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# WIND ENERGY TECHNOLOGY FOR THE BRET PROJECT:

## A CONSULTANCY REPORT


Prepared by:

Roy Smith
Associates in Rural Development, Inc.
362 Main Street
Burlington, VT 05401
U. S. A.



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# PREFACE

This report presents the results of work undertaken by Mr. Roy Smith, a consultant on wind energy systems for Associates in Rural Development, Inc. (ARD), from February 25 through May 6, 1983 at the Botswana Renewable Energy Technology (BRET) project.

Section I gives Mr. Smith's scope of work, along with a description of the activities emphasized and local government officials contacted during the consultancy. Section II describes the BRET project's current program for collecting wind data and examines the adequacy of the monitoring equipment in use. Copies of the data collection forms also appear in this section. Section III provides a brief analysis of the engineering design of the RIIC windmill and some suggestions for improving the current prototype unit. Section IV examines windmill designs now being developed in Botswana, as well as some machines that have not yet been tested in Africa, but appear to have the potential to pump water in the country's low wind regime. A set of windmills for a comparative testing program is recommended. Section V outlines data that should be collected for both short- and long-term windmill testing. Section VI presents an economic analysis of the performance of several different wind systems, given wind regimes of eight, 12 and 16 kilometers per hour and pumping heads of 30 and 100 meters. Section VII covers the training provided to BRET and Ministry of Mineral Resources and Water Affairs (MMRWA) personnel concerning wind regimes and windmill characteristics, and to BRET staff and villagers in Sedibeng on windmill operation and monitoring. The appendices include information on existing wind data for Botswana, performance curves for several families of windmills, detailed methods for analyzing and interpreting wind data, a training program for windmill installation and maintenance, and testing procedures for hand pumps.

Several wind experts assisted in the technical review of the final draft of this report. Dr. Amir Mikhail, of the Solar Energy Research Institute in Golden, Colorado, provided many valuable comments and suggestions regarding wind monitoring and assessment techniques. He also made a major contribution to the plan for analyzing wind data on a national basis (see Appendix B). Mr. Willis Eschenbach prepared a detailed syllabus for a one-week training program in windmill installation and maintenance (see Appendix G) to supplement the in-country training provided by Mr. Smith during the consultancy. Mr. Martin Wulfe contributed to the description of the economic analysis procedure detailed in Section VI.

# I. INTRODUCTION

## A. Work Undertaken

The initial scope of work outlined for this consultancy was to assist the development of a comprehensive wind energy strategy for the BRET project by performing the following tasks:

1. Develop guidelines for a national system of wind data analysis.

2. Establish procedures for performance testing of large- and small-diameter windmills.

3. Complete an economic and engineering assessment of a prototype wind pump currently being tested.

4. Provide on-site guidance in siting, erecting anemometers and wind/hand pump systems. Develop a training program for maintenance and repair of fan-type windmills (for villagers and Water Affairs staff).

5. Participate in ongoing technology selection and testing activities, as appropriate.

6. All of the above to be performed in conjunction with the project's two wind/water technicians and under the supervision of the project coordinator(s).

7. Prepare and submit a written draft report on above for BRET staff review.

8. Submit final written report to ARD's Burlington office immediately upon return to the United States.

Upon arrival in Gaborone, discussions were held with project staff to identify and establish priorities for items listed in the scope of work. As a result, the emphasis of effort was directed toward the following activities.

- Develop a system of wind data analysis for the anemometer sites and coordinate its use through Meteorological Services, the University of Botswana, BRET, and MMRWA.

- Implement an anemometer station installation at the Ditshegwane village training facility, and training of village personnel in equipment operation and the method of data collection for this site--to be done in cooperation with BRET technicians and village personnel.

- Review the photovoltaic (PV) pump installation at Kanye and hand pump work that BRET technicians have done, and

report on any technical problems with these systems and their potential.

- Install a Climax 12-foot mill, tower, pump and anemometer station at Sedibeng on an existing bore-hole in conjunction with Water Affairs, BRET technicians and personnel from the BRET extension service in order to provide experience and training in installation, testing and performance monitoring of a windmill pumping system.

- Evaluate performance and construction of prototype Rural Industry Innovation Center (RIIC) and Serowe Windmill Technical Group (WTGS) windmills in conjunction with BRET technicians, and the RIIC design groups at Kanye and WTGS.

- Consider windmill selection, sizing and performance of multi-bladed fan-type designs on the market today and their application to the Botswana wind regime with BRET technicians and Water Affairs personnel.

- Provide on-site guidance and training in siting anemometers and multi-bladed windmill pumping systems.

B. Contacts

People contacted during the consultancy, besides BRET project staff, included:

- Bart Aarsse, The Botswana Technology Centre (BTC);
- Stafford Baker, U. S. Agency for International Development (AID);
- Dr. Daniell, MMRWA;
- Mr. Elize de Vries, RIIC, Kanye;
- Mr. Ed Desanto, Serowe;
- Dr. Devan, University of Botswana;
- Mr. Kenton Allen, RIIC, Kanye;
- Mr. Max Ewens, RIIC, Kanye;
- Mr. Kees Flink, Water Affairs;
- Dr. Idzenga, University of Botswana;
- Mr. M. Gerrod Jacobs, Serowe;

- Dr. G. Luthi, MMRWA;
- Mr. Derek Medford, BTC;
- Mr. Kit Morei, RIIC, Kanye;
- Mr. Boitshoko Sekwati, Meteorological Services;
- Ms. Rachel Turner, MMRWA; and
- Dr. von Voyer, Geological Services, Lobatse.

## II. WIND ANALYSIS

### A. Introduction

This section is devoted to the evaluation of existing wind data for Botswana. It further emphasizes the importance of collecting additional data to assure that windmill pumping systems are appropriate for the country in general and located in areas where there are adequate wind regimes.

Care should be exercised in choosing suitable sites for windmill systems since there is a significant amount of shear and compression in a normal, horizontal wind stream passing over the earth's surface. Shear results in lower wind speeds near the surface than at heights great enough for free flow to occur. The velocity of free flow at these heights is usually significantly greater than winds either at the surface or standard anemometer heights where velocity is customarily measured. Wind shear, and consequently, available wind power, are also affected by the roughness of the earth's surface at a given location--for example, building, trees and other obstacles. Another significant factor is compression. The stream lines of a wind system are compressed and its flow accelerated as it goes over hills or through narrow valleys or passes.

### B. Evaluation and Potential Utility of Existing Wind Data

One of the first consultancy tasks was to visit Meteorological Services in Gaborone. Mr. Boitshoko Sekwati supplied wind and temperature data that have been collected since 1958-1959 (see Appendix A). Wind speeds have been measured at a height of two meters, with additional values extrapolated to 10 meters. During early March, Mr. Sekwati indicated that only one site was currently measuring wind speed at both heights, but there are plans to continue with additional 10-meter installations. The Meteorological Service is interested in the data that BRET and Water Affairs will be collecting, and offered the project their support. The issue of whether wind speeds extrapolated from two to 10 meters by Meteorological Services are valid for evaluating the potential performance and operation of windmill pumping systems will be considered in the following sections.

### C. Wind Data Collection

The BRET project has arranged for a national system of wind data collection, analysis and instrument installation at a total of 34 sites with the cooperation of Water Affairs and Meteorological Services crews. In addition, the physics department of the University of Botswana has agreed to the use of

the university's computer facilities and student manpower for analysis, computation and storage of the information.

The wind instrumentation system being installed by BRET consists of a Model A30-101 Compilator I coupled with a three-cup wind speed sensor (Model A75-104), mounted on a 10-meter, guyed tower. This self-contained system is powered by an Arco solar panel that supplies a 12-volt DC battery system. BRET technicians have devised a unique enclosure design to protect the compilator from the elements. The wind speed instruments are manufactured by Natural Power, Inc. of New Boston, New Hampshire.

This wind data compilator is particularly well suited to provide accurate, comprehensive site surveys for wind energy conversion systems. It separates wind speed into 32 discrete increments, measuring and storing the number of seconds the wind speed falls in each category. The pictogram on the following page illustrates the increments and how the compilator stores wind speed values in the various categories (bins). On command, the stored information can be displayed on the digital front panel, and then manually recorded on data collection forms for final analysis and use in evaluating the wind speed frequency and power available at a specific site. Frequency distributions and power curves can be prepared using the stored data.

Two anemometer installations have been completely installed and are currently monitoring wind speeds at a height of 10 meters. The first one, at the Ditshegwane Village Training Facility site, has been collecting data since March 15, 1983. The second, in the village of Sedibeng, was installed simultaneously with a 12-foot diameter, Climax wind pump system for performance testing. BRET technicians and extension staff coordinated the instruction of key village personnel in the use and operation of the compilator and windmill pumping system.

Examples of the forms used to collect and analyze wind data are presented on subsequent pages. They include:

- the wind speed and power work sheet--anemometer readings from the information stored in the compilator are recorded on the last day of each month, and computer analysis transforms average wind speed and its duration into power available in the wind at the site;

- formulas used to calculate average wind speed and power; and

- a curve plotting wind speed and available power for a specific site over the period of time that data were collected.

It is recommended that data be gathered on a monthly basis, and calculations then made of the instantaneous power available at

## NATURAL POWER INC.'S MODEL A30-101 COMPILATOR I
## – BIN STORAGE CHARACTERISTICS –

| STEP INCREMENTS (KM/HR) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AVERAGE WINDSPEED (KM/HR) | 1/2 | 1 1/2 | 2 1/2 | 3 1/2 | 4 1/2 | 5 1/2 | 6 1/2 | 7 1/2 | 8 1/2 | 9 1/2 | 10 1/2 |
| WINDSPEED RANGE (KM/HR) | 0-1 | 1-2 | 2-3 | 3-4 | 4-5 | 5-6 | 6-7 | 7-8 | 8-9 | 9-10 | 10-11 |
| CHANNEL BIN # | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 |
| AVERAGE WINDSPEED (MPH | 0.31 | 0.93 | 1.55 | 2.17 | 2.80 | 3.42 | 4.04 | 4.66 | 5.28 | 5.90 | 6.52 |
| AVERAGE WINDSPEED (M/SEC) | 0.14 | 0.42 | 0.69 | 0.97 | 1.25 | 1.53 | 1.81 | 2.08 | 2.36 | 2.64 | 2.92 |

| STEP INCREMENTS (KM/HR) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AVERAGE WINDSPEED (KM/HR) | 11 1/2 | 12 1/2 | 13 1/2 | 14 1/2 | 15 1/2 | 16 1/2 | 17 1/2 | 18 1/2 | 19 1/2 | 20 1/2 | 21 1/2 |
| WINDSPEED RANGE (KM/HR) | 11-12 | 12-13 | 13-14 | 14-15 | 15-16 | 16-17 | 17-18 | 18-19 | 19-20 | 20-21 | 21-22 |
| CHANNEL BIN # | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
| AVERAGE WINDSPEED (MPH) | 7.15 | 7.77 | 8.39 | 9.01 | 9.63 | 10.25 | 10.87 | 11.50 | 12.12 | 12.74 | 13.36 |
| AVERAGE WINDSPEED (M/SEC) | 3.19 | 3.47 | 3.75 | 4.03 | 4.31 | 4.58 | 4.86 | 5.14 | 5.42 | 5.69 | 5.97 |

| STEP INCREMENTS (KM/HR) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AVERAGE WINDSPEED (KM/HR) | 22 1/2 | 23 1/2 | 24 1/2 | 25 1/2 | 26 1/2 | 27 1/2 | 28 1/2 | 29 1/2 | 30 1/2 | 31 1/2+ | |
| WINDSPEED RANGE (KM/HR) | 22-23 | 23-24 | 24-25 | 25-26 | 26-27 | 27-28 | 28-29 | 29-30 | 30-31 | 31-X | |
| CHANNEL BIN # | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | |
| AVERAGE WINDSPEED (MPH) | 13.98 | 14.60 | 15.22 | 15.85 | 16.47 | 17.09 | 17.71 | 18.33 | 18.95 | 19.57+ | |
| AVERAGE WINDSPEED (M/SEC) | 6.25 | 6.53 | 6.81 | 7.08 | 7.36 | 7.64 | 7.92 | 8.20 | 8.47 | 8.75+ | |

# COMPILATOR I
## WIND SPEED AND POWER WORKSHEET

| $\bar{V}$ m/S | $\bar{V}$ mPH | BIN NO. | A $\bar{V}$ Km/H | B DATA | A×B | C HRS | D WATTS/m² | C×D WATT-HRS | $\bar{V}^3$ Km/H | $\bar{V}^3$ m/S |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.14 | 0.31 | 00 | .5 | 472727 | 236363 | 131.31 | .002 | .26 | 0.125 | .003 |
| 0.42 | 0.93 | 01 | 1.5 | 482065 | 723097 | 132.3 | .038 | 5.09 | 3.34 | .074 |
| 0.69 | 1.55 | 02 | 2.5 | 447932 | 119,832 | 124.42 | .147 | 18.29 | 15.6 | .226 |
| 0.97 | 2.17 | 03 | 3.5 | 234887 | 822,104 | 65.25 | .47 | 30.67 | 42.9 | .913 |
| 1.25 | 2.80 | 04 | 4.5 | 166401 | 748,804 | 46.22 | 1.0 | 46.22 | 91.1 | 1.95 |
| 1.53 | 3.42 | 05 | 5.5 | 114537 | 629,953 | 31.82 | 1.8 | 57.28 | 166 | 3.58 |
| 1.81 | 4.04 | 06 | 6.5 | 68801 | 447,206 | 19.11 | 3.05 | 58.29 | 275 | 5.93 |
| 2.08 | 4.66 | 07 | 7.5 | 36832 | 276,204 | 10.23 | 4.63 | 47.36 | 422 | 9.0 |
| 2.36 | 5.28 | 08 | 8.5 | 18589 | 158,006 | 5.16 | 6.77 | 34.92 | 614 | 13.14 |
| 2.64 | 5.90 | 09 | 9.5 | 9684 | 91,998 | 2.69 | 9.48 | 25.49 | 857 | 18.40 |
| 2.92 | 6.52 | 10 | 10.5 | 5895 | 61897 | 1.64 | 12.82 | 21.02 | 1158 | 24.9 |
| 3.19 | 7.15 | 11 | 11.5 | 4001 | 46011 | 1.11 | 16.72 | 18.56 | 1521 | 32.46 |
| 3.47 | 7.77 | 12 | 12.5 | 2692 | 33650 | .745 | 21.52 | 16.03 | 1953 | 41.78 |
| 3.75 | 8.39 | 13 | 13.5 | 1578 | 21303 | .438 | 27.16 | 11.89 | 2460 | 52.73 |
| 4.03 | 9.01 | 14 | 14.5 | 818 | 11861 | .227 | 33.71 | 7.65 | 3048 | 65.45 |
| 4.31 | 9.63 | 15 | 15.5 | 345 | 5347 | .096 | 41.23 | 3.96 | 3724 | 80.06 |
| 4.58 | 10.25 | 16 | 16.5 | 142 | 2343 | .039 | 49.48 | 1.93 | 4492 | 96.07 |
| 4.86 | 10.87 | 17 | 17.5 | 45 | 787 | .012 | 59.13 | .71 | 5359 | 114.8 |
| 5.14 | 11.50 | 18 | 18.5 | 27 | 499 | .007 | 69.94 | .49 | 6332 | 135.8 |
| 5.42 | 12.12 | 19 | 19.5 | 17 | 331 | .005 | 81.99 | .41 | 7415 | 159.2 |
| 5.69 | 12.74 | 20 | 20.5 | 12 | 246 | .003 | 94.87 | .28 | 8615 | 184.2 |
| 5.97 | 13.36 | 21 | 21.5 | 11 | 236 | .003 | 109.6 | .33 | 9939 | 212.8 |
| 6.25 | 13.98 | 22 | 22.5 | 10 | 225 | .003 | 125.7 | .38 | 11,391 | 244.1 |
| 6.53 | 14.60 | 23 | 23.5 | 11 | 258 | .003 | 143.4 | .43 | 12,978 | 278.4 |
| 6.81 | 15.22 | 24 | 24.5 | 8 | 196 | .002 | 162.6 | .325 | 14,706 | 315.8 |
| 7.08 | 15.85 | 25 | 25.5 | 9 | 229 | .002 | 182.8 | | 16,581 | 354.9 |
| 7.36 | 16.47 | 26 | 26.5 | 3 | 79 | .001 | 205.3 | .205 | 18,610 | 398.7 |
| 7.64 | 17.09 | 27 | 27.5 | 8 | 220 | .002 | 229.6 | .459 | 20,797 | 445.9 |
| 7.92 | 17.71 | 28 | 28.5 | 3 | 85 | .001 | 255.9 | .256 | 23,149 | 496.8 |
| 8.20 | 18.33 | 29 | 29.5 | 8 | 236 | .002 | 284.0 | .568 | 25,672 | 551.4 |
| 8.47 | 18.95 | 30 | 30.5 | 0 | 0 | 0 | 0 | 0 | 28,377 | 607.6 |
| | | | | 2,068106 | 5,437,388 | 574.4 | | | | |
| | | | | Σ B | Σ A×B | ΣB/4000 | Σ D | Σ C×D | | |

SITE LOCATION DIETSEGWANE SITE DESCRIPTION LEVEL COUNTRY FT High Grass OCC. TREE 0.16

DATE STARTED MAR 15 DATE DATA TAKEN 4/8/83 DATA FOR MONTH

ALTITUDE 1140 ALT. CORR. FACTOR .872 APPROX. TEMP 26.7°c TEMP CORR FACTOR .963

AIR DENSITY (P) CALC FOR SITE .0019969 SLUGS/FT³ 1.030088 Kg/m³

AVERAGE WIND SPEED @ SITE ($\bar{V}$) 2.63 Km/HR .73 m/S 1.63 MPH FOR

A DURATION OF 574.4 HOURS

## FORMULAS FOR WIND DATA ANALYSIS COMPUTER PROGRAM TO CALCULATE AVERAGE WIND SPEED AND POWER

$\overline{V}_{AV}$ wind speed at site = $\frac{\Sigma\ A \times B}{\Sigma B}$ in km/hour from table

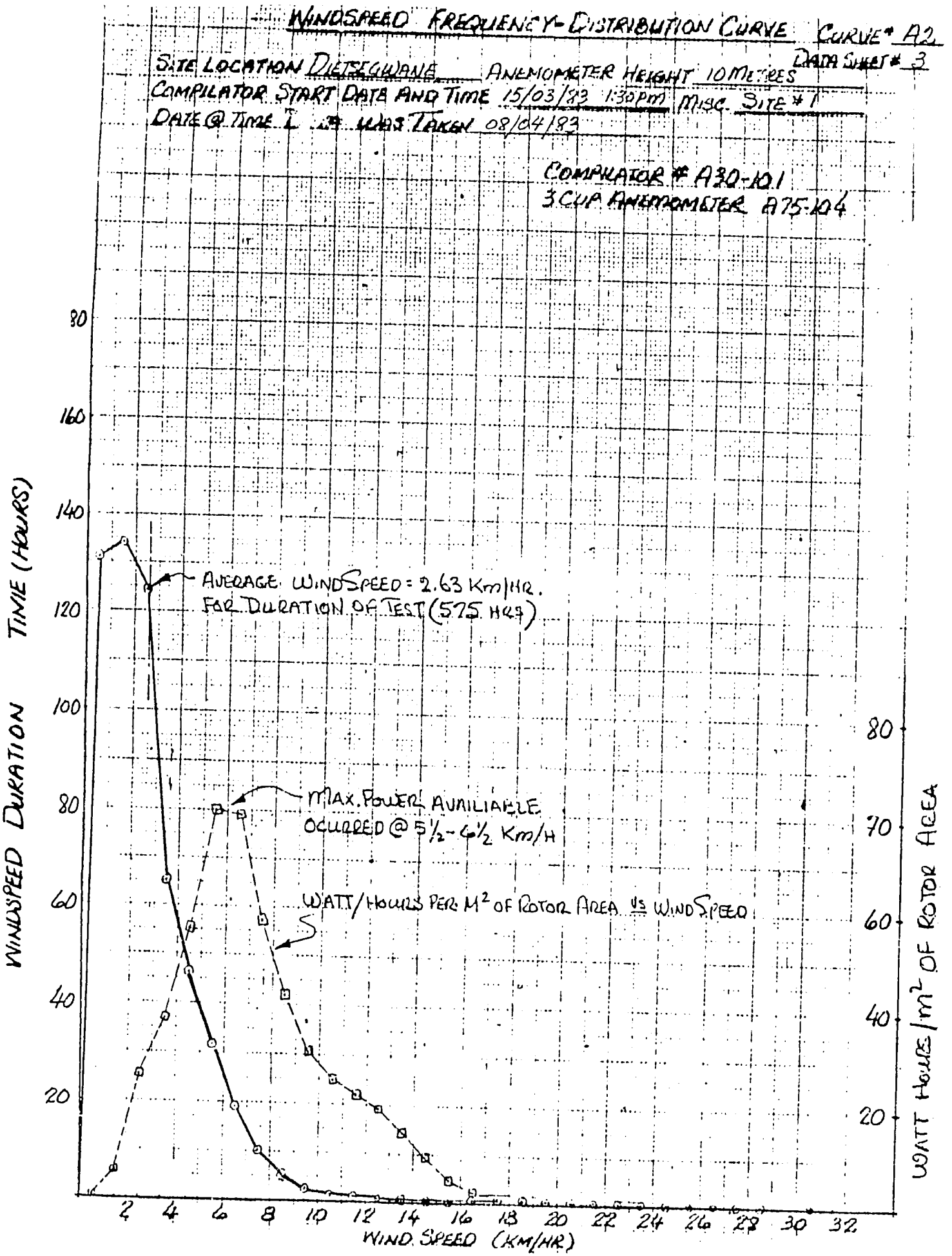
power in watts/$m^2$ at site = $\frac{1}{2} \times P \times \overline{V}^3$

where P = air density in kg/$m^2$

and $\overline{V}^3$ = average wind speed cubed in m/s

power in watts/hour = C x D from table

air density in kg/$m^3$ = air density in slugs/$ft^3$ x 32.2 x 16.02


WINDSPEED FREQUENCY-DISTRIBUTION CURVE
CURVE # A2
DATA SHEET # 3
SITE LOCATION DIETSEGWANA
ANEMOMETER HEIGHT 10 METRES
COMPILATOR START DATE AND TIME 15/03/83 1:30pm
MISC. SITE # 1
DATE @ TIME LAST WAS TAKEN 08/04/83
COMPILATOR # A30-101
3 CUP ANEMOMETER A75-104
AVERAGE WINDSPEED = 2.63 Km/HR.
FOR DURATION OF TEST (575 HRS)
MAX. POWER AVAILIABLE
OCURRED @ 5½-6½ Km/H
WATT/HOURS PER M² OF ROTOR AREA vs WINDSPEED
WINDSPEED DURATION TIME (HOURS)
WATT HOURS/m² OF ROTOR AREA
WIND SPEED (KM/HR)
20
40
60
80
100
120
140
160
180
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32

different wind speeds. Ideally, high-quality wind speed data will be collected at the site of an existing or proposed well. However, it would very costly to monitor wind speed at all the proposed sites and the number of anemometer and data logging equipment installations scheduled for the near future is limited, so alternative extrapolation techniques will have to be employed to provide rough estimates of wind energy potential, based on data collected at a nearby monitoring station.

Appendix B details a step-by-step process for estimating the wind energy potential of a given site. If detailed site data have been collected from the Natural Power A30-301 compilator or similar equipment, the appendix describes how to use wind speed frequency distributions to predict the average power output of a wind machine. If such data are not available, Appendix B provides two methods--least squares fit and average wind speed/ standard deviation--that can be used to approximate the wind speed distribution. The average power output of a wind machine can then be estimated by using a Weibull distribution.

## D. Conclusions and Recommendations

The existing wind regime data being collected by Meteorological Services at a height of two meters should only be utilized as a general guide to locate sites or regions where anemometers should be installed at a height of 10 meters. Extrapolations from data gathered at a height of two meters will tend to underestimate the quality of the resource base because of boundary layer interactions.

The program to install 32 additional anemometers should be continued. The investment in instrumentation has already been made and two successful anemometer installations have been completed by Mr. Smith and BRET technicians. The collection of wind data from the 34 installations will enable Botswana to provide accurate wind regime data to manufacturers of wind systems. This will ensure that equipment can perform the tasks and conditions for which it is intended. It is recommended that the anemometer program be implemented as soon as scheduling and manpower permits, and the BRET schedule for continuing these installations commences in June, 1983.

BRET's projected 34 anemometer sites for wind data collection cover a good cross section of Botswana. In addition, it is recommended that anemometers be installed near either new or existing windmills, or new windmill test units be located close to anemometer installations, where practical and feasible. Anemometers and/or windmills should be installed at locations where there are no obstructions within 100 meters, or should stand five meters above any obstruction closer than 100 meters, to avoid erratic readings.

The readings at all anemometer installations should be synchronized, so that data are always collected at the same time at the end of each month. Monthly averages should refer to a specific month--they should not merely summarize a month's worth of data that might include data from two weeks of one month and two of another. This will permit comparisons with Meteorological Services' existing data. It is recommendecd that data be plotted as wind speed frequency and power distribution curves, with the assistance of the University of Botswana's physics department and computer, so that wind speed and energy maps can be developed for Botswana after a full year's data have been collected. The university has agreed to assist the project in this endeavor, and BRET technicians should review the wind speed and power work sheet, formulas and curves with university staff.

The wind measuring instruments purchased from Natural Power, Inc. are quality devices, yet are reasonably priced and of an adequate design to gather the needed data. It is most important that anemometer installations be made in accordance with the manufacturer's installation and operating instructions (see Appendix I) to protect the equipment from damage and assure its performance.

It is recommended that BRET obtain two wind speed strip chart recorders that interface with the existing compilators and two strip chart flow indicators in order to record wind speed and windmill flow output simultaneously at any site where both an anemometer and windmill are installed.

To review, the steps required to implement a national wind data analysis system are as follows:

- project responsibility--BRET is technically equipped to implement and sustain a national wind data analysis system, but the manpower requirements should be reviewed;

- anemometer installations--personnel who will collect data on a monthly basis need to be assigned and trained, and data collection synchronized when all the installations are complete so data are logged on the same day at the end of each month at every location;

- data sheets--completed forms should be evaluated by BRET before being forwarded to the University of Botswana for processing and curve development, and monthly records maintained at the BRET office as well as the university;

- BRET technicians--these staff members should review the data sheets, average wind speed and power formulas given in this section, and information from Natural Power provided in Appendix B with Drs. Devan and Idzenga at the university in order to formalize the computer program;

- program coordination--BRET should discuss these steps and procedures with Meteorological Services and Water Affairs, so the data from all sites are sent to the project for further action;

- data distribution--BRET should supply monthly wind data to Meteorological Services and Water Affairs;

- program duration--the national wind data analysis system should operate for 12 months to permit the determination of an annual average wind speed and power frequency for each site; and

- additional data collection--the monitoring equipment should be maintained and data collected on a continuing basis.

The national wind data system will provide information about the wind regime at a height of 10 meters for a good cross-section of Botswana, thus enabling analysts to select geographical areas that can support windmill pumping systems and indicate the appropriate size of such units. After a year of data collection, a national map showing variations in average wind speed and available power can be developed and distributed to various government ministries for their individual needs and purposes. In addition, the data can be supplied to wind equipment manufacturers so they will know the actual average wind speeds available to power their units. Finally, the information gathered can be utilized to determine the real potential of Botswana's wind energy resource, its location and how vigorously various wind-related projects should be pursued.

## III. RIIC PROTOTYPE WINDMILL AT KANYE

### A. Design Parameters and Test Site Description

The RIIC prototype is a 15 percent solidity, six-meter diameter, six-bladed windmill, designed to operate a rotary (helix), mono-style pump. The initial design criteria specified in windmill contract between BTC and RIIC were that the mill had to pump 7.5 cubic meters a day, from a total head of 100 meters, in an average wind regime of 3.5 meters per second (12.6 kilometers per hour).

The prototype is installed over bore-hole number 3426 at Mogojogojwe and operates at a total head of 110 meters, although this total pumping head figure needs to verified. The pump in the bore-hole is believed to be a model ES-15 mono pump, and the yield is quoted at 4.4 cubic meters per hour. The mill site is unobstructed and is a good location for this test.

Instrumentation at the site consists of an in-line flow meter calibrated to measure pumped capacity at 10 liters per minute and an anemometer installed at a height of 10 meters to monitor wind speed. The instrument to count the machine's rpm is at the site, but is not functional. It should be made operative, as it could be used in tests to determine the efficiency of the mono pump. A local person, who lives close to the site, is assigned to take performance readings on a daily basis. Instruments should be acquired to check the draw-down, if any, for various pumping rates.

Mr. Smith and BRET technicians visited Mr. Kenton Allen and Mr. Max Ewens at Kanye to review the windmill system and the project's objectives. The timing of the visit did not give Mr. Ewens the opportunity to properly examine the test results to date, as he had just returned from a four-month leave. He is RIIC's windmill engineer and designed the mill. To interpret the data and give a realistic evaluation of the RIIC mill program to BRET, Mr. Allen, the technical director, was formally asked that a number of questions about the prototype system's characteristics (which appear on a separate page at the end of this section) be answered by Mr. Ewens. However, as the bulk of the information requested could not be provided to the project before the end of the consultancy, it will have to be forwarded to the BRET office and ARD. Evaluation of the RIIC windmill will be completed in the United States, and the report returned to BRET and RIIC.

### B. Engineering Assessment

The mechanical integrity of the machine and tower appear sound and well suited to existing manufacturing technology in

Botswana. There will be some problems with the variable centrifugal clutch belts being exposed to sunlight. Most of the mechanical problems with this machine at the start of its test program were related to belts driving the engine transmission. They have been replaced by a chain drive, which has purportedly eliminated the major problems. In any event, if the chain proves successful, it should be encased and run in an oil bath. At present, the chain is greased every month, but this is not practical for machines installed in the field, and a yearly maintenance schedule is far more realistic.

There is some question about the unit's low solidity (approximately 15 percent), and its ability to start and pump water at the lower wind speeds characteristic of Botswana's wind regime--two to three meters per second. It must be understood that pumping conditions, as well as the size of the Mono pump, will greatly affect the mill's start-up speed. Few facts were available regarding the starting torque that the Mono pump requires, but the pump manufacturer should be able to assist Mr. Ewens in this application and should be contacted concerning the project and the pump's use with windmills. On Mr. Smith's return to the United States, he was informed by Stewarts/Lloyds-Climax that Mono is now developing "torqueless" prototype pumps to overcome the need for high start-up torque. As a result, Climax has designed a rotary, multi-bladed, high solidity unit to operate these pump without any variable drive clutching mechanisms. If these pumps prove satisfactory, they could be very cost-effective in conjunction with the RIIC windmill design, as well as enhancing the mill's dependability and reducing maintenance requirements.

The engineering assessment of the RIIC prototype windmill produced the following conclusions:

- the variable clutch belts should be shielded from exposure to the sun;
- the chain-driven rotary mechanism should be encased in an oil bath to extend its life and permit an annual maintenance schedule;
- the start-up pumping speeds of the RIIC mill coupled with the ES-15 Mono pump at Mogojogojwe need to be determined;
- the performance and field evaluation tests being conducted to determine whether to proceed with production should employ prototypes that incorporate all the mechanical design and construction features being considered for the production model;
- units should be tested in the field for a minimum of one year, and more than one unit should be tested, if there are no budget constraints; and

- it is imperative that new prototype developments in Mono pumps be investigated to see if they are applicable to the RIIC rotary windmill.

A final engineering assessment of the RIIC prototype windmill cannot be completed until additional information, listed on the following page, is supplied.

## ADDITIONAL INFORMATION NEEDED FOR EVALUATION OF RIIC WINDMILL

1. Bore-Hole Data at Mogojogojwe

   - Pumping water level.
   - Yield from bore-hole (cubic meters per hour).
   - Total head of installation, including pumping depth plus delivery head.
   - Bore-hole number and construction date.

2. Windmill Monitoring at Mogojogojwe

   - Type of equipment used and general information about anemometer installation.
   - How long data have been taken and information recorded.
   - Average wind speed and power available at site for duration that data have been taken; curves, both for wind speed and power available at site are required.

3. RIIC Windmill Design Characteristics

   - Performance objectives that dictated mill's design characteristics.
   - Tip speed ratio and its variance due to effects of centrifugal unloading mechanism.
   - Number of blades and rotor solidity.
   - Start-up speed using ES-15 mono pump.
   - Optimum wind speed that mill was designed for to achieve performance objectives.
   - Tabulated data showing wheel and pump rpms, and pump output flow at various wind speeds, from start-up through furling velocities.
   - Mill's furling speed.
   - Confirm that pump being used is an ES-15.
   - Average daily output of system over period of mill's installation and monitoring of wind speed at the site.

4. Construction Features and Maintenance Details

   - Record or list of maintenance pulled on the mill, pump and/or anemometer since installation.
   - Maintenance schedule, if available.
   - More specific details on how centrifugal unloading mechanism operates.
   - Installation sketch of total system at the site--this is important.
   - General notes on design advantages and/or disadvantages of RIIC mill versus conventional, multi-bladed water pumping system.
   - Cost to manufacture system in Botswana and production analysis of person-hours involved in building the machine.

# IV. WINDMILL PROGRAM

## A. Introduction

This section covers:

- specific windmill designs,
- the development, testing and monitoring program currently underway, and
- other designs and programs being proposed for consideration and testing to determine appropriate windmills for Botswana's wind regime.

Some units based on new concepts are either undergoing performance and dependability tests at the present time or will be tested soon. The performance and durability of other mills has been proven, but they have yet to be tested in Botswana's wind regime to assure their suitability for water supply systems in this country.

In the initial development stage, it is important that the anemometer program, windmill installation and performance monitoring be implemented simultaneously. These activities complement each other in providing a conclusive answer to the central question behind the wind energy program--is Botswana's wind regime sufficent for windmill pumping systems to supply water?

Regardless of the origin or make of the windmills, it is also important that conventional and new concepts in windmill water pumping be tested. Consideration should be given to the possibility of manufacturing or licensing the production of wind systems in Botswana.

## B. Standard Multi-Bladed Windmill Installation at Sedibeng

On March 15, 1983, an anemometer at a height of 10 meters and a windmill pumping system were installed in the village of Sedibeng, by BRET and Water Affairs technicians, as well as the project's extension personnel. It will serve as a test site for BRET technicians to monitor multi-bladed windmill pumping performance in a known wind regime. Specific details of the installation and equipment are detailed below.

Bore-hole number 3816 has a well depth of 82.5 meters, static water level of 30.6 meters and yield of 1.6 cubic meters per hour. The quality of the water is good and suitable for human consumption.

Information on the windmill equipment was obtained from Water Affairs. It is a Climax Number 12 with a 12-foot diameter, multi-bladed reciprocating design, 3.053 gear ratio and 235-millimeter stroke at 27 strokes per minute. The maximum wind speed the mill can tolerate is 40 kilometers per hour. It has 85 percent wheel solidity, a 69-millimeter diameter cylinder used for reciprocating pumps and is set at a depth of 60 meters. The engine runs in a oil bath, which requires an annual maintenance check and oil change. The total pumping head is 35 meters. Water is discharged into a storage tank, and .50-millimeter galvanized pipe is used throughout. The mill is mounted on a 12-meter, four-post tower, bolted together with concrete foundations for the corner posts. Packing must be installed beneath the hood covering the engine because of possible sand and water contamination of the engine oil.

The instrumentation for wind measurements consists of a model A30-101 compilator with a three-cup sensor (see Appendix B), mounted on a tower at a height of 10 meters. An Arco solar array and 12-volt DC battery supply power to the equipment. The array is mounted on the tower, and the compilator and batteries are locked inside an enclosure also mounted on the tower.

A Kent, two-inch flow meter (serial number 2H48578) was installed to measure total flow through the system. This flow meter is too large and should be replaced with a similar meter that measures 10 liters per revolution. The one installed measures approximately 100 liters per revolution and may give erroneous readings because of slip.

BRET technicians and extension staff have made an extensive effort to train and instruct the village headmaster and schoolteachers in the mill's operation and maintenance, and responsibility of gathering data from the anemometer equipment. It is recommended that BRET technicians monitor windmill performance at this site and record test results on a monthly basis. BRET extension personnel prepared a separate report on their experiences with the Sedibeng installation, which is presented in Appendix C.

A training program was implemented at this installation to acquaint village personnel, as well as BRET staff and the Water Affairs crew, with the installation, operation and maintenance of the windmill and anemometer systems. An important part of all installations is to involve villagers with the project so they become part of the total program. Section VII gives details of the training conducted during this consultancy and continuing training needs.

## C. WTGS Prototype Windmill at Serowe

BRET technicians and Mr. Smith visited the Swaneng School, and met with Mr. M. Gerrod Jacobs and Mr. Ed Desanto. Mr. Jacobs worked with Mr. Elize de Vries on the mill's theory and design, and with Mr. Desanto on the unit's structural and mechanical design. As of April 11, 1983, the bulk of the windmill's parts had been manufactured in Serowe and purchased components received. The tower is of welded construction, rather than bolted together.

The design criteria and objectives were the same as those for the RIIC mill--7.5 cubic meters per day, for a total head of 100 meters, operating in a wind of 3.5 meters per second. The mill has not yet been completely assembled with the tower for testing, but is scheduled for erection in early May at a bore-hole in Serowe near Mr. Jacob's house on school grounds. No specifics on the bore-hole were available, except that it is ready. The general design characteristics of the Serowe tower and windmill prototype are given below.

