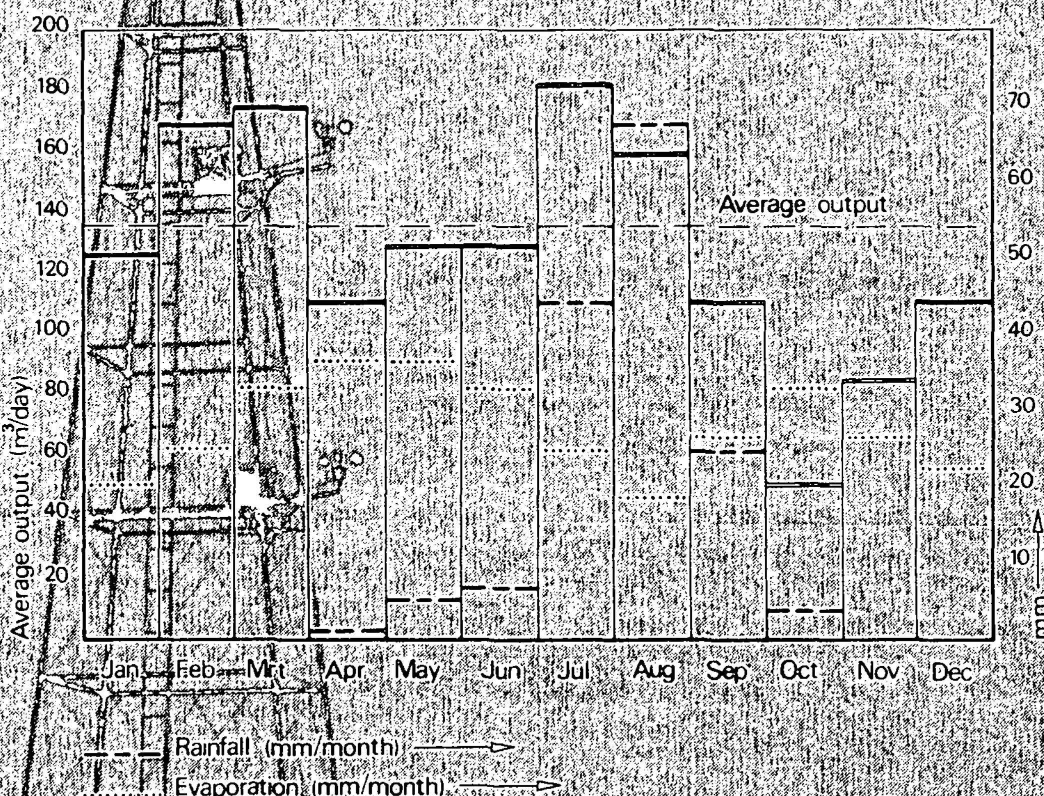
Wind energy in Sudan



by Dr. Yahia H. Hamid
and W.A.M. Jansen
July 1980

SWD STEERING COMMITTEE WINDENERGY DEVELOPING COUNTRIES
P.O. BOX 85
3800 AB AMERSFOORT
THE NETHERLANDS

PUBLICATION SWD 81-2

This publication was realized under the auspices of the Steering Committee Wind Energy Developing Countries S.W.D.
The S.W.D. is financed by the Netherlands Ministry for Development Cooperation and is staffed by:

the Eindhoven Universtity of Technology,
the Twente University of Technology, and
DHV, Consulting Engineers, Amersfoort

and collaborates with other interested parties.

The S.W.D. tries to help governments, institutes and private parties in the Third World, with their efforts to use wind-energy and in general to promote the interest for wind-energy in Third World Countries.

For information address:
SWD c/o DHV Consulting Engineers B.V., P.O. Box 85, 3800 AB Amersfoort, The Netherlands

WIND ENERGY
in
SUDAN

– Potential assessment
– Requirements for a Wind Energy Centre
– Project proposal

by

Dr. Yahia H. Hamid[1]
and W.A.M. Jansen[2]

July 1980

1) COUNCIL FOR SCIENTIFIC AND TECHNOLOGICAL RESEARCH;
INSTITUTE OF ENERGY RESEARCH
P.O. Box 6094 / Khartoum / Sudan

2) SWD STEERING COMMITTEE WINDENERGY DEVELOPING COUNTRIES
P.O. Box 85 / Amersfoort / The Netherlands
Tel. 33/68 91 11 - Cables dehave Amersfoort

ACKNOWLEDGEMENTS

We would like to express our thanks to the people who helped to gathering the information necessary for carrying out this study.

Special thanks are due to:

- Mr. Salah el Natiq, head of the Groundwater Division of the National Administration for Domestic Water Supply in Khartoum
- Mr. Al Herazi and Mr. R. Lageman of the River Gash Basin Groundwater Development Project in Khartoum
- Mr. Abdel Muttalib Balla Zahran, director of Services and Research of the Meteorology Department in Khartoum
- Mr. Bashir Shawgi, chief mechanical engineer of the Gezira Board
- Mr. Fatah Elrahman Osman Elbarondi, Agricultural Inspector of the Loan Section of Agricultural Bank in Khartoum
- Mr. Mohammed Ali Abd El Gadir, of the Petroleum General Administration
- The staff of the Netherlands Embassy in Khartoum
- Mr. James Beebe, project officer of the US Aid Mission in Khartoum
- Mr. J. Heun, Flood Protection Project Kassala
- Mr. J. Vermeer, Horticulture Project Kassala.

SUMMARY

There is a large potential for water pumping windmills in the north of Sudan, if such windmills are appropriately designed and are manufactured in the Sudan. Such local manufacture is considered well possible.

Problems can be expected with maintenance and storms; these aspects must be taken into account.

Pumping with windmills is cheaper than with diesel engine driven pumps. From a national economic point of view windmills are also advantageous, resulting in employment generation and in considerable savings on foreign exchange.
Windmills are especially interesting for small scale irrigation and may, under certain conditions, be interesting for domestic water supply systems. Windmills for electricity generation should be a subject of future research.

If a mere 1 percent of the present irrigation pumping capacity is replaced by windmill pumps, savings on fuel imports alone would exceed one and a half million Sudanese pounds a year in foreign exchange.

To introduce wind energy technology in the Sudan, it is considered essential that a Wind Energy Centre is created. A description of the tasks of and the requirements for such a Centre is given in the report. The aim of such a Centre, during its first two years of existence, should be to design, develop and test water pumping windmills suitable for manufacture in the Sudan, and to prepare and initiate pilot projects. Research on wind, water and agriculture is essential before application is possible.

It is proposed to carry out a project to start a Wind Energy Centre in the Sudan. The aims during the first two years are training of Sudanese staff and building up of an organization. Such a project is considered to require technical assistance for a period of five years. The proposal covers the first two years of the project, followed by a second phase of the evaluation-results justify extension.
The project is to be carried out as a cooperative programme between the Institute of Energy Research of the Council for Scientific and Technological Research in Khartoum and the SWD Steering Committee Wind Enery Developing Countries, which may provide the required technical assistance. An amount of 1.6 million Dutch Guilders (± 0.8 million US Dollars) is required to cover the total cost of the technical assistance during the first two years.

CONTENTS PAGE

CONTENTS PAGE

1. INTRODUCTION

The energy situation in the world has led to consideration of alternative energy utilization. In the Sudan too, the problem of energy supply is growing. One illustration of this problem is that at the moment 80 percent of the export earnings of the Sudan are being spent on the import of fuels.

As early as in 1975 the National Council for Science and Research of the Sudan created the Energy Institute which studies and aims at the implementation of devices using solar, wind and biomass energy.

There have been contacts between the Energy Institute and SWD since 1975.

After a concentrated effort of several years in building up the solar energy department, the Energy Institute is now interested in starting a Wind Energy Department. At a meeting in The Hague on 11 September 1979 between the Director of the Energy Institute, the representative of SWD and officials of the Netherlands Ministry of Development Cooperation it was agreed that an SWD consultant should be sent to evaluate the possibilities in close cooperation, with the Energy Institute.

Furthermore the requirements for a Wind Energy Department were to be discussed and if expectations with regards to wind energy potential could be confirmed, a project proposal was to be formulated.

Consequently an SWD consultant (W.A.M. Jansen) visited the Sudan from 19th March until 9th April 1980.

2. GENERAL

2.1. Principal characteristics of the Sudan *)

Geography

The Republic of Sudan is the largest country in Africa. It is bordered in the north by the United Arab Republic and Libya, in the west by Chad and by the Central African Republic, in the south by Zaire, Uganda and Kenya, in the east by Ethiopia while in the north-east the Sudan borders on the Red Sea.
The total area is 2,505,813 square kilometre which is more than a quarter of Europe.

Topography

The major part of the country is a huge plain which is crossed by the Nile and its tributaries. Three different areas are being distinguished. A desert area in the north (Nubian desert) and a semi desert area in the north-east where the Red Sea hills separate the great plain from the narrow coastal strip. In the centre the land rises to form the Nuba mountains surrounded by sand dunes. A third area consists of a strip with clayey soil which widens to the east until it merges with the marshy lands of the south.

Climate and vegetation (see maps in Annex 6)

North of about latitude 19°N northerly winds prevail for most of the year and rainfall is rare; to the south of that the seasons are characterized by the oscillation, north and south of the boundary, between moist southerly air and dry northerly air. Abu Hamad is the normal northern limit of the rains; a short wet season at Khartoum provides an average rainfall of about 180 millimetres (7 inches); there is 380 millimetres (15 inches) of rainfall at Wad Medani and 1,122 millimetres (44 inches) at Wau, a town in the south on the Jur River.
Most of the rainfall occurs in heavy thundery showers. Except for the Red Sea coast, where the most rain comes in September to November 50-75 percent of the precipitation occurs from June to August, although at Juba, in the far south, there are only two really dry months.
Highest temperatures, which usually precede the rains, occur in July in the extreme north, in May-June in Khartoum, and in April, March or February, progressively farther south. A maximum of 52,2 degrees centigrade (126 degrees Fahrenheit) has been recorded at Wadi Halfa and 47 degrees centigrade (118 degrees Farenheit) at Khartoum, but in the south temperatures reach only 42-43 degrees centigrade (108-109 degrees Fahrenheit). Haboobs (dust storms) occur in the north and north-east.

*) Data for this paragraph were taken from Jeune Afrique and from "travel guides"

Five main vegetation types can be distinguished: the sparse desert vegetation of the north; a zone of semi-arid acacia scrub and short grassland farther south, the woodland savannah of most of the southern half of the country; the vegetation of the floodlands and swamps of the Nile, and the flora of the mountain region.
The desert, with less than 76 millimetres (3 inches) rainfall, supports permanent vegetation only near watercourses. Date palms are frequent along the Nile, and the doum palm, tamarisk, and coarse grasses are found where the banks are not cultivated. There is semi-desert and 76-280 millimetres (3-11 inches) rainfall along the Red Sea coastal plain and a zone running east-west across the country, roughly between the latitudes of Atbara and Wad Madani. Vegetation there is a mixture of grasses and herbs with scattered scrub and bare areas. Acacia tortilis is common, although not on clay soils and Blepharis species with areas of grasses is the typical vegetation.
The woodland savannah, a mixture of grasses, bushes and trees, has several distinct subdivisions. In areas of the north where rainfall is less than 760 millimetres (30 inches) trees are thorny and acacias are dominant. Khaya, or African mahogany, Isoberlinia doka and Anogeissus schimperi are characteristic trees in the drier areas; Terminalia glaucescens, Albizzia zygea, Vitex doniana are among the larger trees found in wetter parts. Elephant grass is common.
In the Nile Valley, north of Juba, and the widening swamps (sudd) to the north, papyrus is common along the waterways but grasses and water plant Pistia are also important. In each of the mountain groups, Jabal Marrah, Red Sea Hills, Imatong, Dongotona, and Didinga, distinctive assemblies and vegetation zones are found.

Population (see maps in Annex 6)

In 1968 the total population was estimated to be 14,370,000. With an estimated yearly growth rate of 2.8%, the population in 1980 is probably around twenty million people. 87% of the active population is occupied in the agriculture and livestock sector.
Geographic distribution (1968): the major part of the population is concentrated in the provinces of the agricultural centre (around 8 million); the south has around 4 million inhabitants; the north, being a desert, is the least populated: average density is 4 persons per square kilometre.
Main towns (figures 1968):

- Khartoum (capital)	:	173,500
- Omdurman	:	185,380
- Khartoum North	:	80,101
- El Obeid	:	62,160
- Wad Medani	:	63,660
- Port Sudan	:	78,940
- Atbara	:	48,250

Etnic composition

The Arabs of Sudan (Moslems) live in the regions of Khartoum, El Obeid, Shendi, Wad Medani and Kassala. They form the most important group (39%). Next come the tribes of the south (30%) most of which are Negro tribes.
The population of the west (13%) live a rather miserable life (agriculture and raising of small cattle).
The Nubas (6%) live in the centre of the Sudan and have a very effective tribal organisation.
The Nubians (3%) live close to the Egyptian border.

Religions

- Moslem : 72%
- Animist : 27%
- Christian : 2%

Languages

Arabic is the official language. The technical language is English. Besides these, there are many local Sudanese languages.

Currency

The currency in Sudan is the Sudanese Pound (£s).
1 £s ≃ US$ 1.25 ≃ Dfl. 2.50.

2.2. Energy in the Sudan

Until the dawn of the century, energy utilization in the Sudan was entirely based on the primitive conventional means and dependent on the surface resources of flora and animal products.
The utilization was almost entirely limited to domestic purposes, particularly heat production.
Since that time the Sudan has undergone development on a comparatively large scale, agricultural projects playing the key role. In step with this modern and highly mechanized development, systems for the supply and distribution of power were established. Improved fuels supply 96%, while hydroelectricity supplies the remaining balance of 4%. The utilization of this supply is highly localized within the central valley, and even further concentrated within the highly developed central part of this region. The Blue Nile grid serving this sub-region supplies about 80% of the total electric energy in the country.

The uses of these modern types of energy supply are limited to the growing industries, to some pumping loads and transport and to domestic use for about 20% of the total population.

The traditional forms of energy are still widely utilized. They cover the whole domestic requirements of about 4/5 of the population and even the other 1/5 of the population is semi-dependent on wood, charcoal and stiff grasses for their domestic heat requirements. Animals still play their part in the rural transport as well as in drawing water from wells.

In trying to raise the different regions to more uniform and better social and economic conditions, the Sudan is adopting a country wide decentralization policy. The ambitious targets set will greatly influence the regional power trends within the coming decades. These targets are:

1. To establish servicable and workable networks of settlements for the nomads, that allow easier and better extension of the important services as well as improved productivity.

2. To improve and modernize pastural and agricultural rural conditions. At present wide areas are being converted to mechanized farming, and the indigenous grasses are being replaced with more valued types of fodder.

3. To set up sub-regional service townships, providing the immediate services needed by the sub-regions as well as conducting the initial processing, storing, or packing of raw products typical of the different localities.

The general aim of raising areas, especially the remote ones, to self-sufficiency, at least within the range of broad fundamental needs, is inherent in these objectives.

2.2.1. Energy resources

Hydro-electric power

The Sudan has a significant hydro-electric potential of about 2000 MW, of which the exploited power amounts to about 8% and is expected to double by 1982. However the entire potential is limited to the Nile basin and it is expected to satisfy the anticipated local requirements of this region until the beginning of the next century.

Mineral fuels

The recent energy crises have induced a heavy burden on the Sudan balance of payments; furthermore they have imposed severe impacts on the development programmes. Approximately 80 percent of the export earnings are now required for fuel imports. With no immediate substitutes for imported fuels, except the localized hydroelectricity, the Sudan will continue to depend on increasing imports, at least for the coming years.

In connection with the geological structure of the country, indications for the presence of mineral oil are positive. Explorations have yielded no substantial results as yet.

Conventional energy resources

As already mentioned, these resources originate mainly from the indigenous forests products and, to a lesser degree, from animal and human exertion.

Although the Sudanese indigenous forests and virgin lands are very extensive, they are mostly populated with low grade species of trees and shrubs of semi-arid tropical types. The southern region has better concentrations and types, but it cannot serve the requirements of other regions, as the transport costs influence the situation.

Although there are ambitious plans to improve the forestry resources, it is expected that the forestry fuel resources will become tighter. This is attributed to the continued taking over of forestry lands by irrigated and mechanized farming and improvement of pasture. The improved forests are planned to supply the country with expensive structural timber and to augment fuel resources.

Atomic energy

The Sudan is a member of the IAEA. Prospects for utilization of atomic energy in the Sudan depend on the economic feasibility of small and medium range reactors compared to conventional generating systems. Since the economic feasibility as well as the political acceptance in the western world is still under fierce discussion it is not certain whether atomic energy will be a realistic option.
In addition to this it is unlikely that rural electrification will be economically feasible and financially acceptable in the next decades if based on large central generating plants; the vastness of the country and the low population density in rural areas would require high investments for a wide network of transmission lines.

Agricultural wastes

The Sudan has extensive agricultural wastes in the form of baggase (the residue of crushed sugar cane), the stalks of cotton, millet and wheat, and other crop wastes. Absence of indigenous fuels, and the continued decrease in the conventional forestry resources, coupled with the high cost of imported oil, suggest the utilization of the agricultural wastes to the fullest possible extent.

Baggase poses no problems being used economically and extensively in the sugar factories in the country, primarily as a source of heat. However, no surplus is available for electricity supply to the public.

On the other hand the considerable heat content is lost in the current practice of burning on the fields. It is estimated, by the Energy Institute, that the output of cotton stalks of Gezira and Managil extensions alone have an annual electric potential of 2,250 GWH, enough to sustain a 500 MW station. Further studies are required to overcome the numerous difficult problems of collection and storage, packing, and developing the use to competitive, feasible standards.

Some products like cassave and water hyacinth are considered good inputs for bio-mass processes especially in the southern region.

Solar energy

The Sudan Government, through the Energy Institute of the National Council for Research, is conducting studies aimed at the design, construction and implementation of solar energy devices.
At the moment the US AID Mission in the Sudan is drawing up proposals for a "Sudanese Village Renewable-Energy Project" aimed at the implementation of renewable energy sources in the villages. Of course solar energy will form an important component and it is intended that the Energy Institute will play a role in this project.

Wind energy

Average windspeeds around 4 metres per second, stable winds, large open areas and low population densities indicate a potential for wind energy utilization. In the previously mentioned "Renewable Energy Project" proposal wind energy applications are considered potential components. The potential is further analyzed in the following paragraphs.

2.2.2. Present energy consumption

The total energy consumption is in the order of 3 million equivalent oil tons per year, categorized as follows:

a.	Direct heat	68%
b.	Transportation	20%
c.	Tractors, pumping and construction plant	7%
d.	Electricity generation	5%
	Total	100%

The annual rate of growth of the total energy demand in the Sudan is estimated at 5.2% which is fairly comparable to world average.

