 MJ/l), and the measured water delivery rate, head, and fuel consumption figures were used to calculate the overall fuel efficiencies. This measures how efficiently the engine/pump combination uses the fuel in performing the work of lifting the water. The efficiency is calculated as follows:

$$\text{fuel efficiency} = (Q \times H \times 9.8\ \text{m/sec}^2)/(F \times 38{,}000\ \text{MJ/l})$$

where: Q = flow rate (m3/hr),
H = total head (m),
F = fuel consumption (l/hr), and
9.8 = gravitational constant.

For the 10 tested cases, these efficiencies ranged from six to 20 percent, and averaged 13 percent. It is interesting to note that the three cases with efficiencies of 10 percent or less (Lotlhokane East, Malotwana and Mmaphashalala) are the three cases with very low loading (20 percent or less). The most efficient case (Mogobane, at 20 percent) is the most optimally loaded engine that was tested. More careful engine selection and

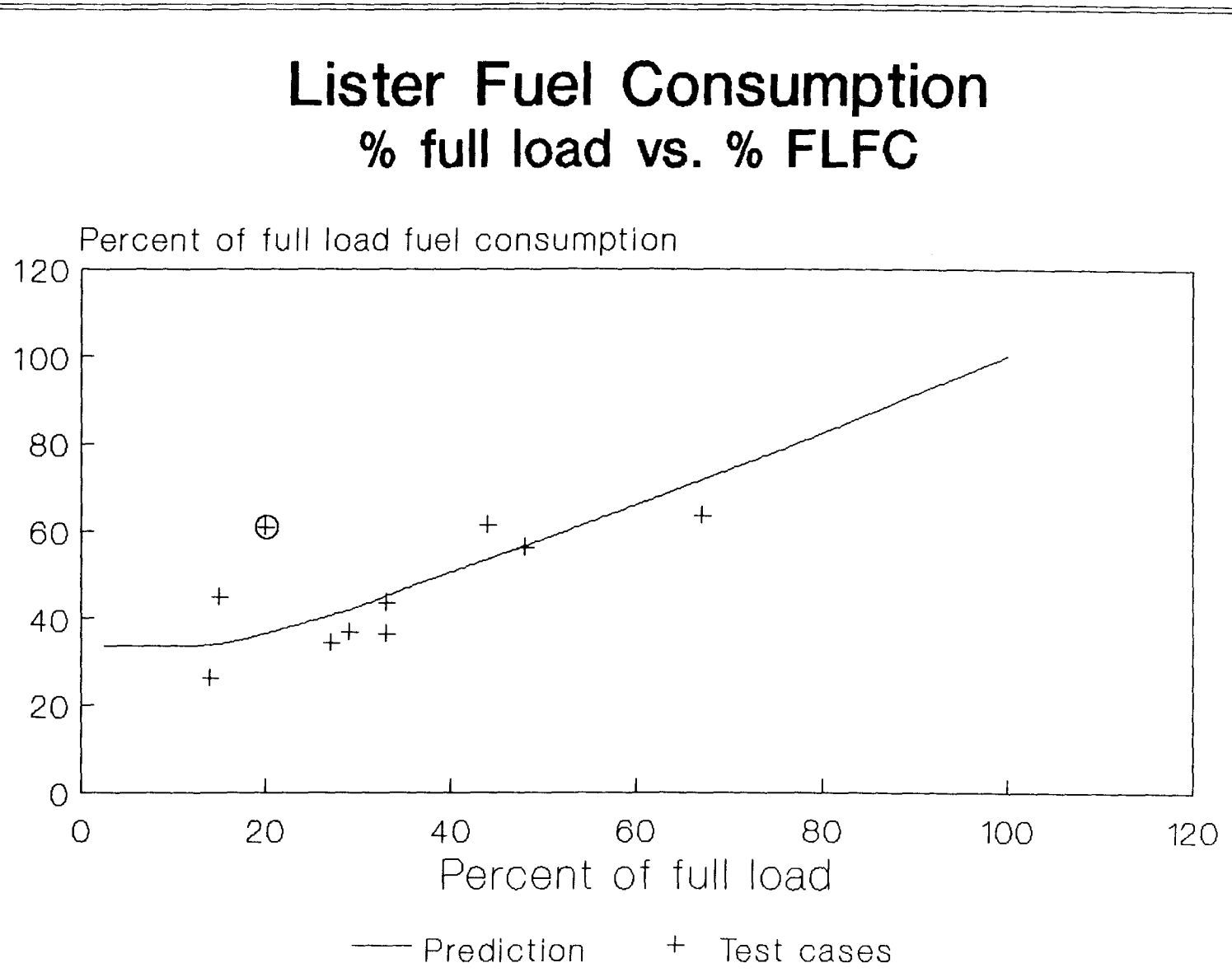

Lister Fuel Consumption
% full load vs. % FLFC
Percent of full load fuel consumption
120
100
80
60
40
20
0
0
20
40
60
80
100
120
Percent of full load
Prediction
Test cases

Figure 4.

better maintenance are factors that could improve energy efficiency, thereby reducing pumping costs.

Engine loading can be improved by increasing the pumping rate while maintaining the same engine speed. This would require being certain that the borehole can be pumped at an increased rate, as well as changing pulleys to increase pump speed. Loading can also be increased by changing pulleys in such a way as to pump at the same rate and decrease engine rpm. Reducing engine size while pumping at the same rate will also improve loading.

C. Technical and Economic Modeling

To perform the technical and economic performance analysis of diesel pump sets, a template for a computer spread-sheet was developed. This model combines the technical aspects of diesel pump performance with a financial and economic analysis summary sheet. The model inputs and outputs are shown in Figure 5. The following sections describe model inputs, the analysis methods used, and results obtained.

1. Model Inputs

The technical and economic model that was developed and used calculates engine loading, anticipated fuel consumption, and present value per cubic meter of water delivered by a specific diesel configuration delivering a given quantity of water. The present value is calculated in both financial and economic terms and is based on capital and recurrent costs over a specified period. The model divides inputs into several categories. These are:

--site-specific information,
--capital costs,
--engine information,
--transportation information,
--recurrent costs, and
--financial and economic information.

The details of all of the information required are specified on the summary sheet (Figure 5). The model's format reflects the form in which the information is available in Botswana. Most of the input parameters are self-explanatory, but several points need comment.

In most real-world situations, the water requirement increases with time. This may be due to growth in population, or growth in demand due to increases in per capita consumption (due to increased private connections). The model allows for growth

Figure 5.

Diesel Analysis : Base Case Rural Village 22-Dec

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

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by including an annual growth factor, which is specified by the user.

The model allows a choice of engines. It is not limited to the LT-1, ST-1, and 8/1 listed at mid-page in Figure 5. However, these are the most common single-cylinder engines sold today in Botswana, thus the de-rated output (at 1,500 rpm) and full-load fuel consumption are included to allow ease of use when considering these engines.

The engine lifetime is not clearly specified, as it is a function of engine hours of operation and is naturally a multiple of the overhaul interval. The engine lifetime can be calculated from the hours of operation per day, overhaul interval, and number of overhauls per lifetime. If the lifetime is less than the amortization period, the engine is replaced. No salvage value is assigned at engine replacement, but if the engine still has useful life at the end of the amortization period, a salvage value of 75 percent of the cost, prorated for the remaining period before overhaul, is assumed. This reflects the fact that very few used engines are available in Botswana, and those that do exist are overhauled as many times as feasible.

Pump replacement costs are included in materials recurrent cost, since the existing data were compiled that way. The total water delivery per day is the product of the hours of operation and the hourly pumping rate. The cost of transportation reflects the prevailing cost to operate the vehicles in question, including depreciation, repairs and fuel.

Recurrent costs are divided into pumper (pump operator) costs, cost and quantity of fuel and lubricants, and number of repair trips (person-days and type of vehicle) per year. The quantity of fuel required is calculated from the algorithm provided by Lister (described in Section V.B and confirmed by ARD's field tests).

Trips to the pump site are divided between repair trips and fuel delivery trips. The number of repair trips included for each user group is based on records and interviews and reflects the best available estimates of the average number required per site. These costs have not been included in the cost per hour of engine operation. Fuel delivery costs depend on the way that fuel is delivered. It has been assumed that the cost for these trips is spread among several sites because delivery will be made to more than one site per trip. The use of the term "chargeable trip" provides an allowance for this factor.

2. Model Outputs (Technical)

The model provides some important technical results, including engine loading, fuel consumption, specific fuel consumption (liters of fuel consumed per cubic meter of water pumped), and fuel efficiency. The loading is calculated from the head, flow rate, pump efficiency, and de-rated power output of the engine (as described in Appendix G). Specific fuel consumption is calculated from the fuel consumption and water flow rate. Fuel efficiency is calculated from the hydraulic energy required to lift a given volume of water, and liters of fuel consumed times the energy content per liter.

Knowing this information allows one to determine, at a glance, whether the engine is well matched (as measured by the engine loading) to the site and demand. It also allows a reasonable estimate of the quantity of fuel required to provide a specified amount of water at the site. This information also allows an analysis of the effects of a different engine choice on the loading, overall efficiency and cost for a particular application. In other words, it can be used as a design tool.

3. Model Outputs (Economic)

The primary financial and economic output variable of the model is a unit cost of water (pula per cubic meter, at a given head) based on the annualized life-cycle cost of the pumping system, and water delivery over the period. A complete discussion of financial and economic parameters is included in Section VIII.

VI. DESIGN AND INSTALLATION

This section addresses the technical issues pertaining to system design and component sizing for diesel pumping systems. The performance characteristics of the standard equipment types used in Botswana are discussed, and typical system designs for each of the four major user groups are described.

A. Equipment Standardization

During the early period of GOB involvement in water resources development, a decision was made to standardize on one make of diesel engine (Lister) and pump (Mono) for water supplies. The impact this policy has had cannot be overemphasized. Although it is easily conceivable that another make of engine could be slightly more efficient (better matched to the load) or less costly, the practical benefits of standardization often far outweigh the possible gains in using a wide variety of equipment makes and models. These benefits include:

- system designers' and technicians' greatly increased familiarity with equipment performance characteristics and proper installation, operation, maintenance and repair procedures;
- cost savings realized by minimized inventory of spare parts and equipment; and
- cost and time savings in technical training courses needed to support fewer equipment models.

1. Lister Engines

The Lister diesel engine was chosen as the standard engine to be used by the GOB. Only a limited selection of Lister models is used. This selection includes the air-cooled, single-cylinder L-series; the single- and multiple-cylinder S-series; the multiple-cylinder H-series (all at 1,500 rpm); and the recently discontinued water-cooled 8/1 and 16/2. These models, with their nameplate and rated conditions and full-load fuel consumption (FLFC) values, are given in the following table.

Lister Engine Characteristics

Engine Model	kW Rating at 1500 rpm	De-Rated (kW)	FLFC (l/hr)
Air-Cooled Engines:			
LT-1*	2.9	2.2	0.9
ST-1	4.5	3.3	1.3
ST-2	8.9	6.7	2.6
ST-3	13.4	10.0	3.9
HR-2	16.0	12.0	4.9
HR-3	24.0	18.0	7.2
Water-Cooled Engines:			
	(at 850rpm)		
8/1	6.0	4.5	2.2

*LT-1 engines are Build 11 models.

Almost all GOB diesel pumping systems are driven by Lister engines, and a small number use Lister copies. The government does not use any other make of diesel engine for water pumping. The dominance of Lister engines is not as complete in the private sector. However, it is estimated that 90 percent of all diesel pump installations in Botswana use Listers or Lister copies.

2. Mono Pumps

During recent years, Mono pumps have become the de facto standard pump used by DWA. The Mono pump is a progressive-cavity screw-type pump that is connected to the diesel engine by means of V-belts. The National reciprocating pump was widely used for many years and continues to be employed by many in the private sector. Today, all new public-sector diesel pump installations are designed for Mono pumps. The Mono pump has the interesting characteristic of having a very flat efficiency curve, meaning that it has a relatively constant efficiency over a wide range of heads (see Figure 5). This characteristic is useful where the exact drawdown is not well known (such as is often the case in Botswana) or where there are seasonal fluctuations in the water table, since pump efficiency will not change significantly as head varies, as is the case with, for example, submersible centrifugal pumps.

The main limitation of the pump is that the efficiency drops off rapidly at low head, making selection of a borehole pump for heads of less than about 15 meters difficult. Fortunately (at least for Mono), those situations are rare in Botswana. Most

low-head cases are sand river extraction situations or river draw-offs, where horizontal Monos (with better efficiency characteristics at low head) or electrically driven submersible pumps are more suitable. The Mono also has relatively high start-up torque characteristics, meaning that considerably greater engine power is required to start the pump than is necessary under normal running conditions. Since manual-start Listers are used, it is important that allowances be made so that the engine operator can start the engine. In deeper borehole cases (over 75-meter rest-water levels), the engines are often fitted with a clutch. For shallower boreholes, oversizing the engine facilitates starting.

3. Nonstandard Equipment

Although Lister-Mono pump systems are almost universally used for public-sector water supply, both for major and rural villages, other equipment is sometimes used on private boreholes. Private individuals usually use Lister engines (or Lister copies). The most common non-Lister engines in use are Lister copies (made in India), such as Metex and Induna, and the Petter (sold by Tarr and Turk in Mahalapye) and Kubota (available at the Oasis Store in Ghanzi for one). Copies of the Lister slow-running (600-850 rpm), water-cooled 6/1 and 8/1 are readily available, and are sometimes chosen by users because they are less expensive. BRS will service these engines, considerably enhancing their attractiveness to potential buyers. However, reports indicate that the Lister copies are generally not as rugged as the Listers, often due to the use of cheaper materials and designs (bearings are a particular problem point).

The U.K.-manufactured Petter engine is considered comparable to the Lister in performance and robustness, and are used near Mahalapye, where spares and service are available. The Kubota diesel engine is increasingly used in the Ghanzi area and along the Molopo river in the south. This is due in large part to local availability. While these Japanese engines have been relatively inexpensive in the past, this situation is changing rapidly as the dollar and pula continue to be devalued compared to the yen. Kubotas (along with several other engines available in Botswana) are high-speed diesels, running in the 2,000- to 3,000-rpm range. They are relatively lightweight and reportedly not as durable as comparable Listers and Petters. It appears that the typical O&M strategy for these engines is to provide whatever service and minor repairs are necessary to keep them running, but then to replace the engines rather than perform major overhauls when that becomes necessary. Expensive spare parts have played a part in the evolution of this strategy.

Other engines recently introduced to Botswana include the Mitsubishi (Japanese), Hatz (German) and Lombardini (Italian).

At this stage, none of these has captured a significant share of the market. They may, however, if prices for Lister engines continue to increase. While private purchasers of diesel engines have a strong sense of brand loyalty (to Lister), this may be eroded in the future by lower cost alternatives.

The use of pumps other than the Mono is quite widespread within the private sector. Almost all non-Mono pumps are positive-displacement, reciprocating-piston pumps, although there are a few centrifugal suction pumps in use in sand river water extraction schemes. The most common alternative to the Mono pump is the National reciprocating-piston pump. These were in widespread use (along with Rapids and Climax pumps) before the successful introduction of the Mono. Where these pumps have been in use, pump owners have seen no reason to change and do not consider the required maintenance excessive. Cylinder cup leathers must be changed periodically, usually at intervals ranging from one to two years. Cylinders themselves require replacement about every five to 10 years, depending on use. The Climax pump head is no longer being manufactured, so Climax users are moving to the National pump, which is more widely available than its competitors.

No systems other than the Lister-Mono pump combination were tested. This was due to the Lister-Mono domination of the market for new equipment. Most of the Lister competitors have not been in use in the country long enough to enable compilation of a meaningful base of information on operation, maintenance, overhaul costs or intervals, and engine lifetimes.

B. Design Considerations and Procedures

The major technical considerations in diesel-pump system design are the desired pumping rate and head, and the consequent power requirement. The pumping rate is a function of borehole yield constraints and water demand. In general, the best policy from a cost standpoint (see Section VIII) is to pump at a high rate for a few hours rather than at a low rate for many hours, since this reduces the hours of engine and pump operation and tends to minimize maintenance costs. In Botswana, the pumping rate is usually limited by the borehole yield. The general rule of thumb used by DWA is that the pumping rate should not exceed two-thirds of the maximum sustainable yield of the borehole.

The total dynamic head (or, simply, head) is the sum of the static (elevation) head plus the friction and velocity losses and drawdown. This can be calculated with relative accuracy from knowledge of the physical layout and system components. The engine output power requirement can then be calculated as follows:

$$P = (Q \times H_t \times 9.81)/(3{,}600 \times N_p]$$

where: P = the power required (in kW),
Q = the pumping rate (in m^3/hr),
Ht = the total dynamic head (in meters of water), and
N_p = the pump efficiency (in %).

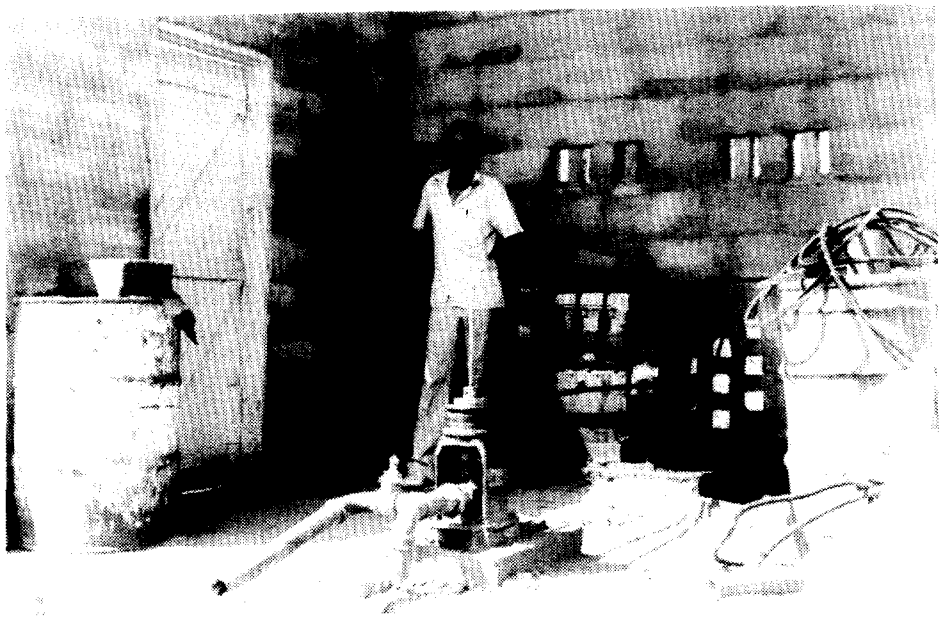
Diesel engines are designed to operate most efficiently in the range of 70 to 80 percent loading (see Appendix G for a description of loading). In practice, this is sometimes difficult to achieve. Diesel engines are only available in fixed sizes, so it may be difficult to precisely match the load, particularly for very low demand conditions. Engine power output can be modified somewhat by changing the speed of the engine, but in Botswana it has been felt that operation of engines at less than optimum loading is less important than standardization on particular engine models and operating speeds. This standardization is a consequence of the common practice in Botswana of swapping engines when shop repairs are necessary. If replacement engines are not set to the same speed as the original engine, pumps may over-speed and over-pump the boreholes.

In Botswana, diesel-pump system design is considerably simplified by the standardization of both pump and engine makes. The steps in the design procedure are as follows:

- determine the flow rate required from the design day water demand and borehole characteristics (yield and drawdown);
- determine the total pumping head;
- select a pump to meet the flow requirement;
- determine the power required to start and operate the pump under the given conditions (taken as two times the power required to operate the pump); and
- select an engine to suit the power requirement.

For domestic water supply, the water demand is based on a 10-year projection of population growth and per capita consumption of 30 liters per day. The system is therefore sized such that it will be able to meet daily expected demand by running about six to eight hours a day after 10 years. Allowances are also made for other uses, such as schools and clinics, where applicable. If possible, the pumping rate (in m^3/hour) is chosen to meet the water output requirement in six to eight hours of daily operation. The total head on the delivery side is determined from the reticulation layout. On the borehole side, the head is assumed to be the lift from the pump level, not the calculated pumping water level.

The pump is nearly always placed near the bottom of the borehole. There are two reasons for this. First, although ideally the rest water level, yield and drawdown should be known from a proper test-pumping of the borehole at the time of drilling, these tests are often incomplete or not completely accurate, so worst-case conditions are usually assumed. Second, both the rest level and yield of boreholes in Botswana seem to decline with time in enough cases that a conservative design approach is considered prudent. In many cases, the actual pumping water level is well above the pump. This means that the actual head will be less than the design condition. When pumping head is decreased, engine loading decreases also. Although with this reduced head, the pumping rate (and friction losses) increase slightly, these increases are secondary effects.



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

The power required by the pump can be found from the pump curves supplied by Mono (see Figure 5). The power indicated is that required to operate the pump only, and includes neither transmission losses nor the greater transient power required to overcome the pump's starting torque. Although there is some disagreement about the next step, the current practice in the Design and Construction division of DWA is to simply double the indicated power required (to cover the starting torque requirement), then choose the next size larger engine from the

table of Listers given previously in Section VI.A.1 (being sure to consider only the de-rated power output). This engine-sizing policy immediately limits the engine loading to 50 percent (due to the doubling of the required power). In addition, actual loading is often less than 50 percent, because of the earlier assumed definition of static head as simply the depth of the pump setting plus tank height. As mentioned in Section V, the net result of all these considerations is that typical engine loading (calculated from the short-term diesel engine tests) ranges from a high of 67 percent to less than 15 percent, averaging between 25 and 40 percent.

Private-sector system designers follow the same series of steps described above, but complete the exercise a little differently. First, the designer attempts to size the engine only about 20 percent over that indicated in the required power graph, resulting in better engine loading. On the other hand, many private buyers already know what engine they want--usually the water-cooled, slow-speed Lister 8/1. This choice is motivated by a common belief that the 8/1 is a relatively trouble-free engine, rather than by any consideration of loading or operating cost. Given the water demand at most private-sector installations, the choice of an 8/1 often leads to under-loading the engine, and consequently increased O&M costs. Low engine-loading results in a cold running engine, allowing oil blow-by past the piston rings, which causes rapid engine-carbon buildup. This requires more frequent engine maintenance (decarbonizing), and premature replacement of more expensive engine components, such as the head and cylinder barrels, since these are sometimes marred during the decarbonizing process. In all fairness, loading considerations and their effects in terms of increased diesel pump-set O&M costs, are secondary to system reliability as far as most users are concerned.

The decision to standardize on certain engine models and operating speeds (often resulting in oversized equipment) has generally been considered a step forward in terms of reliability, even if it appears to be a step backward in terms of system efficiency and cost. But the durability of the Lister engine and flexibility of the Mono pump make these pump sets forgiving in system design, thus somewhat justifying this conservative approach.

C. Typical Designs (by User Group)

Although it is difficult to clearly define typical system designs, it is useful to get some sense of the differences in system configurations and use patterns for several of the more common user groups and applications of diesel pump systems in Botswana.

1. Major Villages

The water supplies of major village are characterized by multiple boreholes, many private connections, and relatively high water requirements. There are often multiple storage tanks, either elevated (if they must be) or located at ground level if the terrain allows it. The use of multiple boreholes allows different pumps to be used depending on the condition of the engines and/or the boreholes, as well as providing several layers of redundancy for backup. Due to the high water demand, high-yielding boreholes (>10 m^3/h) are sought, and relatively longer distances from borehole to village outlet (13 km in one case) are common. This means that more multiple-cylinder, higher capacity engines are used by major villages than is true for other user groups. At present, the pressure of steadily increasing demand has resulted in long pumping hours at many boreholes in major villages. The average pumping rate for these boreholes is seven to 10 m^3/h, with an average pumping duration of more than 12 hours per day.

