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WIND PUMP FIELD TESTS IN BOTSWANA --

PRELIMINARY TECHNICAL AND COST COMPARISONS

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ACRONYMS

AID	U.S. Agency for International Development
ARD	Associates in Rural Development, Inc.
BHEL	Bobs Harries Engineering, Ltd.
BRET	Botswana Renewable Energy Technology project
BTC	Botswana Technology Centre
CWD	Consulting Services for Wind Energy in Developing Countries
DAS	data acquisition unit
DWA	Department of Water Affairs
GOB	government of Botswana
IFPP	Integrated Farming Pilot Project
ITDG	Intermediate Technology Development Group
IT Power	Intermediate Technology Power Ltd.
Met Services	Department of Meteorological Services
MLGL	Ministry of Local Government and Lands
MMRWA	Ministry of Mineral Resources and Water Affairs
P	pula
RIIC	Rural Industries Innovation Centre
RTI	Research Triangle Institute
SIDA	Swedish International Development Agency
TOOL	Technical Development with Developing Countries
USAID	U.S. Agency for International Development
VITA	Volunteers in Technical Assistance
VSU	variable-speed step-up unit
WTGS	Wind Technology Group Serowe

PREFACE

This report presents the results of a comparative testing and evaluation program of wind-driven water pumps conducted by the Botswana Renewable Energy Technology (BRET) project. Mr. Jonathan Hodgkin is a staff engineer and Mr. Richard W. McGowan, senior engineer for Associates in Rural Development, Inc. (ARD), the contractor implementing the BRET project for the U.S. Agency for International Development (AID) under contract number 633-0209-C-00-1024-00. The comparative testing program was undertaken in coordination with the Government of Botswana's (GOB) Ministry of Mineral Resources and Water Affairs (MMRWA). Substantial contributions to these activities were made by the Department of Water Affairs (DWA), Ministry of Local Government and Lands (MLGL), Botswana Technology Centre (BTC) and Rural Industries Innovation Centre (RIIC).

Planning for the wind pump testing program began in early 1983. Preparation of the testing methodology, finding suitable test sites, obtaining the pumping equipment, and development and procurement of the monitoring instrumentation took until mid-1984. Installation of the pumps and monitoring equipment began in July, 1984, and data collection on pump performance was initiated shortly thereafter. The monitoring periods for the performance of all the pumps discussed in this report have been less than one year. The value of the comparative testing program has been recognized and supported by the GOB, and the program has received a 15-month extension to broaden its data base, both for the existing equipment that is currently being monitored and to include additional systems.

Thus, this report must be considered preliminary. Its conclusions and recommendations will be expanded in a final report prepared upon the conclusion of testing in early 1987. The extension of the program will shed considerable light on and permit refinement of critical assumptions regarding system performance, reliability, energy resource availability and long-term recurrent operation and maintenance costs for all the systems being tested. These assumptions are an integral part of the comparative financial and economic analyses described in this preliminary report.

Thanks are due all those who assisted in the completion of the myriad detailed tasks necessary for successful implementation of such an ambitious program. In particular, thanks go to Mr. Modise Motshoge and Mr. Jack Shields, coworkers who responded so well to often demanding requests, as well as the rest of the BRET technical and support staff, whose help was much appreciated, even if that appreciation was not always apparent. Thanks are also extended to MMRWA and MLGL members, especially Mr. Gunnar Settegren of MLGL and Mr. Boikanyo Mpho and Mr. Arild Granne of

DWA, as well as Council Water Unit technicians, who were unstinting with their time and knowledge. Without these and many other individuals, this work would have been infinitely more difficult.

I. EXECUTIVE SUMMARY

The BRET project's wind pump testing program was part of a larger pump comparison program proposed by ARD and first outlined in AID's midterm evaluation of the project in mid-1983. The overall goal of the program was to test and evaluate the potential of a wide range of water pumping technologies either currently in use or under development in Botswana. Over 40 pumps were tested, including grid-electric (mains), diesel, solar, wind, bio-gas, animal-drawn and hand-operated systems.

In addition to the comparative testing program, the BRET project supported several other important wind energy activities. In response to interest in the potential of Mono-coupled wind pumps, the project supported the efforts of RIIC and the Wind Technology Group Serowe (WTGS) to develop wind pumps that can be manufactured locally. The BRET project funded the first such RIIC wind pump installed and tested at Mogojogojwe, and subsequently purchased three additional machines. The project also purchased the original two production prototypes from WTGS, manufactured by Momoso Engineering.

The other major BRET wind energy activity was the wind resource assessment. Initiated by the BRET project and now funded by the Swedish International Development Agency (SIDA), this study is gathering data from 25 anemometer sites (at the 10-meter level) throughout the country to measure Botswana's wind resource availability. Agromet wind data that are currently available were collected at the two-meter level, but surface effects make it difficult to predict wind speeds at higher levels, where wind rotors are installed. The BRET/SIDA study will be completed in early 1986, and the results will permit a more precise determination of locations where wind speeds are sufficient for the economical operation of wind pumps.

In addition to the wind energy resource, technical performance is the other important variable that defines the limits of the economical use of wind pumps. Pump performance was the focus of the BRET project's comparative testing efforts, as its wind pump work included the installation and monitoring of eight wind pumps and monitoring of three others. Thus, the performance of a total of 11 machines of seven different makes or models was measured over periods ranging from five to nine months, so far. This is the most comprehensive wind pump testing program ever undertaken, anywhere in the world.

To adequately evaluate the pumps' various performance parameters, specialized, battery-operated, self-contained, microprocessor-based monitoring equipment was designed and built to the specifications of the BRET project. The parameters that

were measured and recorded in an integrated (totalized) format included wind speed, a wind distribution histogram, volume of water pumped, the study's elapsed time, time the pump was operating and rod strokes or revolutions. By reading the instrument at different intervals, it was possible to calculate the pump's average performance during that interval. This allowed for both short- (instantaneous) and long-term (daily, weekly or monthly) measurements and analysis.

Monitoring instrumentation was installed on each of the different wind pumps:

- five standard, farm-type pumps--one Climax 10, three Climax 12s and one Southern Cross 14;
- three recently designed, imported wind pumps--two Kijitos from Kenya and a Wind Baron from the United States; and
- three models developed and fabricated in Botswana for use with the Mono pump--two RIIC "Motswedi" and one designed by WTGS.

Pumps were located in the southern and eastern parts of Botswana, in boreholes with resting water levels ranging from 19 to 53 meters and at sites with widely varying wind conditions. All the wind pumps were monitored on a monthly basis with more intensive periods of daily and/or weekly readings on occasion. The results of this data collection characterized the performance of each pump by measuring the amount of water pumped as a function of wind speed for a given head (distance from the resting water level to the ground above).

While the performance of each pump depended on site-specific conditions, such as user interaction, head and wind speed, several general observations can be made. First, the reliability of the Mono-coupled systems was reasonably good for prototype machines, when compared to some of the conventional reciprocating-piston pumps. These designs have not yet attained their apparent performance potential, partially due to the fact that the optimal matching of a windmill (rotor and transmission) to the Mono pump has not yet been fully accomplished.

Second, the imported designs generally performed better than the traditional ones, but the capital equipment costs were significantly higher and the availability of spare parts for these machines may present significant problems. The Wind Baron, which is a more complex, counterbalanced wind pump, has not proven particularly reliable in comparison to the Kijito. In addition to its other problems, the blades fell off on several occasions, once due to a failure of the rotor's inner band, which is currently being redesigned by the manufacturer. It appears

that this machine, which seemed to be more of a prototype than a production model, still needs substantial development before it should realistically be considered for widespread use in Botswana.

Since site conditions, such as borehole yield, pumping head and wind speed, are critical factors in the performance of wind pumps and varied considerably across the test sites, it was not possible to use the measured performance data to make direct comparisons. Hence, the program's comparative evaluation consisted of calculating the expected output of each wind pump for a common head and wind speed, taking an iterative approach that utilized the measured data and a computerized output prediction model. The predicted outputs of the various pumps were then used as the basis for cost comparisons. The financial and economic analyses used annualized life-cycle cost as the principal comparative criterion, summing all capital equipment and recurrent costs for operation, maintenance and repair, discounted to the present and amortized over the number of years for the system's expected lifetime. This value was divided by predicted annual water output to yield a unit cost for the water.

The test results indicate that for average wind speeds of two meters per second or less, insufficient water is pumped to justify the capital expense of any wind pump. At wind speeds above three meters per second, wind pumps are likely to be economical (compared to diesel pumps, which are the de facto standard in Botswana), if the demand for water is around 10 cubic meters per day and the pump is large enough to meet the demand--currently, commercial wind pumps are only available with rotors up to seven meters in diameter. For wind speeds in the interim range (between two and three meters per second), there are other factors besides wind speed that determine whether a wind pump is economical. Furthermore, pumps that have rotors with smaller diameters do not appear to be as cost-effective as larger ones. While the Wind Baron, the largest machine tested in this program, has the potential to be the most cost-effective system, based simply on water output, its lack of reliability negates this advantage.

The testing done to date does not definitively characterize the machines' long-term performance because not even a full year of data has been collected to enable an assessment of pump performance over the full range of seasonal variation in wind speeds. However, the following tentative conclusions can be drawn with some confidence:

- for a number of reasons, which are not always the manufacturer's fault, wind pumps often do not perform as well as expected--this may be due to poor installation or improper windmill adjustment;

- due to the typically low wind regimes and deep water tables commonly found in Botswana, wind pumps will not find wide acceptance in this country--still, there are some sites and/or applications where such pumps will be the least-cost solution, particularly at sites with an annual average wind speed that is close to three meters per second (assuming a certain seasonal uniformity), a pumping head of less than 40 meters and where the demand for water is less than approximately 10 cubic meters a day;

- the most likely use for wind pumps is for watering cattle and wildlife--there may also be some applications in smaller settlements or government boreholes at border posts and other such sites;

- the wind-driven Mono pump systems, designed and built in Botswana, are economically competitive with traditional designs and offer the advantages of local manufacture, maintenance and repair capability, and employment generation over imported models--the performance of these pumps can likely be further improved, making them even more attractive, but in the long run, it does not appear that the restricted indigenous market can support both the RIIC and WTGS machines; and

- due to the proven long lifetimes of traditional wind pumps (when properly maintained) and their lower initial capital cost, these machines will continue to have a large place in the market for the foreseeable future.

The recommendations of the comparative wind pump testing program, based on the work completed thus far, include:

- continuation of the testing program to more clearly assess the performance of wind pumps over the full range of seasonal wind speeds, and allow for a more precise analysis of technical and economic constraints that will define the role of wind pumps in Botswana, particularly in terms of long-term recurrent costs and reliability;

- completion of the wind resource assessment and incorporation of this activity into the ongoing work of the GOB's Department of Meteorological (Met) Services, to permit more exact wind pump output predictions and thus, more clearly delineate areas where wind pumps are most likely to be suitable;

- continued support for the development of Mono-coupled wind pumps--although it appears that the long-term market cannot support both the RIIC and WTGS systems, it is premature to make a decision about which pump will be most suitable, based on the data available;

- a study to compile a list of all government boreholes where the demand for water is less than 10 cubic meters per day and the static water level is less than 40 meters--this would allow easy identification of government sites where the demand is within the economical range for wind pumps; and

- making the most up-to-date information on wind pump output and cost available to potential users so they can make informed choices about equipment options.

II. INTRODUCTION

Water is a critical constraint to development in much of Africa. For the most part, small-scale water supply systems are either gravity-fed or powered by human, animal or diesel energy. In Botswana, as in other developing countries, there has been a substantial effort in recent years to address rural needs for clean, reliable water supplies. The GOB has been particularly successful in providing piped water to nearly all villages with over 400 to 500 inhabitants. This has been accomplished largely as the result of a serious effort by DWA to standardize its pumping equipment and engage in an extensive, country-wide, technicians' training program. However, these achievements have often been made at the expense of the efficiency and/or cost-effectiveness of specific systems. As the needs of even smaller villages are addressed, it will become increasingly important to examine cost-effectiveness, since the unit cost of delivered water rises with decreases in system size. An examination of alternatives to the de facto standard diesel pumping systems has the potential to reduce system costs.

It is within this context that the testing program for wind pumps (as well as other types of systems*) was undertaken by the BRET project. Wind pumps have been delivering water reliably for irrigation, stock watering and human consumption for many years in southern Africa. The purpose of this report is to present the results of preliminary tests undertaken by the BRET project to identify the most cost-effective applications of wind pumping in Botswana.

This report includes a detailed discussion of the performance of each machine tested as well as suggested explanations for instances where measured performance did not meet expectations. Also included is a thorough analysis of the costs associated with the purchase, installation, operation and maintenance, and expected necessary repairs for each system. Although the testing performed to date has significantly increased the data base on wind pump performance, the extension of the testing program will considerably refine the tentative conclusions presented here. The program's extension will include formulation of the final results for the wind energy assessment study discussed below, the completion of testing on most of the wind pumps for which data collection has already begun, and testing of additional systems. The extended testing program will continue to provide valuable information about the use of wind

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*WATER PUMP FIELD TESTS IN BOTSWANA -- PRELIMINARY TECHNICAL AND COST COMPARISONS, Richard McGowan and Jonathan Hodgkin, ARD, Burlington, Vermont, April 15, 1986.

pumps, not only for Botswana, but for other countries considering such systems as well.

A. Overview of Wind Water Pumping Technologies

The first recorded use of wind energy occurred in Persia and China many centuries ago, where it was used to grind grain and for low-lift water pumping. These were the primary uses of wind energy through the eighteenth and early nineteenth centuries. During the middle to late 1800s, continuing interest in wind energy along with increased manufacturing ability led to the development of self-governing mechanisms that could be coupled to deep-well piston pumps. This development process culminated in geared, steel, wind pumps that are known today as standard or multi-blade, farm-type windmills. The best known examples of this kind of machine in southern Africa are the Climax and Southern Cross, which have been used in Botswana for many years. Boer farmers probably brought the first such windmills to the country in the early part of this century. These machines are still in use in the Southern District south of Lobatse and in the Ghanzi District at farms near Ghanzi.

Windmill development came to a near standstill in the early 1900s, as designs had been refined to the greatest extent possible given the analytical and design capabilities of that time. Wind pumps of this type that are currently available are not significantly different than the machine produced 50 years ago. The traditional advantages of these windmills were the lack of fuel required, their long useful life (given proper care) and low maintenance requirements. As the availability of petrol (gasoline) and diesel fuel increased during the middle of this century, the use of wind pumps declined, since fossil fuels were often perceived as more reliable and less expensive.

However, this situation changed about 10 years ago, when the oil embargo and consequent increase in the price of petroleum products made the availability of fossil fuels more problematic and expensive. As a result, a number of individuals and organizations were again interested in the potential of wind pumps, and activity in system design was renewed to take full advantage of the more thorough understanding of physical principles now available. Much of this recent work has concentrated on developing more efficient wind pumps, suitable for fabrication and use in developing countries, which were hit hard by increasing fuel prices. In the late 1970s and early 1980s, wind pump development programs were underway in India, Sri Lanka, Thailand, Colombia, Kenya, Tanzania and also Botswana. Today, concerns about the availability of petroleum products have temporarily subsided and prices appear to be declining due to the disintegration of OPEC. Thus, earlier enthusiasm for wind pumps

is now giving way to a more sober, realistic understanding of their potential role and limitations as water pumping devices.

It is clear that if wind pumps are to be considered a serious water pumping option, they must be economically competitive with the various alternatives, such as diesel and solar PV systems. There is no easy way to determine the most suitable pumping system--it is very country- and even site-specific. Various estimates of the average wind speed required for cost-effective use of wind energy have been suggested, ranging from 2.5 to 3.5 meters per second. Similarly, estimates of the maximum head with which windmills can reasonably be employed have been made, usually from 50 to 75 meters. However, these estimates can only be considered very general guidelines as so many other factors must be considered, particularly water demand profiles and the cost of alternate pumping methods. Since these factors are largely site-specific, as are the wind resource and total head, blanket recommendations regarding the use of wind pumps are impossible.

1. System Configurations and Components

Wind pumps normally consist of three major components--the windmill, pump and piping system, and water storage tank. The windmill itself is comprised of a rotor with as few as six up to as many as 25 blades or vanes that catch the wind. This rotor normally rotates around a horizontal axis that also rotates so that the windmill can turn to face the wind. A gear reduction device (if any is used) is usually found at the top of the windmill tower and is intended to improve the machine's start-up characteristics. In traditional designs, the reduction is typically two or three to one, while in modern designs it may be anywhere from one to one up to five to one. The windmill's other major function is to transform the rotation of the rotor shaft to vertical reciprocating motion or, depending on the design, to generate rotational motion about a vertical axis by using a right-angle drive. The windmill tower supports the rotor and other components up in the free wind stream, normally nine to 16 meters above the ground.

The second major component of a wind pumping system is the pump and piping network. While most systems are designed to pump water using a piston pump, the two indigenous Botswana designs utilize Mono pumps. The rest of the piping system is comprised of the rising main in the borehole and the delivery line to the storage tank, and is part of all pumping systems.

The third system component is the water storage tank. Water is usually temporarily stored before use for several reasons. In on-demand systems, such as diesel pumps, required flow-rates can sometimes exceed the pump's capacity (e.g., for irrigation), the

water must be pumped into a tank for a certain period of time, where it is then immediately available for field application. For RET pumps, particularly those that utilize an energy source with variable availability (such as wind and solar systems), it is usually necessary to make the system oversized so that adequate amounts of water can be pumped and stored for periods when little wind energy is available and no water is delivered. Thus, for a wind pumping system, the size of the storage tank is a function of the frequency and duration of periods of low wind speed. In reality, storage tanks are most often chosen on the basis of those that are locally available for a moderate price. Precise storage requirements are difficult to estimate simply because data describing the renewable energy resource base are not well-defined. While these issues are not directly addressed in this report, a general rule of thumb is that wind pumping systems should include storage for a three- to five-day supply of water. Much work remains to be done on sizing storage systems.

2. Typical Commercially Available Systems

The largest class of commercially available systems are known as standard farm-type windmills, which include the American Dempster and Aermotor, Fiasa from Argentina, Thai Sanit, Australian Southern Cross and Comet, Climax machines from South Africa or Zimbabwe, South African Southern Cross and many others. These machines are all similar in their steel, multi-bladed design, usually with some gearing arrangement lubricated in an oil bath. Although high shipping costs would preclude consideration of some of these systems for use in Botswana, very similar ones are available nearby. In Botswana, the most commonly found wind pumps are those fabricated in the neighboring countries of Zimbabwe and South Africa.

In addition to these traditional designs, a number of newer designs are available in the international marketplace. Probably the best known is the Kijito, fabricated by Bobs Harries Engineering Ltd. (BHEL) of Thika, Kenya. This design was developed over the last five years with the assistance of the Intermediate Technology Development Group (ITDG) and Intermediate Technology (IT) Power Ltd., both of the United Kingdom. Arrangements are being made to license the fabrication of this machine in other countries, possibly including Zimbabwe.

Another new wind pumping system is the Wind Baron, manufactured in the United States. This innovative design incorporates the advantages of counterbalancing into the windmill. A mechanism counterbalances a portion of the mass of the pump rod and water to change the performance characteristics of the wind pump, thereby increasing the water that can be pumped by a windmill of a given diameter. The manufacturers claim that the 21-foot diameter model with 4.5 to one gearing can pump water

from boreholes as deep as 600 meters in winds as low as two meters per second. This machine may also be fabricated in southern Africa in the future.

Of obvious interest in Botswana are two wind pumps that are manufactured locally, the RIIC "Motswedi" and WTGS machine, which both use rotary output to drive Mono pumps. The advantages of these systems include the fact that the Mono pump has already found widespread use and acceptance in Botswana, and the ease with which a back-up diesel system can be attached for periods of low wind speed. Although there are a number of subtle differences between the two designs, the major one is the way power is transferred to the pump. The WTGS design utilizes a clutch mounted directly on the head of the Mono pump, while the "Motswedi" has a variable speed unit (VSU) mounted at the base of the windmill tower that changes the gearing ratio as rotor speed increases. Both systems are designed to allow the windmill to overcome the relatively high starting torque of the Mono pump.

Beyond the wind pumps already mentioned, there are several other categories of systems that are of less importance here. They include several designs developed by such organizations as Consulting Services for Wind Energy in Developing Countries (CWD) and Technical Development with Developing Countries (TOOL). Plans are available for these wind pumps, which could be fabricated in a moderately well-equipped machine shop. Another category encompasses low-cost, sail-wing designs that are of little or no interest to the present study, but may merit consideration for situations which are not generally found in Botswana.

B. Advantages and Disadvantages of Wind Pumps

In general, the principal advantages of wind pumps are the lack of recurrent fuel costs and relatively low expected maintenance, while the primary disadvantages are high capital cost and relatively limited output. The first and most important issue to be addressed in selecting a wind pump is whether it can satisfy the need for water at the site. This is more complex than asking the same thing about a diesel system, since a larger diesel pump can always be purchased or a smaller one operated for more hours each day to meet larger water requirements.

For wind pumps, water output is a direct function of rotor diameter (among other things), and there is a maximum size available, a 25-foot diameter Southern Cross. Given this limitation and the typical wind speeds found in Botswana, it is possible to pump an average of approximately 20 cubic meters a day, year-round, from a 20-meter head. This is a rough maximum that should be revised downward if the head were greater or a pump with a rotor of smaller diameter were used. There are

seasonal differences in wind patterns, which may or may not be advantageous depending on the demand schedule and intended use for the water. Fortunately, these seasonal variations often turn out to be an advantage in Botswana, since periods with higher wind speeds coincide with the latter part of the dry season.

A considerable number of wind pumps have been in operation for 30 years or more. Occasionally, one has even operated for over 50 years. Although such lifetimes are certainly atypical, a windmill should last for 15 to 30 years with any sort of reasonable care. Standard farm-type windmills, such as the Climax, have a record that substantiates this claim. The newer innovative designs have not been on the market long enough to prove their durability, but most have been designed for long life. If sufficient time is allowed for system development and field trials, there is no reason to believe that they will not have the same kind of lifetime as standard windmills.

The maintenance requirements for wind pumps tend to be very low, compared to diesel systems. Because the machines run slowly and have a minimal number of moving parts, there are no major rebuilding or replacement expenses. Still, there are some minimal maintenance requirements. It is necessary to grease the machine or change the oil on an annual basis. The below-ground components require attention in that the piping needs to be replaced periodically (as does the submerged piping on <u>any</u> pumping system), and pump leathers will have to be replaced if the windmill drives a piston pump. Above-ground maintenance is minimal.

The greatest advantage of wind pumps is that they require no fuel to operate, which has several implications. Since there are no fuel costs for system operation, up to several hundred pula (P) per year in recurrent costs can be saved. In addition, because no fuel transportation is required, the costs associated with fuel delivery are saved. The operation of a wind pump is not dependent on the variable world price for fuel or its local availability, which is a significant consideration in a country with no ocean port. Wind pumps operate unattended, so the expense of hiring a full-time operator is saved. If the water is to be used as a village supply, it may be necessary to employ someone to take care of the wind pump, along with the associated storage and reticulation systems, but this person need not be hired on a full-time basis.

In sum, the advantages of wind pumping systems are:

- long system lifetimes with high reliability, given that proper maintenance procedures are followed,
- no need for petrol or diesel fuel,

- very low maintenance requirements,
- unattended operation, and
- potentially low delivered cost of the water.

These advantages can make wind pumps an attractive option, if the constraints noted earlier in this subsection can be adequately addressed.

One major disadvantage of wind pumps is their lack of flexibility if the demand for water changes. Once a wind system is installed, the amount of water output is determined by the wind speeds and pumping head at the site--the pump cannot be operated for a longer period of time to produce more water. Because output is dependent on the wind, which is not altogether predictable, it may be necessary to have larger storage facilities to ensure a steady supply of water when it is needed. Thus, another potential disadvantage of wind pumps is that water may not always be available, since the wind is unpredictable. This may or may not be acceptable, depending on whether an auxiliary system (such as a diesel pump) is available or there is another water source nearby. The costs of additional water storage facilities and characteristics of hybrid (wind/diesel) systems are not covered in this study.

The other major constraint to the use of wind pumping systems is often their high capital cost. This may not be such an important issue in Botswana if a Climax or Southern Cross windmill can meet the water demand at the site or the costs of machines currently being fabricated in the country go down. At an installed cost of about P7,000, the Lister diesel/Mono pump combinations that are commonly used are not significantly less expensive than wind pumps. However, if the water requirement and head are within the range of smaller portable petrol pumps, these may be less expensive than wind pumps. Larger and/or more efficient wind pumps tend to be more expensive, so capital cost becomes more of an issue.

In summary, the disadvantages of wind pumps are:

- limited pumping capacity,
- unpredictability in terms of daily water delivery,
- lack of flexibility to meet increased demand, and
- high capital cost of larger machines.

C. Previous Wind Pump Evaluations

During the early part of this century, when steel windmills were being developed, some testing was undertaken. After a long period during which little work was done, testing programs are now underway in a number of locations. In all cases, these are tests of a specific wind pump or system design, rather than comparisons of several different models. The work accomplished to date is as follows:

- Canada--several designs, including the Wind Baron, have been tested for low-head agricultural applications;
- Cape Verde--testing of the Dempster and a recent design by a Dutch group, CWD;
- Honduras--testing of a single Demptser wind pump;
- India--several recent designs have been or are being tested in several places;
- Kenya--the Kijito has been tested and IT Power has a more comprehensive testing program now underway;
- Morocco--Research Triangle Institute (RTI) is testing several wind pumps of standard design at this time;
- Sri Lanka--CWD has built and tested several new wind pump designs as part of its activities here; and
- Thailand--tests have been performed on a wind pump developed recently by ITDG to be used for irrigation.

These tests have focused largely on engineering research and development in that they sought to determine whether a given machine was performing as expected or if performance could be improved. Such tests have already been performed in Botswana for both the RIIC and the WTGS designs. For the most part, this type of test takes a much shorter time than the comparative testing program undertaken by the BRET project. Although the economic aspects of some wind pumps have been examined by such groups as CWD and IT Power, these studies have not emphasized the measurement of long-term output or recurrent costs for operation and maintenance, and do not specifically reflect conditions found in Botswana.

D. Brief History of the Comparative Testing Program

An AID-funded study in late 1982 examined various renewable energy technologies (RETs) that were part of several donor development projects in seven African countries. A number of water pumping technologies, such as wind and solar photovoltaic (PV) pumps, were included in this evaluation. The results of this study* revealed a number of shortcomings with the sample of systems examined, including:

- long inoperative periods for all the different types of RET pumps due to either a shortage or complete lack of spare parts and adequate technical skills to keep them running;

- insufficient training in proper maintenance and operation was characteristic of many of the projects that included water pumping systems; and

- it was often found that RET pumps were poorly designed, both in terms of matching the various components of individual systems (for example, a windmill and pump) as well as using unproven and sometimes unreliable components.

Partly due to the findings of this report, but also because of a growing interest in these pumping technologies by both the BRET project and MMRWA, in late 1983, BRET began to focus its attention on the cost-effectiveness of various pumping system options. This effort has since become one of the most comprehensive pump testing programs ever undertaken, as it includes an examination of diesel, wind, PV, bio-gas substitution, animal-traction and several configurations of hand-operated pumps. The overall results of the entire comparative pump testing program can be found in a summary report, titled WATER PUMP FIELD TESTS IN BOTSWANA -- PRELIMINARY TECHNICAL AND COST COMPARISONS (Richard McGowan and Jonathan Hodgkin, ARD, Burlington, Vermont, April 15, 1986). The present report specifically covers the details of the wind pump testing portion of the overall program.

Although wind pumps have been in worldwide use for many years, there is remarkably little documentation concerning their field performance and repair histories. Recently, this has begun to change, as new wind pump designs are being developed and tested by such groups as the ITDG, IT Power, Volunteers in

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*TECHNICAL FINDINGS ON THE PERFORMANCE OF RENEWABLE ENERGY TECHNOLOGIES IN AFRICA: RESULTS FROM FIFTY-FIVE PROJECTS IN SEVEN SAMPLE COUNTRIES, John Ashworth and George Burrill, ARD, Burlington, Vermont, April, 1984.

Technical Assistance (VITA) and TOOL. However, the testing of older designs of conventional wind pumps has been largely overlooked. Some testing of Dempster windmills has been conducted in Honduras and Cape Verde, and other testing work is being conducted in Kenya, but broad-based, reliable, field performance data are lacking.

To partially address this lack of data, an ambitious program for testing and evaluating standard wind pumps and newer designs was outlined by BRET engineers. DWA had already decided to use wind pumps under certain conditions in Botswana, such as along cattle trek routes and for some agricultural purposes, and installed 11 Climax and Southern Cross machines in the early 1980s. One of these installations was made in an effort to use a wind pump to augment the village water supply in Serowe (without much success, unfortunately). It soon became clear that a more organized testing effort was necessary to determine the appropriate role for wind pumps in Botswana.

DWA's wind pumps were made available for testing by the BRET project, and in some cases, these machines were moved to more suitable locations, as necessary. The project also made a commitment to support two wind pump research and development programs, one undertaken by RIIC and the other by WTGS. Both the RIIC and WTGS designs were unique in that they coupled windmills with Mono pumps, which require rotary output to drive the pump, rather than the conventional reciprocating motion needed for a standard piston pump. Since the value of the testing program would be increased if several newer (and purportedly more efficient) designs were included in the program, two Kenyan Kijito and two U.S. Wind Baron systems were also purchased. The group of systems tested was further rounded out by including three conventional wind pumps installed by the Ministry of Agriculture at the Integrated Farming Pilot Project (IFPP) area. Thus, the BRET project had a unique opportunity to directly compare a number of wind pump designs.

The logistics associated with equipment procurement, location of suitable boreholes and development of appropriate monitoring instrumentation took considerable time. However, 11 of the 15 sites originally planned have been instrumented and data collected for varying periods of time at all the sites.

E. BRET Assistance to Wind Pump Development in Botswana

As part of the BRET project, assistance was provided to the two organizations in Botswana working on wind pump design and prototype development. In the case of RIIC, this assistance took the form of a substantial grant (P12,000) to produce and test a production prototype machine. This wind pump was then installed at a borehole near Mogojogojwe, southwest of Lobatse, where water

was pumped through a total head of 75 meters to provide a major portion of the water supply for that village. To date, this is also the only site to demonstrate the use of a back-up diesel system for protracted calm periods. As part of this activity, RIIC undertook testing of this machine, and the findings have been written up in a report, titled FINAL REPORT: RIIC WINDMILL TEST (M. Ewans and J. Allen, RIIC, Kanye, Botswana), which is available from RIIC or the BTC in Gaborone. As a result of this initial work, the BRET project agreed to purchase two additional machines as an incentive to further development and refinement of a design that might meet the needs of Botswana consumers. Since that time, RIIC has sold and installed several other machines. One of these systems (at Malau) was subsequently included in the BRET comparative testing program.

The BRET project also provided assistance to WTGS, a group based at the Swaneng Hill School in Serowe. This assistance was not as extensive as that given to RIIC, as it consisted largely of the purchase of two production prototype wind pumps from WTGS' chosen manufacturer, Momoso Engineering, based in Kanye. Some additional support was provided for a consultant who visited at the request of the WTGS group and wished to test one of the machines purchased by the BRET project. This work resulted in a draft of a report, TEST REPORT OF THE WTGS WINDMILL IN BOTSWANA (W. Nijoff, TOOL, Amsterdam, The Netherlands, May, 1985), and the overall conclusion that the WTGS windmill could likely be built at a lower cost, while simultaneously improving performance.

F. Wind Data Collection

There has never been a concerted effort in Botswana to collect wind speed data at the 10-meter level (the height at which many wind pumps operate), largely because the GOB has historically not been interested in such data. As interest in determining the potential for wind pumps grew, the need for this information became more apparent. There are data available from Agromet stations placed at two meters, but the wind speeds recorded at this level are generally not the same as at higher elevations. Thus, the BRET project, in collaboration with Met Services, DWA, BTC, the University of Botswana and RIIC, began to install a network of anemometer stations around the country, beginning in mid-1983. To date, some 20 sites have been instrumented, which are listed in Appendix A.

Most of the sites utilize a PV-powered compilator manufactured by Natural Power Inc. (a device that produces a wind histogram in one-meter-per-second "bins"), although a few have chart recorders or other instruments. SIDA has purchased a computer for data analysis and has also funded the part-time services of a meteorologist to complete the analysis work. While the results of the anemometry study were intended to have been an

integral part of this report, the data analysis has not yet been completed. However, the preliminary data provide some grounding for the analysis that follows.

G. Wind Pumps Tested

In addition to testing the RIIC and WTGS wind pumps already mentioned (see Section II.C), the BRET project undertook an ambitious program to evaluate other wind pumps that were either available in Botswana or could be useful in the conditions found there. The original comparative methodology called for testing 15 wind pumps as part of an overall testing program for more than 30 pumping systems of various types and configurations. Little less than a year remained in the project after the major tasks of site identification and equipment procurement were completed, which was insufficient time to perform all of the anticipated tests. However, substantial testing has been done on 11 wind pumps of various configurations. Detailed site and equipment descriptions for those systems are provided in Appendix B, but briefly, they included:

- Dipotsana--Climax windmill, 12-foot (3.66-meter) diameter;
- Kgoro--Climax, 10-foot (3.05-meter) diameter;
- Malau--RIIC "Motswedi," 6.2-meter diameter;
- Malesane--Southern Cross, 14-foot (4.27-meter) diameter;
- Mochudi--Kijito, 20-foot (6.1-meter) diameter;
- Mochudi--RIIC "Motswedi," 6.2-meter diameter;
- Mochudi--Wind Baron, 21-foot (6.4-meter) diameter;
- Mochudi--WTGS, 6.2-meter diameter;
- Pitsane-Botloko--Kijito, 20-foot (6.1 meter) diameter;
- Sedibeng--Climax, 12-foot (3.66-meter) diameter; and
- Tlhareseleele--Climax, 12-foot (3.66-meter) diameter.

In addition to these sites, it was initially hoped that several other wind pumps could be tested. The following systems are still scheduled for testing (perhaps during the extension of

the pump testing project), but no data have been collected to date:

- Dultkwe--Wind Baron, 21-foot (4.6-meter) diameter;
- Ramatlabama--Climax, 18-foot (5.49-meter);
- Serowe--Southern Cross, 25-foot (7.62-meter) diameter; and
- Shoshong--WTGS, six-meter diameter.

These systems are installed at sites with different heads and pumps (cylinders), but the static heads are typical of sites in eastern Botswana, ranging from 20 to 50 meters.