The tower parameters are:

- material -- 76-millimeter diameter, thin-wall pipe,
- height -- nine meters,
- base -- 2.25 square meters,
- top -- 0.75 square meters, and
- turntable -- ball bearing with axial load of 0.75 tons.

The tower is four-legged and fabricated in three sections, each of which is fitted with companion flanges, 156 millimeters in diameter and 6.5 millimeters thick, facilitating four M12 hex bolts with nuts on 130-millimeter PCD. The intersections between legs and bracing were designed and fitted to ensure structural soundness. The cross braces run diagonally top to bottom and are constructed of 100-millimeter diameter rod, threaded on both ends, under tension to minimize racking and stress.

The windmill is a horizontal-axis, multi-bladed design. The eight blades have a sweep 6.2 meters in diameter with a tip speed ratio of 2.5 to one. They are made of reinforced fiberglass, and the angle of attack is adjustable. The transmission is a Fenner gearbox with a three-to-one step-up and bevel gears. The shaft is 60 millimeters in diameter. The chassis is made of 6.5-millimeter mild steel plate with tail assembly and side vane of all-welded construction.

The mechanical and structural integrity of this machine is most impressive. Some of the components purchased to complement

the drive-line shafting, such as the Fenner, right-angle, rotary gearbox and Fenner flex couplings, should provide long machine life with a minimum maintenance requirement. The wheel design and centrifugal clutching mechanism will prove their worthiness under tests and load.

Although the tower is massive in appearance and structurally sound, it should be constructed from angle iron bolted together, rather than the present welded tubular design. Angle-iron construction would be less expensive, structurally adequate and more appropriate to Botswana's manufacturing capabilities.

In spite of obstructions, this is a good site for working out initial problems and fine-tuning the machine prior to a performance test of sustained duration. However, there is not enough wind to thoroughly exercise the unit and indicate its performance potential.

## D. Wind Baron High-Performance Counterbalanced Windmill Design

Wind Baron Corporation, of Phoenix, Arizona, manufactures and markets a high-performance, counterbalanced, 21-foot diameter, multi-bladed wind machine capable of operating in low wind speeds--as low as three mph (4.8 kilometers per hour). This is a new concept in windmill pumping systems that is directly applicable to areas with low wind regimes and/or deep bore-holes. The Mark IV high-performance mill has undergone three years of development testing at a Navajo Indian reservation in Arixona with a wind regime, altitude and climatic conditions similar to Botswana. It would be worthwhile for BRET to evaluate this product as part of the windmill evaluation program.

The counterbalanced windmill was patented in the United States in July, 1980, and patents have also been issued in 16 foreign countries with applications pending in 60 other nations, as of January, 1982. The company is focusing on markets in developing countries, as well as the private and public sectors in the United States. Wind Baron's intentions are to implement an intensive manufacturing and worldwide marketing, distribution and licensing program. Their machine has several applications, including oil pumping, air compression, water purification and electrical generation.

Appendix D presents portions of a comparative performance test between a conventional, multi-bladed water pumping system (Aermotor) and Wind Baron's counterbalanced windmill for a low wind speed regime. In addition, a third-party summary of the tests conducted and results obtained by the Turbo-Machinery Laboratories at Texas A & M University of College Station, Texas is also included. It must be noted that the performance comparison of these two mills for the month of December was conducted with a small (1 7/8-inch or 47.6-millimeter) cylinder

at a very deep head of 720 feet (220 meters). A complete summary of the test conditions and specifications for Wind Baron's high-performance windmill can be found at the BRET office.

## E. Other Windmills

Consideration should be given to other windmills manufactured in Europe and the Stewart/Lloyds Climax mills, produced in South Africa and distributed in Botswana and other SADCC countries. The Southern Cross windmill from Australia is also a proven wind machine, and several Southern Cross mills were observed in operation in Botswana. In addition, there are some windmills of various designs manufactured in Kenya and Zimbabwe that should be investigated. It would be very worthwhile to test and evaluate a hybrid of the best features from the tower and windmill designs of the RIIC and Serowe prototype units. The ability to manufacture these mills in Botswana is close to becoming a reality.

## F. Conclusions and Recommendations

It is recommended that various windmills be procured, installed and their performance monitored by BRET in conjunction with the wind analysis program currently underway as the two activities can complement each other in establishing the true effectiveness of wind-powered water pumping systems in Botswana. The windmill systems suggested for this testing program include:

- two RIIC production, six-meter, rotary windmills with towers; two Serowe production, 6.2-meter, rotary windmills with towers; and/or two RIIC/Serowe hybrid, 6.2-meter, rotary windmills with bolt-together, angle-iron towers;
- two wind systems manufactured in Kenya or Zimbabwe;
- one Wind Baron, high-performance, counterbalanced, 21-foot, multi-bladed, reciprocating water pumping system with hand pump and 47-foot tower; and
- six existing, privately owned windmills, of as many different makes as possible, already installed and operating, that can be utilized by BRET for performance testing and monitoring of wind data.

The RIIC/Serowe hybrid is a unit consisting of the best features of the two mills. In general, the design would consist of the wheel assembly and gearbox from the Serowe mill, the RIIC variable centrifugal unloading mechanism and a bolt-together, angle-iron tower. BRET would be responsible for the system's fabrication, installation and monitoring.

It is important to note that if the program budget permits, the number of windmills tested should be doubled--two of each type is not an adequate sample for a test of system performance and dependability. In addition, the windmill testing program will require monitoring equipment, as discussed in the next section.

## V. MONITORING WINDMILL PERFORMANCE

### A. Data Collection Requirements

This section presents the test data requirements and equipment needs for monitoring the performance output of any windmill pumping system.

The data requirements for a short-term performance test are:

- average wind speed for duration of the test, which demands a chart recorder that interfaces with the anemometer;
- total pumping head during the test period--depth to water level plus discharge head;
- total flow pumped for the test's duration; and
- total number of machine rpms or strokes during the test.

These data permit the determination of pump flow for various average wind velocities for a specific pumping head, volumetric efficiency of the pump or cylinder used, and the system's overall wind-to-water efficiency.

Test data needed for monthly performance monitoring include:

- monthly average wind speed from compilator;
- total pumping head, which may be approximated if the well's yield does not exceed the system's maximum output;
- total flow pumped during the month;
- total number of machine strokes or rpms is useful, though not absolutely necessary, to determine cylinder or pump degradation and efficiency loss; and
- maintenance check for mechanical and/or structural deterioration.

Derivations similar to those for the short-term test can be made, and a truer picture of the system's average daily output and efficiency formed. Monthly performance monitoring should be synchronized with the schedule for logging data from the anemometer and carried out for the duration of the windmill evaluation program. At a minimum, a mill should be monitored for a year to evaluate its design and performance.

Other items to be recorded on the test data sheet are:

- pump or cylinder in the well,
- bore-hole number and location,
- total pumping head and bore-hole yield,
- water quality,
- site description--terrain, etc.
- description of the windmill and pumping system, and
- mechanical and/or structural problems that are either developing or present.

The monitoring equipment needed is as follows:

- strip chart wind speed recorders that interface with existing model A30-101 compilators;
- strip chart flow meters so that flow output can be measured simultaneously with wind speed;
- Kent flow meters calibrated to 10 liters per revolution;
- well depth indicators;
- rpm and reciprocating stroke counters; and
- calibrated pressure gauges.

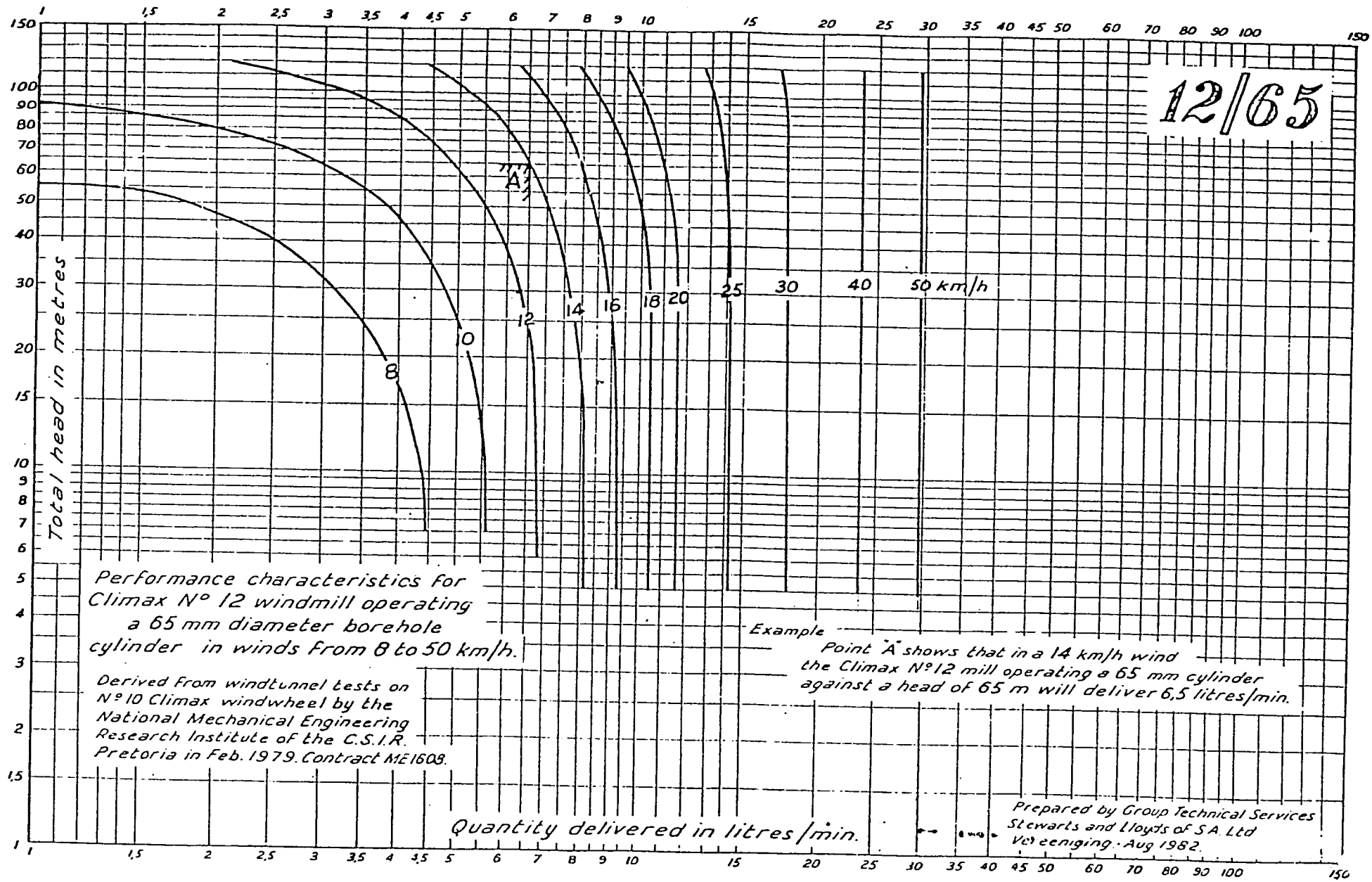
## B. Windmill Performance Curves--Climax Wind Tunnel Tests

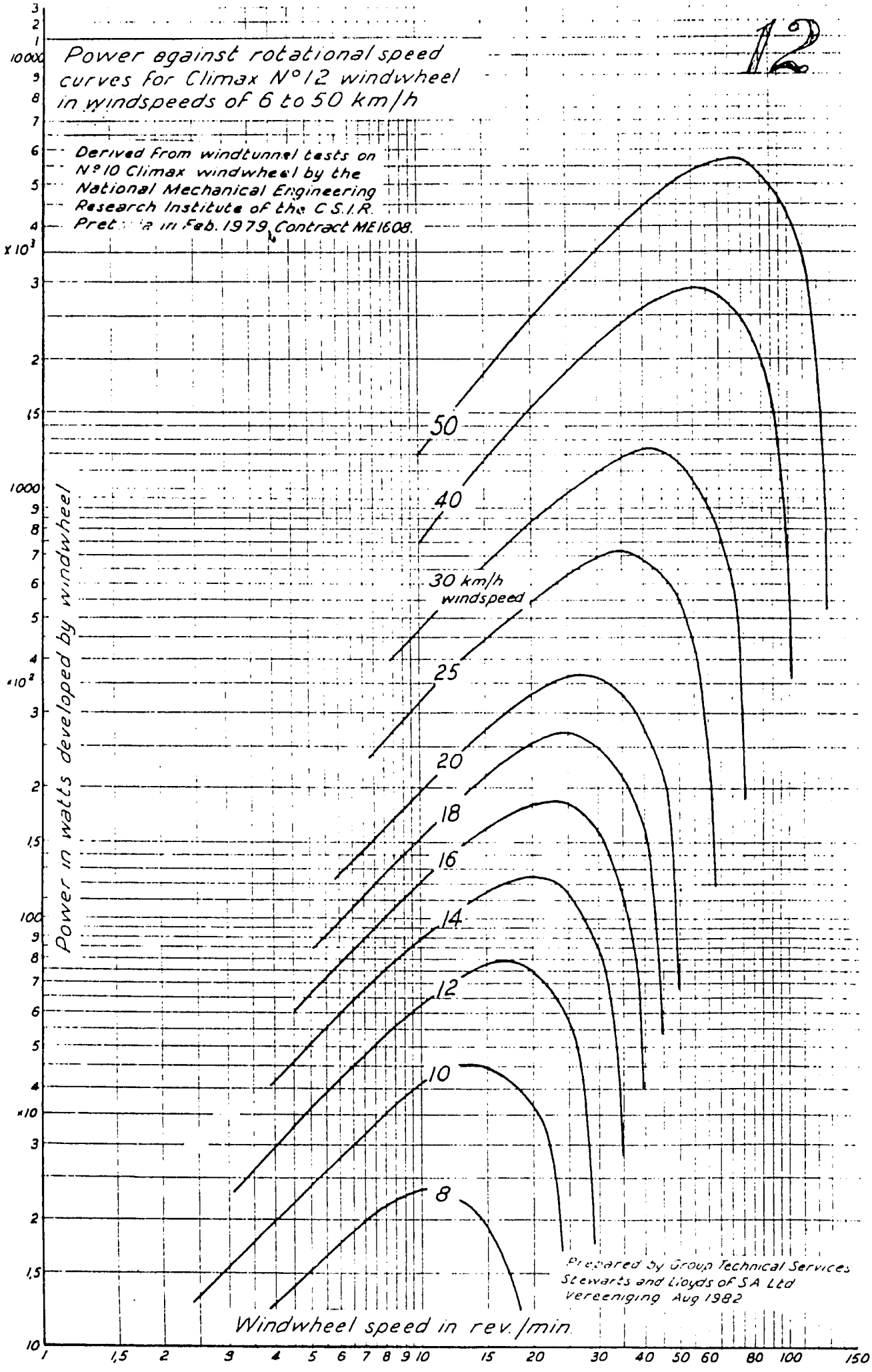
A testing and rating standard for windmill water pumping systems does not currently exist, which makes it extremely difficult to select and size a mill for a given set of bore-hole, wind regime and pumping requirements. Most manufacturers' performance data are tabulated and rated in terms of gallons or liters pumped per day or hour, using a specific cylinder, for a wide range of high wind speeds, which are not the norm in Botswana. This sort of vague data always gives rise to questions such as:

- how many hours a day will the mill pump for a specific average wind velocity; and
- what is the mill's start-up speed when pumping against a certain head, using a specific cylinder?

Through correspondence with the manager of Climax Windmills (Pty) Ltd., performance curves were obtained that clearly answer these questions of windmill selection, sizing and performance. It is some of the best data of its type, and examples of "family curves" for the pumping performance and power developed against rotational speed for the Climax 12-foot diameter, multi-bladed water pumping system in wind velocities from six to 50 kilometers per hour appear on the following two pages. The curves for Climax multi-bladed windmills from eight to 18 feet in diameter are shown in Appendix E. They were derived from wind tunnel tests conducted by the National Mechanical Engineering Research Institute of CSIR in Pretoria, South Africa during February, 1979 under contract ME. 1608. Individual curves were also developed for each mill coupled to specific cylinder sizes. The complete engineering performance catalog for Climax mills can be found in the BRET library.

It is recommended that these curves be used as a <u>standard</u> for selecting Climax windmills and an appropriate guide for choosing other conventional multi-bladed water pumping systems.


12/65
Total head in metres
Quantity delivered in litres/min.
8
10
12
14
16
18
20
25
30
40
50 km/h
A
Performance characteristics for Climax N° 12 windmill operating a 65 mm diameter borehole cylinder in winds from 8 to 50 km/h.
Derived from windtunnel tests on N° 10 Climax windwheel by the National Mechanical Engineering Research Institute of the C.S.I.R. Pretoria in Feb. 1979. Contract ME1608.
Example
Point "A" shows that in a 14 km/h wind the Climax N° 12 mill operating a 65 mm cylinder against a head of 65 m will deliver 6,5 litres/min.
Prepared by Group Technical Services Stewarts and Lloyds of S.A. Ltd Vereeniging. Aug 1982.


12
Power against rotational speed curves for Climax N°12 windwheel in windspeeds of 6 to 50 km/h
Derived from windtunnel tests on N°10 Climax windwheel by the National Mechanical Engineering Research Institute of the C.S.I.R. Pretoria in Feb. 1979, Contract ME1608.
Power in watts developed by windwheel
Windwheel speed in rev./min.
50
40
30 km/h windspeed
25
20
18
16
14
12
10
8
Prepared by Group Technical Services Stewarts and Lloyds of S.A. Ltd Vereeniging Aug 1982

## VI. ECONOMIC ANALYSIS OF WIND AND PV PUMPING SYSTEMS

### A. Estimating Benefits and Costs of Water Pumping Technologies

The chief benefit to be measured for water pumping technologies is the amount of water lifted. While there are a number of secondary benefits, such as employment generation, these are assumed to be similar in size and timing for all the technologies and so, need not be included in this comparative analysis. Thus, the stream of benefits for water pumping systems is based on the daily volume of water pumped.

Because of the scarcity of field data on pumping systems in Botswana, a number of basic assumptions about the resource base and annual system availability were used to calculate performance figures. Wind energy systems were assumed to operate 365 days a year, eight hours a day. For PV systems, eight hours of pumping per day, 350 days a year were assumed, with the total volume pumped approximately equal to five times the system's output between noon and one p.m. Insolation was assumed to be about 1,000 watts per square meter at noon.

Where possible, extraneous environmental variables were eliminated to simplify the analysis and ensure that systems were compared under similar conditions. Thus, two representative pumping heads--30 and 100 meters--were used in the calculations for all systems, unless otherwise noted.

The amount of water pumped daily by each unit was estimated from engineering data provided by the manufacturers for heads of 30 and 100 meters, and given bore-hole dimensions. While these are only estimates, the field engineering tests (including wind tunnel tests of the FIASA and Dempster mills) on which they are based have been independently verified. Data for the Dempster and FIASA windmills were used in the economic analysis because they are physically idential to machines now commercially available in Botswana. The costs presented for each system include not only the initial hardware and its installation, but also subsequent maintenace and periodic replacement of spare parts, such as pump cylinders and seals.

### B. Discounting the Flow of Benefits and Costs

A traditional problem for development planners and project administrators is comparing alternative investment opportunities to determine which should be funded. This is particularly difficult when alternatives' initial capital costs, operation and maintenance requirements, and benefit streams differ widely. The analyst's task is to reduce the stream of benefits and costs to a set of economic values that can easily be compared.

In the case of water pumping technologies, the net discounted present value of the stream of benefits was calculated, as well as the economic value for each cubic meter of water required to equate the streams of benefits and costs over the project's life. In the first instance, the net benefit of a water pumping system in any given year is the economic value of the water produced minus maintenance costs, any capital investments and replacement parts installed during that year.

All benefits and costs are not considered to be of equal value. Benefits received later in a project are generally not valued as highly as those received today. Similarly, costs incurred in a project's tenth year are usually deemed less important than the initial capital investment. The discount rate is a measure of the time-related value of money, goods and services. If an individual or agency is indifferent to receiving 100 pula today versus 110 a year from now, the person or group is has an annual discount rate of 10 percent. Discount rates are specific to groups and individuals and may vary drastically within a society. Those without access to commercial credit or living in poverty may have very high discount rates (50 percent a year or more), while government institutions may use low rates (five percent) in comparing alternative investment opportunities.

An investment's net present value is the sum of net benefits for each year of the project, with each year's net benefit (or loss) reduced by a discount factor (r). To discount net benefits for one year, they are divided by one plus the discount rate (1 + r). To do so for two years in the future, net benefits are divided by $(1 + r)^2$. Thus, net benefits are discounted n years into the future by dividing them by $(1 + r)^n$. At high discount rates, the value of future net benefits drops rapidly. Thus, 100 pula in net benefits to be received four years from today at a discount rate of 25 percent have a current discounted value of only 40.96 pula ((100 pula/$(1 + .25)^4$).

In general, the net present value of an investment can be calculated using the following economic equation:

$$NPV = \sum_{i=1}^{n} \frac{(B_i - C_i)}{(1 + r)^i}$$

where NPV is net present value; i, the year; $B_i$, benefits in year i; $C_i$, costs in year i; r, the discount rate; and n, the life of the project in years.

This very simple, universally accepted methodology was deliberately chosen to compare alternative water pumping technologies. No factors were introduced to differentially weight various types of benefits and costs--the discount rate was applied equally to all costs and benefits. Different inflation rates for production factors (e.g., labor, money, energy, etc.)

are difficult to justify without good data and often distort economic analyses. Such steps are warranted only if hard, empirical data are available on current price changes and there is reason to believe that present trends will continue in the future. For example, a forecasting methodology which assumed in 1980 that fossil fuel prices would rise at a higher rate than inflation would yield estimates for current fuel bills that are far too high for 1983. Similarly, no shadow prices were used for any of the major factors--labor, replacement parts or the initial capital investment. In addition, foreign exchange limitations were not factored into the analysis, since it was assumed that this is a separate issue for consideration by the government of Botswana (GOB).

In the analysis that follows, two annual discount rates were used--15 and 25 percent. The first reflects the rate used by GOB ministries and agencies in making investment decisions, which is based on current GOB interest rates for development project capital, plus a modest amount for expected inflation. The second was chosen to represent a rate that characterizes the investment decisions of private firms and individuals, who are more uncertain about future investments and place a greater value on current, as opposed to future, receipts than government agencies.

In the calculations, water was valued at $1.00 per cubic meter, which while based on reasonable values from potable water systems installed at other locations, is not an empirically derived value for water in Botswana. The actual value of water could be higher or lower, depending on the site and preferences of local populace. However, since the same value was used for all the systems compared, changing that value would affect the net present value of benefits minus costs for each system, but not the relative ranking of the different systems.

One way to deal with the problem of not having an actual observed value for pumped water is to solve the equation for this value. For each system examined, the value of a cubic meter of water was allowed to vary until the discounted stream of benefits equaled the costs for the life of the project.

The tables presented in the following section compare five alternative systems:

- three windmills--the FIASA 14-foot, Dempster 14-foot and Wind Baron 21-foot machines, and
- two PV systems--Blue Sky water pumping units, one configured for a pumping head of 50 meters and the other, 100 meters.

The PV system figures are included primarily for comparative purposes, as PV-powered systems are often considered as an alternative to wind water pumping systems in southern Africa.

## C. Economic Comparison of Five Systems

Machine: Dempster - 14 ft. with 65mm cylinder

Total pumped head: 30 meters

Wind duration: 8 hrs/day, 365 days/year

| | WIND SPEED | | |
|---|---|---|---|
| COSTS | 8 km/hr | 12 km/hr | 16 km/hr |
| 1. Initial capital cost (year 0): | $7157.00 | $7157.00 | $7157.00 |
| 2. Annual operating costs: | $ 200.00 | $ 200.00 | $ 200.00 |
| 3. Present value of additional discounted capital costs @ 15% discount: (replacement cylinders in years 5 and 10) | $ 148.87 | $ 148.87 | $ 148.87 |
| @ 25% discount: | $ 87.01 | $ 87.01 | $ 87.01 |
| BENEFITS | | | |
| 4. Water pumped - cubic meters/year: | 576.7 | 1014.7[a] | 1365.1[b] |
| 5. Annual value of water pumped, valued at $1.00/m$^3$: | $ 576.70 | $1014.70[a] | $1365.10[b] |
| 6. Net annual benefits (water value minus operating costs; line 5 minus line 2): | $ 376.70 | $ 814.70 | $1165.10 |
| 7. Net present value of benefit stream (years 1-10) @ 15%: | $1890.57 | $4088.79 | $5847.37 |
| @ 25%: | $1345.00 | $2908.89 | $4159.99 |
| 8. Net present value of benefits minus costs (years 1-10) @ 15%: | -5415.30 | -3217.08 | -1458.50 |
| @ 25%: | -5899.00 | -4335.10 | -3084.00 |
| 9. Value of water that makes benefits minus costs (line 8) equal 0 @ 15%: | $ 2.87/m$^3$ | $ 1.63/m$^3$ | $ 1.21/m$^3$ |
| @ 25%: | $ 3.86/m$^3$ | $ 2.20/m$^3$ | $ 1.63/m$^3$ |

a. The amount of water pumped is restricted by the use of a 65mm pump cylinder (dictated by the borehole size). With a large diameter (125mm) cylinder, the estimated annual water output would be 2803 cubic meters or 276% higher. Prices per cubic meter of water pumped with the larger cylinder would be reduced to $0.59/cubic meter at a 25% discount rate and $0.80/cubic meter at a 25% discount rate.

b. With a 125mm pump cylinder, estimated annual water output would be 347% higher or 4730 cubic meters. Cost per cubic meter at this flow rate would be $0.35/cubic meter at a 15% discount rate or $0.47/cubic meter at a 25% discount rate.

Machine: FIASA - 14 ft. with 65mm cylinder

Total pumped head: 30 meters

Wind duration: 8 hrs/day, 365 days/year

| COSTS | WIND SPEED 8 km/hr | 12 km/hr | 16 km/hr |
|---|---|---|---|
| 1. Initial capital cost (year 0): | $8571.00 | $8571.00 | $8571.00 |
| 2. Annual operating costs: | $ 200.00 | $ 200.00 | $ 200.00 |
| 3. Present value of additional discounted capital costs @ 15% discount: | $ 256.06 | $ 256.06 | $ 256.06 |
| (cylinder replacement in years 5 and 10) @ 25% discount: | $ 149.66 | $ 149.66 | $ 149.66 |
| **BENEFITS** | | | |
| 4. Water pumped - cubic meters/year: | 576.7 | 1014.7[a] | 1365.1[b] |
| 5. Annual value of water pumped, valued at $1.00/m$^3$: | $ 576.70 | $1014.70 | $1365.10 |
| 6. Net annual benefits (water value minus operating costs; line 5 minus line 2): | $ 376.70 | $ 814.70 | $1165.10 |
| 7. Net present value of benefit stream (years 1-10) @ 15%: | $1890.57 | $4088.70 | $5847.37 |
| @ 25%: | $1345.00 | $2908.89 | $4159.99 |
| 8. Net present value of benefits minus costs (years 1-10) @ 15%: | $-6936.50 | $-4738.30 | $-2979.70 |
| @ 25%: | $-7482.10 | $-5918.20 | $-4667.10 |
| 9. Value of water that makes benefits minus costs (line 8) equal 0 @ 15%: | $ 3.40/m$^3$ | $ 1.93/m$^3$ | $ 1.43/m$^3$ |
| @ 25%: | $ 4.58/m$^3$ | $ 2.60/m$^3$ | $ 1.94/m$^3$ |

a. The amount of water pumped is restricted by the use of a 65mm pump cylinder. With a large diameter (125mm) cylinder, the estimated annual water output would be 2803 cubic meters or 276% higher. Prices per cubic meter of water pumped with the larger cylinder would be reduced to $0.70/cubic meter at a 15% discount and $0.94/cubic meter at a 25% discount rate.

b. With a 125mm pump cylinder, estimated annual water output would be 347% higher or 4730 cubic meters. Costs per cubic meter at this flow rate would be $0.42/cubic meter at a 15% discount rate and $0.56/cubic meter at a 25% discount rate.

Machine: Wind Baron - 21 ft. with 65mm cylinder

Total pumped head: 30 meters

Wind duration: 8 hrs/day, 365 days/year

| COSTS | WIND SPEED 8 km/hr | 12 km/hr | 16 km/hr |
|---|---|---|---|
| 1. Initial capital cost (year 0): | $17,550.00 | $17,550.00 | $17,550.00 |
| 2. Annual operating costs: | $ 200.00 | $ 200.00 | $ 200.00 |
| 3. Present value of additional discounted capital costs @ 15% discount: (replacement cylinders in years 5 and 10) | $ 529.24 | $ 529.24 | $ 529.24 |
| @ 25% discount: | $ 309.32 | $ 309.32 | $ 309.32 |
| **BENEFITS** | | | |
| 4. Water pumped - cubic meters/year: | 735.84 | 3784.32 | 6025.88 |
| 5. Annual value of water pumped, valued at $1.00/m$^3$: | $ 735.84 | $ 3,784.32 | $ 6,026.88 |
| 6. Net annual benefits (water value minus operating costs; line 5 minus line 2): | $ 535.84 | $ 3,584.32 | $ 5,826.88 |
| 7. Net present value of benefit stream (years 1-10) @ 15%: | $ 2,689.26 | $17,988.87 | $30,247.52 |
| @ 25%: | $ 1,913.22 | $12,797.83 | +21,518.99 |
| 8. Net present value of benefits minus costs (years 1-10) @ 15%: | $-15,389.98 | $ -90.37 | $+12,168.28 |
| @ 25%: | $-15,946.10 | $-5,061.49 | $+ 3,659.67 |
| 9. Value of water that makes benefits minus costs (line 8) equal 0 @ 15%: | $ 5.17/m$^3$ | $ 1.00/m$^3$ | $ .63/m$^3$ |
| @ 25%: | $ 7.07/m$^3$ | $ 1.37/m$^3$ | $ .86/m$^3$ |

Machine: Dempster - 14 ft. fanmill with 65mm cylinder

Total pumped head: 100 meters

Wind duration: 8 hrs/day, 365 days/year

| COSTS | WIND SPEED 6 km/hr | 12 km/hr | 16 km/hr |
|---|---|---|---|
| 1. Initial capital cost (year 0): | $7157.00 | $7157.00 | $7157.00 |
| 2. Annual operating costs: | $ 200.00 | $ 200.00 | $ 200.00 |
| 3. Present value of additional discounted capital costs @ 15% discount: | $ 148.87 | $ 148.87 | $ 148.87 |
| @ 25% discount: | $ 87.01 | $ 87.01 | $ 87.01 |
| **BENEFITS** | | | |
| 4. Water pumped - cubic meters/year: | 102.2 | 751.9 | 1189.9 |
| 5. Annual value of water pumped, valued at $1.00/m$^3$: | $ 102.20 | $ 751.90 | $1189.90 |
| 6. Net annual benefits (water value minus operating costs; line 5 minus line 2): | $ -87.80 | $ 551.90 | $ 989.90 |
| 7. Net present value of benefit stream (years 1-10) @ 15%: | -0- | $2769.86 | $4968.08 |
| @ 25%: | -0- | $1970.56 | $3534.34 |
| 8. Net present value of benefits minus costs (years 1-10) @ 15%: | -0- | $4536.01 | $2337.79 |
| @ 25%: | -0- | $5273.45 | $3709.67 |
| 9. Value of water that makes benefits minus costs (line 8) equal 0 @ 15%: | | $ 2.20 | $ 1.39/m$^3$ |
| @ 25%: | | $ 2.96 | $ 1.87/m$^3$ |

Machine: FIASA - 14 ft. with 65mm cylinder

Total pumped head: 100 meters

Wind duration: 8 hrs/day, 365 days/year

| COSTS | WIND SPEED 6 km/hr | 12 km/hr | 16 km/hr |
|---|---|---|---|
| 1. Initial capital cost (year 0): | $8571.00 | $8571.00 | $8571.00 |
| 2. Annual operating costs: | $ 200.00 | $ 200.00 | $ 200.00 |
| 3. Present value of additional discounted capital costs @ 15% discount: | $ 256.06 | $ 256.06 | $ 256.06 |
| @ 25% discount: | $ 149.66 | $ 149.66 | $ 149.66 |
| **BENEFITS** | | | |
| 4. Water pumped - cubic meters/year: | 102.20 | 751.9 [a] | 1189.9 [b] |
| 5. Annual value of water pumped, valued at $1.00/m$^3$: | $ 102.20 | $ 751.90 | $1189.90 |
| 6. Net annual benefits (water value minus operating costs; line 5 minus line 2): | $ -87.80 | $ 551.90 | $ 989.90 |
| 7. Net present value of benefit stream (years 1-10) @ 15%: | -0- | $2769.86 | $4968.08 |
| @ 25%: | -0- | $1970.56 | $3534.34 |
| 8. Net present value of benefits minus costs (years 1-10) @ 15%: | -0- | -6057.20 | -3858.98 |
| @ 25%: | -0- | -6750.10 | -5186.32 |
| 9. Value of water that makes benefits minus costs (line 8) equal 0 @ 15%: | $ 19.17/m$^3$ | $ 2.61/m$^3$ | $ 1.65/m$^3$ |
| @ 25%: | $ 25.86/m$^3$ | $ 3.51/m$^3$ | $ 2.22/m$^3$ |

Machine: Wind Baron - 21 ft. with 65mm cylinder

Total pumped head: 100 meters

Wind duration: 8 hrs/day, 365 days/year

| COSTS | | WIND SPEED 8 km/hr | 12 km/hr | 16 km/hr |
|---|---|---|---|---|
| 1. Initial capital cost (year 0): | | $77,550.00 | $17,550.00 | $17,550.00 |
| 2. Annual operating costs: | | $ 200.00 | $ 200.00 | $ 200.00 |
| 3. Present value of additional discounted capital costs (replace cylinder in year 5 and 10) | @ 15% discount: | $ 529.24 | $ 529.24 | $ 529.24 |
| | @ 25% discount: | $ 309.32 | $ 309.32 | $ 309.32 |
| **BENEFITS** | | | | |
| 4. Water pumped - cubic meters/year: | | 306.6 | 1,103.8 | 1,769.5 |
| 5. Annual value of water pumped, valued at $1.00/m$^3$: | | $ 306.60 | $1,103.80 | $1,769.50 |
| 6. Net annual benefits (water value minus operating costs; line 5 minus line 2): | | $ 106.60 | $ 329.24 | $1,569.50 |
| 7. Net present value of benefit stream (years 1-10) | @ 15%: | $ 535.00 | $1,652.38 | $7,876.96 |
| | @ 25%: | $ 380.62 | $1,175.55 | $5,603.90 |
| 8. Net present value of benefits minus costs (years 1-10) | @15%: | | | |
| | @25%: | | | |
| 9. Value of water that makes benefits minus costs (line 8) equal 0 | @ 15%: | $ 11.75/m$^3$ | $ 3.26/m$^3$ | $ 2.04/m$^3$ |
| | @ 15%: | $ 16.52/m$^3$ | $ 4.71/m$^3$ | $ 2.94/m$^3$ |

Machine: Blue Sky Photovoltaic Units

Total pumped head: 30 meters

Solar insolation: 1000 watts/$m^2$, 350 days/year

| COSTS | 50 METERS |
|---|---|
| 1. Initial capital cost (year 0): | $15,000.00 |
| 2. Annual operating costs: | $ 50.00 |
| 3. Present value of additional discounted capital costs @ 15% discount: (replace pump in years 3.5 and 7) | $ 1,779.70 |
| @ 25% discount: | $ 1,201.80 |
| **BENEFITS** | |
| 4. Water pumped - cubic meters/year: | 8750 |
| 5. Annual value of water pumped, valued at $1.00/$m^3$: | $ 8,750.00 |
| 6. Net annual benefits (water value minus operating costs; line 5 minus line 2): | $ 8,700.00 |
| 7. Net present value of benefit stream (years 1-10) @ 15%: | $43,663.00 |
| @ 25%: | $31,063.37 |
| 8. Net present value of benefits minus costs (years 1-10) @ 15%: | $26,883.30 |
| @ 25%: | $14,861.58 |
| 9. Value of water that makes benefits minus costs (line 8) equal 0 @ 15%: | $ .38/$m^3$ |
| @ 25%: | $ .54/$m^3$ |

Machine: Blue Sky Photovoltaic Units

Total pumped head: 100 meters

Solar insolation: 1000 watts/$m^2$, 350 days/year

| COSTS | 100 METERS |
|---|---|
| 1. Initial capital cost (year 0): | $45,000.00 |
| 2. Annual operating costs: | $ 50.00 |
| 3. Present value of additional discounted capital costs @ 15% discount: (replace pump in years 3.5 and 7) | $ 1,779.00 |
| @ 25% discount: | $ 1,201.80 |
| **BENEFITS** | |
| 4. Water pumped - cubic meters/year: | 8750 |
| 5. Annual value of water pumped, valued at $1.00/$m^3$: | $ 8,750.00 |
| 6. Net annual benefits (water value minus operating costs; line 5 minus line 2): | $ 8,700.00 |
| 7. Net present value of benefit stream (years 1-10) @ 15%: | $43,663.00 |
| @ 25%: | $31,063.37 |
| 8. Net present value of benefits minus costs (years 1-10) @ 15%: | $-2,538.80 |
| @ 25%: | $15,138.43 |
| 9. Value of water that makes benefits minus costs (line 8) equal 0 @ 15%: | $ 1.06/$m^3$ |
| @ 25%: | $ 1.48/$m^3$ |

## D. Findings

In Botswana, wind pumping units are only economically competitive with PV systems at sites with consistent, high-quality wind regimes. The sample calculations in the preceding section show that wind systems begin to be economically attractive for locations with a wind regime of at least 12 kilometers a day, eight hours each day, 365 days a year. Below this level, the amount of water pumped daily drops sharply and the cost per cubic meter rises accordingly. Conversely, since the power available in the wind increases with the cube of wind speed, any site with an average velocity above 12 kilometers per hours will have significantly lower costs per unit of water pumped.