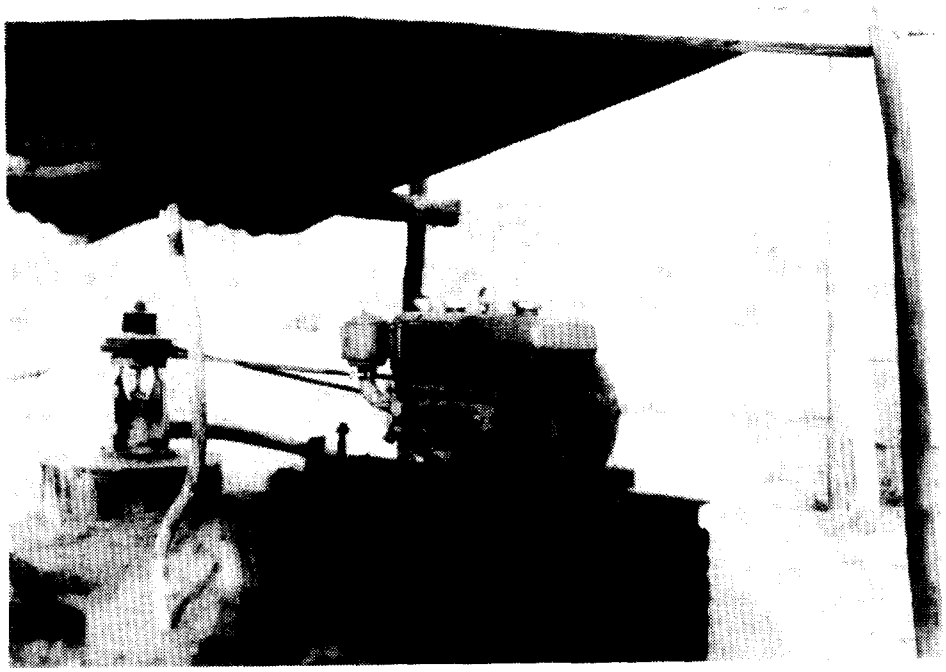
2. Rural Villages

Rural villages normally have only one engine-pump set, which delivers water into a single elevated tank with a capacity of 20 to 50 m^3. Reliance on a single borehole and a single engine make these systems particularly vulnerable to breakdown. There is seldom any back-up capability in the event of system outages. However, at least five small villages do have handpumps installed on separate boreholes for that eventuality. Water demand can and does vary considerably, but averages about 30 m^3/day for a population of roughly 1,800 to 2,000. Typically, most of the water is delivered to users through centrally located public standpipes. Single-cylinder Lister/Mono pump systems dominate (the ST-1 is the most common engine), although a few multiple-cylinder engines are in use. Since demand is not very high, the additional effort to find high-yielding boreholes is not required as it is for major-village water supplies. The average yield for equipped rural village boreholes is in the range of three to five m^3/hr.

3. Other Government Agencies

Other government sites that employ diesel pumping include GOB camps used by Customs and Immigration, the Department of Wildlife, or by MOA in its various activities (see Appendix C). These camps are often small and the water requirement typically low. All of these systems are equipped with single-cylinder engines, and some of the older MOA boreholes are equipped with National rather than Mono pumps. Usually, ground tanks or small

elevated tanks are used, and the reticulation system is minimal. Water consumption is generally low, except in some locations where the MOA waters stock, such as at research stations, and seasonally along trek route sites and at veterinary locations.



Privately owned 7 kW Kubota near Ghanzi.

4. Privately Owned Equipment

Almost all of the privately owned equipment is used for stock watering. These sites normally use single-cylinder engines (most often the Lister 6/1 or 8/1), and often National pumps. Since the Water Apportionment Board authorizes a maximum of 18.2 m^3/day to be extracted from stock boreholes, water demand is moderate. Often, not even that much water is consumed. However, there are a number of cases where significantly more than 20 m^3/day is pumped in defiance of the law. In practice, there is little or no control of water pumping. Ground-level tanks are usually situated close to the borehole. In eastern Botswana, these pumping systems remain idle through the rainy season when water is available in dams and rivers. Moving west, where rainfall is less, there is increased reliance on boreholes for stock watering year-round.

D. Installed Capital Cost

The cost of installing a diesel engine system includes the capital cost of the system components, the civil works, installation labor cost (by convention), and transportation. There are major differences in these costs, depending on whether the work is done by the public or private sector. In the public sector, all diesel pump installations are done by DWA. Private-sector entrepreneurs equip boreholes for most private owners, and some users complete the installations themselves.

1. Equipment Costs

At the end of the design phase at DWA, the designer completes a standard list of materials for borehole equipping (see list on the following page). Other than the engine, pump, number of pipe columns, pulley and V-belt sizes, and pressure release valve, all system components are common to all GOB installations. This materials list is taken as the basis for the materials cost for public-sector installations.

In the private sector, some of these items are not normally installed, including water meters, pressure release valves, non-return (back flow) valves, gate valves and hose taps. One additional significant difference in the cost of private and public systems lies in the fact that GOB materials prices are lower due to a tendering process that allows the government to buy in bulk, thereby affording considerable economies of scale. Most private individuals do not purchase sufficient quantities of materials to buy their materials at the government tender price.

2. Installation Costs

A standard DWA equipping crew consists of eight to workers and a driver. They are provided with a 10-ton truck and camping equipment so that they can stay in the bush and complete the job. All members of the crew (including the crew leader) are Industrial Class employees, making between P6.68 and 15.84 per day. In addition to basic salary, they are paid certain allowances for working away from home. The value of these allowances often matches or can even exceed the worker's base salary. Typically, this means that a borehole-equipping crew cost about P200/day in salary and allowances, not including the crew's transportation to and from the site.

The equipping process involves taking the crew and materials to the borehole, arranging the camping site, mixing and laying the concrete for the engine block and pump house floor (including installing the engine frame), installing the Mono pump and pipes, installing the engine, erecting the pump house, then checking

Materials List, Borehole Equipment

50 mm

Borehole number_____

Location_____

District_____

Description	Nos.	Unit	Rate	Cost
Pump Mono_____@_____ rpm				
Cap_____m^3/h _____m head	1	ea.		
Monostroom discharge head 50/250 mm pulley	1	ea.		
Mono column complete with shafts and bearings 3m x 50mm x 16mm		ea.		
Column stabilizers 50 mm		ea.		
Engine Lister_____@ 1500 rpm; _____clutch	1	ea.		
Engine pulley _____mm	1	ea.		
Baseframe complete with foundation bolts	1	ea.		
V-belts	2	ea.		
50mm barrel nipple	6	ea.		
50mm Helix water meter with drilled flanges	1	ea.		
50mm x 20mm reducing tee	1	ea.		
20mm pressure release valve _____kpa	1	ea.		
50mm brass non-return valve	1	ea.		
50mm union socket	1	ea.		
50mm x 90° GS bend	2	ea.		
50mm x 6.7m GS pipe	1	length		
20mm GS equal tee	1	ea.		
20mm GS barrel nipple	1	ea.		
20mm brass hose tap	1	ea.		
50mm brass gate valve	1	ea.		
Pump house complete with foundation belts	1	ea.		
Cement Portland 50kg	21	bags		
Crushed stone	2.5	m^3		
Sand	2.1	m^3		
Reinforcing mesh--5mm, 200mm, 3000mm x 4000mm	1	sheet		
Lubricating oil, miscellaneous fittings, etc.		sum		
Sum materials_____				
Labor cost_____				
Transport_____km x 0.72				
_____km x 0.34				

Grand Total:

that all of these items work properly. An examination of the records for nine boreholes reveals that the complete borehole-equipping process by a DWA crew takes an average of 20 days and involves about 3.5 times the round-trip distance to the borehole in transportation.

Interviews with private contractors indicate that under ordinary conditions, borehole equipping is done in five or six days, assuming a standard crew of four and several unskilled laborers hired on-site. The usual vehicle used is a 4x4 Land Cruiser or, in some cases, a three- or five-ton truck. The installation usually takes one trip to complete. The four-person crew is paid somewhat better than the DWA crew, earning P100 to 125/day in salary and per diem. Therefore, typical installation, labor and transport costs for a private-sector crew going a 200-kilometer distance is roughly P3,000. The differences in capital costs between the private and public sectors are covered in more detail in Section VIII.

VII. OPERATIONS AND MAINTENANCE COSTS

For the purposes of this report, maintenance costs and considerations have been subdivided into several categories:

- fuel and lubricant costs;
- annual labor costs for operation;
- annual labor and materials costs for maintenance and repair to the engine and pump;
- overhaul labor and materials costs and intervals; and
- engine lifetimes.

Although costs and practices within each of these categories affect costs in each of the others, each category will be discussed separately. In addition, differences will be noted across the spectrum of major user groups.

A. Fuel and Lubricants

The most commonly used measurements of fuel use are consumption per hour of engine operation or consumption per unit volume of water pumped. Actual use of fuel and lubricants varies widely according to several factors:

- hours of engine operation;
- engine model and the associated full-load fuel consumption;
- engine condition;
- water delivery rate;
- pump efficiency; and
- total head (which, with water delivery rate and pump efficiency, defines engine loading).

In Section V (and Appendix G), the relationship between fuel consumption and loading was discussed. Recall that the fuel consumption of the tested engines could be predicted fairly accurately using the algorithm provided by Lister. This algorithm was used to predict the fuel consumption for different engines operated under specified conditions of head and pumping

rate for the different user categories and cases discussed in Section VIII.

Fuel consumption rates, when quoted in terms of liters of fuel consumed per cubic meter of water delivered, can be misleading, since consumption rate is a function of the total head as well as the water flow rate. In the field tests, average fuel consumption ranged between .094 and .216 liters of fuel per m^3 of water pumped, reflecting differences in head, engine condition and loading. Fuel theft is generally not a problem in Botswana, thus is not a factor in the variable fuel consumption rates.

Fuel costs vary somewhat among user groups. At the time of the analysis, DWA was purchasing fuel at P0.54/liter. The District Councils enter into fuel purchase agreements with the oil companies individually. Their prices vary somewhat, depending on how far the fuel must be trucked, but remain in a range under P0.60. These prices reflect low duty (about one percent) for agricultural and government use. Higher duty road fuel is more expensive (above P0.60 depending on location), reflecting the higher duty (about six percent). Private users often use high-duty fuel, most probably because it is easier to do so.

Lubricant (oil) use is usually quoted as a percent of fuel consumption. Appendix J discusses results of an analysis of oil use for engines operated by the District Council water units. Based on this analysis, a figure of oil consumption as four percent of predicted fuel consumption was used for the financial and economic analysis.

Although there are likely to be some differences in fuel and lubricant consumption among user groups, sensitivity analysis has shown that these are insignificant relative to other cost considerations.

B. Annual Operations Labor

Annual labor considerations in this category include only the labor charges for the engine operator (pumper). Additional skilled labor required on an annual basis for servicing the engine is covered under maintenance in Section VII.C, and skilled labor for overhauls in Section VII.D.

1. Major Villages

In major villages, boreholes are often sufficiently close together that one pumper is hired to take care of several boreholes. However, with long pumping hours and several shifts

in many villages, there is an average of one operator per operating borehole. The central government salary structure does not allow for part-time employees, so all pumpers are paid according to Industrial Class scales, which call for salaries in the range of P2,400 to P2,500 per annum, depending upon seniority and experience.

2. District Councils (Rural Villages)

Pumpers working for the District Council usually are responsible for one or, at most, two boreholes in a particular village. In the few cases (16 country-wide) where there are more than one borehole in a village, a second pumper is sometimes employed. Although MLGL is currently working on a salary structure for council employees, none has been implemented to date. In the absence of such a structure, most councils follow the central government salary guidelines. In general, there is one pumper per village, being paid an annual salary of P2,400.

3. Other Government Agencies

Government agencies other than DWA are, for the most part, responsible for providing their own pumpers, although there are a few exceptions where the DWA employs the pumper. In most cases the duties of a pumper are part of a set of broader responsibilities, possibly including such roles as radio operator or driver. In these cases it is difficult to assign a precise value for specific duties involved in pump operation. In some cases (notably, some of the wildlife boreholes), there are no duties other than being the pumper. Some of these locations are fairly remote, and additional allowances (local and frontier allowances) paid to the pumper for living in such circumstances can increase labor costs by 25 to 30 percent. This is one reason why agencies such as the Department of Wildlife are interested in alternative pumping technologies, some of which hold the potential for unattended operation. On average, it has been assumed that the responsibilities will require half of an individual's time. This implies payment at an annual rate of P1,200.

4. Private Sector

Private-sector operators are not covered by a government salary structure, and are often paid much less than the government rate. Information about pay rates is scarce; no records are kept and there are few published reports on this topic. Annual salary figures quoted in the few available reports differ somewhat. For example, rates range from P130 (plus some consumables) in 1978 in the western Sandveld region (Hitchcock),

to P475 in eastern Botswana in 1980 (Bailey), to P475 in a selected part of Southern District in 1983 (Flint). Pumper costs do not appear to have increased much over the past several years. For the purposes of this study, private-sector operators are assumed to earn P450 annually.

C. Annual Maintenance and Repairs

Annual maintenance and repair costs include all field service (including on-site labor) completed at the borehole site, but not that for the tank and reticulation. Overhaul costs are not included because they are not considered annual costs or field service. Maintenance and repair costs are a function of the engine operating hours and condition of the engine. In the following analysis, the condition of the engine has not been specifically considered. Since data at that level of detail are not available, average engine conditions have been assumed. A more complete discussion of service costs can be found in Appendix K. Detailed maintenance and repair procedures and costs are given in Appendix L.

Privately owned Lister 8/1 and Rapid pump head.
During the rainy season, the engine is not used.

1. Public Sector

Spares

For major-village water supplies, the total maintenance and repair costs (for 20 engines) over 188 engine-months (over 70,000 hours) of operation ranged from P0.16 to P0.19 per engine-hour of operation. A sample of 22 rural villages (from six districts and subdistricts) were surveyed to ascertain the field service costs (parts and on-site labor) for council boreholes. The range of values over a one-year period was P0.01 to P1.00 per hour of operation, and averaged P0.20. BRS records indicate that the average cost in spares and site labor for other GOB posts and agencies is P0.13 per operating hour. These figures all fall within a similar range.

The higher values (up to P1.00) indicated for rural villages are considered high over the long term for two reasons. First, due to the recent attention SIDA has given to this user group, the current budget for equipment replacement and spares is higher than can reasonably be expected over the next two years. Second, in one of the districts surveyed, because the SIDA funds were available and the technician wished to standardize on only two engine models, there has been an effort to replace all older engines regardless of actual need. Thus, it is felt that the long-term field service costs will be in line with values for major villages.

Similarly, it is believed that the long-term values for other GOB-agency pumping systems serviced by BRS are similar to those of the major villages. This is because trips (and their costs) made to service this user group are underreported. The underreporting is due to the fact that these services are not billable and hence there is less emphasis on accurate reporting of their costs.

Field Labor

The labor cost for repairs made at pumping sites in major villages was P0.01 per engine-hour of operation. This work was performed by DWA crews stationed at the major villages or by BRS. Records for labor costs of service requirements in rural villages and at government posts are much less reliable. For the purposes of this study, it has been assumed that labor values are similar, as the wage scales are the same.

Service Trips

The cost of service trips depends on the number of trips and the vehicle cost. Each user group's average number of trips is discussed below. For all groups, the vehicle cost is taken as the kilometer cost for vehicles as calculated by the CTO. It appears that these costs are slightly low and do not reflect the true kilometer cost for each vehicle type. A complete analysis of these costs would be similar in scope to the present diesel-pumping cost study and has not been attempted. In addition, transportation costs are different for the District Councils (which maintain their own vehicles) than for the private sector. The assumptions made concerning transportation costs are likely to bias the analysis slightly, but not significantly, when long transportation distances are considered.

The records for major-village water supply indicate that, on average, five trips are made per borehole per year for maintenance and repair purposes. Additional trips are made to check meters, bring fuel, and for other logistic purposes. The records indicate that roughly half of the repair and maintenance trips were made to repair or service the engine, and the remainder for pump-related problems. The relative cost of these trips averaged P36 for engine trips, and P284 for pump-related trips. This difference arises because pump repairs involve pulling the pump/pipe from the borehole, requiring additional equipment and larger vehicles. The average distance from major-village service centers (which are usually within the major village itself) to pumping sites is much lower than for other user groups. In some cases, the pumping sites are within the village itself. With recent installations, greater distances are encountered as suitable well fields are often some distance from the villages. For example, the new well field for Mahalapye is more than 50 km from the village.

Service and repair trips to rural villages vary considerably by district, as does the average trip distance. Records and interviews indicate a range of from one to seven or eight trips per year. The average is between 3.5 and four. This is similar to the number of trips required for major-village service. However, the average distances are much greater, often in excess of 200 km and occasionally more than 350 km. In addition, roads to many rural villages are poor.

Government camps and posts are located throughout the rural part of the country. In cases where their water needs can be served from other public supplies, they usually are. There are fewer BRS outstations to service this equipment than there are district water units and sub-depots. This increases likely service-trip distance considerably. An average of roughly one trip per year is recorded--a much lower average than for village water supplies. Because of transportation constraints at BRS

outstations, engines in these areas receive less regular servicing, and minor repairs are made on-site.

2. Private Sector

The cost for servicing privately owned engines is more difficult to determine than for the government cases above. Several reports (Hitchcock, Bailey) indicate that average use of private boreholes is about 2,000 hours per year. During the remaining part of the year, surface water sources, rather than borehole pumps, are normally used (at least in the eastern part of the country). An analysis of BRS records, along with the above assumption (2,000 hours/year usage), results in the conclusion that annual repair costs are about P0.17 per operating hour. However, since not all servicing is done by BRS, the actual figure will be higher. An examination of other sources (Hitchcock, Bailey, Flint) indicates a similar per hour cost. In light of other information (see Appendices E and F), this figure seems reasonable and agrees with values for the other major user groups. One may expect the cost of spares to be higher than for public-sector use due to lower levels of equipment maintenance. However, it appears that the price is paid in reduced equipment reliability rather than cash for repair.

D. Overhaul Costs and Intervals

Engine overhauls become necessary when an engine no longer functions properly and the causes of poor performance cannot be remedied by minor repairs. Even though there are rare cases where overhauls are done in the field (see below), for the purposes of this study an overhaul is defined as any servicing that requires workshop-based repairs. A number of private firms perform diesel engine overhauls, and BRS operates workshops in Gaborone and Maun where about 400 engines and 50 engines, respectively, are overhauled annually. The private companies overhaul 250 to 300 engines per year each. There are reports that a number of engines are sent out of the country for overhaul, notably to Johannesburg and its environs, Gobabis, and Bulawayo, Zimbabwe. Some freehold farmers perform the overhauls themselves. It appears that the informal sector also occasionally "overhauls" engines in the field, sometimes installing used parts and occasionally even the wrong parts.

One major source for engine overhaul rates and costs are the records kept by the BRS workshops. Investigations into their records are summarized in Appendix F. Interviews with the managers of private workshops were also helpful in this regard. The above does not exhaust the subject, as there are numerous accounts of complete overhauls taking place in the field. In many cases, the results of these field overhauls can be seen when

the engines finally come to a workshop--oil rings made of eight-gage wire, standard pistons in an oversized cylinder, cardboard gaskets, etc.

1. Public Sector

Most, if not all, government engines are overhauled at either District Council or BRS workshops. In these cases, the figures presented in Appendix F can be taken as accurate, with engine overhauls costing about P400 to P1,000, depending on engine model and number of cylinders. The overhaul intervals range from 3,500 to 4,000 hours. These figures are lower than those given by Lister (recommended at 5,000 to 6,000 hours as necessary). The primary reason for this is most likely the typically irregular preventive maintenance program, particularly regarding oil and air filter changes. Low engine loading exacerbates this situation as well.

2. Private Sector

In the private sector, the issues are much more complicated. First, most of the freehold farmers handle repairs and overhauls themselves, or in private workshops in Botswana or over the border. Interviews indicate that, in general, those engines that do come in from freehold farmers are in better condition than those of other private-sector groups. Other private-sector users do not seem to bring engines in for repair until there is clearly no other choice. Often the crank and cylinder must be ground more than one oversize or replaced altogether, significantly increasing the cost of the overhaul. BRS records indicate that for the most popular engines in the private sector (the water-cooled 6/1 and 8/1 models), the overhaul cost is 20 percent higher than the average for public-sector engines. Private workshops indicate that the overhauls they do for engine owners in this category run from P1,200 to P1,500. In comparing this to the BRS cost of P400 to P1,000, bear in mind that when BRS performs an overhaul, engine owners also receive a six-month guarantee on the work. This is seldom (if ever) done in the private sector.

Overhaul rates for private-sector users are difficult to assess. Calculations made in Appendix F indicate approximately 10,000 hours between overhauls. Due to the nature of BRS and the informal sector repair infrastructure, this may overstate the case. It is clear that many private-sector engine users neither service their engines properly nor do the necessary repairs in the approved manner, but they do manage to stretch the limits of engine overhaul intervals by various delay tactics, because they have a sense of the cost of overhauls and cash is often in short supply.

E. Engine Lifetimes

Engine lifetimes are a function of service and maintenance history, and of the owner's assessment of the point where it is cheaper to buy a new engine than continue to overhaul the old. In many cases, it is also a function of the engine manufacturers' willingness to continue to supply spares for older models. Fortunately, Lister continues to make spares available for most discontinued engines. Engine lifetimes range from weeks or months (in those cases where owners do not follow crucial installation or operating instructions) to 50 years or more. However, more typical figures are required for purposes of the analysis.

The approach of this study has been to try to determine engine lifetimes as a multiple of the number of engine overhauls. There are two reasons for this. First, engine lifetimes are a function of engine operating hours and the quality of service they receive. The approach to engine overhaul intervals attempts to account for these factors. Second, the nature of the repair process lends itself to defining lifetimes in this way. Clearly, the end of the engine's useful life will arrive when an overhaul is required and the owner decides that it is no longer cost-effective to do so.

As an example of the relative longevity of Lister diesel engines in Botswana, BRS overhauled 22 3/1 and SL series engines (more than five percent of the engines surveyed) in 1986. Since these engines have not even been produced since 1952 and 1955, respectively, that means they are at least over 30 years old.

1. Public Sector

The design of the Lister engine is such that if competent technicians perform overhauls at a reasonable labor cost, it is nearly always less expensive to overhaul an engine than replace it. This realization has had a strong influence on public-sector repair/replace decisions. Diesel engines are rarely scrapped. After seven years of collecting scraps in the DWA yard, only 36 engines have accumulated. If the average number of engines operated by the GOB over the period is taken to be 300 (75 in major villages, 225 for government agencies), then the lifetime per engine is roughly 60 years, or about 45 overhaul intervals. A more realistic figure emerges if one includes in the calculations the 54 engines which DWA no longer considers useful to DWA, but which have useful engine life remaining (these engines are auctioned). The result is a more realistic 23-year engine life, or about 17 overhaul intervals.

2. Private Sector

Private-sector users, most notably the non-freehold farmers, certainly replace engines more often than every 20 years. There are roughly 500 engines sold in the private sector each year. From the Water Apportionment Board records, there are about 150 approvals for new installations each year. This means that about 350 engines each year must be replacements. If one assumes that there are about 4,000 private boreholes, then replacement occurs about every 11 years, or about three private-sector overhaul intervals. As noted above, overhaul intervals in the private sector tend to be considerably longer than for the public sector.