III. DATA COLLECTION METHODOLOGY

The methodology for the BRET pump testing program was originally described in an earlier report, COMPARATIVE TESTING FOR WATER-PUMPING SYSTEMS INSTALLED IN BOTSWANA (Richard McGowan and John Ashworth, ARD, Burlington, Vermont, July 9, 1984). The procedure presented there was modified somewhat to both reflect additional field experience as well as logistics, instrumentation and personnel limitations. However, the data analysis component of the methodology remained essentially unchanged and conforms to standard procedures accepted by wind researchers throughout the world.

A. Criteria for Comparing Pumping Systems

A number of performance parameters must be measured to compare wind systems of various kinds and sizes. They fall into several broad, yet interrelated, categories:

- technical performance,
- reliability,
- costs, and
- other considerations.

A wind pump's technical performance depends on a number of variables, which can be separated into site- and machine-specific factors. Site-specific factors include the water demand profile (i.e., the amount of water needed at particular times of the day), pumping head and wind regime, while machine-specific variables are the rotor diameter and its torque characteristics, gearing ratio and pump specifications. It is beyond the scope of this study to examine the theoretical interrelationships among these characteristics in detail (for further information, see INTRODUCTION TO WIND ENERGY, E. H. Lysen, CWD, Amersfoort, The Netherlands, August, 1982 and A PERFORMANCE MODEL FOR MULTIBLADE WATER PUMPING WINDMILLS, A. Wyatt and J. Hodgkin, VITA, Arlington, Virginia).

It is important to note that the same wind pump will perform differently at different locations depending on site-specific variables, and certain machine-specific factors can be adjusted to optimize performance at a given site. Also, it should be realized that there are practical, physical limits to wind pump output for a given wind speed--ever larger systems are not available to pump more water from ever deeper boreholes. Thus, to compare wind pumps tested at different sites, it is necessary to consider the <u>optimum</u> potential performance of each system with

respect to head and wind speed. This comparison requires that measured pump performance be adjusted to account for different site conditions, which can be complicated and may produce less accurate results, if adjustment and extrapolation are done over a wide range. Fortunately, this was not the case for the machines tested in the BREW program.

The process used for normalization and extrapolation of the data involved a computer model developed to predict the performance of the various machines tested and compare this performance to the actual measured data (see A PERFORMANCE MODEL FOR MULTIBLADE WATER PUMPING WINDMILLS, A. Wyatt and J. Hodgkin, VITA, Arlington, Virginia). If the correlation was good, it was assumed that for a given restricted range of head and wind speeds, the model's predictions were accurate. If not, the reasons for the discrepancy were sought and the model modified accordingly. The model was applied to data collected during the long- and short-term tests (described in following subsections), and then used to adjust or normalize the predicted output of each machine under specified head and wind speed conditions.

The computer model was not designed to handle the Mono-coupled systems, so data for the reciprocating-piston machines (Kijito, Wind Baron, Southern Cross and Climax) were normalized to simulate performance at the same heads as the RIIC and WTGS Mono-coupled systems. Since the actual output of the RIIC and WTGS machines was known under these conditions, the two different types of pumps could then be directly compared. Once the data from each machine were normalized in this fashion, the primary performance criterion was the amount of water output per day for specific average wind speeds.

Reliability was the second major consideration in comparing pumping systems. For RET pumps, reliability has two meanings--availability of water and dependability of the equipment, in terms of breakdowns due to mechanical failures. For a given site and wind pump, water supply availability is largely a function of wind speeds at the site and the duration of calm periods, which usually occur during months when the wind speed is low. Obviously, when wind speeds are low, water availability will decrease, and larger storage capacity and/or auxiliary (back-up) pumping systems may be required if the demand remains constant. Although this is an important factor, it will not be discussed in depth because there is not yet enough long-term wind speed data available to predict the average duration of calms for most of Botswana. This issue will be addressed in greater detail during the extension phase of the pumping project.

A wind pump's mechanical reliability is a function of the complexity of the particular machine (e.g., standard design versus counterbalanced), use of proper operation and maintenance procedures, and availability of necessary technical skills and

spare parts. For each pump tested by the BRET project, the maintenance requirements were noted and a record of repairs kept. In several instances, maintenance and repair costs appeared to be excessive for reasons that might have been avoided. These will be discussed in some detail, as they point out some of the potential pitfalls of wind pumps. In other cases, repair and maintenance costs may have been excessive because the pumping systems were still in the prototype stage, and presumably, will not be indicative of such costs and problems for production models of similar design.

Costs for development of the necessary support infrastructure to sustain widespread dissemination of wind pumps have not yet been ascertained. For conventional wind pumps, this infrastructure already exists, both in the private and, to some extent, public sectors. For newer machines, determining necessary skill levels and labor rates as well as the ready availability of spare parts certainly have an impact not only on operation and maintenance costs, but also system reliability by extension. Spare parts can be categorized as those that are or can be made in Botswana (with the implication that local individuals possessing the necessary installation and repair skills are also available), those that must be procured in neighboring countries, and those that must be procured outside these geographical limits. Equipment and parts that cannot be procured locally must be shadow-priced to reflect both potential availability problems and foreign exchange costs.

All of this information was used to develop various pumping scenarios and calculate the cost for water output by the various wind pumps. A standard life-cycle costing technique was used, whereby all costs for purchase, installation, operation and maintenance of the wind pump during its useful life were discounted to the present. The total water output of the pump for its lifetime was then calculated based on measured data. A unit water cost, based on annual output and annualized life-cycle costs, was then figured. It should be noted that this technique does not assume any particular value for the water, and the unit cost is the principal criterion for comparing different systems at similar heads.

The cost of pumping water is also a function of both the distance through which it must be lifted (static head), and frictional and velocity losses in the pipes (dynamic head), which combine to yield the total pumping head, simply referred to here as "head." Energy cost are directly proportional to the volume of water lifted times the head (m3*m), which is a measure of the hydraulic energy requirement to perform the work of lifting the water. While this formulation (m3*m or alternatively, m4) is, strictly speaking, an approximation, it is reasonable and convenient as long as all the pumps being compared are working against approximately the same heads and delivering about the

same volume of water. Thus, life-cycle costs were also annualized on the basis of m3*m to permit comparisons of different wind pumps in terms of the useful energy delivered by each system.

The results of the technical and financial/economic analyses yielded a unit cost for pumping water (P/m3*m or if only volumetric units were desired, P/m3). Because long-term recurrent costs cannot be known precisely, the unit costs calculated were not exact. The repair record for each wind pump will be somewhat different, and long-term performance could only be predicted from the limited available data. Thus, it was necessary to perform a sensitivity analysis on each of the assumptions involving recurrent costs, particularly when comparing wind systems to other water pumping options, and this was done in the overall report on the comparative testing program (WATER PUMP FIELD TESTS IN BOTSWANA -- PRELIMINARY TECHNICAL AND COST COMPARISONS, Richard McGowan and Jonathan Hodgkin, ARD, Burlington, Vermont, April 15, 1986).

However, the final selection of a pumping system may depend on factors that could not be readily quantified in this analysis--nontechnical and noneconomic concerns of end users. These factors are dictated by particular situations, preferences and constraints, and are interrelated, both socially and institutionally. This category includes such variables as local availability of required technical skills, whether the pumping system can match the demand profile in terms of scheduling, conflicts between equipment operation and accepted social behavior, the availability of entrepreneurs to provide support to consumers of pumping equipment in the private sector, alternatives for meeting demand during calm periods and a number of similar issues. These concerns need to be addressed in further detail before undertaking any widespread dissemination efforts, and their examination will be part of the extension of the comparative testing program.

B. Data Collection Requirements

The data collection requirements for the comparative pump testing program fell into three categories:

- baseline information on the site and wind pump, including relevant cost information;
- short-term performance data, including a pump curve as well as start-up and furling wind speeds; and
- long-term performance data, including average daily water delivery and wind speed, long-term water delivery, and maintenance and repair records.

The first set of information was compiled from site visits, borehole records, manufacturers' information and equipment suppliers in Botswana. It is presented in Appendices B and C.

Second, short-term performance testing was accomplished through repeated site visits and use of the instrumentation described below. These tests had to be conducted as time and prevailing winds at the site permitted and were not totally completed for all sites by the time this report was written. Partial results for some of the sites are not given here; instead, all of the results will be provided in the final report after data collection is completed.

Third, long-term data collection was performed by local people who were trained to record data from the instrumentation installed at the site on a daily basis. These individuals were instructed to read the instruments every day at the same time and record the values in the site logbook. This procedure was largely satisfactory, and much valuable data have been collected in this fashion.

In addition, BRET staff members made periodic site visits, which were recently fixed at one per month. Up until the last several months of the program, time constraints did not always permit regular visits because of the need to complete the installation of the remaining systems. These periodic site visits permitted reasonable monitoring of breakdowns. In most cases, any necessary repairs were handled directly or supervised by BRET personnel, so a fairly complete repair record is available for this portion of the testing program.

1. Instrumentation for Performance Monitoring

The principal performance monitoring instrument consisted of the microprocessor-based, Modulog, data acquisition unit (DAS). One such battery-operated, self-contained unit was installed at each windmill site. The data recorded by different types of sensors included:

- elapsed time in minutes by the on-board clock,
- pump output in liters on the pulse-output flow meter,
- wind run in kilometers from the frequency-output anemometer,
- pump-rod strokes or revolutions on the reed switch,
- wind pump operating time in minutes from flow-meter pulse monitoring,

- instantaneous wind speed in kilometers per hour by the anemometer, and

- a wind histogram in 16 bins, each two kilometers per hour wide.

This DAS was developed to the BRET project's specifications and has proved durable in field data collection. While it is not fully automated, it is advantageous in that no sophisticated computer programming skills are required to install or operate the device. Although the "C"-size batteries permit uninterrupted operation for several months, a technician must visit the DAS occasionally to collect the data. These site visits allowed the technician to inspect the system and troubleshoot any problems that might have arisen since the last visit. So far, the use of local people hired by the project to record data has been remarkably successful. As a safeguard, some redundancy was built into the system so that data entries could be checked if an incorrect reading was suspected.

The flow meter used for these tests was a Kent series 700 digital output meter, accurate to within two percent. The pressure drop across the meter was minimal at the flow rates that occurred during the tests, except for the Wind Baron. Because of its much higher flow rates, two meters were installed in parallel to reduce the pressure drop to acceptable levels.

Maximus cup anemometers were mounted on independent towers at the hub height of the wind machine. These have been known to give consistently low readings, and some researchers suggest that 0.5 meters per second should be added to the reading displayed to improve their accuracy and obtain a proper reading. The anemometers at some, but not yet all, of the sites have been recalibrated using a reference instrument, and data were adjusted, where necessary. However, no wholesale shifting of the recorded wind speeds by 0.5 meters per second was necessary. At the beginning of the second phase of testing, all of the instruments will be recalibrated to check for variations that might affect the conclusons drawn thus far.

The stroke and revolution counters have been somewhat problematic, usually in terms of suitable mounting arrangements on the pump rod. Since these problems persisted and other activities were deemed more important, efforts to collect this information were temporarily halted, but will be attempted again during the extension of the comparative testing program. Strictly speaking, a measurement of stroke counts is not required for the level of analysis involved in comparative economic evaluation. However, these data would be quite helpful in determining whether certain design characteristics of specific machines (e.g., tip-speed ratio and peak efficiency) are

appropriate for a site, as well as useful to system designers and manufacturers.

Pumping head was measured with a standard ammeter dipper. Initially, the testing plan called for readings to be taken on a weekly basis at least, to determine if there was any seasonal variation in water level. However, at most sites, the pump's full output was not being used, and the overflow was directed back into the well by means of a return line. This has helped minimize any effects of borehole drawdown by keeping the head constant, but it has not been necessary to measure the head as often as planned. Pumping head is now being measured about once a month, depending on the site.

2. Data Collection Procedure

The data acquisition equipment developed for the BRET project required that a person collect the data on a regular basis. The data were then manipulated to determine averages for various parameters since the last set of data were collected. Thus, daily averages required daily data readings. As a result, data were collected in two primary ways:

- short-term data were gathered by BRET technical staff members; and
- long-term data were collected both by BRET personnel and local individuals.

Short-term tests were performed by BRET staff members during site visits. The purpose was to develop curves for water output as a function of wind speed, and determine the cut-in and cutout wind speeds for the various pumps. The pump curves were based on average 10-minute samples of wind speed and water output. Ideally, a complete pump curve would be based on a statistically significant number of data points along the entire range of typical wind speeds encountered at the site. However, the wind does not necessarily cooperate by covering the entire range on the day chosen for data collection. Hence, the process of collecting data for the entire range became very time-consuming, and complete pump curves have not been generated. In those cases where output data were recorded for the full wind spectrum, there is as yet not enough data to provide statistical confidence in the results. Thus, the results of these tests will be more fully discussed in the final report.

For the long-term testing conducted so far, the BRET project has been successful in identifying a local individual at each site to collect data on a daily basis for varying periods of time. In every case, the data collector was engaged for one month, which has resulted in a month of daily averaged values.

Unfortunately, in several cases, some mechanical problem developed with the wind pump or it was inadvertently turned off for some part of the test period. During site visits, BRET technicians collected not only the Modulog data, but also information about site conditions and any repairs that may have been necessary. Together with the other data that have been gathered, this information provides a good picture of the performance of each machine. Details on system performance are given in the next section.

Under ideal conditions, the results of the tests described here would be more complete. Instruments would have been recalibrated on a regular basis, and there would have been time to determine the exact reasons for the performance of each of the systems tested. In addition, it would have been possible to collect all the short-term data necessary for a thorough understanding of the performance characteristics of each type of wind pump. Given the real difficulties of extensive field-testing programs, with inherent staff and resource limitations, and more importantly, limited time, not all of the ambitious list of objectives for the comparative pump testing program have yet been attained. Nonetheless, the data base is the largest ever assembled on the field performance of wind pumps.

IV. TECHNICAL PERFORMANCE RESULTS

This section provides a history of the BRET wind pump tests by site. Although data for an entire year were not available when this report was prepared, measured wind speeds from the test sites were correlated with existing meteorological data from the nearest Met Services weather stations to estimate wind speeds for the months not yet measured. Thus, the results presented here are based partially on performance projections. Ongoing data collection will fill in gaps in the information as the comparative testing program continues.

Strictly speaking, the performance of different wind pumps cannot be compared directly, since the site-specific factors of pumping head and wind speed have a considerable effect on performance. The ideal way to perform direct comparisons is to test different pumps at the same site under the same conditions of head and wind speed, but this is not practical under actual field-testing conditions. An alternative approach to direct comparison utilizes a computer simulation model to normalize pump performance for a common head and wind regime. This technique is discussed in Section VI.

A. Site Histories

The results of the BRET comparative testing program are presented here by site, and include a brief site description, test history, repair record and discussion of the results. First, the standard farm-type wind pumps (Climax and Southern Cross) are covered; then, the new imported designs (Kijito and Wind Baron); and finally, the indigenous systems (RIIC and WTGS). Not all of the anemometers have yet been calibrated, nor have detailed examinations been completed of systems with performance results that were lower than expected. Although some of these wind pumps were not operational for the entire testing period, this was not necessarily due to an inability to repair the machines or a lack of spare parts, but rather to limited staff resources and the ambitious nature of the project, which involved testing not only wind systems, but also solar, diesel, electric and hand pumps.

1. Standard Farm-Type Wind Pumps

Climax

Dipotsana

This Climax 12 wind pump, with three-inch cylinder and 30-meter head, was located at the IFPP area southeast of Kanye. IFPP personnel were responsible for repair and maintenance. The site is exposed on all sides, and the windmill was in the free wind, well up and away from any obstructions. Although some of the water was used by a small settlement nearby for drinking, its main use was for watering livestock.

This site was instrumented in November, 1984, and testing began late that month. About 10 days of data were collected before the wooden section of the pump rod broke. It was not repaired for several months as the rainy season started and there was sufficient water in nearby catchments for stock watering. By late April, 1985, the windmill had been repaired, and testing was undertaken in May. The pump rod has subsequently broken again.

The operational problems at this site were directly related to the National pump-head hand pump attachment fitted to the system so that water could be pumped by hand during calm periods. If the hand pump was at any other position than bottom, dead center while the windmill was in operation, the wooden section of the pump rod and rod guides would break. It appears that the hand pump option was not used very often, and the wind pump would be much more reliable if the National pump head were removed. Although this prevented the wind pump from operating for a significant portion of the test period, this was the only problem encountered and can be easily rectified.

The results of the testing done to date are shown in Figure 1 on the following page. These data represent the total amount of water pumped per day plotted against the daily average wind speed. They are an agglomeration of the limited data collected during the earlier test period and in May. During testing, someone occasionally turned the machine off after the tank had filled, which accounts for several points that fall below the rest of the curve. The performance of this wind pump falls within anticipated ranges, except for very low wind speeds, where output exceeds expectations. This may be a function of the difficulty of accurately measuring wind speed distribution in this low range.

Figure 1

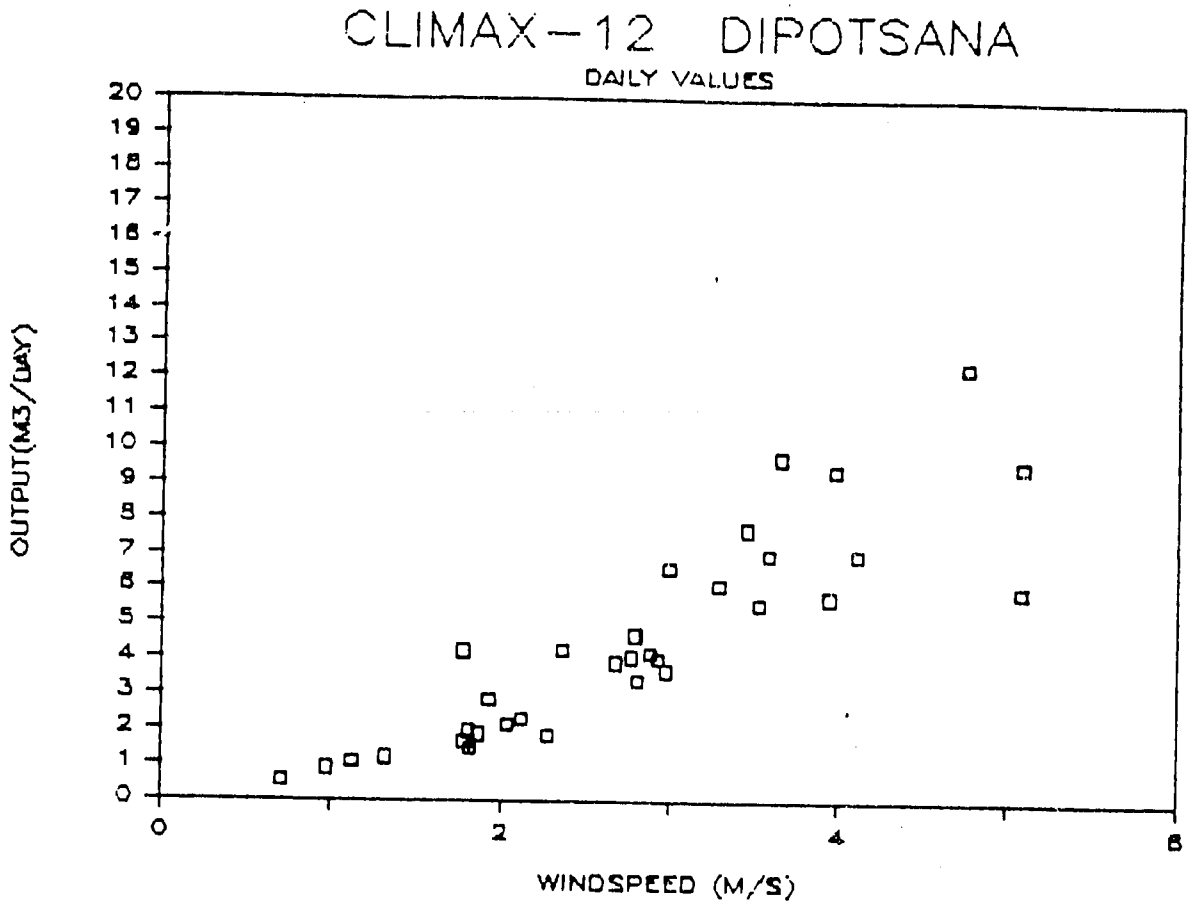
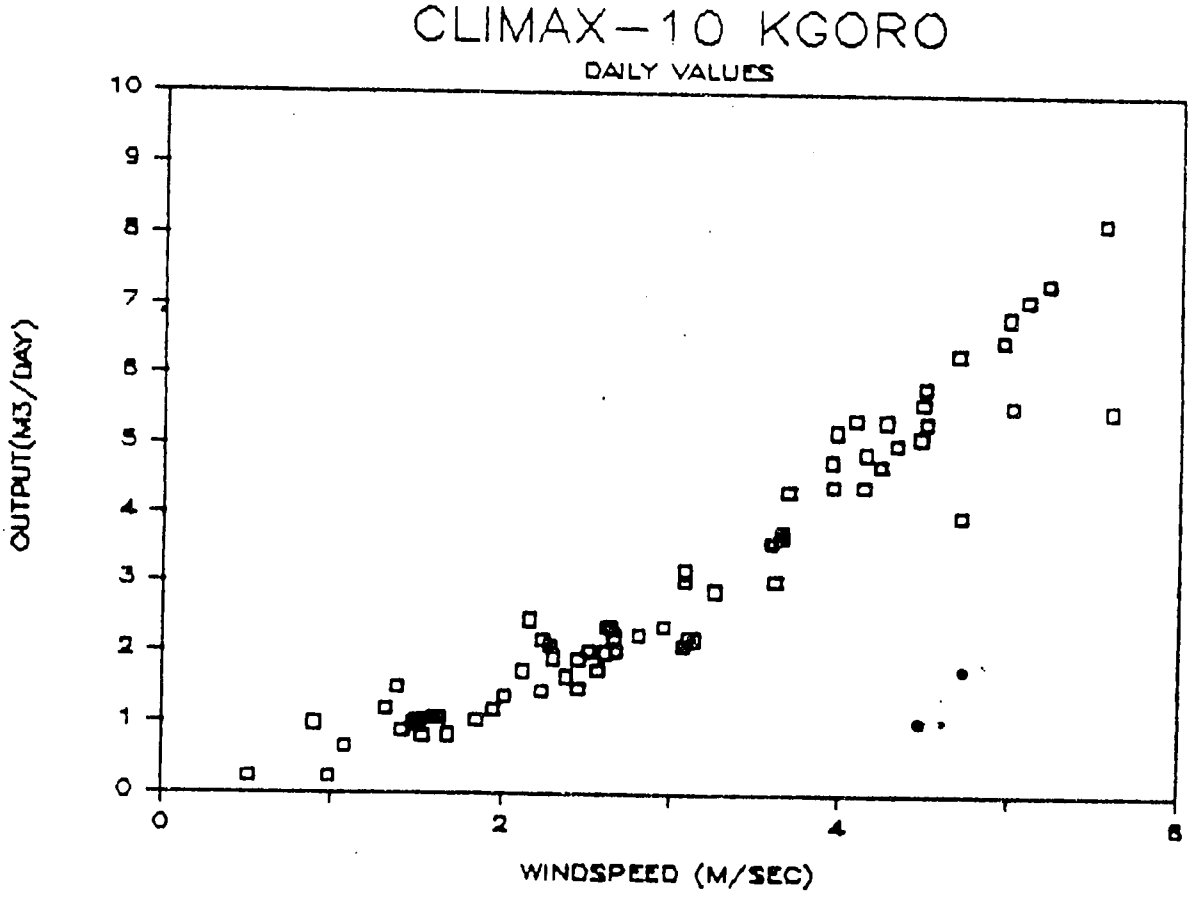


Figure 2



Kgoro

A Climax 10 wind pump, with 2.75-inch cylinder and 35-meter head, was installed as part of DWA's activities in mid-1984. This pump had been installed elsewhere and was moved to the site to replace a hand pump. The wind pump was located near the village of Kgoro, and the water is used for both cattle and human consumption. The pump was installed in a borehole with no records for yield or drawdown, and there is a large, brick storage tank at ground level near it. The site is well exposed on all sides, except for one tree very near the windmill. Although the tree did not appear to be in the path of the prevailing wind, it may well have an adverse effect on the long-term system performance. There have been no problems of any kind at this site--this wind pump has been fully operational since its installation.

Two successful test periods were conducted at this site during February and May, 1985, and the results are summarized in Figure 2 on the preceding page. This machine's performance is far below expectations at higher wind speeds and better than anticipated at the low end of the curve for reasons that are unclear. No short-term tests have yet been done at this site, which would likely pinpoint the explanation for this anomalous finding. The presence of a tree in close proximity to the windmill may have more of a deleterious effect on output than originally supposed. However, there are other potential explanations, including the possibility that the wind pump furls at a lower wind speed than it should, the cup leathers need replacing or the borehole (selected from a number of alternatives which were less than ideal) does not have sufficient yield (it was unrecorded). Often when the latter is the case, the drilling crew estimates the yield at less than one cubic meter per hour, which is not worth the time required to pump test the borehole properly. A more thorough study of site conditions will be undertaken in the future.

Sedibeng

This Climax 12, with a 2.7-inch cylinder and 27-meter head, was the first relocated DWA wind pump to be installed, during a visit by an earlier wind pump consultant in March, 1983. At this time, there was no central reticulation (distribution) system in Sedibeng, so the water was pumped to a nearby galvanized storage tank, primarily to supply drinking water for the village. However, villagers also used the water for their goats and cattle, although they were asked not to do so to avoid pollution of the borehole. The borehole at this site was not strong, with a yield of only 1.6 cubic meters per hour and a tested drawdown to 80 meters. This was one of the boreholes provided through DWA

and was not ideal for testing, except that the site is well exposed on all sides.

The repair record for this site has been very good. There were some difficulties with the round, galvanized-steel storage tank, which leaked quite badly. For some time, there have been plans to replace it with one of sturdier design, but no action has occurred to date. Goats and cattle hang around the wind pump and have caused damage to both the fencing and recording instruments. The villagers seemed to make no effective efforts to keep the animals away from the borehole. In May, 1985, the cup leathers in the cylinder were replaced and were in good condition after two years of use. No other operational problems have been reported at this site.

Testing of this wind pump did not begin until the data recording instrumentation was installed in late January, 1985. A full month of daily data was collected in February and is shown in Figure 3. This machine's performance has been somewhat disappointing, particularly at higher wind speeds. Even though this borehole's yield was fairly low, there is a return line to the well from the top of the tank, so that low yield or inordinate drawdown are not likely to be critical constraints. Determining the cause for the low output of this system is one task of the follow-on pump testing study.

Tlhareseleele

This Climax 12 wind pump, with 3.5-inch cylinder and 19-meter head, was also relocated by DWA. A Swedish Petro hand pump was used at this borehole until the well was needed for the wind pump testing program. This borehole is near Tlhareseleele, and the hand pump was used to provide supplementary water for village needs. Since then, the village's reticulation system has been completed, and the wind pump's output is being used mostly to water cattle. The site is well exposed and appears to be ideal for a wind pump. Unfortunately, the borehole does not have a DWA number, so no yield or drawdown information was available. As has been mentioned, identifying suitable test boreholes was difficult, and some sites that were less than ideal were eventually chosen because there were no other choices. Proper borehole cleaning and testing was performed, and the results indicated a yield of only one cubic meter per hour.

The wind pump here was operational for only a limited time during the test period. The problems at this site have not stemmed from any defect with the machine, but are strictly related to the water's high sand and grit content. On several occasions, the flow meter became clogged, and once, the foot valve stuck in the open position. Recently, in hope of helping alleviate the problem, the well was again cleaned and tested, and

Figure 3

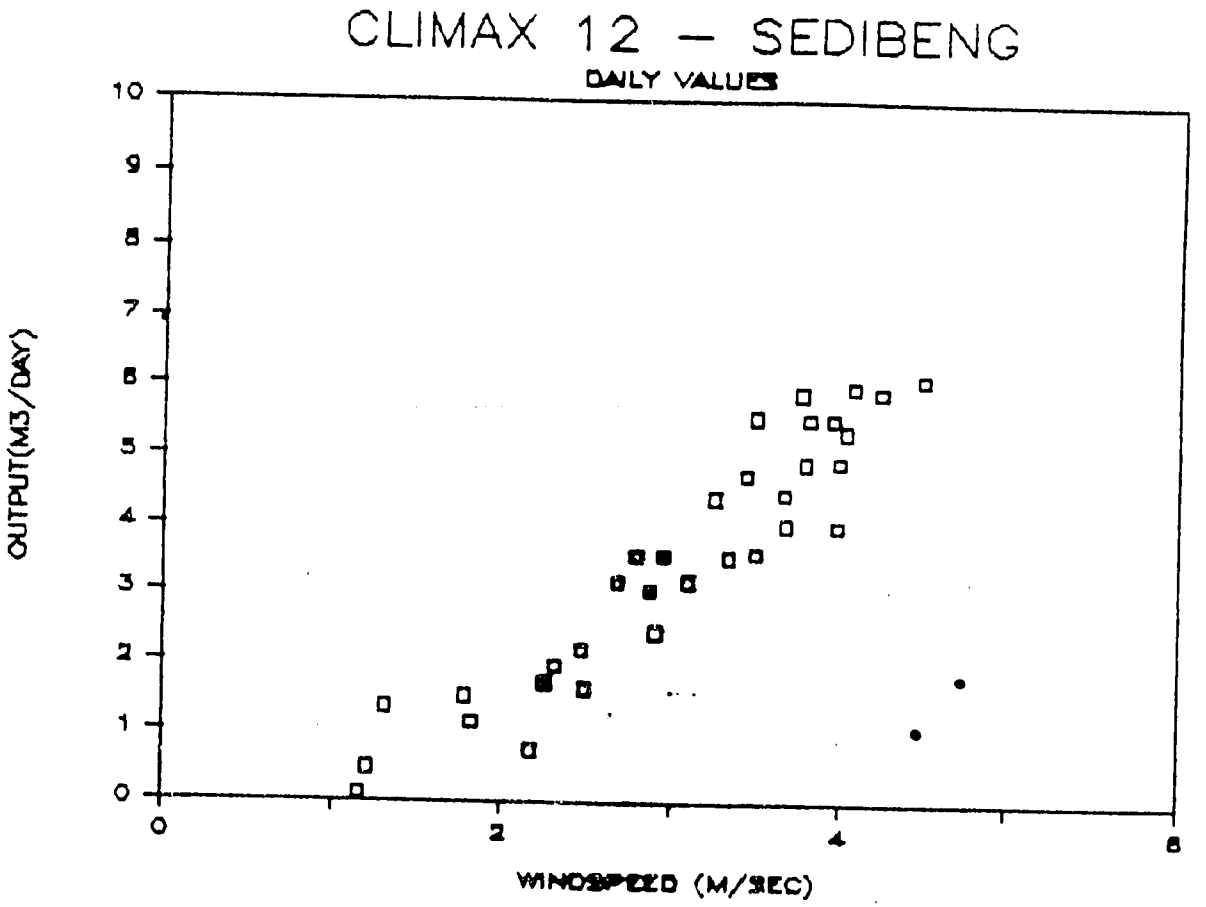
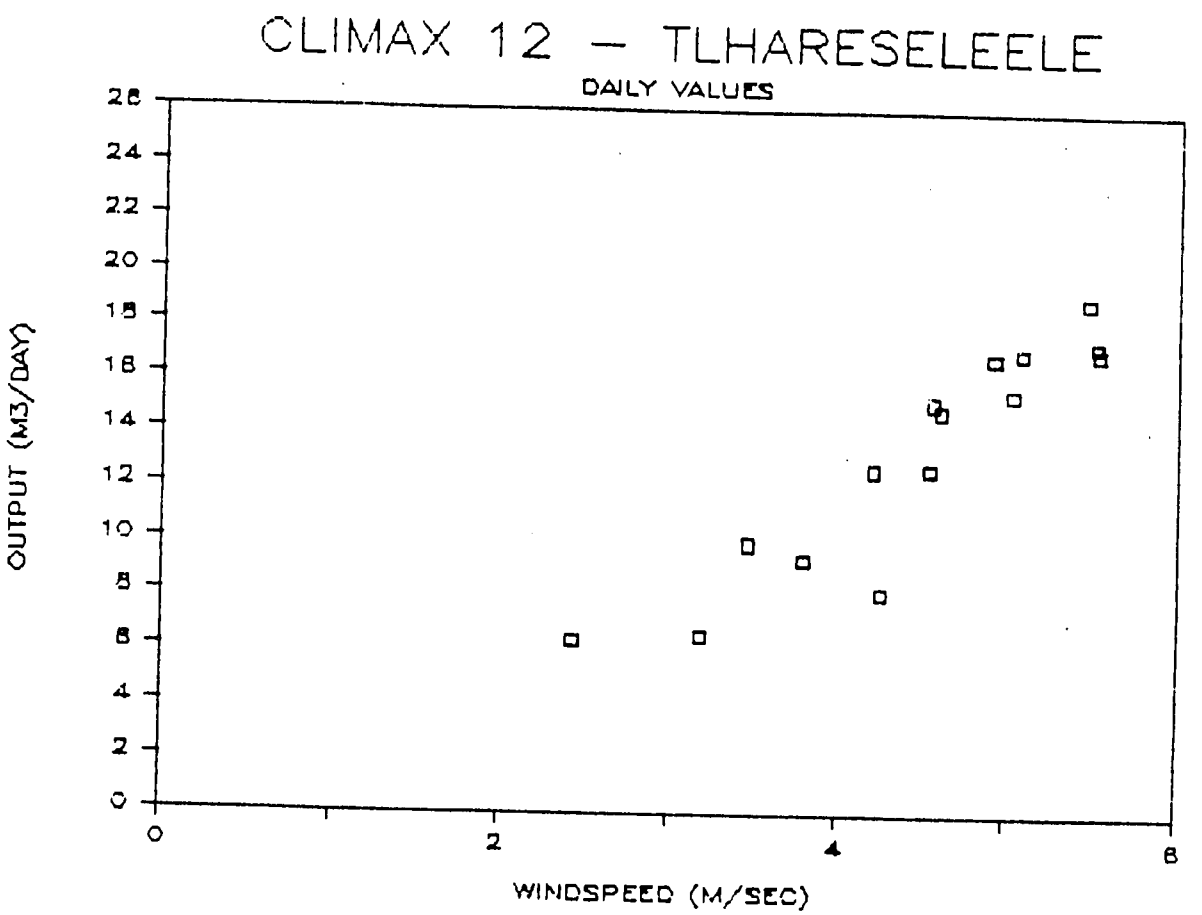


Figure 4



the wind pump reinstalled. Problems with sand and grit are often cited as fairly widespread in Botswana and are at least part of the reason for the use of Mono pumps on many boreholes.

Some testing of this pump was completed before any of these difficulties arose. At the end of January, 1985, a successful test of several weeks was conducted, and the results are presented in Figure 4. Unfortunately, the wind pump stopped functioning at this time because of sand in the water meter. The pump was reinstalled after a complete cleaning and test pumping of the borehole, and is currently operational.