While primary emphasis should be placed on locating sites with high-quality wind regimes, considerable attention should also be paid to minimizing the height that water must be lifted. The economic viability of wind pumping systems in Botswana is directly determined by two factors--the strength of the wind regime and the distance or "head" the water must pumped. For a given wind speed, a greater head means that less water can be pumped, thereby increasing the cost of a cubic meter of water. The effect of pumping head is especially important at sites with low to moderate wind regimes. The tables in the previous section indicate that the Dempster and FIASA machines can only pump one-sixth the amount of water from a depth of 100 meters compared to 30 meters, for a wind regime of six kilometers per hour. At sites with low wind velocities and high heads, the low volume of water pumped by wind systems makes its unit cost prohibitively expensive.

All of the wind systems are much more economical when used in conjunction with a large-diameter (at least six inches or 150 millimeters) bore-hole. The frictional losses for small-diameter pipes are well-known and affect all pumping systems, but appear to have a particularly negative effect on wind systems located in areas with strong wind regimes. For an average wind speed of 16 kilometers per hour, the water output from a large (150-millimeter) bore-hole is 3.5 times greater than the same unit pumping from a hole with a diameter of 75 millimeters. At sites with strong wind regimes but no existing bore-hole, it may be worthwhile to consider drilling a larger bore-hole if the drilling rig, bits and casing required are locally available.

## E. Recommendations

Wind systems should be installed for testing only at sites where they are economically competitive with other stand-alone units, such as PV and/or small-scale diesel pumps. Installing windmills at less favorable sites is neither a good use of

government/project funds nor a valid field test of the capabilities of wind-powered water pumping systems.

Wind machines should be selected to match site characteristics in order to achieve the lowest cost per cubic meter of water delivered. The FIASA and Dempster machines appear to be most appropriate for sites with high pumping heads (50 to 100 meters) and medium to high wind regimes (12 kilometers per hour and up). The Wind Baron system seems best suited to sites with low to medium heads (10 to 50 meters) and moderate to high average wind speeds.

## VII. TRAINING

This section discusses the training activities conducted during this consultancy, as well as ongoing training needs. BRET staff and others were trained in the sizing, selection and installation of windmills, along with some general instruction in wind system maintenance.

Mr. Smith spent several days with BRET technicians covering windmill fundamentals, including proper sizing and unit selection based on water requirements and climatic conditions. Emphasis was placed on difficulties encountered in applying information from manufacturers' published product brochures to areas that have lower wind regimes. Descriptive product literature on various mills, towers and pumping accessories was distributed and discussed in detail to acquaint the technicians with different equipment options and features. Submersible pump designs and characteristics were also covered.

Approximately 35 Water Affairs engineers, instructors and BRET staff members attended a general presentation on multi-bladed windmills and wind characteristics that are pertinent to proper siting.

BRET technicians, staff, extension group and Water Affairs crew spent one week with Mr. Smith in the village of Sedibeng installing a 12-foot, multi-bladed windmill/pumping system and anemometer at a height of 10 meters. This installation will serve as a BRET monitoring site as well as providing Sedibeng with a water supply system. The specific details of the installation have already been discussed in Section III. Training before and during the installation covered the following topics:

- prior to the installation, proper cylinder sizing for the 12-foot mill and bore-hole parameters;
- the correct procedure for assembling the tower and then raising, squaring and leveling it over the bore-hole;
- installation of the drop pipe, cylinder and pump rod in the bore-hole;
- assembly and installation of the engine, wheel and tail vane on the tower;
- necessary maintenance for the mill and pump system; and
- anemometer installation and operation, as well as the procedure for collecting data on a monthly basis.

After the installation was complete, schoolchildren, teachers and selected villagers were instructed in the unit's operation and

maintenance requirements. Finally, villagers were assigned to collect data from the anemometer, and monitor and maintain the windmill system.

The general maintenance of multi-bladed windmills was thoroughly covered at the Sedibeng installation. In addition, BRET and Water Affairs staff were provided with installation, operation and maintenance manuals for different models of multi-bladed windmills.

BRET technicians and Mr. Kees Flink of Water Affairs have the experience and expertise to meet any further training needs concerning sizing, selection, installation and maintenance of windmill systems and anemometer sites, and should be responsible for additional training. Coordination between BRET technicians and extension personnel can enhance ongoing training.

## VIII. OTHER PUMPING SYSTEMS

### A. Hand Pumps

An extensive program for testing hand pumps that are commercially available from a variety of countries, including African nations, is currently being conducted in the United Kingdom for UNDP/World Bank. An accelerated test program that began in 1982 was slated for completion in November, 1982. Previous testing on other styles of hand pumps, including the India Mark II, was done in 1977. Appendix H contains the portion of the interim report on this evaluation that details the testing procedures and endurance requirements for the units.

Other than using a hand pump as the back-up system for a windmill installation, there is no reason to launch an extensive testing program to evaluate hand pump units. The UNDP/World Bank's test results should be used to analyze and select a hand pump that best suits needs and conditions in Botswana. Units installed by Water Affairs should be monitored by BRET in terms of their field use and dependability.

### B. Photovoltaic Systems

Although the evaluation of PV pumping systems was not included in the scope of work, some comments can be made on the unit at Kanye and the DC, brushless, submersible motor/pump design. The PV Mono pump installation at RIIC in Kanye consists of a 1.6-horsepower, 51-volt, DC Honeywell vertical (jet pump-type motor) belt driving a Mono pump set that is coupled to an ES-10 Mono pump running at approximately 580 revolutions per minute. The total pumping head at the installation is about 30.5 meters. On two occasions, the pump output was observed to be 20 liters per minute, and the unit runs four hours a day, for a total daily volume of 4.8 cubic meters of water. With a rated horsepower of 1.6, it would seem that the Mono pump could be driven at a faster speed, as the manufacturer's performance curve shows the minimum pump speed to be 700 revolutions per minute. Any resulting improvement in overall system efficiency might increase daily output.

AC motor-driven, submersible units are now available on the market, but require an inverter to operate a DC pumping system. Work is underway in the United States to couple submersible pumps to DC, brushless, submersible motors, in capacities of 19, 38, 57 and 76 liters. Currently, the maximum motor size is limited to one horsepower and pumping depths no greater than 40 to 45 meters. The hydraulic efficiency of these systems will range between 50 and 70 percent, depending on their capacity, and motor efficiencies are anticipated at 90 to 95 percent, thus producing an overall pump/motor efficiency of 45 to 65 percent. If further

testing confirms these system efficiencies and motors with more horsepower are developed to pump greater heads, these systems could be quite useful in Botswana and other developing countries. It is recommended that the BRET project continue to monitor the development of this product line.

# APPENDIX A

## Wind Data from Meteorological Services in Gaborone

## MEAN MONTHLY WIND SPEED (M/SEC)

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| At 2 m Gaborone (1959-80) | 4.3 | 3.7 | 3.1 | 3.0 | 3.2 | 3.0 | 3.1 | 4.0 | 4.9 | 5.7 | 5.1 | 4.5 | 4.0 |
| At 10 m | 6.9 | 5.9 | 5.0 | 4.8 | 5.1 | 4.8 | 5.0 | 6.4 | 7.8 | 9.1 | 8.2 | 7.2 | 6.4 |
| At 2 m Mahalapye (1959-80) | 3.3 | 2.9 | 2.7 | 2.4 | 2.1 | 2.4 | 2.2 | 2.9 | 3.7 | 4.3 | 3.9 | 3.5 | 3.0 |
| At 10 m | 5.3 | 4.6 | 4.3 | 3.8 | 3.4 | 3.8 | 3.5 | 4.6 | 5.9 | 6.9 | 6.2 | 5.6 | 4.8 |
| At 2 m Francistown (1959-80) | 6.8 | 6.7 | 6.7 | 5.7 | 4.9 | 4.9 | 5.1 | 6.4 | 8.0 | 9.5 | 7.9 | 7.1 | 6.6 |
| At 10 m | 10.9 | 10.7 | 10.7 | 9.1 | 7.8 | 7.8 | 8.6 | 10.2 | 12.0 | 14.4 | 12.6 | 11.4 | 10.6 |
| At 2 m Maun (1957-80) | 5.9 | 5.6 | 5.9 | 5.5 | 5.4 | 5.7 | 6.0 | 6.5 | 7.7 | 8.6 | 7.5 | 6.7 | 6.4 |
| At 10 m | 9.4 | 9.0 | 9.4 | 8.9 | 8.6 | 9.1 | 9.6 | 10.4 | 12.3 | 13.8 | 12.1 | 10.7 | 10.3 |
| At 2 m Shakawe (1959-80) | 3.3 | 3.2 | 3.2 | 2.7 | 2.4 | 2.3 | 2.2 | 3.1 | 3.3 | 3.5 | 3.1 | 3.4 | 3.0 |
| At 10 m | 5.3 | 5.1 | 5.1 | 4.3 | 3.8 | 3.7 | 3.5 | 5.0 | 5.3 | 5.7 | 5.0 | 5.4 | 4.8 |
| At 2 m Gamet (1959-80) | 6.5 | 6.1 | 5.9 | 4.7 | 4.7 | 4.9 | 5.6 | 6.0 | 7.0 | 7.9 | 7.0 | 7.0 | 6.2 |
| At 10 m | 10.4 | 9.8 | 9.4 | 7.5 | 7.5 | 7.8 | 9.0 | 9.6 | 11.2 | 12.6 | 12.5 | 11.2 | 9.9 |
| At 2 m Tshane (1959-80) | 7.4 | 6.5 | 6.2 | 5.3 | 4.9 | 4.9 | 5.2 | 6.1 | 7.0 | 7.5 | 7.7 | 7.6 | 6.4 |
| At 10 m | 11.8 | 10.4 | 9.9 | 8.5 | 7.8 | 7.8 | 8.3 | 9.8 | 11.2 | 12.0 | 12.3 | 12.2 | 10.2 |
| At 2 m Tsabong (1959-80) | 6.0 | 4.9 | 4.3 | 3.4 | 3.0 | 3.3 | 3.9 | 5.2 | 5.7 | 6.5 | 5.8 | 6.4 | 4.9 |
| At 10 m | 9.6 | 7.8 | 6.9 | 5.4 | 4.8 | 5.3 | 6.2 | 8.3 | 9.1 | 10.4 | 9.3 | 10.2 | 7.8 |



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# MAXIMUM AND MINIMUM TEMPERATURES (C°)

| STATION | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **GABORONE** | | | | | | | | | | | | | |
| MEAN MAX (1958-80) | 32.6 | 31.2 | 31.1 | 27.2 | 24.6 | 22.2 | 22.3 | 25.5 | 29.1 | 30.7 | 31.2 | 32.1 | 28.3 |
| MEAN MIN (1958-80) | 19.7 | 19.0 | 18.0 | 13.1 | 7.6 | 4.0 | 3.6 | 6.5 | 11.9 | 15.5 | 17.5 | 18.4 | 12.9 |
| HIGHEST MAX | 42.5 | 39.7 | 39.7 | 35.6 | 33.9 | 30.2 | 29.0 | 33.1 | 37.4 | 40.6 | 39.7 | 43.9 | 43.9 (30.12 |
| LOWEST MIN | 10.4 | 10.9 | 8.0 | -2.2 | -2.2 | -5.0 | -6.5 | -5.5 | -0.6 | 2.8 | 8.5 | 8.5 | -6.5 (19.7.1954) |
| **MAHALAPYE** | | | | | | | | | | | | | |
| MEAN MAX (1961-80) | 30.9 | 30.2 | 28.6 | 26.5 | 24.4 | 22.1 | 22.3 | 25.1 | 29.2 | 29.8 | 30.4 | 30.6 | 27.5 |
| MEAN MIN (1961-79) | 19.1 | 19.2 | 16.6 | 13.2 | 8.1 | 4.9 | 3.9 | 7.1 | 12.6 | 15.6 | 18.0 | 19.0 | 13.1 |
| HIGHEST MAX | 40.5 | 36.6 | 36.5 | 34.6 | 33.0 | 28.9 | 29.8 | 34.1 | 37.6 | 39.3 | 38.6 | 37.9 | 40.5 (14-1-69) |
| LOWEST MIN | 12.5 | 13.5 | 9.8 | 4.5 | 1.0 | -5.4 | -4.0 | -6.0 | 1.7 | 6.2 | 8.6 | 11.6 | -6.0 (15-8-80) |
| **FRANCISTOWN** | | | | | | | | | | | | | |
| MEAN MAX (1959-80) | 30.7 | 29.5 | 29.3 | 27.7 | 25.6 | 23.0 | 23.1 | 25.1 | 29.8 | 31.5 | 31.0 | 30.3 | 28.1 |
| MEAN MIN (1959-80) | 19.0 | 18.2 | 16.9 | 13.7 | 8.5 | 5.3 | 4.8 | 7.7 | 12.3 | 16.2 | 16.9 | 18,5 | 13.2 |
| HIGHEST MAX | 40.6 | 38.4 | 38.8 | 35.6 | 34.0 | 31.1 | 30.6 | 35.5 | 37.0 | 40.2 | 41.1 | 39.5 | 41.1 (30.11.51) |
| LOWEST MIN | 10.6 | 10.5 | 4.0 | 4.0 | -1.0 | -4.5 | -5.0 | -4.2 | 1.5 | 4.0 | 4.1 | 8.8 | -5.0 (3-7-53) |
| **MAUN** | | | | | | | | | | | | | |
| MEAN MAX (1959-80) | 31.6 | 31.4 | 31.3 | 29.9 | 27.5 | 25.0 | 25.1 | 28.3 | 32.2 | 34.1 | 33.0 | 32.1 | 30.1 |
| MEAN MIN (1959-80) | 19.5 | 18.9 | 17.8 | 15.0 | 9.6 | 6.9 | 6.9 | 9.8 | 14.8 | 18.6 | 19.4 | 19.4 | 14.7 |
| HIGHEST MAX | 40.0 | 37.2 | 39.5 | 35.0 | 33.0 | 30.6 | 31.3 | 35.2 | 38.6 | 41.4 | 41.7 | 40.6 | 41.7 (26-11-41) |
| LOWEST MIN | 9.2 | 10.6 | 6.2 | 4.4 | -1.1 | -5.8 | -3.6 | 3.5 | 3.9 | 9.0 | 9.4 | 8.4 | -5.8 (15-6-62) |

# MAXIMUM AND MINIMUM TEMPERATURES (C°)

| Station | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SHAKAWE** | | | | | | | | | | | | | |
| Mean Max (1959-80) | 30.4 | 30.4 | 30.2 | 29.4 | 27.4 | 25.0 | 24.8 | 28.6 | 32.3 | 34.3 | 32.8 | 31.4 | 29.7 |
| Mean Min (1959-80) | 19.3 | 19.2 | 18.5 | 16.0 | 10.8 | 6.5 | 6.0 | 8.6 | 12.5 | 17.1 | 18.4 | 19.0 | 14.3 |
| Highest Max | 39.2 | 36.6 | 36.4 | 36.0 | 32.6 | 30.6 | 31.9 | 34.7 | 38.0 | 39.5 | 39.6 | 39.1 | 39.6 (29.11.1972) |
| Lowest Min | 10.6 | 11.3 | 8.8 | 7.0 | 0.4 | -7.5 | -6.1 | -5.5 | 2.0 | 2.0 | 10.0 | 11.4 | ~~-6.1~~ -7.5 (~~17.7.194~~ 15-6-196 |
| **GANTSI** | | | | | | | | | | | | | |
| Mean Max (1959-80) | 31.6 | 31.3 | 30.9 | 28.7 | 26.2 | 23.3 | 24.0 | 26.8 | 30.8 | 33.2 | 32.8 | 32.9 | 29.4 |
| Mean Min (1959-80) | 19.0 | 18.3 | 16.8 | 14.0 | 8.2 | 4.7 | 4.1 | 7.0 | 11.5 | 15.8 | 17.8 | 18.5 | 13.0 |
| Highest Max | 40.3 | 39.6 | 38.8 | 36.4 | 34.5 | 29.8 | 29.8 | 34.5 | 37.2 | 40.6 | 41.3 | 40.0 | 41.3 (29.11.66) |
| Lowest Min | 6.5 | 5.5 | 3.5 | 0.3 | -2.2 | -8.1 | -8.5 | -5.4 | -1.1 | 3.5 | 5.0 | 6.2 | -8.5 (4.11.62) |
| **TSHANE** | | | | | | | | | | | | | |
| Mean Max (1959-80) | 33.3 | 32.0 | 30.6 | 27.6 | 24.5 | 21.6 | 22.2 | 25.2 | 29.4 | 31.6 | 33.0 | 33.7 | 28.7 |
| Mean Min (1959-80) | 19.3 | 18.6 | 17.1 | 13.0 | 7.0 | 3.9 | 3.5 | 6.0 | 11.2 | 14.2 | 16.9 | 18.3 | 12.4 |
| Highest Max | 41.0 | 38.7 | 38.9 | 34.5 | 34.5 | 29.5 | 31.9 | 32.6 | 37.8 | 39.9 | 39.4 | 40.8 | 41.0 (19.1.73) |
| Lowest Min | 10.5 | 11.0 | 5.7 | 3.6 | -0.5 | -6.4 | -5.0 | -8.0 | -3.9 | 4.9 | 7.0 | 6.0 | -8.0 (15.8.80) |
| **TSABONG** | | | | | | | | | | | | | |
| Mean Max (1959-80) | 34.4 | 33.2 | 31.4 | 27.7 | 24.0 | 21.5 | 22.0 | 24.3 | 28.8 | 31.2 | 33.4 | 34.5 | 28.9 |
| Mean Min (1959-80) | 19.0 | 17.9 | 16.4 | 11.9 | 5.8 | 2.3 | 1.3 | 3.5 | 8.1 | 12.3 | 15.9 | 17.7 | 11.0 |
| Highest Max | 42.1 | 41.3 | 39.3 | 35.2 | 37.5 | 30.0 | 28.9 | 32.6 | 38.5 | 39.6 | 42.6 | 41.1 | 42.6 (19.11.61) |
| Lowest Min | 6.7 | 7.5 | -4.2 | -4.2 | -6.7 | -8.9 | -10.6 | -8.2 | -6.7 | -1.1 | 1.8 | 6.1 | -10.6 (30.7.53) |



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## APPENDIX B

## Utilization of Wind Data for Site Assessment

by Dr. Amir Mikhail

There are various parameters that influence the amount of power required to lift water from a specific well, including the well's depth or total head (H), length of the pipe run and its diameter, number of elbow joints and, more importantly, the required flow rate. The power needed to lift water from a total head (in meters) at a flow rate of $\dot{Q}$ (cubic meters per day) for a pipe run L (in meters) with a pipe diameter D (in centimeters) and N elbow joints is given by:

$$P \text{ (watts)} = 0.114 \ (H + HF) \ \dot{Q}/\eta p \qquad (1)$$

where HF is the head correction due to friction and $\eta p$ is the water pump's efficiency. The head correction due to friction is given by:

$$HF = (L\dot{Q}^2/281.42 \ D^5) + 0.7 \ N \qquad (2)$$

The overall system efficiency ($C_p$) of most commercially available machines ranges from 10 to 20 percent, depending on the solidity of the rotor plane (ratio of blade to swept area), blade shape and water pump efficiency. To obtain the maximum economic return from a water pumping wind machine, site data must be used to calculate the energy available at the site and estimate the size of the rotor required to produce the desired flow rate, given the well's head.

Ideally, wind speed data should be collected at the site of the existing or proposed well. However, as this can prove very costly, certain extrapolation techniques can be used to estimate the wind energy potential for a site, based on data gathered at a nearby monitoring station. This appendix reviews various methods that can be used to estimate the wind energy potential at a particular site.

### Instantaneous Power Output

The instantaneous power (P) available in wind passing through an area (A) is given by:

$$P = 1/2 \ \rho \ V^3 \ A \ C_p \qquad (3)$$

where P is the power output in watts; $\rho$, the air density (1.225 kilograms per cubic meter at sea level); V, the instantaneous wind speed; A, the swept area in square meters; and $C_p$, the maximum limit on extractable energy (0.59).

The power that can be extracted from the wind by a rotor of radius R (in meters) and an efficiency of $C_p$ is:

$$P = 1/2\ V^3\ R^2\ C_p\ (\lambda) \qquad (4)$$

$C_p$ is the power coefficient and $\lambda$, the tip speed ratio of $(2\ \pi\ n\ R)/V$, where n is rotor rpm. The power density at a given site is defined as the power output per swept unit of rotor area.

## Wind Speed Frequency Distribution

Wind speed frequency distributions are important in determining the average energy available at a site and its variability. Table B-1 shows the output of the BRET project's wind monitoring equipment. The wind speed range is divided into 32 intervals (channel bin numbers 0 through 31) and the frequency of occurrence of each of those speeds is given in seconds (see column B, data, in Table B-2). These data can also be used to estimate the coefficients of a theoretical distribution that is often used to describe wind variability. The Weibull distribution is given by:

$$p(V) = (k/C)\ (V/C)^{k-1}\ \exp-(V/C)^k \qquad (5)$$

where C is the scale factor and k, the shape factor. The scale and shape fctors are related to the average wind speed and its standard deviation, respectively.

In the absence of detailed information, the theoretical distribution can provide a better estimate of the average power available in the wind. In addition, estimation of the theoretical distribution parameters allows for horizontal and vertical extrapolation of various techniques used to figure the Weibull distribution scale and shape factors.

### Least Squares Fit to Observed Distribution

Observed wind speed is divided into n intervals (bins), as in Table B-1, of 0 to $V_1$, $V_1$ to $V_2$ ... $V_{(n-1)}$ to $V_n$ with frequencies of $f_1$, $f_2$ ... $f_n$ and corresponding cumulative frequencies of $p_1 = f_1$, $p_2 = (f_1 + f_2)$ ... $p_n = (p_{(n-1)} + f_n)$. By making the following transformations:

$$X_i = \ln V_i$$

$$Y_i = \ln (-\ln (1 - p_i))$$

the best fit linear coefficient values (a and b) can be related to the Weibull parameters by:

Table B-1

NATURAL POWER INC.'S MODEL A30-101 COMPILATOR I
– BIN STORAGE CHARACTERISTICS –

| STEP INCREMENTS (KM/HR) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AVERAGE WINDSPEED (KM/HR) | 1/2 | 1 1/2 | 2 1/2 | 3 1/2 | 4 1/2 | 5 1/2 | 6 1/2 | 7 1/2 | 8 1/2 | 9 1/2 | 10 1/2 |
| WINDSPEED RANGE (KM/HR) | 0-1 | 1-2 | 2-3 | 3-4 | 4-5 | 5-6 | 6-7 | 7-8 | 8-9 | 9-10 | 10-11 |
| CHANNEL BIN # | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 |
| AVERAGE WINDSPEED (MPH | 0.31 | 0.93 | 1.55 | 2.17 | 2.80 | 3.42 | 4.04 | 4.66 | 5.28 | 5.90 | 6.52 |
| AVERAGE WINDSPEED (M/SEC) | 0.14 | 0.42 | 0.69 | 0.97 | 1.25 | 1.53 | 1.81 | 2.08 | 2.36 | 2.64 | 2.92 |

| STEP INCREMENTS (KM/HR) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AVERAGE WINDSPEED (KM/HR) | 11 1/2 | 12 1/2 | 13 1/2 | 14 1/2 | 15 1/2 | 16 1/2 | 17 1/2 | 18 1/2 | 19 1/2 | 20 1/2 | 21 1/2 |
| WINDSPEED RANGE (KM/HR) | 11-12 | 12-13 | 13-14 | 14-15 | 15-16 | 16-17 | 17-18 | 18-19 | 19-20 | 20-21 | 21-22 |
| CHANNEL BIN # | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
| AVERAGE WINDSPEED (MPH) | 7.15 | 7.77 | 8.39 | 9.01 | 9.63 | 10.25 | 10.87 | 11.50 | 12.12 | 12.74 | 13.36 |
| AVERAGE WINDSPEED (M/SEC) | 3.19 | 3.47 | 3.75 | 4.03 | 4.31 | 4.58 | 4.86 | 5.14 | 5.42 | 5.69 | 5.97 |

| STEP INCREMENTS (KM/HR) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AVERAGE WINDSPEED (KM/HR) | 22 1/2 | 23 1/2 | 24 1/2 | 25 1/2 | 26 1/2 | 27 1/2 | 28 1/2 | 29 1/2 | 30 1/2 | 31 1/2+ | |
| WINDSPEED RANGE (KM/HR) | 22-23 | 23-24 | 24-25 | 25-26 | 26-27 | 27-28 | 28-29 | 29-30 | 30-31 | 31-X | |
| CHANNEL BIN # | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | |
| AVERAGE WINDSPEED (MPH) | 13.98 | 14.60 | 15.22 | 15.85 | 16.47 | 17.09 | 17.71 | 18.33 | 18.95 | 19.57+ | |
| AVERAGE WINDSPEED (M/SEC) | 6.25 | 6.53 | 6.81 | 7.08 | 7.36 | 7.64 | 7.92 | 8.20 | 8.47 | 8.75+ | |



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Table B-2

# COMPILATOR I
## WIND SPEED AND POWER WORKSHEET

| $\bar{V}$ m/S | $\bar{V}$ MPH | BIN NO. | A $\bar{V}$ Km/H | B DATA | A x B | C HRS | D WATTS/M² | C x D WATT-HRS | $\bar{V}^3$ Km/H | $\bar{V}^3$ m/S |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.14 | 0.31 | 00 | .5 | 472727 | 236363 | 131.31 | .002 | .26 | 0.125 | .003 |
| 0.42 | 0.93 | 01 | 1.5 | 482065 | 723097 | 133.9 | .038 | 5.09 | 3.37 | .074 |
| 0.69 | 1.55 | 02 | 2.5 | 447932 | 1119,830 | 124.4 | .147 | 18.29 | 15.6 | .226 |
| 0.97 | 2.17 | 03 | 3.5 | 234887 | 822,104 | 65.25 | .47 | 30.67 | 42.9 | .913 |
| 1.25 | 2.80 | 04 | 4.5 | 166401 | 748,804 | 46.22 | 1.0 | 46.22 | 91.1 | 1.95 |
| 1.53 | 3.42 | 05 | 5.5 | 114537 | 629,953 | 31.82 | 1.8 | 57.28 | 166 | 3.58 |
| 1.81 | 4.04 | 06 | 6.5 | 68801 | 447,206 | 19.11 | 3.05 | 58.29 | 275 | 5.93 |
| 2.08 | 4.66 | 07 | 7.5 | 36832 | 276,204 | 10.23 | 4.63 | 47.36 | 422 | 9.0 |
| 2.36 | 5.28 | 08 | 8.5 | 18589 | 158,006 | 5.16 | 6.77 | 34.92 | 614 | 13.14 |
| 2.64 | 5.90 | 09 | 9.5 | 9684 | 91,998 | 2.69 | 9.48 | 25.49 | 857 | 18.40 |
| 2.92 | 6.52 | 10 | 10.5 | 5895 | 61897 | 1.64 | 12.8 | 21.02 | 1158 | 24.9 |
| 3.19 | 7.15 | 11 | 11.5 | 4001 | 46011 | 1.11 | 16.72 | 18.56 | 1521 | 32.46 |
| 3.47 | 7.77 | 12 | 12.5 | 2692 | 33650 | .745 | 21.52 | 16.03 | 1953 | 41.78 |
| 3.75 | 8.39 | 13 | 13.5 | 1578 | 21303 | .438 | 27.16 | 11.89 | 2460 | 52.73 |
| 4.03 | 9.01 | 14 | 14.5 | 818 | 11861 | .227 | 33.71 | 7.65 | 3048 | 65.45 |
| 4.31 | 9.63 | 15 | 15.5 | 345 | 5347 | .096 | 41.23 | 3.96 | 3724 | 80.06 |
| 4.58 | 10.25 | 16 | 16.5 | 142 | 2343 | .039 | 49.48 | 1.93 | 4492 | 96.07 |
| 4.86 | 10.87 | 17 | 17.5 | 45 | 787 | .012 | 59.13 | .71 | 5359 | 114.8 |
| 5.14 | 11.50 | 18 | 18.5 | 27 | 499 | .007 | 69.94 | .49 | 6332 | 135.8 |
| 5.42 | 12.12 | 19 | 19.5 | 17 | 331 | .005 | 81.99 | .41 | 7415 | 159.2 |
| 5.69 | 12.74 | 20 | 20.5 | 12 | 246 | .003 | 94.87 | .28 | 8615 | 184.2 |
| 5.97 | 13.36 | 21 | 21.5 | 11 | 236 | .003 | 109.61 | .33 | 9939 | 212.8 |
| 6.25 | 13.98 | 22 | 22.5 | 10 | 225 | .003 | 125.7 | .38 | 11,391 | 244.1 |
| 6.53 | 14.60 | 23 | 23.5 | 11 | 258 | .003 | 143.4 | .43 | 12,978 | 278.4 |
| 6.81 | 15.22 | 24 | 24.5 | 8 | 196 | .002 | 162.6 | .325 | 14,706 | 315.8 |
| 7.08 | 15.85 | 25 | 25.5 | 9 | 229 | .002 | 182.8 | | 16,581 | 354.9 |
| 7.36 | 16.47 | 26 | 26.5 | 3 | 79 | .001 | 205.3 | .205 | 18,610 | 398.7 |
| 7.64 | 17.09 | 27 | 27.5 | 8 | 220 | .002 | 229.6 | .459 | 20,797 | 445.9 |
| 7.92 | 17.71 | 28 | 28.5 | 3 | 85 | .001 | 255.9 | .256 | 23,149 | 496.8 |
| 8.20 | 18.33 | 29 | 29.5 | 8 | 236 | .002 | 284.0 | .568 | 25,672 | 55.4 |
| 8.47 | 18.95 | 30 | 30.5 | 0 | 0 | 0 | 0 | 0 | 28,377 | 607.6 |
| | | | | 2,068,106 | 5,439,388 | 574.4 | | | | |
| | | | | Σ B | Σ A x B | ΣB/1000 | Σ D | Σ C x D | | |

SITE LOCATION DIETSEGWANE SITE DESCRIPTION LEVEL COUNTRY FT HIGH GRASS OCC. TREE 0-0.16

DATE STARTED MAR 15 DATE DATA TAKEN 4/8/83 DATA FOR MONTH

ALTITUDE 1140 ALT. CORR. FACTOR .872 APPROX. TEMP 26.7°C TEMP CORR FACTOR .965

AIR DENSITY (ρ) CALC. FOR SITE .0019769 SLUGS/FT³ 1.030088 Kg/m³

AVERAGE WIND SPEED @ SITE ($\bar{V}$) 2.63 Km/HR .73 m/S 1.63 MPH FOR

A DURATION OF 574.4 HOURS

$C = \exp(-a/b)$

$k = b$

Average Wind Speed and Standard Deviation or Average of the Cube of the Wind

If the average wind speed ($\overline{V}$) and standard deviation ($\sigma$) are available, the quotient $\sigma/\overline{V}$ can be compared to quotients provided in Table B-3. The same can be done for the quotient $\overline{V^3}/\overline{V}$. For example, from Table B-2:

$$\overline{V^3}/\overline{V}^3 = \frac{\Sigma C_i \times V_i^{\,3}}{(\Sigma C_i \times V_i)^3}$$

This quotient determines a value for k from Table B-3 and for $\overline{V}/C$, from which the value of C can be estimated.

Average Power Output

The average power output of a wind machine can be predicted by combining the wind speed distribution with instantaneous power output. Hence, average power output is given by:

$$\overline{P} = \int_0^\infty 1/2\ \rho\ V^3\ A\ C_p\ p\ (V)\ dv \qquad (6)$$

This integral can be evaluated using observed data (Table B-2) or a theoretical distribution, as discussed in the preceding section.

Estimating Average Power Output Using Compilator I Data

Table B-1 gives the number of hours $B_i$ for each speed interval ($V_{(i-1)}$ to $V_i$). Hence, average power output can be calculated by:

$$\overline{P} = A \sum_{i=1}^{n} 1/2\ \rho\ ((V_{(i+1)} - V_i)/2)^3\ C_p\ (\lambda_i)\ B_i \qquad (7)$$

where $C_p\ (\lambda_i)$ is the power coefficient of the wind machine at various wind speeds. If only an average value for $C_p\ (\lambda)$ is known, then:

$$\overline{P} = A\ \overline{C}_p\ \Sigma\ 1/2\ \rho\ ((V_{(i+1)} - V_i)/2)^3\ B_i \qquad (8)$$

The average power density P/A is given by:

## Table B-3

Weibull Distribution Parameters

| k | $\bar{V}/c$ | $\sigma/\bar{V}$ | $\overline{V^3}/\bar{V}^3$ |
|---|---|---|---|
| 1.2 | 0.941 | 0.837 | 3.99 |
| 1.4 | 0.911 | 0.724 | 3.03 |
| 1.6 | 0.897 | 0.640 | 2.48 |
| 1.8 | 0.889 | 0.575 | 2.14 |
| 2.0 | 0.886 | 0.523 | 1.91 |
| 2.2 | 0.886 | 0.480 | 1.75 |
| 2.4 | 0.886 | 0.444 | 1.63 |
| 2.6 | 0.888 | 0.413 | 1.53 |
| 2.8 | 0.890 | 0.387 | 1.46 |
| 3.0 | 0.893 | 0.363 | 1.40 |
| 3.2 | 0.896 | 0.343 | 1.36 |
| 3.5 | 0.900 | 0.316 | 1.30 |
| 4.0 | 0.906 | 0.281 | 1.23 |
| 5.0 | 0.918 | 0.229 | 1.15 |
| 6.0 | 0.928 | 0.194 | 1.11 |
| 7.0 | 0.935 | 0.168 | 1.08 |
| 8.0 | 0.942 | 0.148 | 1.06 |
| 9.0 | 0.947 | 0.133 | 1.05 |
| 10.0 | 0.951 | 0.120 | 1.04 |

$\bar{V}$ is mean wind speed, c is Weibull scale factor, $\sigma$ is standard deviation, $\overline{V^3}/\bar{V}^3$ is the energy pattern factor

$$\overline{P}/A = \overline{C}_p \; \Sigma \; 1/2 \; ((V_{(i+1)} - V_i)/2)^3 \; B_i \qquad (9)$$

The term under the summation sign is the same as $D_i$ in Table B-2. Hence, average power density is:

$$\overline{P}/A = \overline{C}_p \sum_{i=1}^{n} D_i \qquad (10)$$

Once the power density is estimated, the required rotor area for a certain power requirement can be estimated from formulas 1 and 10.

## Estimating Average Power Output based on a Weibull Distribution

If the Weibull distribution parameters--scale factor C and shape factor k--can be estimated, they can be used to further estimate the probability of occurrence of wind speeds in various intervals from the general Weibull distribution equation (5). Average power density can then be estimated by substituting these probabilities in equation 8 for $B_i$.

A simpler method can be used to provide a quick estimate of average power density. From the instantaneous power output equation (3):

$$P/A = 1/2 \; \rho \; V^3 \; C_p \qquad (11)$$

Average power density is given by:

$$\overline{P}/A = 1/2 \quad \overline{V^3 \; C_p} = 1/2 \; \overline{V^3} \; \overline{C}_p \qquad (12)$$

where $\overline{V^3}$ is the average of the cube of the wind speed. From Table B-3, the value of k will determine the ratio of $\overline{V^3}/\overline{V}^3 = R$. Hence, average power density is given by:

$$\overline{P}/A = 1/2 \; \rho \; R \; \overline{V}^3 \; \overline{C}_p \qquad (13)$$

where $\overline{V}^3$ is the cube of the average wind speed. By comparing average power density equation 12 with the pumping power requirement from formula 1, an appropriate size for the wind system can be estimated.



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# APPENDIX C

## Report on Sedibeng Wind-Water Pump and Anemometer Installation

REPORT ON SEDIBENG WIND-WATER PUMP AND ANOMOMETER INSTALLATION

DATES: 22 March - 29 March, 1983

BY WHOM: Roy Smith (Wind Consultant), Jack Shields (BRET Technician), Modise Motshoge (BRET Technician), Judith Oki (BRET Extension), Nancy McGrath (BRET Extension), Kees Flink (Chief Technical Officer Water Affairs), and eleven members of the Water Affairs Crew.

ACTIVITY: This was the first combined effort of the technical and extension teams in the installation and village introduction of an institutional renewable energy technology.

TECHNOLOGY: 12 ft. Climax mill, 12m four post angle iron tower, 69mm cylinder, 235mm stroke, fourteen 3m sections of 2" pipe to well head then one 3m section up to discharge pipe. 15.20mm x 3m pump rods.
Well Depth - 82.5m , depth to water - 30.8m with a 42m cylinder setting
Yield - $1.6m^3/hr$

Natural Power Inc. cup anemometer and compilator installed with solar array to power the unit. Battery and compilator enclosed in box and mounted on anemometer tower.

Kent flow meter installed on discharge line to measure flow.