VIII. ECONOMIC AND FINANCIAL ANALYSIS

A. Introduction

The purpose of this financial and economic analysis is to provide estimates of the cost of pumping water with diesel-powered pump sets. The analysis is based on actual measured and researched data, applied to specific cases which represent common pumping applications in Botswana. There are a variety of techniques available to facilitate the economic comparison of competing investments in water pumping technologies. The general method used for this presentation is discounted cash flow analysis. Fundamental to the technique is the ability to combine the capital costs with the stream of operating costs so that two investments, having different proportions of capital and operating costs, can be directly compared. Comprehensive discussions of discounted cash flow analysis can be found in the PLANNING OFFICERS MANUAL (Ministry of Finance and Development Planning, June 1986).

The results of the analysis are presented in terms of a "unit cost" of water delivery, given in pula per cubic meter. This unit cost is the present value of all costs incurred over the lifetime of the analysis, including all installed capital and recurrent costs divided by the total discounted water pumped (see Section V). This analytical approach has become the standard method of analysis for water pump cost comparisons, and is used in the HANDBOOK FOR COMPARATIVE EVALUATION OF TECHNICAL AND ECONOMIC PERFORMANCE OF WATER-PUMPING SYSTEMS (CWD, 1987)).

Due to the use of these data for comparison of pumping systems, the costs enumerated here are less than a full accounting of the complete costs of water delivery. It is customary, when comparing the costs of options designed to perform the same task, to omit costs that are common to all options being compared. Therefore, common costs such as the cost of drilling, testing, and casing the borehole and distribution system will be omitted. The unit cost estimates provided herein do not provide estimates of the full cost of pumping water with diesel pump sets. Other costs that have been omitted include training, spare parts inventories and overhead.

The model used in this analysis contains two major elements. The first is an engineering module, which yields performance data about the pump set; the second is the economic module, which yields estimates of the unit cost of the water. In addition to the explanation of the model in Section V, a table showing the data used is included in Appendix N.

The analysis begins with a discussion of a base-case example and includes sensitivity analysis. This base-case example

introduces the variables considered and discusses the relationships among them. The broader analysis of the pumping costs discusses the implications of engine choice, as well as the four major user groups discussed previously. All costs expressed in this section are in pula, the decimalized currency of Botswana. On 1 April 1987, the following exchange rates were in effect:

1 pula = US$0.595 = 1.2079 RSA rands.

B. Base-Case Analysis

To show how the model works, and to give an indication of the relationships among the various physical and cost parameters, a base-case example is described and analyzed. This base case was chosen to represent a typical pump application. Sensitivity analyses have been conducted in order to gauge the effects of varying assumed physical and cost parameters. Bear in mind that the magnitude of these sensitivities depends on the specific case being analyzed and may vary somewhat across the different user groups.

The base case chosen for this representative analysis is a rural village water supply system using a Lister ST-1 engine driving a Mono pump. Since 42 percent of rural villages use these engines, and rural villages represent about 60 percent of all government pumping applications, this is a typical situation. The daily water output was assumed to be 30 m^3/day through a 90-meter total head (including discharge). According to District Council records, this daily water requirement is the average value for all rural villages.

1. Assumptions

The major inputs for the model can be conveniently divided into physical and cost categories.

Physical

The Lister ST-1 chosen as the base-case engine was de-rated for temperature and altitude, according to the method outlined in Appendix G. The scheduling of all maintenance and repair procedures was based on average values determined after an examination of the District Council water unit and BRS workshop records (see Section VII).

As the analysis bases certain recurrent costs on the hours of engine operation, the assumed pumping rate must reflect typically encountered practices. Boreholes equipped for rural

water supply can be pumped at about 3.5 m^3/h, based on a brief survey of pumping rates for this application. This implies that it will take just over 8.5 hours of pumping per day to satisfy the demand. At current water use levels, 30 m^3/day will satisfy the needs of roughly 1,500 to 1,750 people.

Mono-pump efficiency is a function of head and pump speed. Within reasonable speed ranges (i.e., 900-1,200 rpm), efficiency is fairly constant. The Mono pump also has a characteristic of fairly constant efficiency over a wider range of heads than do most submersible borehole pumps. At the 90-meter head and an operating speed of about 1,000 rpm, 75 percent was taken as the efficiency for the pump unit based on the manufacturer's measured tests.

Travel distances from both the service and installation center were chosen to be representative of rural villages. The village is assumed to be 200 km (one way) from the installation center, and 100 km (one way) from the service center. This reflects typical distances from rural villages to District Council water maintenance units (for service centers), and to DWA-crew home bases (for installation).

Over time, water requirements in rural villages have increased, partly due to population increases and partly to increased per capita consumption. The increase has been taken as three percent per year. The growth in demand means that engines operate more hours per day, thereby increasing annual fuel and lubricant consumption as well as annual maintenance and repair requirements.

Economic

The costs of the engine, pump, and associated civil works for public-sector installations were taken from the latest official tender (1987). These costs are shown in the table below:

Installed Capital Cost Components

Lister ST-1 engine	P2,289
Mono pump and pump head	599
Rising main (P18 per meter, x 90 m)	1,620
Pump house and civil works	1,190
Above-ground piping and other components	450
Installation labor	4,000
Installation transport	1,470
Total Installed Capital Cost	P11,618

The costs of installation, including crew labor and travel time, etc., were based on actual records for government installations. Labor and transport costs incurred during installation are properly treated as capital costs, since they are an integral part of the installed cost of the pump set.

A full-time pumper is assigned to operate the pump set, at an annual average salary of P2,400. Other labor, both skilled and unskilled, is included at rates of pay representative of the groups in question--P7 and P12 per day, respectively.

Fuel costs are charged at the official price of P0.54 per liter (which includes duties ordinarily paid). Lubricating oil is included at four percent of fuel use (see Section VII) and is costed at P2 per liter. Trips for refueling are based on records and interviews. While actual refueling trips may be more frequent, trips are ordinarily combined so that stops are made at more than one site. On average, three trips per year are chargeable to each site.

The costs of parts and other materials for routine maintenance are a function of hours of operation and are based on review of actual operating records. Labor costs, for routine maintenance--rather than installation or overhaul--are included as an annual charge for 12 person-days of unskilled labor, and three person-days of skilled labor at P7 and P12, respectively.

The analysis is based on a 20-year time span, and a six percent discount rate for government users.

Costs in future years may or may not be similar to initial-year costs. This may be due to costs in future years not encountered in the initial year (engine overhaul, for example) or initial-year costs not encountered in future years (purchase of the equipment). The analysis assumes every cost item will increase by the prevailing rate of inflation. It is possible that certain items will change in cost at rates other than that of general inflation. For diesel systems, the most likely such cost item is fuel. The model allows for an escalation in fuel cost over and above the general rate of inflation. For the base case, no such escalation is assumed. However, the effects of possible fuel cost escalation is addressed in the sensitivity analysis.

The cost implications of the annual growth in demand were calculated using the cost/performance model. The table below shows the differences in the annual recurrent costs and certain important physical parameters between year 1 and year 20. This does not include non-annual recurrent costs, such as the periodic need for engine overhauls or replacement. Though pumping has increased to 16 hours per day in the twentieth year, a second

pumper was not added to the costs (this reflects actual practice in most cases). No escalation in the price of fuel over and above the general rate of inflation was assumed.

Summary of Cost Changes (Financial Accounting)

	Year 1	Year 20
Annual recurrent costs	P 4,839	P 7,306
Annual fuel and lube costs	1,137	1,993
Annual water pumped (m^3)	10,950	19,201
Engine hours	3,129	5,486

Because of a surplus of unskilled labor in Botswana, the shadow price for unskilled labor is 50 percent of the financial cost. The economic cost for use of foreign exchange is higher than the financial cost because funds that could be used to encourage indigenous industry or employment are used for imported items. The shadow price for imports is 110 percent of the financial price.

All parts of the pump set are imported free of duty under the Southern Africa Customs Union Agreement (SACUA). Engines that do not come from within the Customs Union would be dutiable at 25 percent. However, any duties on equipment imported for use by the government are eligible for waivers. For example, Lister engines imported from the U.K. for DWA use are exempt from duty. This contributes to lower government prices for some equipment than can be found in the private sector.

2. Results

The main item of interest in this analysis is the unit cost (financial and economic). For each case analyzed in this section, two other items are also reported: engine loading (see Appendix G) and fuel use (in liters per hour).

The base-case run of the model, using data described above, yields a unit cost of P0.51 (financial) and P0.44 (economic) per cubic meter of water. These and other base-case figures are summarized in the below.

Summary of Base Case

Loading = 34% Fuel Use = 0.59 liters/hour	Financial	Economic
Total equipment costs	P6,148	P6,763
Installation transport costs	1,470	1,617
Installation labor costs	4,000	3,000
Total installed capital costs	11,618	11,380
Present value of recurrent costs	69,886	59,172
Total	P81,504	P70,552
Discounted volume of water (m^3)	159,449	159,449
Unit cost (P/m^3)	0.51	0.44

The net effect of shadow-pricing on economic costs is to reduce the overall life-cycle costs. The labor component of installed costs is reduced by 25 percent (since only half of the labor component is unskilled labor), subject to shadow-pricing. Unskilled labor is defined as labor earning less than P2,400 per annum. The present value of the recurrent cost is reduced by 15 percent, largely due to shadow-pricing of the pump operator's wages. Equipment and transportation costs increase as all of the material and fuel are imported. The total installed capital cost on an economic basis is 98 percent of the financial figure.

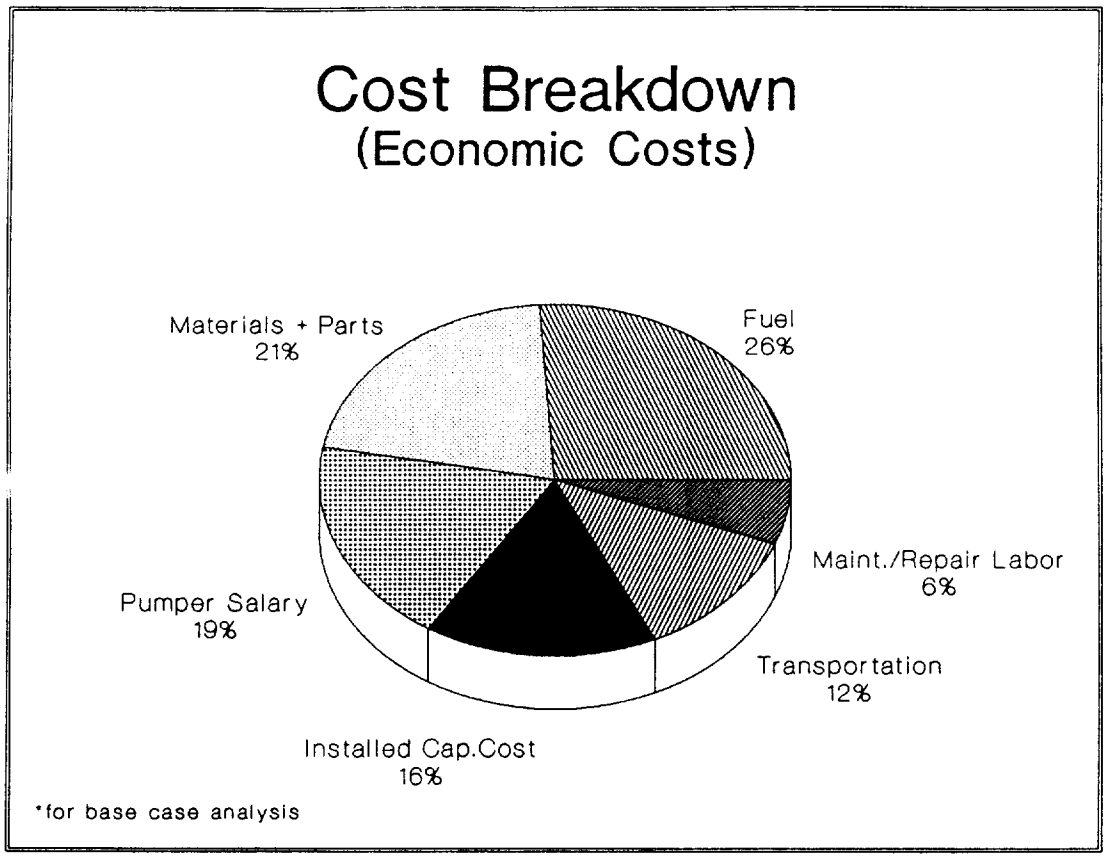
That the economic unit cost is 15 percent below the financial implies that investment in the pump set is of greater value to the national economy than the financial figure would indicate. In other words, relatively less investment in such pump sets would occur if decisions were based on financial rather than economic cost information.

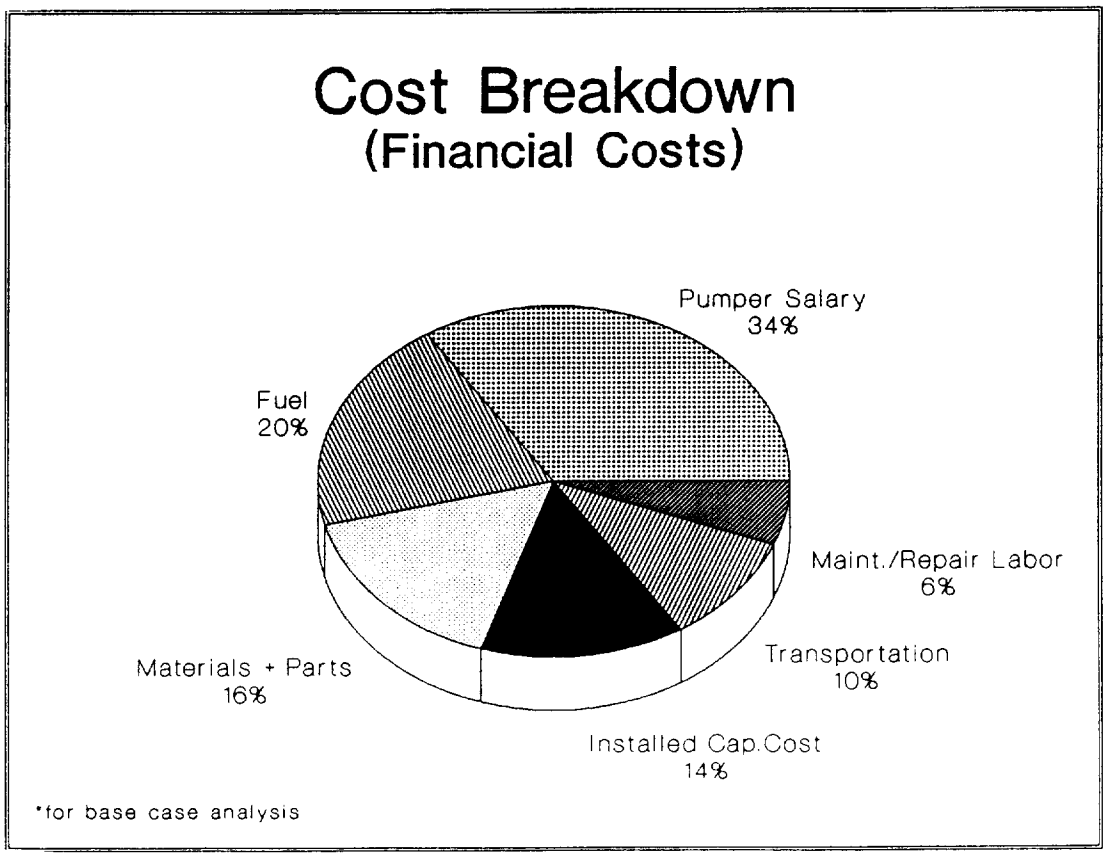
As indicated in Figure 6 (pie charts showing economic and financial costs), the installed capital costs are 16 percent of the total installed costs in the economic case. Fuel costs are slightly more than the capital costs at 26 percent, materials and parts are 21 percent, the pumper salary 19 percent, and transportation 12 percent. For the financial case, the pumper's salary (not shadow-priced) amounts to 34 percent of the total life-cycle cost.

3. Sensitivity Analysis

As noted earlier, the model contains both physical and cost variables. Sensitivity analyses on both types of variables were performed. The first series deals with physical characteristics. The second set of sensitivity analyses deals with changes in

Figure 6.


Cost Breakdown
(Economic Costs)
Materials + Parts
21%
Fuel
26%
Maint./Repair Labor
6%
Pumper Salary
19%
Transportation
12%
Installed Cap.Cost
16%
*for base case analysis


Cost Breakdown
(Financial Costs)
Pumper Salary
34%
Fuel
20%
Maint./Repair Labor
6%
Transportation
10%
Materials + Parts
16%
Installed Cap.Cost
14%
*for base case analysis

costs--over some of which managerial control can be exercised. Others are simply less likely to be controllable (e.g., fuel costs).

Figure 7 summarizes the results of these analyses by ranking the present value of a unit of water in economic terms according to the extent of their impact. First, the changes which resulted in the greatest percentage decline in the value are ranked, and these are followed by those which caused the largest increase. For purposes of discussion, however, changes in physical characteristics will be examined first.

Changes in Physical Variables

Flow Rate

First, as can be seen in Figure 7, shortening the time during which a given quantity of water is pumped (i.e., increasing the pumping rate) with the same engine significantly reduces costs (because the equipment is better matched to the load). The flow rate or maximum sustainable pumping rate is a function of the yield of the borehole. It is important to know with some precision the sustainable yield of a borehole in order to design diesel pumping equipment to take advantage of the maximum sustainable yield.

As the analysis shows, water cost declines as pumping rate increases. However, if the design pumping rate is greater than the maximum sustainable borehole yield, the pump will draw in air, which will certainly increase fuel costs per unit of water pumped (as at Mmaphashalala) as well as damage the pump. The Mono pump will not fail in these cases, but will degrade steadily. The costs associated with pulling the pump and replacing the damaged parts will be on the order of P200 to P1,000.

The costs for underutilizing a borehole can be substantial. In the case cited here, increasing the pumping from 3.5 to 7 m^3/h decreases the number of hours of operation and all of the costs dependent on it. The engine has a higher loading when the pumping rate is increased and hence is running more efficiently (17 as opposed to 14 percent). The first-year annual savings in fuel alone is on the order of 20 percent, and the life-cycle cost savings over 20 years is about 15 percent. These results call attention to the benefits of knowing as accurately as possible the true sustainable yield of the borehole. DWA is currently upgrading its capability to test-pump boreholes and more accurately characterize their yield.

Figure 7.

Base Case--Summary of Results of Sensitivity Analyses

Variable Name	Change Made	Financial	%	Economic	%
Base-case condition	none	.51		.44	
Pumping rate	increase 100% & reduce hours by 50%	.43	-16	.36	-18
Pumper labor	reduce 50%	.43	-16	.40	-9
Distance to service & installation	reduce 50%	.48	-6	.41	-7
Engine type	replace Lister ST/1 with LT-1	.49	-4	.42	-5
Discount rate	reduce 50%	.49	-4	.42	-5
Installation labor	reduce 50%	.50	-2	.43	-2
Fuel and lubes	7% annual increase	.60	+18	.54	+23
Discount rate	increase 100%	.57	+12	.49	+11
Distance to service & installation	increase 100%	.56	+10	.50	+12
Fuel and lubes	4% annual increase	.55	+8	.49	+11
Overhaul rate	reduce interval by 50%	.54	+6	.47	+7
Total pumping head	increase from 90 to 120 m	.54	+6	.47	+7

Distance to Service and Installation

It is important to understand the effects of geography on the costs of water pumping. The problems of covering long distances, sometimes in a 10-ton truck, are significant. The costs can be contained somewhat by planning trips more efficiently, using smaller, less costly vehicles where possible, or making fewer trips. The simplest way to model such a cost reduction is to alter the distances to the service and installation centers. The base case includes values of 100 and 200 km, respectively. While there are no strategies suggested for physically changing these distances, it is useful to note the sensitivity of these assumptions. It is also interesting to note the difference in costs associated with serving a more distant village. Both values were halved for the first case and then doubled. The resulting present-value costs for the half-distance case were P0.49 (financial) and P0.42 (economic) and for the double-distance case, P0.59 (financial) and P0.52 (economic).

Engine Choice

It is difficult to generalize the effect of engine choice, except to show its effect in several specific cases. For the base case, replacing an ST-1 engine with an LT-1 reduces the economic unit cost by five percent. However, for other circumstances or other user groups, savings can be considerably greater. For example, referring to the cost/performance matrix for rural villages in Appendix N, and using the base-case assumptions of 30 m^3/day and 90 meters head, the economic unit cost for an 8/1 engine is P0.52. For the same situation, an ST-1 yields a P0.44 unit cost (the base case shown in Figure 6), and an LT-1 yields P0.42.

For this specific example, then, replacing a clearly oversized (but not unusually so) engine such as the 8/1 with a more appropriate engine such as the LT-1 can yield a reduction in unit cost of as much as 19 percent. Using the same example in the case of a private owner, unit cost would be reduced from P0.52 to P0.36, or 31 percent. The reduction in cost is due not only to higher operating efficiency (and subsequently reduced O&M costs), but also to the fact that the smaller engines are less expensive to begin with. Clearly, particularly for the private sector, this represents significant potential for cost savings in return for essentially no additional investment.

Changes in Cost Variables

Installation Labor

First, the installation labor and allowance costs in the base case are P4,000 (financial) and P3,000 (economic). Since these costs might be reduced by improved management, training and/or the provision of better equipment, they are considered to be controllable costs. The simplest way to model this change is to reduce by 50 percent the number of days per installation from the current average of 20 days to 10. In view of the time estimates to accomplish these tasks in the private sector, this is not an unreasonable goal to set. This reduces the total installed capital cost and lowers the unit financial cost to P0.50 and the economic to P0.43, from P0.51 and P0.44, respectively. Although yielding only a two percent reduction in cost, this reduction should be achievable with a minimum of directed effort.

Fuel and Lubes

There is probably no single component of diesel-pump running cost that is subject to as much discussion as fuel costs. Fuel costs are usually considered a major component of recurrent cost, and future prices are uncertain. Botswana is in a period of lower costs at present, but this situation cannot be expected to last. Moreover, in a politically troubled region, price could increase suddenly and dramatically if longer transport routes became necessary. It is clearly possible that fuel prices could escalate (over and above inflation). It is, of course, possible that the question could be more one of availability rather than simply higher prices.

The base case does not assume fuel price escalation. To test the sensitivity of water pumping to increasing fuel prices, two cases were run--the first at four percent escalation per year, and the second at seven percent. In the base case, the financial costs of fuel and lubrication in the initial year of operation are P1,137; in year 20 they are P1,993 due solely to increased demand for water. With a four percent annual increase in fuel price, costs nearly double by the tenth year (to P2,030) rather than the twentieth. By the twentieth year they have increased by 344 percent (to P3,914). The unit costs are P0.55 (financial) and P0.49 (economic) for the four percent case and P0.60 (financial) and P0.54 (economic) for the seven percent case.

While these changes are significant, they are less than one might expect. The simple fact is that small diesel engines pumping at these rates do not use a great deal of fuel. The cost of the fuel used in the initial year is less than half of the

pumper's salary. On the other hand, the real impact of the costs can be judged by considering the situation from the perspective of its impact on the combined budgets of the District Councils, which have some 525 such pump sets among them. Their collective annual fuel budget in the base case would increase from P530,500 to P947,000 (four percent case) or P1,195,500 (seven percent case) in just 10 years.

Finally, the overhaul interval (5,000 hours) was reduced by 50 percent. In other words, the frequency of overhaul increased. This change increased the financial cost to P0.56 and the economic to P0.48. One way to interpret this item is that it measures the long-term cost reduction that might be associated with a poor maintenance program. This is certainly a counter-intuitive conclusion, possibly explainable in two ways.

First, while a poor maintenance program may reduce the long-term costs of maintenance and repair (under certain circumstances), a severe penalty may be paid in terms of equipment reliability. This is borne out in the private sector in Botswana (where overhaul intervals are much longer than in the public sector), where system reliability appears to be much lower than in the public sector. Reasonable levels of preventive maintenance are not that much more expensive, but may be difficult to achieve given transportation problems as well as other demands on work crews.