At present the Sudan output energy consumption per capita (assuming an overall conversion efficiency of 30%) is 52 kg equivalent of oil against 62 kg per capita for Africa. However the aforementioned figure of 5.2% varies from sector to sector.

The given figures were presented in a report of 1977 (lit. 1).
The observed trend is for an increasing share of energy to be consumed by transportation and electricity generation. The former results from the vastness of the country, which can only be linked together by a network of road systems, while the latter is the most versatile type of energy.

2.3. Previous developments in wind energy in the Sudan

Gezira scheme

The Gezira scheme is a large scale gravity irrigation scheme. In 1955 nearly a hundred "American" type windmills were installed on boreholes for pumping drinking water. For a period of approximately 10 years the windmills worked reasonably well, but at the moment none of the windmills that were installed is still operating.
In Barakat near Wad Medani, the Chief Mechanical Engineer of the Gezira Board, Mr. Bashir Shawgi, gave the following reasons for the fact that the windmills are no longer in operation:

- while the cost is high, capacities of the 5 m diameter windmills are too low
- spare parts are no longer available since the British manufacturer has stopped production
- for storage more overhead tanks are needed than in the case of the diesel-engine driven pumps
- since nowadays the people in the Gezira scheme tend to live closer together for reasons of other services, the villages now generally house some 3000 inhabitants requiring a large volume of domestic water supply
- maintenance of the windmills with 20 m high towers has proved to be dangerous and it is said that 4 mechanics have died during maintenance work
- in 1979 the Gezira Board compared the cost of a windmill drinking water scheme with the cost of a diesel-engine pump drinking water scheme.

The conclusion was that the windmill scheme required an initial investment that was five times as high as the diesel alternative. Total annual cost of the windmill scheme was 2.5 times as high. The high costs were mainly caused by the fact that the storage tank required for a windmill scheme has to be three times as large as for a diesel-engine pump scheme. The storage tanks are costly steel overhead tanks.

University of Khartoum windmill project

In 1974-1975 two students from the University of Khartoum carried out project work in partial fulfillment of the requirements for the degree of B.Sc. The work included an analysis of meteorological data, and the design of a water pumping windmill (lit. 6).

Training

After graduation one of the students, Mr. El Tayeb Idris Eissa was employed by the Energy Institute of the National Council for Research. For the last two years he has been studying windmill technology at Reading University in UK, as a part of his course for an M.Sc. degree. He is to return to Sudan in February 1981.

Wind data

In 1964 Mr. Y.P.R. Bhalotram, meteorologist of the Sudan Meteorological Service in Khartoum compiled and analysed wind data from 13 stations in the Sudan. Rough isovent maps (quarterly as well as yearly) were drawn. The analysis and results were published under the tittle "Wind energy for windmills in Sudan". See lit. 2.

Australian windmills

The Australian Government has agreed to supply the National Administration for Domestic Water Supply in Khartoum with five windmills. These water pumping windmills will be installed in Khartoum, Kordofan and Darfur.
Mr. Salah el Natiq, Head of the Planning and Research Division of the National Administration for Domestic Water Supply, stated that windmill outputs are to be monitored and studied. With 12 substations, each having a workshop and 4 or 5 small centres, this organization may be very suitable for windmill extension projects.

2.4. Wind energy potential in the Sudan

This section contains an analysis of the wind energy potential made on the basis of wind data from the Sudan Meteorological Service.
The data available are discussed, after which some output predictions are made.

2.4.1. Wind data

An excellent start on the evaluation of wind data was already made in 1964 in the report "Wind energy for windmills in Sudan" by Y.P.R. Bhalotram. This report is our main information source. The report was published by the Sudan Meteorological Service as "Memoir N°7". Statistics of hourly mean wind speeds for different months of the year (1949-1953), derived from continuous records of Dines' pressure-tube anemographs installed at 13 stations in the Sudan, were published in Sudan Meteorological Service Pamphlet N°3, and are reproduced in Appendix I of lit. 2.

These statistics give the following information:
- average monthly windspeeds
- maximum hourly averages
- maximum gusts
- monthly and yearly frequency distributions.

As an example Annex 1 shows the data for Khartoum.
Annex 2 shows a compilation of average monthly and yearly windspeeds.
Lit. 2 gives following comments on the data (p. 4):
"The calibration of the pressure-tube anemographs was based upon an assumed air density of 1,226 gm/m^3. The actual air densities at the various stations were normally rather less than the above value and speeds were underrecorded by up to 5%. The statistics were derived from the recorded speeds uncorrected for air density.
The wind speed is affected considerably by the condition of exposure of the site at which the recording instrument is installed and on the topography of the surrounding area. Strictly speaking, therefore, the data are true only for the sites of exposure of anemographs at the different stations. When the instruments were originally installed, no special care was taken to see that the site was suitable for wind measurements, and as such some of the present sites are not well exposed for this purpose. Moreover, with the expansion of towns, at some of the sites the exposure has been vitiated with the construction of new buildings. For instance, the exposure of the instruments installed in town at Kosti, Kassala, Wau and Juba, is not satisfactory. This is also confirmed by the wind speed statistics; for instance, the speeds at Kosti (which is at the same height above mean sea level as Malakal) are appreciably less than at Malakal, during the dry season December to March when the Northeast Trades blow. Normally, one would expect a higher wind speed at Kosti. The presence of big trees and buildings in the vicinity of the site of the observatory at Kosti is responsible for the lower wind speeds recorded at this station.

There are a number of stations in the Sudan at which wind force is estimated on the Beaufort Scale (0-12), at certain synoptic hours. The data from these stations is not sufficiently reliable and therefore, it has not been used in the preparation of this memoir.

At any given site the annual average wind speed remains nearly constant from year to year, the variation being within ± 10 percent or even less. This holds true particularly in the case of the Sudan which lies wholly in the region of the Northeast Trade Winds, and where the pattern of wind flow during the course of the year does not vary much from year to year. Therefore, the analysis of wind data of 4 to 5 years, as studied in this investigation, with a view to estimate the availability of annual wind power at the various stations, may be considered as sufficient for a preliminary survey."

Isovent maps based on the hourly mean wind speed, in mph, for the periods December-March, April-June, July-September, October-November, and for the year as a whole, are given in Annex 3. As the data used are too meagre for the vast area of the country, these maps should be considered to give, at best, only a very general idea of the prevailing wind speeds.

Lit. 2 gives frequency distribution curves as well as duration curves for all 13 stations. As an example Annex 4.1. shows these curves for Khartoum. The frequency distribution curves show the percentage frequency of the number of occasions when the hourly mean windspeed (in mph) obtained a certain value.
They are given for the representative months of January, April, July and October (a-b-c-d) and for the year as a whole (e). The annual speed-duration curve gives the total number of hours in the whole year when speeds exceeding different values were reached (f).
From Annex 3 fig. 1 it is seen that during the dry winter season, December to March, the mean windspeed exceeds 8 mph over most parts of the Sudan north of latitude 9°N.
Annex 3 fig. 2 shows that during the advancing monsoon period, April to June, the mean wind speed exceeds 6 mph over most parts north of latitude 10°N.
Annex 3 fig. 3 shows that during the rainy season, July to September, a mean wind speed exceeding 6 mph occurs in most parts north of latitude 11°N and east of longitude 28°E.
Annex 3 fig. 4 shows that during the period of retreating monsoon, October to November, a mean wind speed exceeding 6 mph occurs generally over parts north of latitude 12°N.
The isovent map of Annex 3 fig. 5 shows that a 6 mph average is exceeded in most parts north of latitude 9°N; an 8 mph average is exceeded in the Nile Valley north of 12°N, the coastal strip along the Red Sea.
It may be mentioned in this connecton that in the Nile Valley, particularly beside the river, wind speeds are generally higher than at places further away. In the coastal area along the Red Sea, a sea breeze of 10-15 mph blows almost throughout the year, between 09.00 h and 10.00 h and lasting till about 17.00 h or 18.00 h. The sea breeze penetrates inland for a distance of about 20 miles, decreasing in speed with distance inland.

Useful power can in general be obtained in areas where the annual average wind speed exceeds 6 mph. However, in areas where the annual average wind speed exceeds 8 mph, the installation of the proper type of windmills is considered to be a practical and economical proposition. The maps given in figs. 1 to 5, indicate in a general way that while the whole area of the Sudan south of the latitude of Malakal is unsuitable for wind power utilization, the area north of latitude 12°N, and between longitudes 28°E and 35°E and the coastal strip along the Red Sea, should be explored for suitable sites for the installation of windmills.

For Khartoum lit. 2 also gives mean hourly windspeeds for every hour of the day. For these data see Annex 4.2.
The following remarks are made on the problem of gusts in lit. 2.
During the southwest monsoon season, thunderstorms in the Sudan may be accompanied with severe ground squalls in which wind speed, particularly, in the North and Central Sudan, may exceed 70 mph on occasions. The maximum gust speed recorded at 13 selected stations, based on the records of a Dines PT anemograph installed at the stations, is given in Annex 2.
The structure of the windmill has, therefore, to be strong enough to withstand such strong winds. The increase of wind speed and the change in the wind direction are both sudden, at the passage of the thunder squalls.
In addition to these comments on gusts, it is noted here that in the Sudan the "haboobs" frequently occur.
A haboob is a strong whirlwind travelling at approximately the same speed as the wind. Diameters are in the order of a few metres upto 10 m, and the haboob carries fine sand. Its frequency of occurrence is such that it is likely that a windmill will be hit by it say at least once a year. It is possible that the gust speeds mentioned above are in fact the wind speeds of the whirlwinds. When a haboob hits a windmill it will probably result in a high angular speed of the head construction which will cause high hygroscopic moments in the windmill main shaft.
Gusts and haboobs will have to be studied seriously and designs for windmills in the Sudan will have to take them into account.
In the annual agro-meteorological report of April 1978-March 1979 wind data for several other stations are given. (Lit. 3.)
In addition to the monthly averages, this report also gives wind speeds at various heights above groundlevel (from 0.2 m up to 12.2 m) for Shambat (near Khartoum) and Wad Medani in the Gezira area. In general these data confirm the data and isovent maps of report lit 2.

As mentioned before, the exposure of the instruments installed in town at Kosti, Kassala, Wau and Juba is not satisfactory. In an attempt to verify and quantify this statement, measurements were taken for one hour on the afternoon of 23 March 1980 at a location approximately 5 km east of the meteorological station in Kassala.
Measurements were taken at 8 m height in an open field that is representative for the area around Kassala. The average wind speed during the hour of measuring was found to be 4.8 m/s while the meteorological station registered in town (at a height of approximately 15 m) the wind speed with a "dynamograph" which resulted in an average wind speed of 5.2 knots = 2.7 m/s. If based on the meteorological station's measurements, the wind speed of the Kassala area would be under estimated by 44 percent. This would lead to output predictions of a windmill that are only 18 percent of the actual output that would have been reached during that specific hour in the open field.

During the hour of measuring the wind speed came distinctly from the northern direction and wind flow was undisturbed by the mountain "Jebel Kassala" which is situated to the east side of Kassala. In general this mountain will seldom have a direct influence on the winds because the winds in the northern half of Sudan rarely come from the east. A secondary influence may result from differences in air temperatures above Kassala town, the open land around it and the mountain (rock surface).

It is concluded here that the available isovent maps and wind data from the meteorological stations can be used as an indication for the wind regimes in the areas. Since most of the areas around the meteorological stations are more open, it is expected that winds are less disturbed and that actually the wind potential is higher than indicated by the available data.

2.4.2. Some output predictions

Because Khartoum is representative for the area around it in which a number of applications of waterpumping windmills are foreseen (Nile Valley), and since this location also seems representative for other large parts of the Sudan, the data from the Khartoum meteorological station will be considered as "typical" for the Sudan.
Further calculations on output predictions and economic comparisons are therefore based on these data.
The average wind speed at Khartoum is 4.3 m/s. A 5 m diameter windmill pump designed for this wind speed will have an average output of approximately 156 watts (net water lifting power).
For calculations see Annex 5.
The average water output per day for various pumping heads will be:

H (m)	Volume (m^3/day)
5	270
10	135
20	67
30	45

At a 10 m pumping head the windmill will have the following average daily outputs (see fig. 1).

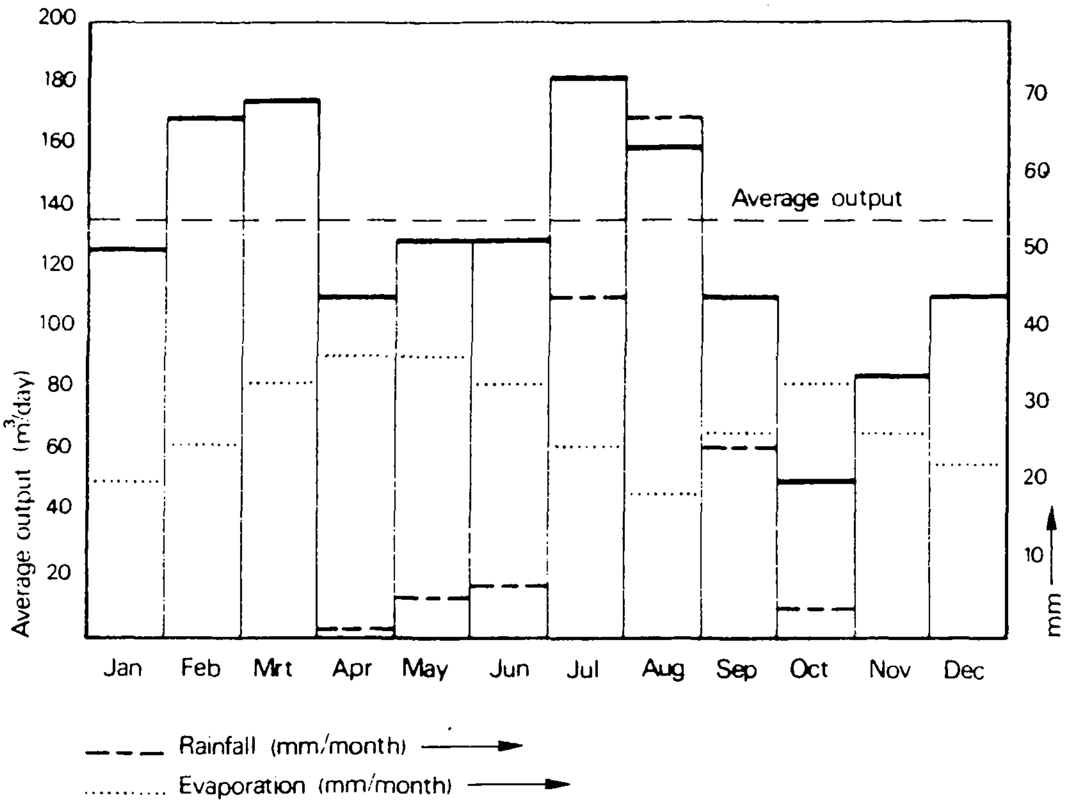


Fig. 1 - Average daily outputs of a 5 m diameter windmill pump in the Khartoum wind regime (head = 10 m)

2.5. Waterneeds and availability

From the climate (see section 2.1.) it follows that in large parts of the country the rainfall is extremely low (desert in the north 76 mm; Khartoum 180 mm; Wad Medani 389 mm and in the south at Wau 1122 mm a year). Dryness and temperatures result in open pan evaporation up to levels of 2500 mm a year. Apart from on the riverbanks almost no cultivation is done north of Khartoum. Between Khartoum and Kassala (see Annex 6) once a year a crop is cultivated on large areas. This crop (dura) starts in the short rains and ripens in hot sun. The dura is a highly drought resistant crop. For the rest of the year these lands lie idle, waiting for the next rains.
The Gezira schema, a 55 year old gravity irrigation scheme producing mainly cotton, lies slightly further south, around Wad Medani. This scheme covers 280,000 ha which accounts for 50 percent of Sudan's irrigated crop land and for 12 percent of all agricultural land.
Along the Nile and the other rivers irrigation can be carried out by pumping water either from the rivers themselves or from the groundwater of the river basins.

In such a dry country it is evident that people depend on ground water, apart from those who live close to rivers or in areas with gravity irrigation schemes.
The short time available for this study did not allow visits to all areas to study them in detail. However some impressions were obtained by visits to the Kassala area and to Gezira.

2.5.1. Kassala

For a few months a year, the river Gash flows through Kassala. The river basin with alluvial deposits forms an excellent aquifer.
A recent inventory of hundreds of wells around Kassala showed that yields range from 500 to 2000 m^3/day while 1000 m^3/day is considered typical.
A well that yields 200 m^3/day is considered poor. Depths of dug wells range from 10-20 m; boreholes are mostly 20 m deep. Waterlevels are typically around 10 m below groundlevel ranging from say 5 m (close to the river) up to 15 m.
Land holdings in the area range from 8 to 60 feddan (3-25 ha) and the crops grown are vegetables and fruit, which require a lot of water. Actual requirements depend largely on the crop to be grown and on the water application efficiency but a general indication is 100 m^3/ha per day.

Kassala town has a piped water supply system. The farmers obtain their drinking water from wells while the nomads roaming the area make use of temporary water holes. Drinking water from the wells is generally considered safe.

In view of the high yields of the wells and the large water requirements in the Kassala area, it is concluded that output capacities of 5 m Ø windmills (see par. 2.4.2.) are too small and that unless larger windmills become available, the windmills are not a good match with the wells.

2.5.2. West Sudan

It was mentioned by the staff of the River Gash Basin Development Project in Kassala that there may be potential for waterlifting by windmills in the west of Sudan near Nyala, where landholdings are smaller than in the Kassala area. The wells there do not have as high yields as those in Kassala. This possibility has not yet been further investigated but needs future attention.

2.5.3. Gezira

In the Gezira area water from the gravity irrigation scheme is used for irrigation while boreholes are pumped for drinking water. The typical community size is 3000 people.

If we set the daily water requirement at 25 liters/person, then the required extraction is 75 m^3/day. The boreholes are 300 ft deep with waterlevels typically around 100 feet below groundlevel. Experience with windmills in the area has indicated daily outputs of 5.2 m diameter windmills are 7,300 galls/day (33 m^3/day). According to the meteo station of Wad Medani the long-term average wind speed is 4 m/s at 12.2 m height. The windmills have towers of 20 m height and the average expected output would therefore be 27.5 m^3/day (see Annex 5).
There are many possible reasons for the fact that the actual outputs were higher than 27.5 m^3/day, but it is probably due to a higher wind speed at the windmills than at Wad Medani.
To obtain the required quantities for the water supply, a windmill with a diameter of 7.8 m would be needed. October, being the month with minimum average wind speed would yield a daily average of 13.6 m^3 with the 5.2 m diameter windmill while a 7.8 m diameter windmill would yield 37 m^3/day (see Annex 5).