$9m^3$ storage tank installed at pump site.

PURPOSES:

TECHNICAL: To further the testing of wind-water technologies.
To augment the Sedibeng water supply.

EXTENSION: To observe a wind-water pump installation for the purpose of designing a training program in the technology
To help coordinate the process of village involvement in pump maintenance and wind data collection.
Photographic documentation.

PROCESS: A kgotla meeting to initiate plans for the pump installation was held on 21/2/83. At that time, the two BRET technicians and a technician from Water Affairs came to an agreement with the people of the village to install the wind-water pump on a borehole which was not being used.

On 18/3/83 the Water Affairs crew began assembling the tower. They were joined by the BRET staff on 22/3/83. It was learned by that time that the tower had collapsed on the first attempt to raise it, hence, o n the day we arrived, they were still in the assembly stage of the process.

The 22nd was spent setting up camp and making contacts in the village, n amely the school headmaster, Mr. Modukanele and the assistant headmaster, Ms. Motseolapile.

The 23rd was spent, for the technicians, diagnosing the cause for the tower collapse, mending bent parts, and making recommendations for strengthening the weaknesses in the structure. For the extension staff, the day was spent becoming familiar with the worksite, the tower, and oth components of the wind-water pump. Observation was especially focussed on the skills being employed by the workers. In addition, arrangements were made for a kgotla meeting on the morning of the 24th.

The kgotla meeting was held to inform the people of the progress of the work and to demonstrate to them the apparatus which was being installed. The cup anemometer, PV panel, battery, and compilator were displayed on the back of the Cantor truck for the inspection of the people of the kgotl The demonstration was accompanied by an explanation by a BRET technician and was followed by a period of questions and answers. It was decided at this meeting that someone from the village would be given responsibility to make regular maintenance checks on the pump while another individual was assigned to record the wind data.

On the 24th the tower was erected, the foundation poured, and the anemometer put into place.

Rain on the 25th interrupted that day's work.

The 26th, 28th, and 29th were spent raising the motor to the tower top, placing the blades and the tail vane, installing the pump into the borehole, connecting the pipes to the water storage tank, and connecting the PV panel, battery, and compilator.

By the last day, the pump was in full operation and water was being produced.

On the 29th, the school teachers brought all of the pupils (129) to t he pump site. They were given a presentation by a BRET technician on the pump and the data collection system. The individuals responsible for the pump maintenance and the wind data collection were given instructions on how to carry out their duties.

MAJOR PROBLEMS:

Old mill- Because this mill had been used for a time in another village and subsequently put into storage, it was found to be missing parts and it was bearing some signs of wear and tear.

CONCLUSIONS: The interfacing of the technicians, the extension staff, and the Sedibeng community proved valuable on many counts:

- the extension staff gained a fuller understanding of wind-water systems
- the technicians were able to further develop and practice some strategies for technology introduction
- the BRET staff was made aware of the villagers concerns and their committment to the technology
- the villagers were taught the basics of the technology and have now assumed some responsibility for it.

NEXT STEPS: In response to Mr. Modukanele's request, photographs of the pump particularly those taken with the school children, will be sent to the school.

Mr, Modukanele will be supplied with the address of BRET and Water Affairs should assisstance be needed with the pump.

The person responsible for recording wind data will do so once per week for the first month, and then on a monthly basis.

The BRET technicians will make monthly visits to Sedibeng to monitor the data collections and the maintenance checks.

RECOMMENDATIONS: Continued interfacing of technical and extension staffs on all levels of technology introduction, from techmology installation to evaluation.

Follow up visits to Sedibeng should monitor not only the technical information but also community feedback on the technology

# APPENDIX D

## Summary of Test Conditions and Results for the Wind Baron High-Performance Counterbalanced Windmill

NAVAJO NATION / WIND BARON CORPORATION

# STATUS REPORT

## EXECUTIVE SUMMARY

HIGH-PERFORMANCE WINDMILL
MASTER TEST SITE

WINDOW ROCK, ARIZONA

---

WIND BARON

WINDMILL POWERED WATER SYSTEMS

WIND BARON CORPORATION 3702 WEST LOWER BUCKEYE ROAD PHOENIX, ARIZONA, USA 85009 (602) 269-6900

SUMMARY

## PERFORMANCE COMPARISON

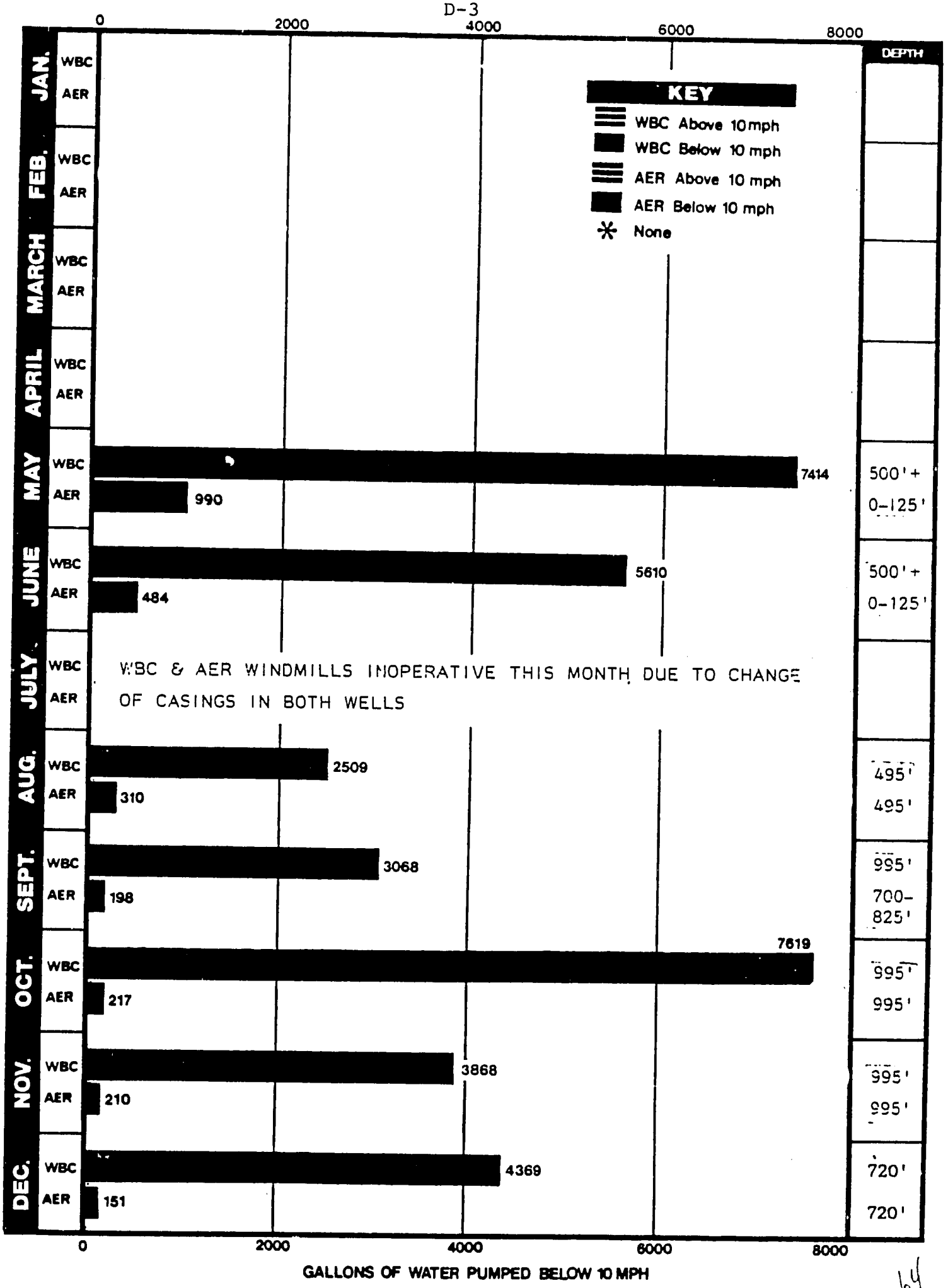
## WBC HIGH PERFORMANCE WINDMILL vs. STANDARD WINDMILL

ANNUAL SUMMARY (1980)

TOTAL OF GALLONS PUMPED AT WIND SPEEDS LESS THAN 10 MPH

| | WBC | AER | DIFFERENCE | % DIFFERENCE | PUMPING DEPTH | |
|---|---|---|---|---|---|---|
| | | | | | WBC | AER |
| MAY | 7,414 | 990 | 6,424 | 749 | 500' | 0-125' |
| JUNE | 5,610 | 484 | 5,126 | 1,159 | 500' | 0-125' |
| JULY | Tests were suspended in July to permit a change of casings in both wells. | | | | | |
| AUGUST | 2,509 | 310 | 2,199 | 1,809 | 495' | 495' |
| SEPTEMBER | 3,068 | 198 | 2,870 | 1,549 | 995' | 750(avg.) |
| OCTOBER | 7,619 | 217 | 7,402 | 3,511 | 995' | 995' |
| NOVEMBER | 3,868 | 210 | 3,658 | 1,842 | 995' | 995' |
| DECEMBER | 4,369 | 151 | 4,218 | 2,893 | 720' | 720' |
| TOTAL | 34,457 | 2,560 | 31,897 | 13.46 to 1 | | |

(with 1-7/8" cylinder)

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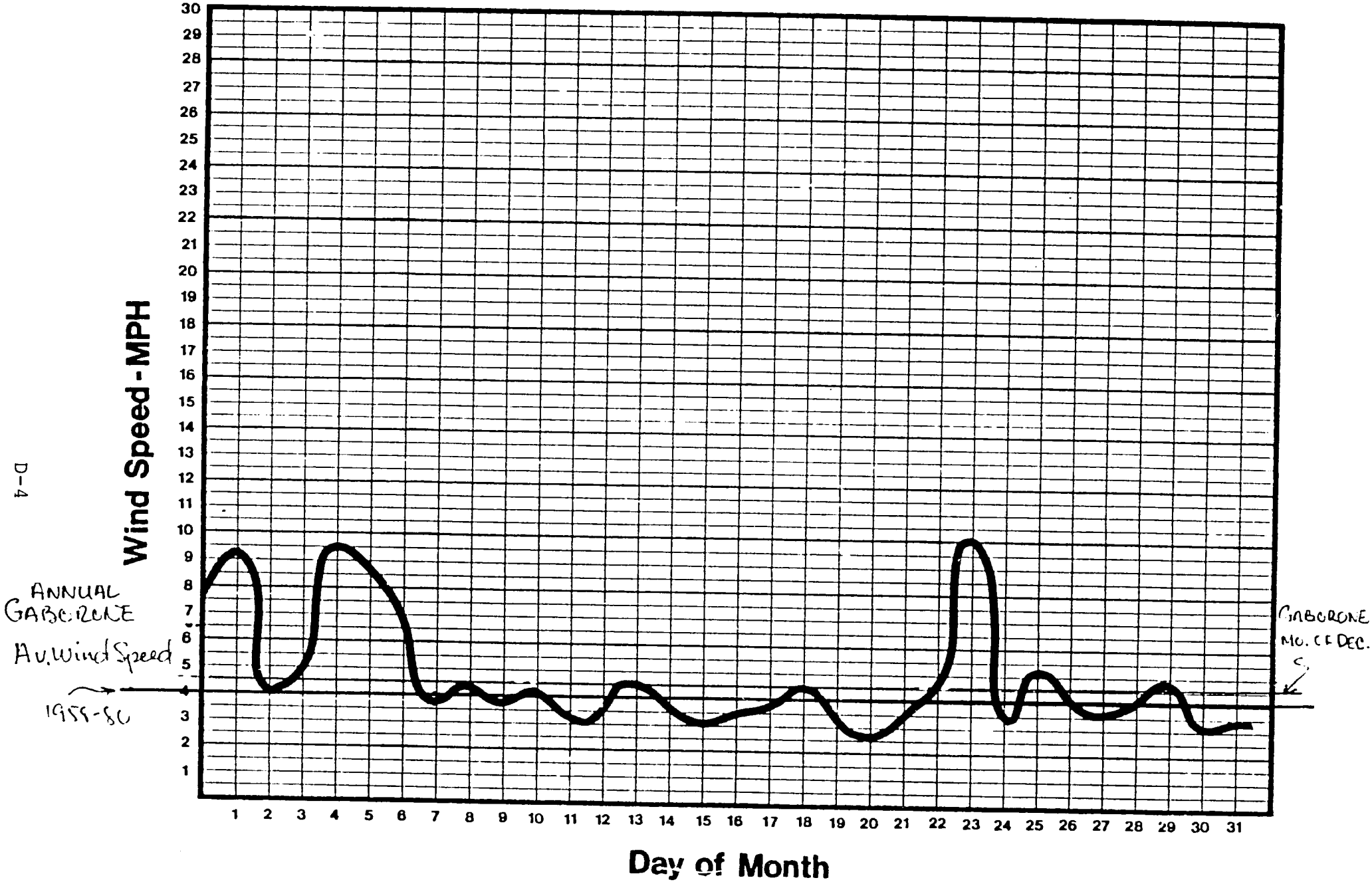
Navajo Nation/Wind Baron Corp. Windmill Master Test Site

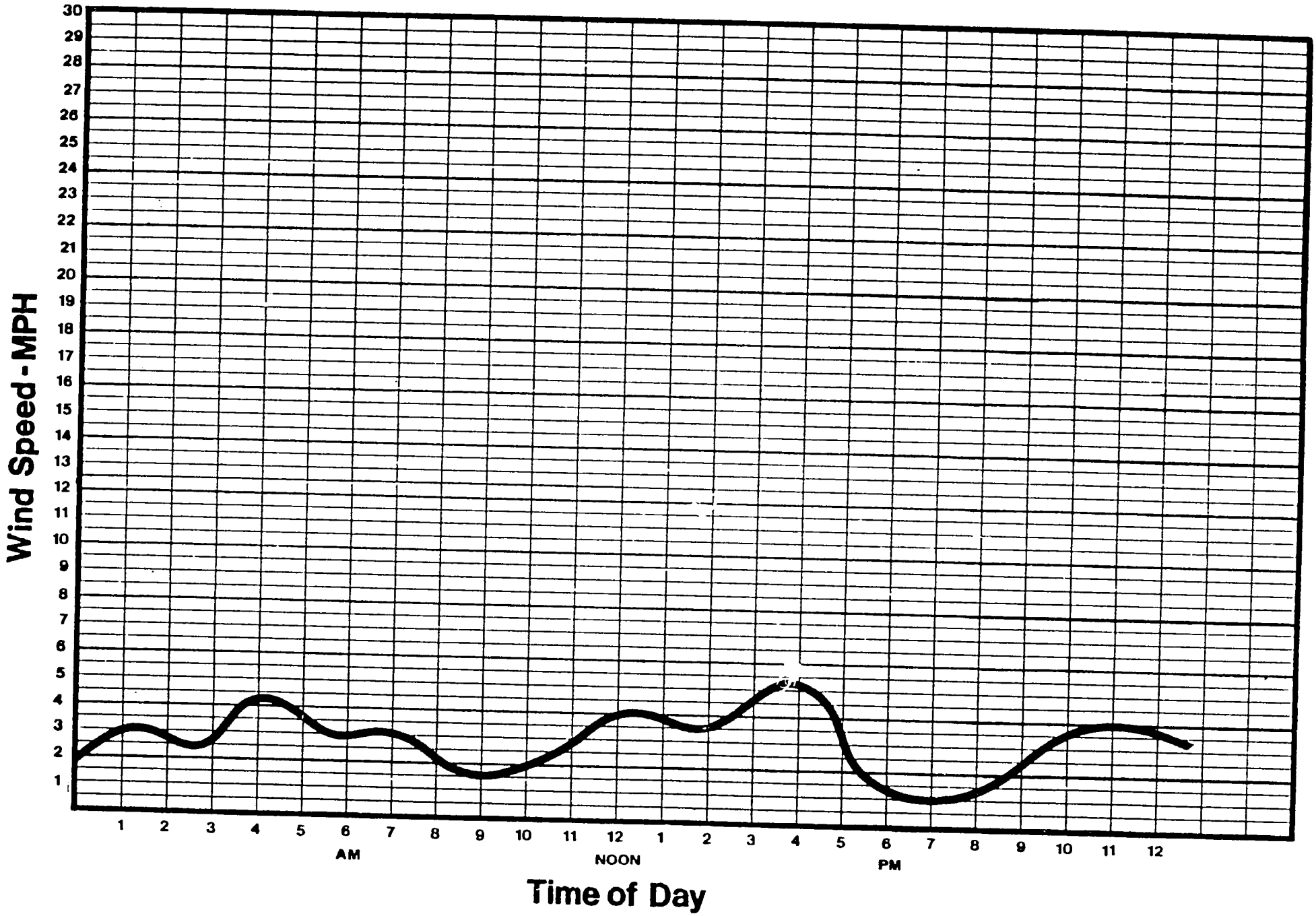



# WIND SPEED DATA

Average Daily Wind Speed

# WINDOW ROCK, ARIZONA

Month of December, 1980

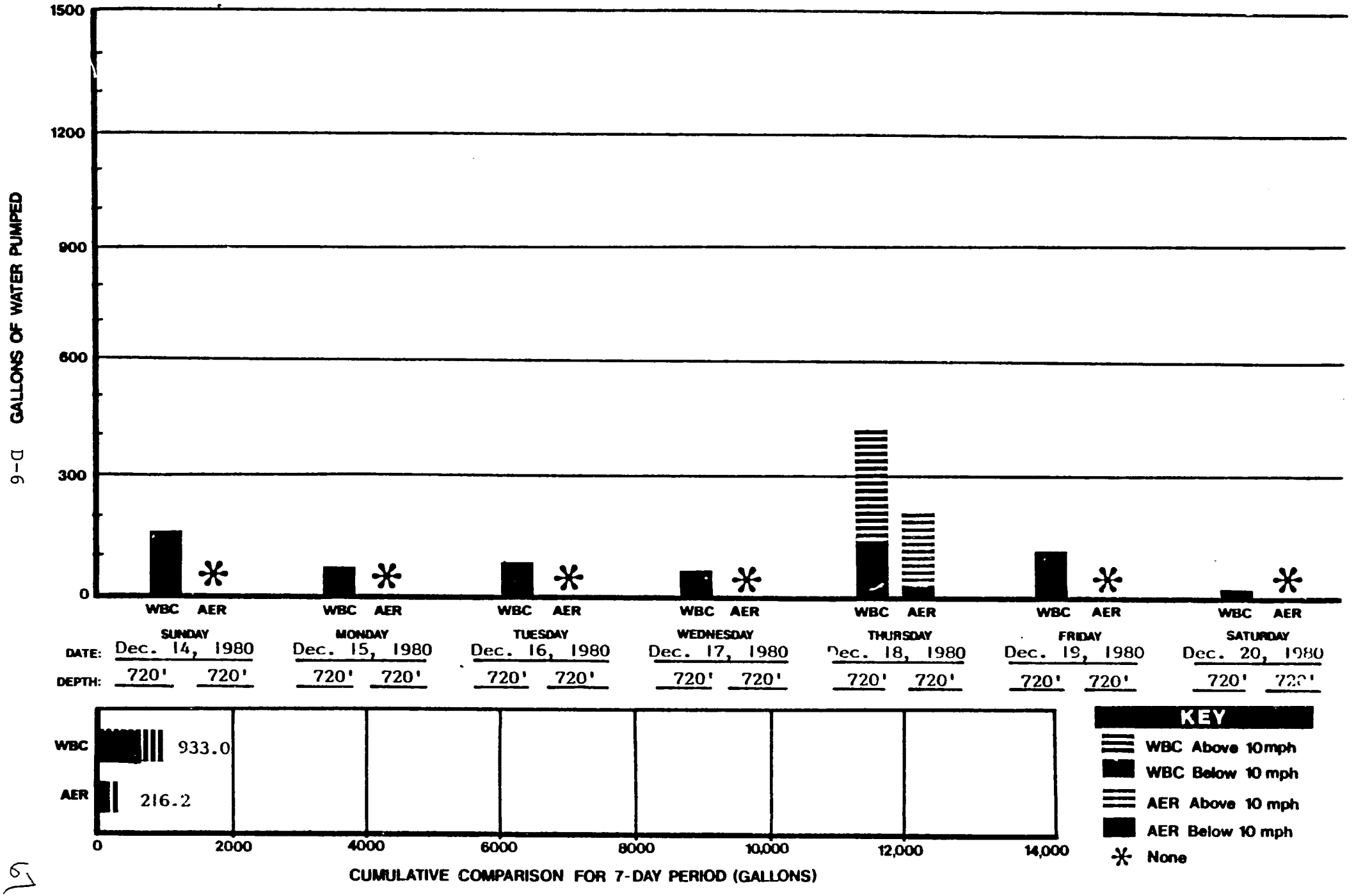



# WIND SPEED DATA

Wind Speed vs. Time of Day

# WINDOW ROCK, ARIZONA

Low Wind Day – December 20, 1980




NOTES:

**Navajo Nation/Wind Baron Corp. Windmill Master Test Site**
**Performance Comparison (Gallons of Water Pumped)**

FOR PERIOD OF:
Dec. 14 thru Dec. 20, 1

Section 6

# THIRD PARTY

# COMPARATIVE PEFORMANCE STUDY

PREPARED BY

Peter E. Jenkins, Ph.D., P.E.
Director- Turbomachinery Laboratories

Texas A & M University
College Station, Texas

and

Richard W. Whittsit

Energy Consultant

## Executive Summary

This third party test report has been prepared to independently and objectively describe the performance of the Wind Baron High-Performance Windmill as compared to the Aermotor windmill as tested and compared in side-by-side test configurations installed on the Navajo Nation during 1980.

The two water-pumping windmills, were scientifically instrumented to demonstrate the performance characteristics in identical pumping situations of well depths varying from about 500 to over 1000 feet.

The wind conditions prevailing on the Navajo Reservation are classified generally as low average wind conditions (less than 10 mph) and generally represent the existing wind conditions of over 90% of the worlds land mass.

Previous results on the Navajo Nation over the last 50 years using about 1800 Aermotor windmills have produced very limited and marginally acceptable water resources for approximately one half of the year. During the annual 4 to 6 month drought period, the wind regime is so low that the Aermotor windmills do not work and emergency water hauling is required. This activity has caused the Navajo Nation to spend in excess of $1.0 million per year over the last 25 years to supply the necessary water.

In general, water-pumping windmills have been used world-wide to successfully supply shallow-water resources where electric power is either non-existent or too expensive to use for this purpose. However, due to the weight of the pumping sucker rod and water, the windmills designed to date require a substantially high wind speed to allow the windmill to overcome the weight of the sucker rod and water. For this reason, the windmills can operate successfully only when the windspeeds exceed 10 mph and the well depths are not greater than about 200 feet.

Most areas of the worlds land masses will not provide either the required windspeed on an average basis and the well depth requirements are generally too deep to support economic utilization of the standard available windmill. Section 1.0 provides more details on the general background of water-pumping windmills.

The Wind Baron High Performance windmill is similar to the Aermotor windmill, which has until recently been considered as the standard water pumping windmill design. The Wind Baron windmill has been designed to include patented changes to allow the Wind Baron dosign to operate successfully at lower average windspeeds and to pump at deep well depths.

This has been accomplished by strategically designed counterbalancing



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structures which, for the most part, completely offset the weight of the pumping sucker rod and water. It has been demonstrated that the Wind Baron counter-balanced system can be adjusted to the exact site conditions for all normally utilized water well depths up to 1000 feet.

In addition, the Wind Baron windmill design has rolling-element bearings instead of the Babbit-metal plain bearings used in the Aermotor design. Other improved features of the Wind Baron design include stronger mastpipe design, improved tail-bone design for improved wind-tracking and steel pinion gears replacing normally used cast iron gears. See Section II for detailed description of the Wind Baron windmill design.

The Master Test Site was developed to demonstrate the performance characteristics of both the Aermotor and the Wind Baron windmill designs in identical installation conditions and in identical wind condition environments. This objective was reached by installing the two windmills in a side-by-side configuration, the provisions of identical variable well depth simulations and identical instrumentation of the wind conditions and the critical windmill performance characteristics. The site is completely described in detail in Section III.

The primary objectives of the tests conducted from May 1980 through December 1980 were to show the relative performance differences between the two windmills at windspeeds greater than and less than 10 mpph.

Both windmills were instrumented to measure the total number of strokes, the prevailing windspeed, and wind direction. The instrumentation was housed in a house trailor type building and the entire site was surrounded by a cyclone type fence to prevent potential vandalization. The instrumentation was designed so that it could be utilized independently of operating personnel so that it would not require full time attendance and maintenance.

The test results have demonstrated that the Wind Baron windmill outperforms the Aermotor windmill significantly in both wind regimes above and below 10 mph. The performance comparison can be simply stated as follows:

1. At windspeeds less than 10 mph, the Wind Baron windmill produced approximately 1346% more water volume than the Aermotor windmill.

2. At windspeeds greater than 10 mph, the Wind Baron produced approximately 131% more water volume than the Aermotor windmill.

3. Total water production during the test period was approximately 178% greater for the Wind Baron windmill under all wind conditions experienced.

4. The Wind Baron demonstrated that its total reliability was improved



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over the Aermotor which is considered to be the industry leader in this regard.

5. In addition, a statistical analysis was completed, using the test data from the 6 month test program which can be used to predict water production capability from both the Wind Baron and the Aermotor designs. This analysis shows a very high potential utilization rate for the Wind Baron windmill in the areas of the world unable to use the existing windmills due to low winds and normal well depths.

This third party test report substantiates the performance summary data previously developed in bar-graph format by the Wind Baron Corporation. In addition Section IV provides the reader with additional insights regarding the potential utilization of the Wind Baron System based upon average wind speed conditions that prevail world-wide.

The appendices contain the following: The Wind Baron Status reports which reflects the summarial test results; the Wind Baron Corporation procedures for extrapolating, annotating and calculating the instrumented data; details of the Master Test Site physical installation; details of the statistical analysis techniques used in verifying the performance results; and detailed description of the Master Test Site Instrumentation equipment installed on the Navajo Reservation.

The undersigned have verified all of the above statements and the Wind Baron Corporation test installation and data retrieval methods to be accurate and represent well designed techniques based on the contract requirements that were applicable to this test project. It is also clear that the Wind baron Corporation has taken great pains to avoid using data which is either incomplete, invalid or inappropriate due to the test conditions prevailing. Where questions have arisen or inconsistencies have developed due to the test conditions or site configuration, the data in question was invariably ignored for analytical purposes.

Dr. Peter E. Jenkins

Richard W. Whitsitt



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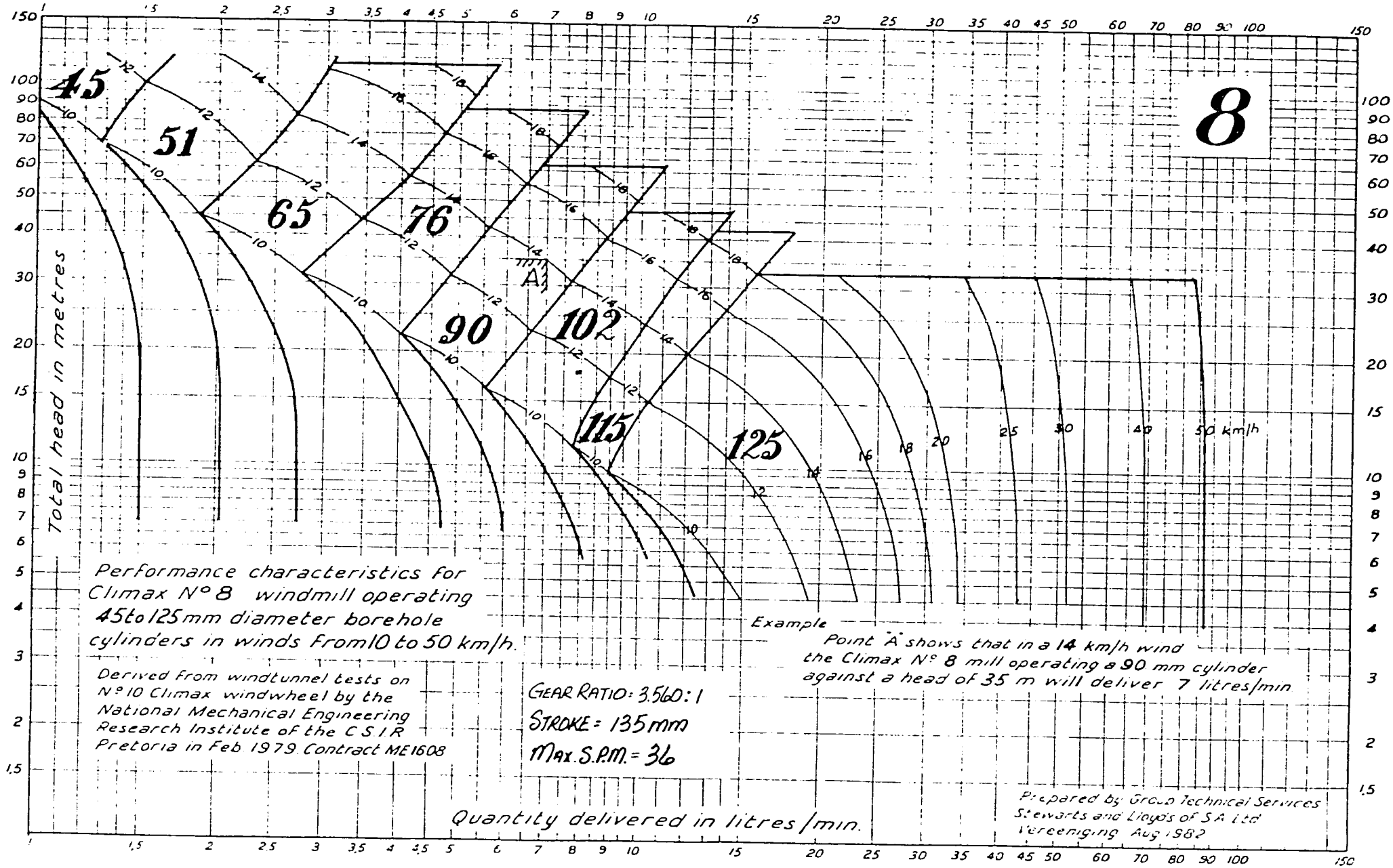
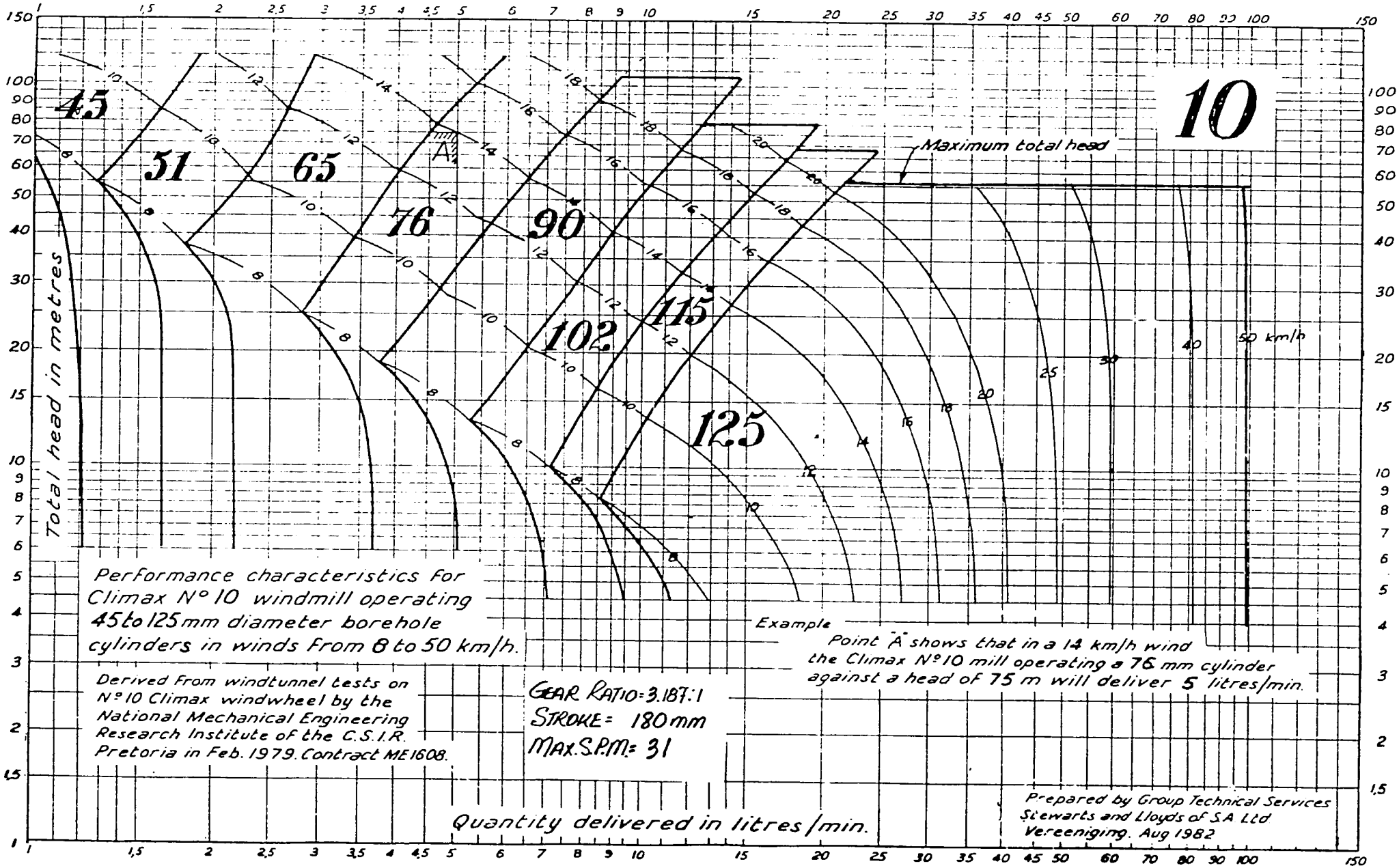
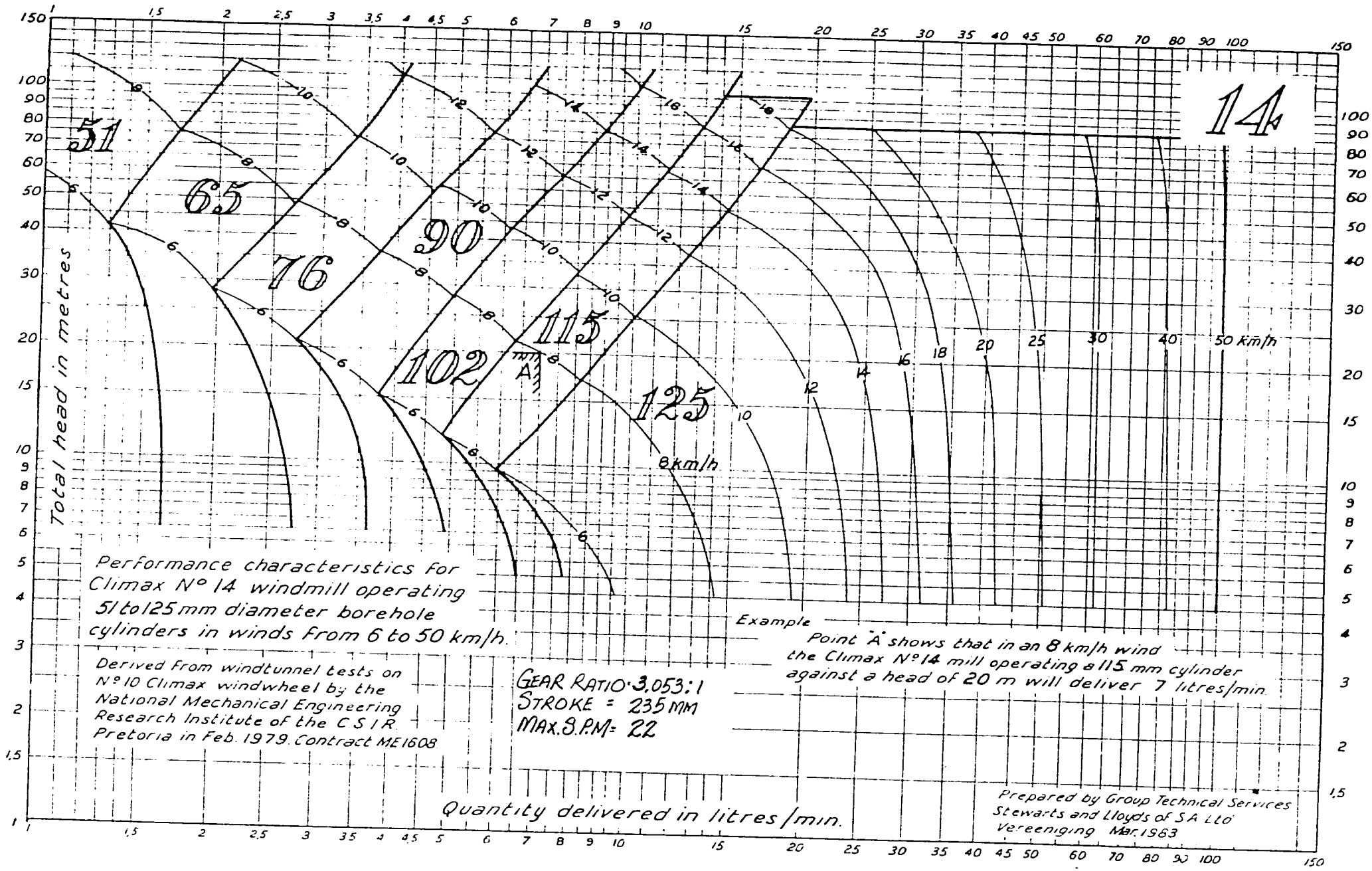
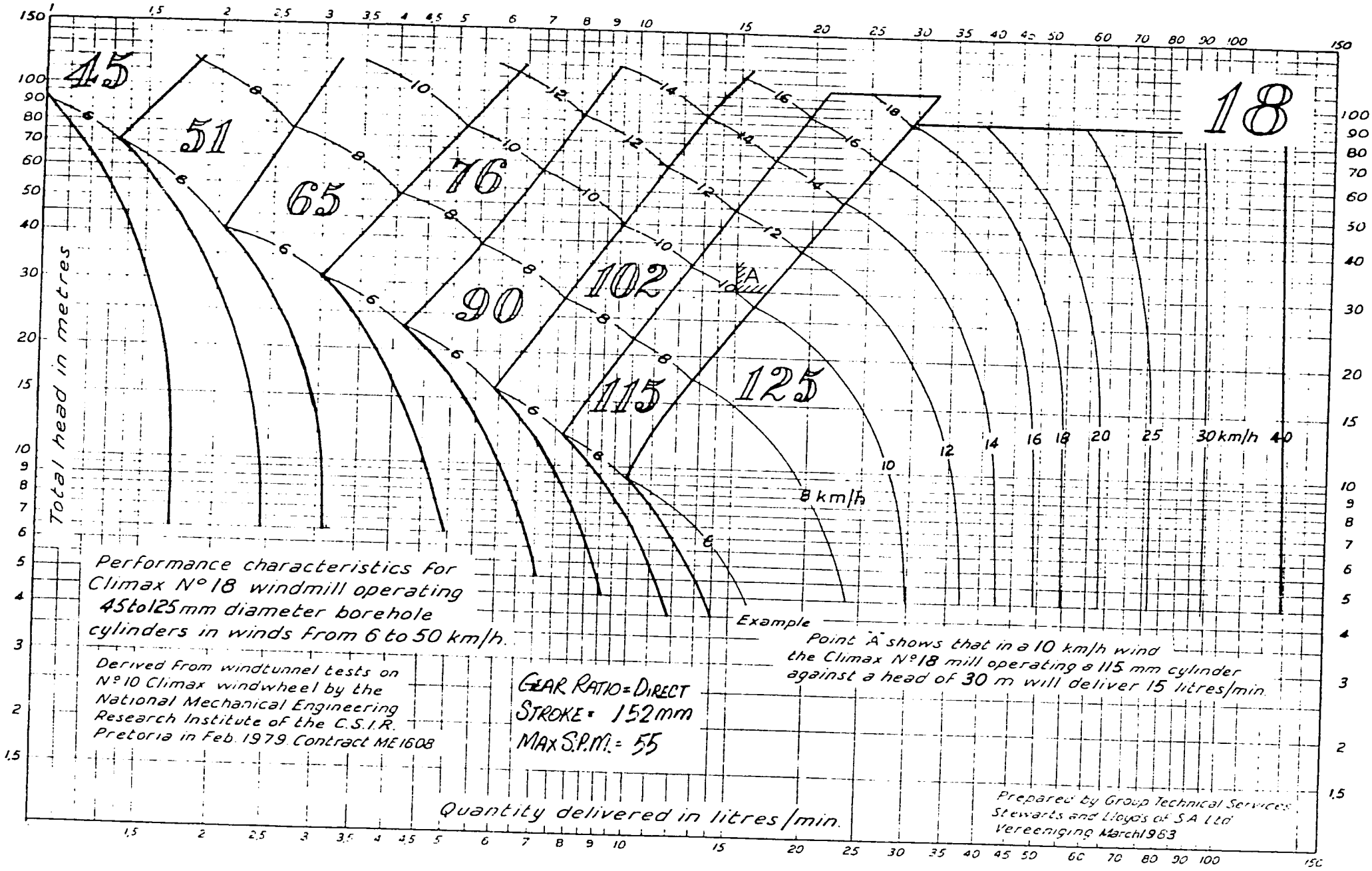
# APPENDIX E