Second, in the model, the annual cost of field maintenance and repair was based on a fixed average cost per hour of operation, based on an overhaul interval of 5,000 hours (from DWA and District Council records). However, it is reasonable to assume that this cost would be reduced if overhaul intervals were also reduced. This potential savings was not specifically accounted for in the sensitivity analysis of overhaul intervals.

Recurrent Labor Costs

It is customary that each pump set is attended by a pumper who runs the engine and is expected to perform other duties as well. These pumpers are paid an average annual salary of P2,400 per year--just more than the cost of the engine used in the base case, a Lister ST-1. It has been argued that there is often no need for a full-time pumper; a half-time person could do the job capably in many instances. If half of the pumper's time is allocated to duties not related to pumping, the annual pump-related cost is reduced to P1,200 and unit costs drop to P0.43 (financial) and P0.40 (economic). There have been efforts to allow the councils to hire part-time pumpers in cases of low demand, where engines may not run every single day. The opportunity for significant savings in such cases is clear.

Discount Rate

The discount rate was changed from six to three percent, which lowers the financial cost by four percent to P0.50 and the economic by five percent to P0.43. Changing the discount rate to 12 percent increases the financial cost by 12 percent to P0.57 and the economic cost by 11 percent to P0.49. For such a significant change in the rate, by a factor of two in either direction, the resulting differences in costs are not very dramatic. The question of the sensitivity of the present value to changes in the discount rate may well become more important when making comparisons among technologies than when analyzing variations within a single technology. Technology choice may depend to some degree on the ratio of capital costs to recurrent costs. This ratio is sensitive to discount rate, since the discount rate does not affect capital costs but does affect recurrent costs.

In summary, the base case shows that the unit costs are moved most dramatically by the physical characteristics and the pumper's salary.

First, changes in the flow rate which permit a given quantity of water to be pumped in a shorter time make a significant change in unit costs. Therefore, knowing the maximum sustainable pumping rate and matching it with a pump set of appropriate size is very important.

Second, the pumper's salary--especially when allocated entirely to pumping duties--is the most important financial cost variable in the model. The effect is significantly less on the economic unit cost because of shadow-priced unskilled labor.

Third, transport costs associated with installation, maintenance, and repair are significant. While these costs can be seen to arise naturally out of the long distances and sparse settlement characteristic of Botswana, efforts to reduce costs through reducing the number of trips for installation and service can yield dividends.

Fourth, for the fuel price to have a substantial effect on costs, it has to increase at a rate of more than four percent above the general rate of inflation.

C. Applied Analysis

As discussed in Section V, an analysis was conducted for four major user groups within Botswana which, because of their location or other specific reasons, face different costs for

pumping similar amounts of water or have different pumping problems to be solved. The four user groups are:

- major villages--DWA,
- rural villages--District Councils,
- private operators, and
- other government agencies.

The same model used to analyze the base case above was used to estimate costs for 16 pumping head/daily output pairs for each of three engines and each of four user categories. Specific output from these cases was assembled in a series of four-by-four cost/performance matrices, displayed at the end of Appendix N. The base case was analyzed in some detail to develop a general understanding of the relationships among variables. However, the intent of this section is to provide more specific guidance to those who select pump sets and others to examine the cost implications of the specific hardware choices available to them. One of the matrices is given in Figure 8 below.

Figure 8.

Sample Matrix: Output in Cubic Meters per Day
Case: Major Village Engine: Lister 8/1

Output:	20	30	50	100
Head				
30 Meters				
Financial	P.48	.36	.26	.20
Economic	P.37	.29	.23	.19
Loading	.17	.17	.17	.17
Fuel Use*	.70	.70	.70	.70
60 Meters				
Financial	P.51	.39	.29	.22
Economic	P.40	.32	.26	.21
Loading	.34	.34	.34	.34
Fuel Use	.98	.98	.98	.98
90 Meters				
Financial	P.54	.42	.32	.25
Economic	P.44	.35	.32	.24
Loading	.51	.51	.51	.51
Fuel Use	1.28	1.28	1.28	1.28
120 Meters				
Financial	P.57	.45	.35	.28
Economic	P.47	.39	.32	.27
Loading	.68	.68	.68	.68
Fuel Use	1.57	1.57	1.57	1.57

*Fuel use in liters per hour. Pumping rate is 7.0 m^3/hour.

The economic analysis is intended to convey as much information as possible. Also, an effort was made to make clear to all readers, regardless of technical background, how physical characteristics affect results. Thus, each cell above contains a) the discounted financial and economic unit water costs for each "head-flow rate pair," b) engine loading (expressed as a percentage), and c) fuel consumption (expressed in liters per hour). Therefore, one can quickly refer to the tables for a particular engine size and institutional setting, and see how pumping rate and head affect both financial and economic costs, engine loading, and fuel use.

The cases considered in this analysis contain representative data and assumptions based on actual cases, They represent typical applications of single-cylinder engines or, in some noteworthy instances, extreme cases that are known to occur.

These cases do not cover the entire range of equipment or applications found in Botswana. They do, however, address the original intent of the work--characterizing the cases where alternative technologies could displace diesel engines (i.e., engine power output range less than about 10 kW).

There are some very important differences between a public supply of water for a village and a private water supply at a cattle post. These include discount rate, financing arrangements, reticulation requirements, water quality prerequisites, as well as the myriad differences already discussed concerning engine use and service practices. At this level of analysis, conclusions about such differences in cost must be made quite carefully. It is much better to make comparisons in a specific case, where the water is to be used for similar or identical purposes and where the quantities are also similar.

Other reasons shape the choices to be made as well. For example, DWA's decision to restrict its choices to the Lister line of engines is reasonable and can be justified by lower cost spare parts inventories, increased familiarity with the engines and their quirks, etc. Physical conditions have an important effect on costs in other ways as well. Recall that one of the strongest conclusions coming out of the sensitivity analysis above is that the major determinants of cost are the physical conditions actually faced (e.g., flow rate and physical distances).

1. Engine Choice

In the cost/performance matrices, there are three ways to view the analysis:

- first, for a given engine and user group, what are the unit cost, loading and fuel use at a given head and daily water demand (a single matrix)?
- second, for a given user group, what is the best engine for its typical needs (the three matrices given under each individual user group)? and
- third, for a given engine, which user group applications are likely to be most cost-effective (the set of matrices for all four user groups)?

This section covers the first two of these approaches to the analysis. The third, from the perspective of user groups, is covered below in Section VIII.C.2.

Looking at a single four-by-four cost/performance matrix, the financial and economic costs of water delivery increased with decreasing water delivery and increasing head in every case. The increase in cost with decreasing water delivery is more pronounced than the increase due to increased head, primarily because the cost of the equipment and pumper's salary are being amortized over a greater volume of water. Also, as head increases, loading (and therefore efficiency) increases, but this is a secondary effect. As water delivery decreases below 10 m^3/day, the unit cost (in financial terms) approaches or exceeds P1.00 for all public-sector cases considered. As 30 m^3/day is delivered, the unit costs fall to roughly half this amount. This highlights the additional cost encountered as smaller village water supply schemes are built to service ever smaller populations.

It should be noted that in all cases the loading and specific fuel use (l/hr) do not increase as water delivery increases. This is because it is assumed that increased water delivery is achieved by increasing the engine-hours of operation, not the pumping rate. As noted in the discussion of sensitivity analysis, if it is possible to increase the pumping rate, doing so will decrease unit water costs. Unit costs increase with head since more energy is required to pump water from a greater depth. Loading increases with increasing head for the same reason.

In most cases, the economic costs are lower than the financial costs. In addition, the differences tend to be greater at lower levels of water delivery. This occurs because the labor component (mostly the pumper), shadow-priced at 50 percent of the wage rate, becomes a larger percentage of unit cost as the hours of operation decrease and the pumper's salary remains constant. As noted in the sensitivity study, the financial (as well as economic) cost could be decreased significantly if full-time pumpers were not required. It is in precisely these instances, where pump use is low, that the effect would be most dramatic.

Examining the matrices from the perspective of a single user group, the most notable trend is the tendency of all costs to decrease as engine size decreases (from the 8/1 to the LT-1). The reasons go beyond the price differences among the engines. As engine size decreases, the fuel consumption per hour decreases also (remember that the pumping rate is constant). This occurs because the loading is higher, hence the overall efficiency of the engine is higher. This is a solid demonstration of the advantages of using a properly sized engine. For example, if a Lister 8/1 were used to pump 30 m^3/day through a head of 120 meters at 3.5 m^3/hr in a rural village (not uncommon--very much like the test case at Oodi), the loading is 34 percent and the unit water cost is P0.60. If a (smaller and better-matched) ST-1 were installed, it would operate instead at 45 percent loading (still well below optimum), and a 10 percent reduction in the

unit cost could be achieved. An LT-1 engine (smaller yet) at 70 percent loading could achieve a reduction of 13 percent.

The models of single-cylinder pumping equipment available to DWA are the three Listers examined. In addition, DWA sets all engine speeds at 1,500 rpm (except the 8/1 at 850 rpm), in effect allowing only three levels of engine power for its entire range of small-scale pumping applications. This virtually guarantees that few pumping systems will be properly loaded. By changing the engine speed, the engine power output changes, and its range of output power can be expanded over a much wider range. While there have been significant benefits from standardization of equipment and engine speed, it appears that even within the constraints of engine model more optimum engine-loading levels can be achieved. It would be worthwhile considering a broader range of engine operating speeds to achieve more cost-effective pumping with diesel engines.

In many cases, boreholes cannot be pumped at more than 2.5 m^3/hr (because higher yielding boreholes simply cannot always be found). If that is the maximum allowable pumping rate, the engine loading will be only 65 percent of that given in the tables for every case (because pumping rates have been reduced accordingly). Even the smallest engine (the LT-1) cannot be loaded above 46 percent when pumping from 120 meters under these conditions. Given these situations, it may be worth considering a diesel engine smaller than the LT-1. Engines smaller than two kilowatts are not easy to find. The difficulty of designing a small diesel engine so that it will run hot enough to be efficient limits these engines. However, Hatz (as one example) offers a model E71 operating fully rated at 1.5 kW at 1,500 rpm, and it is currently available in Botswana.

2. User Group Differences

Pumping costs vary across user groups. There are several reasons for this, including:

- volume of water typically pumped and flow rate for each of the users;
- growth rate of water demand;
- different labor costs (especially for pumpers);
- site location with respect to installation and maintenance centers;
- variations in levels of service typically provided for both field service and overhauls;

- capital equipment and material cost differences (since three of the four user groups have access to government tender prices); and

- discount rate (between the government and private sector).

All differences in costs across the range of user groups can be explained in terms of these circumstances. This section discusses the major cost differences among user groups, and in some cases suggests cost-reduction strategies.

Major Villages

There are several reasons for exercising some caution when making direct comparisons between major villages and other user groups. First, the range of output/day considered in the analysis is higher than for other user groups, reflecting the actual situation for this user group. To address this higher demand situation, the flow rate assumed for this group is seven m^3/hr--also reflecting the fact that higher yielding boreholes are typically used to supply major villages to meet this higher demand. Also, considering only single-cylinder engines (as in this analysis) does not cover the entire range of major-village water supply engines. Finally, a higher demand growth rate (five percent) has been assumed for major villages, reflecting rural-urban migration.

Unit costs for major villages are generally lower than for other users simply because of the higher pumping rate. In addition, major villages are generally closer to service and installation centers, lowering transportation costs. The higher growth rate raises the total costs of water pumping, but reduces the unit cost.

Common use of higher capacity engines (multiple-cylinder HR series) on high-yield (greater than seven m^3/hr) boreholes reduces unit costs even further in many cases. Analysis of these systems is outside the scope of this report; however, they could be analyzed using the model developed for the project analysis.

Rural Villages

The capital costs faced by rural villages are similar to those of other public-sector users in Botswana. Capital equipment is bought at tender prices and provided to the villages by DWA. Costs are different from those of major villages primarily because of typically lower pumping rates in rural villages. In addition, rural villages tend to be located further

from the installation and service centers, making the repair trips longer and more costly.

Unit costs are also higher because of the lower volumes of water being pumped, when compared to the major villages. Where demand is high, fixed costs are allocated over a larger quantity of water and unit costs decline. In general, there is a premium placed on system reliability at rural village sites, due in no small way to the existence of only a single pump and borehole at these sites. The current availability of funds to support O&M programs has insured more effective (and costly) maintenance and repair programs (including full-time pumpers at P2,400 per year) than are typically found at other government sites or in the private sector.

Other Government Agencies

These users typically have much smaller demands than other user groups. The sites are field-serviced by BRS, which does not have the same institutional capacity to provide the level of service of District Councils. Often, BRS is only able to respond to breakdowns, rather than providing preventive maintenance. System reliability suffers accordingly.

The distances from service and installation centers to the typical government agency user, such as a game watering facility, are greater; therefore, the operating expenses are higher. At the same time, the pumper salary, which causes higher prices in rural villages, is not fully allocated to the pumping effort. In the typical situation, the person responsible for pumping also has other duties, thus only half the salary (or P1,200) is allocated to pumping.

It seems reasonable to assume that the level of service typical of other government agency sites will reflect typical costs of other small demand sites in the eventual absence of current levels of support provided to the village supply program in Botswana. Only because half of the pumper cost has been allocated to pumping is the unit cost less than in the rural village case.

Private Users

The unit costs for the private sector are less than those of all major user groups at a similar pumping rate and head. One of the most dramatic factors raising costs for the private user is capital costs--these are nearly 50 percent higher than those reflected in the government tender. Compensating for this are the lower capital costs resulting from the design of the above-ground piping and pump house, typically much less elaborate for

the private user. Further cost reductions arise out of quicker installation times and lower labor costs. The analysis has assumed a 12 percent discount rate (as opposed to six percent in all other cases), to reflect National Development Bank loan rates. This increases the present worth of recurrent costs, hence the unit cost.

For operating costs, the most important factor is the pumper's salary, which is only P450. Private-sector pumpers' duties consist largely of starting and stopping the engine, rather than the performance of minor maintenance tasks typical of other user group pumpers. This lower level of on-site attention is reflected in reduced equipment reliability. In addition, private engines tend to run longer between overhauls than do engines in the public sector. This is not always the case, however, since some (the minority) private pump owners provide a high level of service. Overall, however, the costs of pumping water are lower in the private sector than in the public sector.

In general, considerably less information was available about private-sector pumping costs than for the other user groups. Further examination of the range of private-sector pumping practices and costs would be required before drawing more detailed conclusions.

IX. CONCLUSIONS AND RECOMMENDATIONS

The original purpose of this study was to provide a baseline for the comparative analysis of alternative water pumping technologies. As such, the original goals of the diesel study did not include making recommendations concerning the use of diesel engines per se. However, as the overall comparison of pumping equipment progressed, there were inescapable conclusions and recommendations regarding diesel engines and the existing infrastructure that had important implications for the potential alternative technology market. The study also showed that the cost and reliability of diesel water supply systems were more favorable than initially expected.

The general conclusions of the diesel pump testing and evaluation component of CWPP are divided into two subsections--successes, and matters for concern. The subsequent recommendations in Section IX.B follow directly from the conclusions.

A. General

Diesel pumping costs vary by user group. Other studies have tended to characterize pumping costs on a region- or country-specific basis. In Botswana, user groups can be conveniently grouped into four major categories: major villages, rural villages, other government agencies, and private users. These user groups vary according to size of typical water demand; growth rate; distance from the borehole to water distribution points; distance from service center to borehole; capital equipment costs; and typical operation, maintenance and repair practices. Since costs across user groups do vary considerably, it would not be useful to speak of a "typical" pumping cost.

Generally, water pumping costs are highest in rural villages, due to greater distances from service centers and greater difficulty in assuring reliability (since there is usually only one equipped borehole). Unit costs are further increased because of relatively low demand, so equipment and operator costs are amortized over a smaller volume of water.

Pumping costs for other government agencies are affected by the typically great distances to service centers, balanced by the fact that the pump operator's time is often partially allocated to other duties, reducing the labor cost charged to pumping.

Major villages have lower pumping costs for major villages than the first two user groups, due largely to higher pumping rates and the usual close proximity of service centers, thereby reducing transportation costs. The present analysis has focused

only on single-cylinder (lower capacity) engines. In many major villages, multiple-cylinder engines and higher pumping rates are used, which reduce pumping costs even further.

The first three user groups are all in the public sector. Pumping costs for private users are generally lower due to much lower pump operator costs, which more than compensate for higher capital equipment costs and higher discount rates. However, the typically lower O&M costs for this user group are often reflected in lower equipment reliability.

1. Successes

When compared to the performance and reliability of systems on much of the African continent, Botswana's water supply sector appears to operate remarkably well. A very high proportion (as much as 90 percent of village water supplies) of these systems are operating, they are backed by substantial maintenance and repair capabilities, and their water quality is generally good. Reasons for this success include:

- adequate funding levels;
- standardization of equipment;
- a well-coordinated national water resources development policy, due in part to the presence of a single major donor in the water sector; and
- trained and motivated staff in the various government agencies dealing with water resources development.

Funding

The current estimated 1986-87 expenditure for the Operation and Maintenance division of DWA is P3,842,000, with P890,000 for operation and maintenance (including reticulation) of the 17 major village water supplies. The budget for O&M costs for rural village water supplies operated by District Councils is in the range of P500,000. These budgets only include consolidated funds (funds for recurrent expenditures), not the development or donor funds used for most capital expenditures. These funding levels have been rising in recent years, in an effort to provide the resources to assure that water is delivered reliably. This funding has permitted the regular purchase of new equipment, adequate stocking of spare parts, and purchase of sufficient numbers of vehicles to help insure that proper maintenance and repair take place.

Standardization

The public sector is fully standardized on Lister engines driving Mono pumps for all new diesel pumping installations. A few National pumps remain in use within government departments other than DWA. The private sector, as well, is largely standardized on Lister engines (partly as a result of BRS policy), and commonly uses both Monos and National pumps. This decision to standardize has had several important impacts, including:

- minimizing required spare parts inventories;
- reducing the amount of training necessary for mechanics (who have to be familiar with fewer types of equipment);
- simplifying the design procedure; and
- allowing larger bulk purchases of equipment.

The success of the program can also be attributed partly to the choice of a rugged unit capable of successfully operating (often with minimal attention) under the harsh climatic conditions encountered in the hot, dusty, desert climate of much of Botswana. The proximity of the manufacturer (in South Africa) has helped to insure ready availability of engines and spares.

Single Major Donor

The fact that SIDA has been involved in water-sector activities since 1972, and has been the single major donor over this period, has also contributed to the success of Botswana's water resources development program. The long-term presence of a single donor has contributed heavily to national coordination of water supply policy. The experience gained over the period has allowed SIDA to more fully understand and respond to needs as expressed by the government, DWA and the communities served by the water supply schemes. This long-term involvement has also allowed a natural evolution of policy, which has responded well to the changing needs of Botswana. Other donors also operate within the framework of DWA, including USAID (the CWPP), ODA, Lutheran World Federation, the West German KfW and others.

SIDA has assisted in the institutional development of DWA and MLGL's capacity to plan and implement water resources development projects by providing funding, technical assistance and training for:

- the Village Water Supply Program;

- short-term efforts in planning and evaluation;
- upgrading the capacity of the District Council water maintenance units; and
- developing the technical capability of all divisions of DWA.

Personnel

Having skilled individuals in key positions at all levels has contributed to success in Botswana's water supply sector. The general skill level of both the Batswana and expatriate staff of MMRWA, MLGL and DWA is high. The sense of duty and responsibility exhibited by these staff has contributed substantially to the smooth functioning of the various organizations responsible for the range of specific water supply tasks.

2. Matters for Concern

In spite of the successes, there remain some reasons for concern about the future of the water supply sector. The analysis contained in this report indicates that the current focus of water supply programs--on providing pumped, reticulated water in ever smaller villages--is increasingly expensive. The real difficulties of locating additional water sources for the rapidly growing major villages, when engines on existing boreholes are already operating near their limits, are pressing. There is also no assurance that currently high levels of funding for water resources development will be sustained in the future. In addition, diesel pumping systems are particularly vulnerable to disruption of fuel and spare parts supply. The possibility of disruption due to regional unrest is a growing concern. The current study, although by no means exhaustive in this regard, has identified the following areas of major concern:

System Design

While standardization has been one of the principal reasons for the success of the government's water resources development programs, one of its attendant disadvantages is that a very few standard system designs have been applied to a wide variety of demand situations. In many cases, this has led to systems that do not operate nearly as efficiently as they could. Considerable room for improvement in standard system design practice exists, primarily involving the choice of a more appropriate engine (from existing stock) or an engine speed that better matches the load (in terms of pumping head and flow rate) at a given site.

Integrating such improvements into standard design practice shows the potential for substantial cost savings (as much as 31 percent in certain cases) in return for a minimal (if any) additional investment.

Cases of Low Demand

The Village Water Supply Program has completed more than 280 of the scheduled 354 village schemes, thereby addressing the immediate needs of 95 percent of the target population. The remaining 74 villages in the program have an average population of less than 200 and represent only five percent of the target population. The water requirements for a village with a current population of 200 will be less than 10 m^3/day, even assuming a 10-year planning horizon and three percent growth. The unit cost of providing water in these quantities with diesel-driven pumps is quite high (in excess of P1/m^3). The economic analysis indicates that the cost is nearly twice as great as that for an average rural village (the base case defined in Section VIII) today. Because of the excessively high unit cost of diesel pumping in these situations, the government should consider the implications of not developing water supplies for some of the smallest villages. Alternatively, if this is not acceptable from a policy perspective, studies should be undertaken to investigate the costs of using alternative pumping systems on a site-specific basis (for which the model described in this report could be used), or even trucking water to some of the smallest sites.

District Water Unit Capabilities

Much attention has been paid in recent years to upgrading the skills and capacities of the district water units and departments. This has had a dramatic impact on the reliability of water supplies in rural areas. However, as more schemes are completed, the ability of the water units to cope with the increased number of diesel pumping sites is being taxed. In several districts with relatively few engines to manage, preventive maintenance programs are being instituted. But in several of the larger districts (notably Southern and Kweneng, with more than 60 boreholes each), maintenance consists primarily of emergency repairs just to keep the systems running. These districts seem to be in reasonable control of breakdowns, but routine maintenance suffers.

Low Borehole Yields

There are concerns about borehole yields nationwide. The search for good aquifers for major-village water supplies is a high priority--rapid growth demands it. For rural villages,

ordinarily dependent on one borehole each, the situation is also acute. Yields in many of these boreholes are declining, causing water shortages and damage to pumping equipment. The causes of declining yield in some of these cases are not well understood. There may well be several interrelated reasons, including drought conditions, nature of the geological formations, inadequate borehole development, or faulty initial testing of the boreholes, which resulted in overly optimistic estimates of yield. This problem is not easily solved, but proper test-pumping and more careful equipment selection will help to alleviate problems that arise from these conditions.

Regional Stability

The currently high level of water supply service in Botswana has been made possible by the ready availability of adequate supplies of diesel fuel, capital equipment and spare parts. This has all been possible as a result of Botswana's cash surplus and participation in SACU. Neither of these is necessarily guaranteed for the future. Complete dependence on diesel-engine pumping systems for almost all year-round water supplies in rural areas, both public and private sector, leaves Botswana particularly vulnerable to disruptions in access to equipment and fuel. Alternative sources of fuel and/or a wider variety of equipment would reduce the risk of disruption and limit damage to the program in case of regional conflict or adverse political action.

B. Recommendations

The concerns expressed above cover a much broader scope than simply using small-scale diesel pumping systems for water supply. These concerns highlight the need to continually reevaluate policies and program direction. The recommendations fall into four major categories:

- suggested cost-reduction strategies;
- suggestions for increasing equipment reliability and, hence, water availability, through specific preventive maintenance and training activities;
- suggestions for diversification of system types; and
- suggestions for studies and surveys that would lead to a better understanding of technical and institutional support activities for water resources development, to serve as a basis for future policy decisions.