Southern Cross

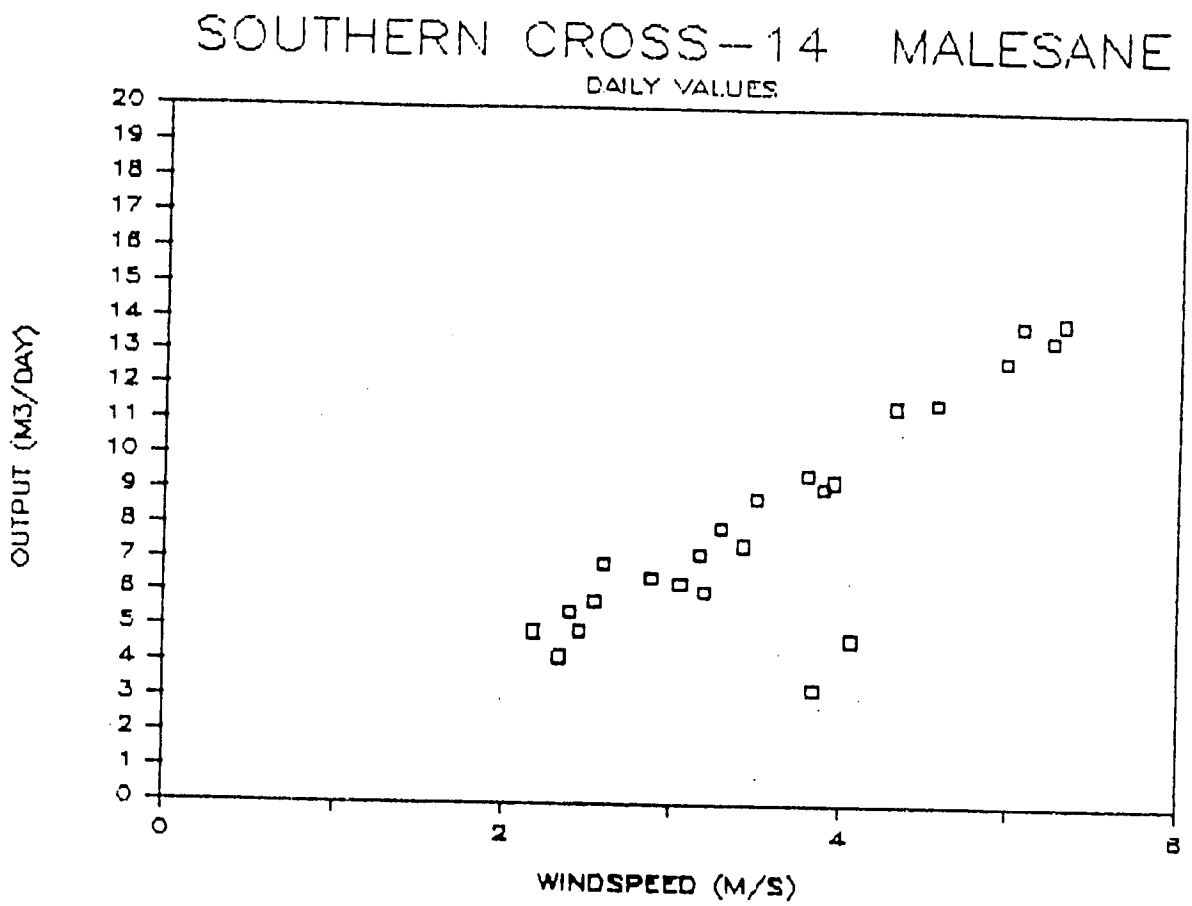
Malesane

This Southern Cross 14 wind pump, with a three-inch cylinder and 35-meter head, was the second tested at the IFPP area. The water was used primarily for cattle during the dry season and human consumption for most of the year. As at Dipotsana, this pump was broken for a major part of the last year, because other sources of water were available for watering livestock during the summer months. Also similar to Dipotsana, the water was pumped to a large reservoir at ground level. The pump site was located in a small depression with a slight rise to the east. Prevailing winds were from the west, and since the windmill was installed on a tall (12-meter) tower, it was one of the better sites in the comparative testing program.

At Malesane, it appeared that the major reason for breakdowns was the fact that the wind pump was not centered directly over the borehole, and this misalignment caused the wooden section of the pump rod to break. This happened three times during the past 10 months. In addition, an adjustment to the National pump head installed at this site might well have alleviated at least some of these problems. These corrections were made recently, and the wind pump has operated satisfactorily for the past several months. These types of difficulties can easily be avoided and are directly related to proper installation of the machine. This points out the necessity for careful installation by a trained crew to ensure that such annoying (and costly) problems do not occur.

Fortunately, the wind pump operated properly for the full testing period in November and December, 1984. The results are shown in Figure 5. The anemometer at this site was found to be somewhat inaccurate, and an adjustment was made to reflect the results of a calibration test conducted in May, 1985. In the figure, the several points that do not lie along the curve are for days when the wind pump was turned off by users. The

Figure 5


SOUTHERN CROSS-14 MALESANE
DAILY VALUES
OUTPUT (M3/DAY)
WINDSPEED (M/S)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
0
2
4
6

analysis of results for this site indicates that the wind system was performing quite well--as a matter of fact, well enough to suspect that there were problems with the tests.

2. New Imported Designs

The Climax and Southern Cross systems represent wind pumping options as of several years ago. They are readily available in Botswana, relatively inexpensive compared to other wind systems, and proven designs with records that enable the manufacturers to claim 20-year lifetimes. However, there are now new designs in the marketplace, and two types of these imported machines were tested as a part of the BRET comparative pump testing project--Kijito and Wind Baron.

Kijito

These wind pumps, imported from Kenya, were designed by ITDG and IT Power of the United Kingdom for fabrication and use in developing countries. The first collaborator in a developing country was BHEL of Kenya. The BRET project purchased two 20-foot-diameter wind pumps from BHEL in March, 1984. They were shipped sea freight from Mombasa, Kenya, and finally arrived via Durban and Johannesburg in late November. It should be noted that the lengthy delay in receiving these machines was not BHEL's fault, but was due to delays with South African shippers. Subsequently, some spare parts were needed and shipped from Kenya by air freight--they finally reached Botswana almost three months later. This delay was also due to problems with the shipper in South Africa. These two wind pumps were finally installed in early 1985.

A couple of inconveniences were experienced during installation of these systems, which are somewhat different. The first was that no borehole template was sent. This made locating the tower foundations cumbersome, as the whole tower had to be assembled and raised into place to be certain that it would be centered and square. The other problem was that the towers supplied by BHEL did not go together well, and some minor distortion was necessary to get all the parts to fit together. Besides these difficulties, there were no other problems with system installation. The instruction manual was very complete and included sufficient drawings to answer any questions that arose from the text. This was greatly appreciated as good-quality manuals are not the norm.

The installation took 10 days of fieldwork, including installation of a separate anemometer at the hub height of the rotor. The installation team consisted of a crew leader and seven other workers whose mechanical skills ranged from excellent

to poor. Undoubtedly, the installation process could be speeded up with practice. A brief history of the two sites follows along with a discussion of the performance of these wind pumps.

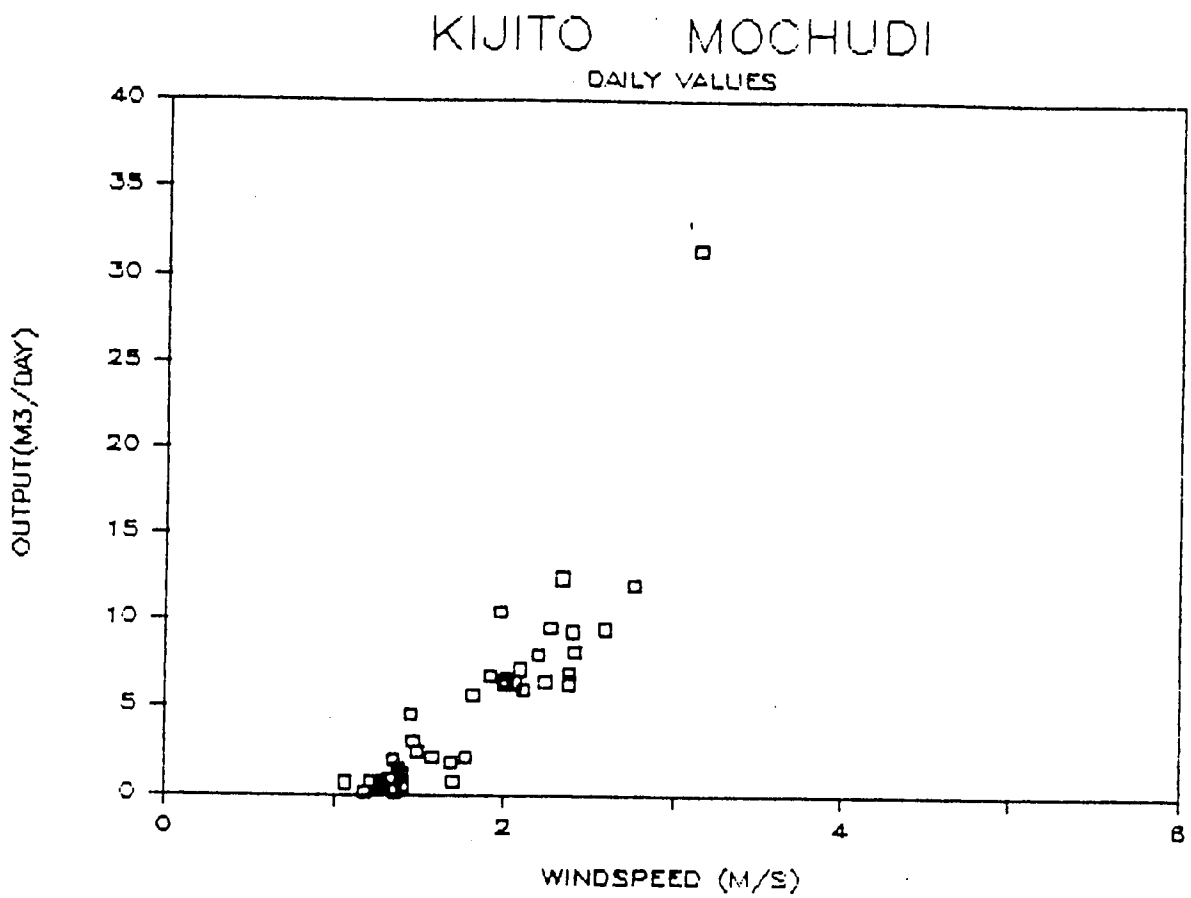
Mochudi

A number of boreholes east of Mochudi had been drilled by Geological Survey crews for test purposes, but were not in use. The BRET project located these sites and obtained permission to use them as part of the comparative pump testing program. As there was some difficulty in locating suitable boreholes, finding these was a great help, particularly because they are in close proximity to Gaborone. A Kijito wind pump was installed at one of these sites, with a 3.25-inch cylinder and 35-meter head, in February, 1985. It was intended that the water pumped by this machine would be used by a gardening group to be organized by the District Agricultural Officer, but this has not occurred. The site is reasonable, although there are some low trees and shrubs around the windmill that may impede the free flow of air somewhat, particularly since the machine is only mounted on BHEL's nine-meter "export" tower. A larger tower might improve the performance of this system to some degree.

To date, there have been no problems with the wind pump at this site except that the shock absorber used as a furling damper had to be replaced at a cost of P40. It had somehow worked loose and the threads became worn, so it could not be tightened properly. This machine runs smoothly and is a favorite because it is very aesthetically appealing.

Data collection began immediately after the pump was installed, but was done only on a weekly basis. In May, 1985, data were collected on a daily basis for one month, and the results from this period are given in Figure 6. It is unfortunate that the test period occurred during the calmest season at this site, which has relatively low wind speeds. However, the results certainly provide a good indication of performance for the important low end of the curve--the Kijito wind pump performed quite well. It appears that the highest point shown indicates an abnormally high output for the wind speed and is almost certainly either an error or a function of an unusual wind distribution that day. It also seemed that the cylinder chosen for this site and wind regime could have been slightly smaller to try to improve output at lower wind speeds A smaller cylinder would have allowed the machine to start up a lower wind speed, thereby producing more water on days wit' average wind speeds. However, the smaller cylinder would provide as much water on days with high wind speeds.

Figure 6


KIJITO MOCHUDI
DAILY VALUES
OUTPUT(M3/DAY)
40
35
30
25
20
15
10
5
0
0
2
4
6
WINDSPEED (M/S)

Pitsane-Botloko

This was the first Kijito installed, in a 3.25-inch cylinder with 23 meters of head. The borehole is very old and is not mentioned in borehole records. A hand-dug well, about 20 meters deep, is located about five meters from the borehole. It has a winch and is used to water cattle. The borehole was once equipped with a Southern Cross windmill, and pieces of that machine are still lying about. The site is exposed, and the low trees and shrubs nearby do not significantly impede the wind.

This wind pump installation was completed in late January, 1985, with no major difficulties other than those generally associated with setting up a Kijito. The only problem was that the wheel was not aligned quite properly, which subsequently caused a much greater problem. Shortly after the installation was completed, a BRET staff member along with a repair crew returned to the site to straighten the wheel. In the process, the "gin" pole, which is used to support the machine while it is being lifted into position, broke in such a way that the tower and machine lurched toward the ground. Fortunately, the machine was caught before it reached the ground, so only the bottom sections of the tower legs were damaged. The wind pump was then dismantled until the tower legs could be replaced. These were the parts in the delayed airfreight shipment already described. It was not until June that the wind pump was finally repaired.

The Modulog instrumentation and anemometer at hub height were installed at the same time as the machine, and data collection began immediately. The results of this testing were limited and complicated by the likelihood that the anemometer was not calibrated properly and some of the water being pumped was lost from the top of the standpipe. For these reasons, the data are not considered representative and are not included in this report. These problems are being rectified, and further tests on this pump will be conducted during the program's extension.

Wind Baron

This wind pump design, imported from the United States, represents the first integrated, counterbalanced machine and as such, has considerable potential for Botswana's fairly low wind regimes and moderate to deep boreholes. It was believed that these pumps could play a role in village water supply schemes by providing larger quantities of water than conventional designs. Consequently, two were ordered from the United States in early 1984 and received in midyear, and installation began at the first site (Mochudi) in September. Although two BRET technicians had attended a training course on the installation, operation and maintenance of these machines at the Wind Baron facility in Arizona, there were numerous installation problems. Some of these problems seemed to stem from factory mistakes and others from design oversights (particularly for an exported machine).

The BRET project was led to believe that it was to receive a production windmill, but this did not appear to be the case. Some parts were missing, others were mis-numbered, and still others did not fit together properly. In addition, the accompanying instructions were inadequate for an assembly this complicated. For example, no clear instructions were included for slinging the machine to place it on the tower using a crane. As a result, the head of the windmill was unbalanced when it was picked up, which made it considerably more difficult to place it on the tower.

There were several design defects as well. First, having to raise the machine into place with a crane is a major problem and inconvenience. Cranes are not readily available in rural Botswana, and the cost of renting one for installation is a major expense. (As this report was being finalized, the second Wind Baron machine had just been installed by a BRET/DWA crew using a gin pole. Wind Baron was quite surprised to hear that this was possible.)

Second, the fact that all the threaded parts are in U.S. standard thread is also a problem, as replacement nuts and bolts are simply unavailable. This problem becomes more significant when a pump cylinder is purchased locally because the coupling, between either the Wind Baron pump rod and the cylinder or the swivel assembly and a pump rod procured locally, requires that a thread adapter be fabricated at a cost of P50. While this may seem a small point, anyone who has had to deal with these problems can attest that it most assuredly is not.

The third major design oversight is the lack of a brake for the mill wheel. The windmill can be furled easily enough, but cannot be completely stopped for maintenance or repair, except by climbing the tower and tying off the blades. This task is certainly unpleasant and potentially dangerous when any breeze is blowing.

Two Wind Baron Mark IV 150 machines were to be installed as part of the BRET comparative pump testing program. To date, only one has been installed for two reasons. First, an adequate test site for the second system could not be found. Since this wind pump was advertised as suitable for boreholes up to 200 meters deep, a decision was made to seek two boreholes for testing, one in the shallower range (less than 50 meters) and a deeper one, over 50 meters. A shallower site was located, but no borehole with a resting water level in excess of 50 meters could be found for the testing program--such boreholes exist, but none were available for use.

The second reason that only one of the Wind Baron systems has been installed was more practical and immediate. Almost from the beginning, parts had to be taken from the second machine to

replace broken parts on the first. Details about the problems that required this action are given below.

The only Wind Baron system installed to date by the BRET project (and the first ever in Africa) is located near Mochudi. Recently, a second site was identified near Dutlwe in western Kweneng District. It is hoped that the second Wind Baron machine can be installed here and tested in the future.

Mochudi

This 21-foot Wind Baron system, with a 3.75-inch cylinder and 33-meter head, was installed in September, 1984. The process took between three weeks and a month, as not all the parts were shipped and replacements had to be taken from the second machine. In addition, the instructions for tower assembly were not sent with the equipment, so this procedure had to be figured out during installation in the field. As already mentioned, some parts were mis-numbered, which caused some initial confusion during system assembly. A crane was rented for final placement of the mill head, but after being lifted, it slipped off center, which made this task much more difficult. Finally, the holes on top of the tower did not line up properly with those in the stub tower, so they had to be redrilled. However, once all these problems were overcome and the pump was in place, the system pumped more than 10 cubic meters of water the first day in a moderate wind while the windmill was still furled.

All the instruments were installed in early November, and monitoring began. No worthwhile data could be collected initially, as the flow rates and friction losses were too high for the water meter. This problem was solved in early December by simply installing two meters in parallel. In the interim, the windmill was furled, although it continued to pump water at the rate of several cubic meters per day. Three days after it was released, the upper bridle assembly broke and the windmill was again furled. It could not be fixed until after Christmas, when installation of the Kijito at Pitsane-Botloko was completed. When the repair work was finally done in early February, 1985, the inner blade ring and several blade supports were found broken just 11 days later. These were fixed after the installation of the other Kijito in mid-March. During this process, the furling cable broke, and two weeks later, when a repair crew went to replace it, they found another blade broken and lying on the ground. At this point, the inner blade ring broke again, and blade bolts were found on the ground. All the blade bolts, the inner blade support ring and another blade were replaced in mid-April.

May was slated as the month for more intensive data collection, and fortunately, the machine did not break during

this time. Late in the month, the pump stopped operating when debris clogged the check valve. However, this was repaired quite promptly and data collection resumed.

The BRET project's experience with this machine has not been satisfactory. When it operates, the Wind Baron does pump a lot of water, but far too much time and energy are required to keep it running. There is little doubt that this machine is not much more than a prototype and a significant effort will be needed to make it reliable. Several other points should be mentioned about its probable long-term reliability, including the alignment of both the lower counterbalance arm and the pump rod in its support tube. Neither of these components are properly aligned, nor do they have any adjustments so that this can be done properly. The latter has already caused excessive wear on several other parts, and although these problems are not likely to cause a catastrophic failure, both will cause more significant difficulties in the future.

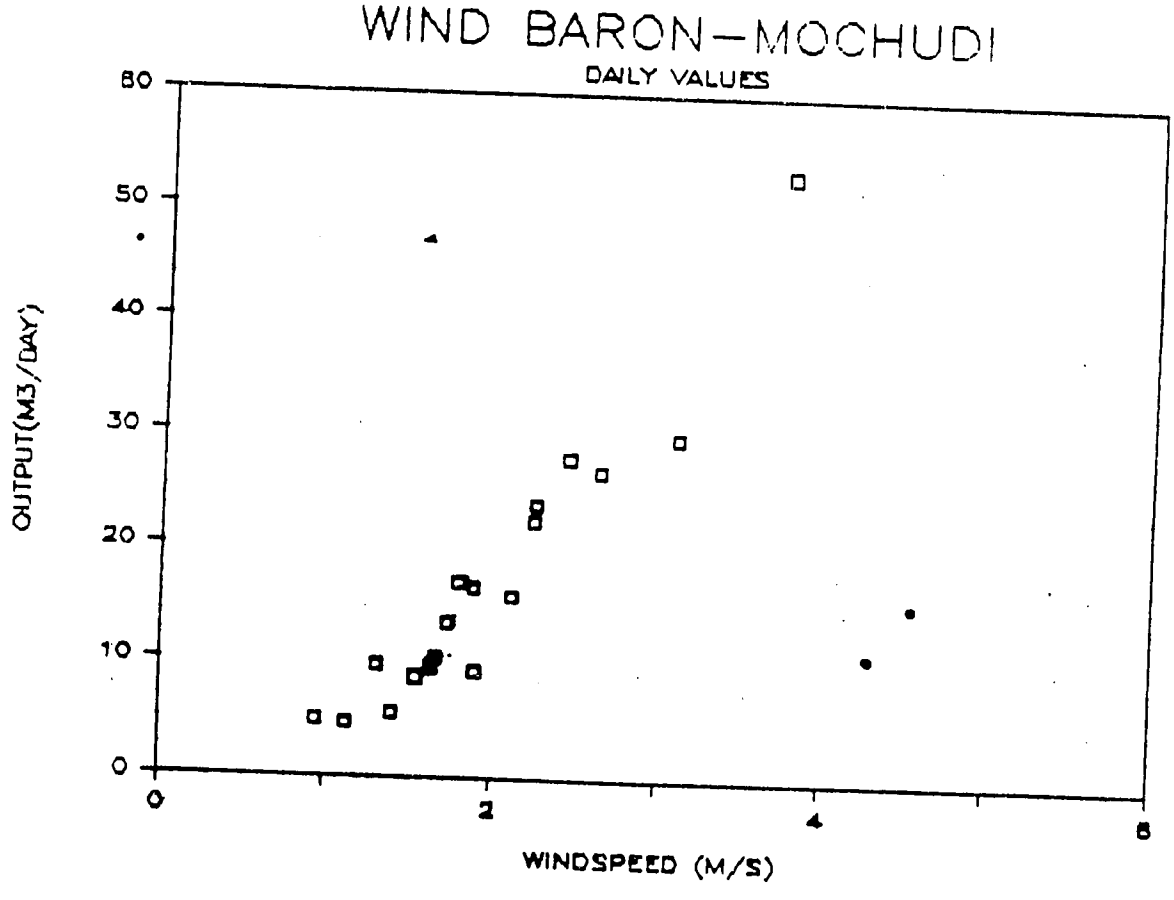
Unfortunately, the data presented in Figure 7 were collected in May during a period with lower wind speeds. However, they do indicate the potential of the Wind Baron for lower wind regimes. The output is quite impressive--15 to 20 cubic meters per day in an average wind speed of two meters per second. The site for this windmill is nicely exposed, and the fact that it was installed on a 12.5-meter tower certainly helps performance.

3. Indigenous Wind Pumps

In addition to the new imported designs just discussed, two other wind pumps have been developed indigenously over the last several years that are specifically designed for Botswana's relatively low wind regimes--the RIIC "Motswedi" and WTGS designs. It must be pointed out that these machines are not yet fully developed, but the tests performed by the BRET project certainly provide an indication of their potential. The systems are similar in that both have low solidity (for wind pumps, this is roughly the number of blades), are designed to be manufactured in Botswana, and intended to operate the positive-displacement, progressive-cavity, Mono pump, which is popular locally. Still, the two machines have some significant differences.

Some features of the Mono rotary pump make it difficult to drive with a windmill. Foremost is its high starting torque, and secondarily, its requirement for a high number of revolutions per minute (RPM) to achieve reasonable efficiency. The WTGS and RIIC groups chose different ways to overcome these design limitations. The WTGS system utilizes a clutch arrangement that allows the rotor to be disengaged from the pump until it has stored enough energy to overcome the starting torque. After the clutch is engaged, the pump will turn at a fixed multiple of rotor speed.

Figure 7


WIND BARON—MOCHUDI
DAILY VALUES
OUTPUT(M3/DAY)
WINDSPEED (M/S)
0
10
20
30
40
50
60
0
2
4
6

On the other hand, in the RIIC design, the pump is always engaged. However, the gearing is such that at low wind speeds, the pump will turn slowly, while at higher wind speeds, the gearing will increase at a rate faster than the increase in rotor speed. This is accomplished through a variable-speed step-up device or unit (VSU), located at the base of the tower.

Both systems should benefit from the introduction of a "renewable energy" pump by the Mono Pump manufacturers that utilizes a nitrile stator in place of the normal stator compound and also features a foot valve. This pump has a significantly lower starting torque than the current design, which should allow RIIC and WTGS to rethink the load matching characteristics of the VSU or clutch to improve the performance of their machines.

The BRET project tested two RIIC systems and also planned to include two WTGS wind pumps in its program. However, only one WTGS machine was tested, since the prototype that was reinstalled in Shoshong never ran smoothly and the second machine purchased by the project was being installed during the preparation of this report. The remainder of this section provides an account of the BRET project's experiences with the RIIC and WTGS systems.

RIIC

Malau

This RIIC Motswedi, with an ES-10 Mono pump and 53-meter head, was the third wind pump tested at IFPP sites near Kanye. The site was originally equipped with a 25-foot Southern Cross, but after a catastrophic failure, the IFPP staff decided to install one of the newly designed RIIC wind pumps. This was the first of the "B" series machines. The BRET project had funded development of the "A" series design and had performed some preliminary tests on it at a site in Mogojogojwe. The project's involvement with the "B" series machines has been limited to testing.

When testing began in late November, 1984, the wind pump had been in place for seven months, and some initial problems with the transmission support tube had been resolved. During the test period, which continued until August, 1985, there were no serious problems, although the VSU was replaced on one occasion as its cam profile was not in the proper shape. The test results presented in Figure 8 are the product of two periods in November to December, 1984 and May, 1985. This system was pumping against a greater head than any of the other wind pumps tested in the program and performed satisfactorily. However, its performance could be improved by utilizing the new "renewable energy" nitrile pump now being offered by the Mono Pump manufacturers.

Figure 8

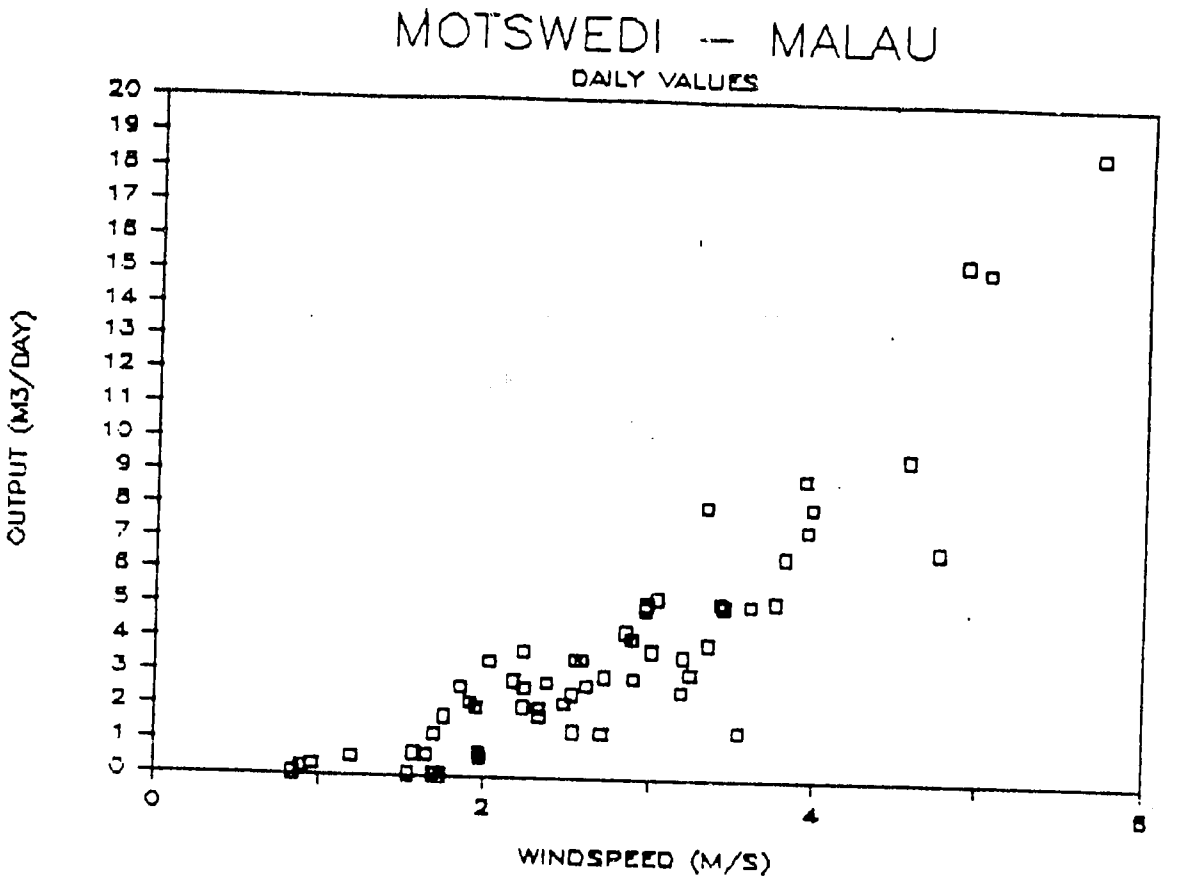
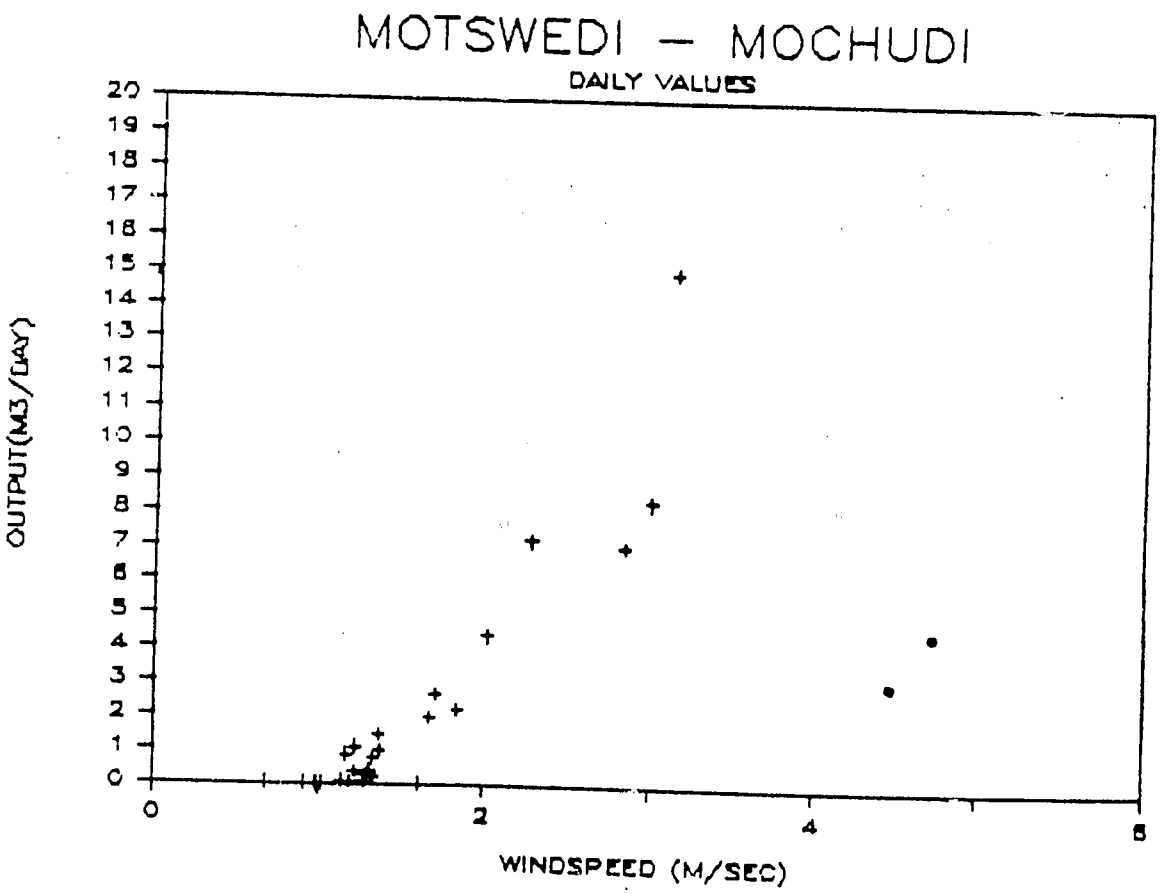


Figure 9



Mochudi

This RIIC wind pump was the second redesigned "B" series machine. It was installed at this site (37 meters of head), with first an ES-15 and then an ES-15S Mono pump, in September, 1984 by the RIIC installation crew. The site is located along the Mochudi-Sikwane road. east of Mochudi and is one of the Geological Survey boreholes mentioned earlier. Unfortunately, this site has proved to have low wind speeds, and the nine-meter tower does not get the rotor much above the surrounding trees. In addition, no gardening group has yet utilized the water being pumped, as was originally envisioned.

The BRET project installed an ES-15 Mono pump here, and performance monitoring began in early November, 1984. The initial results revealed a very high start-up wind speed, so the final drive ratios were changed to facilitate earlier starting. RIIC continued to be dissatisfied with system performance and blamed the high starting torque of that particular Mono pump. In March, 1985, it was noticed that the VSU which varies the gearing was sticking and not operating properly. RIIC replaced the VSU and realized that the cam profile was incorrect. These problems were remedied.

In late May, as the result of a visit by Mr. Stan Payne, a representative of Mono Pump S.A., the ES-15 was replaced with a nitrile-stator, ES-15S model fitted with a foot valve. (It should be noted that Mono pumps are classified in a number of ways, but the difference between an ES-15 and ES-15S is essentially only in length. For these pumps, adding length is equivalent to adding stages in a centrifugal pump, in that the design head is increased.) As a result of this substitution, starting torque decreased significantly, but the performance of the wind pump has not changed because no attempt has yet been made to alter the final drive ratio to take advantage of the lower starting torque.

The results of the testing conducted to date are shown in Figure 9. These data were collected during May, which is a month of low wind speeds, both before and after the change of Mono pumps. In a strict sense, this should not have been done, but there appeared to be no noticeable difference in overall system performance due to the change of pumps, at least for the level of monitoring conducted by the BRET project. These results suggest that there was definitely not a good match between the windmill and its load (pump). This was especially true of the performance observed after the pump was switched. As was the case for several other cases already described, the performance of this RIIC system did not meet expectations, largely due to the early change in the final drive ratio.

WTGS

Mochudi

The BRET project agreed to purchase and test two WTGS wind pumps from Momoso Engineering in Kanye. The first was installed at a Mochudi test site (37-meter head), with an ES-15 and then an ES-15S Mono pump, in October, 1984. This site, like the RIIC system just discussed, was intended to be the location for a gardening group that would use the water produced, but which has not yet formed. This site was also situated in a particularly poor wind area, but was slightly more exposed than the RIIC one.