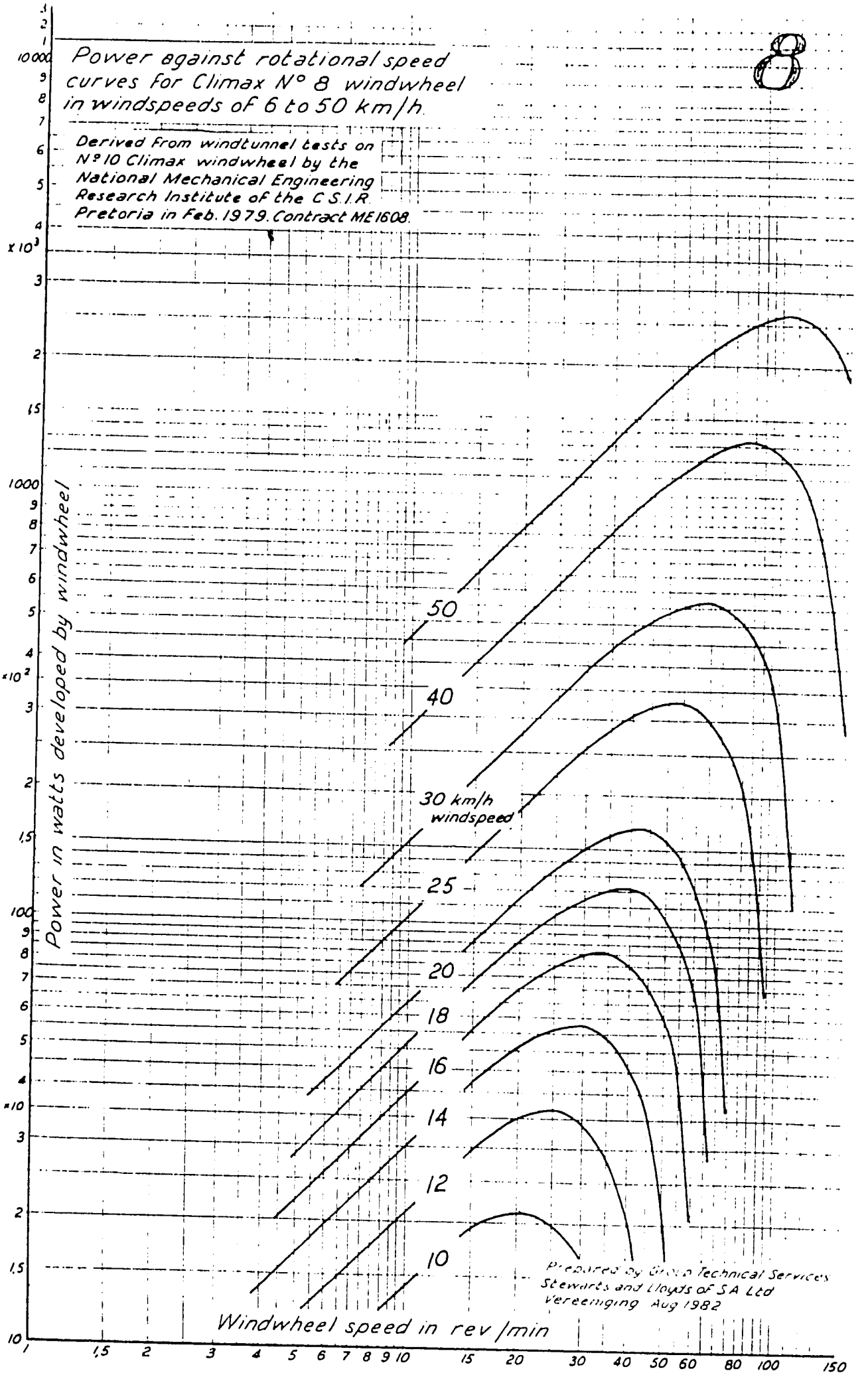
## Performance and Power Curves for Climax Multi-Bladed Windmills

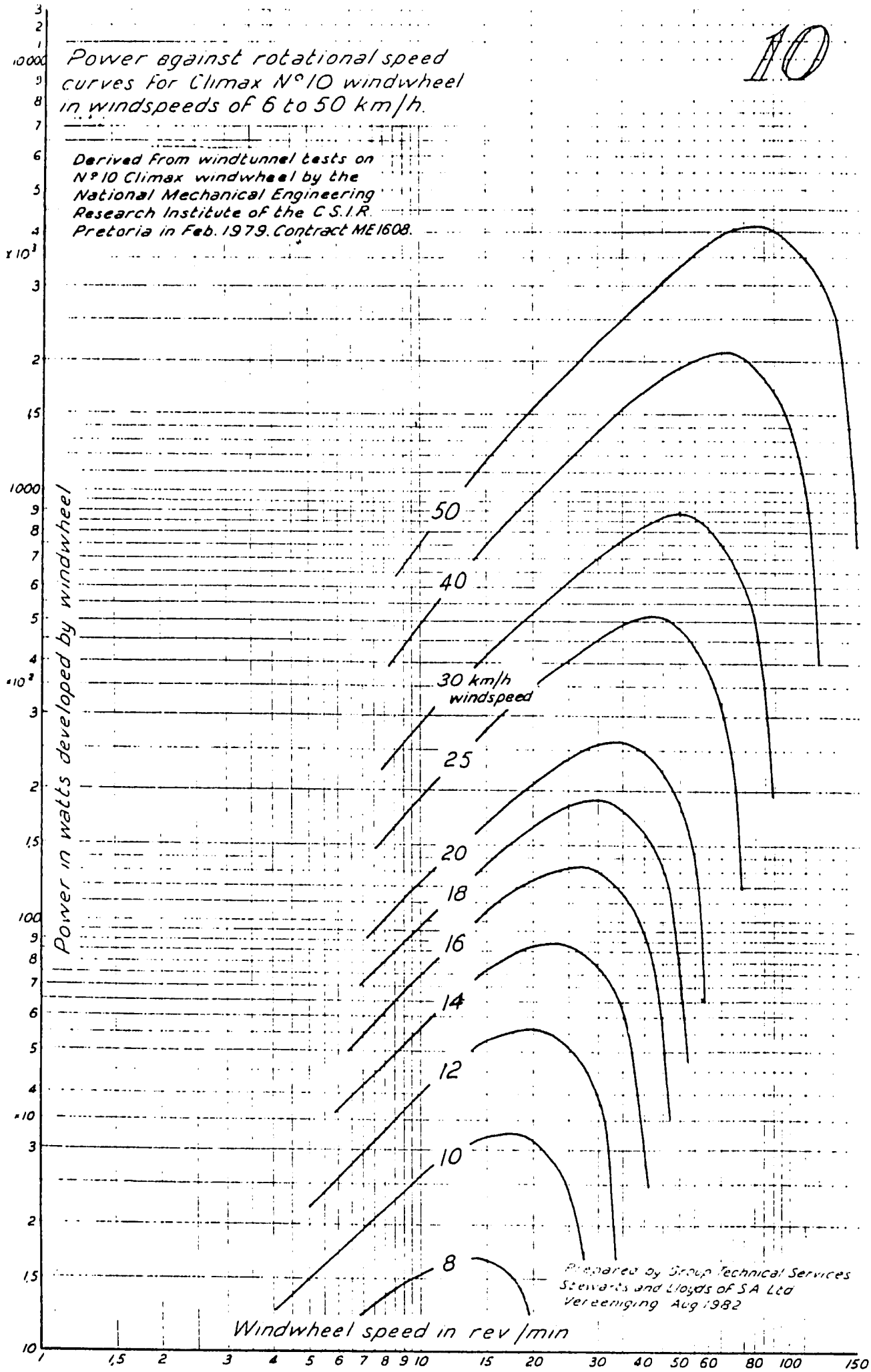

8
45
51
65
76
90
102
115
125
A
Total head in metres
Quantity delivered in litres/min.
km/h
Performance characteristics for Climax Nº 8 windmill operating 45 to 125 mm diameter borehole cylinders in winds from 10 to 50 km/h.
Derived from windtunnel tests on Nº 10 Climax windwheel by the National Mechanical Engineering Research Institute of the C S I R Pretoria in Feb 1979. Contract ME1608
GEAR RATIO: 3.560:1
STROKE: 135 mm
MAX. S.P.M. = 36
Example
Point 'A' shows that in a 14 km/h wind the Climax Nº 8 mill operating a 90 mm cylinder against a head of 35 m will deliver 7 litres/min
Prepared by Group Technical Services Stewarts and Lloyds of S.A. Ltd Vereeniging Aug 1982

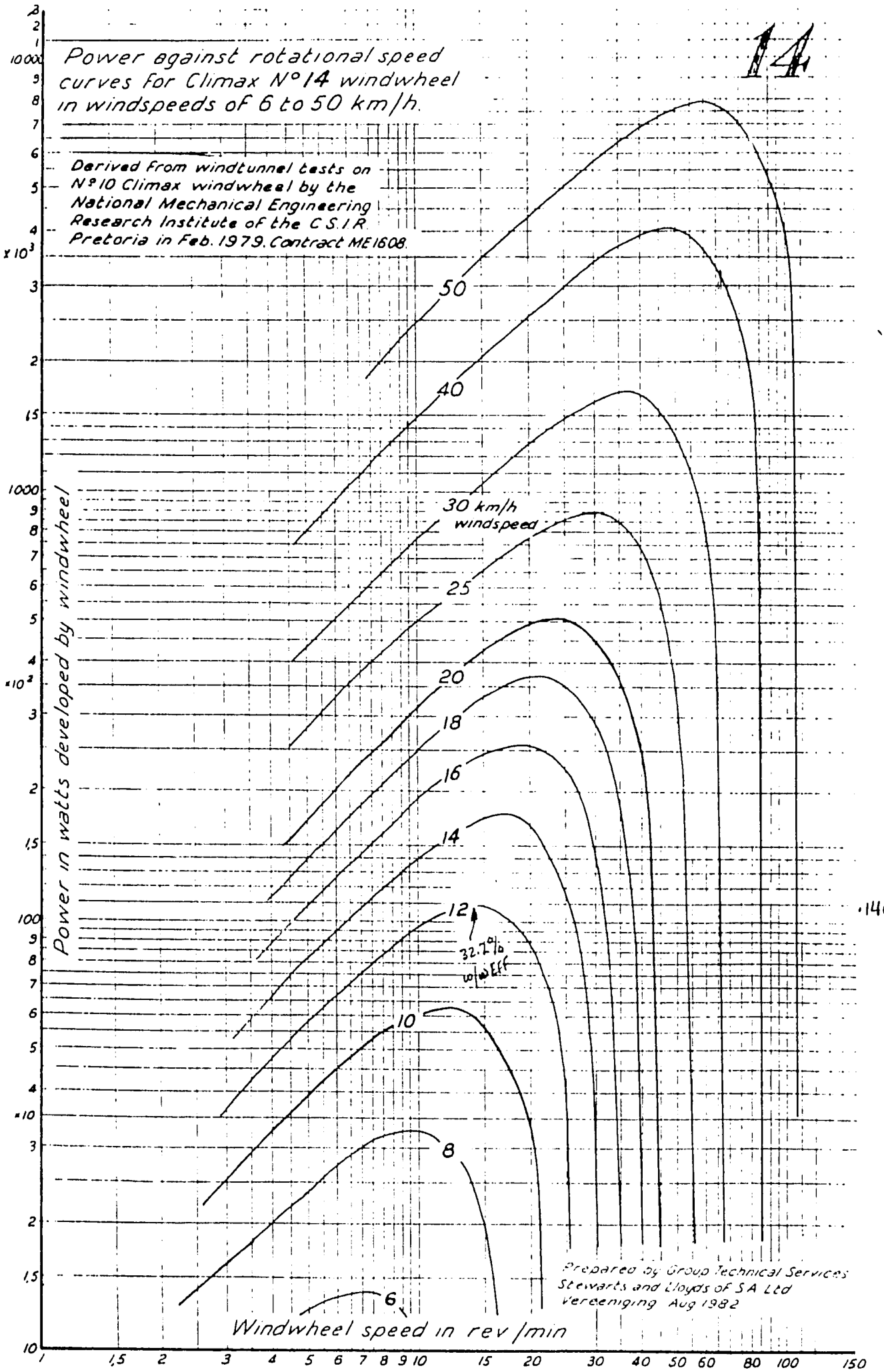

10
45
51
65
76
90
102
115
125
Maximum total head
50 km/h
A
Total head in metres
Quantity delivered in litres/min.
Performance characteristics for Climax N° 10 windmill operating 45 to 125 mm diameter borehole cylinders in winds from 8 to 50 km/h.
Derived from windtunnel tests on N° 10 Climax windwheel by the National Mechanical Engineering Research Institute of the C.S.I.R. Pretoria in Feb. 1979. Contract ME1608.
GEAR RATIO = 3.187:1
STROKE = 180 mm
MAX. S.P.M. = 31
Example
Point "A" shows that in a 14 km/h wind the Climax N° 10 mill operating a 76 mm cylinder against a head of 75 m will deliver 5 litres/min.
Prepared by Group Technical Services Stewarts and Lloyds of S.A. Ltd Vereeniging. Aug 1982


Total head in metres
Quantity delivered in litres/min.
51
65
76
90
102
115
125
14
8 km/h
50 km/h
A
Performance characteristics for Climax N° 14 windmill operating 51 to 125 mm diameter borehole cylinders in winds from 6 to 50 km/h.
Derived from windtunnel tests on N° 10 Climax windwheel by the National Mechanical Engineering Research Institute of the C S I R. Pretoria in Feb. 1979. Contract ME1608
GEAR RATIO: 3.053:1
STROKE = 235 MM
MAX. S.P.M = 22
Example
Point 'A' shows that in an 8 km/h wind the Climax N° 14 mill operating a 115 mm cylinder against a head of 20 m will deliver 7 litres/min.
Prepared by Group Technical Services Stewarts and Lloyds of S A Ltd Vereeniging Mar. 1983

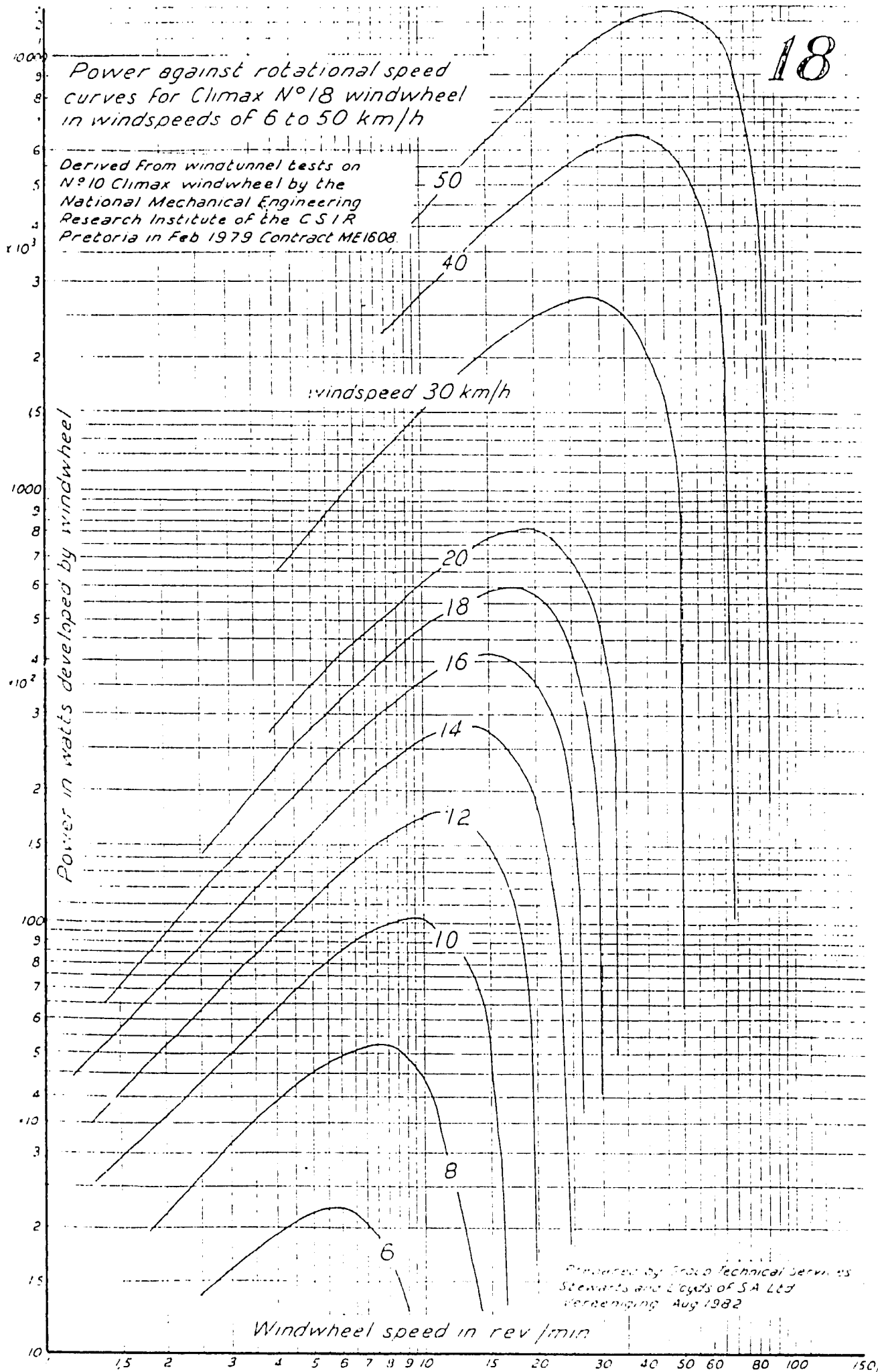

Total head in metres
Quantity delivered in litres/min.
45
51
65
76
90
102
115
125
18
A
8 km/h
10
12
14
16
18
20
25
30 km/h
40
Example
Point "A" shows that in a 10 km/h wind the Climax Nº18 mill operating a 115 mm cylinder against a head of 30 m will deliver 15 litres/min.
Performance characteristics for Climax Nº18 windmill operating 45 to 125 mm diameter borehole cylinders in winds from 6 to 50 km/h.
Derived from windtunnel tests on Nº10 Climax windwheel by the National Mechanical Engineering Research Institute of the C.S.I.R. Pretoria in Feb. 1979. Contract ME1608
GEAR RATIO = DIRECT
STROKE = 152 mm
MAX S.P.M. = 55
Prepared by Group Technical Services Stewarts and Lloyds of S.A. Ltd Vereeniging March 1983


Power against rotational speed curves for Climax N° 8 windwheel in windspeeds of 6 to 50 km/h.
8
Derived from windtunnel tests on N° 10 Climax windwheel by the National Mechanical Engineering Research Institute of the C.S.I.R. Pretoria in Feb. 1979. Contract ME1608.
Power in watts developed by windwheel
x10³
x10²
x10
50
40
30 km/h windspeed
25
20
18
16
14
12
10
Prepared by Group Technical Services Stewarts and Lloyds of SA Ltd Vereeniging Aug 1982
Windwheel speed in rev/min
1
1,5
2
3
4
5
6
7
8
9
10
15
20
30
40
50
60
80
100
150


Power against rotational speed curves for Climax N°10 windwheel in windspeeds of 6 to 50 km/h.
10
Derived from windtunnel tests on N°10 Climax windwheel by the National Mechanical Engineering Research Institute of the C.S.I.R. Pretoria in Feb. 1979. Contract ME1608.
Power in watts developed by windwheel
Windwheel speed in rev/min
50
40
30 km/h windspeed
25
20
18
16
14
12
10
8
Prepared by Group Technical Services Stewards and Lloyds of S.A. Ltd Vereeniging Aug 1982


Power against rotational speed curves for Climax N°14 windwheel in windspeeds of 6 to 50 km/h.
Derived from windtunnel tests on N°10 Climax windwheel by the National Mechanical Engineering Research Institute of the C.S.I.R. Pretoria in Feb. 1979. Contract ME1608.
50
40
30 km/h windspeed
25
20
18
16
14
12
10
8
6
32.7% w/w Eff
Power in watts developed by windwheel
Windwheel speed in rev/min
Prepared by Group Technical Services Stewarts and Lloyds of S.A. Ltd Vereeniging Aug 1982

·146 Hp Dev.


18
Power against rotational speed curves for Climax N°18 windwheel in windspeeds of 6 to 50 km/h
Derived from windtunnel tests on N°10 Climax windwheel by the National Mechanical Engineering Research Institute of the C S I R Pretoria in Feb 1979 Contract ME1608
50
40
windspeed 30 km/h
20
18
16
14
12
10
8
6
Power in watts developed by windwheel
Windwheel speed in rev/min
Prepared by Food Technical Services Stewarts and Lloyds of S A Ltd Vereeniging Aug 1982

APPENDIX F

Technical Information

## Introduction

Wind energy systems are characterized primarily by the intermittent nature of wind as an energy source and the fact that power output varies according to both the swept area of the rotors and the cube of wind velocity. As a result, the actual power output of wind machines over a long period of time may be significantly greater than an estimate of power output based on average wind speed. Exact siting is critical since wind velocity increases with height above ground level. Local anomalies in wind speed occur because of both increased rates of flow over or around smooth hills and other objects, and decreased rates due to nearby trees, obstructions and differences in terrain.

## Characteristics of Multi-Bladed Windmills

Multi-bladed windmills for water pumping evolved from a need for high starting torque--the windmill has to begin turning and lift water at the same time. High torque requires a large lifting surface area, so the total blade surface almost equals the windmill's frontal area--high solidity. An extra bonus of many blades placed close together is the so-called "cascade effect." Each blade aids the next by acting as a guide vane for the air flowing over the next blade. The air flow at very low tip speed ratios (peripheral speed of the rotor tip divided by the wind velocity) occurs at a nearly optimum angle for each blade to develop maximum lift.

Multi-bladed rotors have the following desirable features:

- high starting torque required for water pumping,
- simple design and construction,
- simple control requirements, and
- durability--minimum maintenance.

The disadvantages include:

- not readily adaptable to end-uses requiring high rpm, and
- exerts high rotor drag on the tower.

The maximum rotor efficiency that can be attained with a multi-bladed water pumping system is about 30 percent, but 15 to 20 percent is more common in practice.

## Energy in the Wind

Theoretically, the energy available in wind can be calculated using the laws of mechanics. Any mass in motion, including air, has a kinetic energy expressed by the relationship:

$$KE = 1/2\ M\ V^2$$

where M is the air's mass and V, the wind's velocity. The mass of air that actually supplies energy to a wind machine is proportional to the cross-sectional area (A) covered by the windmill's rotating blades. For the revolving blades of a horizontal-axis windmill, this is a circular section, whose area is given by the relationship:

$$A = \left(\frac{\pi\ D^2}{4}\right)$$

where D is the diameter swept by the windmill blades. Therefore, the kinetic energy available in a circular section of wind can be expressed as:

$$KE = \tfrac{1}{2}\ M\ \left(\frac{\pi\ D^2}{4}\right)\ V^2$$

In calculating the wind power input to a windmill, the kinetic energy present in a circular section of wind is translated into the power or useful work that can be done by an invisible tube of wind in one second multiplied by the distance through which it moves (velocity--V) by the expression:

$$\text{power} = (KE)(V) = \left[\tfrac{1}{2}\ m\ \left(\frac{\pi\ D^2}{4}\right)\ V^2\right](V) \text{ or power} = \tfrac{1}{2}\ M\ \left(\frac{\pi\ D^2}{4}\right)\ V^3$$

This formula for power in a wind column cannot be applied to the continuous extraction of energy (power) from wind because it assumes that the wind speed changes from a velocity, V, to rest or zero. If the air behind the windmill blades is brought to rest or stopped, there would be no space available for the column of air that arrives next and in succeeding moments. It is necessary to allow the wind to pass through the blade area and extract energy by reducing the wind speed. A. Betz of Germany demonstrated that the maximum fraction of power that could actually be extracted was 16/27 or 59.3 percent of the total power in the wind column. Thus:

$$\text{power} = \frac{.593}{2}\ M\ \left(\frac{\pi\ D^2}{4}\right)\ V^3$$

With air density as 0.08 pounds per cubic foot, power as watts, cross-sectional area (A) in square feet and wind velocity in miles per hour (mph), this equation can be simplified to:

power (watts) = $0.00314\ A\ V^3$

Air density varies only slightly, being lower with both increasing humidity or water vapor content and altitude or height above sea level. Since air density also varies over any period of time with changes in barometric pressure and temperature, an average air density is typically used in wind power calculations. This equation can be further simplified to express the swept area (A) of the windmill in terms of the blade diameter in feet:

<u>Formula One:</u> power (watts) = $0.00246\ D^2\ V^3$

From this, it can be seen that the power extracted from wind increases with the square of the diameter swept by the blades and the cube of wind speed. The importance of selecting the windiest possible site is readily realized from these expresssions. Although doubling the diameter of the windmill increases the power available from the wind four times, doubling the wind speed increases the power eight times.

Formula one expresses power in watts. Formula two, below, gives power in horsepower (hp), where D is the blade diamemter in feet and V, the wind velocity in mph.

<u>Formula Two:</u> power (horsepower) = $(3.3 \times 10^{-6})\ D^2\ V^3$

One horsepower is equivalent to 746 watts or raising 33,000 pounds one foot in one minute.

The overall wind-to-water efficiency of a multi-bladed windmill water pumping system ranges from 15 to 20 percent at best. Therefore, the power values derived from formulas one and two must be multiplied by the product of the estimated pump and win windmill efficiencies (EFF) to determine the actual power than can be used to pump water. Thus:

<u>Formula One:</u> power (watts) to pump water = $.00246\ D^2\ V^3$ (EFF)

and

<u>Formula Two:</u> power (hp) to pump water = $(3.3 \times 10^{-6})\ D^2\ V^3$ (EFF)

where (EFF) is the product of estimated pump and windmill efficiencies due to mechanical and hydraulic losses, which depend on the type of system design. The maximum of 59.3 percent power that can be extracted from the wind is included in the formulas' constants.

## Wind Speed Characteristics

### Effect of Measurement Height

Various references agree that the surface friction coefficient ($\alpha$) may range from a value of 0.10 for smooth hard ground, lake or ocean up to a maximum value of 0.40 for urban areas with tall buildings. The surface friction coefficient used by Meteorological Services falls in the range of 0.28 to 0.30. Mr. H. Terral's 1981 BTC report found the 0.28 value suitable, but also suggests using the proper coefficient for the actual terrain of the site being evaluated. In other words, measurements taken at any one site and extrapolated to different heights are site-specific and should be treated as such. Due to the variation of terrain in Botswana, and windmill installation sites in general, the following table and formulas are suggested for use in estimating wind speeds at specific sites.

| Terrain | Surface Friction Coefficient |
|---|---|
| smooth hard ground, lake or ocean | 0.10 |
| short grass on untilled ground | 0.14 |
| level country, foot-high grass, occasional tree | 0.16 |
| tall row crops, hedges, a few trees | 0.20 |
| many trees, occasional buildings | 0.22-0.24 |
| wooded country, small towns and suburbs | 0.28-0.30 |
| urban areas with tall buildings | 0.40 |

From this table, the wind speed at a new height $H_B$ can be readily estimated from data gathered at a given height $H_A$ using the formula:

$$V_B = V_A * \left(\frac{H_B}{H_A}\right)^{\alpha}$$

where $V_A$ is the wind speed measured at height $H_A$ and $V_B$, the wind speed estimated at height $H_B$ (Park, 1981).

The importance of using the correct coefficient for the terrain at the measuring site is readily seen. For example, if data were taken at a height of two meters and extrapolated to 10 meters using a coefficient of 0.29, while the coefficient

indicated for the site was 0.16, only 80 percent of the extrapolated wind speed would actually occur. The importance of appropriate terrain description for sites where wind speed is being monitored cannot be overlooked.

## Effects of Altitude and Temperature on Air Density

The density of a substance is a measure of how much of it can fit in a given volume. For windmills, the amount of air interacting with the rotors as the wind passes through them must be known. The kinetic energy in wind is a function of the density of the air mass and wind speed. Thus, the density of the air mass (P) is required to calculate the energy and power that are available. The density value is based on air temperature and altitude, usually referenced to sea level. The Standard Day Condition for air at sea level in English units are:

- temperature = 59°F;
- pressure = 14.7 pounds per square inch (PSI); and
- density = 0.0024 slugs per cubic foot (one slug is 32.2 pounds at sea level),
  = 0.077 pounds per cubic foot, or
  = 1.225 kilograms per cubic meter.

To calculate the air density at a specific site, altitude and temperature differences from the Standard Day Condition must be corrected for. The following tables (Park, 1981) give correction factors for these differences.

Air Density Correction Factors ($C_A$)

| Altitude in Feet | Altitude in Meters | Correction Factor |
|---|---|---|
| 0 | 0 | 1.0 |
| 1,000 | 305 | 0.965 |
| 2,000 | 610 | 0.930 |
| 3,000 | 914 | 0.899 |
| 3,281 | 1,000 | 0.890 |
| 4,000 | 1,219 | 0.861 |
| 5,000 | 1,524 | 0.832 |
| 6,000 | 1,829 | 0.800 |
| 7,000 | 2,134 | 0.770 |
| 8,000 | 2,438 | 0.740 |
| 9,000 | 2,743 | 0.712 |
| 10,000 | 3,048 | 0.687 |

Temperature Correction Factors ($C_F$)

| Degrees Fahrenheit | Degrees Celsius | Correction Factor |
|---|---|---|
| 0 | -17.8 | 1.130 |
| 10 | -12.2 | 1.100 |
| 20 | - 6.7 | 1.083 |
| 30 | - 1.1 | 1.060 |
| 40 | 4.4 | 1.040 |
| 50 | 10.0 | 1.022 |
| 55.5 | 13.0 | 1.011 |
| 60 | 15.5 | 1.0 |
| 70 | 21.1 | 0.985 |
| 77.5 | 25.3 | 0.970 |
| 80 | 26.6 | 0.963 |
| 90 | 32.2 | 0.950 |
| 100 | 37.7 | 0.929 |
| 110 | 43.3 | 0.910 |
| 120 | 48.8 | 0.890 |

Using these correction factors, the air density (P) at a specific site can be calculated from:

$$P = C_A * C_T * 0.0024 \text{ slugs per cubic foot}$$

An example of the change in air density from summer to winter at an altitude of approximately 1,000 meters is as follows. The average summer temperature in Gaborone from December through March (see Appendix B) is 25.3°C. The correction factors from the tables are $C_A = 0.890$ and $C_T = 0.970$. Thus, the summer air density would be:

$$0.00207 \text{ slugs/ft}^3 = 0.890 * 0.970 * 0.0024$$

This value of 1.066 kilograms per cubic meter is approximately 80 percent of the standard air density. Conversely, the average winter temperature in Gaborone during June and July (see Appendix B) is 13.0°C. The correction factors are $C_A = 0.890$ and $C_T = 1.011$. The air density is:

$$0.00216 \text{ slugs/ft}^3 = 0.890 * 1.011 * 0.0024$$

This figure of 1.114 kilograms per cubic meter is 90 percent of standard air density.

The effect of summer and winter air densities on available power are illustrated in the following calculations. Wind power is the amount of energy flowing through the surface of the rotor per unit of time and is proportional to the cube of the wind available to the rotor (P or air density in slugs per cubic foot). Where V is wind velocity in mph; A, the rotor area in

square feet; and K, the correction factor to convert to power in watts (4.31):

$$\text{power (watts)} = 1/2 * P * V^3 * A * K$$

To figure watts of power in metric terms, P is air density in kilograms per cubic meter; V, wind velocity in meters per second; and A, rotor area in square meters.

Using these data, the power available in an eight-mph wind acting on a 14-foot diameter rotor can be calculated for the two different air densities. In the summer, P = 0.00207 slugs per cubic foot, V = 8 mph, A = 153.93 square feet and K = 4.31, so:

$$\text{power (watts)} = 1/2 * 0.00207 * 512 * 153.93 * 4.31$$

or 351.5 watts of available wind power. In winter, P = 0.00216 slugs per cubic foot, V = 8 mph, A = 153.93 square feet and K = 4.31, so:

$$\text{power (watts)} = 1/2 * 0.00216 * 512 * 153.93 * 4.31$$

or 366.8 watts of available wind power.

This example readily shows that power varies directly with air density--doubling the air density doubles power--and also as a cube of wind speed--doubling the wind speed increases power by eight times. It is also clear that air density variations are a small factor in wind power, when compared to the effect of wind speed and the wind-to-water efficiency of the windmill system, as discussed earlier.