Some of the recommendations have implications in several of these categories.

Cost-Reduction Strategies

The primary objective of the GOB's water supply programs has been to provide clean water to both urban and rural populations. There have been efforts to perform this work as efficiently as possible, but the commitment to fulfill these goals, along with the government's capacity to subsidize this effort, has made cost-effectiveness a secondary goal. With the end of the Village Water Supply Program on the horizon, and smaller, more remote villages being served, it is now time to think more carefully about reducing costs. The financial and economic analysis included in Section VIII indicates that there are two types of strategies worth considering. These are: a) strategies that could have a major impact on cost, and b) those which, although the impact may be minor, could be quickly and easily implemented at low cost.

The biggest single cost-reduction mechanism for public-sector diesel pumping systems would be the employment of pumpers on a part-time basis where possible. The current policy mandates employment of full-time pumpers for all major and rural village water supplies. The base case analyzed in Section VIII reveals that the cost of employing a pumper full time was 34 percent (in financial terms) of the total unit cost. This is a greater percentage than for fuel, O&M or capital equipment costs. Since the cost of the pump operator is fixed, regardless of the hours of pump operation or the amount of water pumped, this percentage will be greater for systems supplying smaller villages and settlements.

A review of the current policy that mandates the employment of a full-time pump operator at each borehole is recommended. It is clear that in many cases a full-time pumper is not required for technical reasons. The employment of full-time pump operators contributes to the goal of rural income generation (when employed in rural areas). The cost of furthering the goal in this way should be understood.

It is recommended that system design procedures be revised to ensure more optimum engine loading and more efficient operation. This cost-reduction strategy can be quickly and inexpensively implemented. As has been pointed out, optimum engine loadings are in the range of 70 percent of full load. The design procedures currently in use at DWA ensure that loading will be less than 50 percent in all cases. This was indeed the case for almost all engines surveyed. Engine loading closer to the optimum will reduce fuel consumption per unit of water delivered. Maintenance and repair costs should also be reduced

with more optimum loading. Engine overhaul intervals should be extended as well.

In addition it is possible to carefully match engines to sites and applications if operating speeds other than the current one-speed-per-engine model are considered. The current policy of using 8/1, ST-1, and LT-1 Lister engines at one engine speed limits to three increments the power output range for applications under five kilowatts. This helps to ensure that many engines will be poorly loaded. In a number of cases, the power requirements are low enough that reasonable loading cannot be achieved with the current selection of engines. The possibility of using smaller diesel engines and other engine-operating speeds for these cases should be examined.

Transportation represents another area where savings could be realized with a modicum of effort. More careful attention should be given to transportation and job duration issues. This is particularly true during the installation phase. Records indicate an average of 3.5 round trips from the installation center to the engine site per borehole installation. This seems excessive. More efficient trip planning, and use of vehicles that are less expensive to operate, could save on the order of P1,000 per installation. In addition, the length of time required for installation of a diesel engine seems excessive. Government installation crews routinely take three to four times as long as private-sector crews. More careful supervision of transportation and installation should reap immediate rewards. However, it will probably be necessary to strengthen the construction section of DWA's Design and Construction division because current management capacity is insufficient to oversee all operations and ensure cost-effective use of time and vehicles.

While on the issue of transportation, it should be pointed out that neither DWA nor the district water units have full control of their vehicles. In the case of DWA, CTO is responsible for repair and maintenance of equipment. Council workshops handle this task for district water units. In neither case are those responsible for vehicle service and repair fully responsive to the need for constant availability of vehicles for emergency situations or the need for optimum transportation planning.

Reliability

Although public water supply systems in Botswana are remarkably reliable when compared to those on much of the rest of the continent, there is always opportunity for improvement. On the other hand, privately operated systems appear more prone to

breakdown and seem less dependable. Three initiatives are recommended:

- greater attention to preventive maintenance,
- greater attention to pump operator training, and
- development of private owner awareness of the cost implications of maintenance.

Adoption of a preventive maintenance program, especially at the most basic (and inexpensive) level of more frequent replacement of fuel, oil and air filters, contributes substantially to engine and pump reliability. The proof is in the breakdown records of District Council water units, where the number of repair trips is clearly tied to the level of preventive maintenance. In several districts where preventive maintenance is not regularly scheduled, as many as six or seven trips to deal with breakdowns are required per borehole per year. In the area with the most advanced maintenance scheme (which includes two additional trips per year), this has been reduced to an average of one breakdown trip per year. Clearly, in some districts it may be difficult to institute an adequate preventive maintenance scheme due to the demands for immediate repair of breakdowns. However, if preventive maintenance were introduced, the repair requirement would be reduced accordingly.

An important aspect of breakdown response (particularly for other government agencies and rural villages) is communications. The response to breakdowns is usually quite rapid, once the service center knows about the problem. There are two issues. First, there is no formally accepted procedure for operators to notify service centers of problems. Second, in some cases, operators are unable to exactly describe the nature of the problem prior to arrival of the repair crews, so that crews often arrive ill-prepared to address the particular problem and sometimes make additional trips.

<u>A broader technical training program for pump operators and technicians is recommended</u>. This would contribute to improved reliability by reducing both the frequency and duration of outages. Some districts are already conducting pumper training seminars, and DWA has requests for further training to be conducted through its Training division. Several important topics to be covered include (but are not limited to) performance of routine inspections (to check such things as belt condition, bolt tightness, and water flow rates) and proper fault diagnoses and reporting procedures. To the degree that pump operators can perform minor servicing (changing oil and filters, for example) cost savings can be realized as well. Fewer service trips would be required.

A campaign to raise awareness among private engine owners of the costs for engine and pump service and repair should be undertaken. BTC is well positioned to follow up on this. Reliability is a greater problem in the private sector. The greatest contribution to this problem is most likely a lack of awareness and planning for maintenance and repair. The most significant issues that should be covered in such a public awareness campaign are how to avoid overly frequent breakdowns, the cost associated with preventive servicing, and its relationship to the cost of pump outage and repairs.

System Diversification

Almost all water supplies for major and rural villages are currently dependent on Lister diesel engines and spare parts, and on fuel delivery. The vulnerability of this support infrastructure to factors beyond Botswana's control (being a landlocked country; possibility of regional unrest) suggests that issues other than the strictly economic and technical ones considered herein are important in a complete analysis of diesel systems.

Concerns about energy dependence and cost with respect to other system alternatives were major factors leading to the current work. These concerns are addressed in detail in the companion report, SMALL-SCALE WATER PUMPING SYSTEMS IN BOTSWANA, VOLUME I: A COMPARISON. The two main targets of opportunity for displacement of diesel pumping systems are in the high-cost, low-demand sites (particularly those sites where demand is less than 10 m^3/day), and low-cost, high-demand sites (where there may be considerable potential for grid electric pumps).

Continuing Activities

The unit costs of operating and maintaining diesel pumping systems decrease when they pump at higher flow rates (due to better loading in most cases and fewer operational hours for a given water requirement). However, certain precautions must be taken before simply increasing the flow rate. More precise borehole test-pumping procedures are required, and these procedures must be followed to avoid possible over-pumping of boreholes. Good test-pumping results will help assure designers that estimated yields are in fact those which can be expected under actual pumping conditions. This will allow better load matching and reduce the possibility of excessive drawdown or damage to the pump. DWA has recognized the importance of test-pumping and is upgrading its capacity in this area. This pump-testing work must be encouraged and supported by MMRWA.

The technical considerations, costs and their implications for public-sector water supply are well understood. This is not the case for the majority of private-sector users. The diversity of this group, and the fact that private owners represent the largest number of diesel pump users, highlights the need to understand this sector more completely. A survey of private-sector diesel pumping practices and costs should be undertaken to quantify these issues by user subgroup (e.g., freehold farmers, syndicates, private cattle posts).

The analysis in this report is necessarily dependent upon conditions existing during the project (e.g., exchange rates, fuel costs). As these variables change, the results of the analysis will change as well. So that DWA can take these changes into account in policy decisions, a training program should be developed that would institutionalize the capability for performing the type of performance/cost analysis embodied in this report. This will allow DWA (and other groups directly involved with water resources development) to develop the capability to continuously evaluate the impact of the recommended strategies as program implementation proceeds. It is recommended that this be included in the course of instruction for water technicians studying at the Botswana Polytechnic.

Incorporation of these recommendations in the design of future water development activities will help to ensure that the people of Botswana continue to enjoy the high level of water availability and reliability to which they have fortunately become accustomed.

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APPENDIX A

Distict Council Water Units and Departments

Water Departments

Ghanzi District Main Offices - Ghanzi Sub-depot - Charleshill	23 Boreholes
North West District Main Offices - Maun Sub-depots - Gumare, Kasane	45 Boreholes

Water Units (under Works Departments)

Central District Water Engineer in Serowe with water units at the five subdistrict office locations	168 Boreholes
1. Bobirwa Subdistrict Main Offices - Bobonong	23 Boreholes
2. Boteti Subdistrict Main Offices - Letlhakane	19 Boreholes
3. Mahalapye Subdistrict Main Offices - Mahalapye	33 Boreholes
4. Serowe-Palapye Subdistrict Main Offices - Serowe	54 Boreholes
5. Tutume Subdistrict Main Offices - Tutume	32 Boreholes
Kalagadi District Main Offices - Tsabong Sub-depot - Hukuntsi	40 Boreholes
Katleng District Main Offices - Mochudi	35 Boreholes
Kweneng District Main Offices - Molepolole Sub-depot - Letlhakeng	70 Boreholes
North East District Main Offices - Francistown (scheduled to move to Masunga)	45 Boreholes
Southern District Main Offices - Kanye Sub-depots - Mabutsane, Goodhope(planned)	78 Boreholes
South East District Main Offices - Ramotswa	16 Boreholes

APPENDIX B

DWA Operations and Maintenance Division

Major-Village Water Supplies

Village	Est. 1985 Population	Water Prod. M^3/day	Number of Boreholes
Ghanzi	4180	264	3
Kanye	26500	1009	6
Kasane	3030	650	2
Letlhakane	6800	382	4
Mahalapye	28400	964	8
Maun	19600	1461	10
Mochudi	23900	1005	8
Mogoditsane	4080	864	--*
Molepolole	26900	1167	8
Moshupa	8500	366	5
Palapye	12600	739	7
Ramotswa	16500	611	2
Serowe	31000	1741	15
Thamaga	8500	362	2
Tlokweng	8700	483	--*
Tonota	8700	729	3
Tsabong	2260	149	3
Totals	240150	12948	86

*Purchases water from Water Utilities Corporation.

Note: The number of boreholes in operation at any one time varies due to water requirement, borehole yields and equipment availability.

BRS Outstations

Village	Number of Crews	Private Subscriber	Gov't Bh.	1985 Number Repair Trips
Francistown	3	201	83	259
Ghanzi	2	75	32	122
Hukuntsi	2	12	13	36
Letlhakane	2	47	13	36
Lobatse	3	165	31	183
Mahalapye	2	91	13	88
Maun	3	126	56	238
Mochudi	3	108	15	150
Molepolole	4	90	11	75
Palapye	3	45	28	124
Serowe	2	140	2	100
Tsabong	1	16	9	70
Totals	30	1116	306	1481

Village	Ave Km/Trip (one way)	Ave. Charge per Trip
Francistown	150	117
Ghanzi	100	150
Hukuntsi	70	242
Letlhakane	110	260
Lobatse	60	339
Mahalapye	130	159
Maun	75	340
Mochudi	90	518
Molepolole	140	467
Palapye	100	233
Serowe	100	238
Tsabong	255	1406

Notes: Distance and cost information is a summary of a detailed examination of four months of data from each station.

The weighted averages for repair round trips is 216 km, and the weighted average repair costs are P298 per trip.

All transportation costs are covered by CTO and are not directly included in charges to customers.

A service call charge of P80 is charged for each job (even if it requires two trips).

BRS Workshops:

Total staff 40

Gaborone:	Overhauls 400
Maun:	Overhauls 50

See Appendix F for analysis of engine overhauls and costs.

APPENDIX C

Government Boreholes

DWA, through its Design and Construction division and BRS, provides design, construction and repairs to boreholes used and operated by other government agencies in other ministries. In most instances the water needs of public-sector users are met by already established urban or rural water systems. The following list of nearly 300 boreholes includes those where water needs are not met in this way. MOA is by far the largest user because of the decentralized nature of its activities. The Roads Division of the Ministry of Works and Communication establishes water points during road construction, and the totals here fluctuate with road building activity. Several boreholes currently at police camps will be handed over to District Councils in the near future.

Office of the President	13 Boreholes
Botswana Defense Force	
Police	
Ministry of Finance and Development Planning	11 Boreholes
Customs and Excise (operated jointly with Immigration)	
Ministry of Agriculture	205 Boreholes
Department of Veterinary Services	
Animal Health (Cordon Fence & Quarantine)	
Trek Routes	
Tsetse Fly Control	
Agricultural Research	
Animal Production Research Unit	
Department of Agricultural Field Services	
Rural Training Centres	
Division of Animal Production (AI Unit)	
Botswana Agricultural College	
Ministry of Home Affairs	1 Boreholes
Immigration (see Customs and Excise)	
Prisons	
Ministry of Education	8 Boreholes
Secondary Education	
Jr. Secondary Schools	
Ministry of Commerce and Industry	20 Boreholes
Department of Wildlife and Parks	

Ministry of Works and Communications Roads	23 Boreholes
Ministry of Local Government and Lands Refugee Camp - Dukwe	4 Boreholes
Ministry of Health Hospitals and Clinics	2 Boreholes

This group represents a distinct population of pumping equipment, as service and repair are provided free of charge for these government boreholes. Therefore, the service history is not likely to include repairs made by informal-sector mechanics, and regular maintenance and service should have been provided by BRS. Unfortunately, certain weaknesses (staff, transport and spares) within BRS have resulted in less than ideal service and, since no charges are made, there is some question about the accuracy of record-keeping as well. However, certain valuable information about engine care and maintenance costs can be inferred from the data available.

APPENDIX D

Summary of Interviews with Water Unit Technicians

At this stage there are 13 districts and subdistricts in Botswana that administer water units or departments. These districts are responsible for the operation and maintenance of about 520 borehole water supply systems. Roughly half of these have been established during the last 10 years as part of the Village Water Supply Program. The districts vary in size and in number of boreholes for which they are responsible. South East District is the smallest and has 16 schemes. The largest geographically is North West District where there are 47 schemes. Southern District is responsible for the most boreholes with 78, followed closely by Kweneng with 70. During May 1986, the water unit technicians responsible for these water supply systems were interviewed. The following questions were asked; a summary of responses is given.

1) How many of each model of engine do you have?

The Lister engine is used almost exclusively (North East reported some portable Honda petrol engines are used for drought relief; other districts apparently use these engines occasionally too). The most common Lister model is the ST-1 with 42 percent of boreholes equipped with this engine. This was followed by the 8/1 model (26 percent) and the LT-1 (15 percent). The use of the LT-1 engine is increasing, with a larger percentage being used in recently completed schemes. Only seven percent were equipped with two- and three-cylinder engines (a total of seven with three in Ghanzi District). Not including the recently discontinued 8/1 model, only 44 sites (nine percent) are equipped with older, discontinued models such as the 6/1 or the SR-1.

2) Do you have your engines on a regular preventive maintenance schedule yet, or do you have plans for this? What is the schedule and what is the service?

Of the 13 water units, only five have any kind of preventive maintenance schedule in place. Several of these perform maintenance on a twice-yearly schedule regardless of the hours of engine operation. The others make an effort to perform these tasks on a schedule that reflects, as much as possible, the use the engines get. All technicians agreed that this is a problem and all who are not presently performing regular maintenance say they are planning to in the near future. The lack of a set schedule does not mean that no maintenance is being done, just that it is not well organized. It does appear, though, that on the average, the service intervals go well beyond those specified by the manufacturer. In several districts (Southern is the most obvious example), it appears that it will be difficult to break

the cycle of the priority of immediate repair in order to get onto a maintenance schedule and lighten the burden of breakdowns.

3) Do you do all your engine rebuilding at the water unit and, if not, what work is sent out and where do you send it? What about machine work?

Almost universally the water units can do their own engine rebuilding, sending out the machining and the fuel pump rebuilding. Most say they do most of this work themselves. The exceptions are Tutume, where the engines are sent to the local Brigade, and Kgalagadi, where their engines are often sent to DWA or to a shop in South Africa. However, a number of District Council engines end up at the DWA workshop, primarily from Southern and Kweneng Districts. Most districts seem to use a technique of swapping engines, if possible, when problems are difficult to diagnose or major problems occur. Many say that they swap engines rather than doing decarbonizing in the field. When this technique is possible, it may be the best alternative. It may be slightly more expensive, but seems to provide the surest method of restoring service quickly.

4) How long does it take to get engines/pumps repaired once the water unit is informed (on average and in extreme cases)?

This question about response time to problems elicited a lot of comments about communications and the difficulty of finding out about problems in a timely manner. Rural communication is often difficult; messages may not arrive quickly or be accurate in description of the problem. A message that there is no water in a particular village is not very helpful when trying to decide what tools and spares to send. Most indicated that after notification they would have a crew at the site within two days, sometimes three. South East District claimed one-day service. Given the good roads and small district, this seems reasonable. Kweneng and North West said that occasionally it took up to five days to a week to respond in the more remote parts of the district. Several technicians indicated that availability of drivers or transport sometimes hampered these repair trips.

5) Do you have any idea of the average breakdown rate per borehole?

Several people said that they did not know the rate but those who did indicated an overall average of 3.5 per year per borehole. All respondents except three gave two or three per year as the average. Letlhakane (with few boreholes and a maintenance schedule in place) indicated one per year. The only districts with more than 50 engines, Southern and Kweneng Districts (with 78 and 70), indicated 7.3 and eight, respectively. These two figures seem rather high as it would mean about 1.5 breakdowns per day throughout the year and, given

the transport situation, it seems unlikely that engines could be repaired at this rate. Further examination of this question is necessary.

6) How far is it to your most distant borehole? Which borehole is visited least often? Are these the same? Do you have a particular "problem" borehole, and if so, do you understand why?

The distance to the furthest borehole ranged from 40 km (to Tlokweng in South East) to about 600 km (Beetsha in North West which must be reached via the ferry at Mohembo). Five districts reported maximum distances of between 100 and 200 km (South East is the only one less than 100 km). Only one reported a maximum distance of between 200 and 300 km. And the rest (six) indicate that the furthest borehole is more than 300 km (with only North West more than 350 km). In no cases was this furthest borehole reported as the one visited least often. Usually the fewest visits were made to new schemes, schemes that pump few hours, or cattle boreholes that are of lower priority and are only used heavily on a seasonal basis. The problem sites tended to be the larger schemes where the systems are being pushed hard (many of the sites so identified are in the rehabilitation program). In one case (Letlhakane), problems with pumpers were mentioned for several sites. These problems related to pumpers who were not performing their duties properly.

7) How is diesel fuel delivered? Is there a set schedule and does the schedule work?

Fuel deliveries are made in a variety of ways. These can be divided into those who use bowsers (three) and those who deliver fuel in drums (10). A second division can be made between those who deliver on a schedule (six) and those who deliver on demand (seven). All districts with a bowser deliver on a set schedule. One district (Kgatleng) has a bowser but is not presently using it due to transport problems (the truck that normally carries it is in need of repair). The demand system seems to work reasonably in smaller districts. In several cases, it seems to be rare to have to make a special trip with fuel, as delivery trips are combined with other work. However, for districts that are more spread out, delivery on demand appears to be a poor system. Two such districts (Ghanzi and Kgalagadi) remain. In Ghanzi, at least, there are plans to purchase a bowser and, by implication, to deliver diesel on a set schedule.

The main problems with the set schedule are that occasionally it cannot be adhered to because of transportation difficulties, or the pumper cannot be found and so fuel cannot be left at the borehole. The first problem can be solved by supplying the site with enough fuel to last longer than the re-supply interval. The second could be solved with a master pump

house key. Other problems sited involved the need for river crossings at certain times of the year.

The major problem with the demand system seemed to be communication and allocation of resources to deliver on demand. In on-demand cases, the pumper usually sends a message to the water unit when he has about 20 liters of diesel left. Sometimes he waits too long and/or the message does not arrive, resulting in no fuel and no water. In Ghanzi, under the present system, this seems to happen about once a month.

Fuel delivery usually involves two people. In districts with scheduled delivery, this is the senior operator and a driver. The truck also carries spare belts, taps, soap, oil and other things that may be needed by the pumpers. In Bobonong a lorry attendant also goes on this trip; in Kgatleng a "permanent and pensionable" employee goes along as the stores man insists on it for signature purposes. On-demand delivery is made by a driver and laborer in most cases.

8) Do you have engine-hour meters installed? Pressure gages? Water meters?

Engine-hour meters are only installed district-wide in Tutume Subdistrict. In several other districts, there are a few that were installed by BRET for its tests. Pressure gages are even rarer. There are probably only 10 countrywide, with most installed by BRET or for the BRET program. Water meters are much more common. All new schemes are equipped with them. In all districts, water meters are installed at almost every site. The exceptions seemed to be older council boreholes and those that serve for cattle watering. Technicians indicated that in some cases the meters are broken, especially if they were the old type. The newer Kent meters seem to be more reliable.

9) Do you have full-time and relief operators at all boreholes? Do you have any boreholes without a full-time pumper?

Six districts have full-time and relief operators at all sites and consider themselves fully staffed in this regard. The relief operators are on duty during weekends and when the primary operator is on leave. Three districts are still filling the relief operator slots. Four districts have full-time pumpers at each site and a central pool of relief pumpers who do temporary duty throughout the district. In these cases, if the engine must be operated every day, the primary pumper gets paid for seven days at the five-day rate.

In Letlhakane, there is one case where there is one pumper for two villages that are not far apart. This is the only case of a village not having a full-time pumper of its own.

10) How many villages have more than one borehole equipped?

All districts have at least one village with more than one equipped borehole. There are 84 such villages throughout the country. In 64 of these cases, there is only one pumper for the two boreholes. In 16 cases, there are two pumpers for two boreholes or occasionally three. The most common reasons for employing two pumpers were that the two boreholes were far apart or the total operating hours for the scheme exceeded full-time duty for one. There were three quoted cases of multiple boreholes and pumpers--Bobonong with five engines and five pumpers, Hukuntsi with six engines and four pumpers, and Tutume with five engines and two pumpers.

11) What are the duties of the pumpers in your district?

In most cases, the answers to this question were predictable. The duties do vary a bit though. In general, the duties include starting and stopping the engine, cleaning the engine and pump house, changing oil, reporting breakdowns, keeping the logbook (where it has been introduced, which seems to be at well over half the sites), check and change the V-belts if needed, inspect the pipelines, tank and standpipes, and also, in most cases, prevent misuse of water. In all cases, a minimal tool kit is part of the pumpers' inventory, and the pumper tightens engine-mounting bolts as needed and replaces taps (except in three cases). In five cases, the technicians said that at least some of the pumpers also changed oil filters. In some districts, the duties also covered cleaning soak-aways around the standpipes, coordinating fencing of the standpipes, collecting cattle fees as appropriate, and recording the fuel received and used. In one district, the pumpers in villages with only one borehole will soon be required to report in-person when there is a breakdown that prevents pumping. The idea is that there is no work for the pumper in these cases and the report will get to the water unit in a timely manner.

12) Have you installed handpumps and, if so, how many and what kind? Do you have plans to install handpumps?