2.5.4. Nile Valley

In the area of Khartoum itself there are many possibilities; both groundwater from tubewells, with waterlevels around 20 m under groundlevel, and surface water to be pumped from the Nile are feasible. The potential there was indicated by Mr. Stuart S. Wilson in his report "Wind power in the Sudan". The report describes a study visit made by Mr. Wilson of the University of Oxford in 1975 (lit. 5). He concluded that windmills along the Nile will be very effective especially because often "there is the problem of ensuring an adequate supply of fuel oil to the remoter sites, in view of the virtual absence of roads and the impossibility of using wheeled vehicles during the rainy season".
Lit 5 gives no indication of the required windmill sizes evaluated on the basis of required daily quantities, but the general impression from Lit. 5 is that there too the farmers are used to large pumps.

Conclusions:
From the visits in Kassala and Gezira as well as from Lit. 5 it must be concluded that where water is being pumped, this is mostly done in large quantities. For this reason, 5 m diameter windmills are too small. On the other hand, many locations may not have been used up to now because people are used to big size pumping equipment (see next paragraph). 5 m diameter windmills might be suitable equipment in areas where well capacities and pumping requirements are not so high (e.g. Nyala area).
At the moment, no appropriate designs with diameters larger than 5 m diameter, which would be suitable for local production, are available.
In view of the water needs and availability described, the cost comparisons of section 2.8. are carried out on the basis of a 7 m diameter machine. This 7 m size has been chosen because:

a. water requirements are large
b. SWD feels confident that windmills, designed on the basis of similar concepts as used in 5 m diameter designs, can be designed upto 7 m diameter

c. experience with cost of 5 m diameter windmills can be scaled up if the design concept remains the same.

2.6. Present pumping technology

At present most of the pumping is done by diesel engine driven pumps. In the recent past large petrol engines from automobiles were often used. However, such engines are not designed for years of stationary operation and the sharp increases in petrol prices during the last 10 years has made their operation too expensive.
The pumps being driven are mainly of two types:

a. centrifugal pump with suction line
b. deep-well turbine pump driven with a long shaft.

Because the cost of a centrifugal pump is much lower than the cost of the deep-well pump, the centrifugal pump is used where possible.
A brief impression of investment costs of pumps and engines is given in Annex 7.
Where electricity supply is available pumping is done with centrifugal or deep-well pumps driven by electric motors. Since electricity is only available on some locations and is not expected to become available in most areas (see par. 2.2.), pumps have to be driven by diesel engines or other independant sources such as may become available by the development of solar power, wind power or biogas.

2.7. Import versus local manufacture of windmills

Windmills that can be imported are of the socalled "American-type". These are slow running, multi bladed windmills. They were designed around the turn of the century and have been developed through long experience into highly reliable, long lasting machines. The main problem with these windmills is that they are too costly to be really competitive with fuel engine driven pumps (except in those wind regimes where the winds are very favourable). The high cost results mainly from:

- the heavy weight of these models
- transport cost (sea freight).

One of the chief goals of the SWD program of the last 5 years was to design modern waterpumping windmills which are light and which can be locally manufactured in developing countries. In Sri Lanka, where a wind energy project was started in 1977, this approach has resulted in an initial cost reduction by a factor 4 compared with imported windmills of similar capacities. Secondary advantages of this approach are:

- maintenance is easier because, as a result of local manufacture, more people (mechanics) get familiar with the technology
- spare parts are manufactured locally and do not depend on imports, except for basic materials such as steel and ball bearings
- employment generation
- foreign exchange savings.

In the Sudan, workshops were found to be sufficiently equipped for windmill manufacture and the required materials are available. The results of a small material survey made in Khartoum are presented in Annex 8.

2.8. Cost comparison of windmill pumps versus diesel engine driven pumps

Cost comparisons are sensitive to many variables such as pumping head, required amount of water, wind regime, choice of pumping equipment, loan conditions and application (irrigation or drinking water).
However, as an indication, two examples are given here. The examples are hypothetical cases based on data which can be considered typical for many situations in the Sudan. One example deals with irrigation water, the other with domestic water supply.
The calculations are based on a 7 m diameter windmill.
The cost (including installation) is estimated to be £s 3000 (US$ 3750). For cost estimate see Annex 9.
The wind data from Khartoum will be used to calculate the expected outputs of the windmill.
The Agricultural Bank in Khartoum provides medium term loans (4 years) to farmers on the basis of 9 percent annual interest. Therefore, a 9 percent interest rate is used in the calculations.
Exact figures on the rate of inflation in the Sudan could not be obtained but in discussions with staff of the Agricultural Bank 6 percent was considered the best estimate. Cost of operation, maintenance and fuels are therefore expected to rise by at least 6%.
The windmills are designed for a lifetime of 10 years while the expected lifetime of the diesel engine-pump is 7 years.

2.8.1. Irrigation water

Annexes 9.1. to 9.4. contain the calculations on the cost of water per m^3 useful output (as the windmill output depends on the winds, not all the water that can be pumped can be used).
In the case of pumping for irrigation the cost is £s 0.012 per m^3 if the windmill is used. If a diesel pump set is used, the cost of the water ranges from £s 0.023 to £s 0.015 per m^3 depending on the type of pump (turbine, deep-well pump or centrifugal pump).

2.8.2. Domestic water supply

In the case of domestic water supply the cost is £s 0.16 per m^3 if the windmill is used while the cost is £s 0.22 where the diesel-engine with deep-well pump is used.
The costs in the case of domestic water supply are much higher than in the case of irrigation water supply, because comparatively large and expensive overhead tanks are used.
The results of the calculations indicate that windmills manufactured in the Sudan can pump water for irrigation as well as for domestic water supply at a lower cost than diesel pump sets.

The investment cost of the windmill system (including storage) is in some cases similar to the investment cost of the diesel pump sets; in other cases, the investment cost of the windmill system can be twice as high, depending on application and storage tank construction. Again, the expensive overhead tanks have a great influence. In practice it may be possible to have domestic water supply schemes with storage tanks on groundlevel or only slightly elevated on a small hill.

2.9. Macro-economic considerations

The cost comparisons from the users point of view (see par. 2.8.) represent the micro-economic view point and compare the costs as they appear to the user of the pumping equipment: they include taxes, subsidies and duties on fuel and foreign components and take the (estimated) price increases in future years into account.
The question whether introduction of windmills is beneficial for the Sudan as a whole, in other words for Sudan's national economy, should be analysed in a different way.
Taxes, duties and subsidies should be excluded as they have nothing to do with the real costs. According to the information obtained from the Petroleum General Administration, the diesel price in the Sudan reflects the real cost (not subsidized, not taxed). No information was obtained regarding taxes on imports of diesel-engine pump sets and construction materials (steel, ball bearings etc.).
For the calculations it is assumed that the tax on these imports is 20%.
The interest rate for a macro-economic evaluation should reflect the so-called opportunity cost of capital or the productiveness of capital in viable sectors of the economy. In most countries it is higher than the prevailing interest rates on medium term loans. For the Sudan it is estimated to be 10% which is 1% higher than the interest rate of the bank loans (see par. 2.8.). No price increase rate (cost escalation) is taken into account.
Furthermore, the macro-economic evaluation should be based on shadow prices rather than on the prevailing prices. The shadow price is the price that would prevail if there was an equilibrium between demand and supply. In most developing countries the shadow prices of unskilled labour are lower than the prevailing labour rates while the shadow price of foreign exchange can be considerably higher than the official exchange rate. We have no indication of what the shadow price for labour should be for the Sudan but the scarcity of foreign exchange justifies calculating with a foreign exchange rate which is at least 20% higher than the official rate.

The evaluation from the point of view of the national economy was carried out in two ways: one without a shadow price for foreign exchange and based on a shadow price which is 20% higher. It was found that the difference between the results was less than 4% in the cases where diesel pump sets are used and that no differences exist in the windmill cases. This is because the deduction of import taxes (estimated 20%) balances with the shadow pricing of the foreign exchange (official rate plus 20%). Because the diesel fuel is neither taxed nor subsidized, the shadow pricing leads to a 20% higher fuel cost while other figures remain unchanged.
Since the differences were small (less than 4%), we present here only the figures that were found from calculations without tax deduction and shadow pricing:

Irrigation (Head = 10 m):

- Windmill (7 m dia.)
  The cost of water per m^3 (at present value) is: £s 0.015
- Diesel deep-well pump (4.5 hours of pumping a day)
  The cost of water per m^3 is: £s 0.027
- Diesel centrifugal pump (4.5 hours of pumping a day)
  The cost of water per m^3 is: £s 0.016

Domestic water supply (Head is 40 m):

- Windmill (7 m dia.)
  Cost per m^3 £s 0.220
- Diesel deep-well pump
  Cost per m^3 £s 0.264

The cost figures indicate that also from a macro-economic point of view the windmills are an interesting proposition.
Two other effects on the national economy can be taken into consideration:
1. Employment generation
2. Foreign exchange savings

1. Employment generation

Since diesel pump sets are not manufactured in the Sudan, the work involved in sale and installation of one pump set is estimated to be less than a week (one person).
If a windmill pump set is manufactured in the Sudan, the manufacture, sale and installation will provide work for one man for at least 2 months.
It is clear that the introduction of windmills if produced in Sudan, will create much more employment than is provided by the imported diesel pump sets.

2. Foreign exchange savings

The imported diesel pump sets require an investment in foreign exchange of approximately £s 5000 per installation.
For the windmill pump systems, only basic construction materials such as steel and ball bearings have to be imported. It is estimated that per installation an investment in foreign exchange is required of less than £s 1000.
In addition to this foreign exchange saving of £s 4000 per installation, the use of a windmill will save foreign exchange because no fuel import is required. This will mean a yearly saving in foreign exchange in the range of £s 125 to £s 325 per installation.
Calculated over a period of 7 years (life time of diesel engine) the fuel saving represents £s 600 to £s 1600 at present value.

Conclusion:
Windmill pumps, if locally manufactured, result in foreign exchange savings of around £s 5000 per installation.

In the Sudan approximately 2 million acres are irrigated by pumping (Lit. 1).
If we assume that at least 1% of this area can be irrigated with windmill-pumps, and that for every 2.5 acre we need one windmill, then 8000 windmills will be required. The total foreign exchange saving would amount to £s 5000 * £s 8000 = £s 40,000,000.--.

Savings on fuel imports alone would amount to approximately 8000 * £s 200 = £s 1,600,000.-- a year in foreign exchange.
It is expected that the area that can be irrigated with windmills is larger than 1% of the total pump-irrigated area. Already from these very conservative estimates it becomes clear that in the Sudan the potential of water pumping windmills is considerable.

2.10. The need for a wind energy centre in the Sudan

Previous paragraphs have indicated the potential in the Sudan for wind energy utilization.
Local manufacture of water pumping windmills is feasible if designs are adapted to the materials available in the Sudan. The relative economics of the windmills are promising especially in view of rising oil prices on the world market and the expectation that electricity will not reach most rural areas during the next decades. As further increases in the price of energy and a growth in energy demand are expected, other applications, apart from pumping water, are likely to become feasible in the future.

The introduction of windmill technology involves more than the erection and testing of a few prototype windmills. It is a long process of re-designing and adapting existing designs, testing and experimenting, pilot projects, training of mechanics, promoting the interest of local manufacturers, demonstration and extension towards manufacturers and consumers. To steer this process and to carry out the work involved, a body or an institute is needed where a Wind Energy Centre can be created.

2.11. The tasks of a Wind Energy Centre

During the first two years of its existence, the main goals of the Centre will be:

- to answer the question whether and, if so, how wind energy can contribute to the development of the Sudan
- assuming that the answers to these questions will be positive, the Centre will build up an organization that can introduce and promote wind energy.

The tasks of the Centre will be to adapt and develop wind energy technology to such a degree that:

- manufacturers in the Sudan can handle the technology
- windmills are an attractive alternative for conventional pumping equipment
- windmills are psychologically and sociologically acceptable.

The goals set imply that a further task will be the regular evaluation and reassessment of the potential of this technology.

The Centre will fulfil its tasks by carrying out activities related to the following subjects (which are detailed in sections 2.11.1-2.11.15):

- meteorology
- water data
- adaptation of designs
- construction of windmills
- testing and technical evaluation of windmills
- area classification
- application classification
- pilot project preparation
- pilot project execution, monitoring
- publicity
- manufacturing promotion
- training
- extension
- design
- consultancy.

2.11.1. Meteorology

The collection and evaluation of meteorological data involves:
- visits to existing meteorological sites to evaluate the merit of hitherto collected data for the purposeof wind energy utilization: height of anemometer, surrounding trees and buildings and their effect on the collected data
- evaluation of existing wind data
- correlation between wind, rain and water data
- selection of areas where wind energy utilization is foreseen but wind data are lacking or insufficient; selection of sites in these areas to set up wind metering equipment, taking into account the availability of suitable manpower to read the instruments
- selection and purchase of wind metering equipment for 10 sites
- installation of the equipment
- monitoring and evaluation of incoming data
- development of a plan for further collection and evaluation of wind and other data relevant for wind energy application purposes.

2.11.2. Water data

Ground water and surface water data and existing reports on this subject must be collected. Well capacities and pumping heights are required input data for analysis as well as design of windmills.

2.11.3. Designs adaptation

Initially an existing design will be selected. Since no suitable windmill designs are available with rotors larger than 5 m diameter, it is proposed to start with a 5 m diameter design. This design should be adapted to the materials available in the Sudan, to the special constraints resulting from Sudan's wind regimes (e.g. sand-storms, haboobs etc.) and to other physical and socio-economic constraints.

2.11.4. Construction of windmills

One prototype is to be constructed on the basis of the adapted design. After a first round of testing and modification, another fve windmills of the prototype model should be constructed to be installed close to the workshop (maximum distance say 25 km).
Further work will consist of modifications to improve the reliability of the systems and construction of windmills for pilot projects. As soon as designs are available and have been adapted to materials available in the Sudan, construction of larger diameter windmills can be started.

2.11.5. Testing and technical evaluation of windmills

The main goals are to evaluate the windmill performance in terms of output characteristics as function of average hourly wind speeds and to test the systems reliability.

2.11.6. Area classification

An area classification can be made on the basis of wind data, water data (ground water tables etc.), and the agricultural, domestic and animal husbandry needs. This must take into account socio-economic factors, organizational aspects and available skills in specific areas.

2.11.7. Application classification

Consideration is to be given to other applications e.g. electricity generation, desalinization etc.; these possibilities should be studied so thoroughly that the questions that come from the public can be answered and that policy decisions can be taken regarding whether or not certain applications should be pursued.

2.11.8. Pilot project preparation

- On the basis of the experience and know how gained from the other activities, selection of say 10 sites in the country is to be made.
- A plan of activities, including monitoring, is to be drawn up for each pilot project.
- Several of the sites for pilot projects may pose special design problems (for example pump fixation).
- Construction and installation of the pilot project windmills will have to be carefully planned.
- Construction and installation of windmills. Agreements on who is responsible for what (e.g. maintenance, repairs, monitoring etc.)
- Programmes for studies during the pilot projects (e.g. which crops will be grown under windmill irrigation) will have to be formulated.

It is not intended that the Wind Energy Centre will actually "run" small scale irrigation projects. However, to create a sort of bridge between mechanical windmill engineering and agriculture with small scale irrigation, it is considered essential that the Centre gets involved with small scale irrigation.

2.11.9. Pilot project execution

Keeping track of the progress of the pilot projects; making sure that installations remain in a proper operating condition and that records of wind speeds, outputs, watergifts for irrigation and breakdowns of windmill installation are well kept, will place a heavy responsibility on the Wind Energy Centre.
In many cases the Centre will also have to take responsibility for a proper guidance and monitoring of agricultural aspects (e.g. cropping pattern) of the pilot projects.

2.11.10. Publicity

Through publications in newspapers and magazines (e.g. Sudan Now) the general public, manufacturers and government officials should be kept objectively informed of the progress and the status of the developments. Such publicity is important as a preparation for social and psychological acceptance. At the same time as the prototypes are ready for use in the pilot projects, the design drawings, together with building manuals, can be offered for sale to the public.

2.11.11. Manufacturing promotion

It is not intended that the Wind Energy Centre will start a windmill factory. The idea is to develop interest from existing manufacturers and entrepreneurs and to transfer know how from the Centre to those parties at an early stage. Only in case that it is found that the introduction of windmills in Sudan is delayed by lack of interest from the potential manufacturers, it will be considered to include production organization in the tasks of the Wind Energy Centre.
Through a procedure of tendering orders for windmills can be placed with several manufacturers. These windmills can either be used for pilot projects or can be sold to interested public or private parties. This procedure will allow the manufacturers concerned to get aquainted with the technology without running major risks.

2.11.12. Training

To transfer basic know how on operation, maintenance and repairs of windmills, the centre must provide training of mechanics, staff-members and officers from the places where windmills will be installed. Training on windmill construction and erection is to be provided for the mechanics of manufacturers and government workshops that want to start windmill production. Before real extension work starts, training in the form of demonstrations and lectures will have to be given to extension officers of the organizations through which the extension is to be done.

2.11.13. Extension

Once the results from pilot projects are available extension can start. If possible, existing extension networks of other organizations are to be used. Before extension starts, a good plan or programme will have to be drawn up. It is foreseen that the role of the Centre will be limited here to coordination of the activities and to technical support in the form of site selection and advice in special situations.
Apart from the extension towards the users (e.g. farmers), extension towards manufacturers will be required. This is in fact a continuation of the earlier mentioned "manufacturers-promotion" but now more direct, in the form of, for example, training of mechanics, provision of short term credit facilities, adaptation of designs on the basis of the manufacturers experiences etc.

2.11.14. Design

This will be a continuous activity. Once the design problems related to the adaptation and modification of the 5 m diameter windmills are reduced to a further gradual improvement of the reliability, design work should start on larger diameter windmills. Criteria for this design will be derived from the information that has become available by that time. If suitable existing designs are then already available, these can be adapted to conditions in the Sudan. One of the major constraints in the Sudan is that regular maintenance cannot be relied upon. The great distances and the difficulties with communications make extremely high demands on any equipment to be used in rural areas. The ultimate goal in the design work must therefore be to design maintenance-free windmills with a lifetime of at least 10 years. However, it may be necessary to make provisions for systematic overhauls after five years.

2.11.15. Consultancy

In the long run, the task of the Centre will become more and more that of consultants. Feasibility studies will be carried out for other institutes and projects where wind energy utilization is foreseen.
For special situations special designs (adaptations) will be required.
The Centre will have the function of a reference centre on wind energy matters for Sudan.