# APPENDIX G

## Syllabus for a One-Week Training Program in Windmill Installation and Maintenance

by Mr. Willis Eschenbach

One-week training in Windmill Installation and Maintenance
Tentative Training Schedule

Monday

8:00 - 10:00
Introduction and objectives
10:00 - 12:00
Siting Considerations
1:00 - 3:00
Pumps and Pump Design, Windmills in general
3:00 - 5:00
Shop Safety and Tool Care
Begin assembly of tower
Site cleanup

Tuesday

8:00 - 8:30
Start of day session - comments, changes
1:00 - 2:00
Water and Numbers
Remainder of day
Tower assembly
Site cleanup

Wednesday

8:00 - 8:30
Start of day session - comments, changes
8:30 - 12:00
Finish tower assembly
1:00 - 2:00
Large Projects and Community Analysis
2:00 - 5:00
Prepare site for tower raising

Thursday

8:00 - 8:30
Start of day session - comments, changes
8:30 - 9:30
Tower raising theory
1:00 - 2:00
Maintenance -- Preventive and Routine
Remainder of day
Raise tower
Level and center tower
Pour concrete

Friday

8:00 - 8:30
Start of day session - comments, changes
1:00 - 3:00
Exploration for wind sites
Remainder of day
Install windmill, hookup and setup

Saturday

Morning
Testing and measurement
11:00 - 12:00
Wrapup, final work

Session Title
Introduction and Objectives

Session Objectives

To introduce ourselves and to meet each other

To find out about the group resources -- who knows what, who has done what, what are the skills we have, what are the skills we need

To get clear about and mutually agree upon the objectives of the training and the agreements among ourselves

Materials Needed

Blackboard or equivalent

Activities

Begin by going around the room and introducing ourselves to the group and giving a short description of our knowledge and experience regarding windpower, and our expectations about the training and what we hope to get from it. Have a volunteer note the expectations on the board as they are mentioned.

After all have spoken, discuss the expectations that have been noted on the board. Come to agreement about which of the expectations are likely to be met, and which are not.

Discuss and agree upon the things we will need to do in order to meet the expectations. These should include attending all of the sessions, being on time, assisting others with our own knowledge, etc.

Discuss the logistics -- library use, evaluations, presentations, dividing into work groups, after hours time, meals, breaks, etc.

Session Title
Siting Considerations

## Session Objectives

To learn how to distinguish a good wind site from an inadequate site.

To understand the realities of siting windpumps

## Materials Needed

Blackboard or equivalent

## Activities

Water is at the center of siting considerations for wind powered pumps, so the real question is, what wind is available above or next to the water?

In addition, other factors.....

Ground -- is the ground firm enough to support a tower or structure?

can the structure be anchored?

Winds -- maximum?

River -- if next to a river, which way will the river flood?
which direction is the bank being eaten away?

Ownership -- water?
mill?
land under mill?

Effect on erosion?

Other factors (who builds it, who maintains it, weather extremes, noise, or any other factors which are important to you or the people around)

Finally, discuss the use of wire lines to transmit mechanical power for use at a distant site. Use a model to demonstrate the principles, and note the 1/4 mile limitation using this system.

Session Title
Pumps and Pump Design

## Session Objectives

To look at and learn from examples of pump design

To learn the basic operating principles common to all displacement pumps

## Materials Needed

Blackboard or equivalent

## Activities

Begin by discussing the pump design shown in the xerox listed in the references. Discuss the various methods for attaching the pump to the mill, and the necessity of securing the sections of sucker rod firmly together. Explain the construction and use of swivels and crossheads.

Extract from the examples the minimum parts common to the displacement type pump -- inlet valve, outlet valve, something to displace the water

Discuss the difference between a pump that works submerged in the water (borehole type or other) and a pump that works above the water level and must suck the water up to it. Note the approximately 20 foot (7 meter) limit to the height the pump can be located above the water level.

## Reference Materials

| Type | Contents |
|---|---|
| Xerox | "Hand pump" with single-acting, bucket piston |

Session Title
Shop Safety and Tool Care

## Session Objectives

To create enough awareness of safety of people and safety of tools to allow both tools and people to come through the program undamaged

## Materials Needed

Shop and tools

## Activities

As this is the people's first time in the shop, draw people's attention to the general facets of the shop -- layout, general location of materials and tools, exits, fire-fighting equipment, etc.

Personal safety is first in importance, so discuss the various dangers in the shop -- fire, tools with edges, heavy things, tripping and falling, and, of course, each other. Stress awareness of the others.

Tool care is the second aspect. Go around the shop together, discussing the individual tools. Discuss them in related groups, discussing care of edges, protection from rust, etc. Include any special safety precautions to be taken with that tool or kind of tools.

Session Title
Tower Raising

Session Objectives

Nobody gets hurt

Towers get raised

Machines get installed

Materials Needed

Shovels, Tamping bars or poles

Tower poles, gin poles, enough rope, diagonal bracing poles

Model materials

Activities

Demonstrate the action and sequence of raising a large timber or tower, using a model

Discuss and explain safety considerations--falling off tower, if the rope breaks, tower or poles falling on you, dropping tools from hands and pockets on high, etc.

Assemble the tower, and measure and dig footing holes

Prepare for raising, including safety precautions

Raise tower, using gin pole if necessary

Level and center tower, and pour concrete footings

Prepare machine for installation

Install machine

References

Xeroxes Directions for Erecting H-A Towers
Parts and Assembly of H-A Towers

## Session Title
## Water and Numbers

### Session Objectives

To learn how to size windmills and pumps with as little use of formulas as possible

### Materials Needed

Blackboard or equivalent

### Activities

Discuss "Aermotor Pumping Capacity" chart, using examples

Have a volunteer do a sample problem

Discuss "Recommended Size, Standard Steel Pipe" chart, using examples.

Have a volunteer do a sample sizing problem

Have a volunteer do a sample combined sizing problem

(Everyone can do the sample problems along with the volunteers)

Discuss any difficulties in using the charts

### Reference Materials

| Type | Contents |
|---|---|
| Xerox | Aermotor Pumping Capacity |
| | Recommended Size, Standard Steel Pipe |

Session Title
Large Projects and Community Analysis

## Session Objectives

To learn some of the factors affecting large projects

To learn how to analyze a community situation regarding the possibility of a community wind project

## Materials Needed

Blackboard or equivalent

## Activities

The difference between the big projects and the small ones is the increase in stress on all the people and systems involved.

Examine and discuss this increase in stress in terms of:
- The windmill
- The pump
- The water resources
- The material resources
- The people involved in building and maintenance
- The community

In terms of the community, discuss some of the important issues:
- Who will pay for the system?
- Who will build it?
- Who will gain by it?
- Who will lose by it?
- Who supports it being built?
- Who opposes it being built?
- Who will maintain it?
- Who will pay for the maintenance?
- What skills and crafts are available?
- What tools and materials are available?
- What changes might occur in the community (cultural, environmental, health, religious beliefs, agricultural methods, traditional gender roles, economy) if the system is built?



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Session Title
Maintenance -- Preventive and Routine

Session Objectives

To understand the maintenance needs of various types of windmills and pumps

To learn the ways to meet those needs

Materials Needed

Blackboard

Activities

Have the group develop a list of the various parts of the mills and pumps that will wear out, and, in a parallel column, what is causing that wear

Have the group develop another list showing the maintenance necessary for each of the parts that is wearing, and, in a parallel column, an estimate of the frequency of maintenance necessary for that part

Note that the windmill and pump, with the exception of sealed, oilbath commercial units, is usually a fairly high maintenance item

Resources

| Type | Contents |
|---|---|
| Xerox | Mill Maintenance |



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Session Title
Exploration for Wind Sites

Session Objectives

To learn how to visualize the flow of the wind

To locate the good windsites on or around the training area

To learn about the wind

Materials Needed

Bubble materials

Activities

This is an outdoor session. Walk around the area and investigate the wind, using bubbles to show the wind flow in various areas.

Notice areas of stronger wind, and quiet areas.

Notice areas of turbulence, and areas of smooth flow.

Discuss the causes of the differences, noting that the wind has the same kinds of motion that water has -- eddies, backflows, rough and smooth areas, etc.

Discuss the use of vegetation as an aid to judging average wind speed, pointing out examples

Explain the local peculiarities of wind flow -- flow over ridges, flow in valleys, day and night winds

Note some sites to avoid -- side of the hill, just beyond the ridgeline, near trees or buildings

Discuss and select the best local site for a windmill.

Reference Materials
Xerox Ecological Indicators of Site Suitability

Session Title
Testing

## Session Objectives

To set up test conditions to allow us to test what we have built

To gather some data about the performance of the system

## Materials Needed

Two 5 gallon drums (kerosene cans)

Watch and anemometer

Pond or well or river or tank or 55 gallon oil drum for a water source

## Activities

Build the test setup, which is a hose or pipe that can reach from the outlet of the pump system to fill a measured container in order to check the amount of water pumped in a certain amount of time by a certain wind.

When the mill is set up, start it pumping and start measuring at a certain moment. Note the variables on paper. If possible, change stroke length and repeat the test, to see which combination does better.

For the data collection, accurate recording of windspeed, height pumped, amount pumped, and time pumped are required. In addition, the exact capacity of the cans used must be measured. Make a number of runs at various speeds, and then make a graph of windspeed versus foot-gallons per hour (meter-liters per hour).

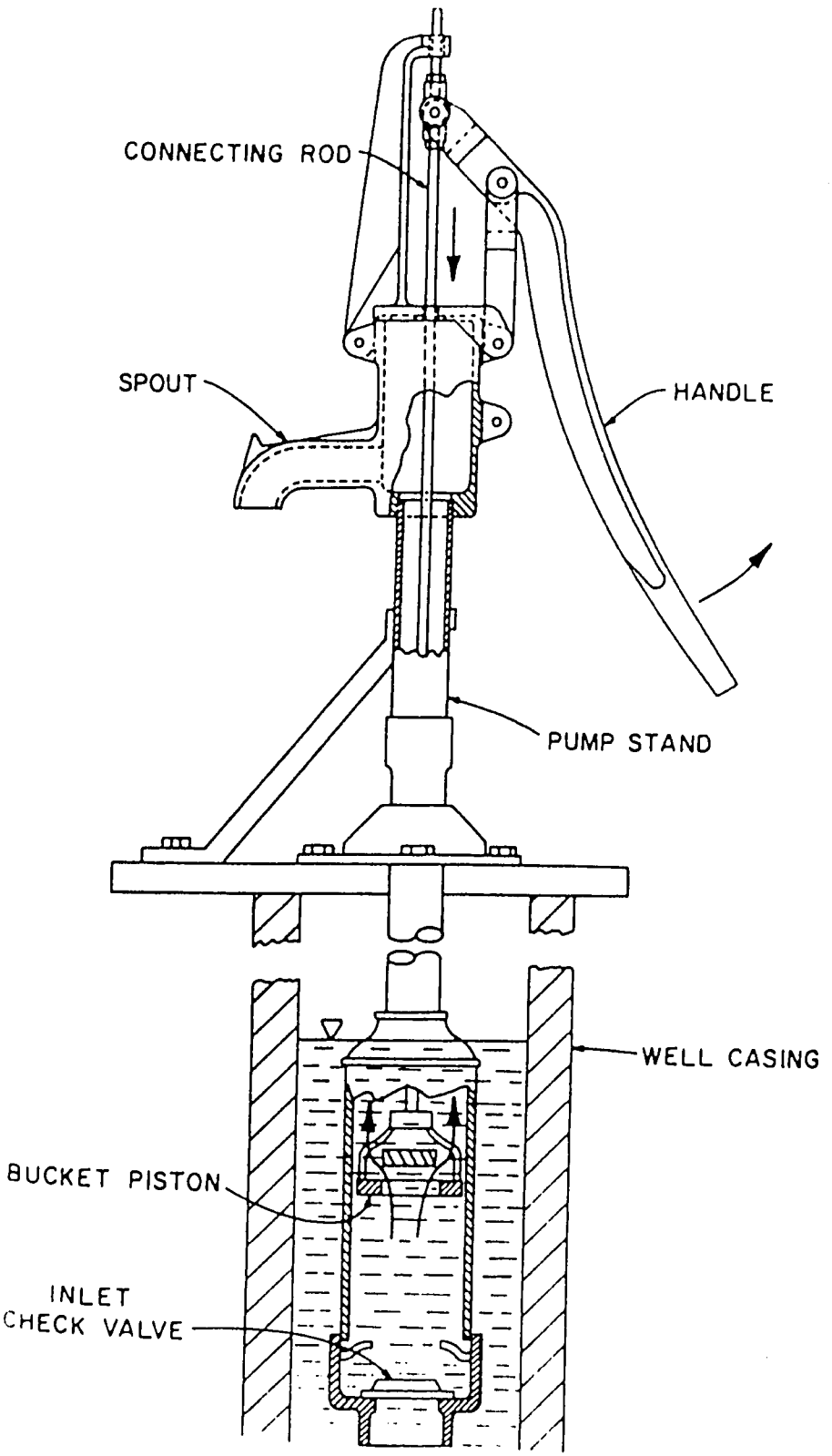
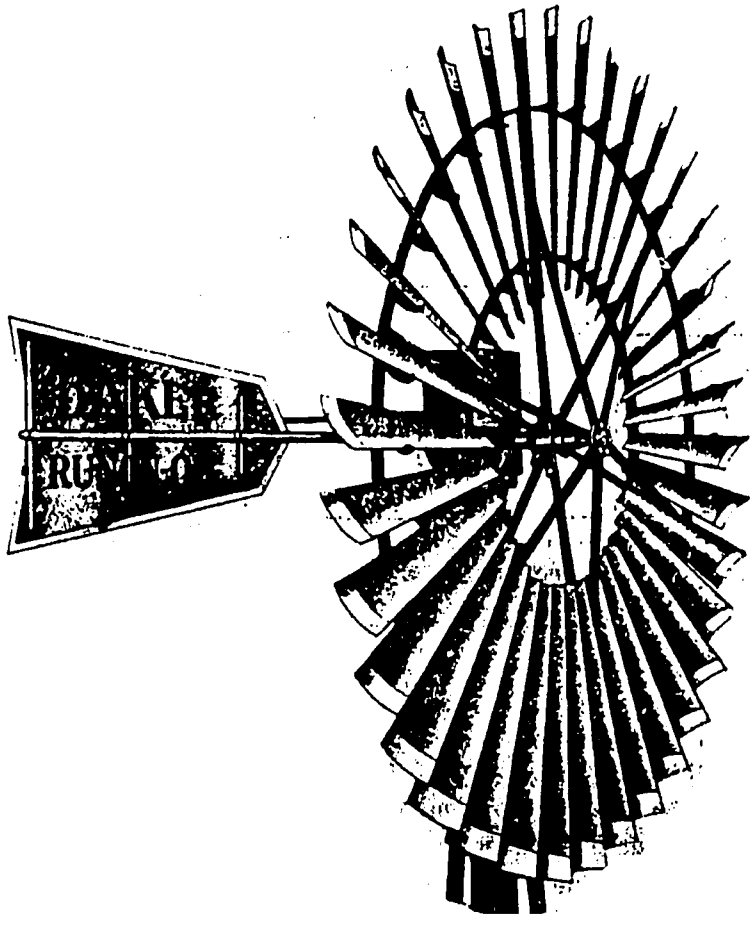



Figure 5.12 "Hand pump" with single acting, bucket piston

*Reference Pumps and Water Lifters for Rural Development*

# Directions for Erecting H-A Towers

# Directions for Erecting BAKER Windmills



Manufactured by

## THE HELLER-ALLER COMPANY

ESTABLISHED 1886

Napoleon, Ohio

THE HELLER-ALLER CO., Napoleon, Ohio

## DIRECTIONS FOR ERECTING BAKER WINDMILLS AND TOWERS

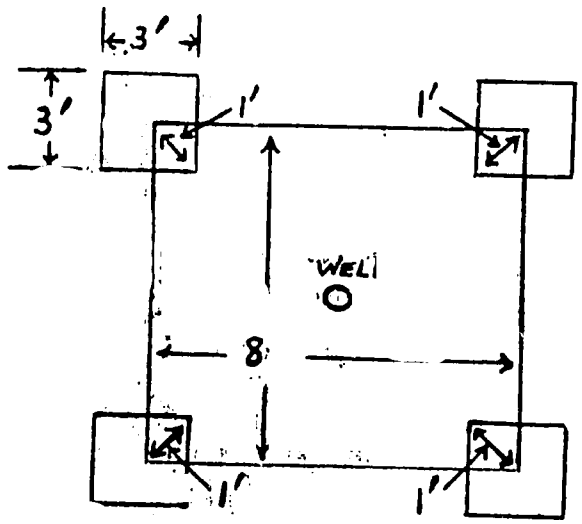
READ ALL INSTRUCTIONS CAREFULLY BEFORE STARTING

Today, the method most commonly used in the erection of a windmill tower is to raise a completely assembled tower by means of a boom truck or tractorized front end loader. The steps to be taken in this procedure are as follows:

ANCHOR POST HOLES:

After the well is drilled, figure the spread of the tower by dividing the height of the tower by 5. (Normally the base spread is 1/5th of the height.) Lay out a square, using the above formula, with the well exactly in the center. Measure in 1 foot from each corner of the square towards the well. Using the 1 foot as a starting point, measure off a 3 feet square at each corner and away from the well. Dig the holes 3 feet square and 4 feet deep.

EXAMPLE: 40 foot tower

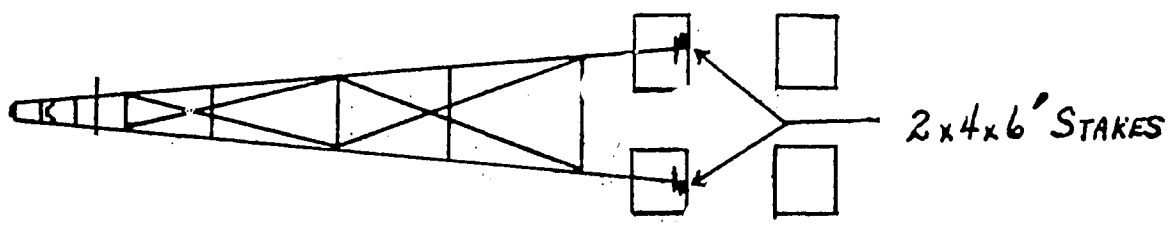



TOWER ASSEMBLY:

Lay out the corner angles in their sequence, that is; the bottom bundle, then the middle bundle, and finally, the top bundle in the order of the numerals on the outer angle of the bundle. The larger numbers begin at bottom towards the anchor post holes. Cut the straps (and/or wires) and remove two (2) angles from each bundle, one being the angle with the ladder holes marked "L". Lay them in a pattern similar to the taper of the tower and bolt them together loosely. At all joints the rising section should overlap the lower section. Bolt the anchor plates (8" square and packaged in with tower bolts) to the lower end of anchor posts. Now bolt the completed anchor posts to the lower end of the tower corner angles. Prior to bolting the turntable onto the two (2) angles, the ball-bearing race should be checked to be sure there is ample grease covering the bearings in it. If, for some reason, the grease has leaked away, it is necessary that grease be added prior to putting up the mill. After the turntable has been checked, then bolt it loosely onto the angles through holes marked "T T" at the top of tower. Now install the truing center loosely into the holes marked "T C". Now, position the bundles of braces (flat steel pieces) so that the end of the bundle marked with the larger numbers lay toward the bottom end (wide end) of the tower. These numerals correspond to the band holes in the corner angles where they are fastened.

Now cut the banding straps, (and/or wire) on the bundle of angle iron bands. Lay them out (4 pieces each length) away from tower so that the number on the band corresponds to the number on the corner angle. All tower angle bands have mitered (slant cut) ends, except the platform angle bands which are straight cut.

Now continue to assemble tower from the truing center down. Bolt Band No. 4 loosely onto the outside of the corner angles at the holes with corresponding numbers. Then bolt the platform angle bands loosely onto the outside of the tower. The long platform angle bands are fastened to opposite sides of the tower. (EXCEPTION: On 25 foot towers, the upper ends of the upper braces are bolted to the inside of the corner angles at the platform angle holes.) Now install the next lower band. If brace is to be installed at this hole, then place brace first and band over it on the inside of the corner angle. Place bolt from inside to outside and fasten loosely. (NOTE: All bands below platform angle bands are fastened to the inside of the corner posts.) Now proceed downward on the tower in the same manner. As braces are installed check to be sure that the tension holes in the braces (holes in the neighborhood of the center of the brace) will register, but do not insert tension bolts at this time. Now position this assembled section so that it is in the place from which it is to be raised. See sketch below.




Prepare two 2 x 4 x 6 feet long stakes and drive them down along the back side of the two holes (as shown in above sketch) so as to anchor them in the bottom of the holes at a point immediately opposite of where the anchor post attaches to the anchor post plates. These stakes will serve as backstops when tower is raised.

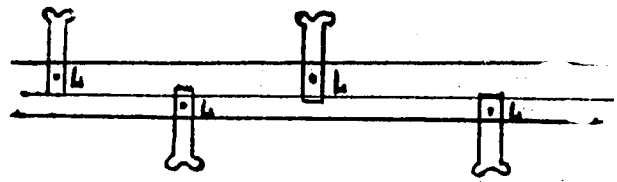
Lay some wooden pieces over the section which you have just assembled and proceed to lay out another section in the same manner; except you should reverse it so that when it is completed you can raise it and begin putting the bands and braces into place.

Now elevate this section at the wide end of tower so that the second lowest band can be installed in the proper holes. When these bands have been installed on both sides, then go to the top end of tower and insert the corner angles of this section into the turntable casting and bolt loosely. Now continue on down the sides to install the bands and braces just as in the previous section. NOTE – If the tower is quite tall it may be necessary to put in an additional band for support.

At this time, lift the small end of tower (top end) so as to place a saw-horse, or blocking, at a point a foot or so below the platform bands. Now the wooden platform can be placed on to the bands and holes drilled in the platform to permit fastening to bands.

Now put the tension bolts through the braces where they cross, or where they cross at the bands. This then puts the tower in tension, and it may be necessary to use a drift pin and vise grip pliers in order to insert the bolts. Next tighten all the bolts in the tower beginning at the top and continue downward to the anchor posts. Also fasten the tower steps to the 1 corner post,

using the holes marked "L" as shown in sketch.




The tower will now have a slight concave appearance through the center section. Tower is now ready for erection.

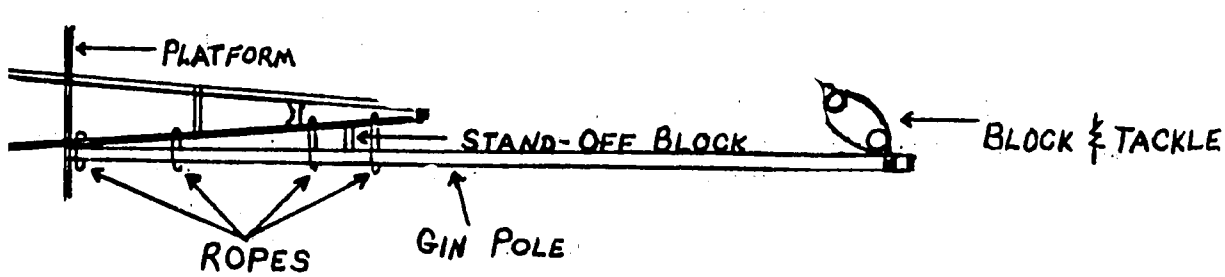
YOU MAY CHOOSE TO ERECT THE TOWER ONLY – OR – TO ERECT THE TOWER WITH THE WINDMILL INSTALLED INTO THE TOWER.

If you choose to erect the tower only – this is the procedure:

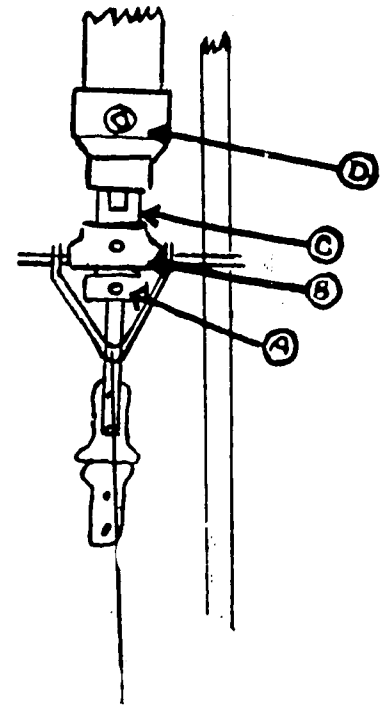
Make sure the anchor post plates are against the 2 x 4 x 6 feet stakes which you have driven into the anchor post holes as backstops. Secure a tow rope (or cable) a few feet below the truing center (make sure it will pull evenly) and run the tow rope back to an elevated bucket of a front end loader, or to the boom of a boom truck. Now attach SNUBBING ropes to each of the corner posts opposite the place where tow rope is attached to the tower. You now raise the tower; and as it rises, two people operating the snubbing ropes, must keep the tower under control. As the tower rises, the anchor posts should slip into the anchor post holes. When tower is erect, place blocks under the lower bands across the holes and get the tower to rest solidly on the blocking. Now a plumb line should be dropped from the center of the hole in the turntable through the truing center, then tower should be shifted to bring the plumb directly over the well (or the center of the tower.) Place a wheel barrow load of concrete, (or as much as is needed) in each anchor hole, making sure to tamp it down completely around the anchor post plates. When the concrete has set up, replace a foot or so of ground and tamp solidly. Repeat this operation until all holes are completely filled. This completes tower erection.

## INSTALL WINDMILL ON ERECTED TOWER

Prepare a gin pole, using a 4" x 4" x 12 feet long wooden pole, and a stand-off block 2" x 4" x 1 foot long. A block and tackle with sufficient rope to permit the tackle to go to the ground is secured to the upper end of the gin pole. Now, the lower end of the pole is set against a corner post at the platform bands. Place the stand-off block at some point to permit gin pole to stand erect. Secure the pole with short pieces of strong rope, as per sketch, and bring tackle to ground level.



## PREPARE WINDMILL ENGINE FOR RAISING




Referring to the sketch remove the collar (A) immediately below the Pull-Out swivel and Ball (B) from the 1 inch pipe sleeve (C). You will find the set screw in this collar which must be released so that the collar can be unscrewed from the sleeve. When the collar is removed, then remove the Pull-Out swivel from the tube and also, the Mast Pipe Cap (D).

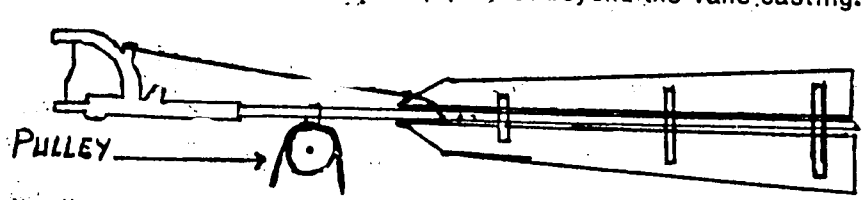
Now remove the vane casting by first removing cable from it and tie cable in such a manner that it will not slip back through the gear box. Now remove pin which holds casting to gear box.

Windmill engine is now ready for raising. Prepare a sling hitch of strong rope or chain through the large holes of the big gears and raise with block and tackle. A guide rope is fastened to the engine so as to keep it off the tower as it is being raised. When engine gets to the top, simply lower the mast pipe through the turn-table and truing center, and now replace the mast pipe guide casting (D) in the same position it was prior to removal, and reinstall the Pull-out swivel casting (B) and the collar (A) as they were.

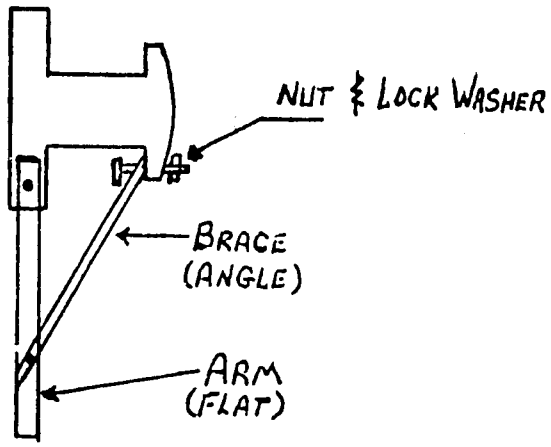
Now assemble the vane casting to the pipe of the vane, making sure that the pipe is completely engaged in the hole of the casting. From the truss rod remove the first nut and turn the other nut onto the rod as far as possible. Then as pipe is being engaged into the vane casting, let the truss rod enter the hole in the projection of the vane casting. When pipe is fully engaged the vane and vane casting should be parallel and the truss rod nut can be replaced on truss rod. This truss rod may have to be adjusted after vane is up, to let vane set level. Then both nuts should be tightened to lock truss rod in position.

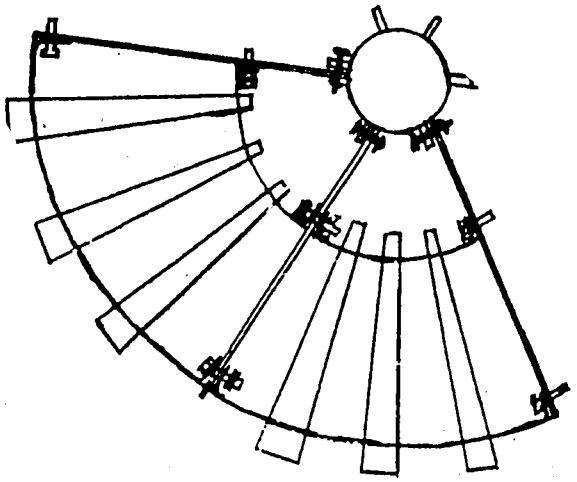
Now raise vane assembly with the block and tackle and reinstall vane casting to gear bowl as it was. Then reinstall cable to the same position from which it was removed. The governor spring is adjustable to provide for various loads of the mill. This adjustment is accomplished by moving the spring in the series of holes provided in the vane pipe. If the load is light (shallow well), the spring should be placed in the hole closet to the mill and as the load increases (deeper wells), it should be moved outward to create more spring tension to keep mill in the wind during higher winds. Now remove the bolt from the long cast projection of the oil bowl and insert the eye of the governor spring. Replace the bolt to hold spring to this projection. The gin pole can be removed from the tower after vane has been put in place.

Secure a single sheeve pulley to the vane pipe just beyond the vane casting. (See sketch)




Raise the bundle of arms (flat iron) and braces (angle iron) and place on platform. Begin assembling these arms and braces to hub as per sketch following.



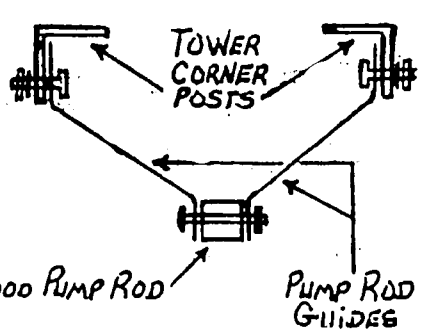
Leave the bolts fairly loose so that they can shift to adjust. When all arms and braces are in place then raise wheel sections and install between arms as shown in sketch above. Be sure that the concave configuration is to the outside, or away from the tower. Secure loosely with bolts and raise another section and set it into the next set of arms. Again, secure loosely and continue this routine until wheel is complete. Now tighten all bolts.

## INSTALLING THE STEEL PUMP ROD

Turn the wheel of the mill until the swivel block is at its highest position, then tie the wheel to the tower so that it cannot turn. Remove the cotter pin, castelate nut and both flat washers from the pump rod. Insert the pump rod up from the bottom through the Pull-Out tube and bring it up into the bowl to a point where one flat washer can be replaced, making sure it goes down to the offset of the rod. Now cut only the wire that provides protection for the bearings in the swivel block and remove same. Push the pump rod up through the bearings in the block and replace second washer and castelated nut. Adjust or tighten nut loosely so that pump rod will turn freely in the bearing. Engage the cotter pin through castelation of nut and spread pin.

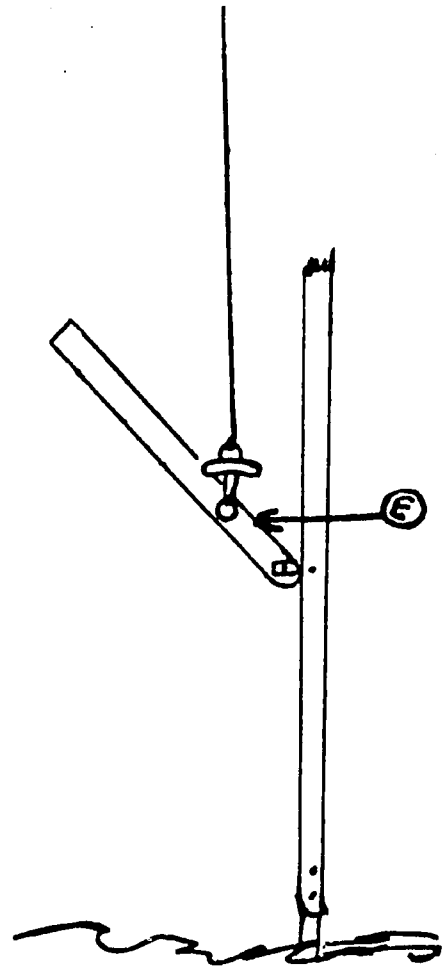
## INSTALLING WOOD PUMP ROD

As a result of installing the steel pump rod, the windmill is in an up position, at the top of the stroke. Now secure one length of wood rod into the casting provided at the lower end of the steel pump rod. Pull sucker rod of pump up as far as it will come and cut a second length of wood-rod 1 inch longer than the distance between sucker-rod coupling and end of upper wood-rod. Now, using the steel splices (one on either side of the wood-rod) couple the wood-rod sections tightly together. Fasten the sucker-rod coupling to the wood-rod. After wood-rod is installed, consult the tower print furnished with your tower and locate the guide holes in the corner posts. Now install the pump rod guides to the pump rods as per sketch



## INSTALLING CANTILEVER LEVER PULL OUT SYSTEM

Mount the cantilever lever (E) at a comfortable position on one of the corner posts with the bracket provided. If no hole is available in the corner post, you may have to drill one for attaching. Secure the pull-out wire (No. 11 galvanized wire supplied with tower) to the bail of the pull-out swivel. Bring wire down to ground level and pull until the vane has swung around parallel with wheel. Bring the loose end of wire through the hole in the casting on the cantilever lever, and while having the lever down and across center, bend wire to make connection at this point. Secure wire to the hole in casting.




To complete installation, put the oil provided into gear box and install hood onto gear box. Now remove the rope which is holding the wheel.

NOTE – It is advisable that a safety belt or a cinch rope be worn by all people working on tower.

If you choose to

ERECT THE TOWER WITH THE WINDMILL INSTALLED INTO THE TOWER

Follow this procedure:

Tower is completely assembled with upper end elevated, setting on a saw-horse or blocking as described above. Now, as described, remove the Pull-out mechanism and the Mast Pipe Cap, then place the windmill into the tower while in the prone position and reinstall the Mast Pipe Cap and Pull-out mechanism. With windmill hub toward the ground assemble the wheel sections thereon as described above. Now install vane into vane casting in the manner similar to that described above. Now secure wheel to the tower with rope so that the mill cannot swing as the tower is being raised.

Follow the procedure as described in the paragraph concerning erection of tower only. We would caution here that to erect the tower and windmill as a unit, it requires a higher lift front-end loader or boom truck since more purchase is required to elevate the heavier unit.

After windmill and tower is erected follow the final steps of procedure as described in the foregoing paragraphs.

NOTE – Lockwashers are included with all nuts and bolts. Be sure to use them, placing them beneath each nut.

TOOLS RECOMMENDED FOR ERECTING TOWER AND WINDMILL

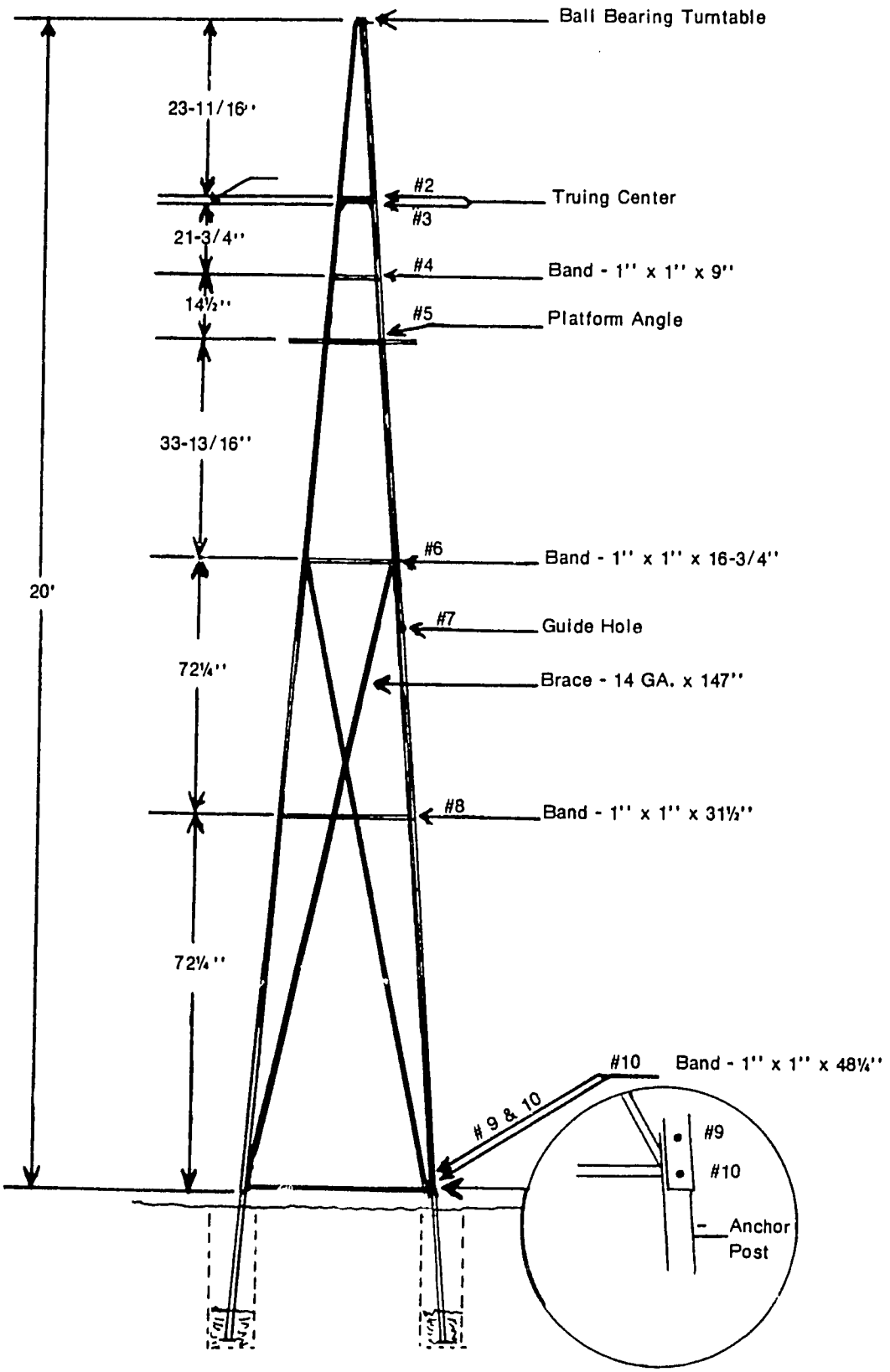
2 - Pairs vise grip pliers
2 - Drift punches
Box and open end wrenches
Crescent wrenches

# THE HELLER – ALLER CO.

Napoleon, Ohio

# 20 Ft. Windmill Tower

Parts and Assembly




ANCHOR POST HOLES - - -

Dig or drill four (4) holes; 18" to 24" dia. x 48" deep, on square-equidistant from the well.