Ghanzi and North West Districts are the only districts without any handpumps installed at this time. Ghanzi is the only district with no plans for handpumps due to the depth of the water level in most boreholes. North West District will soon have a number of handpumps as there is a Hand Dug Well Program attached to the water department there. About 30 villages have already been identified for eventual inclusion in the program. At present, there are 34 handpumps installed (17 India Mk II, 11 Mono direct drive, one geared Mono, three National and two Thebe pumps). All districts except Ghanzi have plans for more handpumps and most have sites selected and pumps on hand. The major concern is the inability to obtain the Mark II pump.

Several districts are using the Mono, at least partly, for lack of this alternative. Technicians who have some experience with the Mono feel that it will be a robust pump, but the pumping action can be tiring.

13) How complete are the records that you have at your office?

Almost all technicians contend that they have good records at their water units (in at least several cases this has been verified). The most common information lacking seems to be pulley sizes, number of pipes and size of rising main, and occasionally the pump element. Apparently, a lot of information on the original equipping of the boreholes is sent to the council offices where it is placed in the registry and becomes hard for technicians to find. Several technicians indicated that they had all the information in their files but in some cases did not trust it completely as changes are sometimes made in the field without changing the records. The people who have good records indicate that it's very helpful for making sure that the schemes are operating properly and that repair crews have the right equipment.

APPENDIX E

Summary of BRS Outstation Visits, 1986

There are 12 outstations within the BRS section of DWA's Operation and Maintenance division. Nine of these were visited and interviews were conducted with each Chief of Station. The purpose of these interviews was to determine the level of service offered, discover what problems they may have, and gain their insights about private-sector water pumping.

Each outstation is responsible for providing service to government agencies that operate boreholes for their particular needs. There are about 300 such installations throughout the country. These outstations also have the responsibility to respond to requests for service from private subscribers. These subscribers must be registered with BRS and must have their accounts paid up in order to receive service. Over the last year or so, this policy seems to have been enforced reasonably well. In some cases, BRS also assists major-village water supplies (which also fall under the Operation and Maintenance division) with borehole repairs. In order to accomplish these tasks the outstations are equipped with both light (4x4) and heavier (seven-ton) trucks and operate from one to four crews of four to five each. A listing of the outstations along with other pertinent information is included in Appendix B.

BRS was first instituted as the Borehole Preventative Maintenance Service (BPMS) during the 1970s. It rapidly became apparent that the preventive aspect of this service was rarely accomplished due to transportation and staffing difficulties. In recognition of this fact, the name was changed. In recent years, efforts have been made to upgrade staff and provide more vehicles. Today, most BRS service calls are made in response to equipment breakdown, particularly for private subscribers. Engines and pumps operated by government agencies are supposed to receive regular servicing. However, it appears that this servicing is often not performed as necessary. Proper service schedules do not appear to be in place at most outstations. The reality is that breakdowns receive first priority and little time or resources remain available for preventive maintenance. It appears that a large proportion of BRS services rendered are in cases where specialized equipment is necessary. This is particularly true for private-sector subscribers.

The major problems of the outstations continue to be transportation and spares availability, particularly at the more remote outstations. Although trucks are provided for BRS calls, in many cases these spend far too much time in the shop for servicing. On average, the vehicle fleet spends more than 50 percent of the time out of service. In addition, the fleet is

diminishing as unserviceable vehicles have not yet been replaced. Spares are often a problem as the stock of spares in most outstations is not adequate to cover all of the contingencies.

In all cases, the outstations reported that the most common engines in use in the private sector were the slow-running, water-cooled 6/1 and 8/1 models. Only one station was able to provide detailed information (Molepolole), and 74 of 90 private engines within their jurisdiction are these models. Although other outstations were unable to provide details, all agreed that these engines make up from two-thirds to three-fourths of the engine population. There are some Lister copies in the field as well, largely Induna and Metex. Reports are that the material used in these machines is not as good as that used in the Listers and that the bearings do not hold up as well.

Unlike equipment used in major and rural villages, reciprocating pumps make up a large part of the pump equipment. Molepolole BRS records reveal that 55 of 90 private subscribers have National reciprocating pumps. This appears to be the case for the rest of the outstations as well, although several reported some use of the Rapid and the discontinued Climax pump heads as well. Many private-sector installations pre-date the widespread use of the Mono pump which did not come into general use in Botswana until its introduction in the late 1970s and early 1980s. This range of equipment (both engines and pumps) is consistent with the age of these installations. Many of the private boreholes were first equipped many years ago, hence the use of the discontinued 6/1 model and the widespread use of reciprocating pumps.

All stations reported that many private subscribers were in arrears. In fact, examinations at BRS headquarters indicate that roughly half of all private subscribers owed money for services rendered. A policy of not serving these subscribers has been in place for several years. This policy does not seem to have resulted in significant repayment yet. Those interviewed (both at BRS and elsewhere) indicate that the prevailing public view is that the BRS service is too expensive. This initially seemed strange in view of the cost of BRS services. At present, any field service in any part of Botswana costs a P80 service charge plus spares invoiced at the tender price. In a country where transportation is scarce and expensive, service at these rates appears to be quite heavily subsidized. No careful analysis of this subsidy was completed, but preliminary indications are that it is in the range of 50 percent or perhaps a bit more. For example, with engine overhauls, BRS will remove the engine to be serviced, provide a spare (at P3/day to a maximum rental of P180), transport it to the BRS workshops, overhaul it, return and reinstall it for P160 (P80 service call and P80 workshop labor) plus parts (again charged at the tender price). Why only a quarter of private engine owners (half in arrears and not

receiving service) avail themselves of the service requires some explanation.

There are several reasons why BRS services are not used by more people. The most serious of these appears to be cost. In view of the above discussion, this needs clarification. First, the P80 service call charge for each visit is a significant deterrent. Many argue that to pay P80 for minor servicing is far too expensive, particularly if it is not far to the outstation. This charge means that it costs an owner P80 just to get BRS to visit, even if it is only to tighten engine bolts or to clean the injector nozzle.

This has led to the growth of owner servicing and a largely informal engine-servicing sector. This informal sector seems to be made up of mechanics working days at other jobs (for government or the private sector) as well as any other people who have demonstrated an ability to get an engine running and keep it going. The level of training of this group must vary a great deal from qualified borehole mechanics to those who do not even understand how the engine works. These individuals manage, for the most part, to keep engines going and reduce costs to the bare minimum. This is apparent, from just a glance, when looking at some of these engines (with wire holding the fuel tank in place and tape keeping the cooling system hoses from leaking). Closer inspection sometimes reveals the use of incorrect or used parts. The activities of this sector have virtually eliminated the minor servicing role of BRS in the private sector.

In addition, engine overhauls are often considered expensive. This appears to be at least partly the result of BRS policy. The policy is that, since BRS provides a guarantee on workmanship, it must perform a complete overhaul as dictated by the manufacturer and use manufacturer's parts (rather than pirates). This results in what may seem to be inflated overhaul costs (even though overhauls performed by private contractors are roughly 40 percent more expensive). A number of so-called "overhauls" must be done in the field without proper equipment and without doing the necessary machine work. The fact that these engines appear to operate as well as they do, after all of the evidence of abuse, is testimony to their durability.

An additional complaint about BRS is that its services are often not available when needed. Part of this complaint arises from the fact that its staff does not work on weekends. The chronic lack of transportation also means that they often cannot respond when requested. In addition, the request is often difficult to make as communications in the rural areas are not easy. Sometimes when BRS does respond, the necessary spares are not available and the repair must wait for them to be procured. It should also be said that several BRS users commented that the

BRS was pretty good at responding to emergencies even if they could not always make repairs at the time of initial response.

All of this has resulted in BRS service calls being the more difficult ones--such as pulling rising mains, doing major overhauls (after extensive service by others) and fishing dropped pipes (at P30/day). As several BRS officials said, BRS is called as a matter of last resort (at which time payment is rapidly forthcoming from those in arrears).

All of this has led to roughly 1,500 service trips made to 1,300 subscribers (both private and government). With about half of the subscribers in arrears, this means that the crews make about two trips per year, per borehole. There are about 30 outstation repair crews nationwide, so each crew makes, on average, one repair trip per week. It would appear that from this level of visits, very little preventive maintenance or minor servicing is done by BRS crews. With 30 crews, the coverage rate is about 40 boreholes per repair crew, or about two to three times the council water unit level. From a close examination of the structure and service of the council water units, it appears that for adequate maintenance and repair services to be maintained with the skills level, training and work habits of local repair crews, the coverage should be no more than 15 to 20 boreholes per crew. With this in mind, it is apparent that the BRS has a problem coping with the needs of the private sector, regardless of the subsidy levels available, and it is not surprising that the private engine owner has sought other sources of assistance.

APPENDIX F

BRS Workshop Overhauls

The major sources of information on overhaul costs are the BRS workshop records and interviews with workshop foremen. From these, it is clear that there are substantial differences in the costs and intervals for overhauls, depending on engine model and user. The BRS workshop overhauled 406 engines during the 1985-86 fiscal year. The records for these overhauls were examined in detail. The table below summarizes overhaul costs of Lister diesel engines by type and user group.

Overhauls--BRS/Gaborone, 1985-86

Categories:	1	2	3	4	5
	(No. of overhauls/average overhaul cost in pula)				
DWA	23/403	5/700	70/548	30/1030	5/772
Councils	2/633	6/385	16/555	0/0	0/0
Other Gov't	24/871	15/379	22/547	3/1524	2/265
Loan	44/593	7/469	8/681	0/0	3/427
Private	88/857	14/474	12/521	4/872	3/559
Totals	181/744	47/457	128/558	37/1028	13/612

*Categories: 1 - Slow-running, water-cooled Listers
2 - L Series Listers (LR, LD, LT, LV)
3 - S Series Listers (SL, SW, SR, ST)
4 - H Series Listers (multi-cylinder HR, HL)
5 - VA Series Lister Engines

The categories above do not break the engines down by number of cylinders. Of the 406 engines total, only 87 (21 percent) are multiple-cylinder models, largely S Series and all of the HR Series. Of these, 72 are overhauls for major villages. For the major villages, 54 percent of the engine overhauls are for multi-cylinder models, with three being HR-4. These high numbers are the result of the need for high-yielding boreholes, which are found away from the villages so that the engines must pump at a high rate against a high head. This situation is not found in most cases.

Of the privately owned engines, only six of 115 (or five percent) are engines of more than one cylinder. This gives a good indication of the reliance on the single-cylinder Lister models. Note also that 73 percent of the engines overhauled for private subscribers of BRS are the water-cooled 6/1 and 8/1 models. This finding supports other BRS records and interviews that revealed that most private-sector engines were of this type.

BRS also overhauls engines for other government agencies and its own loaner engines. These engines are owned by BRS and loaned to BRS customers while their engines are being overhauled. BRS owns 125 of these loaner engines. Because there is no charge to overhaul engines operated by other government agencies, all overhauls for this group are done by BRS.

Overhauls for District Councils represent a small portion of the overhauls in relation to the size of the engine population. This is for two reasons. First, most of the District Council water units perform their own overhauls. Of the 13 water maintenance units, only three sent their engines to the BRS shops. Even these did not send all of them--only those time did not permit them to work on themselves. Second, due to recent efforts to upgrade the council water units and to the Village Water Supply Program, the engines are quite new and do not yet require overhaul.

There are still a number of VA engines in use and being overhauled. These engines, essentially air-cooled versions of the 6/1 and 8/1, were not produced after 1975. This supports the contention that the Lister engine is a durable one and that engine lifetimes can be long. In fact within the water-cooled category, there are 22 3/1 and SL-series engines that have not been produced since 1952 and 1955, respectively, making these engines more than 30 years old.

Costs

When an engine arrives at the shop and is assigned to a mechanic, he strips the engine, measures parts that may be worn (piston, crankshaft, etc.), arranges for the necessary machine work and orders the spares necessary for the overhaul job. The cost of each overhaul is the sum of the spare parts fitted, the P80 fixed labor charge and charges for machine work. The machine work often involves grinding the crank more than one undersize, effectively shortening its lifetime. Likewise, cylinders must often be bored more than one oversize. This appeared to be particularly true of privately owned engines.

Because of the fixed workshop labor cost, the differences in cost for overhauls by engine type and owner group indicate differences in engine condition (within engine category) when

they enter the shop. The lower average costs for DWA overhauls (for the major villages) appear to be the result of frequent overhaul intervals and the relatively good condition of the engines. The much higher cost for the private-sector engines is a result of poor maintenance and long intervals between overhauls. The high cost for this group prompted further investigation. Of the 40 overhauls costing more than P1,000 per cylinder, 63 percent were private-sector cases. One examination was conducted to determine the likely causes that required replacement of parts costing more than P100. These parts included Governor assemblies, main bearing bushes and housing as well as crankshafts. The necessity to replace these parts arises from vibration (indicating poor installation) and clogged oil channels (indicating improper servicing). These replacements were much more common on privately owned engines.

The cost figures given above are for the financial year 1985-86. Annual increases in spare parts cost per overhaul have been about P50 per year over the last several years. This is roughly a 10 percent increase and is not out of line with the inflation rate. The labor cost per overhaul averages P100. This figure includes the P80 workshop charge for the overhaul plus the average charges for machine work (currently sent to private shops). This labor charge probably covers the mechanic's time. However, the total charges do not cover workshop overhead costs or transportation costs to bring the engine to the workshop or return it to the field.

Total Overhauls by Category

	Overhauls/ Cost	% of Work	Total Engines*
DWA	132/645	33%	100
Councils	24/519	6%	n/a
Other Gov't	66/694	16%	300
Loans	62/577	15%	125
Private	116/709	30%	600

*For the private sector, only paid-up subscribers are included.

Intervals

If, for the DWA major villages, the average number of hours of operation per engine per day is as found in the survey of four of the major villages (13 hours per day), then the average overhaul interval for these engines is roughly 3,500 hours. This seems a very low figure in light of the Lister recommended interval of 6,000 hours. This prompted further investigation by village. Most villages seem to overhaul their engines at the

rate of a little more than one per year. At least two villages (Serowe and Molepolole) overhauled engines at a rate exceeding two per year per borehole. It is difficult to say exactly why this is, but it would appear that rather than do repairs at the DWA shops in these villages, technicians send them to the Gaborone workshop where they get the overhaul treatment whether they need it or not. This helps to explain the lower costs for DWA overhauls by engine type. The overall average is higher for DWA because of the larger percentages of multi-cylinder engines.

The council figures cannot be used as a measure of the overhaul intervals of those engines for the reasons outlined above.

There are roughly 300 boreholes being operated by other government agencies and serviced by BRS. For these, it is almost certain that all overhauls are done in the BRS workshops. If one assumes that on average these engines operate three hours per day, then the overhaul interval for this group of engines would be 4,500 hours.

Loaner engines are loaned to BRS subscribers while their own engines are in the workshop for repair. The charge for this service is P3/day with a maximum charge of P180. If one assumes that private-sector users operate their engines 2,000 hours/year (Hitchcock), then the overhaul interval of these engines is about 4,000 hours.

If one assumes that there are about 600 private subscribers still getting service (who are not in arrears or who pay quickly when overhaul work looms), then using the same 2,000 operating hours per year, the overhaul interval for this group of engines is roughly 10,000 hours or once in five years.

APPENDIX G

Engine Loading

Loading for diesel engines can have a significant effect on fuel consumption and on maintenance costs. Engine loading is the ratio of the power required by an engine to perform a given task divided by the power available. It is usually expressed as a percent of full load. Full load is the de-rated power output of the engine at its normal operating speed (see below). For water lifting, the power required can be calculated from the amount of water lifted (in m^3) and the rate at which it is being lifted (m^3/h). The power available is the de-rated engine output at the specified operating speed (rpm).

Diesel engines have a manufacturer's nameplate which identifies the engine model and the rated output of the engine. The rated (or nameplate) output is given at a specific rpm. For the Lister ST-1, the nameplate rating is 6.0 kW at 2,000 rpm. The output of the engine at other speeds is proportional to the operating speed, and is different than the nameplate rating. In Botswana, the normal operating speed of the ST-1 is 1,500 rpm. At this speed, the output of the engine is 4.5 kW (or 75 percent of the nameplate rating).

The power output of an engine decreases with increased barometric pressure (elevation), temperature and humidity. Diesel engines must be de-rated for conditions other than the rating conditions. De-rating factors for Lister engines are:

- 3.5 percent for every 300 meters above 150 meters above sea level;
- two percent for every 5.5^{o} above $30^{o}C$ for air inlet temperature;
- up to six percent for relative humidity (a look-up table must be used for the exact figure); and
- losses for power absorbing equipment (belts, five percent; transmissions, five percent; etc.).

In Botswana, the de-rating factor used by DWA totals 25 percent. This figure includes five percent for belt losses, 10 percent for elevation (at a bit more than 1,000 meters) and 10 percent for elevated temperature (due to the normally elevated temperatures in the pump-shed). The humidity-related de-rating in Botswana is negligible. The overall de-rating factor will vary somewhat from site to site and over the course of the year. These variations can be significant. Using this average de-

rating factor, the ST-1 engine mentioned above will have a de-rated output of 3.38 kW.

The power required can easily be calculated from the head and flow rate. The formula is:

$$P = (H \times Q \times 9.81)/3{,}600$$

where P = power (kW),
H = total head (m),
Q = flow rate (m^3/hr).

For example, at a flow rate of six m^3/hr and a head of 100 meters, the power required is 1.64 kW. To calculate the engine loading, the pump efficiency (at its specified operating speed) must also be known. For example, according to the manufacturer's specifications, the efficiency of a BP6M Mono pump at 1,000 rpm is 66 percent. For Mono pumps, these figures seem to be reasonable, at least at higher operating speeds.

With this information, the engine loading can be calculated for this example. Expressed as a percent, the loading is then:

$$L = (P_{req'd} / N_{pump} \times P_{de\text{-}rated}\ \text{engine}) \times 100\%$$

where:

$P_{req'd}$ = hydraulic power required (kW),

N_{pump} = pump efficiency at specified rpm (%),

$P_{de\text{-}rated}$ = de-rated engine power output (kW).

For the example given, the engine loading is 74 percent. Typical engine loadings found in Botswana are in the 30 to 50 percent range. Note that loading is not a function of the water pumped over time and is not affected by how many hours the engine operates. However, if it is possible to increase the flow rate while holding the engine speed constant (by changing pulley ratios), then the loading increases and the same amount of water can be pumped in fewer hours. This will reduce costs, as demonstrated in Section VIII.

Proper engine loading is important for several reasons. First, fuel consumption and fuel efficiency are functions of loading. Increasing the load will increase the fuel consumption. But the efficiency increases also, and the fuel use per unit of water delivered declines. More importantly, low loading increases maintenance costs and, in a country with minimal preventive servicing, increases breakdowns. This is because engines operating at low load level never have the chance to warm

up properly. They run cold and this causes carbon build-up on the upper parts of the cylinder walls and in the exhaust manifold. When this build-up eventually makes it impossible to start the engine, it must then be decarbonized or "decoked." A major cause of water system outages in Botswana is engines not starting. Although technicians know how to solve the problem, the process involves an unscheduled trip to effect the repair. Longer term costs may increase also as cylinders and cylinder heads can be damaged if the decarbonizing is not performed carefully.

APPENDIX H

Diesel Test Sites

Site: Bonwapitse
Est. Population: 600
Daily Delivery (m^3): 19
Engine: ST-1 @ 1600rpm
Pump: ES-30S @ 980rpm
Pumping Rate (m^3/h): 7.66
Total Head (m): 58
Engine Loading: 48%
Diesel Cons (l/hr): .780
Diesel Cons (l/m^3): .102
Fuel Consumption as a % of Prediction: +6%
Pump Set Efficiency (fuel to pumped water): 15%

Site: Mogobane
Est. Population: 1980
Daily Delivery (m^3): 100
Engine: ST-1 @ 1600rpm
Pump: ES-30 @ 1010rpm
Pumping Rate (m^3): 8.67
Total Head (m): 74
Engine Loading: 67%
Diesel Cons (l/hr): .820
Diesel Cons (l/m^3): .094
Fuel Consumption as a % of Prediction: -12%
Pump Set Efficiency (fuel to pumped water): 20%

Site: Malotwana
Est. Population: 200
Daily Delivery (m^3): 10
Engine: SR-1 @ 1400rpm
Pump: ES-15S @ 850rpm
Pumping Rate (m^3): 3.24
Total Head (m): 48
Engine Loading: 15%
Diesel Cons (l/hr): .520
Diesel Cons (l/m^3): .161
Fuel Consumption as a % of Prediction: -37%
Pump Set Efficiency (fuel to pumped water): 8%
Note: Cattle may be watered here also.

Site: Mmankgodi
Est. Population: 3200
Daily Delivery (m^3): 22
Engine: LT-1 @ 1500rpm
Pump: ES-15 @ 990rpm
Pumping Rate (m^3): 2.70
Total Head (m): 82
Engine Loading: 33%
Diesel Cons (l/hr): .405
Diesel Cons (l/m^3): .150
Fuel Consumption as a % of Prediction: 21%
Pump Set Efficiency (fuel to pumped water): 10%
Note: Antoher borehole is in use as well.

Site: Oodi
Est. Population: 1900
Daily Delivery (m^3): 36
Engine: 8/1 @ 700rpm
Pump: ES-15 @ 1040rpm
Pumping Rate (m^3): 3.86
Total Head (m): 101
Engine Loading: 27%
Diesel Cons (l/hr): .740
Diesel Cons (l/m^3): .192
Fuel Consumption as a % of Prediction: -20%
Pump Set Efficiency (fuel to pumped water): 14%

Site: Kopong
Est. Population: 2200
Daily Delivery (m^3): unavailable
Engine: TS-2 @ 1300rpm
Pump: BH-50D @ 1130
Pumping Rate (m^3): 7.80
Total Head (m): 89
Engine Loading: 29%
Diesel Cons (l/hr): 1.233
Diesel Cons (l/m^3): .158
Fuel Consumption as a % of Prediction: -7%
Pump Set Efficiency (fuel to pumped water): 15%

Site: Mabalane #3
Est. Population: 800
Daily Delivery (m^3): 33
Engine: HR-2 @ 1500rpm
Pump: BH-100D @ 1065rpm
Pumping Rate (m^3): 14.08
Total Head (m): 83
Engine Loading: 33%
Diesel Cons (l/hr): 1.764
Diesel Cons (l/m^3): .125
Fuel Consumption as a % of Prediction: -27%
Pump Set Efficiency (fuel to pumped water): 17%
Note: One of several boreholes serves more than one village.

Site: Mogojogojwe
Est. Population: 500
Daily Delivery (m^3): 10
Engine: ST-1 @1500rpm
Pump: ES-30S @ 930rpm
Pumping Rate (m^3): 3.66
Total Head (m): 99
Engine Loading: 44%
Diesel Cons (l/hr): .792
Diesel Cons (l/m^3): .216
Fuel Consumption as a % of Prediction: +13%
Pump Set Efficiency (fuel to pumped water): 12%

Site: Mmaphashalala
Est. Population: 800
Daily Delivery (m^3): 16
Engine: ST-1 @ 1500rpm
Pump: ES-30S @ 780rpm
Pumping Rate (m^3): 5.12
Total Head (m): 52
Engine Loading: 20%
Diesel Cons (l/hr): .786
Diesel Cons (l/m^3): .154
Fuel Consumption as a % of Prediction: +28%
Pump Set Efficiency (fuel to pumped water): 9%

Site: Lotlhokane-East
Est. Population: 900
Daily Delivery (m^3): 43
Engine: ST-2 @ 1500rpm
Pump: ES-30 @ 1000
Pumping Rate (m^3): 7.36
Total Head (m): 27
Engine Loading: 14%
Diesel Cons (l/hr): .942
Diesel Cons (l/m^3): .128
Fuel Consumption as a % of Prediction: 2%
Pump Set Efficiency (fuel to pumped water): 6%

APPENDIX I

Diesel-Pump Test Procedure

Approach

The diesel tests consist of a series of short, consecutive tests of from 10 to 15 minutes' duration. During each period, the water pumped is recorded, and at the end of each period, the pump and engine RPM are checked, and the fuel required during the interval is recorded. To measure the fuel consumption accurately, the normal fuel tank is by-passed and a plastic container with a fill line is substituted. At the conclusion of each time interval, the fuel level is restored to the fill line from a graduated cylinder. The amount required is determined from graduated cylinder readings.