After installation, the head assembly would not rotate to face the wind properly and some adjustment to the top bearing was necessary. This was done and an ES-15 Mono pump installed in early 1985. Since that date, there have been two other major problems. On one occasion, a taper lock on the down-shaft had to be replaced, which was completed efficiently and on short notice by Momoso Engineering. Recently, the wind pump ceased to operate. Indications were that the taper lock had failed again, but this has not yet been determined with certainty. Second, there has also been an annoying and persistent problem with the V-belt drive, as the belts either flip over or sometimes come off the clutch pulley entirely. This happens about once a month. The belts now show signs of this abuse and need to be replaced.

As was the case for the RIIC machine in Mochudi, the ES-15 pump was replaced with an ES-15S model (also donated by Mono Pump S.A.). At this time, it was discovered that either the original pump had been installed incorrectly or slipped in such a way that part of the drive shaft was being driven into the shaft guide at the top of the pump, thus increasing friction in the system and decreasing efficiency. During the fall of 1984, Mr. Willem Nijhoff, a Dutch consultant, conducted tests on this wind pump to determine if its performance could be improved and whether it could be produced more cheaply. A draft report on the test results (TEST REPORT OF THE WTGS WINDMILL IN BOTSWANA, Willem Nijoff, TOOL, Amsterdam, The Netherlands, May, 1985) indicate that performance can be improved by perhaps as much as 50 percent and production costs reduced as well, but this may be overly optimistic.

Some performance data were gathered at this site after the change of pumps. As with the RIIC system, there was no noticeable change in performance after the switch. However, this was not surprising since the design of this machine cannot take advantage of the change of pumps unless it is reconfigured. No concerted effort has yet been made by WTGS or Momoso Engineering to optimize the load matching, and no significant increase in

performance can be expected until this is successfully accomplished. Figure 10 gives some indication of the performance of the WTGS system. However, wind speeds were uniformly low during the test period, so the pump curve generated is certainly not wholly inclusive. Continued testing through the windier season will provide a more complete picture of its performance.

Summary

It should be noted that although these three systems were state-of-the-art designs when they were purchased, they were not truly production machines. Considerable work remains to be done on both load matching and cost reduction. It is noteworthy that none of these three wind pumps suffered any major failures during the test period. This may be partially due to the relatively low wind speeds experienced during the testing period, but not entirely, as gusts of over eight meters per second (the upper limit of the monitoring instruments) were recorded at all three sites. Both basic designs can likely be improved in terms of cost and performance. What remains to be seen (and will have to wait until the complete results of the wind regime analysis are available) is whether system performance and price can be improved sufficiently to attract buyers in Botswana.

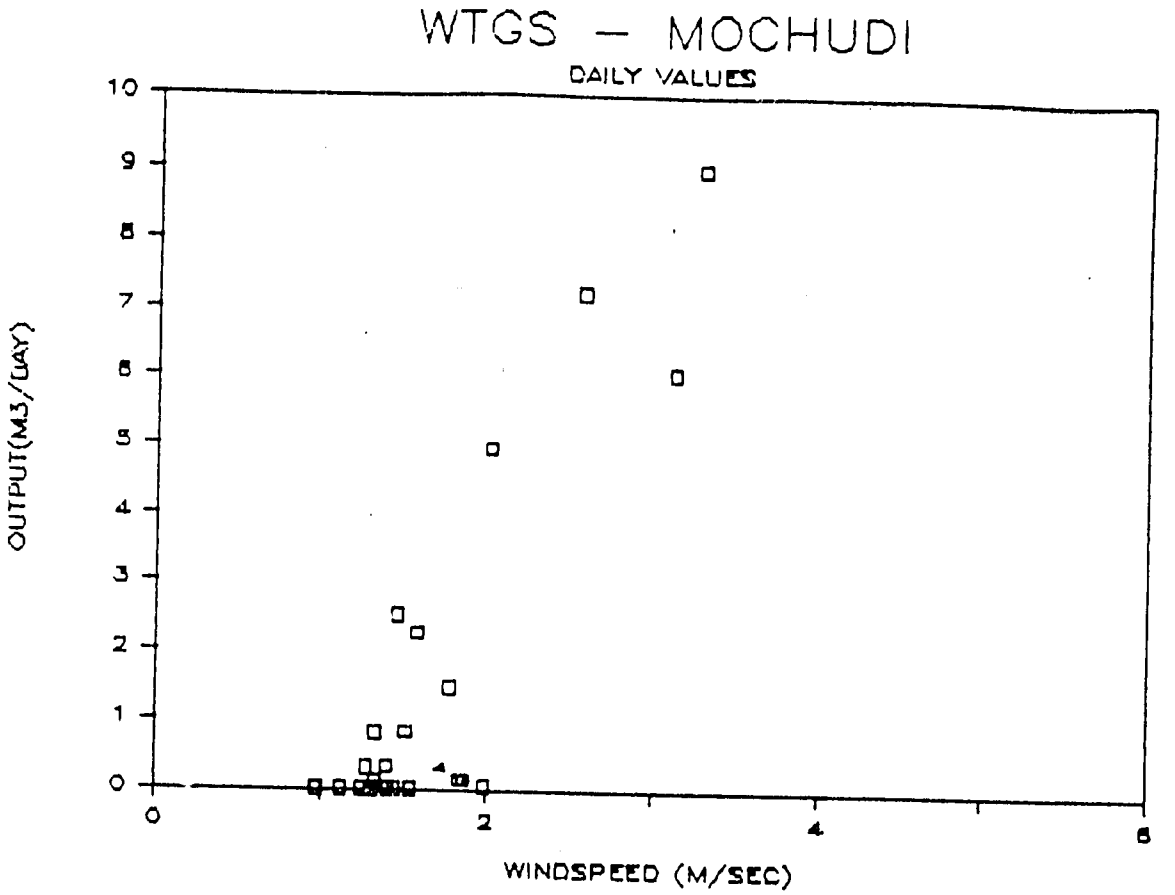
B. Output Projections

Since a full year of testing has not yet been completed, it was necessary to project wind pump performance for the period during which no tests were conducted to estimate output for the month with the lowest wind speed and the entire year. This was an ad hoc process to some extent, as wind speeds at the pump sites were also unknown for the unmonitored periods. These shortcomings will be rectified as the comparative testing program continues, but approximations had to be made for this report.

Still, some information on annual wind speed trends was available. In general, the data gathered for the wind resource assessment agree with that collected from the Agromet installations at two meters. The lowest wind speed periods occur in winter, and the highest during spring and early summer. With this information and the data collected thus far from the various sites, estimates could be made for the months of missing data with 90 to 95 percent accuracy. Also, in most cases, the month with the lowest wind speeds, which is critical for system design, was part of the existing set of data, so estimates for this worst case did not have to be made.

The method used to project wind pump performance for months when data were not gathered used the estimated wind speed for the month to select a corresponding value from a graph of collected

Figure 10


WTGS — MOCHUDI
DAILY VALUES
OUTPUT(M3/DAY)
WINDSPEED (M/SEC)
0
1
2
3
4
5
6
7
8
9
10
0
2
4
6

performance data as the average output for that month. This is not strictly correct, as monthly wind speed distributions may well vary on a daily and monthly basis, which will affect output somewhat.

The last concern was that the wind speed data collected during the test period may not be representative of long-term trends over several years. If this is the case, it will not be known until the wind regime analysis is completed, and it can be determined whether late 1984 and early 1985 are representative of similar periods in other years. For these reasons, the results of the analysis presented in this report cannot be considered definitive. Further data collection will refine the analysis and permit a more accurate assessment of the performance of these wind pumps.

Bearing these comments in mind, current output estimates for the wind pumps tested by the BRET project are given in the following subsections. These figures were used as performance estimates in the financial and economic analyses for the 11 sites. It should be noted that these analyses can yield results that are only as good as the output estimates and thus, should be treated with caution until more complete data are collected and analyzed.

1. Dipotsana

This site is particularly good for Botswana, with an average annual wind speed estimated at 3.5 meters per second (based on eight months of data gathered at the site and information about monthly wind speed patterns) and the month with the lowest wind speed at 2.3 meters per second. Given these estimates, this wind pump should produce about 2.5 cubic meters of water a day during the lowest wind speed month and approximately 2,600 cubic meters per year.

2. Kgoro

At Kgoro, the average annual wind speed was estimated to be 3.4 meters per second, with the low wind speed month at 2.3 meters per second. The 10-foot Climax system at this site should pump about 1,300 cubic meters per year and 1.8 cubic meters a day during the month with the lowest wind speeds. As previously mentioned, these figures do not meet expectations, which were about the same for the low wind speed month, but suggested an annual output of 1,700 cubic meters per year.

3. Malau (RIIC Motswedi)

The anemometer here has not yet been calibrated and may be reading somewhat incorrectly, as it does not seem reasonable that the wind speeds at this site would be .5 to one meter per second lower than nearby Dipotsana for the nine months of simultaneous data collection. Any necessary corrections in the data will be made when the anemometer is recalibrated. Bearing this in mind, the anticipated annual average wind regime should be 2.8 meters per second and two meters per second for the month with the lowest wind speeds. This Motswedi system should produce about 1,700 cubic meters a year or two cubic meters per day for the low wind speed month.

4. Malesane

The wind speeds at this site were not quite as good as at Dipotsana, which is more exposed, but based on eight months of data and an understanding of the annual wind patterns, the annual average wind speed was estimated at about 3.4 meters per second, with a low wind speed month of 2.2 meters per second. Based on these figures, the output of this wind pump should be about 4.3 cubic meters per day during the month with the lowest wind speeds and around 3,200 cubic meters a year.

5. Mochudi (Kijito)

The projected wind speeds for this site were estimated from data collected at Mochudi and nearby sites. These data suggest that the annual average is 2.3 meters per second, with a low wind speed month of 1.5 meters per second. As it is currently configured, the Kijito can be expected to pump 3,200 cubic meters per year and an average of 2.8 cubic meters per day during the month with the lowest wind speeds.

6. Mochudi (RIIC Motswedi)

This test site had one of the poorest wind regimes. The average annual wind speed is expected to be about 2.4 meters per second, with a low wind speed month of about 1.5 meters per second. For such a low wind regime, the RIIC Motswedi with its current configuration should pump about 2,300 cubic meters per year and approximately 1.6 cubic meters a day during the month with the lowest wind speeds. Because these figures represent projections based on incomplete data, they do not necessarily indicate the machine's true potential.

7. Mochudi (Wind Baron)

The projected average annual wind speed for this site, at the 12.5-meter level, is 2.9 meters per second, with a low wind speed month of two meters per second. The expected output of this machine should be about 10,200 cubic meters a year and 16 cubic meters per day during the month with the lowest wind speeds.

8. Mochudi (WTGS)

This was also a relatively poor wind site. The average annual wind speed was not expected to exceed 2.4 meters per second, with a low wind speed month of 1.5 meters per second. It was estimated that the WTGS system could pump approximately 2,200 cubic meters per year and about 1.8 cubic meters a day during the month with the lowest wind speeds. As with the RIIC design, this figure does not necessarily reflect the true potential of this wind pump as much as a poor wind site.

9. Pitsane-Botloko

At present, only limited data are available for this site since it was one of the last machines installed. The anemometer had some initial calibration problems, so no conclusions can be drawn concerning the pump's expected output as the site's average wind speeds have not yet been determined.

10. Sedibeng

From data recorded at this site and the anemometer at Mabule, the annual average wind speed for Sedibeng was estimated at about 3.1 meters per second with a low wind speed month of 2.3 meters per second. Thus, water delivery for the month with the lowest wind speeds would be about 2.1 cubic meters a day and annual output, 1,300 cubic meters. Again, these figures did not meet expectations.

11. Tlhareseleele

Although only limited data were available from this site, the results indicate fairly good system performance, which was anticipated with the good wind speeds and shallow water table. The average annual wind speed at this site is expected to be 3.6 meters per second, with a low wind speed month of 2.5 meters per second. This means that 3,700 cubic meters could be pumped each year, with output for the low wind speed month averaging 5.3 cubic meters per day.

C. Advantages and Disadvantages of Models Tested

Each of the wind pump models tested by the BRET project has advantages and disadvantages that make it more or less suitable for certain applications. These aspects of the systems are covered below for the various types of wind pumps. It should be noted that this discussion focuses solely on wind pumps--it does not consider their relative merits over other pumping technologies. For comparisons of wind systems with alternative pumping technologies, see WATER PUMP FIELD TESTS IN BOTSWANA -- PRELIMINARY TECHNICAL AND COST COMPARISONS (Richard McGowan and Jonathan Hodgkin, ARD, Burlington, Vermont, April 15, 1986).

1. Climax

Climax models are readily available in Botswana. They can be purchased through Stewart and Lloyd's representative in Gaborone, at a cost that includes delivery there. Spare parts can be easily obtained, and a number of individuals, both at DWA and in the private sector, are familiar with this system's installation and maintenance requirements. The Climax also has a long history of reliable operation, if properly installed and maintained. These windmills are relatively inexpensive, ranging from P2,500 to P9,300 for various sizes, including the tower. Thus, several models are in the same price range as diesel pumps. Climax windmills are currently the most popular type in Botswana, and quite a number of them are installed in the Southeast and Ghanzi Districts.

One disadvantage of Climax wind pumps is that water delivery is not as great as for some other makes. This is partly a function of the size of the windmills tested by the BRET project, but it is expected that the amount of water pumped by an 18-foot Climax machine would still not be as much as for some of the other designs tested. The Climax uses a piston pump that has been found to be unsatisfactory in some boreholes in Botswana due to sand and other particulate matter in the water. Under such conditions, the cup leathers wear rapidly and must be replaced on an accelerated schedule, which significantly increases recurrent operation costs.

2. Southern Cross

Southern Cross machines have all the advantages of Climax windmills in terms of cost and familiarity of operation, but to a slightly lesser extent. While Southern Cross does have the added advantage of offering the largest windmill currently available (25 feet in diameter), there is no representative in Botswana, so all purchasing must be done through the factory in Bloomfontein,

South Africa. IFPP staff members found this sufficiently difficult that they decided not to repair a Southern Cross machine and purchased an RIIC wind pump instead. The Southern Cross uses a piston pump, which has the potential disadvantages already noted in the preceding discussion of Climax machines. The Southern Cross wind pump tested by the BRET project performed well. Although its output was limited by head and wind speed, as is true for all wind pumps, the financial analysis was favorable in comparison to the other systems tested.

3. Kijito

The Kijito tested by the BRET project was a new model that takes advantage of a number of fairly recent theories in wind pump design. As a result, it performed well and has some design features that make it attractive. By utilizing a higher tip-speed ratio and simple direct-stroke design, water delivery is increased over traditional wind pumps of the same diameter. In terms of installation, the machine and tower can be raised and lowered with a winch and gin pole, which eliminates the need to do any major maintenance or repairs from the tower. It also means that the tower can be moved out of the way to raise and lower the rising main when it has to be replaced or repaired.

At present, the major disadvantage of this system is its high cost and the lack of readily available spare parts. Part of the high cost is due to the fact that materials costs in Kenya, where the Kijito is manufactured, are relatively high. Shipping costs (about 15 percent of the total installed cost) drive the price up even further. If this machine were fabricated somewhere in southern Africa, these disadvantages would have less of an impact, since presumably, the cost would decline and parts would be more readily available. The Kijito also suffers from the problems associated with all piston pumps.

4. Wind Baron

The Wind Baron has a unique design that utilizes an integrated counterbalancing system, which appears to be both its major advantage and disadvantage. It is an advantage in that counterbalancing some of the weight the windmill must lift on each stroke improves performance by a considerable margin. Although no testing has been done to date on a system installed in a deep borehole, counterbalancing should allow the system to pump from higher heads (and start at lower wind speeds) than conventional designs. It should be noted that counterbalancing is not a new concept, and optional counterbalance kits are available for Climax and Kijito machines, which should improve their performance as well.

The primary disadvantage of the counterbalancing system was that it added both complexity and weight to the wind pump. These and other factors, which have already been discussed, led to a high rate of breakdowns. A large part of the problem was the poor design of several critical system components, such as the mill wheel and furling system. If these design flaws could be corrected, this machine holds some promise.

The Wind Baron's exceptionally high cost (which includes a significant 12,000-mile shipping charge) is also a deterrent. At a delivered cost of over P30,000, this system cost 10 times as much as a Lister diesel engine. In this instance, part of the high cost was due to the particularly strong U.S. dollar. Discussions are underway concerning possible joint-venture or licensed manufacturing of the Wind Baron in southern Africa. If these discussions are successful, dramatic capital reductions in the system's cost might be possible. Should this occur in combination with neccessary design revisions, it could very favorably alter the Wind Baron's competitive advantage relative to the other machines tested by the BRET project.

5. RIIC Motswedi

There were several advantages to this and the WTGS design, primarily their use of the Mono pump and local manufacture. The Mono pump is well-known and widely accepted in Botswana. One of its distinct advantages is the ability to pump water with a high percentage of suspended solids with a minimum amount of wear on the pump. In addition, the Mono pump can be operated without major damage when it is pumping a percentage of air--this often occurs due to reduced well yields or during inaccurate test pumping (which then results in selection of an inappropriate pump). Thus, this type of pump is particularly robust and well suited to conditions found in Botswana.

The fact that the Motswedi is manufactured locally has several ramifications. First and foremost from a user's perspective, both spare parts and maintenance/repair capability are locally available, which is a major difference compared to the Kijito or Wind Baron. Second, local fabrication of this wind system provides employment and could reduce imports into Botswana. A third advantage of the Motswedi is that it is designed to accommodate a back-up power system. The drive belts can easily be changed to allow the pump to be driven by a diesel or petrol engine during prolonged calm periods.

The major disadvantage of the RIIC system is that its long-term reliability is not yet proven. Although the BRET project has not experienced any major failures in nearly a year of operation, a wind pump must give many years of trouble-free service to attract buyers. The Motswedi has not been in

production long enough to demonstrate such long-term reliability and is still in a development phase. The final design for a VSU that can stand the test of time is yet to come. Some further refinement of load matching and selection of appropriate pumps for various conditions is also necessary.

6. WTGS

This system shares many of the advantages of the RIIC design in that it also utilizes the Mono pump, is fabricated in Botswana and can be driven by a diesel or petrol engine, if necessary. There are differences between the two designs, but neither has yet truly reached the production stage. The disadvantages of the WTGS wind pump are also similar to those for the RIIC design, with two major exceptions and the fact that design work must be done on the clutch rather than a VSU. First, the Motswedi appears to be considerably closer to production than the WTGS system. At present, only two WTGS wind pumps have been installed, and one of these is the original prototype, which is not in good operating condition. Second, the RIIC organization is much stronger than Momoso Engineering. Consequently, if design modifications or repairs become necessary, it can respond more quickly and has a greater reservoir of engineering skills. However, the situation for Momoso Engineering may change if WTGS finds the necessary funds to implement the recommendations of a recent evaluation of its wind pump,* and the development process continues.

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*TEST REPORT OF THE WTGS WINDMILL IN BOTSWANA (draft), W. Nijoff, TOOL, Amsterdam, The Netherlands, May, 1985.

V. FINANCIAL AND ECONOMIC ANALYSIS

This section presents financial and economic analyses for the various wind pumps tested by the BRET project. The long-term reliability of these systems (and the resulting operation and maintenance costs, a critical input for the financial/economic analysis) is not yet well established due to the length of the testing period, and for some models, needs considerable improvement. The analysis here assumes that any design modifications needed to ensure adequate reliability have been made, so that typical system reliability would be characteristic of production, rather than prototype, machines. The analysis also assumes a minimum amount of downtime due to institutional or logistic problems, such as delayed responses to breakdowns because of the unavailability of trained maintenance and repair crews. In many cases during the testing program, the length of downtime was a function of the small technical support staff available to handle routine maintainenance or quickly attend to even minor problems. Under any reasonable dissemination program, training technical support personnel would be critical to guarantee timely responses to maintenance and repair needs.

A. Methodology

A convenient method for comparing the costs of various water-lifting technologies is life-cycle cost analysis, which calculates the present worth of all costs--capital, operation and maintenance, and repair--over the system's lifetime. An annualized cost per unit volume of water pumped per unit head was figured, which is called the unit cost of water for convenience. At MMRWA's request, this calculation was done for both the undiscounted total annual amount of water pumped as well as the total annual amount of water pumped discounted by the assumed discount rate.

From an energy perspective, it costs more to pump water as both total volume and head increase. Hence, it is helpful to consider the cost of pumping water as a function of the hydraulic energy requirement. In addition to the simple cost per unit volume (pula per cubic meter), the cost per unit volume multiplied by total pumping head (volume pumped times total head, or P/m3*m) was also figured. This calculation had the effect of normalizing costs by head, thus permitting comparisons of systems of similar size pumping through somewhat different heads.

A benefit-cost ratio was also determined, which required an assumed unit volume cost for water. Although most government-supplied water outside towns is free to users, DWA's major village reticulation schemes have a tariff for private connections. The present rate is P0.30 per cubic meter, so this

value was used in the benefit-cost calculations. However, there is a new tariff study underway, and it is anticipated an increase in this charge will be recommended.

This analysis has been simplified somewhat in that the costs assigned to each pumping system included only those that were not common to all systems and thus, do not have a direct effect on the relative costs of the systems. For example, in nearly all cases, pumps were installed in boreholes that had already been drilled and cased, so the cost of developing a well was not included in the site costs. Similarly, the costs of overhead for DWA or Council Water Units, training technicians to handle new and unfamiliar systems (such as windmills that are new designs), water reticulation networks and water storage were not included. Under some circumstances, water storage costs can vary from one type of system to another, but relative storage costs were not examined during the BRET testing program. Thus, the last assumption introduces some uncertainty into the analysis presented here.

An additional analysis was done for the wind pumps installed on a borehole with a 37-meter head, 100 kilometers from the repair center (to avoid having to simulate the systems coupled to Mono pumps). It included simulated costs at average wind speeds of 2.0, 2.5 and 3.0 meters per second, and points out the importance of adequate wind speeds at sites selected for wind pumps.

Economic analysis differs from financial analysis in that it attempts to place a value on a system's impact on the overall economy by shadow-pricing such real costs to the economy as the value of government subsidies, employment generation, scarcity of foreign exchange and importing raw materials or finished products. Thus, such an analysis is of less interest to individual system end-users than GOB planners, who need information on the broader implications of their policy decisions. Standard GOB pricing analysis assigns a shadow-price to unskilled labor (taken as any laborer earning less than P2,360 per year) of 0.5, so that the unskilled labor component of the economic analysis is one-half the figure in the financial analysis, the implication being that the government values employment generation for unskilled laborers. Similarly, the GOB shadow-prices foreign exchange at 1.1, implying that it places a negative value of 10 percent of the financial cost on the use of imported goods and materials.

Sensitivity analysis of assumptions is important to determine which ones have the greatest effect on overall costs or are most volatile. Since the assumptions for discount rate, system lifetime, shadow-pricing, etc. have little effect when comparing similar systems (such as different wind pumps), the sensitivity analysis for all the pumping systems tested by the

BRET project is only presented in the overall comparative testing report,* where the effects of varying the assumptions are examined for the different types of systems.

Detailed cost breakdowns for the different wind pumps, and the assumptions made to project the long-term operation and maintenance costs are discussed in Appendix C.

B. Results

The financial analysis provided in this section does not explicitly permit a direct comparison of the wind pumps tested by the BRET project, since no effort was made to normalize head, wind speed or other variables. When these results are compared to the normalized analysis given in subsequent sections, the effects of site-specific parameters become clear.

Extrapolations from the measured outputs given in Section IV.B are summarized below. The number for each site corresponds to the numbers found on the graphs presented in this section. This summary table also shows estimates for average output during the design month with the lowest wind speeds, annual output and average daily output, which is derived from the annual output.

	m3/day (low month)	m3/year (total)	m3/day (average)
Dipotsana	2.5	2,600	7.1
Kgoro	1.8	1,300	3.6
Malesane	4.3	3,200	8.8
Sedibeng	2.1	1,300	3.6
Tlhareseleele	5.3	3,700	10.1
Kijito, Mochudi	2.8	3,200	8.8
RIIC, Mochudi	1.6	2,300	6.3
RIIC, Malau	2.0	1,700	4.6
Wind Baron, Mochudi	16.0	10,200	27.9
WTGS, Mochudi	1.8	2,200	6.0

For wind pumps, a site's daily and annual wind speed distributions have a profound effect on the amount of water pumped. Since wind speeds and their distribution vary seasonally, it must be decided whether to assign a value to water that is pumped in excess of the design-month requirement (usually the month with the lowest wind speeds). If the wind pump is

*WATER PUMP FIELD TESTS IN BOTSWANA -- PRELIMINARY TECHNICAL AND COST COMPARISONS, Richard McGowan and Jonathan Hodgkin, ARD, Burlington, Vermont, April 15, 1986.

routinely turned off when the tank is full, so that no further water is pumped, the incremental value would be zero. If there are secondary demands, some value should be assigned to additional water delivered during months when the pump's output exceeds that of the design month. In Botswana, the periods with the highest wind speeds coincide with the end of the dry season and start of the planting season, which argues in favor using the second approach, but the analysis below presents both extremes--first, excess water is assigned no value, and then, it is given the same unit value as for design-month demand. The water's actual value probably lies somewhere between the two figures, depending on the site and water-use patterns.

The cost results are presented in Tables 1 and 2, and the annualized life-cycle costs per unit volume (pula per cubic meter) and per unit volume per unit head (P/m^3*m) are shown in Figures 11 and 12. It should be reemphasized that these costs are only for lifting the volume of water indicated to ground level plus several meters to the storage tank--they do not include reticulation or storage costs. Nor do these values differentiate between installations in terms of head or local wind regime.

For example, the high costs of the Kijito not due to a wind pump that performs poorly, but rather, are the result of low average wind speeds at the site. Similarly, the RIIC machine at Malau is actually more attractive than the costs would indicate because it is pumping against a relatively higher head. The unit water costs for Sedibeng are higher because this wind pump is not operating up to its potential, for mechanical reasons that have not yet been determined. The Malesane machine appears relatively attractive due to the high wind speeds at this site. While the costs for Wind Baron appear reasonable, this is largely a function of the "idealized" repair record (which it has yet to approach in reality) in addition to its counterbalanced design.

It is clear that these figures cannot be taken at face value as an indication of the potential for wind pumps in Botswana, but they do indicate the range of costs for fairly random sites throughout the country, which will be important when considering the installation of wind pumps at these sites. In addition, direct performance comparisons of the different wind pumps cannot be made from these results since the heads at these sites differ by almost 300 percent and the wind speeds by 50 to 60 percent. Further, these windmills are located at varying distances from service centers, which affects long-term operation and maintenance support costs. To permit a more valid comparison of the different systems, it was necessary to normalize site conditions. Section VI addresses these issues.

Table 1

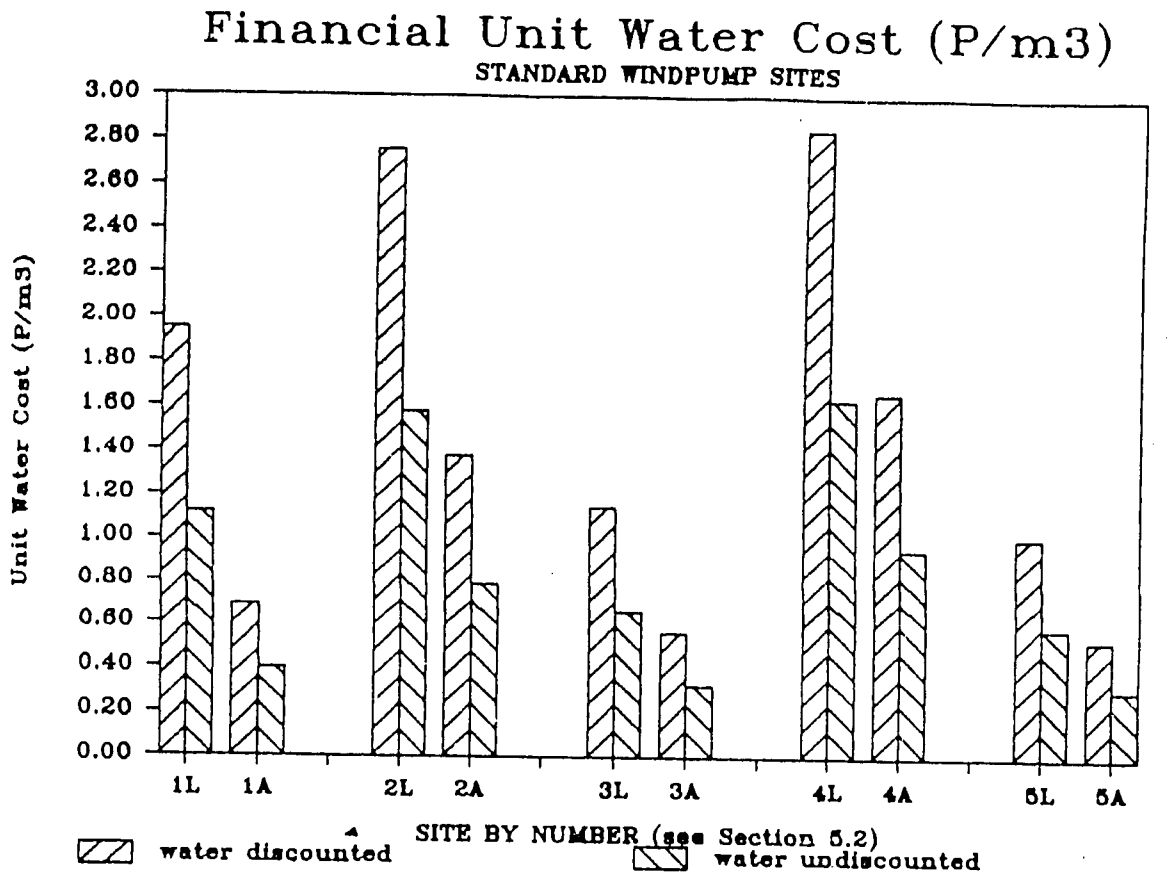
FINANCIAL ANALYSIS OF STANDARD WINDPUMPS

Note: For each machine, the lower output in the left column is based on design month windspeed (L in the graph). The higher output in the right column is based on the average annual output (A in the graph).

Type of Machine	Climax 12		Climax 10		So.Cross 14		Climax 12		Climax 12	
Site Location	DIPOTSANA (1)		EGORO (2)		MALESANE (3)		SEDIBENG (4)		TLHARESEELE (5)	
Avg.Water Output (m3/dy):	2.5	7.1	1.8	3.6	4.3	8.8	2.1	3.6	5.3	10.1
Total Pumping Head (m) :	30	30	35	35	35	35	27	27	19	19
Amortizatn. Period (yrs):	20	20	20	20	20	20	20	20	20	20
Pump life :	20	20	20	20	20	20	20	20	20	20
Discount Rate (%) :	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%
COSTS										
Initial Capital Cost :	4437	4437	3363	3363	4538	4538	5104	5104	4315	4315
Installation Cost :	1226	1226	1242	1242	1242	1242	1382	1382	1226	1226
Total Installed Cost :	5663	5663	4606	4606	5780	5780	6486	6486	5541	5541
PV of Recurrent Costs :	6064	6064	7294	7294	6037	6037	7892	7892	7309	7309
Life Cycle Cost (LCC) :	11727	11727	11900	11900	11817	11817	14378	14378	12850	12850
BENEFITS	Cubic meter water value assumed =								0.30	
Ann. Flow :	913	2592	657	1314	1570	3212	767	1314	1935	3687
Disc. Ann. flow :	523	1486	377	754	900	1842	440	754	1109	2114
Ann. Head*Flow (m4/year):	27,375	77,745	22,995	45,990	54,933	112,420	20,696	35,478	36,756	70,044
Value of Output @P.30/m3:	274	777	197	394	471	964	230	394	580	1106
PV of Benefit Stream :	3140	8917	2261	4521	5401	11052	2638	4521	6657	12685
Benefit/Cost Ratio :	0.27	0.76	0.19	0.38	0.46	0.94	0.18	0.31	0.52	0.99
Annualized LCC (P/m3) : (Water Discounted) :	1.954	0.688	2.753	1.377	1.145	0.559	2.852	1.663	1.010	0.530
Annualized LCC (P/m3) : (Water Not Discounted):	1.120	0.395	1.579	0.790	0.656	0.321	1.635	0.954	0.579	0.304
Annualized LCC (P/m3*m) (m3*m = Volume delivered X Head)	0.037	0.013	0.045	0.023	0.019	0.009	0.061	0.035	0.030	0.016

NOTES: Water output is based on projections of the annual performance at the site.
A pumper one day per week is included.
Recurrent costs have been estimated based on data collected thus far, and do not necessarily accurately reflect actual long-term O+M costs.