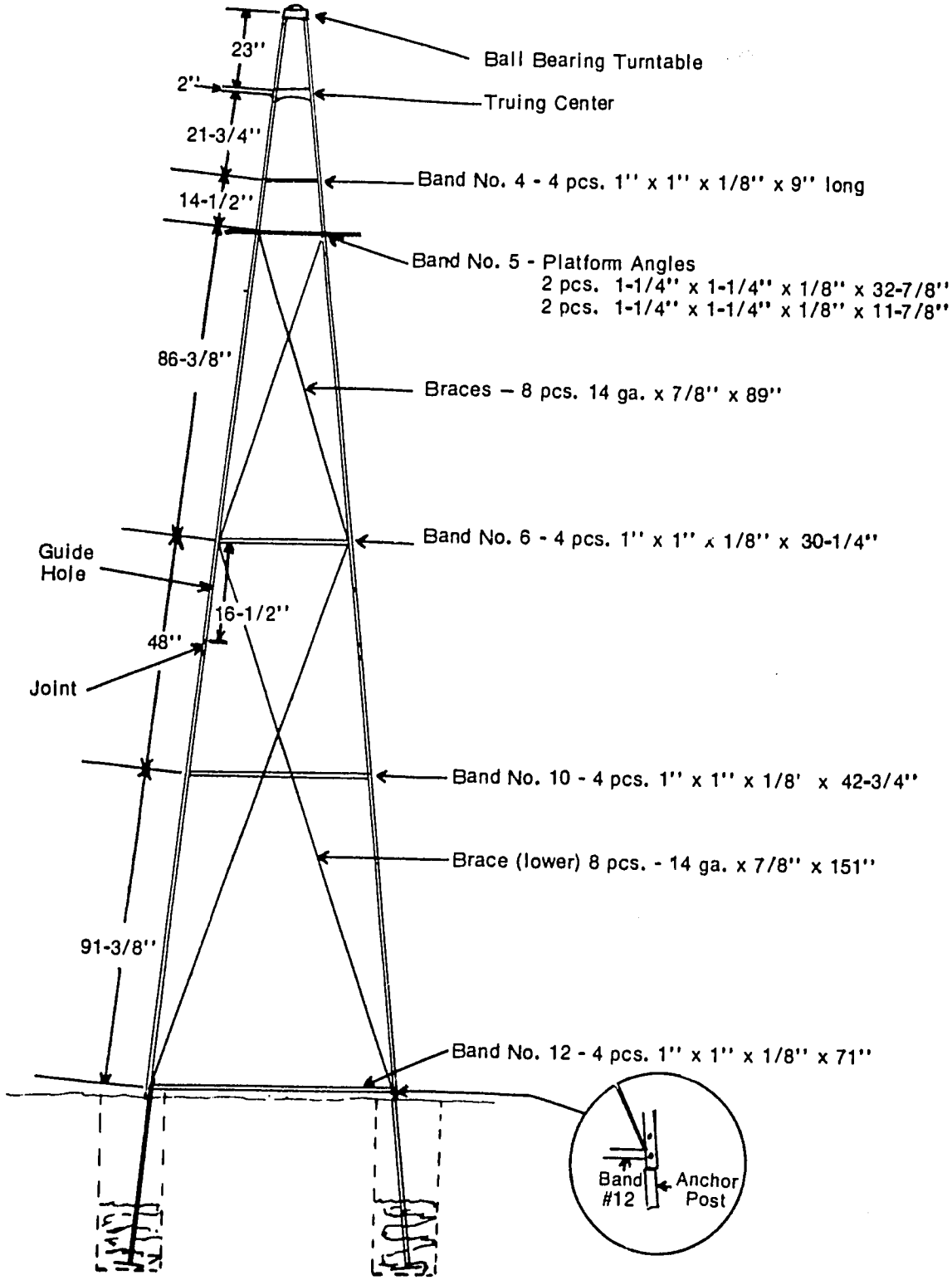
After the tower is assembled; either fully or partially, be sure that it stands plumb and then place concrete into the holes and around the anchor posts to a depth of 18" to 24". Tamp the concrete to be sure that it settles solidly around the post and over the anchor post plate.

# THE HELLER – ALLER CO.

**Napoleon, Ohio**

# 25 Ft. Windmill Tower

**Parts and Assembly**




ANCHOR POST HOLES - - -

Dig or drill four (4) holes; 18" to 24" dia. x 48" deep, on square-equidistant from the well.

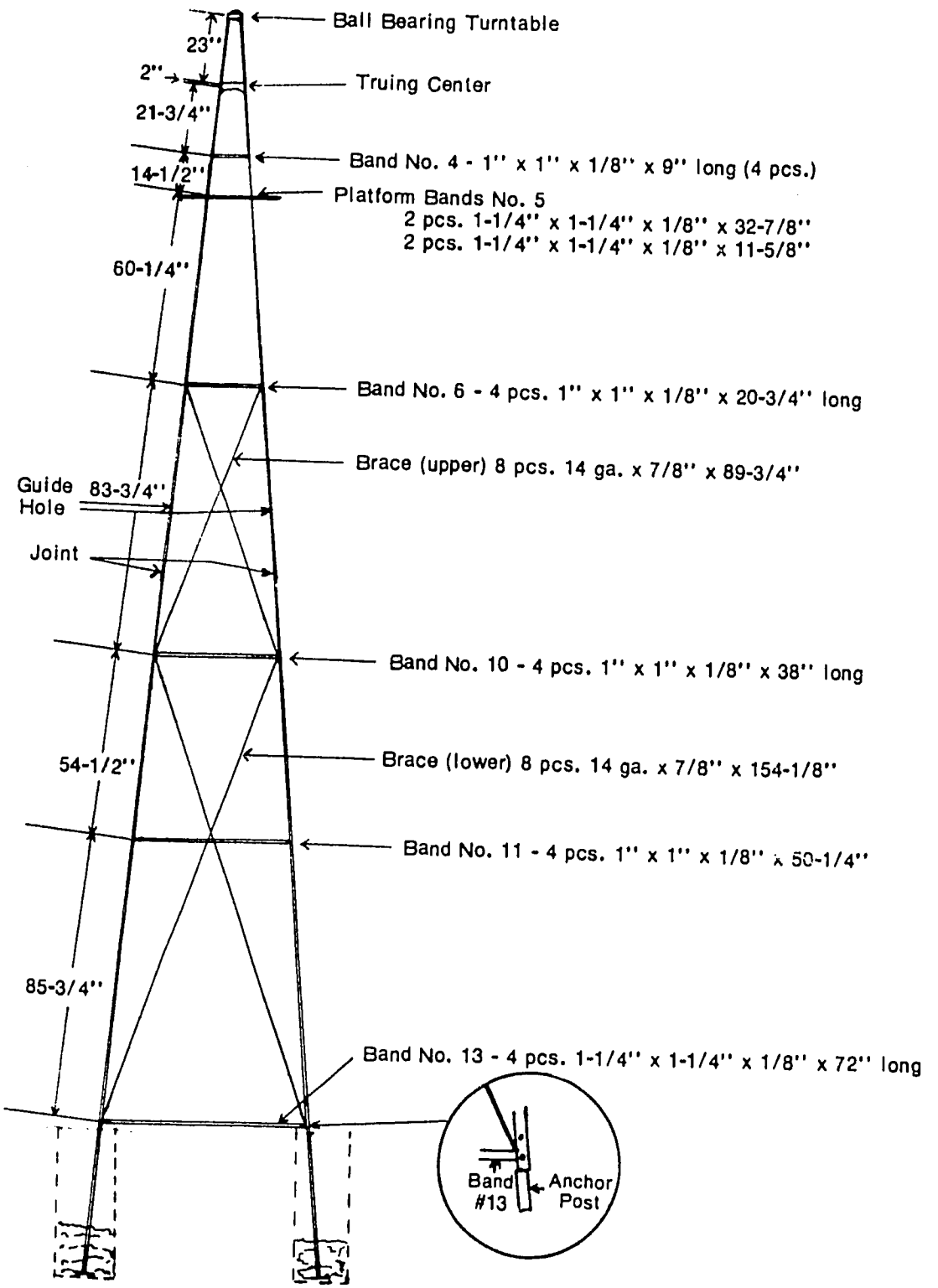
After the tower is assembled; either fully or partially, be sure that it stands plumb and then place concrete into the holes and around the anchor posts to a depth of 18" to 24". Tamp the concrete to be sure that it settles solidly around the post and over the anchor post plate.

# THE HELLER – ALLER CO.

**Napoleon, Ohio**

# 30 Ft. Windmill Tower

**Parts and Assembly**




ANCHOR POST HOLES - - -

Dig or drill four (4) holes; 18" to 24" dia. x 48" deep, on square-equidistant from the well.

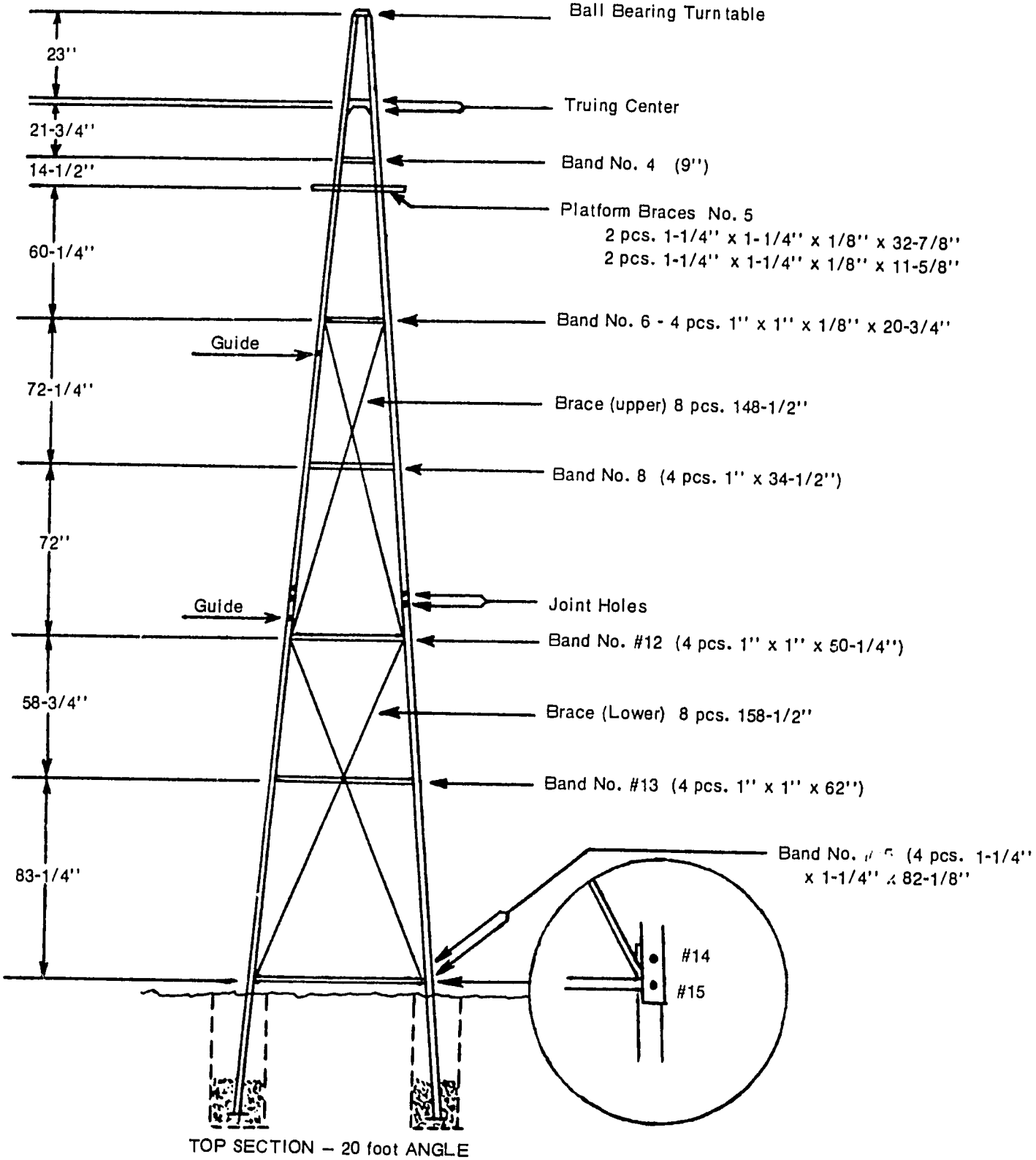
After the tower is assembled; either fully or partially, be sure that it stands plumb and then place concrete into the holes and around the anchor posts to a depth of 18" to 24". Tamp the concrete to be sure that it settles solidly around the post and over the anchor post plate.

# THE HELLER – ALLER CO.

Napoleon, Ohio

# 35 Ft. Windmill Tower

**Parts and Assembly**




TOP SECTION – 20 foot ANGLE
BOTTOM SECTION – 15 foot ANGLE

ANCHOR POST HOLES - - -

Dig or drill four (4) holes; 18" to 24" dia. x 48" deep, on square-equidistant from the well.

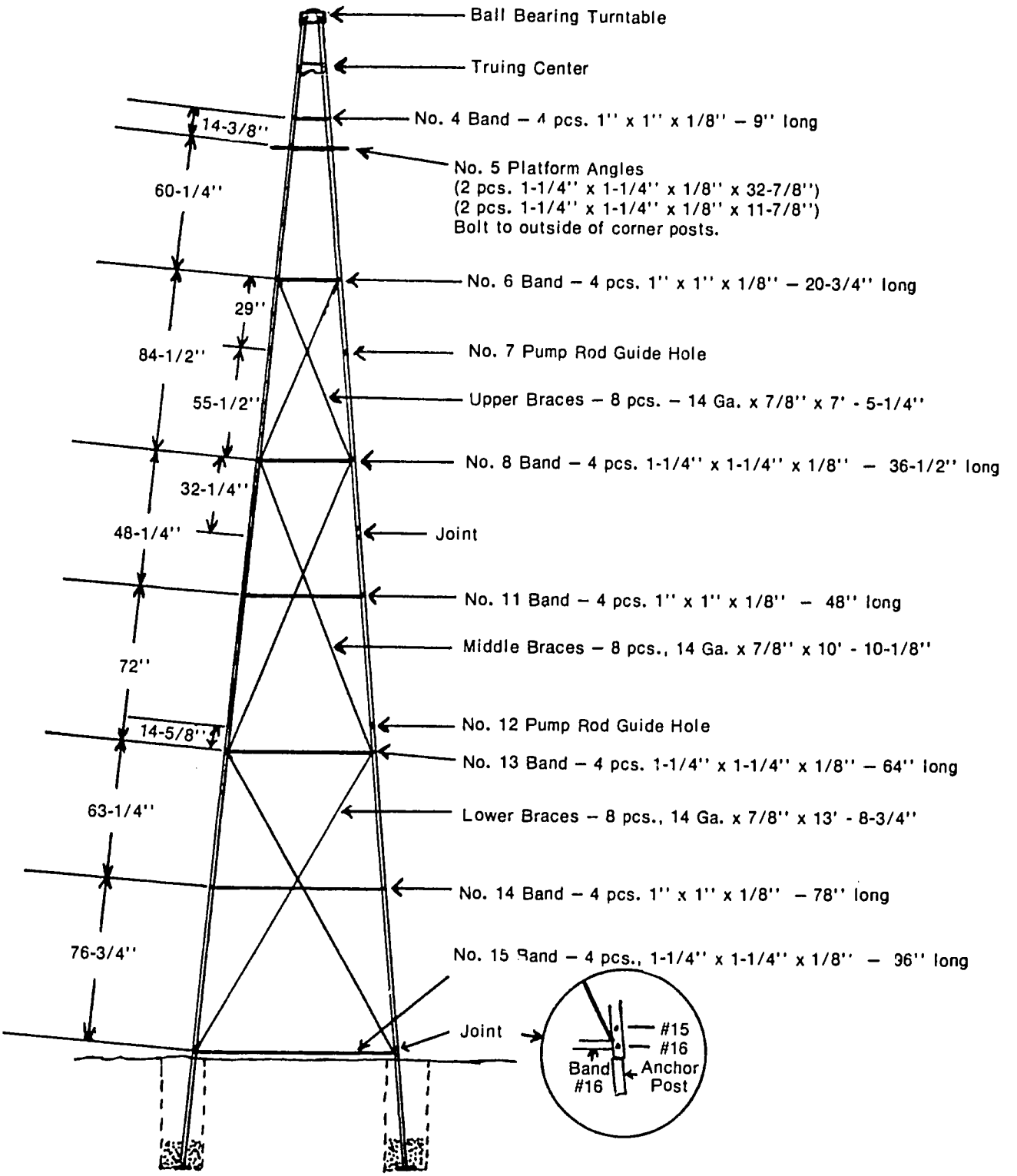
After the tower is assembled; either fully or partially, be sure that it stands plumb and then place concrete into the holes and around the anchor posts to a depth of 18" to 24". Tamp the concrete to be sure that it settles solidly around the post and over the anchor post plate.

# THE HELLER – ALLER CO.

**Napoleon, Ohio**

# 40 Ft. Windmill Tower

**Parts and Assembly**




AHCHOR POST HOLES - - -

Dig or drill four (4) holes; 18" to 24" dia. x 48" deep, on square-equidistant from the well.

After the tower is assembled; either fully or partially, be sure that it stands plumb and then place concrete into the holes and around the anchor posts to a depth of 18" to 24". Tamp the concrete to be sure that it settles solidly around the post and over the anchor post plate.

# Directions for Erecting H-A Towers

Excavate anchor post holes by taking the four bottom bands and placing them on the ground forming square. Measure in from the corners toward the pump 6 inches, then from that point in each direction 3 feet. Dig holes 3 feet square and 4 feet deep.

Lay out the different parts of the tower as follows.

The corner posts first and remember the end of the bundle with the stencil marks is ALWAYS the top end.

Lay out one corner complete with holes punched for corner steps.

After the tower is laid out and before cutting the wire on the flat braces, place the bundle with the stencil marked end toward the foot of tower. This will save turning any of the braces end for end.

Commence at the top to build tower. Build one side complete, then place some pieces across it and build another side on top of it; then go to the foot and raise the top sections the desired height and stay it by putting in the bottom bands. Commencing at top, put on the cap or turntable, then truing center and platform, then side bands and braces, on down to the foot. Then bolt on two upper anchor posts and the steel plates to bottoms of anchor posts.

It is important to remember that the lower holes on the bottom corner posts of the tower also receive the bands and braces.

Do not put in tension bolts where braces cross until everything is finished and tower is raised. It is the placing of these bolts that gives our towers their TENSION and GREAT STRENGTH and makes the BEST tower on the market today.

The bands go inside with braces between bands and corner posts.

The lower ends of lower set of braces on all towers should be bolted to the outside of the corner posts of the tower, and this enables the erector to readily bolt anchor posts, **the bolts that receive the anchor posts also receive the lower ends of lower braces**, by this plan a double thickness is made for braces to pull against, which is a vital point in all proper tower construction.

Bolt a plank of sufficient length (about 8 feet longer than the spread of the tower) to the two lower corner posts. Drive stakes against this plank to keep tower in place while raising. Remove the plank and bolt on the anchor posts.

Fasten a strong rope to the top of tower just above the truing center, using block and tackle.

After tower is raised ten or fifteen feet at the top, hold in position with pike poles. Proceed to raise tower gradually.

It is well to fasten guy ropes to either side of tower so that same may not swerve in raising. When all is in readiness raise tower slowly, by hand as far as possible, then with heavy wood pikes, at the same time using the block and tackle, after same has been raised to the highest point in this manner, all hands should be turned to the block and tackle. Then plumb and square the tower, see that same stands directly over pump, and thoroughly tamp anchor post holes, remove all ropes. The same ropes may then be used in raising the engine and after same has been placed the vane and sections may be readily bolted to engine, adjust wood pump rod to iron pump rod at proper length, see that nuts are tight. Pour Baker Zero oil into oil case.

Some erectors prefer to erect towers from the ground up, in sections, which may be done if desired with assistance. Place the anchor securely in the ground and see that same is **perfectly level**, so the tower will be **plumb**.

Care must be taken to see that tower centers with well, so that well rod will not bind. Bolt on lower set of corner posts, etc., placing plank across corners on bands on which to do the work.

**Note**—On 20 ft. and 55 ft. towers the lower bands and braces should be placed in upper splice hole. All other size towers these are placed in the lower splice holes.

**Important**—When cutting wood pump rod be sure that pump stroke corresponds to the stroke of Wind Engine. Do not allow cylinder plunger to strike upper or lower cylinder cap at stroke extremities. Securely tighten set screw and bolt through Wind Engine wheel hub. When windmill is in gear and pump handle is attached—make certain that handle has full stroke.

# Arrangement of Braces on Different Towers

Twenty-foot towers have only one set of braces and are bolted to the four bands close to where same cross, using eight 7/16 x 3/4-inch bolts.

Twenty-five and thirty-foot towers have two sets of braces. On the lower set the braces are bolted to the four bands close to where the same cross. The upper set of braces do not bolt to bands but are bolted together where they cross, using twelve 7/16 x 3/4-inch bolts.

Thirty-five foot towers have two sets of braces. The lower set of braces are bolted together on the bands where same cross. The upper set of braces are bolted to the four bands close to where the same cross, using twelve 7/16 x 3/4-inch bolts.

Forty-foot towers have three sets of braces. The lower set of braces bolt to band where same cross. The second set of braces bolt same as lower braces, and third or upper set of braces do not bolt to bands but together where same cross, using twelve 7/16 x 3/4-inch bolts.

Forty-five-foot towers have three sets of braces. The lower set of braces are bolted to four bands where same cross, the second and third set bolt to four bands close to where same cross bands, using twenty 7/16 x 3/4-inch bolts.

Fifty-foot towers have four sets of braces. The lower and second set are bolted to bands where same cross, with four 7/16 x 1/2-inch bolts. The third and upper set of braces do not bolt to bands but together, where same cross, using sixteen 7/16 x 3/4-inch bolts.

Sixty-foot towers have five sets of braces all of which are bolted to bands, using forty 7/16 x 3/4-inch bolts.

Recommended Sizes
Standard Steel Pipe

| Flow Gallons per minute | Flow Gallons per hour | Recommended Pipe Size | Flow Liters per Minute | Flow Liters per Hour |
|---|---|---|---|---|
| 1 | 60 | 1/2 inch | 4 | 240 |
| 3 | 180 | 3/4 inch | 11 | 660 |
| 5.5 | 330 | 1 inch | 21 | 1260 |
| 10 | 600 | 1 1/4 inch | 38 | 2280 |
| 16 | 960 | 1 1/2 inch | 61 | 3660 |
| 32 | 1920 | 2 inch | 122 | 7320 |

Recommended Sizes
Plastic Pipe

| Flow Gallons per minute | Flow Gallons per hour | Recommended Pipe Size | Flow Liters per Minute | Flow Liters per Hour |
|---|---|---|---|---|
| 1.5 | 90 | 1/2 inch | 6 | 360 |
| 4.5 | 270 | 3/4 inch | 17 | 1020 |
| 8 | 480 | 1 inch | 30 | 1800 |
| 15 | 900 | 1 1/4 inch | 57 | 3420 |
| 24 | 1440 | 1 1/2 inch | 91 | 5460 |
| 48 | 2880 | 2 inch | 182 | 10920 |

Note -- these sizes will give fairly low flow speed, which is desirable because it keeps friction losses small. Friction loss in all cases is about 5% of the length of the pipe. This is the same as having to pump 5 feet (or meters) higher for every 100 feet (or meters) of pipe in the system.

## Aermotor Pumping Capacity

| Diameter of cylinder (inches) | Area of cylinder (Square inches) | Gallons per hour with 15 miles per hour wind | | Total Elevation in feet — Size of Windmill | | | |
|---|---|---|---|---|---|---|---|
| | | 6 foot mills | 8-16 foot mills | 6 foot 28 sq/ft | 8 foot 50 sq/ft | 12 foot 113 sq/ft | 16 foot 201 sq/ft |
| 1.75 | 2.40 | 105 | 150 | 130 | 185 | 420 | 1000 |
| 2.00 | 3.14 | 130 | 190 | 95 | 140 | 320 | 750 |
| 2.5 | 4.91 | 225 | 325 | 65 | 94 | 210 | 490 |
| 3 | 7.07 | 320 | 470 | 47 | 68 | 155 | 360 |
| 4 | 12.56 | 570 | 830 | 27 | 39 | 86 | 200 |
| 5 | 19.62 | 900 | 1300 | 17 | 25 | 55 | 130 |
| 6 | 28.26 | Too big | 1875 | Too big | 17 | 38 | 85 |
| 8 | 50.24 | Too big | 3300 | Too big | Too big | 22 | 50 |

Note--Pumping ability decreases about 3% for every additional 1000 feet (300 meters) above sea level

| Diameter of cylinder (cm) | Area of cylinder (square cm) | Liters per hour with 24 kilom. per hour wind | | Total Elevation in meters — Size of Windmill | | | |
|---|---|---|---|---|---|---|---|
| | | 1.8 meter wind-mills | 2.4-4.8 meter wind-mills | 1.8 meter 2.54 sq/met | 2.4 meter 4.52 sq/met | 3.6 meter 10.17 sq/met | 4.8 meter 18.09 sq/met |
| 4.45 | 15.51 | 399 | 570 | 40 | 56 | 128 | 305 |
| 5.08 | 20.26 | 494 | 722 | 29 | 43 | 98 | 229 |
| 6.35 | 31.65 | 855 | 1235 | 20 | 29 | 64 | 149 |
| 7.62 | 45.58 | 1216 | 1786 | 14 | 21 | 47 | 110 |
| 10.16 | 81.03 | 2166 | 3154 | 8 | 12 | 26 | 61 |
| 12.70 | 126.61 | 3420 | 4940 | 5 | 8 | 17 | 40 |
| 15.24 | 182.32 | Too big | 7125 | Too big | 5 | 12 | 26 |
| 20.32 | 324.13 | Too big | 12540 | Too big | Too big | 7 | 15 |

wind profiles will vary from pass to pass, wind measurements are recommended before a final decision on WECS placement is made.

Passes to avoid are those not open to the prevailing wind (because there will be much less flow through them) and passes, or portions of passes, which are extremely narrow and canyon-like (because these may have turbulence and strong horizontal wind shear).

## 4.3 Ecological Indicators of Site Suitability

Vegetation deformed by high average winds can be used both to estimate the average speed (thus power) and to compare candidate sites. This technique works best in three regions: 1) along coasts, 2) in river valleys and gorges exhibiting strong channeling of the wind, and 3) in mountainous terrain. Ecological indicators are especially useful in remote mountainous terrain not only because there are little wind data, but also because the winds are often highly variable over small areas and difficult to characterize. The most easily observed deformities of trees (illustrated in Figure 33) are listed and defined below:

- **Brushing** - Branches and twigs bend downwind like the hair of a pelt that has been brushed in one direction only. This deformity can be observed in deciduous trees after their leaves have fallen. It is the most sensitive indicator of light winds.

- **Flagging** - Branches stream downwind, and the upwind branches are short or have been stripped away.

- **Throwing** - A tree is wind thrown when the main trunk and the branches bend away from the prevailing wind.

- **Carpeting** - This deformity occurs because the winds are so strong that every twig reaching more than several inches above the ground is killed, allowing the carpet to extend far downwind.

Figure 33 is one of the best guides to ranking tree deformities by wind speed. Both a top view and a side view of the tree are shown to demonstrate the brushing of individual twigs and branches and the shape of the tree trunk and crown. The figure uses the Griggs-Putnam classification of tree deformities described by indices from 0 to VII. When WECS sites are ranked by this scheme, only like species of trees should be compared, because different types of trees may not be deformed to the same degree.

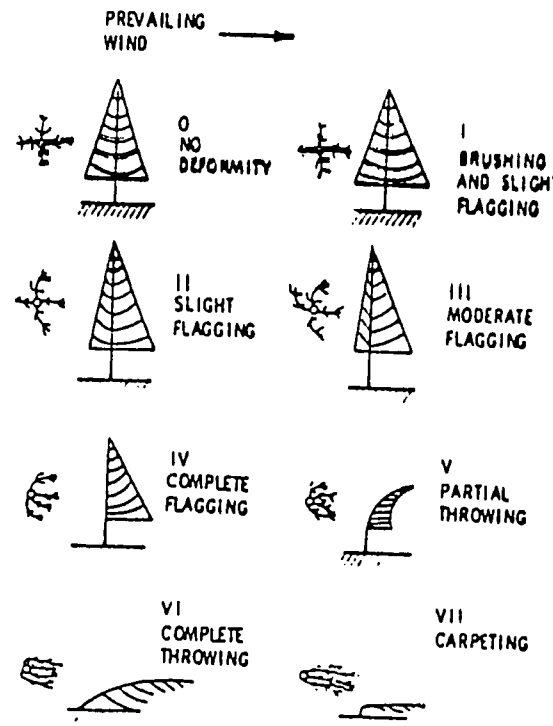



FIGURE 33. Wind Speed Rating Scale Based on the Shape of the Crown and Degree Twigs, Branches, and Trunk are Bent (Griggs-Putnam Index; Hewson, Wade and Baker, 1977)

Another good indicator of relative wind speeds is the deformation ratio (Hewson, Wade and Baker, 1977). It also measures how much the tree crown has been flagged and thrown. Figure 34 shows the tree angles, A, B, and C, that must be measured to compute the deformation ratio "D". To measure these angles, the trees can either be photographed or sketched to scale. (The user might sketch the tree on clear acetate while he looks at it through the acetate.) He should draw or take the tree pictures while viewing the tree perpendicular to the prevailing wind direction so that he can see the full effects of flagging and throwing.

To compute D, the three angles shown in the figure (A on the downwind side, B on the upwind side and C, the angle of deflection) should be measured in degrees using a protractor. The larger the value of D, the stronger the average wind speed.



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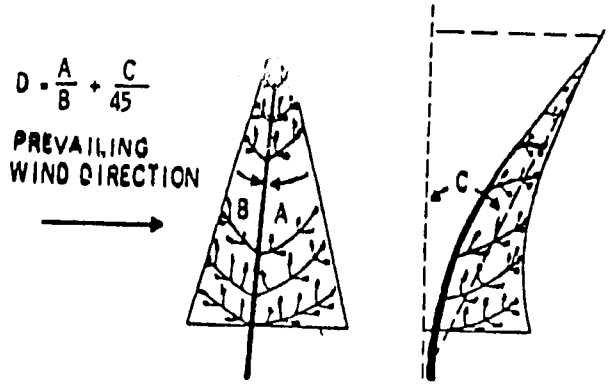


**FIGURE 34.** Deformation Ratio Computed as a Measure of the Degree of Flagging and Throwing (Hewson, Wade and Baker, 1977)

Mean annual wind speed is correlated with the Griggs-Putnam Index (Figure 33) in Table 8, and with the deformation ratio (Figure 34) in Table 9. These reflect only preliminary research results based on studies of two species of conifers, the Douglas Fir and the Ponderosa Pine. Further studies are examining these and other tree species to improve predictions of mean annual winds with ecological indicators. However, these tables do agree well with similar research conducted by Griggs and Putnam on Balsam and Fir trees in the Northeast (Frost and Nowak, 1977).

Estimates of mean annual wind speed using vegetation can be improved if several trees in a siting area are sampled, using the Griggs-Putnam Index and the deformation ratio. The results of all the sampling should then be averaged. However, ecological indicators should be used primarily to identify possible high wind areas, to locate candidate sites, and to estimate roughly the annual average wind speed. Selection of a WECS should not be based solely on ecological indicators. WECS economics and performance analysis should include either a wind measurement program or available wind data in addition to ecological indicators.

Though the presence of one type of deformity (or a combination) may indicate an area of high average winds and the degree of deformity may give estimates of the relative strengths of the winds, there are still pitfalls to rating sites according to tree deformity. Because past or present growing conditions can greatly affect the size and shape of trees, only isolated trees appearing to have grown under similar conditions should be compared. For example, a tree in or near a dense stand of timber should not be compared to an isolated tree. In addition, trees being compared should be of nearly the same height (preferably 30 ft or more). Another fact to be aware of is: limbs are stripped from trees not only by strong flagging. They can be damaged by man, disease, other trees that once grew nearby, or possibly ice storms. Misinterpreting such signs could lead to the wrong assumptions about the prevailing wind direction and the average speed. Common sense, however, should reveal whether or not all the deformities observed in an area fit together into a consistent pattern.

**TABLE 8.** Mean Annual Wind Speed Versus the Griggs-Putnam Index[a]

| Griggs-Putnam Index (as in Figure 33) | I | II | III | IV | V | VI |
|---|---|---|---|---|---|---|
| Probable Mean Annual Wind Speed Range (mph) | 7-9 | 9-11 | 11-13 | 13-16 | 15-18 | 16-21 |

**TABLE 9.** Mean Annual Wind Speed Versus the Deformation Ratio[a]

| Deformation Ratio (as in Figure 34) | I | II | III | IV | V | VI |
|---|---|---|---|---|---|---|
| Probable Mean Annual Wind Speed Range (mph) | 5-9 | 8-11 | 10-13 | 12-16 | 14-18 | 15-21 |

[a]These data were prepared by E. W. Hewson, J. E. Wade, and R. W. Baker of Oregon State University.

The following guidelines summarize this section and suggest how to use ecological indicators effectively:

1. detect ecological indicators of strong wind;
2. compare isolated trees of the same species and height within the strong wind areas to select candidate sites;
3. consider flow patterns over barriers, terrain features, and surface roughness in the final selection;
4. measure the wind in complex terrain to ensure that a suitable site is selected; and
5. base selection of a particular WECS and any detailed estimation of its power output on wind measurements, not on ecological indicators alone.

Supplement to Erection Booklet

## MILL MAINTENANCE

This Heller-Aller "BAKER" windmill engine is a fine piece of machinery. It is made of quality material, the best grades of cast gray iron, and the use of cold-rolled steel for all shafting and pins.

The use of cold-rolled shafting in a gray iron bearing is probably the best trouble-free type of bearing for slow speed operation, such as the mill, and when lubrication of the bearing surfaces is properly maintained.

The graphitic content of iron, plus the adequate lubrication, tends to bring about a mirror finish which gives very long life. It is necessary, therefore, that the lubricant be there to make this fine bearing surface.

Accordingly, the Company recommends that the oil in the bowl of the windmill be changed at least once a year with a good grade of low temperature oil.

It is our suggestion that this be done in the fall of the year, prior to the winter months, because we wish to have all moisture... or water... removed from the bowl.

Water in the oil can accumulate as a result of changing temperatures on the humid air, which has a tendency to drive the water from the air, and because of the total enclosure, the water is then dispersed into the oil.

It has been known that, in some instances, where the mill was neglected, sufficient water had gathered in the bowl to freeze and cause breakage of the bowl. It is for this reason that we recommend that the lubricant be removed from the windmill bowl in the fall of the year, and the user should be sure that all the liquid content is removed.

When the mill is being serviced, the user may find that the oil in the oil bowl has become laden with a thick sludge, usually resulting from the use of a lower quality of oil. If the user finds the situation to be thus, then we would suggest that after he has removed the drain plug and drained out most of the material in the bowl, he use some gasoline or coal oil, and rinse off all the operating parts so that the sludge that may hang on, will be removed.

This sludge, if not removed regularly, can move through the bearing and into the return oil slot, and cause the damming of this return oil slot. When this happens, the oil cannot travel freely through the bearing, and it is possible that the bearing would begin to wear.

It is for this reason that we caution, that if sludge is present in the bowl when the mill is serviced, something be done in the way of rinsing all of it free and flushing it from the bowl before refilling with new oil.

THE PULL OUT CABLE SHOULD BE INSPECTED AT LEAST TWICE A YEAR AND IF THE CABLE STRANDS ARE FOUND TO BE FRAYING, THE CABLE SHOULD BE REPLACED.