In most cases, the chosen test sites have engines and pumps that were installed as part of the Village Water Supply Program. This is because at these sites there are water meters and 20 mm brass taps in place. This facilitates measuring water flow and discharge pressure. Also, it was not necessary to pull pipes at these sites to determine pump model. Accurate records of the equipment used exist for these sites.

Equipment Used

- Stop watch
- Electronic well sounder
- Digital tachometer
- Pressure gage and hydraulic hose set up to connect to the brass tap
- Two-liter, clear-plastic container and hose to connect to the engine fuel line
- Graduated cylinder (250 ml)

Preliminary Checks

A preliminary visit is made to each site. The pump operator is located to ensure access to the pump house and engine (the operator is supposed to keep the pump house locked). Each site is initially checked to determine if the water meter is functioning and the engine operating satisfactorily. Notes are made of the engine model and the general condition of the engine and pump house. The engine is run and the tap opened to see if a steady stream of water results. If water spits out of the tap, the water level is likely to be at the pump level and some percentage of air is entering the system. This is not an altogether uncommon occurrence for several reasons. First, if

the pump set design is not correct or the well yield has declined, the drawdown may be greater than anticipated in the system design. Second, if the water demand has grown, the pump may have been replaced with a larger one that pumps at too high a rate for the borehole. This condition occurred at one of the test sites (Mmaphashalala).

Set-Up and Test

The test requires at least two people. The set-up procedure requires several steps. The first is to disconnect the engine fuel tank. Using a short section of tubing, a two-liter plastic container with a marked fill line is connected to the engine in place of the normal tank. The battery-operated well sounder is dropped in the borehole beside the rising main. The deflection of a needle on the well sounder indicates when the probe reaches the water level. The water level can be read directly from marks on the well sounder line. A pressure gage is attached to the brass tap via a short section of pressure hose and the appropriate fittings. The engine is then started. The water level is measured during the initial drawdown period. Equilibrium conditions are assumed when the water level no longer drops in the borehole.

Once a steady condition is reached, the pump and engine rpm, well sounder reading and pressure gage measurement are recorded, and the fuel level returned to a predetermined marked level on the plastic tank. Simultaneously, the stopwatch is started. The test interval is determined as the test progresses. The interval is selected as five, 10 or 15 minutes--such that less than 250 ml of fuel are consumed during the interval. Once the interval is selected, the graduated cylinder is filled to the 250 ml level and diesel fuel is poured almost to the original mark in preparation for the end of the test interval.

At the end of the time interval, diesel fuel is added to bring the level to the fill line on the plastic container and the water meter is read. Then the pump and motor rpm and the water level and pressure gage readings are made. This is the critical step, and care must be taken to work quickly and accurately. Figure I.1 is an example of the data sheets used for recording information.

Fuel consumption during the interval can now be determined. The level of remaining fuel in the graduated cylinder is noted and the difference between 250 ml and the final reading is the amount of fuel used. Diesel is then poured to restore the fuel level in the cylinder to 250 ml in preparation for the end of the next interval. This process is repeated six to 10 times.

Figure I-1

Diesel Pump tests

Site: _____ Date: _____

Time at beginning of test (sec)	-0-
water meter reading (liters)	
fuel used (mliters)	—
pump rpm	
pressure gauge reading (.1 kpa)	
water level (.1 meter)	

time	
water meter reading	
fuel used	
pump rpm	
pressure gauge reading	
water level	

time	
water meter reading	
fuel used	
pump rpm	
pressure gauge reading	
water level	

Results

At the end of each interval, calculations are made of the fuel consumption per hour, fuel consumption per cubic meter of water pumped, the pumping rate and the overall efficiency of the system from diesel to delivered water (assuming 38,000 MJ/liter is the energy content of the diesel). An example of the calculation sheets used is given in Figure I.2 on the following page. These calculations are performed in the field. At the completion of the test, the intervals with the highest and lowest fuel consumption are discarded and the values for the remaining intervals averaged to provide the data presented in this report.

Figure I-2

Site: _____

Date: _____

Diesel calculations:

1) Fuel consumption in liters/hour

$$\frac{(\quad\quad)\text{ ml of fuel}}{(\quad\quad)\text{ minutes}} \times \frac{60}{1000} = \_\_\_\_\_ \text{ liters/hr.}$$

2) Fuel consumption per cubic meter pumped

$$\frac{(\quad\quad)\text{ ml of fuel}}{(\quad\quad)\text{ liters of water}} = \_\_\_\_\_ \frac{\text{liters of fuel}}{\text{cubic meters of water}}$$

3) Water delivery rate in cubic meters per hour

$$\frac{(\quad\quad)\text{ liters of water}}{(\quad\quad)\text{ minutes}} \times \frac{60}{1000} = \_\_\_\_\_ \text{ m}^3\text{/hr}$$

4) check - cubic meters/hr.

$$\frac{(\quad\quad)\ \ell\text{/hr (1)}}{(\quad\quad)\ \ell\text{/m}^3\text{ (2)}} = \_\_\_\_\_ \text{ m}^3\text{/hr}$$ [should be equal to 3)

5. Fuel efficiency

$$\frac{(\quad\quad)\text{ liters of water} \times (\quad\quad)\text{ meters head} \times 9.8}{(\quad\quad)\text{ m}\ell\text{ of fuel} \times 38{,}000} = \_\_\_\_\_$$

meters head = dipper measure + (kpa/10)

fuel efficiency is normally in the range .05 to .20

APPENDIX J

Petrochemical Use

Petrochemical consumption for diesel pumping systems includes both diesel fuel and oil use. Both vary considerably with engine application and operating conditions. For the purposes of this report, average conditions for Botswana can be assumed. It must be recognized that there will be deviations from these average conditions. Fuel consumption for vehicles involved in installation, field support and fuel delivery is not considered here. These costs are included as part of the transportation items in the analysis.

Fuel Costs

Fuel costs are a function of engine loading, which in turn is a function of de-rated engine output, full-load fuel consumption, total pumping head, flow rate, and condition of the engine. Lister has provided a formula for the fuel consumption as a function of full-load fuel consumption and loading. This formula is shown graphically in Figure 4 (found in Section V.B.3 of the main body of this report). Note that in the format given, the fuel consumption is a percentage of the full- load fuel consumption, and the graph can be used for the entire range of Lister diesel engines. Full-load fuel consumption for the range of Lister engines can be obtained as a function of engine and rpm.

Tests were conducted to verify the accuracy of this graph as a predictive tool. The results of 10 short-term tests are indicated on the graph and, except for one point (included to show the results of pumping air due to too high a pumping rate), all tests verify the general relationship. At loadings below 20 percent, Lister warns that predictions become unreliable as the fuel consumption curve becomes asymptotic. This method of predicting fuel consumption was the basis for fuel consumption estimates used in this report.

Oil Consumption

Lister documentation indicates that oil consumption should be less than .75 percent of full-load fuel consumption. This does not include oil changes. The economic analysis requires inclusion of total oil consumption, including oil changes. An analysis of 15 engines in use for rural water supplies indicates a total oil consumption of 3.4 percent of actual fuel consumption. If one assumes an average loading of from 40 to 60

percent, then the oil use as a function of full-load fuel consumption is about two percent.

To determine whether this finding is reasonable, a hypothetical case was considered. If oil were changed at the rate the manufacturer recommends (every 250 hours), then the oil consumption would be about 1.5 percent of full-load fuel consumption. For example, if an ST-1 (FLFC = 1.29 liters/hr at 1,500 rpm and sump capacity of two liters) received an oil change every 250 hours, then the oil use would be 1.4 percent (.75 percent consumption and .62 percent for oil changes). If one again assumes an average loading of 50 percent, this level of oil use would be roughly three percent of actual fuel consumption. Oil use by the engines surveyed is somewhat higher than this figure due to engine condition (causing higher oil consumption), leakage and spills.

Other engine user groups may have higher oil consumption, if oil leakage and are is high. They may also have lower consumption if, as indicated by BRS overhaul records, oil changes are not made regularly. Records from these other groups were either unavailable or not examined.

For purposes of analysis, an oil consumption figure of four percent of actual fuel consumption was used.

APPENDIX K

Field Servicing

Field servicing of diesel engines, as defined here, includes all service and repairs completed at the borehole site. However, it does not include labor or transportation costs of the trip to the borehole. It also does not include overhaul costs. It does include repair and maintenance costs for both the engine and the pump (but not the reticulation, if applicable) or the tank. It also includes on-site labor costs. Field-servicing costs are a function of engine-hours of operation and engine condition. In the following analysis, the condition of the engine has not been considered as the data will not support such analysis. Average engine conditions must be assumed. The analysis is divided by user group, as service conditions appear to vary.

Major Villages

The total engine and pump repair costs for four major-village water supplies over 188 engine-months (over 70,000 total hours on 20 engines) were surveyed. The engines operated an average of almost 13 hours/day (not all 20 engines were in use during the period in question). The survey included data on engine-hours of operation, fuel consumption and water production by month. It also included work done by both the DWA crews at the station and by BRS. Detailed repair and maintenance costs for the engines in each village were separated into labor and spare parts categories. The results were remarkably consistent at all sites, with labor charges of about P0.01/hr of engine operation and spares costs ranging from P0.16 and P0.19/hr of engine operation. A further analysis of these figures indicated that the trips were evenly divided into trips relating to the engine and those relating to the pump. However, closer examination revealed that the costs were not evenly divided. The average cost of trips made to service engines was P36, while those to service the pump averaged P284. This is due to the much higher cost for Mono pump components than for diesel spares fitted in the field. The conclusion that the pumping component of the system is responsible for the major part of field-servicing costs is inescapable. It is not known whether this would be true for pumps other than the Mono.

Repair and/or maintenance trips were made at different rates. The number ranged from 2.5 to seven per operating borehole per year. The average number of trips was about 4.1 per operating borehole per year.

Rural Villages

Rural-village water supply schemes operated by District Councils run far fewer hours than the major village systems. The design goal is from six to eight hours per day in the design year (20-year design horizon). This means that, with both actual per capita consumption and total population less than design levels, most engines are operating for fewer hours than the design level. In some documented cases, the engine and pump are operated less than two hours per day. However, in some older schemes and some with particular problems, the engines operate for 10 to 12 hours.

Many engines used in rural villages are quite new, having been recently installed as part of the Village Water Supply Program or drought relief schemes. At other sites, new equipment has been installed with the upgrading funds made available to the District Water Units over the last several years. While this should decrease typical maintenance costs in the future, the upgrading work has significantly increased current expenditures.

In a survey of 22 villages, the spares cost per engine hour of operation was P0.20. The range was P0.01 to P1.00, which indicates the wide range of costs that can be expected as new installations need little attention and older systems are being fitted with new spares to upgrade them. Other costs can be divided into transport and labor (including travel time and time on-site). The on-site labor cost is likely to be similar to the major villages (i.e., less than P0.01/hr of engine operation). However, the dispersed locations of rural villages make transport a much costlier item than in the major villages.

The average rural village is about 200 km from the water unit, which makes vehicle and labor costs per trip much higher than for major villages (where distances are on the order of 30 km one way). An analysis of records from seven water units indicate that, on average, 4.2 trips/year are made to each borehole. Of these, one is likely to be for a breakdown.

Government Agencies

The engines operated by government agencies, such as Customs and Immigration or the Veterinary Department, are serviced by BRS. For a listing of these sites, see Appendix C. This is done free of charge for the agencies involved, so it is reasonable to assume that all repair and maintenance not done by the agency itself will be done by BRS. Records for individual boreholes are available, but time has prevented a thorough examination of these primary data. Instead, secondary sources have been used. These include the BRS monthly summaries (by outstation) and interviews with the heads-of-station at most outstations (see Appendix E).

The most important information lacking for this group of engines was number of hours of operation per year. Interviews suggest that two to eight hours per day is typical, with an average of roughly three, as many of the sites need only to provide water for a small staff stationed at the site. If this average figure of three hours per day and BRS records for spares purchases are used, then P0.13 for spares per hour of operation results. This figure appears reasonable in light of the results above and the sense that government agencies do not get quite as good service as the villages, due to transportation and staffing constraints.

BRS visits each of its subscribers' boreholes (which include these government agency cases and private subscribers) an average of once a year. This rate is skewed to the low side as roughly half of the private subscribers are in arrears and thus are not supposed to be receiving service. This would indicate a trip rate to government boreholes of at least two per borehole per year. It is assumed that BRS will make three trips per government borehole per year as service calls are free.

Private Sector

Trying to characterize private-sector maintenance and repairs is extremely difficult. There is very little information to go on because almost no one keeps records. In addition, there are many approaches to the use and care of engines. There are some users who seem to operate on similar assumptions as the government--that engines can be cared for and repaired and, if one is careful, an engine will last many years. Anecdotal accounts of 30- and 40-year-old engines are easy to find. On the other extreme, there are stories of people who never service the engine at all, and engines lasting only several years before replacement is necessary. In some cases, the whole philosophy of engine use seems to be to do minor repairs and, when a major overhaul becomes necessary, get a new engine. In general, private-sector engine users seem to fall into three groups with differing approaches and, as a result, differing costs for diesel engine use. Unfortunately, the data are not complete enough to do much more than discuss, in broad terms, actual costs for engine maintenance and repair.

Freehold farms are fenced and, as such, careful grazing policies and reliable water supplies are necessary. This is because there is no recourse to communal grazing or watering points outside the farms if major problems occur. For these reasons, the freehold farmers, as a group, pay more attention to their water pumping equipment. They appear to perform most of the minor servicing themselves. In many cases, farmers have spare engines so that when major engine problems occur, they can replace the ailing engine and bring the other to their own shops

or to commercial shops for repair. Transportation for repair and maintenance is expected to be lower than for the public sector, due to use of lighter vehicles by farmers.

Sole ownership of equipment is common for two groups (in addition to freehold farmers)--leasehold ranches and privately owned equipment on communal land. There are several thousand water pumping systems that fall into this category, and the range of repair and maintenance practices as well as costs is wide. Most of this category of engine users are absentee and leave the operation of the engine in the hands of a pumper (usually poorly trained, if at all). About 600 are paid-up subscribers to the BRS program. Most seem to either manage minor repairs themselves or rely on the informal sector. As the BRS is so highly subsidized, it is surprising that there are not more people taking advantage of the scheme. However, the informal sector is active, responsive and cheap.

BRS records reveal that an average of P170 in spares is spent on each repair trip to private-sector subscribers. There appear to be about two repair trips per borehole, once non-paying subscribers (who do not receive service) are accounted for. This implies a materials repair cost per borehole per year of about P340. If private-sector users operate their engines 2,000 hrs/yr (Hitchcock), then the materials repair cost per year is P0.17/per engine-hour of operation. This is consistent with the costs indicated in the public sector. This is somewhat surprising, given the perception that engine condition is poorer in the private sector and breakdowns more common. This aberration appears to be largely a function of the way public- sector maintenance is performed. Expensive and more complex jobs are performed by BRS; less expensive maintenance is performed by the owner and/or informal sector. Engine lifetimes and overhaul costs, not considered in this portion of the analysis, are higher for the private sector, increasing their overall recurrent costs (see Appendix F).

Many private-sector users seem to believe that BRS is expensive (particularly for the smaller jobs) because of the P80 basic charge for each job. This seems to lead many people to informal-sector repair services for at least the small jobs (and for the larger ones as well, as the BRS subscribers list indicates). Indications are that even most BRS subscribers utilize the informal sector to some degree. This increases the cost per hour of operations. Several studies (Hitchcock, Flink, Bailey) indicate that the actual repair cost per borehole per year is in the range of P500, which translates into about P0.20 for spares per engine-hour (after making allowances for transportation and labor components). This seems consistent with figures quoted earlier. It appears that there is no financial gain by using the private sector, but there may be other advantages including response time and lower cost.

Communal ownership of equipment is largely a response to the financial constraints or lack of access to credit which individual users face. As such, repair and maintenance costs are often difficult to meet. It appears that these users (as well as the poorer individual owners) pay a steep price in system reliability, as it takes time for them to organize the funds to pay for spares and labor once a problem occurs. It is anticipated that the annual maintenance and repair costs are on the higher end of the spectrum (in the range of P0.25 per operating hour) but are still within the ranges quoted for the other user groups. The major differences from other groups are that there are periods when the engine is not operating, overhaul costs are much higher, and engine lifetimes are shorter, which thus increases the long-term costs.

APPENDIX L

Engine Manufacturer's Recommendations

There are three main factors that affect the service life of a diesel engine used to drive a pump set--application, installation and servicing.

Application

Proper use and care of diesel engines begins with proper sizing of the engine. This should be assured during the borehole design phase when the power requirement is calculated. Once the power requirement is known, an engine can be chosen. However, the engine cannot be chosen based on the nameplate rating alone. The engine operating rpm affects the power availability under standard conditions and the engine must be derated to allow for local (non-standard) conditions of temperature, altitude and humidity. See Appendix G for details of the derating procedures.

Ideally, diesel engines should operate at from 60 to 80 percent of full load. Operating at too high a load reduces engine life. Low loading conditions result in cold running and carbon buildup, which increases maintenance and decreases the life of some engine components.

Low engine loading is usually assumed for engines operated by both the government and the private sector. This has been confirmed by tests that fail to find any engines operating at as high as a 70 percent load. All other tests indicate loadings less than this, with more than half tested at less than a 30 percent load. Much of this is the result of current design procedures and the public-sector fascination with the water-cooled models.

Installation

Proper installation may be the single most important factor affecting the service life of an engine. Improper installation can often result in excessive vibration, which causes damage to air filters and other sheet-metal parts, oil leakage, and loosening of nuts and bolts. Many problems are caused by not allowing for a sufficient foundation for the engine. Foundations designed by DWA should have sufficient mass to keep vibration to a minimum. However, installation in the field is sometimes not up to standard. Privately installed engines (often installed by the users themselves) are more prone to these problems because insufficient reinforcing and/or cement is often used.

Once the foundation is in place, it is necessary to mount the engine tightly to it. Current practice in Botswana is to use a prefabricated steel frame that allows the engine to be bolted down and also places the pump over the borehole at a pre-set distance from the engine (to ensure that the V-belts will fit properly). This system is good, provided that the frame is well fabricated and the engine is securely bolted down.

Servicing

There are several important requirements for getting the best performance from a diesel engine. These are clean fuel, clean oil of the proper type, clean air and continual observation and adjustment (as necessary) by a good operator. These, along with proper application and installation, are the best guarantee of trouble-free engine operation.

Clean fuel is assured by proper storage of the fuel, taking care that dust and foreign matter do not contaminate the fuel while filling the tank, and periodically replacing the fuel filters. District Council files indicate that fuel filters are being changed at the rate of less than once a year. The recommended rate is several times this. It also appears that water in the fuel is a problem in Botswana. This may be due, at least partially, to condensation in the fuel tank overnight. Filling the tank in the evening, after the engine is stopped, can help to alleviate this problem.

Detergent oils that hold carbon in suspension are usually recommended. The oil should be changed at regular intervals (Lister recommends every 250 engine operating hours for engines running at less than 3,000 rpm). It is clear that these recommendations are not being followed. This is indicated in the records kept by pumpers in most districts (although not all). Another indication is the high replacement rates, during overhaul, of components damaged by infrequent oil changes (crankshafts, main bearing bushes, etc).

Clean air is assured by periodic replacement of air filters. The dusty conditions found in Botswana make this an important consideration, and careful attention should be paid to assuring that air filters are in good condition. Failure to do so causes worn piston rings, pistons and cylinders, necessitating premature engine overhaul. Again, it appears that manufacturer's recommendations are not being followed in many cases. A sample of engines indicates air filter replacement rates are in the range of once in five years or longer.

The diesel operator is the one individual who can make the greatest difference in trouble-free engine operation. Operators should keep the pump house and engine clean and be observant.

They should ensure that the foundation bolts are tight to keep vibrations to a minimum, check V-belt condition and tension, and change the oil periodically. Moreover, operators should report any abnormalities that they are unable to repair or adjust themselves, so that these can be attended to.

The following summarizes the recommended service intervals for Lister engines. However, it is clear that they are only rarely followed with any care. Normal filter replacements are made much more rarely than indicated, and overhauls are usually at much reduced intervals, except in the private sector where it appears that these intervals are also longer than recommended (with a resultant increase in overhaul cost).

Daily	Check supply of diesel fuel and oil level Check air filter (in dusty conditions)
125 hrs	Check air filter (in moderately dusty conditions, renew if necessary) Check for oil and fuel leaks Check and tighten nuts and bolts as necessary Clean engine and mounting
250 hrs	Change engine oil Clean the restrictor banjo union in the lubricating oil feed line Renew oil filter if fitted (ST) Clean injector nozzle if exhaust is dirty Renew fuel filter if necessary Check belt tension
500 hrs	Decarbonize if necessary (LT) Renew fuel filter element (ST) Adjust valve clearances (LT) Change oil in oil bath air filters (8/1 so equipped)
1000 hrs	Decarbonize (8/1) and if necessary (ST) Change filter elements (8/1) Adjust valve clearances (ST)
1500 hrs	Decarbonize (LT) Examine and clean fan blades (LT) Check governor linkage and adjustment (LT) Drain and clean fuel tank (LT) Renew fuel filter (LT) Clean and test injector nozzle (LT) Check fuel pump timing (LT) Check oil pump and its valves (LT) Renew air filter element (LT)

2000 hrs	Decarbonize (ST) Clean inlet and exhaust system (ST). Examine and clean fan blades (ST) Check governor linkage and adjustment (ST) Drain and clean fuel tank (ST) Renew fuel filter (ST) Clean and test injector nozzle (ST) Check fuel pump timing (ST) Check oil pump and its valves (ST) Renew air filter element (ST)
5000 hrs	Check big end and main bearings and overhaul as necessary (LT)
6000 hrs	Check big end and main bearings and overhaul as necessary (ST)

APPENDIX M

How User Groups Differ

First, it is useful to examine the relative costs faced by the different user groups chosen for the analysis. The table below shows data specific to the purchase of pumps and engines. Government purchases are made from specific tenders and the prices below come from the current tender. Private prices were obtained directly from suppliers.

Summary of Current Capital Costs

	Public	Private	Difference
Lister LT-1	P1,785	P2,439	+37%
Lister ST-1	P2,289	P3,763	+64%
Lister 8/1	P4,043	P6,389	+58%
Mono BP4M	320	444	+39%
Mono BP6M	497	783	+58%
Discharge head--40 mm	279	412	+48%
Discharge head--50 mm	289	458	+58%
Balance of system--40 mm	450	20	*
Balance of system--50 mm (ex-Mono column)	530	30	*
Mono column, 40 mm, per meter	18	26	+44%
Mono column, 50 mm, per meter	24	38	+58%
Pump house and civil works	1,190	600	*

*As might be clear from the figures, the balance of system and pump house facilities used in public-sector projects are quite different and, in an important sense, not comparable. Therefore, the costs are reported, but the percentage difference is omitted.

The following table includes values for those variables which change according to user group.