Figure 11


Financial Unit Water Cost (P/m3)
STANDARD WINDPUMP SITES
Unit Water Cost (P/m3)
3.00
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1L
1A
2L
2A
3L
3A
4L
4A
5L
5A
SITE BY NUMBER (see Section 5.2)
water discounted
water undiscounted

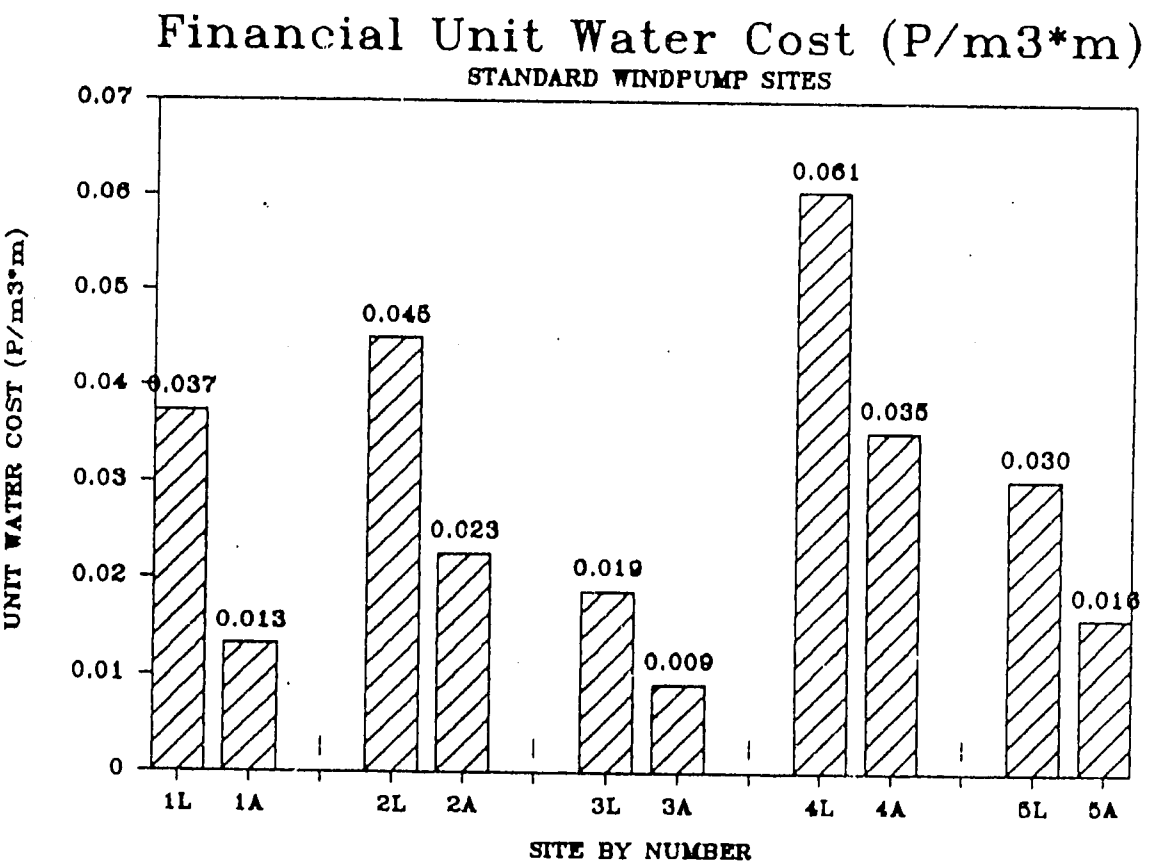

Financial Unit Water Cost (P/m3*m)
STANDARD WINDPUMP SITES
UNIT WATER COST (P/m3*m)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.037
0.013
0.045
0.023
0.019
0.009
0.061
0.035
0.030
0.016
1L
1A
2L
2A
3L
3A
4L
4A
5L
5A
SITE BY NUMBER

Table 2

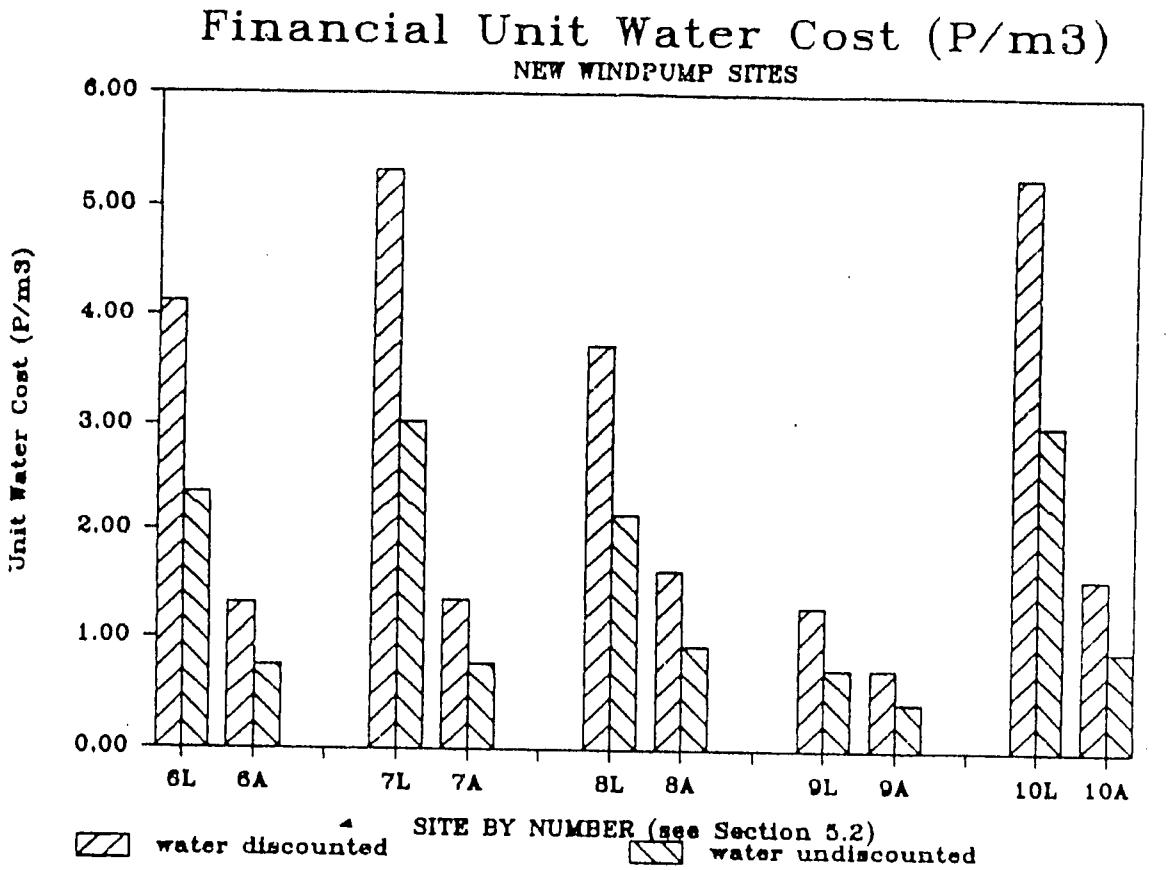
FINANCIAL ANALYSIS OF NEW DESIGN WIND SYSTEMS

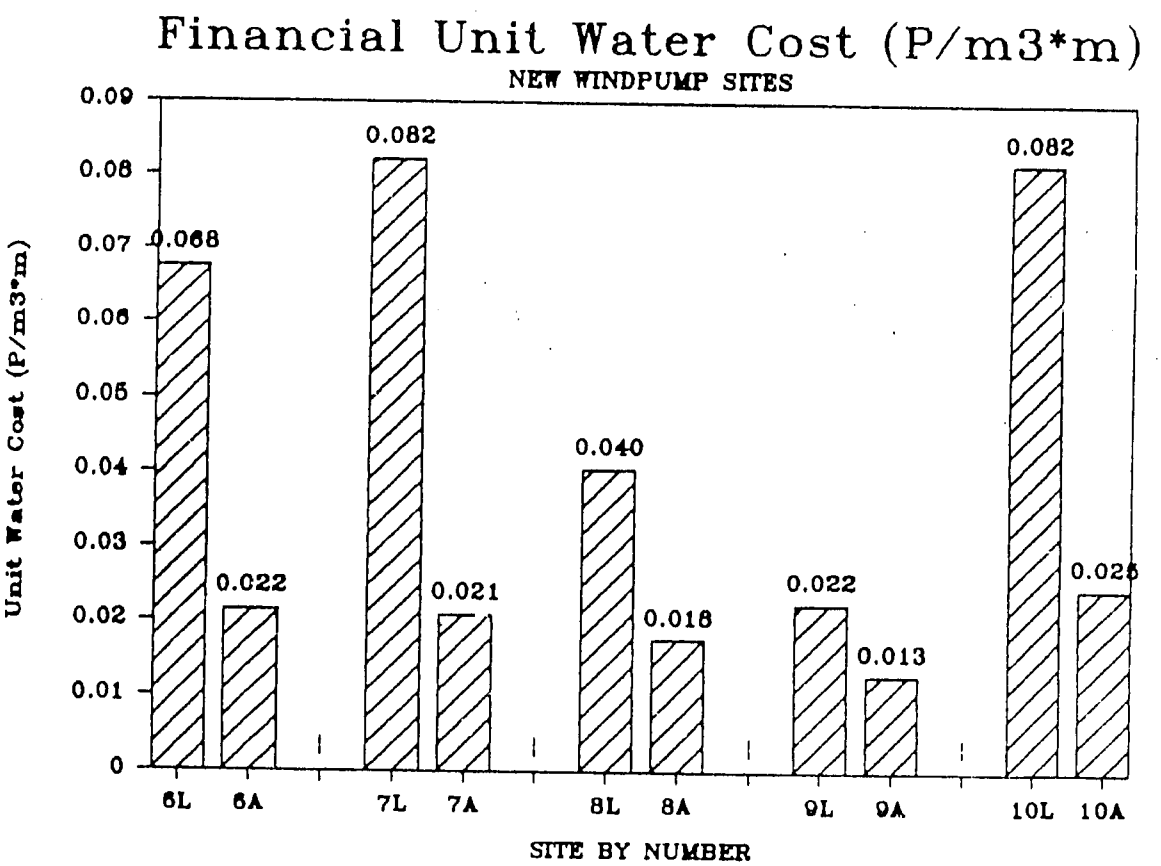
Note: For each machine, the lower output in the left column is based on design small windspeed (L in the graph). The higher output in the right column is based on the annual average output (/. in the graph).

Type of Machine	KIJITO		RIIC "MOTSWEDI"		RIIC "MOTSWEDI"		WINDWARD		WTGS	
Site Location	MOCHUDI (6)		MOCHUDI (7)		MALAU (8)		MOCHUDI (9)		MOCHUDI (10)	
Avg.Water Output (m3/dy):	2.8	8.8	1.6	6.3	2.0	4.6	16.0	27.9	1.8	6.0
Total Pumping Head (m) :	35	35	37	37	53	53	33	33	37	37
Amortizatn. Period (yrs):	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Pump life :	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Discount Rate (%) :	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%
COSTS										
Initial Capital Cost :	20162	20162	10858	10858	11267	11267	36671	36671	11885	11885
Installation Cost :	1580	1580	0	0	0	0	3883	3883	1401	1401
Total Installed Cost :	21742	21742	10858	10858	11267	11267	40554	40554	13286	13286
PV of Recurrent Costs :	6013	6013	9490	9490	6680	6680	8941	8941	9490	9490
Life Cycle Cost (LCC) :	27755	27755	20348	20348	17947	17947	49494	49494	22776	22776
BENEFITS	Cubic meter water value assumed :						0.30			
Ann. Flow :	1022.00	3212.00	584.00	2299.50	730.00	1679.00	5840.00	10183.50	657.00	2190.00
Disc. Ann. flow :	586	1842	335	1319	419	963	3349	5840	377	1256
Ann. Head*Flow (m4/year):	35,770	112,420	21,600	85,082	38,690	88,987	192,720	336,056	24,309	81,030
Value of Output @P.30/m3:	307	964	175	690	219	504	1752	3055	197	657
PV of Benefit Stream :	3517	11052	2010	7913	2512	5777	20095	35041	2261	7536
Benefit/Cost Ratio :	0.13	0.40	0.10	0.39	0.14	0.32	0.41	0.71	0.10	0.33
Annualized LCC (P/m3) : (Water Discounted) :	4.129	1.314	5.297	1.345	3.737	1.625	1.288	0.739	5.270	1.581
Annualized LCC (P/m3) : (Water Not Discounted):	2.368	0.753	3.038	0.771	2.143	0.932	0.739	0.424	3.022	0.907
Annualized LCC (P/m3*m): (m3*m = Volume delivered X Head)	0.068	0.022	0.082	0.021	0.040	0.018	0.022	0.013	0.082	0.025

NOTES: Water output is based on projections of the annual performance at the site.
A pumper one day per week is included.
Recurrent costs have been estimated based on data collected thus far, and do not necessarily accurately reflect actual long-term O+M costs.

Figure 12


Financial Unit Water Cost (P/m3)
NEW WINDPUMP SITES
Unit Water Cost (P/m3)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
6L
6A
7L
7A
8L
8A
9L
9A
10L
10A
SITE BY NUMBER (see Section 5.2)
water discounted
water undiscounted


Financial Unit Water Cost (P/m3*m)
NEW WINDPUMP SITES
Unit Water Cost (P/m3*m)
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.068
0.022
0.082
0.021
0.040
0.018
0.022
0.013
0.082
0.025
6L
6A
7L
7A
8L
8A
9L
9A
10L
10A
SITE BY NUMBER

VI. TECHNICAL COMPARISON

To permit a reasonable comparison of the potential of the different wind pumps tested, an understanding of the range of typical wind regimes and pumping heads in Botswana is necessary. At presently, much of this information is not well documented. However, preliminary estimates are available, and the following comparisons are made within this context.

A. Wind Speeds

Due to surface effects caused by hills, trees and ground friction, wind speed normally increases with height above ground level. Hence, windmill rotors are typically mounted about 10 to 15 meters above the ground. However, no comprehensive examination of wind speeds in Botswana above two meters has yet been conducted.

The small amount of 10-meter data that exists, along with extrapolations of two-meter data to the 10-meter level, suggest that the country's average annual wind speeds are around two to three meters per second and during the low wind speed months, average only two meters per second at best. Still, it is difficult to have confidence in data extrapolated from the two-meter level because surface effects can dramatically affect the reliability of these data. Thus, in collaboration with several other organizations, the BRET project proposed the establishment of a national network of 10-meter wind observation sites.

This wind resource assessment got underway in late 1983. Although the data collected to date have not been fully analyzed, the results for some of the sites provide an indication of wind regimes at the operating level for typical wind pumps in Botswana. The table below summarizes data collected from nine anemometer sites in 1984.

Site	Average Wind Speed (meters/sec)	Notes
Bokspits	2.9	2.0 meters per second in July
Ditshegwane	3.1	2.5 meters per second in June
Mabule	2.9	2.3 meters/second in April and May
Nata	2.6	2.0 meters/second in May and July
Ncojane	3.1	Data for March-December only.
Pandematenga	2.4	2.0 meter/sec in February and March
Rakops	3.1	
Serowe	3.6	Anem. may need calibration.
Tsau	2.8	2.3 meters per second in May

Bar graphs of the monthly wind speed values for four representative sites in Figures 13 to 16 show that average wind speeds vary somewhat throughout Botswana. These data indicate that the average annual wind speeds at many sites are in the range of 2.5 to 3.0 meters per second or higher, with the low wind speed months averaging 2.0 to 2.5 meters per second. In the following analysis, the water delivery of each pump (in cubic meters per day) is estimated for winds of 2.0, 2.5 and 3.0 meters per second.

B. Borehole Depth

There has been considerable discussion about borehole depth as a constraint to the use of alternative pumping technologies in Botwana. As yet, there is no complete aggregation of borehole drilling data, which would permit an accurate determination of average water tables in specific areas. However, it appears that in the eastern part of the country, average borehole depth ranges from 30 to 40 meters and increases to the west, where resting water levels of 80 to 100 meters are not uncommon. Near the Okavango, many wells are very shallow.

For villages with reticulation systems, there is additional head associated with the piping network, such that the total head is often in the 100-meter range. This head is at or beyond commonly accepted limits for the use of conventional windmills to meet village-scale water demands (10 cubic meters per day or more), given the wind speeds commonly found in Botswana. Hence, such cases will not be considered further. However, at lower heads, many wind pumps can produce enough water for this level of demand.

C. Comparative Methodology

To permit a justifiable comparison between the technical merits of the different wind systems, it was necessary to normalize their performance for the same head and wind speed conditions. There are no computer simulation models for wind-driven Mono pumps, so the standard head chosen to compare all the wind pumps was 37 meters because the output of the Mono pumps was measured at this head. This is a fairly typical head for eastern Botswana, provided the discharge head is reasonable (i.e., there are no excessively long pipe runs to distant users). Fortunately, many of the wind pumps tested by the BRET project were pumping against heads in the range of 30 to 40 meters, so unnecessarily large extrapolations were not required.

Extrapolation of each machine's performance to the standard head was done using a combination of actual measured results and

Figure 13

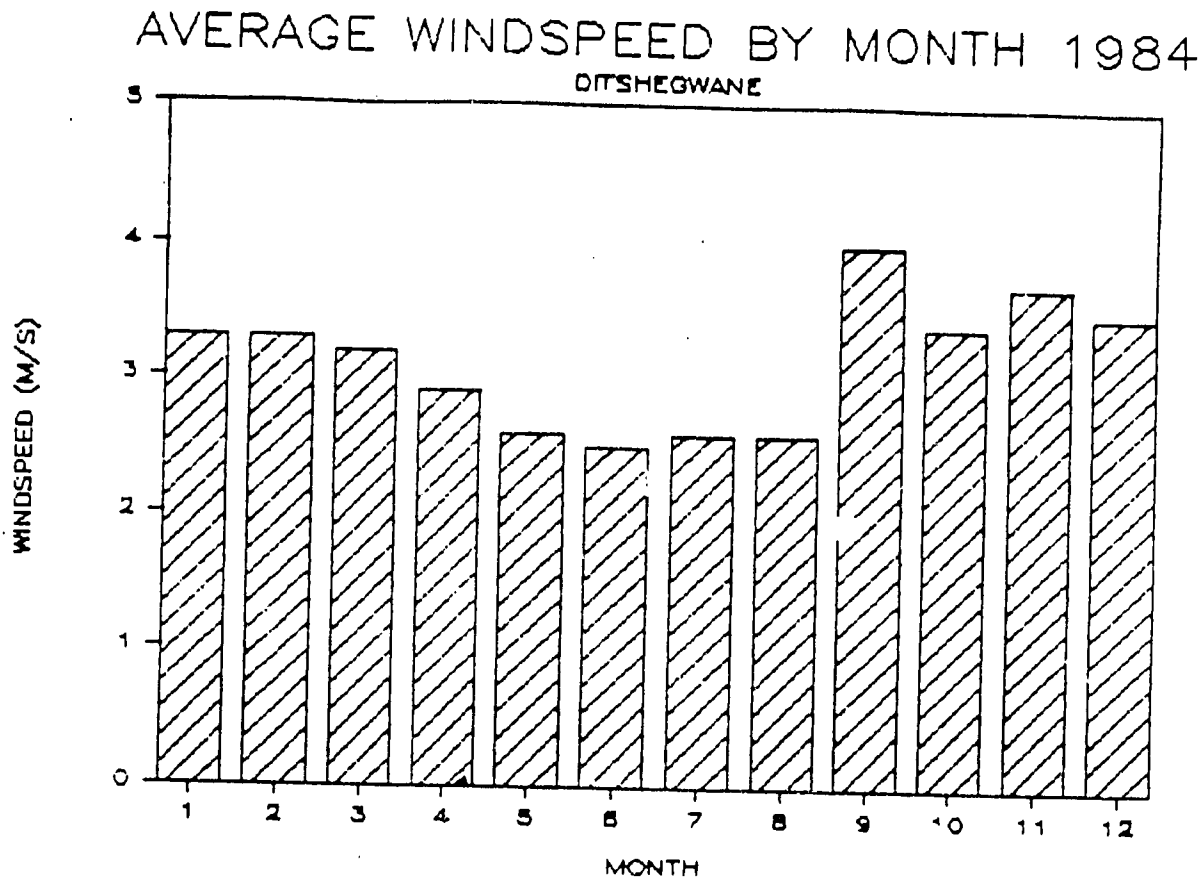


Figure 14

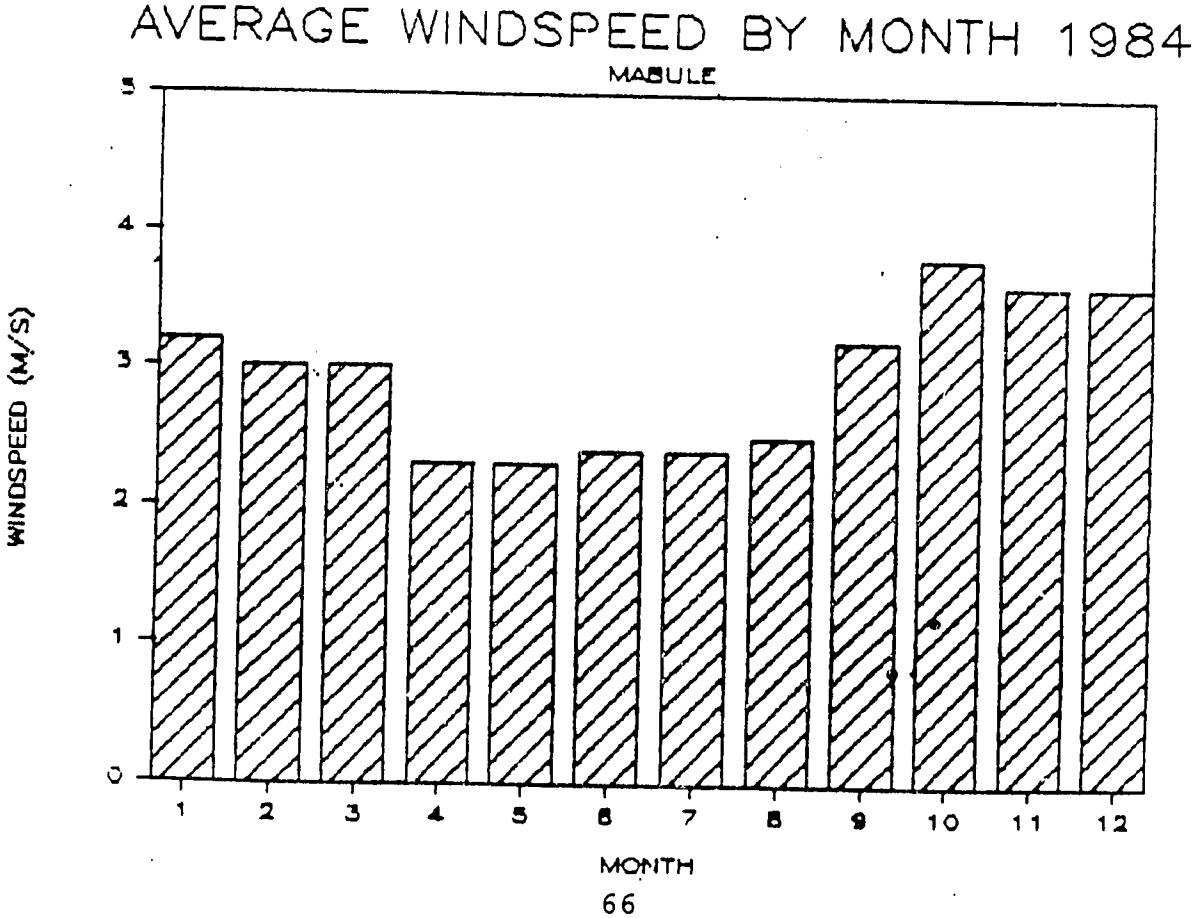


Figure 15

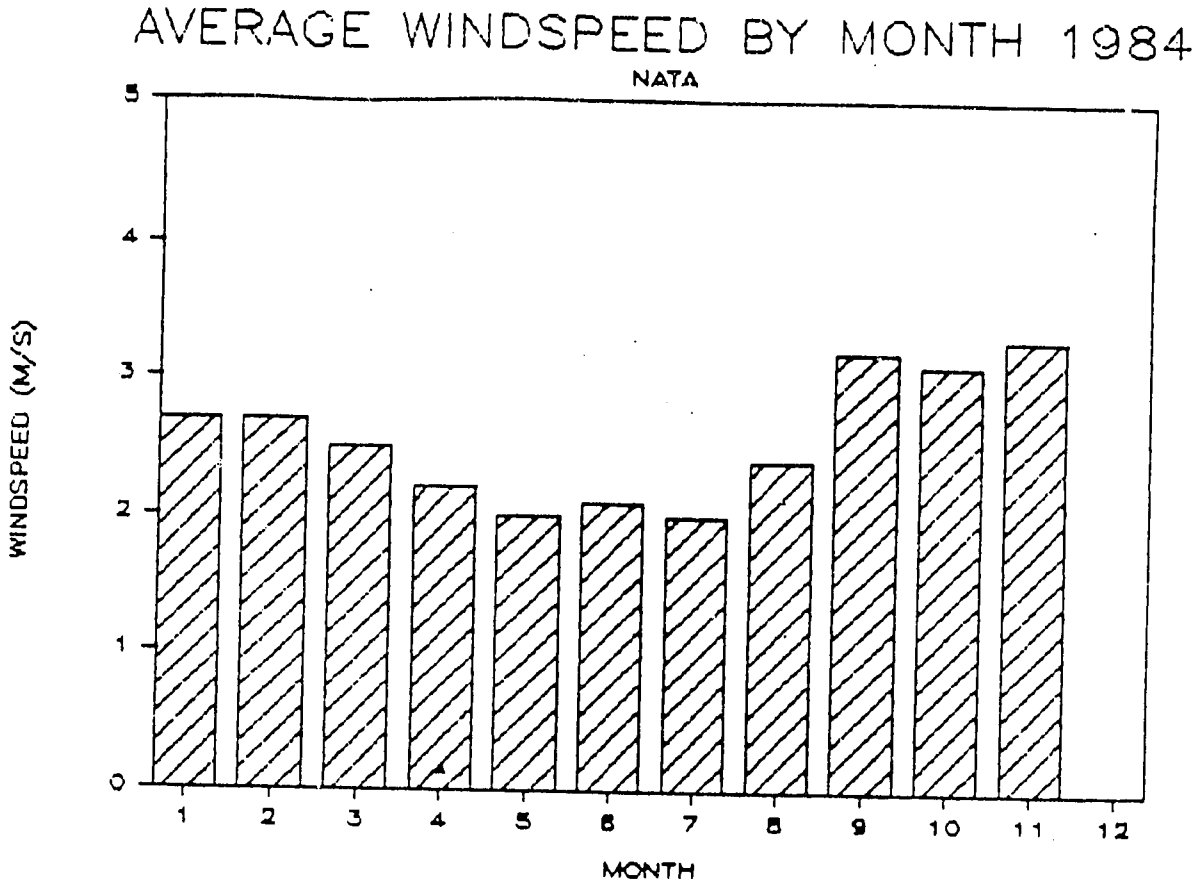
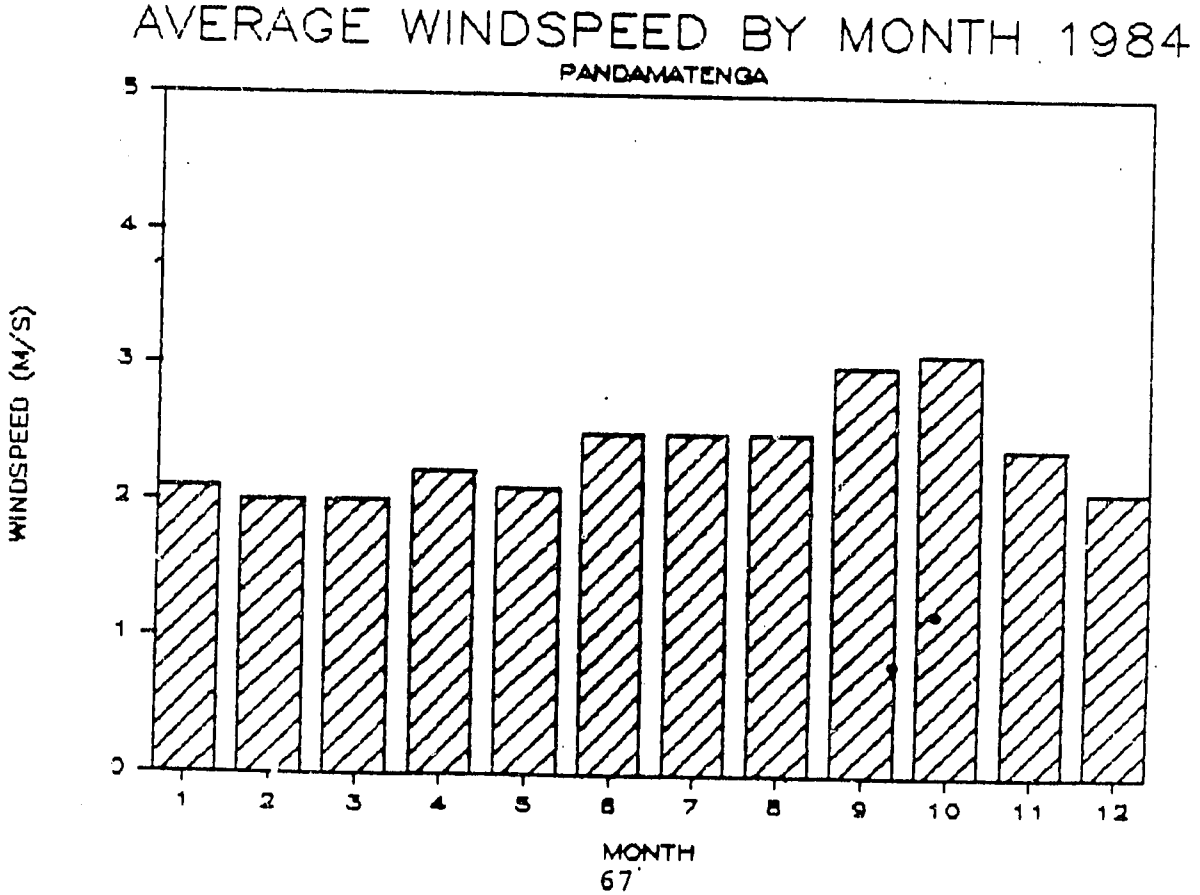


Figure 16



the VITA wind pump output performance model (A PERFORMANCE MODEL FOR MULTIBLADE WATER PUMPING WINDMILLS, A. Wyatt and J. Hodgkin, VITA, Arlington, Virginia). The model's basic approach defines the total average load torque due to pumping and compares this to the average torque produced by the rotor for a given wind speed. During operation, these two figures will be equal, thus allowing the rod strokes to be computed and water delivery calculated for a given cylinder size. The pump curve developed in this way, for a specific wind pump and particular site conditions, can then be integrated over any wind speed distribution to obtain the pump's output for that regime.

Various program input parameters were adjusted so that the results would reflect the actual measured performance of the wind pumps. The simulated head was then changed and size of the pump cylinder optimized for the standard head condition. The latter adjustment was necessary since proper cylinder sizing can dramatically affect a wind pump's output, and it would have been imprecise to generate an artifically low output for a given machine simply because the cylinder size was chosen improperly. The resulting pump curve for the standard head was then integrated over Weibull distribution wind regimes of 2.0, 2.5 and 3.0 meters per second to produce the output estimates. The expected daily outputs of the seven different sizes and types of wind pumps, tested in average winds of 2.0, 2.5 and 3.0 meters per second, are presented in the table below.

Windmill (Pump)	Water Output in Cubic Meters per Day 2.0 m/sec	2.5 m/sec	3.0 m/sec
Climax 10 (cylinder diameter)	1.1 (1.5")	2.1 (1.75")	3.5 (2.0")
Climax 12 (cylinder diameter)	1.5 (1.75")	3.1 (2.25")	4.9 (2.5")
Southern Cross 14 (cylinder diameter)	2.5 (2.25")	5.1 (2.75")	10.0 (3.0")
Kijito 20 (cylinder diameter)	4.0 (2.25")	8.3 (2.75")	12.6 (3.0")
Wind Baron 21 (cylinder diameter)	15.6 (3.75")	22.7 (3.75")	20.7 (3.75")
WTGS (Mono ES-15)	4.0	6.3	8.5
RIIC "Motswedi" (Mono ES-15)	3.9	6.9	10.6

A number of points should be made about this table. First, for each average wind speed, a different pump cylinder size was selected to optimize performance. Since the cost of cylinders is relatively small in comparison to the resulting difference in output, there are clear economic ramifications if cylinders are improperly sized.

Second, it must be remembered that the values for some machines are based on a relatively short testing period, and since several systems are prototypes, there is still room for improvement in their performance and reliability. The performance of both the RIIC "Motswedi" and WTGS might be improved in a number of ways, particularly better load matching between the windmill and pump. Other possible approaches to improving the performance of these machines include redesigning the WTGS clutch and slightly larger rotors. Some guidelines for new design goals for these systems are suggested in subsequent sections.

Third, although this analysis normalizes wind pump output for site conditions, it does not do so for rotor diameter, pump type or other unique design features, such as the Wind Baron's counterbalance system. Machine-specific variations in such parameters may well make one system appear more attractive. However, these issues were not addressed in this study.

VII. COMPARATIVE FINANCIAL AND ECONOMIC ANALYSIS

This analysis follows the format outlined in Section V.A, where a unit water cost for delivering a certain volume of water through a given pumping head was calculated. This is the most important comparative cost criterion. Here, costs were normalized and extrapolations made from actual measured data to compare the various types of wind pumps as if they were operating under the same head and wind conditions. It should be noted that the long-term recurrent operation and maintenance costs presented in this section are based on actual installations in Botswana and elsewhere, but they necessarily involved extrapolation from measured data. The accuracy of these estimates will increase as more recurrent cost data become available during the extension of the comparative pump testing program.

A. Results

The performance results for the Climax 10 and 12, Southern Cross, Kijito, Wind Baron, RIIC and WTGS systems are given below. Baseline costs for these seven wind pumps and the assumptions used in the analysis are covered in Appendix C, with two exceptions. The distance from the equipment pickup point to the installation site was standardized at 200 kilometers to calculate installation costs, and the distance from the service center to the site was assumed to be 100 kilometers in figuring recurrent operation and maintenance costs. The results of comparative financial and economic analyses for three wind speeds (2.0, 2.5 and 3.0 meters per second) are presented in Tables 3 (a and b) to 5 (a and b) and shown graphically in Figures 17 (a and b) to 19 (a and b). The detailed cost breakdowns that were used as inputs for the spread-sheets are provided in Appendix C. Both the capital and recurrent costs of the various systems are slightly different from those presented in Section V, due to updated costs (current quotes were used in the analysis here, rather than the actual prices paid) and changes in the assumptions (e.g., drop pipes were standardized at a common length).

Three comparative criteria were calculated:

- unit cost per cubic meter of water, with the volume of water discounted over the system's lifetime, which is analogous to discounting the benefit stream;
- undiscounted unit cost per cubic meter of water; and
- the unit cost per cubic meter of water times the meters of head, not discounted.