3. REQUIREMENTS FOR A WIND ENERGY CENTRE

To create a Wind Energy Centre that can fulfil the tasks described in the previous chapter, several requirements have to be met.

3.1. Institutional requirements

The Wind Energy Centre should preferably be created within the existing administrative, research and development structure of the country. The institute in which the Centre could best be created, would be one which:

- takes an active interest in research on and development of alternative energy sources, amongst others wind energy; wind energy development should fit in well with other activities of the institute as well as with the institutes future plans
- is able to provide or recruit the required staff
- is able to obtain funds for running costs and material costs
- has good connections with and good access to other institutes such as Agricultural Department, Rural Water Corporation and Universities
- can provide workshop facilities and a suitable test site.

3.2. Staff

Initially, the Centre will require the following staff:

- 1 senior mechanical engineer
- 1 graduate mechanical engineer
- 2 technicians
- 1 trainee technician
- 1 draughtsman
- 2 mechanics (welders/fitters/lathesman)
- 2 assistant mechanics
- 1 civil works foreman.

After approximately six months (from the start), one agronomist, familiar with irrigation, will be required.
Labourers will be hired as and when required.

3.3. Equipment

Wind meters

It is envisaged that the Wind Energy Centre will require approximately 15 wind meters (anemometers) during the first two years of its activities. These anemometers will be installed on possible pilot project sites to assess the wind potential and to evaluate the performance of the windmills.

Water meters

To evaluate output performance 5 water meters of the low pressure type are required.

Stroke counters

To evaluate the performance of the pumps 5 mechanical counters are required.

Engine driven water pumps

For installation work on open wells, 2 engine driven 2" water pumps are required.

Other equipment

During the process of adaptation of the existing designs to suit the available materials and local conditions, additional equipment may be required, depending on the problems that are encountered. For the first two years of activities of the Wind Energy Centre, funds are to be reserved for this.

For field work a small mobile generator welding set will be required.

3.4. Office space and services

The Centre will require office space, furniture and stationary in Khartoum.
Services such as typing, telephone, electricity etc. will be needed. Accomodation will be needed after the initial year as it is expected that trainees will then be spending periods at the Centre.

3.5. Test site

A test site will be required where prototype windmills can be erected and tested. The test site should be an open field with good winds througout the year. Ground water should be available so that several wells can be dug or drilled. It should be located close to the head office to facilitate communications.

3.6. Workshop and materials

The tasks to be entrusted to the Wind Energy Centre, make it essential that the Centre has immediate access to a workshop at all times. The workshop should be equipped with basic equipment such as a turning lathe, a drilling machine, welding equipment (electric-as well as gas-welding) and several sets of basic tools such as spanners, hammers etc.

The only good solution seems to be for the Centre to have its own workshop located at or near the test site.
A good stock of materials will have to be stored to prevent stagnation because of material shortages.

3.7. Transport

To carry out the programme, the Wind Energy Centre will require the following vehicles:

- 1 landrover, long wheel base, equipped with winch
- 1 Toyota landcruiser
- 1 trailer, to be used in combination with both landrover as well as landcruiser
- 1 Toyota pick up.

3.8. Training and documentation

Training of the staff is to be the primary goal of the first two years of the programme. The training will take place in a natural and practical way, that is by taking part in proposed activities of the first two years.
In addition to this, specialists will be invited to give lectures and to work for short periods with the staff of the Wind Energy Centre.
Main subjects of the training will be:

- wind data analysis
- site selection
- rotor design
- pump design
- rotor-pump matching
- safety mechanism design
- tower design
- windmill construction and installation
- output predictions
- testing and analysis
- project management
- small scale irrigation
- crop selection
- pilot project selection and management

To facilitate the training, a library will be started with literature on wind energy and related subjects. In a later stage of the programme this library will be the basis for the Wind Energy Centre's function as a reference centre on wind energy matters for the Sudan.

3.9. Technical assistance

The activities described will require the assistance of several expatriate experts.

N°1. Wind energy expert with design and management capacity; during the first year.

N°2. Wind energy expert experienced in windmill construction and installation; during the first two years.

N°3. Wind energy expert with university degree in agricultural engineering.

Specific details for job description and profil descriptions are given in Annex 10.1, 10.2 and 10.3.
In addition to this, the programme will need technical and organizational back stopping from an organization that has experience with programmes such as proposed here.

4. PROPOSAL

It is proposed to start a programme on wind energy in the Sudan, to be initiated with the support from the SWD, Steering Committee Wind Energy Developing Countries.
The minimum duration of such a programme is considered to be at least five years. It is difficult to plan such a programme for a full five years, so the parties involved will be asked to commit themselves for a period of two years only (phase I).
The programme will be called Wind Energy Project Sudan (WEPS).
The responsibility for the project will be, for the Sudan, in the hands of the Energy Institute which is part of the National Council for Research of the Government of the Sudan. For the foreign assistance to the project, the responsibility will be in the hands of the party that finances the assistance to the project, which will be provided by SWD, Steering Committee Wind Energy Developing Countries.
This committee, being a cooperative programme contributed to by several institutes in the Netherlands, is coordinated by DHV Consulting Engineers. In its capacity as coordinator of SWD, DHV will bear the formal responsibility for the execution of the project. SWD is a programme that assists developing countries in the development of wind energy utilization (see Annex 11).
The long term aim of the Wind Energy Project Sudan is to create and establish a Wind Energy Department (within the Energy Institute) that can develop and introduce wind energy technology in the Sudan. The aim during the first two years of the project (phase I) is to design, develop and test water pumping windmills that are suitable for local manufacture in the Sudan, and to prepare and initiate pilot projects.

4.1. Institute

The project will be carried out at the Energy Institute in Khartoum. This institute was established in 1976 as an organ of the National Council for Research.
The objectives of the institute were, from the start, to carry out R and D in the field of new forms of energy and to popularize their application. A second aim was to establish a base within the institute for training and expertise on solar, wind and biomass energy.
In the field of solar energy the Institute has been active in all areas of research pertaining to the application of solar energy to the long-term needs of the country. These include water desalination, water heating, steam generation, drying processes, refrigeration and water pumping.
Concurrently a concentrated effort of development of staff and research facilities has been in progress. Bilateral cooperative programs with European countries are being established, giving priority to training, exchange of information and joint project undertakings.

The Solar Energy Department (formerly Institute of Solar Energy, established in 1973) is comparatively well established with 3 physicists and 7 engineers of whom 4 are being further trained in Europe and the United States. The Solar Energy Laboratory is now housed in the Faculty of Engineering and Architecture of the University of Khartoum.
International assistance is specially needed for the establishment of the wind energy and the biomass departments. A programme of recruitment and training of staff for these departments was started years ago. This programme has been slowed down by the Institute itself because of lack of housing and research facilities.
Germany has agreed to provide assistance for the establishment of research facilities (including a workshop) and laboratories at the Institute premises near Soba (18 km south of Khartoum).
Being part of the National Council for Research, the Energy Institute has good access to other government departments and institutes and it is historically linked with the University of Khartoum.

4.2. Staff

The senior mechanical engineer, Mr. El Tayeb Idris Eissa, has been studying wind energy technology at Reading University in UK for the last 2.5 years.
In 1974 and 1975, Mr. El Tayeb Idris Eissa was already working on water pumping windmills, as part of his BSc course. He will return from the UK in February 1981.
Other staff required (lit. 6), as specified in paragraph 2.3., will be provided by the Energy Institute.
For expatriate staff see par. 4.9. "Technical assistance".

4.3. Equipment

In accordance with the requirements as laid down in par. 3.3., the donor of the foreign assistance will finance the supply of:

- 15 anemometers (Dfl. 20,000)
- 5 water meters (Dfl. 25,000)
- 5 stroke counters (Dfl. 1,500)

and a budget for "other equipment" to be defined during the execution of the project (Dfl. 10,000).
If separate anemometer masts are required, they can be manufactured in Khartoum and the cost will be borne by the Energy Institute (the cost of 15 masts will be approximately £s 7,500).
The Energy Institute will purchase 2 engine driven 2" water pumps for the project (£s 3,500).
A diesel generator welding set (Dfl. 6,500) will be supplied by the donor.

4.4. Office space and services

The Energy Institute will provide office space, furniture, stationary, typing facilities, telephone and electricity at the office in Khartoum as well as on its premises near Soba.
The donor will supply one copying machine (Dfl. 5,000).

4.5. Test site

The Energy Institute has been allocated a site of 50 ha near Soba at approximately 18 km from Khartoum.
This location is considered very suitable as a test site. On the site are several small buildings, a tube well and a solar pumping installation. The site is located right on the main road from Khartoum to Wad Medani. The land is very open and well exposed to winds from all directions. The wind regime can be considered representative for the northern half of the Sudan.
The water level is approximately 15 m under groundlevel and the yield of the existing tube well is higher than 1 l/s which is sufficient for testing windmills. Three more wells will be required for the testing of the prototype windmills.
A meteorological station, consisting of thermometers, solar radiation meters, rain gauges and a low level cup counter anemometer, has already been set up by the Energy Institute.
The cost of the additional wells that are needed will be borne by the Energy Institute.

4.6. Workshop and materials

Under the development cooperation programme between Germany and Sudan a complete workshop will be constructed and equipped at the Soba test site. This is expected to take place by the end of 1980.
If circumstances should result in a delay in this construction work, the project will initially be able to make use of the well equipped workshop of the Khartoum University, faculty of Engineering and Architecture. The Energy Institute has close ties with the University and cooperates also on other projects with the University.
A good stock of materials will have to be stored at Soba test site to prevent the progress of the project being hampered by the sudden occurrence of material shortages.

4.7. Transport

As specified in par. 3.7. three vehicles will be required. These vehicles will remain the property of the donor until the termination of the donor participation in the project. The cost of insurance, maintenance and drivers will be borne by the donor while Sudan will bear the cost of the fuel.
Costs of other transport required inside the Sudan will be borne by the Energy Institute.

4.8. Documentation

Literature on wind energy (Dfl. 5,000).

4.9. Technical assistance

The technical assistance described in par. 3.9. and to be provided by SWD will be financed by the donor.
This assistance includes the following:

- a total of 50 man-months of experts working on the project in the Sudan, distributed as follows:
  - 12 months wind energy expert (design and management)
  - 24 months wind energy expert (construction and installation)
  - 14 months agricultural graduate (small scale irrigation)
- 3 visits per year to Sudan by the project coordinator or senior experts; the duration of each visit will be about 10 days
- project coordination by SWD in the Netherlands
- project administration by SWD in the Netherlands
- project backstopping by SWD in the Netherlands
- complete design of a 5 m diameter windmill pump installation at the start of the project
- complete design of a 7 m diameter windmill pump installation before the end of the first six months of the project
- complete design plus building manual of a 3 m diameter windmill pump installation, if during the course of the project useful and interesting applications are found for this smaller type.

4.10. Workplan

A workplan in the form of a bar chart is presented in Annex 12. The plan shows approximately at what time after the start of the project certain activities are planned. A brief description of the activities is given here:

Organization

Especially at the beginning, a lot of time will be spent on organizing the work of the Wind Energy Department. The work also includes the clearing of vehicles and equipment.

Meteorology

This involves the study and evaluation of existing data, selection of sites for anemometers and monitoring of the data that become available. This activity also includes the collection and study of rainfall data for the preparation of the pilot projects.

Water

At the beginning information must be collected regarding ground water and surface water in the area of Khartoum. This information will be vital for the selection of potential sites for the first pilot project series. The area to be covered by this activity is to be gradually expanded from the areas near the test site to the complete northern half of the Sudan, where water pumping by wind energy is feasible as far as available wind speeds are concerned.

Design adaptation

The project will start immediately with the adaptation of a 5 m diameter design to the materials available in the Sudan.
Six months after the start, a design of minimum 7 m diameter will be available from SWD and this design will be adapted in a similar way.

Construction

During the design adaptation of the first prototype, construction of the simple parts, such as the tower, can already be started. After the prototype has performed acceptably for one month, construction can start of 5 more windmills of this type. These windmills will be installed in the area of Khartoum, preferably close to the workshop, to form the first pilot projects. After the design of the larger windmill has been adapted, a similar process can start for this type.

Testing

Immediately after its construction, the first model of each prototype must be thoroughly tested on the test site. In this phase of the development the testing is to be concentrated on performance and strength. The pilot projects will form a test for reliability but in that stage monitoring of the performance must also be continued.

Redesign

The test results and the experience from the first pilot projects will indicate where the designs need improvement and modification. For specific applications (e.g. higher pumping head), the designs will also require modifications.

Design training

The SWD experts will transfer SWD knowledge on water pumping windmills to their counterparts in as early a stage of the project as possible. Preference will be given to a systematic transfer of knowledge (e.g. by concentrating on training one day a week).

Agro training

On the basis of data on wind, rainfall, ground water and surface water, agriculture, population density, accessibility etc., a classification will be made to enable the selection of pilot project sites as well as a further assessment of potential.

Application classification

During the process of the area classification, an inventory will be made of the possible applications of water pumping windmills in the Sudan (irrigation domestic water supply, cattle water supply). Looking ahead, the project will investigate what other applications of wind energy (e.g. electricity generation) may be interesting in the future.

Pilot projects I - preparation

On the basis of the data collected, 5 sites will be selected in the Khartoum area, preferably in the area close to the workshop.
For each site a plan will be made regarding windmill installation, land preparation, crops to be grown, irrigation schedule etc.
Decision will be taken with regards to the size of the storage tank required and the design of the pump fixation in or on the water source.

Pilot projects I - execution

Project execution starts with the construction of the storage tank, the preparation of the land and the installation of the windmill. After a few weeks of satisfactory pumping, the cultivation of the crops can start, supposing that other factors (such as time of the year, availability of labour etc.) allow this. Wind speed and pumping rate will be recorded daily with the help of integrating recorders. The pilot project will be visited regularly for technical inspections as well as to monitor and to discuss with the farmers the progress and difficulties encountered. It is expected that it will take at least three years before everything and everybody is optimally adjusted to new conditions. However, after six months to one year preliminary conclusions can be drawn regarding the reliability of the pumping systems as well as some preliminary conclusions regarding agriculture and irrigation.

Pilot projects II - preparation

On the basis of the expected outputs of the second prototype (large diameter) and other data, sites will be selected in a similar way as was done for the pilot projects I. The distance between the sites and the workshop may be gradually increased, depending on the difficulties anticipated.

Pilot projects II - execution

This can be carried out along similar lines to those of pilot projects I.

Manufacturing promotion

At the start of the first pilot projects but after more than six month of experience regarding the technical performance of the 5 m Ø windmills, manufacturers promotion can start. In spite of the fact that, at that moment, little is known about the long term reliability of the systems, it is considered wise to start this promotion at an early stage because:

a. in this way the project will receive feed back information from manufacturers regarding difficulties encountered in the construction of the windmills; if necessary, redesigns can be made
b. an educative process can take place in anticipation of a demand from the public; such a demand cannot be met by the project's workshop.

It is proposed to initiate this manufacturing promotion by placing orders for windmills with several manufacturers, after completing a tendering procedure. The windmills supplied can either be used for pilot projects, or can be sold to the public.

Publicity

The same time as the manufacturers promotion begins, publicity can be started by publishing articles in newspapers and magazines (e.g. "Sudan Now"). It may also be decided to advertise and sell the design drawings to any party interested in trying out a windmill. The Wind Energy Department can provide free consultancy regarding manufacture and site selection.

Extension

Plans for extension have to be made during the project. It is recommended to effect the extension through and with the help of existing extension organizations.

Reports

After one month from the start of the project, an inception report will be written.
Every three month a report will be written to document the progress of the project. In this way, both the Sudan Government and the party which provides the financial assistance will be kept informed. After one year, the progress report (N°4) will have the character of an interim evaluation which will allow a decision to be made whether or not the project should be continued. The same will apply to report N°8, which will be written after the second year.

LITERATURE

1. Sudan Energy Issues by the National Council for Research; presented at the 10th World Energy Conference in Turkey (Septembre 1977).

2. Wind Energy for Windmills in Sudan, by Y.P.R Bhaldram; memoir No7 of the Sudan Meteorological Service.

3. Annual Agro-meteorological Report; April 1978-March 1979; Meteorological Department, Khartoum, Sudan.

4. Output predictions and selection of design wind speeds for windmills driving piston pumps, by W.A.M. Jansen; March 1979; Wind Energy Unit, Water Resources Board, 2 Gregory's Avenue, Colombo-7, Sri Lanka.

5. Wind power in the Sudan, by Stuart S. Wilson, Department of Engineering Science, University of Oxford, Januari 1975.

6. Power generation from the wind, by Mr. El Tayeb Idris Eissa and Mr. Hashim Mohamed Ahmed, University of Khartoum, faculty of engineering and architecture, department of mechanical engineering, 1975.

7. "Landendocumentatie Soedan" (country documentation Sudan by KIT, Koninklijk Instituut voor de Tropen (Royal Institute for the Tropics, dept. of Agricultural Research). From this publication, the maps in Annex 6 were copied.