## The Beaufort Scale of Wind Speeds

| Beau-fort Number | Description | Miles /hour | Kilom. /hour | Effect |
|---|---|---|---|---|
| 0 | Calm | 0 | 0 | Still: smoke rises vertically |
| 1 | Light air | 1-3 | 1-5 | Smoke drifts |
| 2 | Light breeze | 4-7 | 6-11 | Wind felt on face, leaves rustle |
| 3 | Gentle breeze | 8-12 | 12-19 | Leaves and small twigs move constantly, streamer extended |
| 4 | Moderate breeze | 13-18 | 20-29 | Raises dust and papers, moves twigs and thin branches |
| 5 | Fresh breeze | 19-24 | 30-38 | Small trees in leaf begin to sway |
| 6 | Strong wind | 25-31 | 39-50 | Large branches move, over head wires whistle, umbrel las hard to control |
| 7 | Moderate gale | 32-38 | 51-61 | Whole trees move, offers some resistance to walker |
| 8 | Fresh gale | 39-46 | 62-74 | Twigs break off trees, hard to walk |
| 9 | Strong gale | 47-54 | 75-86 | Blows off roof shingles |
| 10 | Whole gale | 55-63 | 87-100 | Trees uprooted, much stru( tural damage |
| 11 | Storm | 64-72 | 101-115 | Widespread damage (rare inland) |

Bibliography

Appropriate Technology Sourcebook Two volumes
by Ken Darrow and Rick Pam $4.00/volume
Available from: Appropriate Technology Project
Volunteers in Asia
Box 4543
Stanford, CA

An excellent book on where to find information. It reviews hundreds of books and papers on all aspects of appropriate technology.

How to Build a 'Cretan Sail' Windpump
by R. D. Mann
Intermediate Technology Publications Ltd.
9 King Street
London WC2E 8HN
U. K.

A how-to book about the author's experiences in building metal windmills in Africa.

Proceedings of the Meeting of the Expert Working Group on the Use of Solar and Wind Energy
Energy Resources Development Series, Number 16
United Nations. Sales number E.76.II.F.13

Fairly technical, with an interesting section on historical pump types.

Pumps and Water Lifters for Rural Development
by A. D. Wood, J. F. Ruff and E. V. Richardson
Colorado State University CER76-77ADW-JFR-EVR61
Fort Collins, Colorado
USA

An excellent resource on low-cost, locally built pumping mechanisms of all types, including animal powered pumps.

Windmills & Watermills
by John Reynolds $17.50
Praeger Publishers, Inc.
111 Fourth Avenue
New York, New York 10003

Many photos and line drawings show the internal workings of many historical mills. A marvelous book.

# APPENDIX H

Part of the UNDP/World Bank Interim Report on Laboratory Tests of Hand-Operated Water Pumps for Use in Developing Countries

Harpenden Rise Laboratory
Harpenden Rise
Harpenden
Hertfordshire
AL5 3BJ
England

Tel: 05827-64411
Telex: 826619 CALAB G

The Control Tower
Gosfield Airfield
Gosfield
Halstead
Essex CO9 1SA
England

Tel: 07874-72688

CA TESTING AND RESEARCH

1981-1990

# INTERIM REPORT A9940/2

# LABORATORY TESTS ON HAND-OPERATED WATER PUMPS FOR USE IN DEVELOPING COUNTRIES

FEBRUARY 1982

This interim report contains results of Laboratory tests carried out on 12 hand pumps for the World Bank. Various recommendations have been made for improvements in performance, safety and durability. These recommendations will be strengthened when the final results of the 200 day endurance test have been completed and analysed. A final report will be issued in November, 1982.

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Testing & Research Conference

In 1979 an International Conference on Testing and Evaluation of Handpump was run jointly by the International Reference Centre and CA Testing & Research in Harpenden, to which delegates from Developing Countries, aid organisations and the World Bank were invited.

With the impending start of the International Decade of Drinking Water & Sanitation, the World Bank considered that pump evaluation should be continued, but with the inclusion of more samples from manufacturers in Developing Countries. Results could then be sent back to manufacturers to help them identify and remove weak points of design and of manufacturing techniques so that improved and more reliable pumps could be produced.

World Bank/UNDP Sponsored Laboratory Testing

In 1980 the World Bank contracted CA Testing & Research to carry out a further series of tests on handpumps and with the experience from the ODA testing programme a new pump-testing tower was built at their Gosfield Laboratory site in Essex, UK. Following discussions between the World Bank, UNICEF, IRC and other aid organisations, 12 brands of deep and shallow-well pumps were selected for testing.

| | | |
|---|---|---|
| Korat 608 A1 (deep-well) | - | Thailand |
| Bandung (shallow-well) | - | Indonesia |
| Briau Nepta (deep-well) | - | France |
| Nira AF-76 (deep-well) | - | Finland |
| New No. 6 (shallow-well) | - | Bangladesh |
| Moyno IV 2b (deep-well) | - | USA |
| Kawamoto Dragon No. 2 (shallow-well with deep-well conversion and tested in this form) | - | Japan |
| IDRC Ethiopia Type BP (shallow well) | - | Ethiopia |
| VEW (deep-well) | - | Austria |
| AID/Battelle (deep-well) | - | Indonesia |
| Atlas Copco (deep-well) | - | Kenya |
| Jet-matic (deep-well) | - | Philippines |

Other pumps have since been nominated for testing: Volanta - The Netherlands, Abi-Vergnet - Ivory Coast, New Petro Pump - Sweden, modified AID/Battelle - Plastic deep-well pump - Malawi. It is hoped that a sixth will be identified so that the next batch of pumps can be started early in 1982.

## INTRODUCTION

### History

In 1977 the Overseas Development Administration of the UK Government were anxious to respond to growing criticism of field failures of handpumps which had been provided as aid to Developing Countries. They also wanted to obtain better "value for money" in their purchases of handpumps. CA Testing & Research Laboratories were approached for assistance since they were an independent organisation with many years of practical experience in comparative testing and product assessment. CATR devised a comprehensive and long-term testing programme for hand- and foot-operated pumps, using novel testing techniques and obtained a great deal of information which had not previously been available to institutional buyers. The ODA also required the technical data on performance, manufacturing quality, engineering design assessment, ergonomic and user information, abuse and endurance tests to be sent to the manufacturers of the pumps to assist them in improving the quality and reliability of their products.

### Pumps Selected for ODA Test

The products tested were all deep-well models and were a mixture of traditional and newer designs of both hand- and foot-operated types. The selection was made from 8 countries as the following list indicates:

| | | |
|---|---|---|
| Petropump Type 95 | - | Sweden |
| Vergnet Type AC2 (foot-operated) | - | France |
| Dempster 23F | - | USA |
| Mono ES30 | - | UK |
| Climax | - | UK |
| Godwin W1H 51 | - | UK |
| Abi Type M | - | Africa |
| GSW (Beatty) 1205 | - | Canada |
| Monarch P3 | - | Canada |
| Kangaroo (foot-operated) | - | Africa |
| India Mk II | - | India |
| Consallen LD5 | - | UK |

Laboratory evaluation of handpumps under properly controlled conditions is cheaper and quicker to carry out than field trials which, by their very nature are likely to be far less controlled. Engineering assessments can indicate potential areas of weakness and provide manufacturers with early warning of failure, and endurance tests can telescope 3 years of field use into a 6 month period. However, field trials are indispensable for providing wide-scale information on real-use situations to compare with the laboratory results. Hopefully the initial laboratory testing will have filtered out the most unsuitable pumps and will have already stimulated manufacturers to make changes based on the initial laboratory assessments.

## SUMMARY OF TERMS of REFERENCE

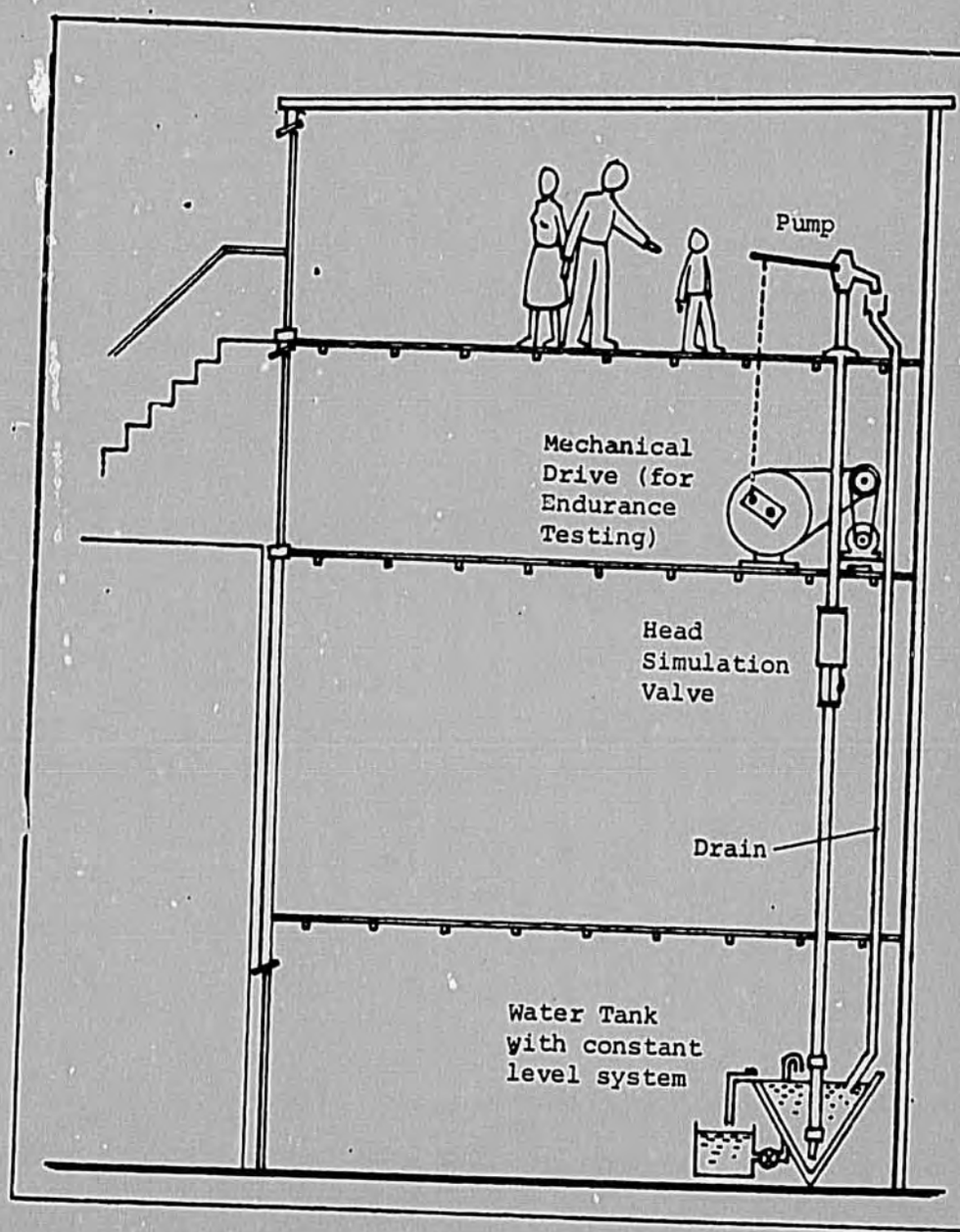
1. Initial inspection
   - packaging
   - literature
   - pumps
2. Construction and Installation
   - technical drawings
   - photographs
   - tabulation of components
3. Engineering/Design Assessment
   - materials
   - manufacturing processes and skills
   - ease of maintenance and repair
   - resistance to contamination and abuse
   - potential safety hazards
   - suggested design improvements
4. Ergonomics
   - handle heights
   - mechanical advantage of handle
   - angular movement of handle
   - exit water pattern
5. User Tests
   - 10 groups of men, women and children of varying heights and weights
6. Performance tests
   - leakage
   - volume flow, work input and efficiency
7. Endurance tests
   - 4 stages of 1000 hours each, using 4 different and increasingly severe qualities of water
   - dismantling and inspection
8. Abuse tests
   - simulation of impact loads
9. Review
   - ease of pump installation
   - ease of maintenance and repair

INSTALLATION for TESTING

The pumps have been installed on the top floor of a purpose-built 10 m tower. They are arranged in two batches of six, with a motor and ta for each batch. For clarity, the illustration below shows only one pump, motor and tank

The floor beneath the pumps houses the mechanical drive which will be for the forthcoming endurance tests. Beneath that, each pump is fitt with an adjustable valve designed to simulate well depths down to 45 metres.

The level of water in the tank on the ground floor is maintained by a pump and constant level device.



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BATCH 1 PUMPS
**********

| CODE | MANUFACTURER | MODEL | DEEP OR SHALLOW WELL | FREE DISCHARGE OR DELIVERY LIFT | COUNTRY OF ORIGIN |
|---|---|---|---|---|---|
| A | Saha Kolkarn | Korat 608 608 A-1 | Deep | Delivery Lift | Thailand |
| C | Robbins and Myers | Moyno IV 2.6 | Deep | Delivery Lift | U.S.A. |
| D | Briau SA | Nepta | Deep | Free discharge | France |
| F | UNICEF | New No. 6 | Shallow | Free discharge | Bangladesh |
| G | Vammalan Konepaja Oy | Nira AF-76 | Deep | Free discharge | Finland |
| L | UNICEF | Bandung | Shallow | Free discharge | Indonesia |

BATCH 2 PUMPS
**********

| CODE | MANUFACTURER | MODEL | DEEP OR SHALLOW WELL | FREE DISCHARGE OR DELIVERY LIFT | COUNTRY OF ORIGIN |
|---|---|---|---|---|---|
| B | Kawamoto | Dragon No. 2 (D) | Deep | Delivery Lift | Japan |
| E | Atlas Copco | Kenya | Deep | Free Discharge | Kenya |
| H | IDRC Ethiopia | type BP | Shallow | Free Discharge | Ethiopia |
| J | Vereinigte Edelstahlwerke | A18 | Deep | Free Discharge | Austria |
| K | Sea Commercial Co. | Jetmatic | Deep | Delivery Lift | Philippines |
| M | [3] | AID/ Battelle | Deep | Free Discharge | Indonesia |

For your convenience this table is duplicated in the last page to be unfolded while reading the report.



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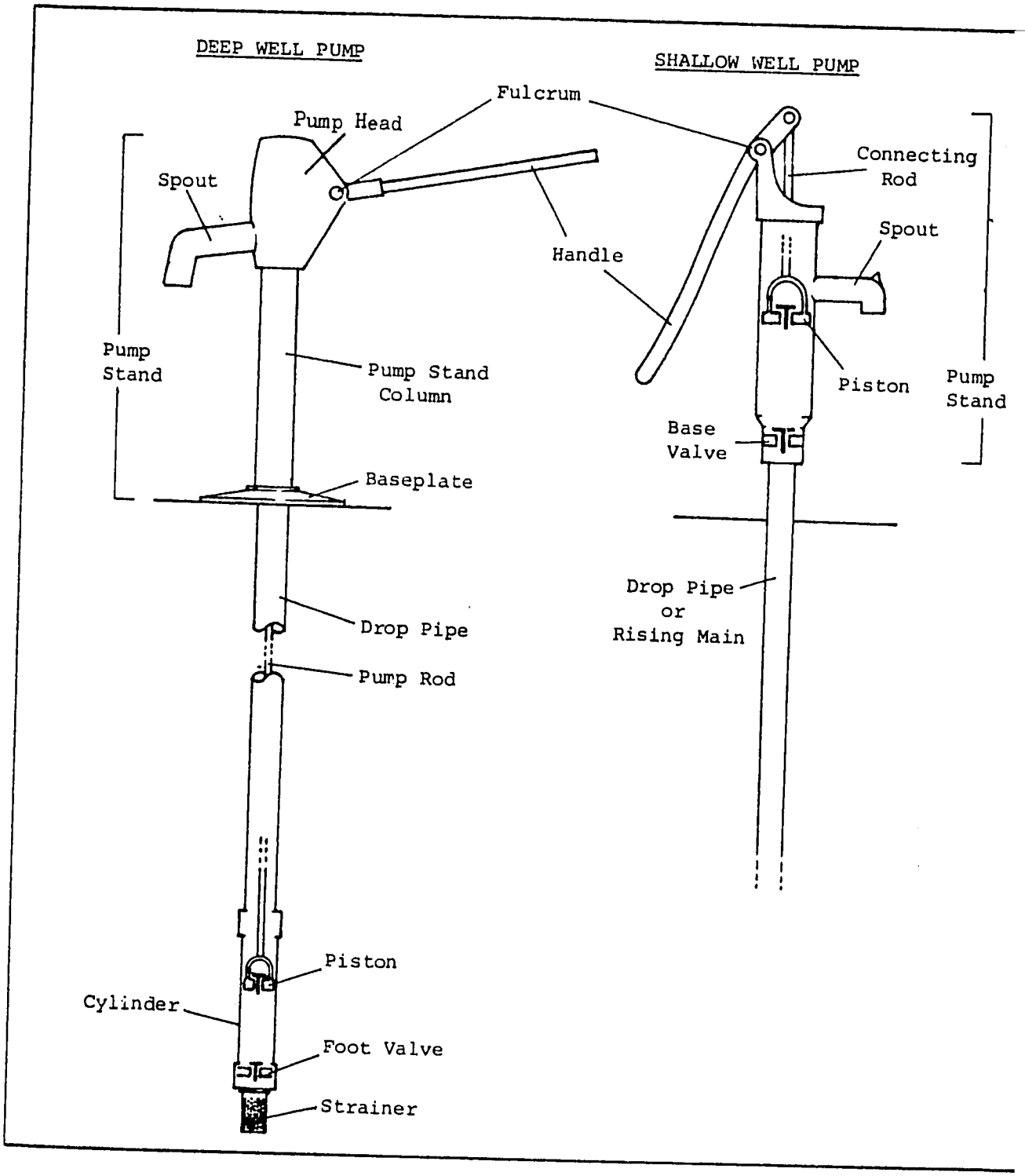
BASIC PUMP NOMENCLATURE



# APPENDIX I

## Installation/Operating Instructions for Natural Power, Inc. Wind Instruments

May 15, 1979

Compilator I., II, & III

**Instructions for Clearing Bins**

To simultaneously clear all bins when using a Compilator I simply pull out and throw the ERASE switch up to the erase position. This action also blanks the display as a reminder that the unit is in the erase mode.

When using a Compilator II or III only the bins in the selected channel will be erased. Simply advance the channel selector switch through the remaining channels to complete the clearing operation. As above, the displays will be blanked while in the erase mode.

The Compilator will resume data collection when the erase switch is thrown down to the OFF position or the channel selection switch is advanced to erase another channel.



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WIND DATA COMPILATOR - I

OPERATING MANUAL

The NPI Wind Data Compilator is uniquely suited to provide accurate and comprehensive site surveys for wind energy conversion systems. It separates the wind speed into thirty-two discrete increments and measures and stores the number of seconds the wind speed is in each category.

The stored information is read our on command by means of front panel digital displays. Once the data has been extracted and recorded, the memory can be erased and fresh data accumulated. From the stored data one may easily prepare a wind speed/frequency distribution curve.

ELECTRICAL SPECIFICATIONS

| | |
|---|---|
| INPUT POWER | 105 - 127 VAC, 60 Hz, 5W<br>Three-prong line cord<br>or<br>8.5 - 14.5 VDC<br>Input to screw terminals at 40 ma in accumulate mode, 150 ma in display mode. |
| INPUT DEVICE | 4-pole cup-type anemometer<br>(2mph resolution)<br>or<br>Other models on special order (Option 01) |
| DISPLAY | Eight-digit LED display<br>Two-digit LED channel number |
| CONTROLS | ON/OFF, DISPLAY, ERASE, CHANNEL ADVANCE, CHANNEL WIDTH<br>(Normal supplied set for 2 mph steps with 4-pole anemometer) |

| | |
|---|---|
| TEMPERATURE | 0 to 70°C<br>-20 to 85°C extended (Option 02) |
| STORAGE CAPACITY | Three years/channel |

GENERAL DESCRIPTION

The ac input signal from the anemometer generator first passes through a lightning protector. It is then amplified and "squared" by means of a Schmitt trigger. These input pulses are counted for a period of 850 ms. This count is the address of one of the thirty-two storage channels: Any count which exceeds the selected maximum speed for Channel 30 is stored in Channel 31, which is the spillover channel.

During the next 150 ms the display is blanked and one count is added into the selected memory register.

Additionally, during this 850 ms sample period, the existing data may be examined. When the Display switch is turned on, the Channel Number register is returned to Channel 00. Each time the Channel Advance button is pressed, the counter advances one count. The channel counter causes the contents of the corresponding memory to be displayed.

When the Erase button is depressed, it causes the memory being displayed to return to zero. (If the Erase button is released during the period when the display is blanked, a false number may be entered in that data since it is possible to release the Erase button inside an add cycle causing only a portion of the byte being examined to be set to zero.)

The compilator has an internal power supply capable of maintaining operation for up to two hours when the display is not on.

The timing of the unit is controlled by a crystal oscillator accurate to within ±15 minutes per month.

The step width is set by means of a dip switch inside the cabinet. It is normally set to divide the input from the anemometer by one. It can be set to divide the input by as much as eight. This would increase the step width eight times. Only one switch should be on at a time. The switch nearest J.C. 3 will select a divide ratio of eight, the next seven, the next six, etc.

## OPERATING INSTRUCTIONS

First, connect the earth ground terminal of the Compilator to a suitable ground. This is necessary to ensure adequate lightning protection. Connect the two leads from the anemometer generator to the two terminals on the back of the Compilator marked "Anemometer Input."

If the Compilator is to be operated from nominal 120V AC 60 Hz supply, plug in the line cord. If it is to be powered from a twelve-volt battery, connect the positive battery terminal to the terminal on the back of the Compilator marked "12+," and connect the battery negative to the terminal on the Compilator marked "COM."

Be certain that the power is connected as the Compilator will run off its internal power supply for only a few hours. Application of external power will be indicated by a slight brightening of the LED displays.

Pull out the Power Switch handle, and throw it to ON. Throw the Display switch to ON. The Channel Number display should read 00. The Data display may have missing digits and will usually display a random number. All thirty-two registers must be cleared before data can be accumulated. This is accomplished by depressing the Erase button and cycling the Channel Advance button until the channel number display returns to 00. (If the channel number exceeds thirty-one (31) or resets to zero (00) during this operation, stop; throw the Display switch off and wait five seconds. Repeat the above procedure.

Now the Compilator is ready to accumulate data. If power consumption is a consideration, turn the display to OFF.

To interrogate the Compilator, first throw the Display switch to ON. This resets the Channel Number to 00. Now write down the number in the Data Display. If the Compilator is set for ~~two mph~~ ONE KPH steps, this number will read out the number of seconds the anemometer has sensed wind blowing between zero and ~~two mph~~ ONE KPH. Next, push the Channel Advance button once. The Channel Number should read 01, and the Data display will read out the number of seconds the wind speed was between ~~two~~ ONE and ~~four mph~~ TWO KPH.

Proceed until all thirty-two channels have been examined. The total of all the data registers is the total number of seconds the unit has been gathering data.

If, upon interrogating the Compilator, the data registers show random numbers, it is likely that the input power to the machine was outside its specified limits for a period exceeding two hours or was inadvertently turned off.

The data garnered should have a shape similar to the curve of Anemometer #1 in Fugure #1.

## INTERPRETING DATA

After writing down all the data, sum the number of seconds recorded. This will provide the total number of seconds ($S_t$) the unit has been gathering data.

### Average Wind Speed

To use the wind speed data, first obtain an average of the step width; the easiest method is an algebraic average. Thus, for a Compilator set up for ~~two mph~~ ONE KPH steps, Channel 00 would contain in it the number of seconds the wind averaged ~~one mph~~ 1/2 KPH; Channel 01 would contain the number of seconds the wind averaged ~~three mph~~ 1 1/2 KPH, etc., discarding Channel 32 data.

To obtain the average wind speed, multiply the average wind speed represented by the channel number by the number of seconds contained in that data register. Then sum this product for thirty-one channels and divide by the total number of seconds the Compilator has been gathering data, thus:

Average wind speed $\overline{V}(N)$ contained in Channel No. N with step width W and Data display in seconds $S_d$:

$$\overline{V}(N) = N \cdot W + \frac{W}{2} \tag{1}$$

Total number of seconds the compilator has been gathering data, $S_t$:

$$S_t = \sum_{N=0}^{30} S_d(N) \tag{2}$$

The average wind speed over time

$$\overline{V}(S_t) = \frac{1}{S_t} \sum_{N=0}^{30} \overline{V}(N) \cdot S_d(N) \tag{3}$$

Power Computations

To compute the watt-hours per square foot available at sea level and 59°F:

First compute the watts available at the wind speeds $\overline{V}(N)$ for all thirty-one channels, thus:

$$\frac{W}{Ft^2} = 0051\ \overline{V}(N)^3 \tag{4}$$

Then multiply each by the number of hours the wind spent at that average velocity. Finally, sum the products thus obtained:

$$\frac{W - Hr}{Ft^2} = \frac{1}{705,000} \sum_{N=0}^{30} \bar{V}(N)^3 \, S_d(N) \qquad (5)$$

Correction factors must be taken into account for the variations in the density of air with temperature and air pressure if conditions vary extremely from the above.

(Altitude $>$ 2500 ft., $100^o \geq T \geq 25^oF$)

To calculate the power available from a specific machine, given the power output characteristic:

First, calculate the wattage $P(\bar{V}(N))$ which the wind driven generator is capable of producing for each $\bar{V}(N)$. Then multiply that power by the number of seconds $S_d(N)$ at that power level. Finally, sum these values for all thirty-one channels and divide by 3600 sec/hr to convert to watt-hours:

$$E(S_t) = \frac{1}{3600} \sum_{N=0}^{30} P(\bar{V}(N)) \, S_d(N) \qquad (6)$$



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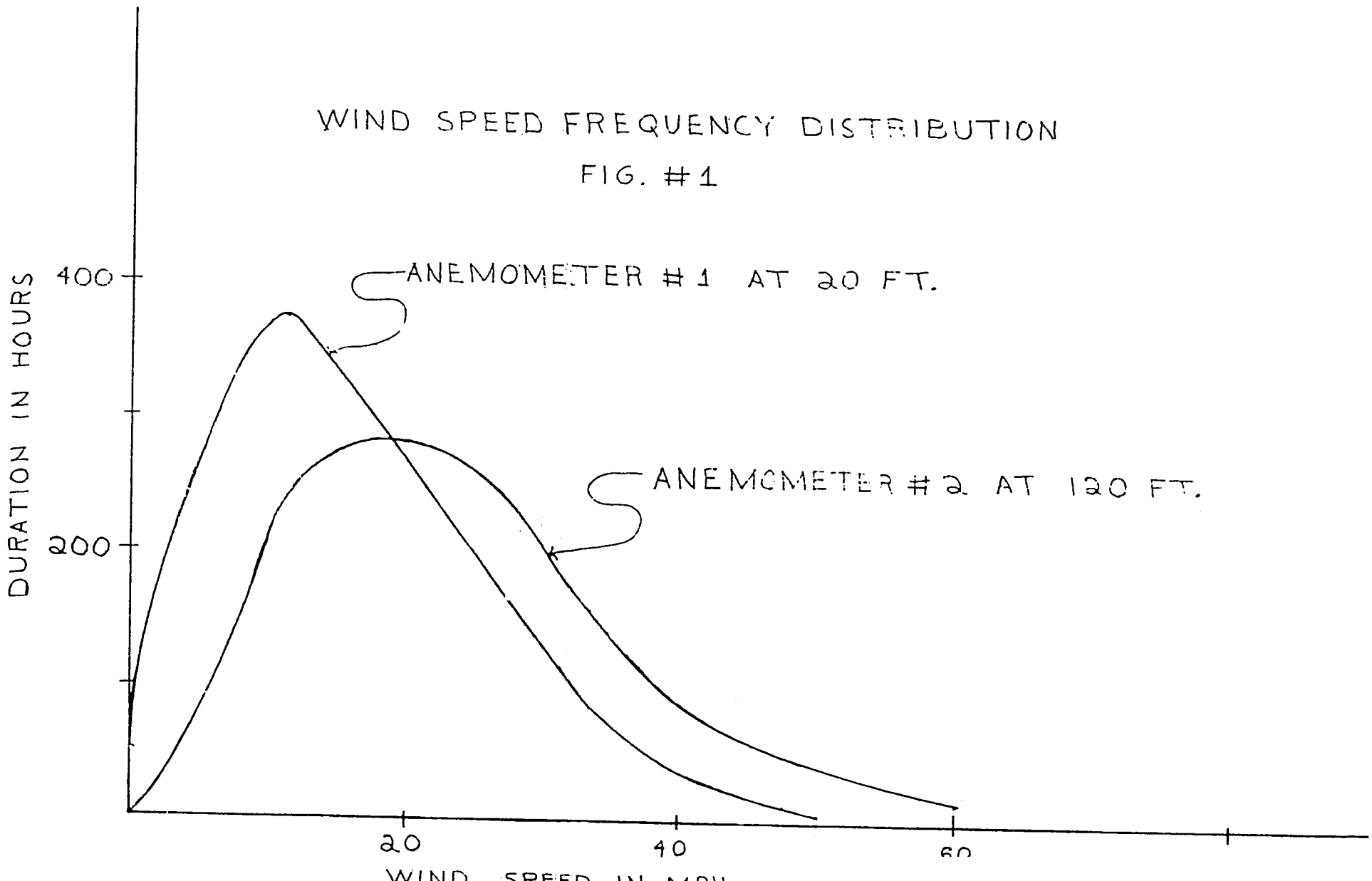
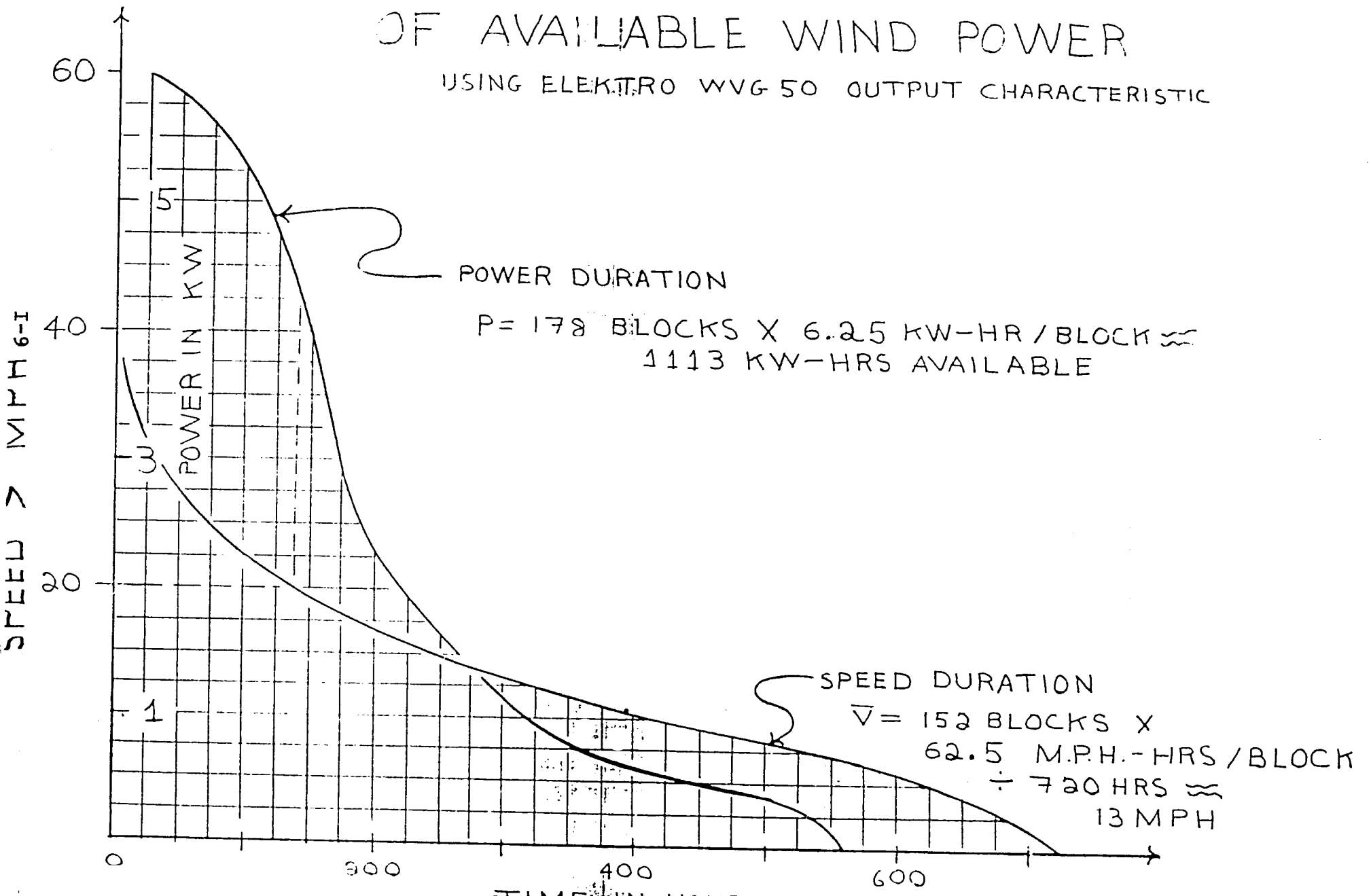
WIND SPEED FREQUENCY DISTRIBUTION

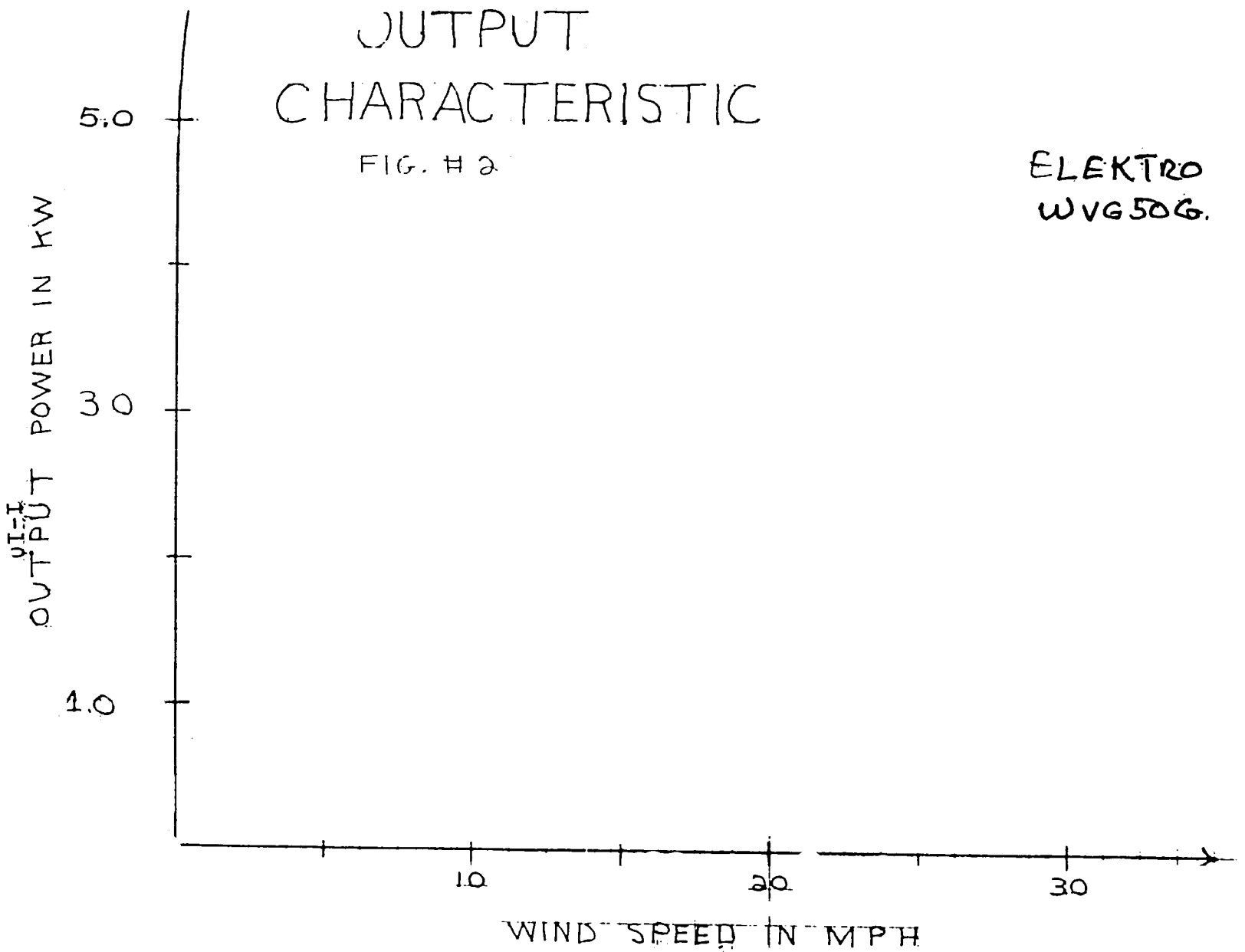
FIG. #1



# GRAPHICAL COMPUTATION OF AVAILABLE WIND POWER

USING ELEKTRO WVG 50 OUTPUT CHARACTERISTIC




OUTPUT
CHARACTERISTIC
FIG. #2
ELEKTRO
WVG50G.
5.0
3.0
1.0
OUTPUT POWER IN KW
VI-I
10
20
30
WIND SPEED IN MPH

LBN 6/22/77