Table 3(a)

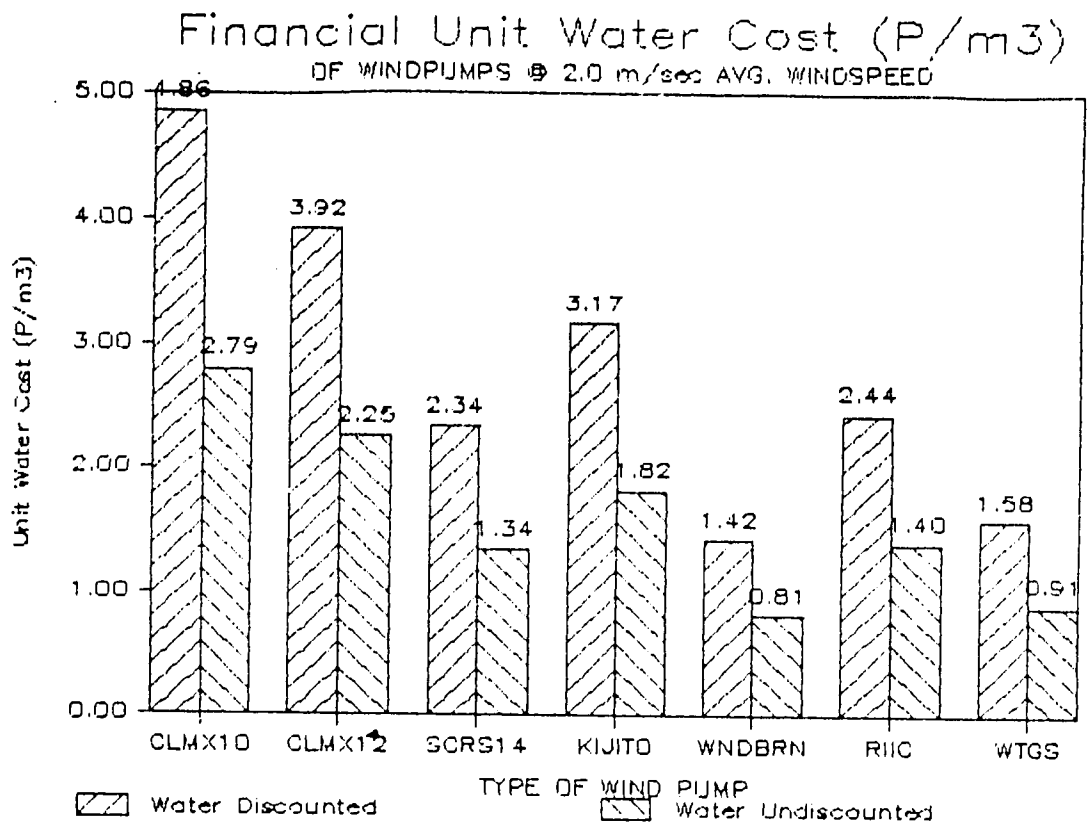
FINANCIAL ANALYSIS OF WINDPUMPS

AVERAGE WINDSPEED = 2.0 m/sec

Type of Windpump :	CMAX10	CMAX12	SC 14	KIJITO	W.BARON	RIIC	WTGS
Avg. Output (m3/dy):	1.1	1.5	2.5	4.0	15.6	3.9	5.2
Total Pump Head (m):	37	37	37	37	37	37	37
Amort. Per. (yrs) :	20	20	20	20	20	20	20
Pump Life (yrs)* :	20	20	20	20	20	20	20
Discount Rate (%) :	6%	6%	6%	6%	6%	6%	6
COSTS							
Init. Cap. Cost (P):	3457	4683	4479	20156	36708	4343	4754
Installation Cost :	246	262	262	460	721	600	600
Install. Cost-Labor:	980	980	980	1120	3203	7075	7691
Tot. Installed Cost:	4683	5925	5721	21736	40632	12018	13045
Recurrent Costs PW :	8165	8199	8327	8717	12591	10848	10848
Life Cycle Cost (P):	12848	14124	14048	30453	53223	22866	23893
BENEFITS (Assumed Water Value = 0.30 Pula/m3)							
Annual Flow (m3/yr):	402	548	913	1460	5694	1424	2300
Discount. Ann. Flow:	230	314	523	837	3265	816	1319
Head*Flow (m3*m/yr):	14,856	20,258	33,763	54,020	210,678	52,670	70,226
Benefits @P.30/m3 :	120	164	274	438	1708	427	690
Benefit Stream PW :	1382	1884	3140	5024	19593	4898	7914
Benefit/Cost Ratio :	0.11	0.13	0.22	0.16	0.37	0.21	0.33
Unit Cost (P/m3) (Water Discounted):	4.86	3.92	2.34	3.17	1.42	2.44	1.58
Unit Cost (P/m3) (Water Undiscount.):	2.79	2.25	1.34	1.82	0.81	1.40	0.91
Unit Cost (P/m3*m) :	0.075	0.061	0.036	0.049	0.022	0.038	0.030

Note: This 20 year lifetime is for the windmill head and tower. The actual pump (reciprocating cylinder or Mono pump) is assumed to require replacement every five years (see Appendix A).

Figure 17(a)


Financial Unit Water Cost (P/m3)
OF WINDPUMPS @ 2.0 m/sec AVG. WINDSPEED
Unit Water Cost (P/m3)
5.00
4.00
3.00
2.00
1.00
0.00
4.86
2.79
3.92
2.25
2.34
1.34
3.17
1.82
1.42
0.81
2.44
1.40
1.58
0.91
CLMX10
CLMX12
SCRS14
KIJITO
WNDBRN
RIIC
WTGS
TYPE OF WIND PUMP
Water Discounted
Water Undiscounted

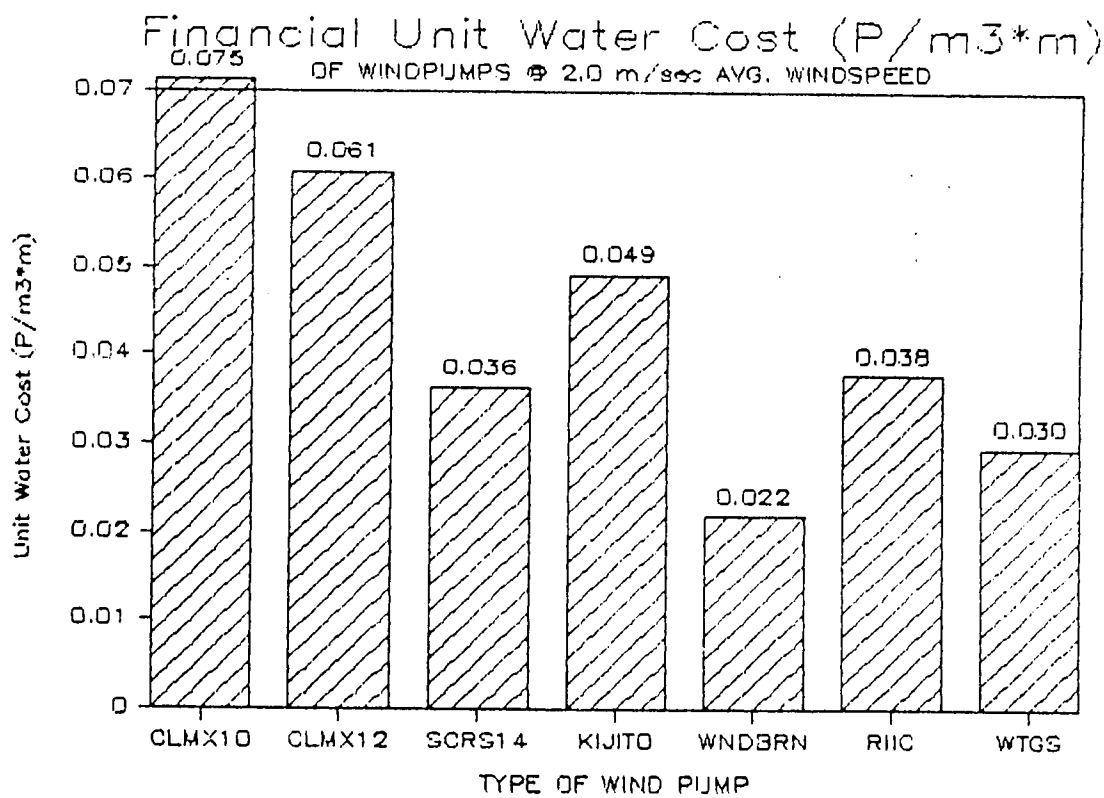

Financial Unit Water Cost (P/m3*m)
OF WINDPUMPS @ 2.0 m/sec AVG. WINDSPEED
Unit Water Cost (P/m3*m)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.075
0.061
0.036
0.049
0.022
0.038
0.030
CLMX10
CLMX12
SCRS14
KIJITO
WNDBRN
RIIC
WTGS
TYPE OF WIND PUMP

Figure 3(b)

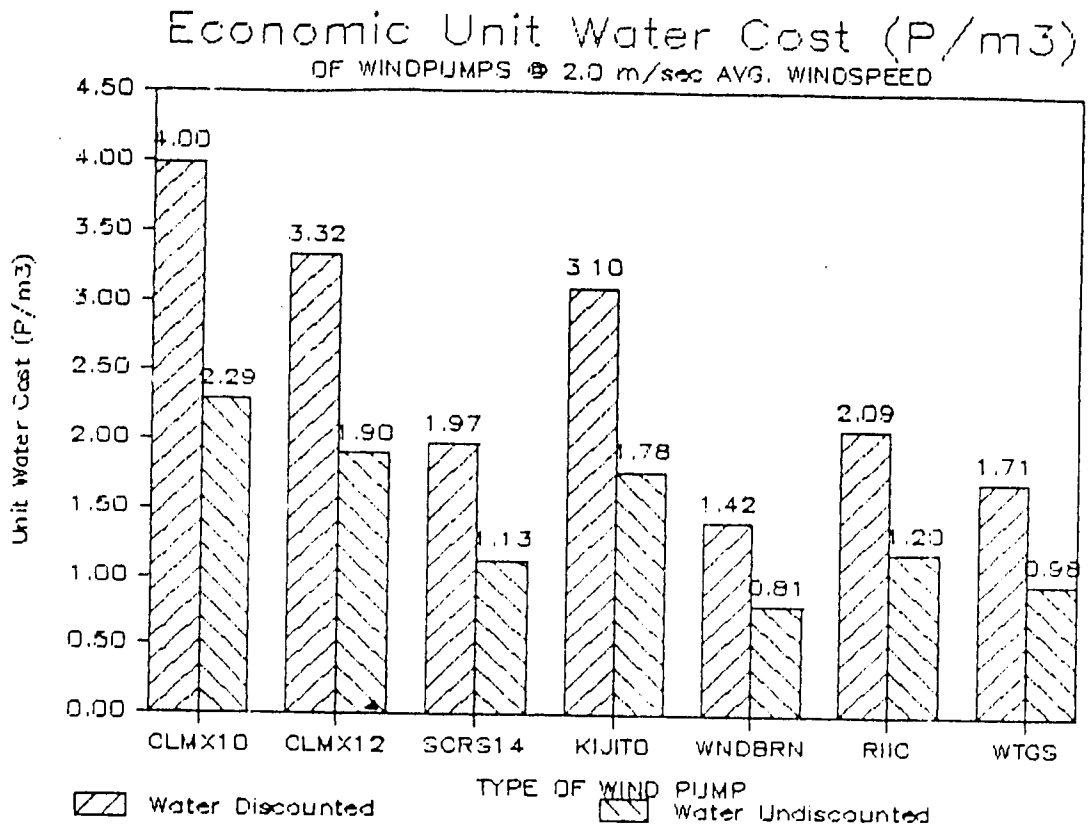
ECONOMIC ANALYSIS OF WINDPUMPS

AVERAGE WINDSPEED = 2.0 m/sec

Type of Windpump :	CMAX10	CMAX12	SC 14	KIJITO	W.BARON	RIIC	WTGS
Avg. Output (m3/dy):	1.1	1.5	2.5	4.0	15.6	3.9	5.2
Total Pump Head (m):	37	37	37	37	37	37	37
Amort. Per. (yrs) :	20	20	20	20	20	20	20
Pump Life (yrs)* :	20	20	20	20	20	20	20
Discount Rate (%) :	6%	6%	6%	6%	6%	6%	6
COSTS							
Init. Cap. Cost (P):	3803	5151	4927	22172	40379	4777	5229
Installation Cost :	246	262	262	460	721	600	600
Install. Cost-Labor:	490	490	490	560	1602	5538	6846
Tot. Installed Cost:	4539	5903	5679	23192	42701	10915	12675
Recurrent Costs PW :	6013	6047	6175	6565	10349	8654	8654
Life Cycle Cost (P):	10551	11950	11854	29757	53050	19569	21329
BENEFITS (Assumed Water Value = 0.30 Pula/m3)							
Annual Flow (m3/yr):	402	548	913	1460	5694	1424	1898
Discount. Ann. Flow:	230	314	523	837	3265	816	1088
Head*Flow (m3*m/yr):	14,856	20,258	33,763	54,020	210,678	52,670	70,226
Benefits @P.30/m3 :	120	164	274	438	1708	427	569
Benefit Stream PW :	1382	1884	3140	5024	19593	4898	6531
Benefit/Cost Ratio :	0.13	0.16	0.26	0.17	0.37	0.25	0.31
Unit Cost (P/m3) (Water Discounted):	4.00	3.32	1.97	3.10	1.42	2.09	1.71
Unit Cost (P/m3) (Water Undiscount.):	2.29	1.90	1.13	1.78	0.81	1.20	0.98
Unit Cost (P/m3*m) :	0.062	0.051	0.031	0.048	0.022	0.032	0.026

Note: This 20 year lifetime is for the windmill head and tower. The actual pump (reciprocating cylinder or Mono pump) is assumed to require replacement every five years (see Appendix A).

Figure 17(b)


Economic Unit Water Cost (P/m3)
OF WINDPUMPS @ 2.0 m/sec AVG. WINDSPEED
Unit Water Cost (P/m3)
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
4.00
2.29
3.32
1.90
1.97
1.13
3.10
1.78
1.42
0.81
2.09
1.20
1.71
0.98
CLMX10
CLMX12
SCRS14
KIJITO
WNDBRN
RIIC
WTGS
TYPE OF WIND PUMP
Water Discounted
Water Undiscounted

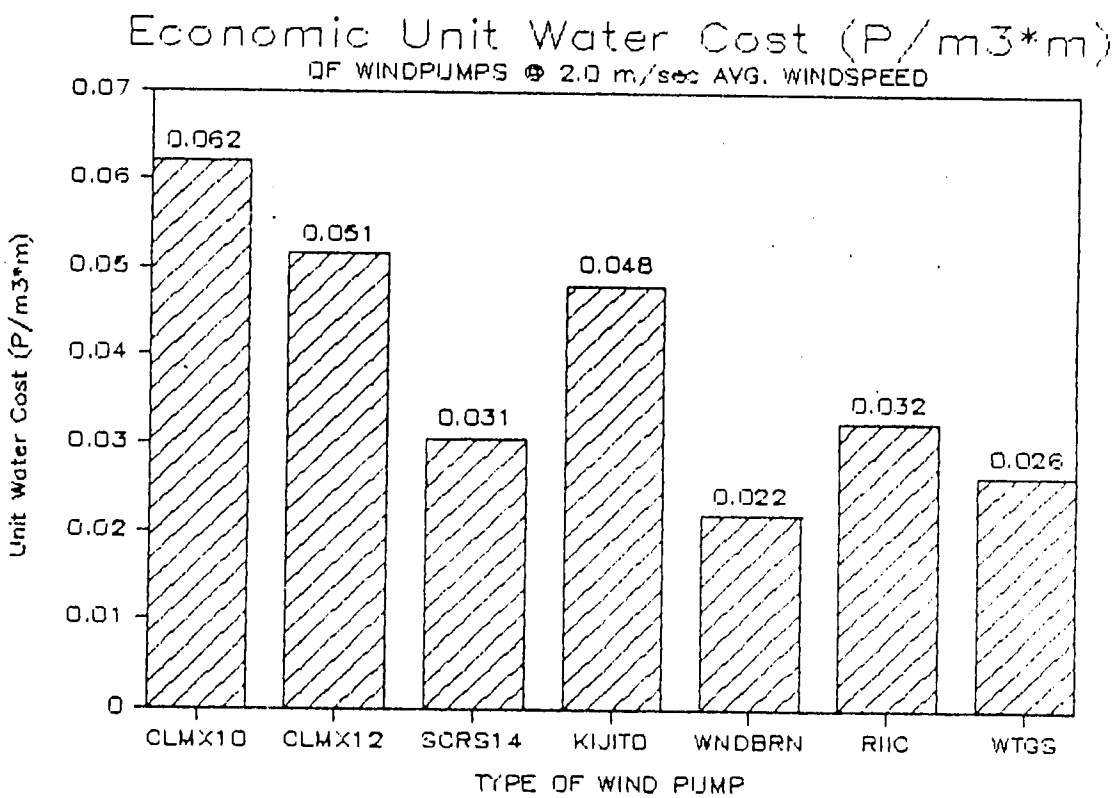

Economic Unit Water Cost (P/m3*m)
OF WINDPUMPS @ 2.0 m/sec AVG. WINDSPEED
Unit Water Cost (P/m3*m)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.062
0.051
0.031
0.048
0.022
0.032
0.026
CLMX10
CLMX12
SCRS14
KIJITO
WNDBRN
RIIC
WTGS
TYPE OF WIND PUMP

Table 4(a)

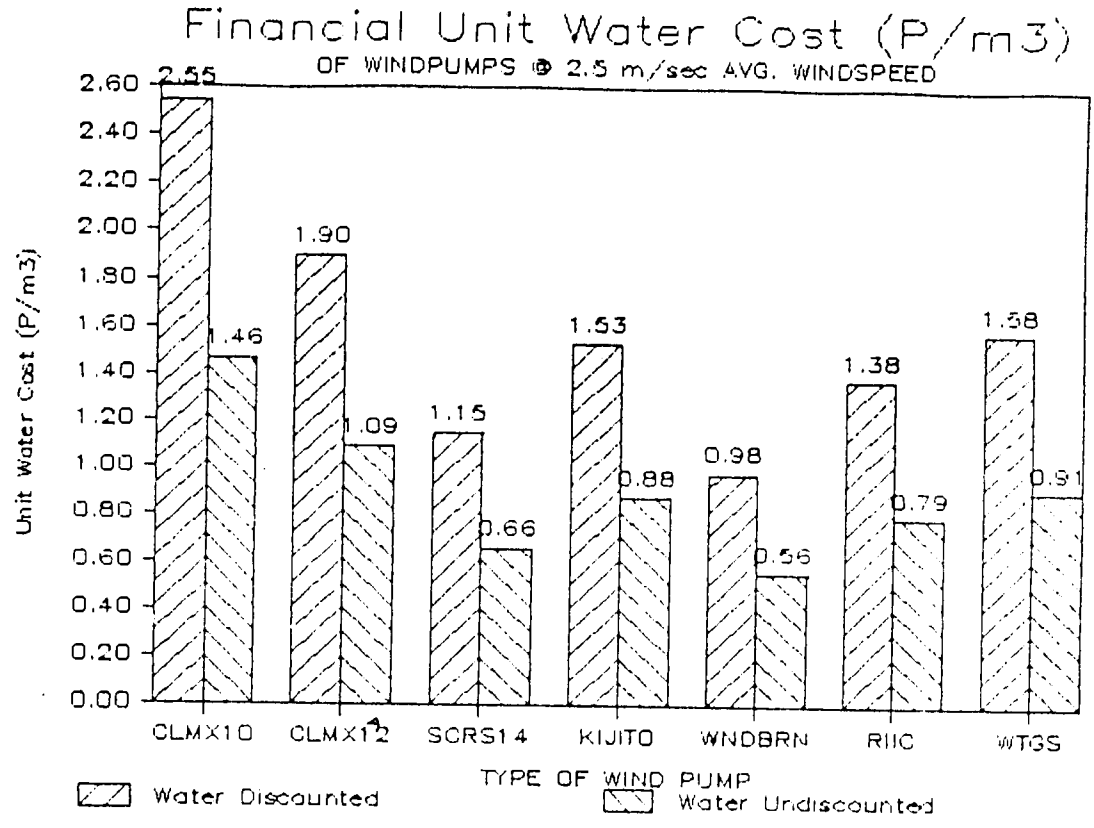
FINANCIAL ANALYSIS OF WINDPUMPS

AVERAGE WINDSPEED = 2.5 M/S

Type of Windpump :	CMAX10	CMAX12	SC 14	KIJITO	W.BARON	RIIC	WTGS
Avg. Output (m3/dy):	2.1	3.1	5.1	8.3	22.7	6.9	6.3
Total Pump Head (m):	37	37	37	37	37	37	37
Amort. Per. (yrs) :	20	20	20	20	20	20	20
Pump Life (yrs)* :	20	20	20	20	20	20	20
Discount Rate (%) :	6%	6%	6%	6%	6%	6%	6
COSTS							
Init. Cap. Cost (P):	3457	4683	4479	20156	36708	4343	4754
Installation Cost :	246	262	262	460	721	600	600
Install. Cost-Labor:	980	980	980	1120	3203	7075	7691
Tot. Installed Cost:	4683	5925	5721	21736	40632	12018	13045
Recurrent Costs PW :	8165	8199	8327	8717	12591	10848	10048
Life Cycle Cost (P):	12848	14124	14048	30453	53223	22866	23893
BENEFITS (Assumed Water Value = 0.30 Pula/m3)							
Annual Flow (m3/yr):	767	1132	1862	3030	8286	2519	2300
Discount. Ann. Flow:	440	649	1068	1737	4752	1444	1319
Head*Flow (m3*m/yr):	28,361	41,866	68,876	112,092	306,564	93,185	85,082
Benefits @P.30/m3 :	230	339	558	909	2486	756	690
Benefit Stream PW :	2638	3893	6405	10424	28510	8666	7914
Benefit/Cost Ratio :	0.21	0.28	0.46	0.34	0.54	0.38	0.33
Unit Cost (P/m3) (Water Discounted):	2.55	1.90	1.15	1.53	0.98	1.38	1.58
Unit Cost (P/m3) (Water Undiscount.):	1.46	1.09	0.66	0.88	0.56	0.79	0.91
Unit Cost (P/m3*m) :	0.039	0.029	0.018	0.024	0.015	0.021	0.024

Note: This 20 year lifetime is for the windmill head and tower. The actual pump (reciprocating cylinder or Mono pump) is assumed to require replacement every five years (see Appendix A).

Figure 18(a)


Financial Unit Water Cost (P/m3)
OF WINDPUMPS @ 2.5 m/sec AVG. WINDSPEED
Unit Water Cost (P/m3)
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
2.55
1.46
1.90
1.09
1.15
0.66
1.53
0.88
0.98
0.56
1.38
0.79
1.58
0.91
CLMX10
CLMX12
SCRS14
KIJITO
WNDBRN
RIIC
WTGS
TYPE OF WIND PUMP
Water Discounted
Water Undiscounted

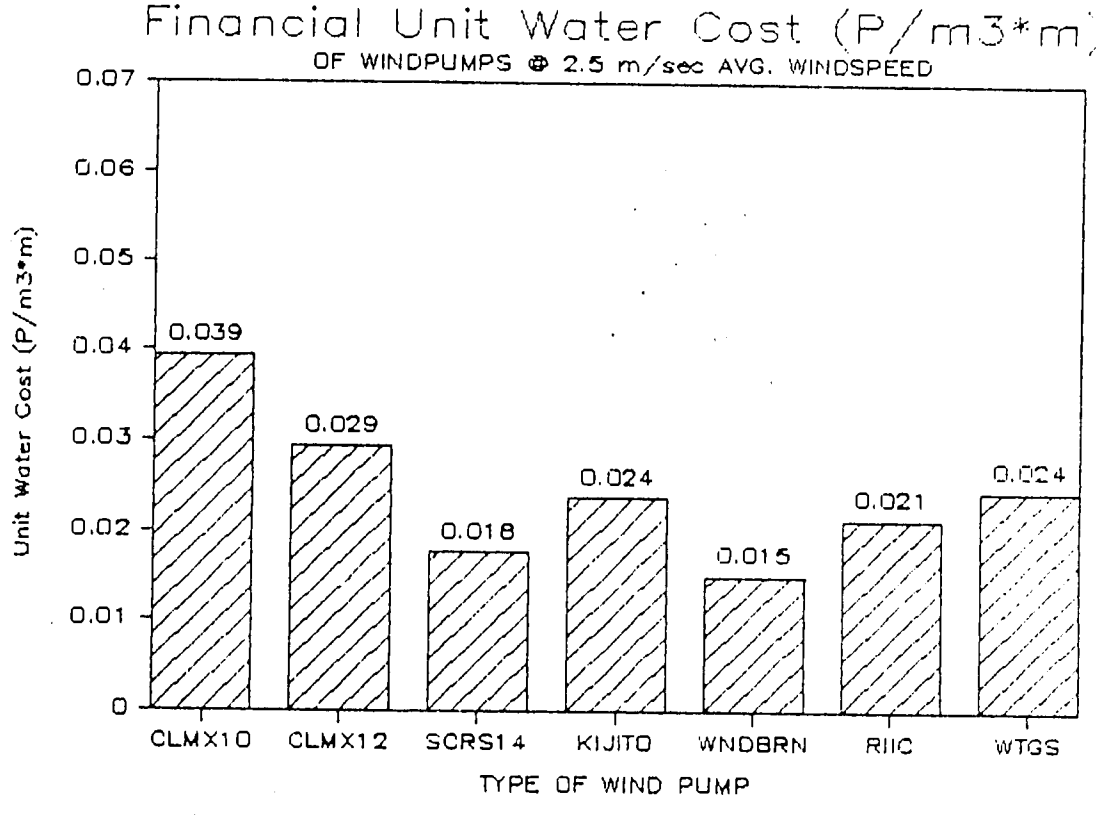

Financial Unit Water Cost (P/m3*m)
OF WINDPUMPS @ 2.5 m/sec AVG. WINDSPEED
Unit Water Cost (P/m3*m)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.039
0.029
0.018
0.024
0.015
0.021
0.024
CLMX10
CLMX12
SCRS14
KIJITO
WNDBRN
RIIC
WTGS
TYPE OF WIND PUMP

Table 4(b)

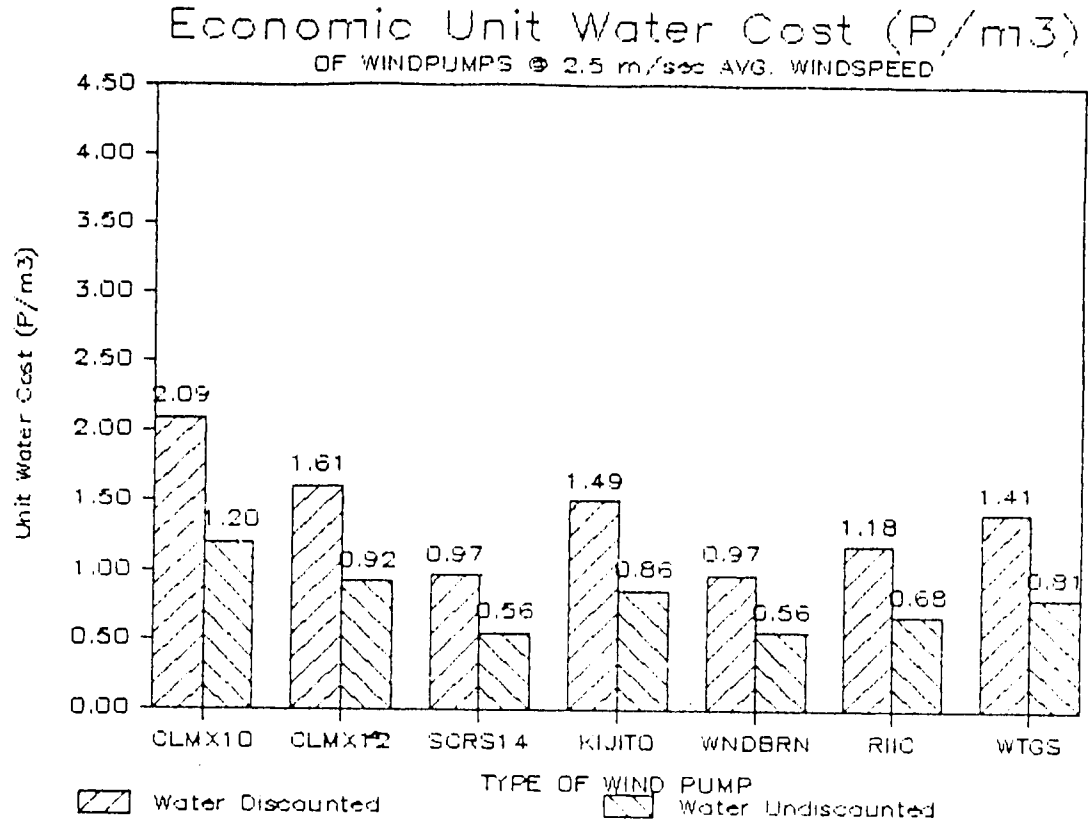
ECONOMIC ANALYSIS OF WINDPUMPS

AVERAGE WINDSPEED = 2.5 M/S

Type of Windpump :	CMAX10	CMAX12	SC 14	KIJITO	W.BARON	RIIC	WTGS
Avg. Output (m3/dy):	2.1	3.1	5.1	8.3	22.7	6.9	6.3
Total Pump Head (m):	37	37	37	37	37	37	37
Amort. Per. (yrs) :	20	20	20	20	20	20	20
Pump Life (yrs)* :	20	20	20	20	20	20	20
Discount Rate (%) :	6%	6%	6%	6%	6%	6%	6
COSTS							
Init. Cap. Cost (P):	3803	5151	4927	22172	40379	4777	5229
Installation Cost :	246	262	262	460	721	600	600
Install. Cost-Labor:	490	490	490	560	1602	5538	6846
Tot. Installed Cost:	4539	5903	5679	23192	42701	10915	12675
Recurrent Costs PW :	6013	6047	6175	6565	10349	8654	8654
Life Cycle Cost (P):	10551	11950	11854	29757	53050	19569	21329
BENEFITS (Assumed Water Value = 0.30 Pula/m3)							
Annual Flow (m3/yr):	767	1132	1862	3030	8286	2519	2300
Discount. Ann. Flow:	440	649	1068	1737	4752	1444	1319
Head*Flow (m3*m/yr):	28,361	41,866	68,876	112,092	306,564	93,185	85,082
Benefits @P.30/m3 :	230	339	558	909	2486	756	690
Benefit Stream PW :	2638	3893	6405	10424	28510	8666	7913
Benefit/Cost Ratio :	0.25	0.33	0.54	0.35	0.54	0.44	0.37
Unit Cost (P/m3) (Water Discounted):	2.09	1.61	0.97	1.49	0.97	1.18	1.41
Unit Cost (P/m3) (Water Undiscount.):	1.20	0.92	0.56	0.86	0.56	0.68	0.81
Unit Cost (P/m3*m) :	0.032	0.025	0.015	0.023	0.015	0.018	0.022

Note: This 20 year lifetime is for the windmill head and tower. The actual pump (reciprocating cylinder or Mono pump) is assumed to require replacement every five years (see Appendix A).

Figure 18(b)


Economic Unit Water Cost (P/m3)
OF WINDPUMPS @ 2.5 m/sec AVG. WINDSPEED
Unit Water Cost (P/m3)
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
2.09
1.20
1.61
0.92
0.97
0.56
1.49
0.86
0.97
0.56
1.18
0.68
1.41
0.81
CLMX10
CLMX12
SCRS14
KIJITO
WNDBRN
RIIC
WTGS
TYPE OF WIND PUMP
Water Discounted
Water Undiscounted

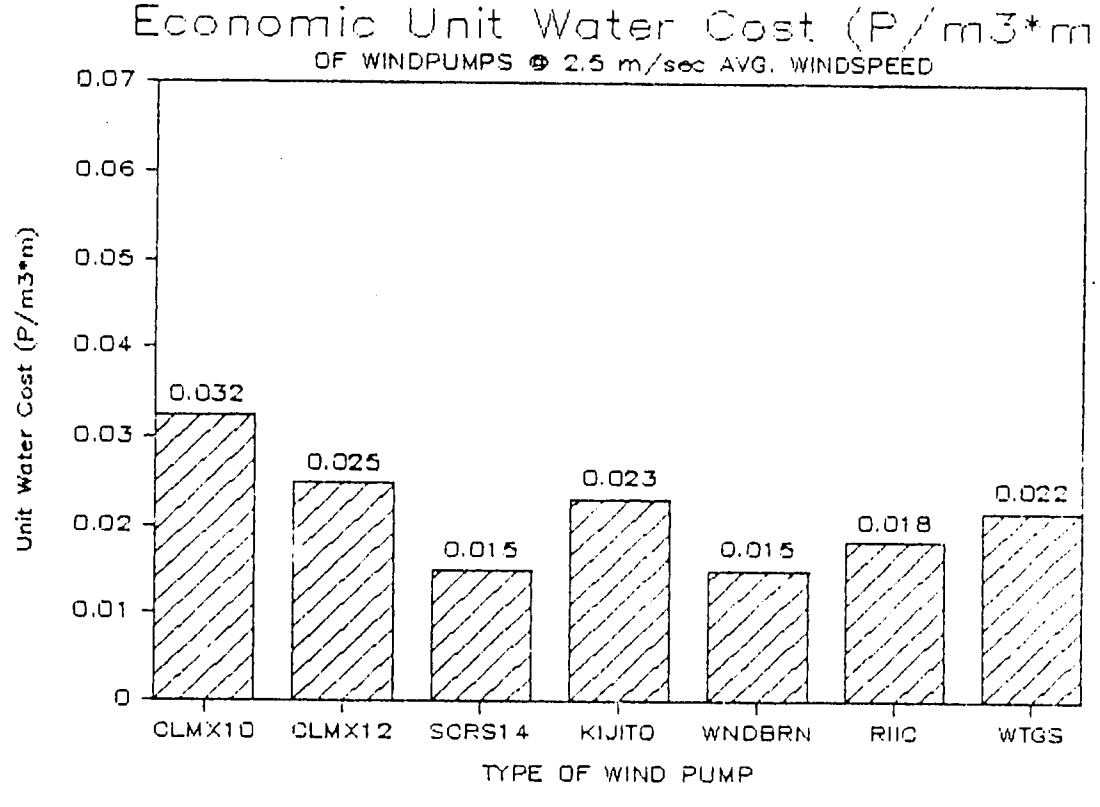

Economic Unit Water Cost (P/m3*m)
OF WINDPUMPS @ 2.5 m/sec AVG. WINDSPEED
Unit Water Cost (P/m3*m)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.032
0.025
0.015
0.023
0.015
0.018
0.022
CLMX10
CLMX12
SCRS14
KIJITO
WNDBRN
RIIC
WTGS
TYPE OF WIND PUMP

Table 5(a)

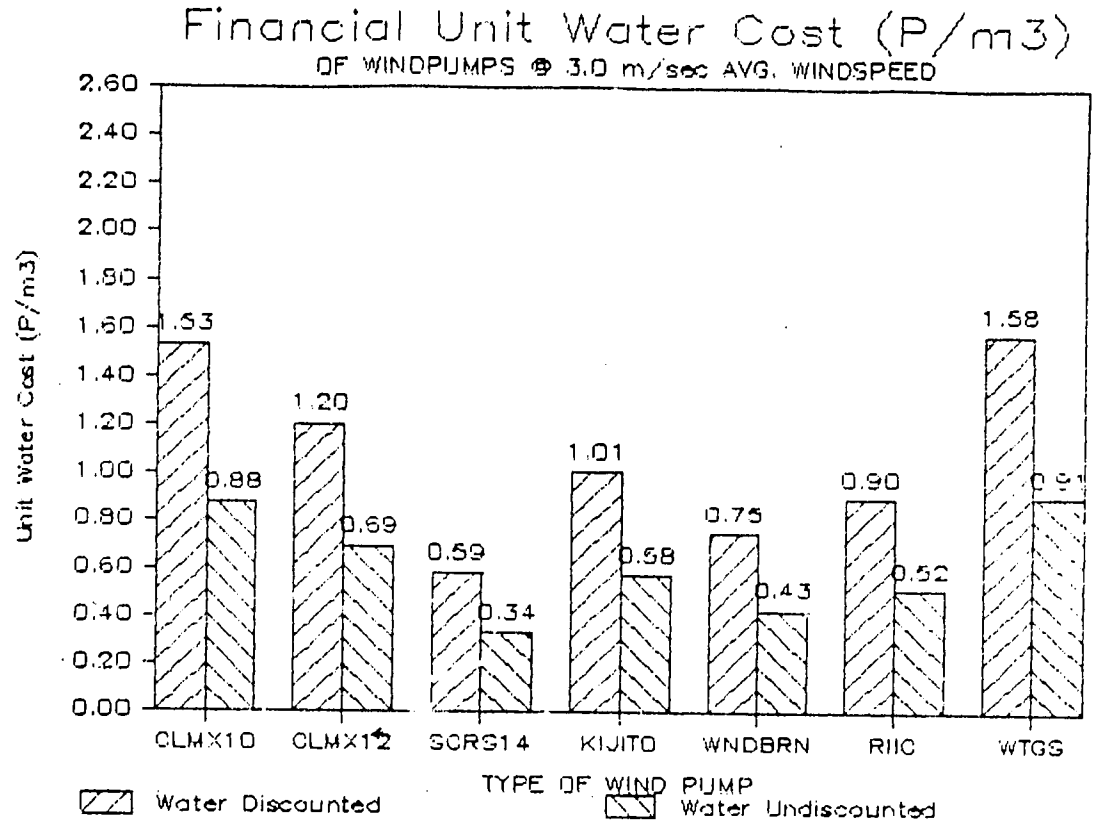
FINANCIAL ANALYSIS OF WINDPUMPS

AVERAGE WINDSPEED = 3.0 m/sec

Type of Windpump :	CMAX10	CMAX12	SC 14	KIJITO	W.BARON	RIIC	WTGS
Avg.Output (m3/d):	3.5	4.9	10.0	12.6	29.7	10.6	8.6
Tot Pump Head (m):	37	37	37	37	37	37	37
Amort. Per. (yrs):	20	20	20	20	20	20	20
Pump Life (yrs)* :	20	20	20	20	20	20	20
Discount Rate (%):	6%	6%	6%	6%	6%	6%	6
COSTS							
Init.Cap.Cost (P):	3457	4683	4479	20156	36708	4343	4754
Installation Cost:	246	262	262	460	721	600	600
Install.Cost-Lab.:	980	980	980	1120	3203	7075	7691
Tot.Install. Cost:	4683	5925	5721	21736	40632	12018	13045
Recurr. Costs PW :	8165	8199	8327	8717	12591	10848	10848
Life Cycle Cost :	12848	14124	14048	30453	53223	22866	23893
BENEFITS (Assumed Water Value = 0.30 Pula/m3)							
Ann. Flow (m3/yr):	1278	1789	3650	4599	10841	3869	2300
Discot. Ann. Flow:	733	1026	2093	2638	6217	2219	1319
Head*Flow m3*m/yr:	47,268	66,175	135,050	170,163	401,099	143,153	116,143
Benefits @P.30/m3:	383	537	1095	1380	3252	1161	690
Benefit Stream PW:	4396	6154	12560	15825	37302	13313	7914
Bene./Cost Ratio :	0.34	0.44	0.89	0.52	0.70	0.58	0.33
Unit Cost (P/m3) : (Water Discount.):	1.53	1.20	0.59	1.01	0.75	0.90	1.58
Unit Cost (P/m3) : (Water Undiscnt.):	0.88	0.69	0.34	0.58	0.43	0.52	0.91
Unit Cost(P/m3*m):	0.024	0.019	0.009	0.016	0.012	0.014	0.018

*Note: This 20 year lifetime is for the windmill head and tower. The actual pump (reciprocating cylinder or Mono pump) is assumed to require replacement every five years (see Appendix A).