ANNEX 1

KHARTOUM (1949-1953)

LATITUDE 15° 36'N - LONGITUDE 32° 33'E - ELEVATION 380 METRES (1,245 FEET) ABOVE MSL

	Hourly mean wind speed (m.p.h.)											Maximum gust (m.p.h.)
	< 1	1-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	Average	Maximum	
	Percentage frequency											
January	0.1	5.9	29.1	45.8	17.4	1.5	0.1	0.0	0.0	9.3	27	36
February	0.4	1.7	14.7	49.2	28.6	5.0	0.3	0.1	0.0	11.2	32	49
March	0.4	1.8	15.3	47.3	30.1	4.7	0.7	0.0	0.0	11.4	28	41
April	0.6	8.5	34.6	36.8	16.9	2.4	0.2	0.0	0.0	8.9	30	41
May	1.8	13.1	30.8	30.9	15.8	4.9	2.3	0.6	0.0	9.4	36	59
June	2.5	13.5	30.1	26.9	17.9	6.7	2.0	0.2	0.0	9.5	37	54
July	1.9	6.7	18.6	27.8	31.6	10.2	2.7	0.5	0.0	11.9	39	59
August	1.5	8.6	21.3	33.2	27.3	6.0	1.6	0.4	0.0	10.8	38	79
September	2.2	16.7	28.1	29.1	18.0	3.8	1.4	0.5	0.1	9.0	35	64
October	2.9	16.8	41.2	31.0	7.4	0.5	0.3	0.0	0.0	7.0	34	57
November	1.0	9.3	33.9	44.9	11.0	0.0	0.0	0.0	0.0	8.2	19	30
December	0.6	7.8	27.3	47.5	16.1	0.7	0.0	0.0	0.0	9.0	24	35
Year	1.4	9.5	27.3	37.0	19.6	3.9	1.0	0.2	0.0	9.6	39	79

ANNEX 2

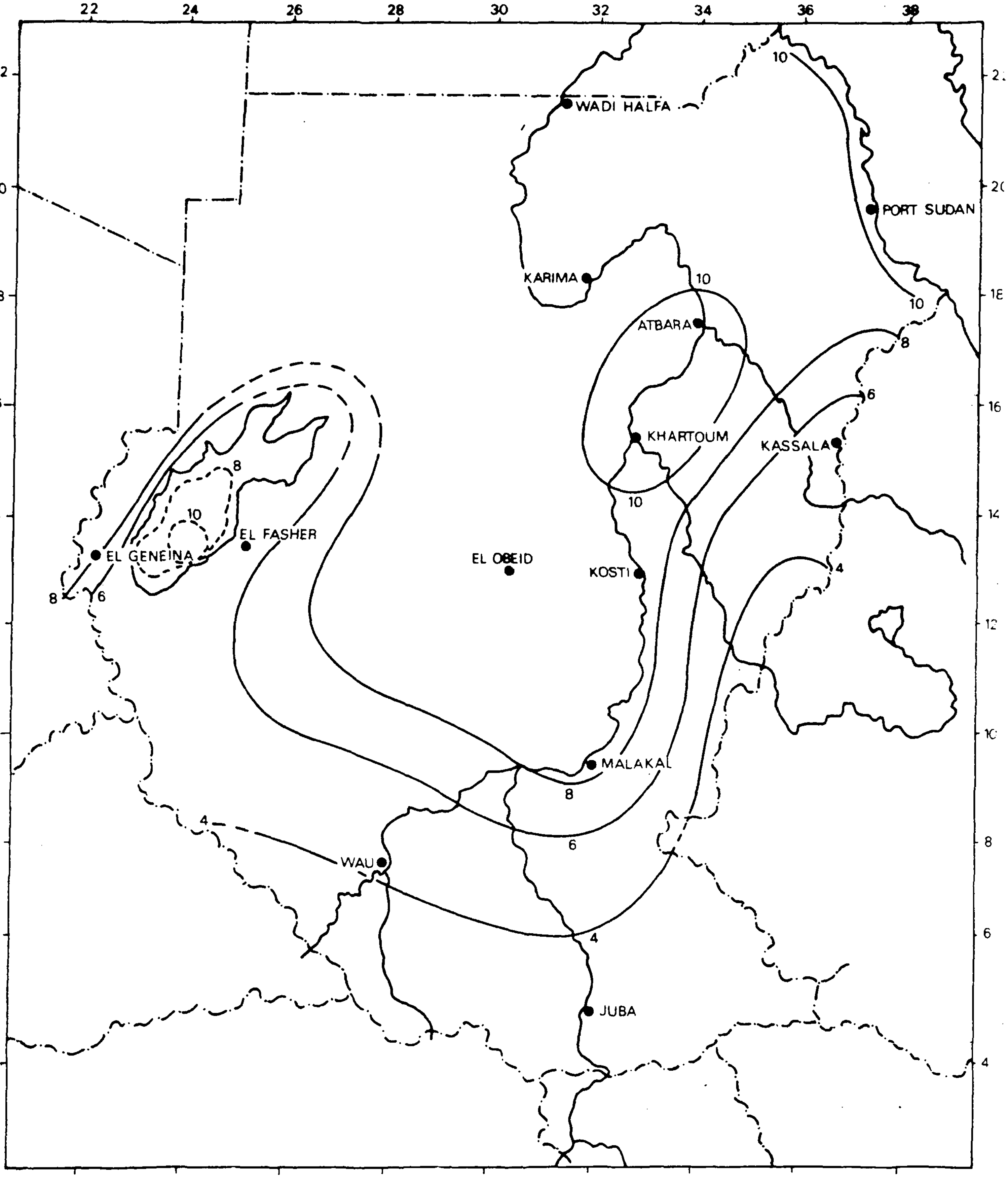
AVERAGE MONTHLY WIND SPEEDS AND MAXIMUM GUSTS (M/S)

Place Month	WADI HALFA 50-53	KARIMA 50-53	ATBARA 50-53	PORT SUDAN 50-53	KHARTOUM 50-53	KASSALA 50-53	EL OBEID 50-53	KOSTI 50-53	EL FASHER 50-53	EL GENEINA 50-53	MALAKAL 50-53	WAU 50-53	JUBA 50-52
1	4.1	3.5	4.5	5.0	4.2	2.3	4.1	3.1	2.2	3.3	3.9	1.7	1.5
2	4.6	4.2	4.6	5.1	5.0	2.2	4.2	3.5	2.8	3.9	4.0	2.0	1.3
3	4.6	4.4	4.6	4.7	5.1	2.5	4.5	3.8	3.0	3.4	3.4	2.0	1.6
4	3.8	3.9	3.4	3.7	4.0	1.9	3.2	3.0	2.5	3.5	2.8	2.1	1.7
5	4.6	3.6	3.0	3.2	4.2	1.9	3.1	3.1	2.6	2.6	2.5	1.6	1.5
6	4.2	3.5	2.9	3.4	4.2	3.0	3.9	3.9	2.3	2.5	2.5	1.4	1.3
7	4.1	3.4	4.0	3.8	5.3	3.2	4.6	4.0	2.3	2.8	2.5	1.5	1.1
8	3.7	2.7	3.5	3.2	4.8	2.6	3.5	3.1	1.6	2.1	2.0	1.3	1.1
9	3.6	3.3	2.9	2.6	4.0	2.4	2.5	2.5	1.3	1.7	1.7	1.4	1.3
10	4.3	3.5	3.0	3.0	3.1	1.7	2.9	2.3	1.9	2.5	1.8	1.4	1.3
11	4.5	3.8	4.2	4.2	3.7	1.8	3.5	3.3	2.1	3.8	2.6	1.9	1.5
12	3.8	3.7	4.7	4.8	4.0	2.0	3.9	3.8	1.9	3.9	4.0	2.3	1.3
Year	4.2	3.6	3.8	3.9	4.3	2.3	3.7	3.3	2.2	3.0	2.8	1.7	1.4
Max. gust	32.2	29.9	37.5	34.9	46.9	37.5	37.1	38.4	38.9	34.4	36.2		

MEAN WIND SPEED IN M. P. H (Approximate)

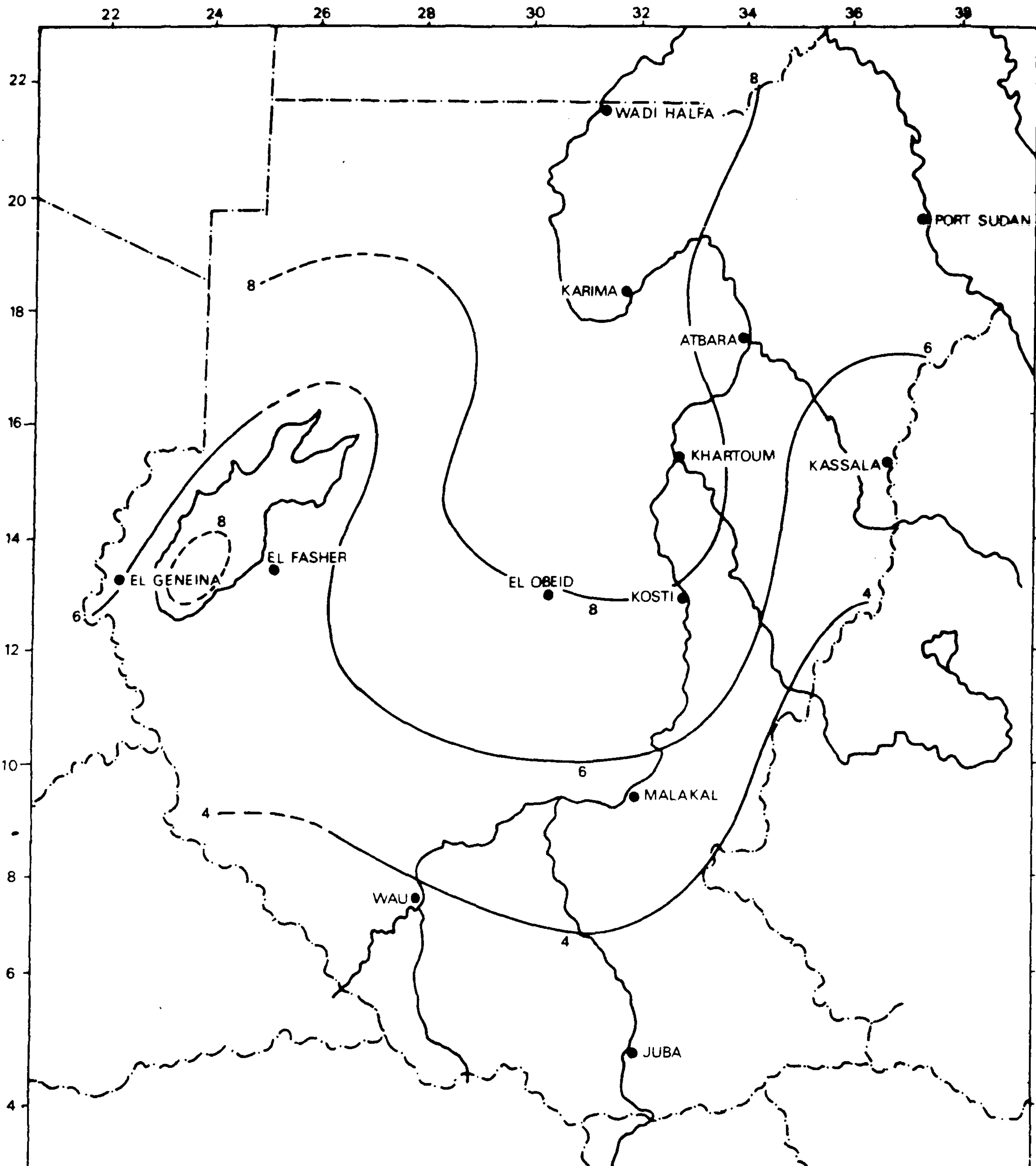
(December–March)

FIG 1



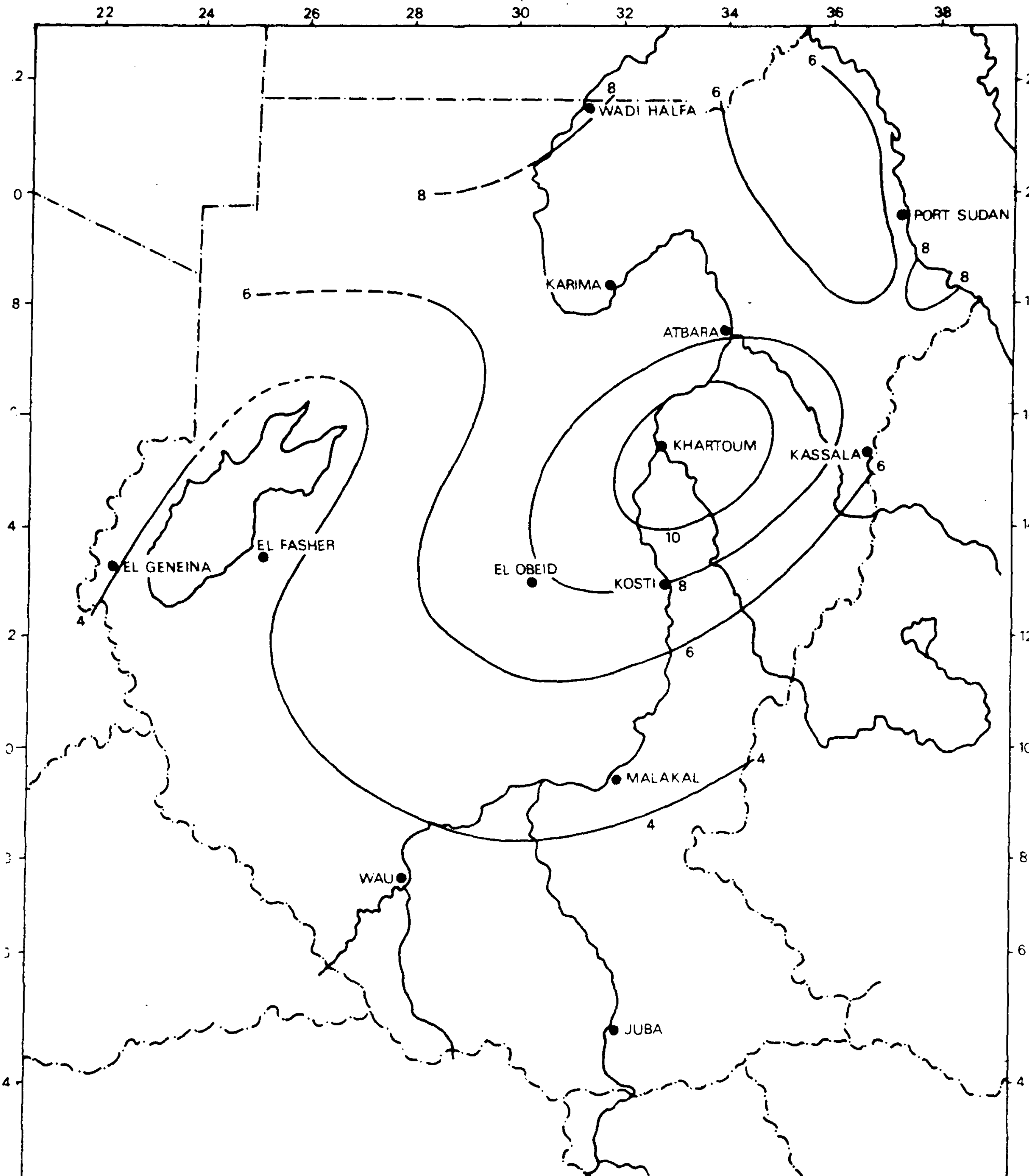
MEAN WIND SPEED IN M P H (Approximate) FIG 2

(April—June)



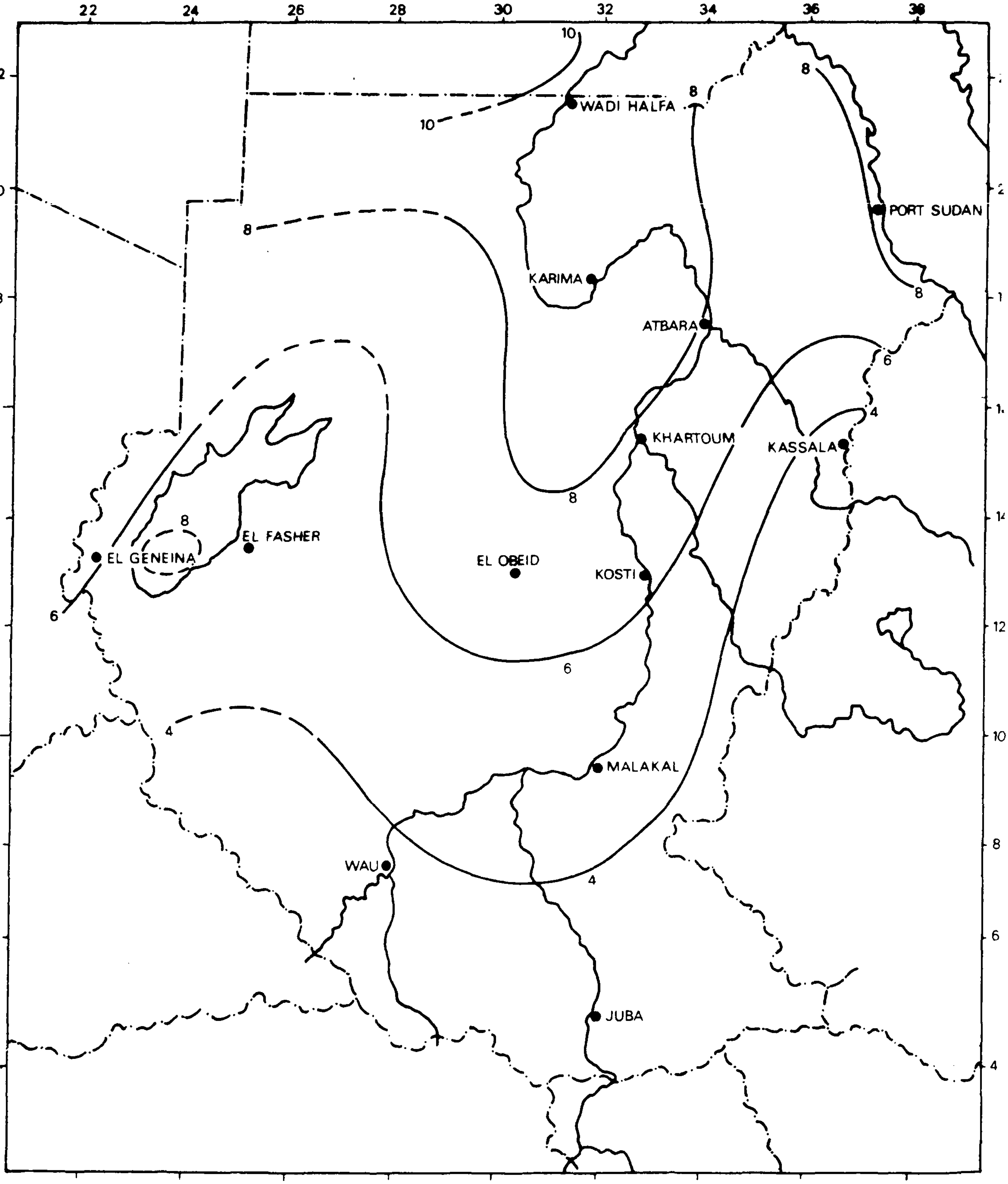
MEAN WIND SPEED IN M P H (Approximate) FIG.3

(July – September)