Variation Among User Groups

Site Information	User Groups: Rural Village	Major Village	Other Gov't	Private Sector
Total pumping head				
Annual consumption growth factor	.03	.05	0	0
Pump level				
Km one way from installation center	200	150	200	200
Km one way from service center	100	30	300	300
Capital Cost Information				
Cost of engine				
Cost of pump and Mono head				
Cost of rising main per meter				
Cost of pump house				
Cost of piping and components				
Cost of installation crew per day	200	200	200	150
% of installation cost for allowance	50	50	50	100
Number of days to install	20	20	20	7
1-, 7- or 10-ton truck install transp	10	10	10	1
Times return trip dist transp	3.5	3.5	3.5	1.2
Engine Information				
Hours of operation per day				
Pumping rate (m^3/hr)	3.5	7.0	3.5	3.5
De-rated engine output				
Liters of fuel/hour-full load				
Assumed pump efficiency				
Hrs between overhauls	5000	3500	5000	10000
Pula per overhaul (materials)				
Pula per overhaul (labor)				
Overhauls per lifetime	8	16	8	4
Transportation Information				
Pula/km Light 4x4 truck				
Pula/km Heavy 7-ton truck				
Pula/km Heavy 10-ton truck				

Recurrent Costs

Pula/year for pumper	2400	2400	1200	450
Unskilled labor cost (pula per day)	7	7	7	7
Skilled labor cost (pula per day)	12	12	12	12
Pula/liter for diesel fuel	.54	.54	.54	.62
Fuel escalation rate				
Oil as a fraction of fuel use				
Pula/liter oil cost				
For materials per hour of operation				
Person-days unskilled labor per trip	4	4	4	4
Person-days skilled labor per trip	1	1	1	1
Trips at 0.47 pula/km	1	3	0	1
Trips at 0.85 pula/km	2	2	1	0
Average allow./trip (per diems)/person	12	6	12	1
Trips/year for fuel delivery	3	12	3	1

Financial Information

Years amortization period				
Discount rate	.06	.06	.06	.12

An annual growth factor was included in the model which permits cases to be run with growth rates appropriate to the site. The rates selected were:

other government: zero growth
rural villages: .03% per year
major villages: .05% per year
private: zero growth

The interpretation that should be given to this assumption is not, for example, that there will be no growth in overall demand in water use by other government agencies. Rather, that on average, there will be no increase per site and overall increases will be met by additional sites.

The water requirements of both major and rural villages are expected to grow at the above rates. This growth may be a result of growth in water consumption because the population grows, there is increased per capita water use, or some combination of the two.

Private-sector water use, largely for cattle watering, will not grow significantly. The national cattle herd could grow to pre-drought levels, but this is not anticipated in the near future. In addition localized stocking rates are already high and water consumption on or by a site cannot grow significantly.

APPENDIX N

Performance Matrices

Explanation

This appendix will show by example what information is contained in these matrices and how to use and interpret this information. In Table N.1 below, the sample chosen is that which describes the use of a Lister 8/1 in a major village. There are two other matrices for major villages--one for the Lister ST-1 and one for the Lister LT-1. By following the explanation for this one matrix, the reader will be able to use and understand not only the two other matrices for major villages, but also, the nine others covering the other users and engine types as well.

Table N.1

Sample Matrix: Output in Cubic Meters Per Day
Case: Major Village Engine: Lister 8/1

Output:	20	30	50	100
Head:				
30 Meters				
Financial	P.48	.36	.26	.20
Economic	P.37	.29	.23	.19
Loading	.17	.17	.17	.17
Fuel Use*	.70	.70	.70	.70
60 Meters				
Financial	P.51	.39	.29	.22
Economic	P.40	.32	.26	.21
Loading	.34	.34	.34	.34
Fuel Use	.98	.98	.98	.98
90 Meters				
Financial	P.54	.42	.32	.25
Economic	P.44	.35	.32	.24
Loading	.51	.51	.51	.51
Fuel Use	1.28	1.28	1.28	1.28
120 Meters				
Financial	P.57	.45	.35	.28
Economic	P.47	.39	.32	.27
Loading	.68	.68	.68	.68
Fuel Use	1.57	1.57	1.57	1.57

*Fuel use in liters per hour. Pumping rate is 7.0 m^3/hour.

Step One: Examine the captions for the columns.

The quantities at the top of each column were selected to represent typical quantities demanded by major villages. It must be said, however, that a major village may well have more than one such pump or other water supply facilities as well. By expressing this demand on a daily basis and selecting a pumping rate (per hour) for the entire matrix, one can calculate the daily pumping time for any quantity. The pumping rate chosen for major villages is seven cubic meters per hour; the rate for the other user groups is 3.5 cubic meters per hour. Each value is typical of the boreholes serving that particular group.

It should be said that due to the difference in pumping rate between the major village matrix (7.0 cubic meters per hour) and that of the other three users (3.5 cubic meters per hour), comparisons cannot readily be made between major villages and other user groups.

For example, in the case of the matrix reproduced as Table N.1, the cell at the upper lefthand corner of the matrix, which represents 20 cubic meters per day at 30 meters head, reveals that the engine has to run 2.9 hours to meet the demand. It takes 14.3 hours to pump 100 cubic meters per day at that same rate. It is important to note here that there is a practical limit to how many hours per year an engine can operate. There are 8,760 hours in a year, but it is unrealistic to expect to get more than 7,000 hours of running time out of an engine. Of course, there will be the odd engine that runs more--and that which runs less, too. Nonetheless, 7,000 hours is an 80 percent capacity factor, and that represents a reasonable maximum number of operating hours for a year.

Step Two: Examine the captions for the rows.

The captions for the rows denoted as financial and economic are the net present values (NPVs) per discounted cubic meter in pula of the total cash flows required to achieve the level of output represented by the cell. In the main report, these are referred to simply as unit costs. The difference between the financial and economic NPVs is accounted for by shadow-pricing of unskilled labor and imports, as discussed in Section VIII.B. The quantity used to arrive at the per unit cost is the discounted quantity of water that would be pumped over the 20-year period, using a six percent discount rate for the public sector, and a 12 percent rate for the private sector.

Below the financial and economic figures are two items that describe the status of the pump set. Loading is a term that denotes the current amount of work being performed relative to

the unit's potential, de-rated output. Here, it is expressed as a decimal fraction. The row of data for fuel use, expressed in liters per hour, is a function of loading and the specific full-load fuel consumption of the de-rated engine.

Interpretation: Comparisons Within a Matrix

Fuel use and loading. Hourly fuel use does not change as output per day changes (as one moves right across the matrix), because fuel consumption per hour depends on engine loading and not on the quantity pumped per day (the engine is simply run more hours). Engine loading, likewise, does not change as output per day changes. Loading and fuel consumption do change, however, as head increases. Simply put, it requires more units of work to pump a given quantity of water as the total pumping head (roughly the vertical distance over which it is being moved) increases.

Loading is an important figure by itself. Engines are designed to run at a particular range in the neighborhood of their maximum efficiency. Too light a loading causes maintenance problems, as does too heavy a loading. If the loading is not sufficiently high, for a given head-output pair, then the solution is to choose a smaller engine or increase the pumping rate--either choice will increase loading. In general, for the engines under study, a good target is a loading of about 70 percent of full load.

Discounted unit costs. The two cost figures can be seen to increase as head increases. This occurs for two reasons. First, the capital costs have increased because of the longer run of rising main, shaft and bearings that make up a Mono pump column. Second, operating costs increase also, as can be seen from the fuel consumption figure. Specifically, as one moves from the upper left corner of the matrix to the lower left, engine-hours and annual quantity of water remain constant. Total installed capital costs, however, increase from P12,209 to P14,585 (economic), or 19 percent. Moving from left to right across the matrix, since engine-hours increase with volume of water pumped, the initial-year running costs increase from P2,425 to P3,042 (economic), or 25 percent.

On the other hand, if one moves from the upper left corner to the lower right corner, the only constant is the hourly pumping rate and engine model. Capital costs increase 19 percent, initial-year running costs increase 242 percent, the annual quantity of water increases 400 percent, and annual engine-hours increase 400 percent.

Interpretation: Comparisons Among Matrices

Comparing matrices within a user group. By comparing matrices for a given user group, it is possible to see the differences in cost and fuel use that occur for a constant quantity of water when a smaller or larger engine is chosen. For example, using the matrices for the major villages (reproduced in part below), if one examines the contents of the cells for 20 cubic meters per day at 60 meters of head for each of the three engines, the following data are found.

Table N.2

Major Village Output in Cubic Meters Per Day: 20

Engine: Lister 8/1

60 Meters	
Financial	P.51
Economic	P.40
Loading	.34
Fuel Use	.98

Engine: Lister ST-1

60 Meters	
Financial	P.48
Economic	P.37
Loading	.45
Fuel Use	.71

Engine: Lister LT-1

60 Meters	
Financial	P.47
Economic	P.36
Loading	.70
Fuel Use	.69

What this reveals is that with moving to a smaller engine, loading increases and fuel use per hour of operation is reduced. At the same time, the discounted unit costs decline from P0.51 (financial) and P0.40 (economic) to Po.47 and P0.36, respectively. The corresponding percentage decreases are eight and 10. The limits of this sort of engine swapping are found in the loading value, which is to say that there really are good reasons for having different sizes of engines. As a practical matter, a loading of .60 to .70 is a reasonable target.

Interpretation: Comparisons Among User Groups

Comparing matrices among user groups. By choosing a given cell (i.e., for a given engine, an output level and daily demand pair), and examining that same pairing for each user category, it is possible to judge the effects of the differing circumstances in which the users find themselves. For example, for the Lister ST-1, examine the cell representing 20 cubic meters per day at 90 meters head. Please note, due to the difference in pumping rate between the major village matrix (7.0 cubic meters per hour) and that of the other three users (3.5 cubic meters per hour), this comparison only covers three groups. The appropriate data are given in Table N.3.

Table N.3

Engine: Lister ST-1 Output in Cubic Meters Per Day: 20

Head	Rural Village	Other Govt	Private
90 Meters			
Financial	P.66	P.61	P.49
Economic	P.55	P.55	P.50
Loading	.34	.34	.34
Fuel Use	.59	.59	.59

It can be seen that on a financial basis (but not on an economic basis), the cost of providing a given quantity of water to a rural village is greater than for any of the user groups. Since the pumping rates for all three of these examples are equal at 3.5 cubic meters per hour, the cost difference does not arise from operating the engine longer hours. Engine size and loading are also held constant in this example. Therefore, the reason for this difference is to be found in the costs particular to the user group. If the base-case example (which was a rural village) is recalled for a moment, the answer becomes clear. The major difference between the rural village and the other government case is the assignment of the full cost of the pumper (in the financial case, P2,400 rather than P1,200) to the rural village. In the other government case, the pumper has other duties to perform and, as a result, the costs are reduced. Note the effect of the shadow-pricing, however, which results in an equal economic cost for rural villages and other government. For the private case, it is primarily the very low wage paid to the private pumper which makes it the least expensive case. For a specific discussion of how user groups differ, please see Appendix M.

PRESENT VALUES; PULA per Cubic Meter

Rural Village, Lister 8/1

		Output In Cubic Meters/Day			
		5.00	10.00	20.00	30.00
Head = 30M	Financial	2.03	1.14	.71	.55
	Economic	1.52	.89	.60	.49
	Loading	.08	.08	.08	.08
	Fuel Use (l/hr)	.70	.70	.70	.70
Head = 60M	Financial	2.04	1.13	.70	.54
	Economic	1.53	.89	.59	.48
	Loading	.17	.17	.17	.17
	Fuel Use (l/hr)	.70	.70	.70	.70
Head = 90M	Financial	2.10	1.18	.74	.58
	Economic	1.60	.94	.63	.52
	Loading	.25	.25	.25	.25
	Fuel Use (l/hr)	.88	.88	.88	.88
Head = 120M	Financial	2.14	1.21	.76	.60
	Economic	1.65	.98	.66	.54
	Loading	.34	.34	.34	.34
	Fuel Use (l/hr)	.98	.98	.98	.98

Rural Village, Lister ST-1

Head = 30M	Financial	1.89	1.03	.61	.47
	Economic	1.37	.78	.50	.40
	Loading	.11	.11	.11	.11
	Fuel Use (l/hr)	.38	.38	.38	.38
Head = 60M	Financial	1.94	1.07	.64	.49
	Economic	1.42	.82	.53	.42
	Loading	.23	.23	.23	.23
	Fuel Use (l/hr)	.51	.51	.51	.51
Head = 90M	Financial	1.97	1.09	.66	.51
	Economic	1.46	.84	.55	.44
	Loading	.34	.34	.34	.34
	Fuel Use (l/hr)	.59	.59	.59	.59
Head = 120M	Financial	2.01	1.12	.69	.54
	Economic	1.50	.88	.58	.47
	Loading	.45	.45	.45	.45
	Fuel Use (l/hr)	.71	.71	.71	.71

Rural Village, Lister LT-1

Head = 30M	Financial	1.86	1.00	.59	.44
	Economic	1.34	.75	.47	.37
	Loading	.18	.18	.18	.18
	Fuel Use (l/hr)	.31	.31	.31	.31
Head = 60M	Financial	1.90	1.04	.61	.47
	Economic	1.38	.79	.50	.40
	Loading	.35	.35	.35	.35
	Fuel Use	.44	.44	.44	.44
Head = 90M	Financial	1.94	1.07	.64	.49
	Economic	1.43	.82	.53	.42
	Loading	.53	.53	.53	.53
	Fuel Use	.56	.56	.56	.56
Head = 120M	Financial	1.99	1.10	.67	.52
	Economic	1.48	.86	.56	.45
	Loading	.70	.70	.70	.70
	Fuel Use	.69	.69	.69	.69

PRESENT VALUES; PULA per Cubic Meter

Other Government, Lister 8/1

		Output in Cubic Meters/Day			
		5.00	10.00	20.00	30.00
Head = 30M	Financial	1.85	1.05	.67	.54
	Economic	1.55	.92	.61	.51
	Loading	.08	.08	.08	.08
	Fuel Use (l/hr)	.70	.70	.70	.70
Head = 60M	Financial	1.87	1.05	.66	.53
	Economic	1.57	.92	.61	.50
	Loading	.17	.17	.17	.17
	Fuel Use (l/hr)	.70	.70	.70	.70
Head = 90M	Financial	1.93	1.10	.70	.56
	Economic	1.65	.97	.65	.50
	Loading	.25	.25	.25	.25
	Fuel Use (l/hr)	.88	.88	.88	.88
Head = 120M	Financial	1.99	1.14	.73	.59
	Economic	1.70	1.01	.68	.56
	Loading	.34	.34	.34	.34
	Fuel Use (l/hr)	.98	.98	.98	.98

Other Government, Lister ST-1

Head = 30M	Financial	1.68	.93	.55	.43
	Economic	1.37	.78	.49	.39
	Loading	.11	.11	.11	.11
	Fuel Use (l/hr)	.38	.38	.38	.38
Head = 60M	Financial	1.74	.97	.59	.46
	Economic	1.43	.82	.52	.42
	Loading	.23	.23	.23	.23
	Fuel Use (l/hr)	.51	.51	.51	.51
Head = 90M	Financial	1.79	1.00	.61	.48
	Economic	1.48	.85	.55	.44
	Loading	.34	.34	.34	.34
	Fuel Use (l/hr)	.59	.59	.59	.59
Head = 120M	Financial	1.84	1.03	.64	.50
	Economic	1.55	.90	.58	.47
	Loading	.45	.45	.45	.45
	Fuel Use (l/hr)	.71	.71	.71	.71

Other Government, Lister LT-1

Head = 30M	Financial	1.64	.89	.53	.40
	Economic	1.32	.74	.46	.36
	Loading	.18	.18	.18	.18
	Fuel Use (l/hr)	.31	.31	.31	.31
Head = 60M	Financial	1.70	.93	.56	.43
	Economic	1.38	.78	.49	.39
	Loading	.35	.35	.35	.35
	Fuel Use	.44	.44	.44	.44
Head = 90M	Financial	1.75	.97	.59	.46
	Economic	1.44	.82	.52	.42
	Loading	.53	.53	.53	.53
	Fuel Use	.56	.56	.56	.56
Head = 120M	Financial	1.81	1.01	.62	.49
	Economic	1.51	.87	.56	.45
	Loading	.70	.70	.70	.70
	Fuel Use	.69	.69	.69	.69

PRESENT VALUES; PULA per Cubic Meter

Major Village Lister 8/1

		Output in Cubic Meters/Day			
		20.00	30.00	50.00	100.00
Head = 30M	Financial	.48	.36	.26	.20
	Economic	.37	.29	.23	.19
	Loading	.17	.17	.17	.17
	Fuel Use (l/hr)	.70	.70	.70	.70
Head = 60M	Financial	.51	.39	.29	.22
	Economic	.40	.32	.26	.21
	Loading	.34	.34	.34	.34
	Fuel Use (l/hr)	.98	.98	.98	.98
Head = 90M	Financial	.54	.42	.32	.25
	Economic	.44	.35	.32	.24
	Loading	.51	.51	.51	.51
	Fuel Use (l/hr)	1.28	1.28	1.28	1.28
Head = 120M	Financial	.57	.45	.35	.28
	Economic	.47	.39	.32	.27
	Loading	.68	.68	.68	.68
	Fuel Use (l/hr)	1.57	1.57	1.57	1.57

Major Village, Lister ST-1

Head = 30M	Financial	.46	.24	.24	.18
	Economic	.34	.20	.20	.16
	Loading	.23	.23	.23	.23
	Fuel Use (l/hr)	.51	.51	.51	.51
Head = 60M	Financial	.48	.36	.26	.20
	Economic	.37	.29	.23	.18
	Loading	.45	.45	.45	.45
	Fuel Use (l/hr)	.71	.71	.71	.71
Head = 90M	Financial	.50	.38	.29	.22
	Economic	.40	.32	.25	.21
	Loading	.68	.68	.68	.68
	Fuel Use (l/hr)	.94	.94	.94	.94
Head = 120M	Financial	.53	.41	.31	.24
	Economic	.43	.35	.28	.23
	Loading	.91	.91	.91	.91
	Fuel Use (l/hr)	1.19	1.19	1.19	1.19

Major Village, Lister LT-1

Head = 30M	Financial	.45	.33	.23	.17
	Economic	.33	.26	.19	.15
	Loading	.35	.35	.35	.35
	Fuel Use (l/hr)	.44	.44	.44	.44
Head = 60M	Financial	.47	.36	.26	.19
	Economic	.36	.29	.22	.18
	Loading	.70	.70	.70	.70
	Fuel Use	.69	.69	.69	.69
Head = 90M	Financial	Loading Exceeds 100%			
	Economic				
	Loading				
	Fuel Use				
Head = 120M	Financial	Loading Exceeds 100%			
	Economic				
	Loading				
	Fuel Use				

Discounted Pula per M3 of Annual Output

Private Owner, Lister 8/1

		Output in Cubic Meters/Day			
		5.00	10.00	20.00	30.00
Head = 30M	Financial	1.42	.83	.55	.45
	Economic	1.40	.83	.56	.47
	Loading	.08	.08	.08	.08
	Fuel Use (l/hr)	.70	.70	.70	.70
Head = 60M	Financial	1.49	.85	.55	.45
	Economic	1.47	.85	.56	.46
	Loading	.17	.17	.17	.17
	Fuel Use (l/hr)	.70	.70	.70	.70
Head = 90M	Financial	1.61	.93	.61	.45
	Economic	1.60	.94	.63	.52
	Loading	.25	.25	.25	.25
	Fuel Use (l/hr)	.88	.88	.88	.88
Head = 120M	Financial	1.71	.99	.65	.53
	Economic	1.72	1.01	.67	.56
	Loading	.34	.34	.34	.34
	Fuel Use (l/hr)	.98	.98	.98	.98

Private Owner, Lister ST-1

Head = 30M	Financial	1.15	.65	.41	.33
	Economic	1.09	.63	.40	.33
	Loading	.11	.11	.11	.11
	Fuel Use (l/hr)	.38	.38	.38	.38
Head = 60M	Financial	1.26	.72	.45	.37
	Economic	1.22	.70	.46	.37
	Loading	.23	.23	.23	.23
	Fuel Use (l/hr)	.51	.51	.51	.51
Head = 90M	Financial	1.36	.77	.49	.39
	Economic	1.32	.77	.50	.41
	Loading	.34	.34	.34	.34
	Fuel Use (l/hr)	.59	.59	.59	.59
Head = 120M	Financial	1.46	.84	.53	.43
	Economic	1.44	.84	.54	.45
	Loading	.45	.45	.45	.45
	Fuel Use (l/hr)	.71	.71	.71	.71

Private Owner, Lister LT-1

Head = 30M	Financial	.98	.56	.35	.28
	Economic	.91	.53	.34	.28
	Loading	.18	.18	.18	.18
	Fuel Use (l/hr)	.31	.31	.31	.31
Head = 60M	Financial	1.06	.61	.39	.32
	Economic	1.00	.59	.39	.32
	Loading	.35	.35	.35	.35
	Fuel Use	.44	.44	.44	.44
Head = 90M	Financial	1.15	.66	.43	.35
	Economic	1.09	.65	.43	.36
	Loading	.53	.53	.53	.53
	Fuel Use	.56	.56	.56	.56
Head = 120M	Financial	1.23	.72	.47	.39
	Economic	1.18	.71	.47	.40
	Loading	.70	.70	.70	.70
	Fuel Use	.69	.69	.69	.69

APPENDIX O

Diesel Pump Questionnaire

District:_____

Location of borehole:_____

Borehole number: _____

Water level in the borehole: _____ meters.

Name of owner/syndicate/group (indicate which):_____

1. Engine make and model:_____

2. Pump type and size:_____

3. Storage tank size:_____

4. Year of engine purchase:_____

5. How long is the engine operated per year?

   1-3 months ____
   4-6 months ____
   7-9 months ____
   10-12 months ____

6. How many hours does it operate per day?

   1-5 hours _____
   6-10 hours _____
   More than 10 hours _____

7. What is the borehole used for?

   Domestic purposes _____
   Livestock purposes _____
   Domestic and livestock _____
   Vegetable watering _____
   Other (specify) _____

8. Who operates the engine?

   Owner _____
   Employee _____
   Relative _____
   Other (specify) _____

9. Does the engine operator have training in operating and maintaining engines?

Yes_____ No_____

10. If yes, where was the training acquired?

Vocational school _____
Brigade school _____
On-the-job training _____
Other (specify) _____

11. How often is the oil changed in actual fact?

Once a month _____
Once every four months _____
Once every eight months _____
Once a year _____
Other (specify) _____

12. How often is a regular service performed on the engine?

Once a month _____
Once every six months _____
Once a year _____
When the engine needs it _____
Other (specify) _____

13. Who performs the servicing?

Self _____
Engine operator _____
Private contractor _____
Borehole Repair Service _____
Friend or relative _____
Other (specify) _____

14. How far must this person come to do the servicing?

Less than 25 km _____
26 to 50 km _____
51 to 75 km _____
76 to 100 km _____
101 to 150 km _____
More than 150 km _____

15. How many times was the pumping system out of order last year?

_____ times

16. How many of these were engine problems and how many were pump and piping problems?

Engine	_____
Pump and pipes	_____
Other problems	_____

17. How many weeks total was the pump out of order on these occasions?

_____ weeks

18. Who performed the necessary repairs? (mark once for each repair)

Self	_____
Engine operator	_____
Private contractor	_____
Borehole Repair Service	_____
Friend or relative	_____
Other (specify)	_____

19. How much was spent last year on engine servicing and repairs?

_____ Pula

20. How many trips were taken last year to the borehole just because of borehole problems, delivering fuel, or servicing the engine?

None	____
1-3	____
4-5	____
6-7	____
8-10	____
More than 10	____

21. When was the last time the engine had to be overhauled?

____(month)_____(year)

22. How much did this overhaul cost?

_____ pula

23. Who performed this work?

Self	_____
Engine operator	_____
Private contractor	_____
Borehole Repair Service	_____
Friend or relative	_____
Other (specify)	_____

24. When is it expected that a new engine will have to be bought?

Next year	_____
The year after next	_____
Before 5 years	_____
Before 10 years	_____
Before 15 years	_____
Before 20 years	_____