Table 19(a)


Financial Unit Water Cost (P/m3)
OF WINDPUMPS @ 3.0 m/sec AVG. WINDSPEED
Unit Water Cost (P/m3)
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1.53
0.88
1.20
0.69
0.59
0.34
1.01
0.58
0.75
0.43
0.90
0.52
1.58
0.91
CLMX10
CLMX12
SCRS14
KIJITO
WNDBRN
RIIC
WTGS
TYPE OF WIND PUMP
Water Discounted
Water Undiscounted

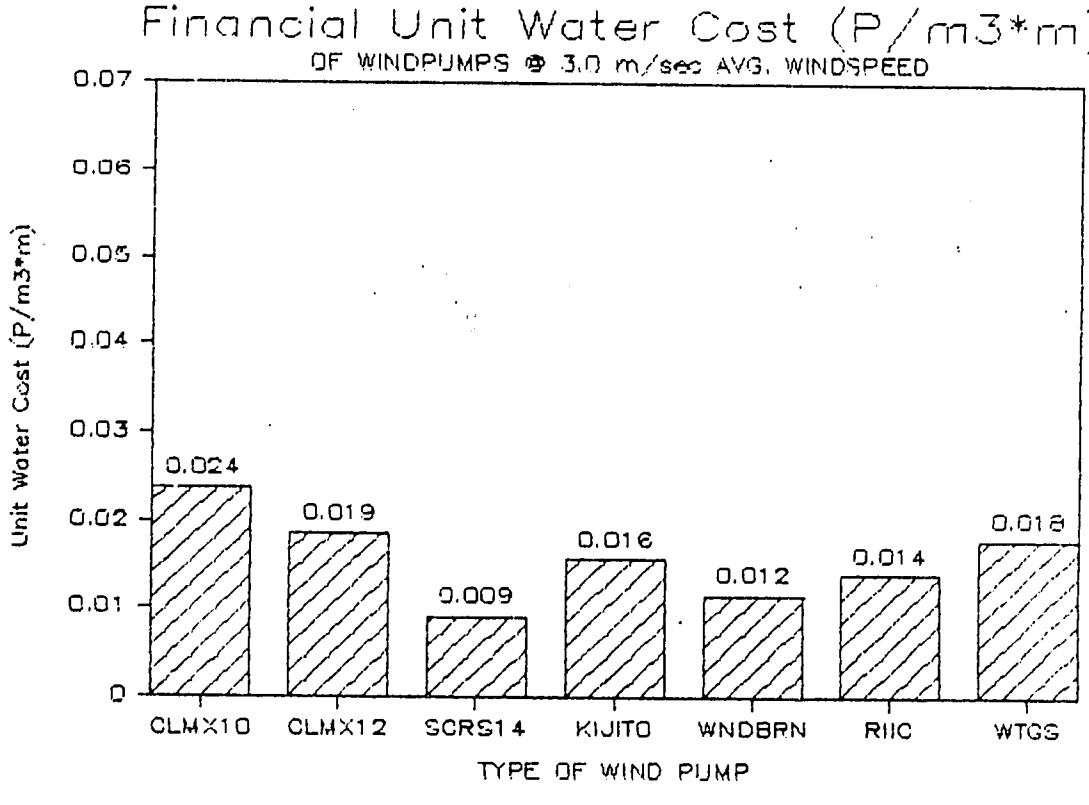

Financial Unit Water Cost (P/m3*m)
OF WINDPUMPS @ 3.0 m/sec AVG. WINDSPEED
Unit Water Cost (P/m3*m)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.024
0.019
0.009
0.016
0.012
0.014
0.018
CLMX10
CLMX12
SCRS14
KIJITO
WNDBRN
RIIC
WTGS
TYPE OF WIND PUMP

Table 5(b)

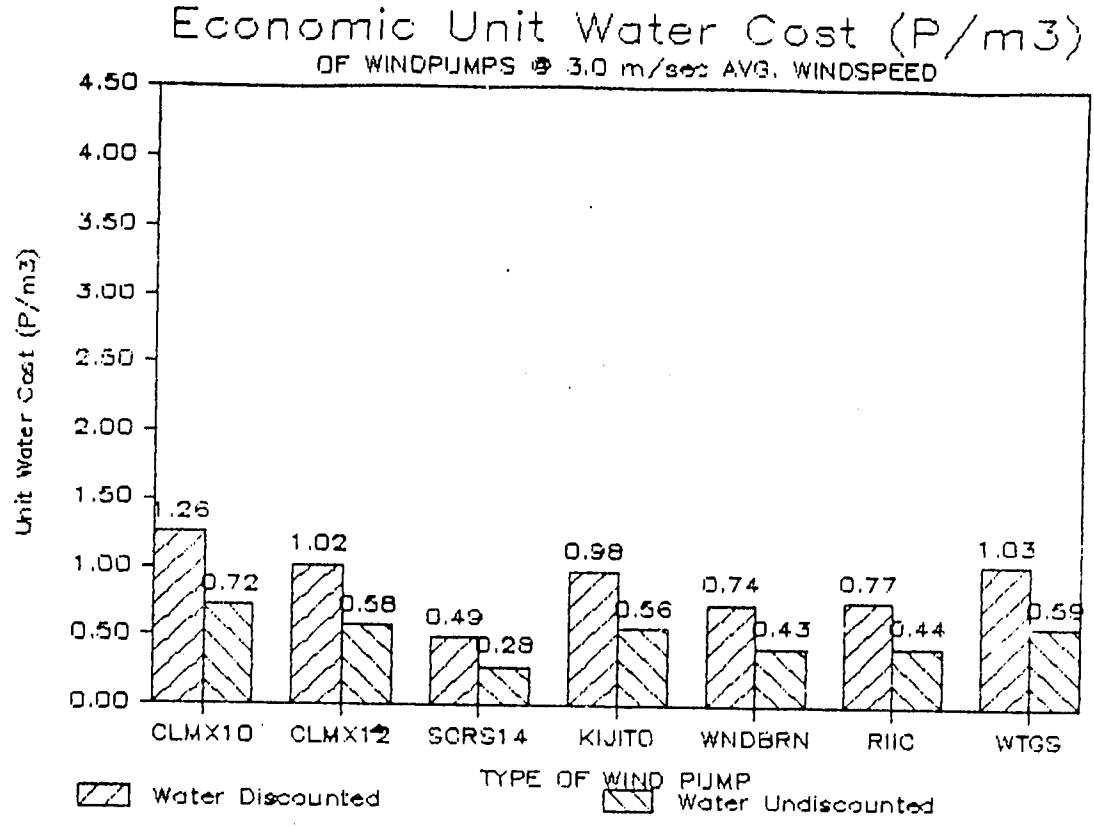
ECONOMIC ANALYSIS OF WINDPUMPS

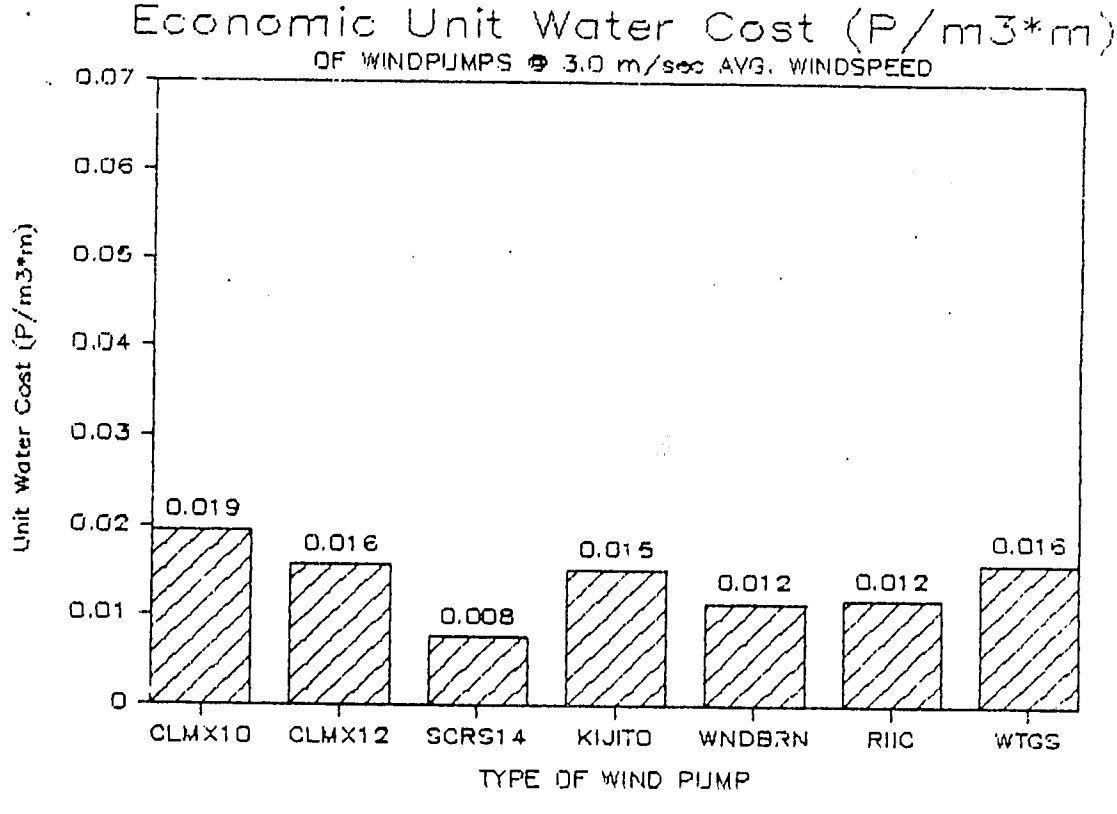
AVERAGE WINDSPEED = 3.0 m/sec

Type of Windpump :	CMAX10	CMAX12	SC 14	KIJITO	W.BARON	RIIC	WIGS
Avg.Output (m3/d):	3.5	4.9	10.0	12.6	29.7	13.6	8.6
Tot Pump Head (m):	37	37	37	37	37	37	37
Amort. Per. (yrs):	20	20	20	20	20	20	20
Pump Life (yrs)* :	20	20	20	20	20	20	20
Discount Rate (%):	6%	6%	6%	6%	6%	6%	6
COSTS							
Init.Cap.Cost (P):	3803	5151	4927	22172	40379	4777	5229
Installation Cost:	246	262	262	460	721	600	600
Install.Cost-Lab.:	490	490	490	560	1602	5538	6846
Tot.Install. Cost:	4539	5903	5679	23192	42701	10915	12675
Recurr. Costs PW :	6013	6047	6175	6565	10349	8654	8654
Life Cycle Cost :	10551	11950	11854	29757	53050	19569	21329
BENEFITS (Assumed Water Value = 0.30 Pula/m3)							
Ann. Flow (m3/yr):	1278	1789	3650	4599	10841	3869	3139
Discot. Ann. Flow:	733	1026	2093	2638	6217	2219	1800
Head*Flow m3*m/yr:	47,268	66,175	135,050	170,163	401,099	143,153	116,143
Benefits @P.30/m3:	383	537	1095	1380	3252	1161	942
Benefit Stream PW:	4396	6154	12560	15825	37302	13313	10801
Bene./Cost Ratio :	0.42	0.51	1.06	0.53	0.70	0.68	0.51
Unit Cost (P/m3) : (Water Discount.):	1.26	1.02	0.49	0.98	0.74	0.77	1.03
Unit Cost (P/m3) : (Water Undiscnt.):	0.72	0.58	0.28	0.56	0.43	0.44	0.59
Unit Cost(P/m3*m):	0.019	0.016	0.008	0.015	0.012	0.012	0.016

*Note: This 20 year lifetime is for the windmill head and tower. The actual pump (reciprocating cylinder or Mono pump) is assumed to require replacement every five years (see Appendix A).

Figure 19(b)


Economic Unit Water Cost (P/m3)
OF WINDPUMPS @ 3.0 m/sec AVG. WINDSPEED
Unit Water Cost (P/m3)
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1.26
0.72
1.02
0.58
0.49
0.28
0.98
0.56
0.74
0.43
0.77
0.44
1.03
0.59
CLMX10
CLMX12
SCRS14
KIJITO
WNDBRN
RIIC
WTGS
TYPE OF WIND PUMP
Water Discounted
Water Undiscounted


Economic Unit Water Cost (P/m3*m)
OF WINDPUMPS @ 3.0 m/sec AVG. WINDSPEED
Unit Water Cost (P/m3*m)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.019
0.016
0.008
0.015
0.012
0.012
0.016
CLMX10
CLMX12
SCRS14
KIJITO
WNDBRN
RIIC
WTGS
TYPE OF WIND PUMP

Since the head is the same in all cases, the relative ranking of the systems remains the same for the last criterion. Also, given that the stream of benefits (i.e., the amount of water pumped on an annual basis) was assumed to be constant over the equipment's lifetime, the relative rankings of the systems for the first two figures (discounted versus undiscounted volumes of water) are identical. Hence, for all practical purposes, only one of the three criteria need be examined here. Nevertheless, the entire standard spread-sheet was calculated for consistency in this presentation.

In comparing the financial and economic analyses, the latter predictably favor indigenous systems because of the shadow-price of 0.5 on local labor inputs and the increase in the apparent cost of imported machines due to foreign currency shadow-pricing, although this also affects the imported steel and fabricated parts used to manufacture the indigenous machines. Since much of the manufacturing costs for the indigenous systems is for local labor, that part of the initial capital costs was shadow-priced accordingly and included in the labor portion of the installation cost for convenience. Hence, the installation labor charges given for the RIIC and WTGS machines appear unreasonably high, but actually reflect the labor costs for both manufacturing and installation. The capital cost of each system was determined as follows:

- for machines purchased by the BRET project, the actual dollar costs incurred were adjusted by the present foreign exchange rate;

- for the RIIC and WTGS pumps, the imported steel, bearings, shafts, etc. used to manufacture those machines were summed; and

- for the standard wind pumps, either a current quote (if available) or the actual price paid by DWA was used.

In general, since more water is pumped at higher wind speeds, while equipment and operation and maintenance costs remain essentially constant, the unit water costs were lower for higher wind speeds, as expected. This assumes that the wear and tear on the equipment is not significantly greater for these relatively small incremental increases in wind speed. For the standard-design wind pumps (Climax and Southern Cross), unit ts decreased as rotor size increased. This was also cted--the increase in power output normally rises at a ter than linear rate compared to the incremental cost of the er rotor, since the majority of the other equipment costs er, sucker rod, etc.) remain constant.

This relationship was not as clear for the nonstandard machines (i.e., Wind Baron, WTGS, RIIC and Kijito) for several reasons. The cost to import wind pumps from Kenya and the United States was quite high, so delivered capital costs for the imported machines (Wind Baron and Kijito) were much greater than for wind pumps manufactured in Botswana or South Africa. However, these increased costs were largely offset by the superior performance of the imported machines, at least over the short term. Nevertheless, the BRET project has found that the procurement of spare parts may well be a significant deterrent to the use of imported machines, primarily due to unreasonable delays in freight forwarding once equipment arrives in South Africa. If these systems were fabricated in southern Africa (and this appears to be a possibility for both the Kijito and Wind Baron), the results of this analysis could change dramatically.

The indigenous systems coupled to Mono pumps are an interesting and unique development. Compared to the other reciprocating-piston wind pumps, the unit water costs for the WTGS and RIIC systems were considerably less than for the 10- and 12-foot Climax machines (although the former had much larger rotors), and in the same range as the Kijito (with a rotor of the same size) and Southern Cross (smaller rotor). However, the RIIC and WTGS designs do not enjoy the presumed economies of scale associated with the production of standard wind pumps, although higher production levels might well reduce unit costs for the indigenous machines. In addition, it was not clear whether the prices paid for the RIIC and WTGS machines represented actual production costs--i.e., whether implicit subsidies were involved or research and development costs were being recovered over a small number of machines. From a technical perspective, the Mono systems have another distinct advantage over reciprocating-piston machines in that they permit convenient coupling to auxiliary diesel engines for back-up power during periods of low wind speeds, since only the belts need be switched. All in all, the Mono-coupled systems are prototypes that show significant promise.

The Wind Baron has the potential to deliver a lot of water at a relatively low unit cost, if it is assumed (perhaps unjustifiably) that redesign efforts will reduce currently unacceptable maintenance requirements to levels which are characteristic of standard, production-model wind pumps. The Wind Baron's potential is largely a function of its counterbalanced design. Both Kijito and Climax sell counterbalance kits that should have the same effect on performance as the integrated Wind Baron system, but these were not tested by the BRET project, so their potential to reduce the unit cost of water delivery is speculative. Because performance is enhanced by counterbalancing, especially in areas with low wind speeds, such as Botswana, it is a bit misleading to compare counterbalanced to non-counterbalanced systems. However, this is

a moot point at present, since the repair record for the Wind Baron was so poor that recommending its use would be inappropriate at its current level of development, regardless of potential performance.

The comparatively high installation cost for the Wind Baron was due to the use of a drop pipe with a considerably larger diameter to accommodate the greater flow of water expected, an imported pump cylinder that was larger than the ones locally available and a rented crane to install the machine on its tower. In a subsequent installation, a gin-pole arrangement was used instead of the crane, and this will greatly decrease installation costs in the future. However, changing the installation cost in the present analysis to reflect this decrease would not affect the ranking of the various wind pumps.

One other major point must be raised. Unlike diesel pumps, a windmill's output depends on the availability of the wind, which is a highly variable energy resource. The estimated performance figures given here are only statistical averages for the conditions cited. A wind pump's output during periods of low wind speed cannot be augmented without incurring the additional costs of a back-up system. If the site under consideration has long periods of low wind speeds (greater than the maximum capacity of a reasonable storage system), a back-up power source, such as a diesel engine, must be included in the system's design. Otherwise, a wind pump is inappropriate for the site.

B. Alternatives

Although this report is concerned primarily with the performance and economics of wind pumps, their financial and economic implications must be considered relative to alternative pumping systems. This is the main subject of a companion report, titled FIELD TESTS OF SMALL-SCALE WATER PUMPS IN BOTSWANA (draft, Richard McGowan and Jonathan Hodgkin, ARD, Burlington, VT, October 25, 1985). However, a few comments on the economics of diesel pumping systems are needed here to gain some insight on the potential for wind systems in Botswana.

As part of the BRET project's overall pump testing program, five diesel systems were tested. Initial indications are that wind pumps will be the least-cost choice only in cases where the design wind-speed condition is greater than 2.5 to 3.0 meters per second and average daily demand is less than 10 cubic meters per day. If a wind system can pump this amount of water per day (remembering, of course, that this depends on the head as well), it will very likely be the least-cost option, compared to a diesel engine. However, as the demand for water increases, it is not only more difficult for a wind pump to meet the demand, due

to the inherent size limitations of the available equipment, but the comparative unit water cost for diesel pumps also improves.

Preliminary results indicate that all of the new-design wind pumps have the potential to meet this criterion for heads of less than 35 meters and wind speeds in the range of three meters per second or for lower wind speeds in conjunction with less head. The next step is determining the areas where these conditions coincide and the potential market for wind pumps in those areas. While these issues will be examined in considerably greater detail during the extension of the comparative pump testing program, it appears from the limited data which are currently available that the number of sites in Botswana where wind pumps are a cost-competitive option are limited.

VIII. LIMITATIONS

The introduction of a new technology or a novel application of an existing technology requires both the identification of its proper role and overcoming the inertia of established ways. Specifying the technical, economic and institutional constraints to adoption of a new technology helps determine the steps that must be taken if the device is to fulfill its role.

A. Technical

Technical limitations are the major constraint to wind pump use in Botswana. As has already been discussed, average wind speeds in this country range from 2.5 to 3.0 meters per second, and areas with pumping heads of less than 40 meters are limited. These are the most serious limitations to wind pump utilization. However, there are locations where the head is less than 30 meters and wind speeds are close to 3.0 meters per second. In fact, the BRET project is testing wind pumps at several such sites (e.g., Tlhareseele and Pitsane-Botloko). Still, it appears that there are few sites which are as appropriate as these.

The areas where the wind conditions appear most favorable are the southern and western parts of Botswana, while wind speeds in the east are generally low. Unfortunately, the average depth to the water table also seems to increase to the west, although there are some areas with shallow water. Areas that are suitable for wind pumps remain to be defined more closely by the wind resource assessment and a survey of the depth to the water table.

B. Applications

Whether wind pumps are an acceptable water-pumping technology depends to a large degree on their application. In Botswana, water is primarily used for human and cattle consumption, with some irrigation and very little industrial use, outside of one or two areas. DWA's major activities consist of maintaining water delivery systems in the major villages and at government establishments, and building reticulation systems for approximately 354 villages in the village water supply program (many of which are now complete). To date, the water requirements for most of these villages have been beyond the capability of wind pumps. During later stages of the DWA program, when smaller villages with lesser demands for water are considered, wind pumps may be competitive with the standard diesel system, based on the unit cost of water, but this will ultimately depend on the technical limitations outlined above. Thus, it does not appear that wind systems will play a large role in village-scale water supplies. However, as district councils

become involved in water supply schemes for small settlements and lands areas, the use of wind pumps may be more appropriate.

Water for livestock seems to be the area where wind pumps can make the greatest impact. This application includes the provision of water at Department of Wildlife sites and cattle posts. Stock syndicates are also potential users. The advantage of using a wind system to supply water for livestock is that cattle can be moved to a borehole with a diesel pump if there is no wind, rather than incurring the additional cost of a back-up system at the wind pump site. More work needs to be done to further define this potential market, but technical constraints will eliminate many possible sites. However, there are places and applications where wind systems will represent the least-cost pumping option.

C. Economic

In the long run, economic constraints are tied to the long-term performance of wind pumps. It appears that wind systems will only be economically viable in areas of Botswana with higher wind speeds and heads of less than 40 meters. In addition, the capital cost of a wind pump can be a significant constraint, particularly for syndicates or private farmers who must borrow funds (at an interest rate of 16 percent) to buy a system. Foreign exchange demands, the availability of financing and costs to develop an infrastructural network to provide training, spare parts inventories, and support for system design, installation, and long-term operation and maintenance are further constraints that should be examined in greater detail.

D. Institutional

If wind pumps are to be used sucessfully in Botswana, there must be an institutional framework for skilled installation, maintenance, repair and parts procurement. For the Climax machines, at least, there are individuals in the private sector who possess these skills, in addition to the DWA windmill crew. If windmills are installed at Department of Wildlife sites or by syndicates, DWA's Borehole Repair Service also needs to be trained to maintain and repair them, which represents a costly and time-consuming constraint. Before such a training program is undertaken, the wind resource survey should be completed and studied closely to determine whether the potential number of wind pumps would justify this expense.

For the imported wind pumps (Kijito and Wind Baron) the major problem is parts procurement. Unless there is a broad program to import these machines, it is unlikely that their use would be a reasonable option. If either or both of these systems

are eventually fabricated in southern Africa, this situation may change.

The RIIC and, to a lesser extent, WTGS designs have a distinct advantage in terms of institutional limitations. Because they are being manufactured in Botswana, all the necessary repair and maintenance skills can be found there. This is particularly true for the RIIC Motswedi, as an installation crew has been specially trained to install and repair these wind pumps.

E. Summary

The limitations on the use of wind systems discussed in this section are of two types--those that can be overcome by further development or training efforts and those that cannot, which represent more serious constraints. An accurate characterization of the potential for wind pump usage in Botswana is not yet available, since the wind resource assessment is not complete and borehole records have not been carefully examined for average depths to the water table and yields by area. Once the extent of the potential market for wind pumps is established, it will be much easier to define the constraints which are operating and steps that can be taken to overcome them.

IX. CONCLUSIONS

Conclusions drawn from the results of the comparative pump testing program to date must be considered tentative because two majcr portions of its work remain to be finished:

- an assessment of the true potential for wind pumping in Botswana, and
- fully defining the performance of wind pumps in this environment.

The potential for wind pumping systems in this country is largely a function of the wind regime and depth to the water table, and neither topic has yet been examined comprehensively. The wind resource assessment and map of depths to the water table, planned as part of the wind survey, will be completed in early to mid-1986 and will provide the basis for evaluating the actual potential for wind systems in Botswana.

While a significant amount of performance and cost data was collected during the past year, this work is not finished. For example, some anemometers have not been calibrated, which may have an impact on both the measured and extrapolated long-term output of wind pumps at other sites. Also, it appears that several of the systems should be performing better than they have been. In some cases (RIIC and WTGS), the reasons for such shortcomings are understood; in others (the pumps at Sedibeng and Kgoro), they are not. To fully describe the performance of the wind systems tested, it is necessary to collect enough data for a pump curve to understand the pump's characteristics over the entire range of wind speeds that are commonly encountered. While this data collection effort is certainly well underway, a significant amount of information remains to be gathered.

Despite these cautionary notes, it is possible to draw some useful conclusions from the initial phase of the BRET comparative pump testing program, bearing in mind that they may require refinement as further results become available. First, and perhaps not surprisingly, the performance of most of the wind systems was not as good as expected. Although all of the reasons behind the performance results are not yet known, it appears certain that often the problem was not the wind pump, but poor borehole yield, inappropriate pump selection and/or load matching, improper adjustment or inadequate installation. In the case of the WTGS and RIIC designs, the windmill was not well matched to the pump through the power transfer device.

Second, because of the wind regime and pumping heads found in much of Botswana, it is not likely that wind pumps will be found to be widely cost-effective. However, there are areas of

the country where the wind speeds average nearly three meters per second and heads are less than 35 meters. If the water demand at such sites is in the range of 10 cubic meters per day, a wind system appears to be the most economical alternative. Thus far, the results indicate that the larger the rotor diameter of the wind pump, the more cost-competitive it would be.

Third, at the other end of the spectrum, it is clear that there are areas where wind systems are not an economical solution, even if it were possible for them to meet the demand. In between these two extremes fall a large number of sites where other factors besides wind speed and depth to the water table come into play. The BRET comparative pump testing project sought to specify these factors, but the data required to do so are not yet complete.

Fourth, the most promising application for wind systems appears to be livestock watering, both by the Department of Wildlife and syndicates or private farmers. In addition, there may well be a place for wind pumps in small settlements, lands areas and on some government boreholes at border posts, veterinary or police stations, or other locations with limited water requirements.

Fifth, the RIIC and WTGS machines clearly have the potential to be cost-competitive with traditional wind pump designs, and their performance can still be improved. They have substantial advantages over the other new designs tested by the BRET project in that they are produced locally and use of the Mono pump system permits convenient coupling to a diesel back-up engine. However, it does not appear that the potential market in Botswana justifies the development of two such similar systems.

Sixth, due to the proven longevity, ease of procurement and lower capital costs of the Climax machines, they will continue to have a place in the wind pump market in Botswana. The Climax is the best known wind pump, and there are dealers in Botswana who are ready and able to provide installation and service. A significant number of these systems are already in use in several areas of the country.

X. RECOMMENDATIONS

First, the work initiated by the wind pump testing program should be continued, as it is a major effort that will lead to a determination of sites where wind pumps are an economical option. At present, it is necessary to follow up on this initiative and build on the work already accomplished. An 18-month to two-year program is recommended (and has been funded) to ensure repair and maintenance for the wind systems installed, support the continued collection of data for a full year, and allow sufficient time to properly analyze results. This extension of the wind pump testing program should be undertaken as a part of a larger comparative effort to examine alternatives to wind pumps. A lower level of effort is recommended in subsequent years to continue gathering data on the long-term recurrent costs of wind systems.

Second, continuation and expansion of the wind resource assessment is required. Complete information concerning Botswana's wind potential is a necessary component of understanding the implications of wind pump use in this country. Such work is currently being performed as a part of an SIDA consultancy, the results of which should be available by mid-1986. It is anticipated that Met Services will continue to collect wind data beyond that time, as long-term recording periods are necessary for a statistically accurate evaluation of the wind resource.

Third, technical and economic support should be sought to continue development of the RIIC and WTGS designs. These machines have unique attributes that would make them more attractive than nonindigenous wind pumps if they were more fully developed. Although it appears that there will only be room for one of these designs in the Botswana market, it is too early to determine which is the most suitable. In addition, both may have potential markets in other developing countries where rotary pumps are available. Technical and economic assistance for the development of these designs should be sought on the basis of more widespread utilization of these systems.

Fourth, although the imported wind pumps that are newer designs show considerable promise in terms of their technical performance, no further purchases of these systems should be made until they are fabricated in southern Africa. In the case of the Wind Baron, additional purchases should also be contingent on the necessary redesign work and assurances that the problems encountered during this testing program have been solved.

Fifth, research to quantify the costs of developing an adequate support infrastructure for wind pumps should be undertaken. This work should include the costs of training

personnel to design, size, install, operate, maintain and repair all system components. It should also study constraints (both institutional and financial) to importing foreign components as well as government policies (e.g., import duties, licenses, wage rates, etc.) that could significantly affect the adoption of wind technologies for water pumping.

Sixth, a study to compile a list of government sites that require less than 10 cubic meters of water per day should be conducted. In conjunction with the wind resource assessment and map of depths to the water table, this will provide a good sense of the market potential for wind pumps in the public sector.

Seventh, information generated by the wind pump study should be made available to the private sector as it becomes available. This group, particularly farmers and syndicate members, represents one of the largest populations of potential wind pump users. It is important that they have current and relevant information to permit them to make the most knowledgeable decisions possible about pumping options.