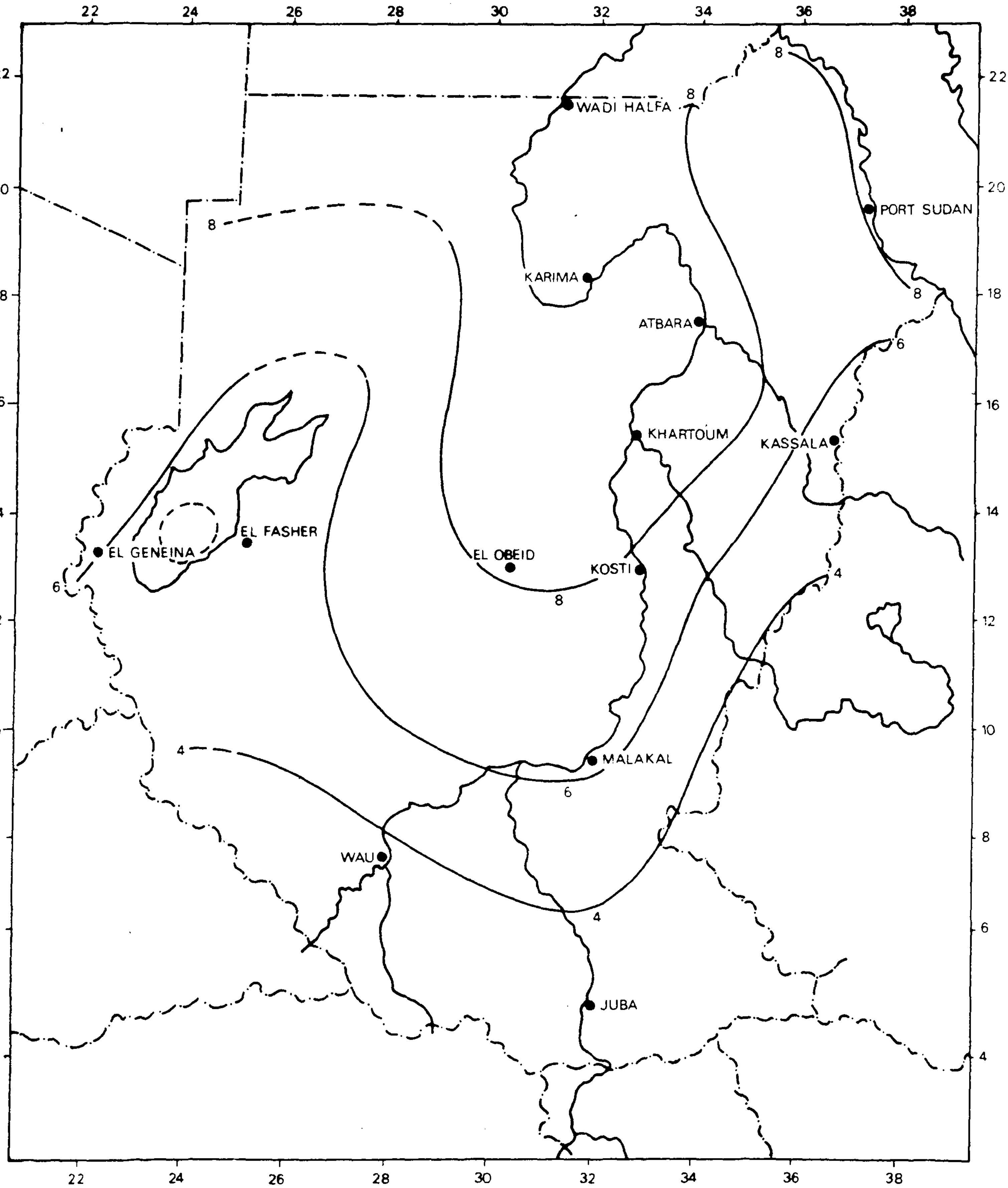
MEAN WIND SPEED IN M P.H (Approximate) FIG 4

(October—November)

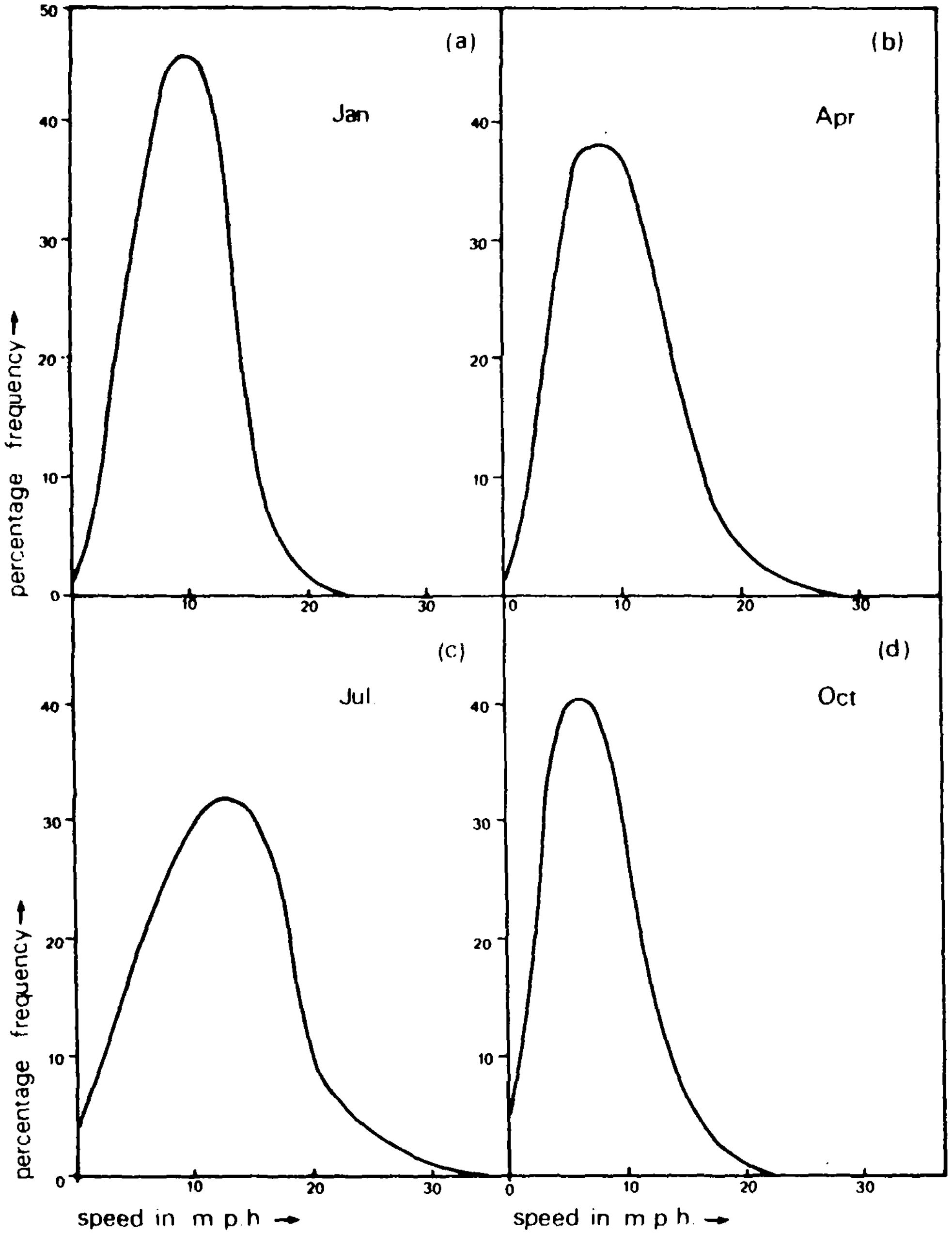


MEAN WIND SPEED IN M. P H (Approximate)
(ANNUAL)

FIG 5



KHARTOUM (1950 – 53)



KHARTOUM (1950 – 53)

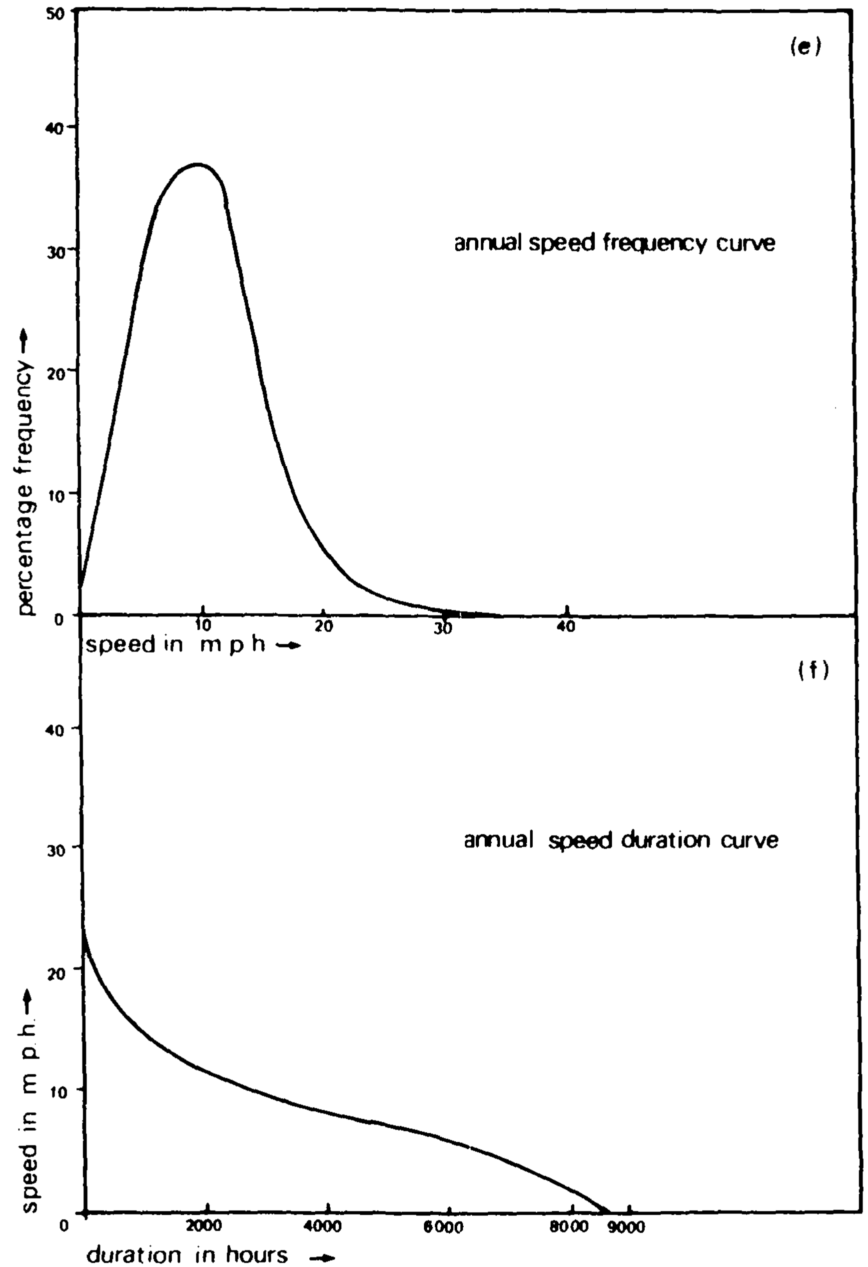


FIG10

ANNEX 4.2.

MEAN HOURLY WIND SPEED AT KHARTOUM (M.P.H.) - 1949-1953)

Hour (L.T.)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
00-01	9.4	9.4	9.3	7.6	8.1	8.9	11.7	9.7	8.0	6.2	8.4	8.2
01-02	9.4	9.9	9.3	7.9	8.5	9.5	11.8	10.0	8.6	6.5	8.7	8.2
02-03	9.6	10.2	9.5	7.7	8.2	9.4	12.1	9.4	9.1	6.4	8.7	8.5
03-04	9.6	10.2	9.9	7.9	8.0	9.3	11.3	9.5	10.0	6.5	8.6	8.7
04-05	9.4	9.9	9.6	8.0	8.4	9.3	10.9	10.2	9.0	6.2	8.2	8.3
05-06	9.3	10.0	9.3	7.8	7.8	9.0	10.2	9.4	8.0	6.0	8.0	8.1
06-07	9.2	9.8	8.7	7.7	7.9	10.0	11.5	10.4	7.8	5.5	7.5	7.8
07-08	9.3	9.8	9.8	9.5	9.4	11.9	13.8	11.7	9.7	6.8	9.0	8.8
08-09	11.0	12.7	13.3	11.5	11.6	12.6	14.9	12.7	10.5	8.0	11.2	11.0
09-10	12.0	14.0	15.1	12.5	11.7	11.7	14.4	13.0	10.4	8.0	11.1	11.8
10-11	11.9	13.7	14.8	12.0	11.0	10.7	13.6	13.0	9.8	7.8	10.4	11.7
11-12	11.2	12.8	14.0	10.8	9.6	9.6	12.8	12.6	9.5	7.2	9.3	10.7
12-13	10.6	12.1	13.1	9.5	8.8	8.7	11.2	12.0	8.7	6.9	8.2	9.7
13-14	10.6	11.9	12.3	9.2	8.2	7.6	10.6	11.1	8.5	6.6	7.9	9.4
14-15	10.7	12.2	12.2	8.8	8.0	7.2	9.8	10.1	8.0	6.5	7.8	9.1
15-16	10.9	11.9	12.0	8.7	7.7	6.6	9.2	9.6	7.1	6.5	7.5	9.2
16-17	10.6	11.7	11.9	8.3	7.5	6.3	8.8	8.7	6.5	6.3	7.2	8.6
17-18	9.3	10.2	10.5	7.4	7.1	5.7	8.5	8.1	6.4	6.0	6.7	7.3
18-19	8.4	8.7	8.7	5.6	6.5	4.9	7.6	7.7	6.2	5.2	6.1	7.2
19-20	8.4	8.2	8.6	6.1	6.3	5.2	8.5	7.4	6.7	5.5	6.9	7.9
20-21	8.7	8.6	8.4	6.2	6.8	6.6	9.2	8.0	7.8	5.5	7.2	7.4
21-22	8.5	8.7	8.7	7.1	7.2	7.7	10.4	8.6	7.4	5.6	7.6	7.5
22-23	8.7	8.6	8.9	7.6	8.0	7.7	10.9	8.8	7.8	6.0	8.2	7.6
23-24	9.3	8.8	8.5	7.5	8.7	9.2	11.5	9.3	8.0	6.2	8.3	8.0

ANNEX 5

OUTPUT PREDICTIONS

Yearly outputs can be approximated with:

$$P_{av} = 0.1\ V_{av}^3\ A \text{ (watts)}$$

where

P_{av} = average net water lifting power (W)

V_{av} = yearly average wind speed (m/s)

A = rotor area (m^2)

With a 5 m diameter rotor for a windmill pump in the Khartoum wind regime (V_{av} = 4.3 m/s) the average output is expected to be:

P_{av} = 156 watts

This output prediction is reasonably accurate if the design wind speed of the system is equal to the yearly average wind speed. If the design wind speed is lower than the average wind speed, outputs will be reduced by a factor

$$\frac{V_{design}}{V_{average}}$$

For monthly average output predictions based on monthly average wind speeds

$$P_{average} = 0.1\ V_{design}^{1.5}\ V_{average}^{1.5}\ A \text{ (watts)}$$

can be used if $V_{average} > V_{design}$

In other cases:

$$P_{average} = 0.1\ V_{av}^3\ A \text{ (watts)}$$

For more information on these prediction methods see Lit. (4)

Output predictions for windmills in Gezira area for domestic water supply.

Wad Medani: average wind speeds (yearly):

at 12.2 m height is 4 m/s

at 20 m height is 4.4 m/s.

Average wind speed in October:

at 12.2 m height 2.8 m/s

at 20 m height 3.1 m/s

The windmills that were used had 5.2 m Ø rotors and 20 m high towers.
Waterlevel 30 m below groundlevel.
Tanklevel 10 m above ground level
Total head = 40 m.
Assume design wind speed = 3.1 m/s.

$$P_{av,\ year} = \left(\frac{3.1}{4.4}\right) * 0.1 * 4.4^3 * \frac{\Pi}{4} * 5.2^2 = 127 \text{ watt}$$

$$P_{av,\ october} = 0.1 * 3.1^3 * \frac{\Pi}{4} * 5.2^2 = 63 \text{ watt}$$

$$P = \emptyset_v * \Delta p = \emptyset_v * 4 * 10^5$$

$\emptyset_{v\ (average,\ year)} = 0.317$ l/s = 27.4 m^3/day
$\emptyset_{v\ (average,\ october)} = 0.158$ l/s = 13.6 m^3/day

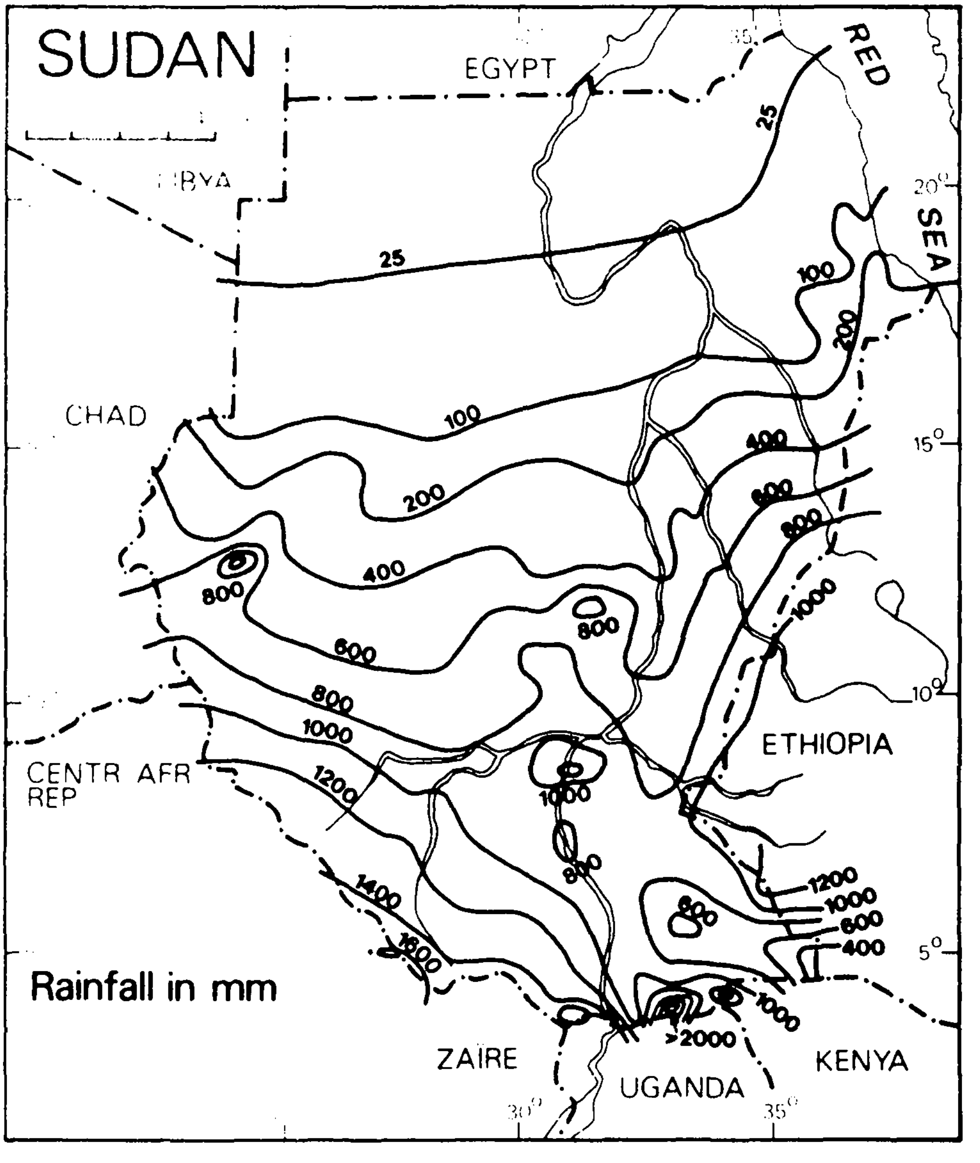
Required diameter for average output of 73 m^3/day would be:

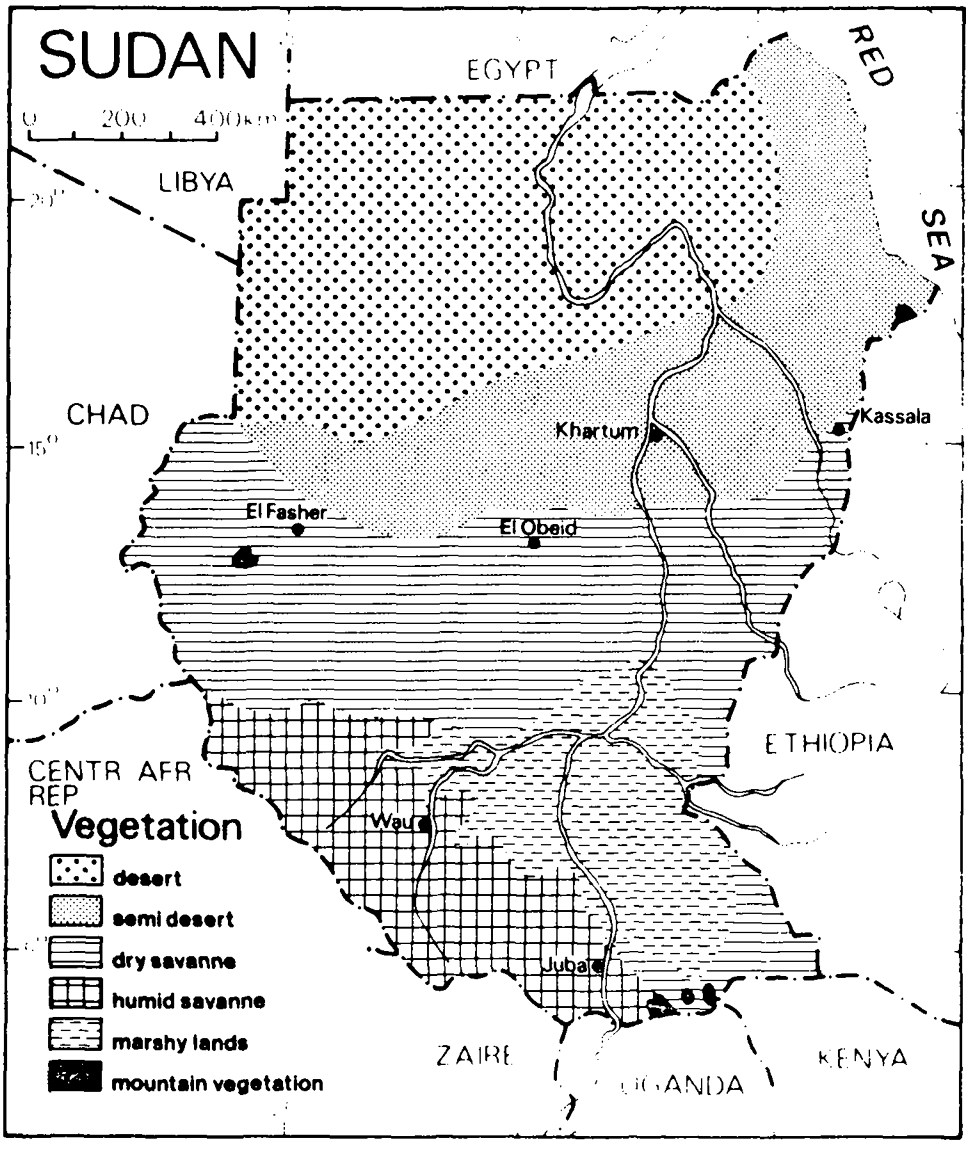
$$D = \sqrt{\frac{75}{27.4}} * 5.2 = 8.6 \text{ m}$$

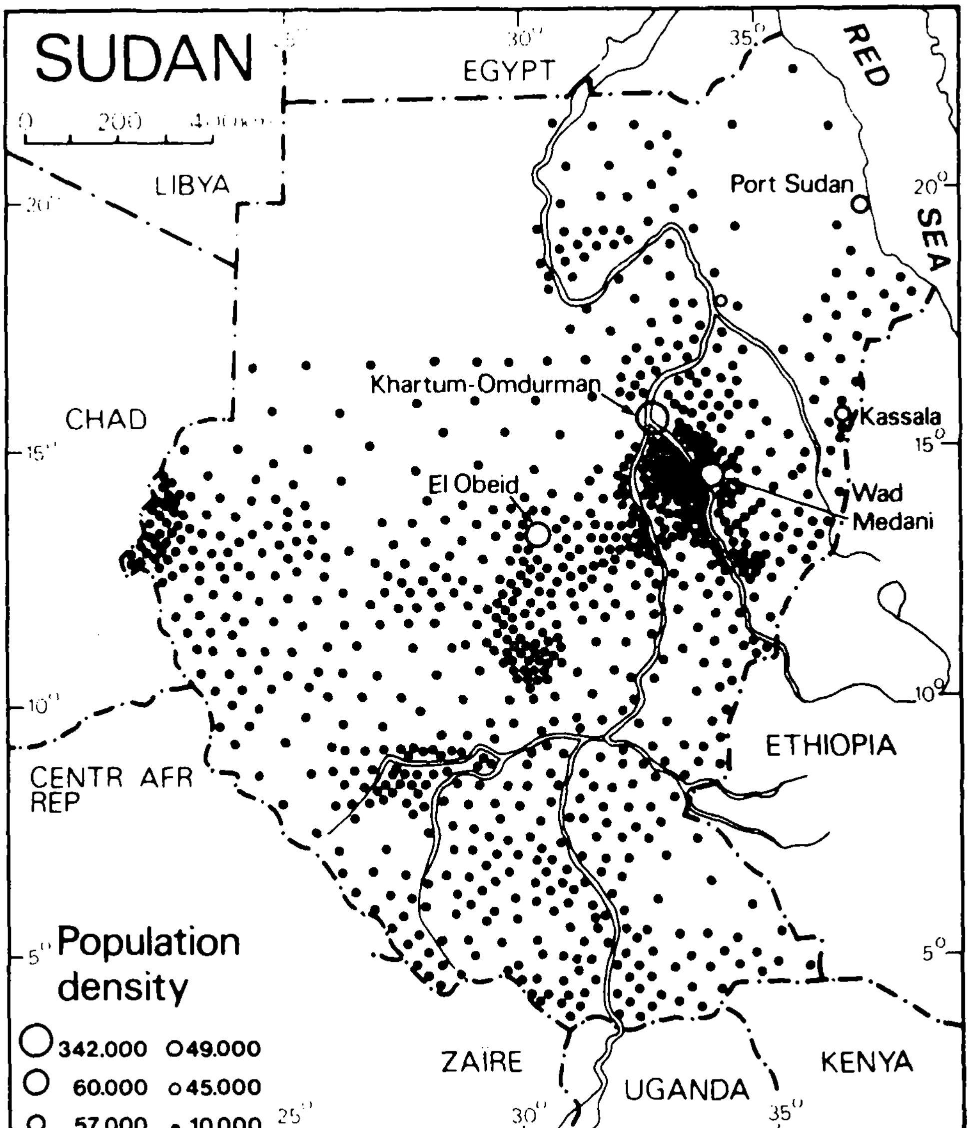
Actual outputs of 5.2 m Ø windmills were 33 m^3/day. Based on this the required diamter would be:

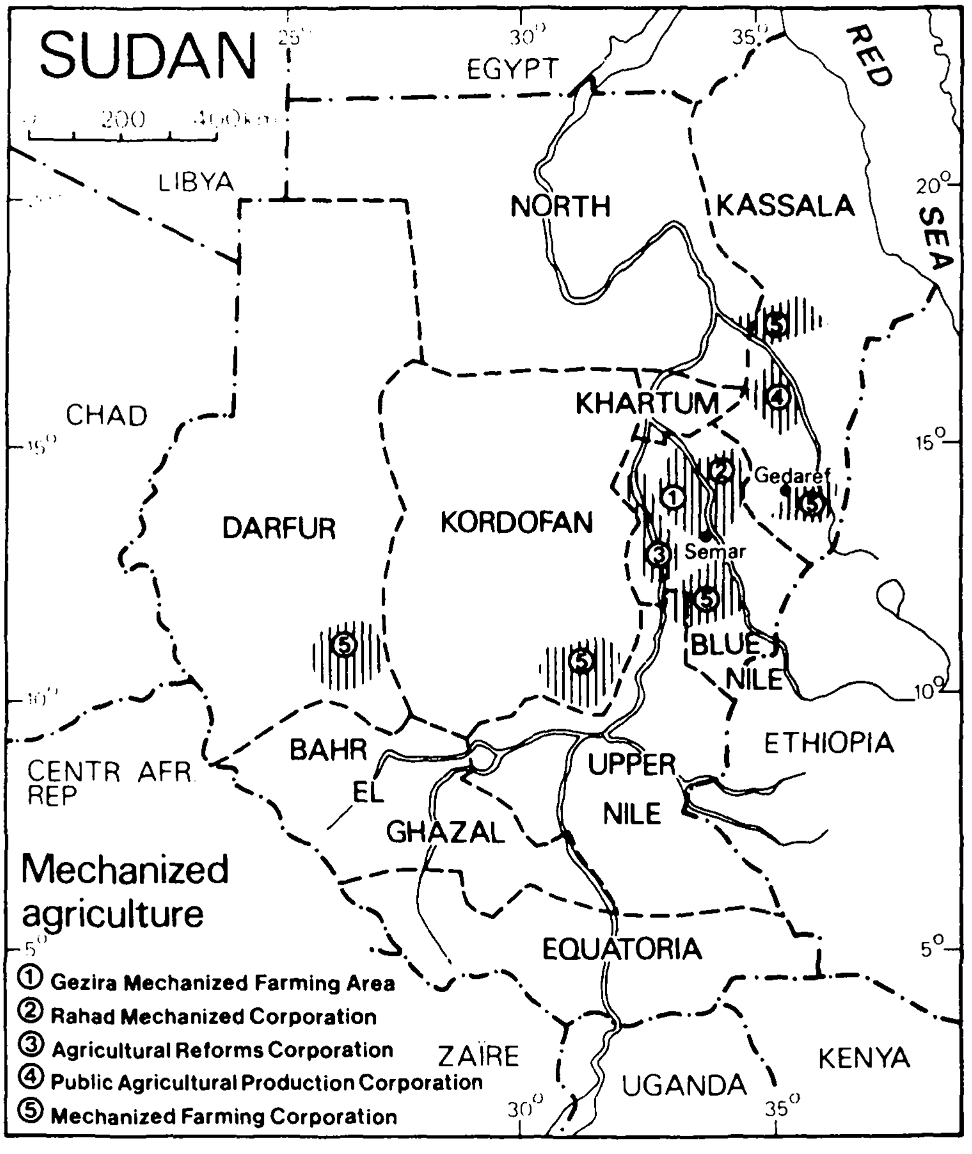
$$D = \sqrt{\frac{75}{33}} * 5.2 = 7.8 \text{ m}$$

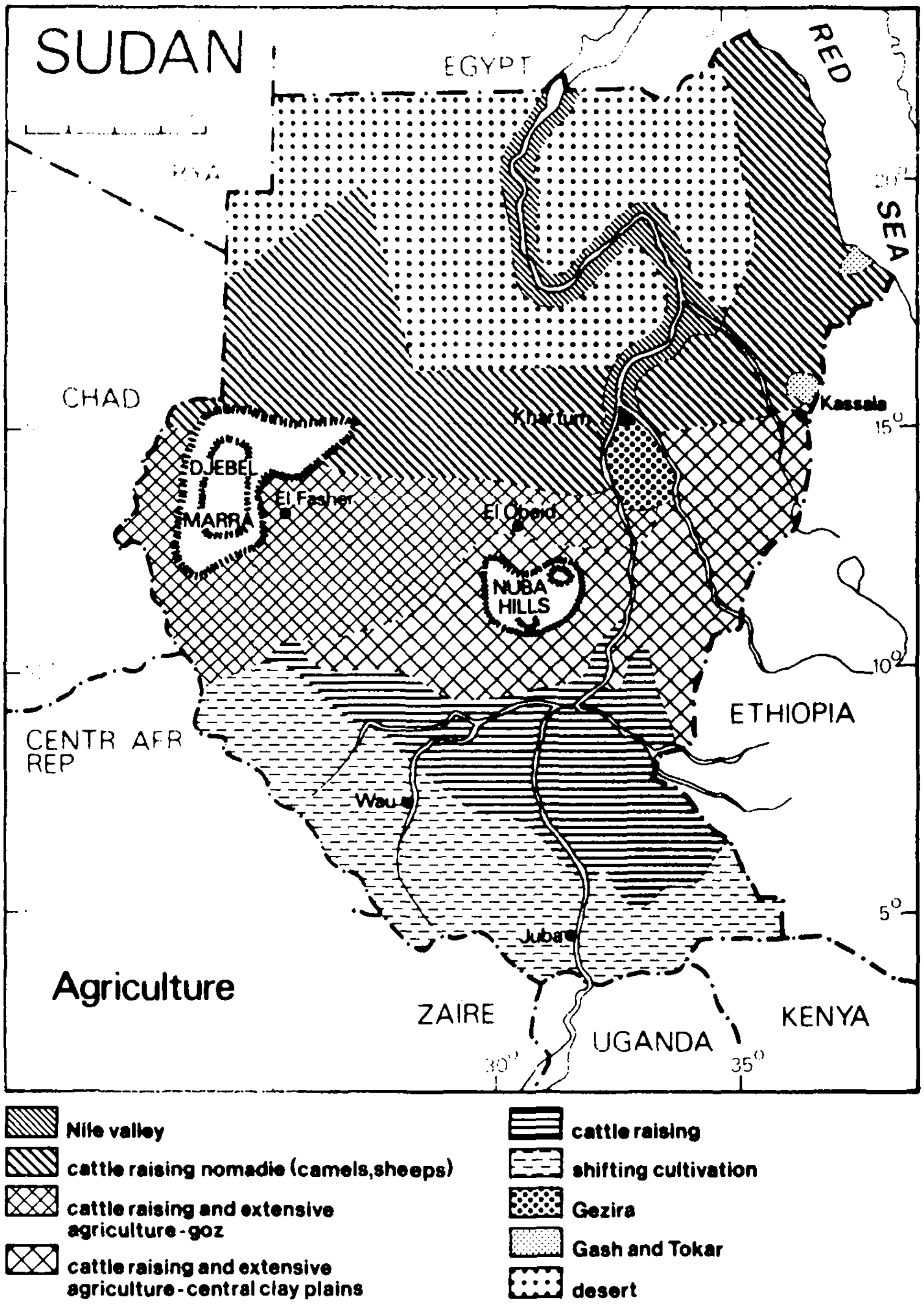
Such a windmill would supply 75 m^3/day on average. In October the average daily output would be 37 m^3/day.

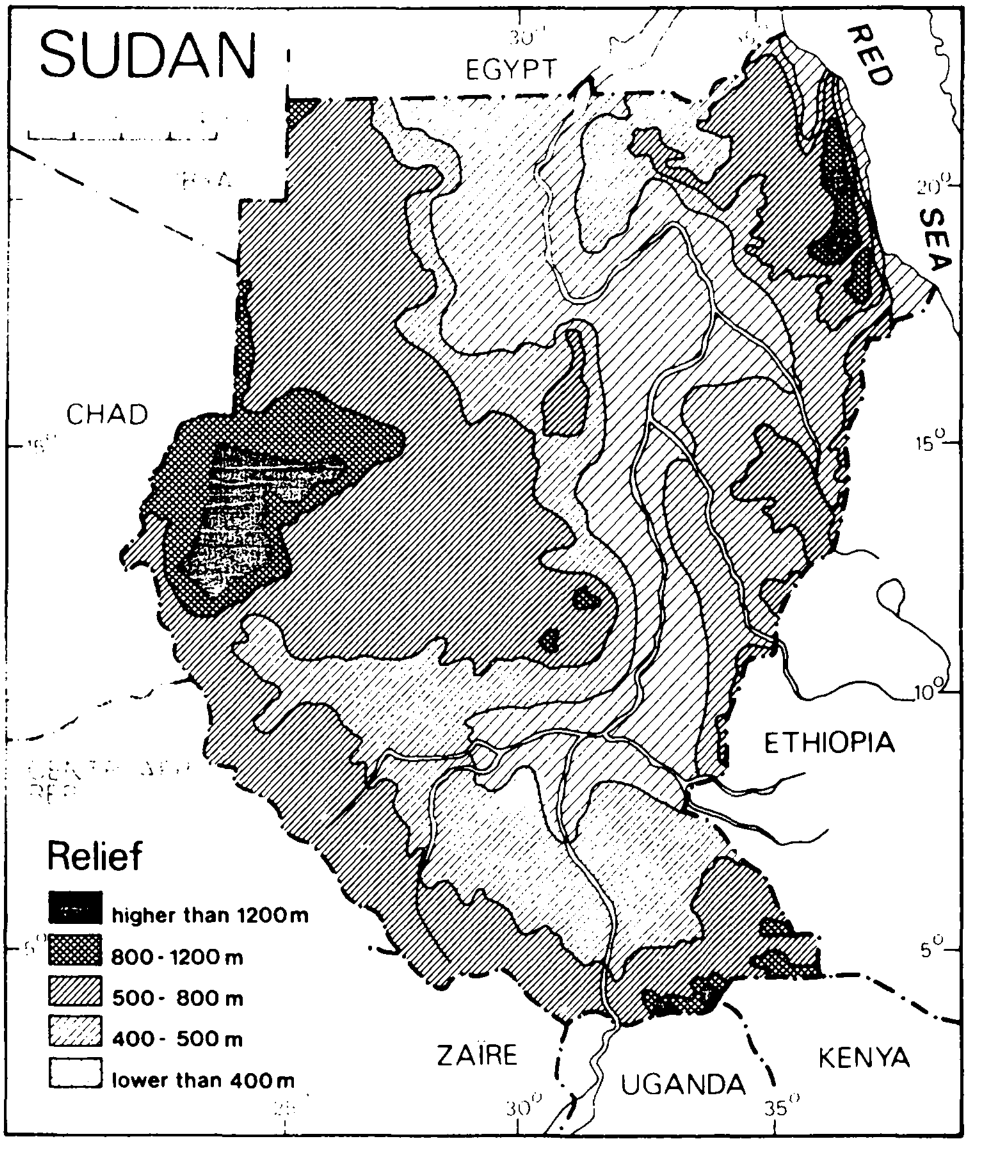

SUDAN
EGYPT
LIBYA
RED
SEA
CHAD
CENTR AFR REP
ETHIOPIA
ZAÏRE
UGANDA
KENYA
Rainfall in mm
25
100
200
400
600
800
1000
1200
1400
1600
>2000
20°
15°
10°
5°
30°
35°