APPENDIX A

Wind Resource Assessment Sites

Installed	Planned
Central District	
Bobonong	Mahalapye
Dibete	
Gweta	
Nata	
Orapa	
Rakops	
Serowe	
Selibi-Pikwe	
Shoshong	
Tutume	
Chobe District	
Kasane	none
Mababe Gate	
Pandematenga	
Gaborone	
Ghanzi District	
Kuke	Ghanzi
Ncojane	Xadi
Kgalagadi District	
Bokspits	Tsabong
Mabuasehube	Tsane
Kweneng District	
Ditshegwane (now moved)	Motokwe
Kutse	
Ngamiland District	
Qangwa	Maun
Tsau	Shakawe
Southern District	
Jwaneng	none
Kanye	
Khakhea	
Mabule	

System Descriptions

BRET WIND PUMP INSTALLATIONS (STANDARD DESIGNS)

SITE:	DIPOTSANA
DISTRICT:	SOUTHERN
B.H. NO.:	#821
MANUFACTURER:	CLIMAX
DIAMETER:	12 FEET
TOWER:	9 METER
PUMP TYPE:	3.0" PISTON PUMP
GEAR RATIO:	3:1
TOTAL HEAD:	30 METERS
SYSTEM INSTALLED COST:	5,663 PULA

SITE:	KGORO
DISTRICT:	SOUTHERN
B.H. NO.:	#806
MANUFACTURER:	CLIMAX
DIAMETER:	10 FEET
TOWER:	9 METER
PUMP TYPE:	2.75" PISTON PUMP
GEAR RATIO:	3.18:1
TOTAL HEAD:	35 METERS
SYSTEM INSTALLED COST:	4,606 PULA

SITE:	MALESANE
DISTRICT:	SOUTHERN
B.H. NO.:	#810
MANUFACTURER:	SOUTHERN CROSS
DIAMETER:	14 FEET
TOWER:	12 METER
PUMP TYPE:	3.0" PISTON PUMP
GEAR RATIO:	2.33:1
TOTAL HEAD:	35 METERS
SYSTEM INSTALLED COST:	5,780 PULA

SITE:	SEDIBENG
DISTRICT:	SOUTHERN
B.H. NO.:	#3815
MANUFACTURER:	CLIMAX
DIAMETER:	12 FEET
TOWER:	12 METER
PUMP TYPE:	2.75" PISTON PUMP
GEAR RATIO:	3:1
TOTAL HEAD:	27 METERS
SYSTEM INSTALLED COST:	6,486 PULA

SITE:	THARESELEELE
DISTRICT:	SOUTHERN
B.H. NO.:	UNKNOWN
MANUFACTURER:	CLIMAX
DIAMETER:	12 FEET
TOWER:	9 METER
PUMP TYPE:	3.5" PISTON PUMP
GEAR RATIO:	3:1
TOTAL HEAD:	19 METERS
SYSTEM INSTALLED COST:	5,541 PULA

BRET WIND PUMP INSTALLATIONS (NEW DESIGNS)

SITE:	MOCHUDI
DISTRICT:	KGATLENG
B.H. NO.:	#4205
MANUFACTURER:	KIJITO
DIAMETER:	20 FEET
TOWER:	9 METERS
PUMP TYPE:	3.25" PISTON PUMP
GEAR RATIO:	1:1 (DIRECT STROKE)
TOTAL HEAD:	35 METERS
SYSTEM INSTALLED COST:	16,768 PULA (3/84) 21,742 PULA (7/85)

SITE:	PITSANE-BOTLOKO
DISTRICT:	SOUTHERN
B.H. NO.:	UNKNOWN
MANUFACTURER:	KIJITO
DIAMETER:	20 FEET
TOWER:	9 METER
PUMP TYPE:	3.25" PISTON PUMP
GEAR RATIO:	1:1 (DIRECT STROKE)
TOTAL HEAD:	23 METERS
SYSTEM INSTALLED COST:	16,749 PULA (3/84) 21,715 PULA (7/85)

SITE:	MOCHUDI
DISTRICT:	KGATLENG
B.H. NO.:	#4202
MANUFACTURER:	RIIC (MOTSWEDI)
DIAMETER:	6 METERS
TOWER:	9 METERS
PUMP TYPE:	ES-15S MONOPUMP
GEAR RATIO:	VARIABLE (.9:1 TO 1:6.2)
TOTAL HEAD:	37 METERS
SYSTEM INSTALLED COST:	10,858 PULA

SITE:	MALAU
DISTRICT:	SOUTHERN
B.H. NO.:	#817
MANUFACTURER:	RIIC (MOTSWEDI)
DIAMETER:	6 METERS
TOWER:	9 METERS
PUMP TYPE:	ES-10 MONOPUMP
GEAR RATIO:	VARIABLE BY VSU
TOTAL HEAD:	53 METERS
SYSTEM INSTALLED COST:	11,267 PULA

BRET WIND PUMP INSTALLATIONS (NEW DESIGNS) CONTINUED

SITE:	MOCHUDI
DISTRICT:	KGATLENG
B.H. NO.:	#4232
MANUFACTURER:	WIND BARON MK4
DIAMETER:	21 FEET
PUMP TYPE:	4.0" PISTON PUMP
GEAR RATIO:	1.5:1
TOWER:	12.5 METERS
TOTAL HEAD:	33 METERS
SYSTEM INSTALLED COST:	28,487 PULA (7/83) 40,554 PULA (7/85)

SITE:	MOCHUDI
DISTRICT:	KGATLENG
B.H. NO.:	#4220
MANUFACTURER:	MOMOSO ENGINEERING (WTGS)
DIAMETER:	6.1 METERS
PUMP TYPE:	ES-15S MONOPUMP W/ CLUTCH
TOWER:	9 METERS
GEAR RATIO:	1:8.5
TOTAL HEAD:	37 METERS
SYSTEM INSTALLED COST:	13,269 PULA

APPENDIX C

Detailed Cost Breakdowns

This appendix provides a detailed cost breakdown and the rationale for estimating long-term recurrent costs, since a full life cycle of real costs are obviously unavailable. The two major types of costs associated with pumping systems--capital cost of the installed system and recurrent operations, maintenance and repair costs--are discussed separately.

Capital Costs

The cost of an installed system includes the purchase price of the system and all its associated components (e.g., pipes, valves, fencing, etc.), shipping costs (if any) and installation, including both labor and materials. The purchase price of each system was defined as the current cost of all its components. For the Climax and Southern Cross machines, a current price quote was obtained. For the RIIC and WTGS designs, the BRET project's purchase price was used. A price for the Kijito was determined by requesting a current quote and using the prevailing currency exchange rate. (It should be noted that the price rise since the BRET project purchased its two Kijito machines is partly due to a increase of the machine's price in Kenya, but also to a change in the exchange rate.) For the Wind Baron, the original U.S. dollar cost was used and the price in pula figured using the current exchange rate. The cost of the Wind Baron has increased by about 40 percent as a result of exchange rate fluctuations alone. All of these costs may change over time due to more efficient construction techniques, higher raw materials costs and changes in exchange rates. As far as possible, the costs provided here reflect the prevailing rate, as of mid-1985, P0.57 equals $1.00.

Pump and piping costs were divided into above- and below-ground components, since the cost of the latter is directly related to the level where the pump is set, which is a function of the resting water level and borehole drawdown characteristics. In addition, the below-ground components corrode more rapidly than those above-ground and hence, require replacement on an accelerated schedule. The above-ground components include valves, elbows, the water meter and other parts used in a normal DWA installation. They do not include water storage components or any piping for reticulation, as costs for these are assumed to be common to all the wind systems, and so do not affect the relative cost of each system. The costs for all components were taken from DWA tender prices (where quotes were available) or the lowest retail price, if quotes were unavailable. These prices were used because this study was conducted for MMRWA, largely for

its use in developing policy regarding the necessary equipment for DWA boreholes.

In cases where shipping was necessary, such costs were included as part of cost of the equipment. Obviously, no direct shipping costs were associated with wind pumps fabricated in Botswana, and shipping for the raw materials used to build these machines was reflected in the purchase price.

In instances where the BRET project installed the wind pump, actual installation costs were used. However, there were several cases where others handled system installation, which fail into two categories. First, the project was charged for installation of the WTGS system and the RIIC machines, although only indirectly. The amount that Momoso Engineering charged the BRET project to install the WTGS wind pump was used in this analysis. The overall cost of the RIIC machines included installation, but these costs were broken out for the financial analysis summary.

The second category included systems that were not installed by the BRET project, either directly or indirectly. In these cases, an estimate of installation costs was used, based on similar work done by the crew that handled the BRET installations. The crew consisted of eight people, with a driver and driver's assistant. During an installation, the crew usually camped at the site and received an allowance for being away from home, in addition to their normal pay. The current installation cost for this crew is P140, of which approximately 40 percent is base wages. The crew is supplied with a seven-ton truck for hauling the windmill and related supplies as well as camping gear, when necessary. This crew is experienced in erecting wind systems, and it is not likely the time it takes them to install a windmill can be significantly improved. The cost to install the Wind Baron was much higher because it is more complex and required the rental of a crane.

Transportation costs reflect the use of a seven-ton truck at the government's current estimated cost of 82 thebe per kilometer. (This figure is under review and may be adjusted in the near future.) For the wind pump installations, transportation included one round trip from DWA in Gaborone to the site and one round trip to the stone crusher to obtain sand and gravel for footings and foundations.

Recurrent Costs

The wind pump testing program has not gone on long enough to establish long-term recurrent costs. Furthermore, the nature of the project's testing requirements were such that significantly more attention was given to each system than would normally be required. Although the long-term reliability of traditional wind

pumps is historically well established (if they are installed correctly), this is not yet true for the newer designs. In several cases, the wind pumps installed under the BRET project must be considered production prototypes, and the required minor repairs and system refinements do not accurately reflect the long-term recurrent costs of a fully developed machine. Thus, it was necessary to estimate recurrent cost schedules for the different pumps tested. Naturally, this topic stimulated intense discussion. However, for the present study, recurrent cost estimates were based on projected operation and maintenance requirements for production machines that are properly installed. Since this assumption was somewhat optimistic, additional inspection and site visits were included, as deemed necessary.

The base-case assumption was that DWA will be the primary purchaser of wind pumps, which will be installed in rural areas and serviced by council water units or water departments. For systems installed at border posts, police camps or any other location that DWA is responsible for, the recurrent costs should be similar, since the closest DWA unit would handle system operation and maintenance.

Recurrent costs were broken down into several major categories--pumper costs, annual and non-annual costs, and salvage. Although a pumper would not normally be required for the day-to-day operation of a wind pump, the basic assumption was that a pumper would be hired for one day per week (at the rate of six pula per day) because this individual is responsible for more than simply pump operation. Their tasks include taking care of the rest of the reticulation system and storage tank, keeping records and contacting the water maintenance unit for problems that are beyond their capabilities.

Annual recurrent costs include the cost of a yearly maintenance trip to the site from the nearest water maintenance unit to grease the machine, change the oil and cup leathers (in reciprocating pumps), and replace drive belts in Mono-coupled systems. For these maintenance trips, it was assumed that a four-wheel drive vehicle will be used (at a rate of 47 thebe per kilometer), except when the leathers must be changed and a larger crew with more tools is required to pull the pump. There was some difficulty in determining the number of additional trips to be figured for each installation. As a guideline, water maintenance units, which are responsible for about 20 to 70 boreholes, visit each of their pump sites from one to three or four times a month, depending on their location. They normally stop and visit any site that is on the way to or from another job. Thus, each site is visited more often than is actually required, and there is no reason to assume that this practice would differ for wind pump installations. However, an additional site visit (or two, depending on the site) was included in the

annual recurrent costs to allow for unforeseen difficulties that occasionally arise.

In terms of non-annual recurrent costs, the replacement of Mono columns, bobbins and shafts or, in the case of piston pumps, the cylinder and rising main is periodically required, but the exact schedule for such replacements depends on borehole conditions, such as water quality, straightness of the borehole and depth from the surface to pump level. Replacement periods in Botswana range from less than a year to 10 years or more. Although no detailed study of this has been done, DWA officials indicate that five years is about average, with the Mono shafts lasting somewhat longer as they are made of stainless steel. For this analysis, a replacement period of five years was assumed for the below-ground piping, pump rod, cylinder or Mono column, bobbins and one-half of the drive shafts. Most Mono pumps can be repaired locally at little or no cost, and a 20-year lifetime was assumed for these components. Such work is typically done by the local water unit, so labor and transportation costs were figured on this basis.

The tables on the following pages show the annual recurrent costs for each specific site. It should be remembered that these costs are not exactly the same as those given in Section VII, where the analysis was performed for normalized wind speed and head conditions.

Site:	Dipotsana	Climax 12

Capital Costs:	
Wind pump costs including shipping as applicable	3325.00
Below ground components (pump at 55 meters)	407.00
Above ground components	498.36
Fencing	206.29
Labor: 7 days at P140/day for the crew	980.00
Transport: Gaborone-Dipotsana return 220 km at 82 Thebe/km	180.40
Dipotsana-Lobatse return 80 km at 82 Thebe/km	65.60
Total installed cost	5662.65
Recurrent costs	
Annual	
Pumper at one day per week at P 6.00 per day	312.00
Change oil and change cup leathers	12.75
One day labor crew of eight	48.00
Transport from Kanye water unit (70 km @ 82 Thebe /km)	57.40
One additional trip (labor and transport)	44.90
Total annual costs:	475.05
At five year intervals	
Replace below ground components	
Materials	407.00
Labor (an additional day over annual maintenance)	48.00
Transport (an additional trip from Kanye)	57.40
Total costs at five, ten, and fifteen years	512.40

Notes: Oil change and cup leather change not included in the first year recurrent cost.
Additional annual trip supposes a 4-wheel vehicle at 47 Thebe per km and a crew of two.
At the five year intervals an additional day of labor is assumed to cover the additional work of replacing components.
Salvage value of the whole pumping system placed at P 500 at the end of its useful life.

Site: Kgoro Climax 10

Capital Costs:	
Wind pump costs including shipping as applicable	2495.00
Below ground components (pump at 49 meters)	338.65
Above ground components	376.12
Fencing	153.47
Labor: 7 days at P140/day for the crew	980.00
Transport: Gaborone-Kgoro return	188.60
230 km at 82 Thebe/km	
Kgoro-Lobatse return	73.80
90 km at 82 Thebe/km	
Total installed cost	4605.64
Recurrent costs	
Annual	
Pumper at one day per week at P 6.00 per day	312.00
Change oil and change cup leathers	12.75
One day labor crew of eight	48.00
Transport from Kanye water unit (165 km @ 82 Thebe /km)	135.30
One additional trip (labor and transport)	89.55
Total annual costs:	597.60
At five year intervals	
Replace below ground components	
Materials	338.65
Labor (an additional day over annual maintenance)	48.00
Allowance for staying out over two days	64.00
Total costs at five, ten, and fifteen years	450.65

Notes:
- Oil change and cup leather change not included in the first year recurrent cost.
- Additional annual trip supposes a 4-wheel vehicle at 47 Thebe per km and a crew of two.
- At the five year intervals an additional day of labor is to cover the additional work of replacing components in this case rather than make two trips it is assumed that the crew will stay out overnight.
- Salvage value of the whole pumping system placed at P 500 at the end of its useful life.

Site: Malau RIIC Motswedi

Capital Costs:	
Wind pump costs including shipping as applicable	8700.00
Below ground components (pump at 60 meters)	1747.40
Above ground components	619.92
Fencing	199.73
Labor: Included as part of the cost of the wind pump	
Transport: Included as a part of the cost of the wind pump	
Total installed cost	11267.05
Recurrent costs	
Annual	
Pumper at one day per week at P 6.00 per day	312.00
Change drive belts and grease	20.00
One day labor crew of two	12.00
Transport from Kanye-RIIC (70 km @ 47 Thebe /km)	32.90
One additional trip (labor and transport)	44.90
Total annual costs:	421.80
At five year intervals	
Replace below ground components	
Materials	1289.40
Labor one day for a crew of eight	48.00
Transport from Kanye-RIIC (70 km @ 47 Thebe /km)	57.40
Total costs at five, ten, and fifteen years	1394.80

Notes:
- Servicing of the RIIC machine is done by the RIIC windmill crew as RIIC requests.
- Changing of the drive belts and greasing not included in the first year recurrent cost.
- Additional annual trip supposes a 4-wheel vehicle at 47 Thebe per km and a crew of two.
- At the five year intervals a full day of labor for a crew of eight is assumed to accomplish the task of replacing Mono column, bobbins and half the shafts.
- Salvage value of the whole pumping system placed at P 500 at the end of its useful life.

Site: Malesane Southern Cross 14

Capital Costs:	
Wind pump costs including shipping as applicable	3354.00
Below ground components (pump at 51 meters)	481.00
Above ground components	492.14
Fencing	210.48
Labor: 7 days at P140/day for the crew	980.00
Transport: Gaborone-Malesane return 230 km at 82 Thebe/km	188.60
Malesane-Lobatse return 90 km at 82 Thebe/km	73.80
Total installed cost	5780.02
Recurrent costs	
Annual	
Pumper at one day per week at P 6.00 per day	312.00
Change oil and change cup leathers	12.75
One day labor crew of eight	48.00
Transport from Kanye water unit (60 km @ 82 Thebe /km)	49.20
One additional trip (labor and transport)	40.20
Total annual costs:	462.15
At five year intervals	
Replace below ground components	
Materials	481.00
Labor (an additional day over annual maintenance)	48.00
Transport (an additional trip from Kanye)	49.20
Total costs at five, ten, and fifteen years	578.20

Notes: Oil change and cup leather change not included in the first year recurrent cost.
Additional annual trip supposes a 4-wheel vehicle at 47 Thebe per km and a crew of two.
At the five year intervals an additional day of labor is assume to cover the additional work of replacing components.
Salvage value of the whole pumping system placed at P 500 at the end of its useful life.

Site:	Mochudi	Kijito

Capital Costs:	
Wind pump costs including shipping as applicable	18748.89
Below ground components (pump at 49 meters)	798.75
Above ground components	407.92
Fencing	206.29
Labor: 10 days at P140/day for the crew	1400.00
Transport: Gaborone-Mochudi return 110 km at 82 Thebe/km	90.20
Mochudi-Gaborone stone crushers return 110 km at 82 Thebe/km	90.20
Total installed cost	21742.25
Recurrent costs	
Annual	
Pumper at one day per week at P 6.00 per day	312.00
Grease and change cup leathers	9.75
One day labor crew of eight	48.00
Transport from Mochudi water unit (25 km @ 82 Thebe /km)	20.50
One additional trip (labor and transport)	23.75
Total annual costs:	414.00
At five year intervals	
Replace below ground components	
Materials	798.75
Labor (an additional day over annual maintenance)	48.00
Transport (an additional trip from Mochudi)	20.50
Total costs at five, ten, and fifteen years	867.25

Notes:
- Grease and cup leather change not included in the first year recurrent cost.
- Additional annual trip supposes a 4-wheel vehicle at 47 Thebe per km and a crew of two.
- At the five year intervals an additional day of labor is assume to cover the additional work of replacing components.
- Below ground components are more expensive as a ball valve cylinder is used at this site.
- Salvage value of the whole pumping system placed at P 500 at the end of its useful life.

Site: Mochudi RIIC Motswedi

Capital Costs:	
Wind pump costs including shipping as applicable	8500.00
Below ground components (pump at 52 meters)	1527.35
Above ground components	630.47
Fencing	199.73
Labor: Included as part of the cost of the wind pump	
Transport: Included as a part of the cost of the wind pump	
Total installed cost	10857.55
Recurrent costs	
Annual	
Pumper at one day per week at P 6.00 per day	312.00
Change drive belts and grease	20.00
One day labor crew of two	12.00
Transport from Kanye-RIIC (245 km @ 47 Thebe /km)	115.15
One additional trip (labor and transport)	127.15
Total annual costs:	586.30
At five year intervals	
Replace below ground components	
Materials	1527.35
Labor one day for a crew of eight	48.00
Transport from Kanye-RIIC (245 km @ 82 Thebe /km)	200.90
Total costs at five, ten, and fifteen years	1776.25

Notes:
- Servicing of the RIIC machine is done by the RIIC windmill crew as RIIC requests.
- Changing of the drive belts and greasing not included in the first year recurrent cost.
- Additional annual trip supposes a 4-wheel vehicle at 47 Thebe per km and a crew of two.
- At the five year intervals a full day of labor for a crew of eight is assumed to accomplish the task of replacing Mono column, bobbins and half the shafts.
- Salvage value of the whole pumping system placed at P 500 at the end of its useful life.

Site: Mochudi Wind Baron

Capital Costs:	
Wind pump costs including shipping as applicable	33689.47
Below ground components (pump at 57 meters)	2247.27
Above ground components	571.48
Fencing	512.76
Labor: 20 days at P140/day for the crew	2800.00
Transport: Gaborone-Mochudi return (2 times) 115 km at 82 Thebe/km	188.60
Mochudi-Gaborone stone crushers return 115 km at 82 Thebe/km	94.30
Extra charges: crane and operator	450
Total installed cost	40553.88

Recurrent costs	
Annual	
Pumper at one day per week at P 6.00 per day	312.00
Oil change and change cup leathers	15.00
One day labor crew of eight	48.00
Transport from Mochudi water unit (30 km @ 82 Thebe /km)	24.60
Two additional trip (labor and transport)	52.20
Total annual costs:	451.80
At five year intervals	
Replace below ground components	
Materials	2247.27
Labor (an additional day over annual maintenance)	48.00
Transport (an additional trip from Mochudi)	24.60
Total costs at five, ten, and fifteen years	2319.87

Notes:
- Oil change and cup leather change not included in the first year recurrent cost.
- Additional annual trips supposes a 4-wheel vehicle at 47 Thebe per km and a crew of two (two trips supposed due to the complexity of the system.
- At the five year intervals an additional day of labor is assumed to cover the additional work of replacing components.
- Below ground components are more expensive as larger rising main and an imported cylinder are used.
- Salvage value of the whole pumping system placed at P 500 at the end of its useful life.

Site: Mochudi WTGS

Capital Costs:	
Wind pump costs including shipping as applicable	9500.00
Below ground components (pump at 52 meters)	1527.35
Above ground components	630.47
Fencing	210.19
Installation costs charged seperately and include labor and transport except to get the windmill to the site	1200.00
Transport of the windmill to the site (245km trip Gaborone-Kanye-Mochudi-Gaborone @82 Thebe/ km)	200.90
Total installed cost	13268.91
Recurrent costs	
Annual	
Pumper at one day per week at P 6.00 per day	312.00
Change drive belts and grease	20.00
One day labor crew of two	12.00
Transport from Kanye-Momoso Eng.(245 km @ 47 Thebe /km)	115.15
One additional trip (labor and transport)	127.15
Total annual costs:	586.30
At five year intervals	
Replace below ground components	
Materials	1527.35
Labor one day for a crew of eight	48.00
Transport from Kanye-Momoso Eng. (245 km @ 82 Thebe /km)	200.90
Total costs at five, ten, and fifteen years	1776.25

Notes:
- Servicing of the WTGS machine done to date by Momoso Eng.
- Changing of the drive belts and greasing not included in the first year recurrent cost.
- Additional annual trip supposes a 4-wheel vehicle at 47 Thebe per km and a crew of two.
- At the five year intervals a full day of labor for a crew of eight is assumed to accomplish the task of replacing Mono column, bobbins and half the shafts.
- Salvage value of the whole pumping system placed at P 500 at the end of its useful life.

Site: Pitsane-Botloko Kijito

Capital Costs:	
Wind pump costs including shipping as applicable	18748.89
Below ground components (pump at 37 meters)	705.55
Above ground components	407.92
Fencing	206.29
Labor: 10 days at P140/day for the crew	1400.00
Transport: Gaborone-Pitsane return	180.40
220 km at 82 Thebe/km	
Pitsane-lobatse stone crushers return	65.60
80 km at 82 Thebe/km	
Total installed cost	21714.65
Recurrent costs	
Annual	
Pumper at one day per week at P 6.00 per day	312.00
Grease and change cup leathers	9.75
One day labor crew of eight	48.00
Transport from Kanye water unit (160 km @ 82 Thebe /km)	131.20
One additional trip (labor and transport)	87.20
Total annual costs:	588.15
At five year intervals	
Replace below ground components	
Materials	705.55
Labor (an additional day over annual maintenance)	48.00
Allowance for staying out over two days	64.00
Total costs at five, ten, and fifteen years	817.55

Notes:
- Grease and cup leather change not included in the first year recurrent cost.
- Additional annual trip supposes a 4-wheel vehicle at 47 Thebe per km and a crew of two.
- At five year intervals an additional day of labor is assumed to cover the additional work of replacing components in this case rather than make two trips it is assumed that the crew will stay out overnight.
- Below ground components are more expensive as a ball valve cylinder is used at this site.
- Salvage value of the whole pumping system placed at P 500 at the end of its useful life.

Site: Sedibeng Climax 12

Capital Costs:	
Wind pump costs including shipping as applicable	3821.00
Below ground components (pump at 43 meters)	572.25
Above ground components	546.38
Fencing	164.88
Labor: 7 days at P140/day for two crew	980.00
Transport: Gaborone-Sedibeng return 320 km at 82 Thebe/km	262.40
Sedibeng-Lobatse return 170 km at 82 Thebe/km	139.40
Total installed cost	6486.31
Recurrent costs	
Annual	
Pumper at one day per week at P 6.00 per day	312.00
Change oil and change cup leathers	12.75
One day labor crew of eight	48.00
Transport from Kanye water unit (185 km @ 82 Thebe /km)	151.70
One additional trip (labor and transport)	91.90
Total annual costs:	616.35
At five year intervals	
Replace below ground components	
Materials	572.25
Labor (an additional day over annual maintenance)	48.00
Allowance for staying out over two days	64.00
Total costs at five, ten, and fifteen years	684.25

Notes: Oil change and cup leather change not included in the first year recurrent cost.
Additional annual trip supposes a 4-wheel vehicle at 47 Thebe per km and a crew of two.
At five year intervals an additional day of labor is assumed to cover the additional work of replacing components in this case rather than make two trips it is assumed that the crew will stay out overnight.
Salvage value of the whole pumping system placed at P 500 at the end of its useful life.

Site: Tlhareseleele Climax 12

Capital Costs:	
Wind pump costs including shipping as applicable	3325.00
Below ground components (pump at 40 meters)	390.35
Above ground components	422.55
Fencing	176.80
Labor: 7 days at P140/day for the crew	980.00
Transport: Gaborone-Tlhareseleele return 220 km at 82 Thebe/km	180.40
Tlhareseleele-Lobatse return 80 km at 82 Thebe/km	65.60
Total installed cost	5540.70
Recurrent costs	
Annual	
Pumper at one day per week at P 6.00 per day	312.00
Change oil and change cup leathers	12.75
One day labor crew of eight	48.00
Transport from Kanye water unit (160 km @ 82 Thebe /km)	131.20
One additional trip (labor and transport)	87.20
Total annual costs:	591.15
At five year intervals	
Replace below ground components	
Materials	390.35
Labor (an additional day over annual maintenance)	48.00
Allowance for staying out over two days	64.00
Total costs at five, ten, and fifteen years	502.35

Notes: Oil change and cup leather change not included in the first year recurrent cost.
Additional annual trip supposes a 4-wheel vehicle at 47 Thebe per km and a crew of two.
At five year intervals an additional day of labor is assumed to cover the additional work of replacing components in this case rather than make two trips it is assumed that the crew will stay out overnight.
Salvage value of the whole pumping system placed at P 500 at the end of its useful life.

PRICES in PULA (P 1.00 = $0.57)
JUNE 1985

	Tender	Haskins	Ass.Eng.	Taurus	Sharps	Other
-ELECTRICAL COMPONENTS-						
40 WT AC FIXTURES 1.2M					25.52	
100 A-HR BATTERIES				90.00		
12 MODULE SUPPORT ST.				300.00		
12 WT DC LIGHTS				27.00		
300 WT INVERTER						420.00
4mm ELEC. WIRE (100 M)				65.00	29.99	
6mm ELEC. WIRE (100 M)				75.00	43.62	
8 MODULE SUPPORT ST.				150.00		
ARCO M-53 MODULES				570.00		
ARCO M-63 MODULES				500.00		
ARRAY INTRCONECTS				10.00		
BATT. TERMINALS				0.80		
BTC CONTROLLER						150.00
BULB (AC)					2.75	
BULB (DC)				5.00		
CONDUIT PER METER		0.71			0.58	
JCT. FOR CONDUIT					.75-1.	0
GROUND ROD					17.60	
GROUND WIRE PER METER					1.71	
GRUNDFOS PUMP						6150.00
JACUZZI PUMP						2275.00
JCT. BOX (150*150)					6.24	
JCT. BOX (300*300)					12.08	
JCT. BOX (230*230)					6.24	
KNIFE SWITCH						
MARVEL PV REFER						
MODULE INTERCONNECTS				6.00		
POLAR PROD RR-1						
POLAR PROD RR-2						
SUBMERS.PUMP CABLE(PER M)		1.70			3.74	
SUN FROST PV REFER						
PULL SWITCHES					5.14	
SINGLE POLE SWITCHES					4.70	
BATTERY 100 AHr				90.00		
BATTERY 200 AHr				193.27		
-WIND PUMPS-						
12mm ROD 3M		5.95				
16mm ROD 3M	8.16	10.85	16.75			
20mm ROD 3M	11.85	15.90	20.94			
CLIMAX 10 (w/9 m tower)						2495.00
CLIMAX 12 (w/12 m tower)						3821.00
CLIMAX 18 (w/15 m tower)						9224.00
CYLINDER (2.75*18 BALL)	281.75	322.00				378.75
CYLINDER (3*18 POPPET)	101.47					147.60
CYLINDER (3.25*18 BALL)	362.25	414.00				480.00
CYLINDER (3.5*18 POPPET)						173.30
CYLINDER (3.75*18 BALL)	409.50	465.00	444.30			585.00
CYLINDER (4*18 POPPET)	147.90					214.00

CUP LEATHERS	1.50					
FORCE HEAD (3")		155.61				
KIJITO 20 FT.						20397.72
SOUTHERN CROSS 14						2184.00
30' TOWER FOR 14'IZ						670.00
SOUTHERN CROSS 25						11838.00
55' TOWER FOR 25'R						2981.00
WIND BARON (INCL SHIPPING)						34609.83
D-9 NATIONAL PUMP HEAD			740.00			
-GENERAL-						
100-50mm REDUCER		19.34				
100-80mm REDUCER	13.09	20.29				
100mm ELBOW	31.30	33.54	33.54			
100mm GS PIPE 3M	33.62	56.40	61.48			
100mm NIPPLE	3.28	4.25	6.39			
100mm TEE	20.23	46.76	46.76			
100mm UNION	48.36					
12mm FOUNDATION BOLTS		0.60				
20mm BRASS TAP	6.92					
20mm ELBOW	0.94					
20mm EQUAL TEE	1.34					
20mm GS PIPE 3M	4.32					
20mm NIPPLE	0.19					
20mm PLUG	0.32					
25mm ELBOW	1.77	2.30	2.30			
25mm GS PIPE 3M	6.45	11.10				
25mm NIPPLE	0.28	0.32	0.46			
25mm TEE	2.24	3.20	3.20			
25mm UNION	3.65	5.63	5.63			
32mm BARREL NIPPLE		0.69	0.77			
32mm ELBOW		4.34	4.34			
32mm GS PIPE 3M		14.10	16.21			
32mm TEE		5.68	5.68			
32mm UNION		7.62	7.62			
40-20mm REDUCER	3.57					
40-25mm REDUCER	1.96	3.00	2.27			
40-32mm REDUCER		3.45	1.91			
40mm BARREL NIPPLE	0.46	0.77	0.86			20.00
40mm ELBOW	3.92	5.42	5.42			
40mm FLANGE	4.53					
40mm GATE VALVE	6.92					
40mm GATE VALVE		9.50				
40mm GS PIPE 3M	8.13	15.90	18.42			
40mm KENT WATER METER	231.00					
40mm NON-RETURN VALVE	14.48					
40mm TEE	4.56	7.04	7.04			
40mm UNION	6.16	9.50	9.50			
50 Kg CEMENT		4.05				
50-20mm REDUCER	5.57					
50-40mm REDUCER	3.35	5.17				
50mm BARREL NIPPLE	0.68	1.12	1.24			
50mm FLANGE	5.20					
50mm GATE VALVE	10.13					
50mm GATE VALVE		14.20				
50mm GS PIPE 3M	13.95	22.95	26.67			

50mm KENT WATER METER	234.00					
50mm NON-RETURN VALVE	22.16					
50mm TEE	6.83	10.56	9.75			
50mm UNION	10.14	15.64	15.64			
50mm ELBOW	6.27	7.70	8.63			
5mm ANGLE STEEL (6M)		2.15				
65mm ELBOW	12.76	13.70	13.70			
65mm GS PIPE 3M	17.67	30.15	34.32			
65mm NIPPLE	1.56	2.75	1.65			
65mm TEE	11.82	18.25	18.24			
65mm UNION	15.37	23.95	23.94			
6mm ANGLE STEEL (6M)		3.10				
6mm STEEL WIRE ROPE		2.45				
80-50mm REDUCER	6.62	10.26				
80mm ELBOW	15.12	17.40	17.40			
80mm FLANGE	7.68					
80mm GS PIPE 3M	21.44	38.10	43.63			
80mm KENT WATER METER	279.00					
80mm NIPPLE	2.05	3.37	2.79			
80mm TEE	18.99	29.30	29.30			
80mm UNION	19.25	29.98	29.98			
BOREHOLE CLAMP 2"		27.08				
BOREHOLE CLAMP 2.5"						
BOREHOLE CLAMP 4"						
CRUSHED STONE (M3)						
ENGINE MOUNTING FRAME 8/1	200.00		205.00			
ENGINE MOUNTING FRAME ST-1	200.00		195.00			
PRES.RELIEF VALVE(1000KPA)	27.30					
PRES.RELIEF VALVE(700KPA)	27.30					
TEFLON TAPE		0.43				
-PUMPS AND ACC.-						
13mm MONO ROD (1.5M)	4.36	6.00				
16mm MONO ROD (1.5M)	6.48	8.10				
BOBBINS (40mm)	5.08	6.35	5.72			
BOBBINS (50mm)	6.72	8.40	7.29			
MONO ES-10	291.20	364.00	327.60			
MONO ES-10S	291.20	291.00	234.90			
MONO ES-15	423.20	529.00	476.10			
MONO ES-15S	291.20	364.00	327.60			
MONO ES-30	505.40	633.00	569.67			
MONO ES-30S	400.00	500.00	450.00			
MONO ES-4	208.80	261.00	234.00			
MONO COLUMN (50mm)	44.55					
MONO COLUMN (40mm)	31.77					
MONOSTROOM (250*50*2B)	280.80	213.00	278.91			
MONOSTROOM (250*40*2B)	268.80	213.00	270.90			
STABILISERS (40*152)	6.20	9.45	8.96			
STABILISERS (50*152)	7.56	7.75	6.68			
16mm TOP SHAFT	22.40	28.00	20.50			
MONO COL ADAPTER		23.00				
-FENCING AND FOUNDATIONS-						
1.6mm WIRE	37.85	44.70				44.30

4mm WIRE	39.60	42.50			38.15
CORNER BRACES (1.2)	5.62	6.95			5.62
CORNER POSTS 91.2)	9.13	15.75			9.13
DIAMOND MESH (1.2)	37.90	36.45			32.42
GATE (HOMESTEAD)	41.58	71.25			45.48
STANDARDS (1.2)	3.90	3.25			3.39
TALL CORNER BRACES (1.8M)	10.23				7.39
TALL CORNER POSTS (1.8M)	13.04				11.90
TALL DIAMOND MESH (30 M)	58.20	54.70			50.59
TALL STANDARDS (1.8M)	4.85				4.60
-DIESEL ENGINES & ACCESS.-					
LT-1 (BLD 11)	1104.00	1187.00			1268.75
ST-1C	1324.00	2394.00			2094.75
ST-1C W/CLUTCH	2268.00				2996.00
B/1	2660.00	3954.00			3459.75
V BELTS 17*2500	10.16				
V BELTS 17*4060	11.72				
V BELTS 17*5000	14.44				
V GROOVE PULLEY 160mm	47.50				
V GROOVE PULLEY 200mm	66.00				
PUMPHOUSE (3M*4M)	890.00				890.00
PUMPHOUSE (2.4M*3.6M)	780.00				
PULLEY 140mm DIA	41.30				
PULLEY 160mm DIA	47.50				
PULLEY 180mm DIA	58.00				
PULLEY 200mm DIA	66.00				

APPENDIX D

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