SUDAN
0 200 400km
EGYPT
LIBYA
RED SEA
CHAD
Khartum
Kassala
El Fasher
El Obeid
ETHIOPIA
CENTR AFR REP
Wau
Juba
ZAIRE
UGANDA
KENYA
Vegetation
desert
semi desert
dry savanne
humid savanne
marshy lands
mountain vegetation


SUDAN
EGYPT
LIBYA
CHAD
CENTR AFR REP
ZAIRE
UGANDA
KENYA
ETHIOPIA
RED SEA
Port Sudan
Khartum-Omdurman
Kassala
El Obeid
Wad Medani
Population density
342.000
49.000
60.000
45.000
57.000
10.000


SUDAN
200
EGYPT
LIBYA
NORTH
KASSALA
RED
SEA
CHAD
KHARTUM
Gedaref
DARFUR
KORDOFAN
Semar
BLUE
NILE
ETHIOPIA
BAHR
EL
GHAZAL
CENTR AFR REP
UPPER
NILE
EQUATORIA
ZAIRE
UGANDA
KENYA
Mechanized agriculture
① Gezira Mechanized Farming Area
② Rahad Mechanized Corporation
③ Agricultural Reforms Corporation
④ Public Agricultural Production Corporation
⑤ Mechanized Farming Corporation


SUDAN
EGYPT
RED
SEA
CHAD
DJEBEL
MARRA
El Fasher
El Obeid
Khartum
Kassala
NUBA
HILLS
ETHIOPIA
CENTR AFR
REP
Wau
Juba
Agriculture
ZAIRE
UGANDA
KENYA
15°
10°
5°
35°
Nile valley
cattle raising nomadie (camels,sheeps)
cattle raising and extensive
agriculture - goz
cattle raising and extensive
agriculture - central clay plains
cattle raising
shifting cultivation
Gezira
Gash and Tokar
desert


SUDAN
EGYPT
RED
SEA
CHAD
ETHIOPIA
ZAIRE
UGANDA
KENYA
20°
15°
10°
5°
30°
35°
Relief
higher than 1200m
800 - 1200 m
500 - 800 m
400 - 500 m
lower than 400m

ANNEX 7

PRICES OF PUMPING EQUIPMENT

Rotos Deepwell Pumps	3"	4"
Capacity (GPH)	10,000	15,000
Price (£s)	3,000	4,000
Yanmar diesel engine (HP)	16	23
Price (£s)	2,000	2,500
Installation cost (£s)	300	300
Centrifugal Pumps	3"	4"
Chinese Pumps	120	150
KSB (£s)	300	400

- 2" centrifugal pump with 4 HP "Peter engine" (diesel) costs £s 1,545
- 3" centrifugal pump with 6 HP "Lister engine" (diesel) costs £s 2,665
- 4" centrifugal pump with "Lister engine" (2 piston-diesel) costs £s 5,065
- 4" centrifugal pump with "Peter engine" (single piston) costs £s 3,392

ANNEX 8

MATERIAL PRICES KHARTOUM (MARCH 1980)
(1 £s = 1.25 US $)

- Steel sheets in several sizes and thicknesses:
  large quantities £s 600/ton
  small quantities £s 650/ton
- Bright mild steel shaft
  2¼" dia £s 160/6m
  2½" dia £s 187/6m
  1¼" dia £s 42/6m
  1½" dia £s 80/6m
- Self aligning single row plummer block type ball bearings RHP (British)
  1 No 50 mm dia £s 15.015
  1 No 60 mm dia £s 13.385
  1 No 65 mm dia £s 29.595
  These and many other sizes available ex stock. Inch-sizes and for example hanger bearing units can be ordered.
- Galvanised sheets 120 * 240 cm
  Gauge 22 1 No £s 13.90
  Gauge 18 1 No £s 7.50
- Galvanised pipes
  1" dia £s 11/6m
  2" dia £s 24/6m
  3" dia £s 47/6m
  4" dia £s 75/6m
- I-beam 120 * 50 mm £s 25/6m
- Angle iron 404003 £s 8/6m
  505005 £s 17/6m
- Mild steel $\frac{5''}{8}$ dia £s 7.25/6m
- 10 Nos bolts $\frac{3''}{8}$ * 2" £s 1.00
- PVC pipe thin wall
  100 mm dia £s 18/4m
  110 mm dia £s 20/4m
  1 No T joint 100 * 100 mm 9 £s
- Cement pipe 4" dia £s 6.00/m
- One bag cement £s 7.50

ANNEX 9

COST ESTIMATE FOR 7 M DIAMETER WINDMILL TO BE MANUFACTURED IN THE SUDAN.

Considerations:

- Early 1979 a light weight, locally manufactured 5 m Ø windmill cost in Sri Lanka US $ 900.-
- Steel prices in Sudan (1980) are 60% higher than steel prices were in Sri Lanka in 1979
- It is foreseen that in Sudan the maintenance and repair problems will be greater than in Sri Lanka.
  Therefore designs for Sudan should be more reliable and this is estimated to cost 25% extra.
- The cost will rise with less than the square of the diameter.
  Therefore a 7 m Ø windmill will be maximally twice as costly as a 5 m Ø windmill.

On this basis the cost of a 7 m diameter windmill will be calculated:

- 5 m Ø Sri Lanka	:	US $ 900.-	
- factor for material cost	:	1.6	x
- factor for stronger design	:	1.25	x
- factor for increase in size	:	2	x
7 m Ø Sudan	:	US $ 3600.-	
1 US $ ≅ £s 0.8	:	0.8	x
7 m Ø Sudan	:	£s 2880.-	
Installation	:	£s 100.-	+
Total	:	£s 2990.-	

Rounded off, the cost for a 7 m diameter wndmill is expected to cost a maximum of £s 3,000.-.

ANNEX 9.1

Cost of irrigation water pumped with a windmill

- Output of the 7 m diameter windmill is based on a yearly average windspeed of 4.3 m/s and is calculated as in para 2.4.2. The average pumping rate (if pumping head is 10 m) will be 3 l/s.
- Because it is expected that only 75 percent of the output can be considered "useful", the total useful yearly pumped volume will be V = 73,000 m^3/year.
- A storage tank of approximately one average daily output will be required. Storage volume is 260 m^3. The cost of this storage is expected to be £s 3,000.- (groundlevel storage tank).
- Operation, maintenance and repairs are assumed to cost £s 150.- per year (= 5% of the windmill investment).

With following "present-value" model we can evaluate the cost per unit volume of the water during the first year.

$$I + \sum_{n=1}^{N} O \left(\frac{1 + p}{1 + i} \right)^n = \sum_{n=1}^{N} V \times C \left(\frac{1 + p}{1 + i} \right)^n$$

I = initial investment
N = lifetime
O = operation, maintenance and repairs per year
V = useful output per year (m^3)
C = cost of water per m^3
p = price increase rate
i = interest rate
n = index for year
n = index for year 1 to N

With I = £s 6,000
N = 10 years
O = £s 150 year at present value
V = 73,000 m^3/year
p = 6%
i = 9%
the cost C of the irrigation water pumped by the windmill is £s 0.012/m^3 at present value.
(During the nth year the cost C will be £s 0.012 x $(1 + 0.06)^n$).

ANNEX 9.2

Cost of irrigation water pumped with a diesel pumpset

- A 16 HP Yanmar diesel engine with 3" Rotos deepwell pump costs including installation £s 5,300.-
- The expected lifetime is 7 years
- Fuel to lift energy efficiency = 10%
- Fuel energy content = 10 kWhr/liter
- amount of water pumped per year V = 73,000 m^3
- Net lift energy = 7.3×10^9 J/year
  = 2,028 kWhr
- Fuel consumption 2,028 liters/year
- Operation, maintenance, repairs £s 530.-/year
- Fuel costs £s 0.167/liter = £s 338.-/year

With following present value model we can evaluate the cost per unit volume of water during the first year:

$$I + \sum_{n=1}^{N} O \left(\frac{1+p}{1+i} \right)^n + \sum_{n=1}^{N} F \left(\frac{1+p}{1+i} \right)^n = \sum_{n=1}^{N} V \times C \left(\frac{1+p}{1+i} \right)^n$$

Apart from the third term, the model is the same as the one in annex 9.1 with: F = yearly fuel cost at present value.
With I = £s 5,300
N = 7 years
O = £s 530 /year
V = 73,000 m^3/year
p = 6%
i = 9%
F = £s 329 /year
the cost C of the irrigation water pumped with the diesel pumpset is 0.023 £s/m^3.
In case a centrifugal pump can be used instead of a deepwell pump, the investment cost would be £s 2,600 while operation and maintenance cost might go down to £s 300 a year. Other variables remaining the same, the cost per m^3 water would then be £s 0.014/m^3.
The diesel pumpset, pumping 73,000 m^3 a year, is utilized on average only 4.5 hours a day (10,000 galls/hr). One could argue that the same installation can pump twice as much. Supposing that only the fuel cost doubles and that other variables (investment, interest, maintenance etc.) remain the same, the cost per m^3 water from the diesel-centrifugal pump combination would then be £s 0.010/m^3.
It is highly doubtful whether this system, pumping on average 9 hrs a day, will last for 7 years.

ANNEX 9.3

Cost of water for domestic water supply pumped with a windmill

- Drinking water supply requires a rather constant supply throughout the year. Every day a specific minimum demand has to be met. Therefore the windmill system will be designed for maximum output during the month with the lowest wind speed. Annes 2 gives an average windspeed of 3.1 m/s for Khartoum in October.
- In most drinking water problems the water source is a tubewell with the waterlevel, for example, at 30 m below groundlevel.
- The water is to be pumped into overhead tanks 10 m above groundlevel.
- Windmill output (7 m dia) in October will be 25 m^3 a day. In all other month the output will be higher with a maximum of 50 m^3/day in March. Average daily supply throughout the year is 45 m^3.
- For the cost analysis the windmill will be credited with a useful output of 25 m^3/day. The volume per year is then 9125 m^3.
- The required storage is three times the minimum daily demand = 75 m^3. Storage cost is assumed to be £s 8,000 (steel tank 10 m above ground).
- Investment cost of the windmill is £s 3,000. Lifetime is 10 years. Operation maintenance and repairs is £s 150 a year (5% of investment).
- Total investment (windmill + storage) = £s 11,000.
- Interest rate is 9%; price increase rate is 6%.

With I = £s 11,000
N = 10 years
O = £s 150/year
V = 9,125 m^3/year
p = 6%
i = 9%
the cost C per m^3 water is £s 0,16 per m^3. (Calculation model annex 9.1).

ANNEX 9.4

Cost of water for domestic water supply pumped with diesel pumpset

- Investment cost of pumpset (diesel engine + deepwell pump) is £s 5300
- Daily pumped volume is 25 m^3/day
- Required overhead storage is 25 m^3 costing £ 3,000
- Operation plus maintenance is £s 530/year (10% of diesel pumpset investment cost)
- Lifetime is 7 years
- Yearly pumped volume V = 9,125 m^3
- Fuel comsumption £s 127/year

With I = £s 8,300
N = 7 years
V = 9,125 m^3/year
O = £s 530/year
p = 6%
i = 9%
F = £s 127/year
the cost C per m^3 water is £s 0.22/m^3. (Calculation model see annex 9.2).

ANNEX 10.1

Job and profile descriptions for the required expatriate staff

Job description expert no.1 (windenergy)

- assisting the senior engineer
- training of senior engineer as and when required
- training of designs engineer
- training of technician in processing, analysis and evaluation of wind data and test results
- the expert will together with the senior engineer:
  - evaluate the progress and review the planning of the project
  - write three monthly progress reports
  - organize the logistics
  - communicate (by mail) with SWD in The Netherlands so as to enable SWD to provide the necessary backstopping
  - have regular meetings with the Director of the Energy Instituе to discuss progress and difficulties encountered
  - prepare, if required, proposals for continuation of the project and of the cooperation with SWD

Profile description expert no. 1

- experience with windmill design and testing
- broad knowledge of windenergy technology
- organizational capabilities and initiative
- MSc degree of a University of Technology
- thorough knowledge of the English language in speaking, reading and writing
- basic knowledge of the Arabic language is recommended

ANNEX 10.2

Job description expert no.2 (windenergy)

- training of production engineer and workshop technician in windmill construction and installation work
- assist the workshop engineer in work planning
- assist the designs engineer as and when required
- assist expert no.1 as and when required

Profile description expert no.2

- experience with windmill constrution and installation work
- BSc degree Mechanical Engineering
- practical attitude
- good knowledge of English and basic knowledge of Arabic

ANNEX 10.3

Job description expert no.3 (agriculture)

- training of counterpart
- studying the possibilities and constraints of small scale irrigation with windmills in the Sudan

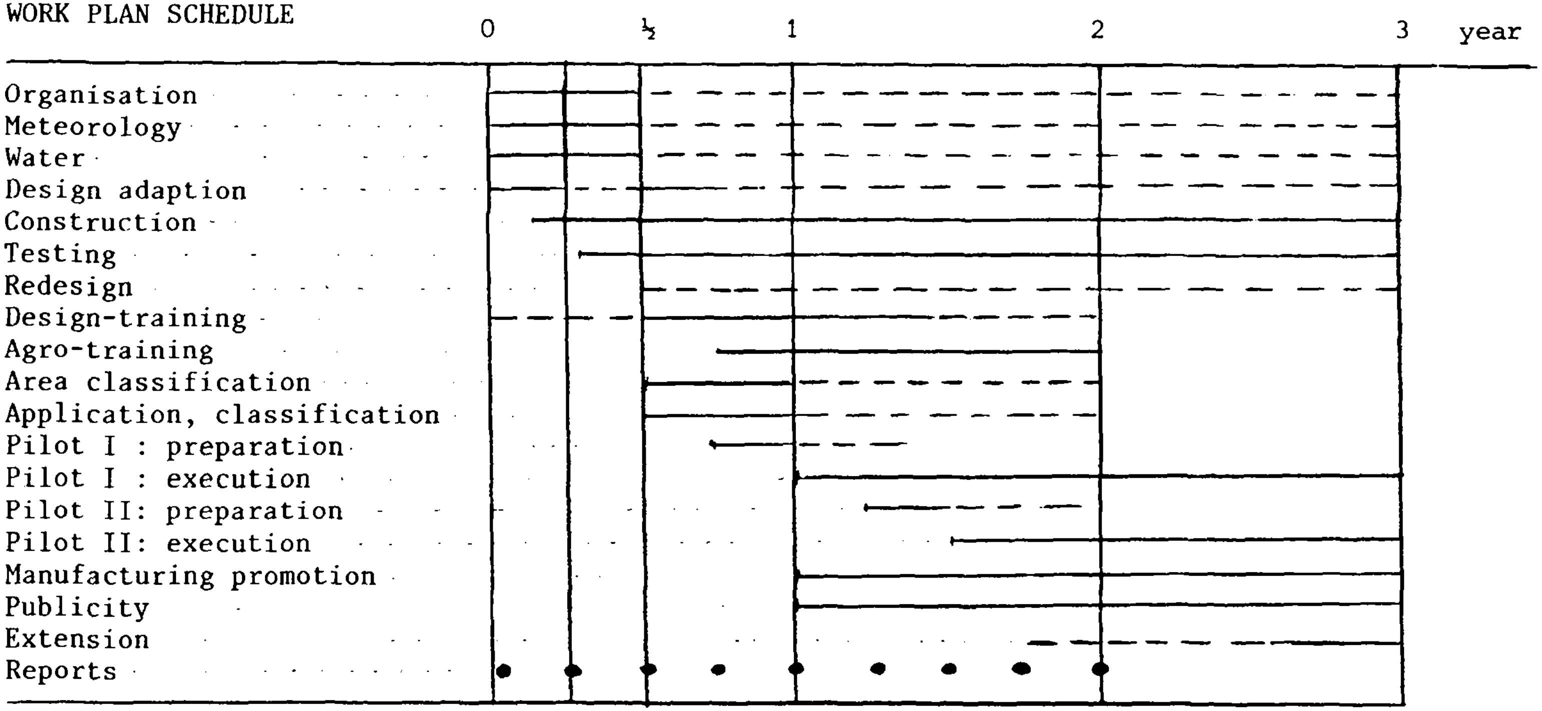
Together with the counterpart, he will:

- select pilot project sites
- design the irrigation system
- select suitable cropping patterns
- monitor the results
- write reports on agro-economic evaluations of the pilot projects
- improve the base for cost comparisons as presented in this report
- take over the "team-leader" functions of expert no.1 when the latter leaves the project

Profile description expert no.3

- MSc degree of a university of agriculture
- good knowledge of small scale irrigation
- good knowledge of agro-economic analysis
- organizational capabilities and initiative
- thorough knowledge of the English language in speaking, reading and writing
- basic knowledge of the Arabic language

WIND ENERGY PROJECT SUDAN
WORK PLAN SCHEDULE



ANNEX 11

SWD PUBLICATIONS

Serial number		Price (incl. mail) US $	Dfl
SWD 76-2	Literature survey; horizontal axis fast running windturbines for developing countries. By W.A.M. Jansen, 43 p., March 1976	3,–	6,–
SWD 76-3	Horizontal axis fast running windturbines for developing countries. By W.A.M. Jansen, 91 p., June 1976	7,–	14,–
SWD 76-4	L'énergie éolienne au Cabo Verde, une étude préparatoire des besoins et des possibilités de l'utilisation de l'énergie éolienne. Par J.C. van Doorn et L.M.M. Paulissen, 54 p., Août 1976	3,–	6,–
SWD 77-1	Rotor design for horizontal axis windmills. By W.A.M. Jansen and P.T. Smulders, 52 p., May 1977	4,–	8,–
SWD 77-2	Cost comparison of windmill and engine pumps. By L. Marchesini and S.F. Postma, 49 p., December 1978	4,–	8,–
SWD 77-3	Static and dynamic loadings on the tower of a windmill. By E.C. Klaver, 39 p., August 1977	4,–	8,–
SWD 77-4	Construction manual for a Cretan windmill. By N. van de Ven, 59 p., October 1977	5,–	10,–
SWD 77-5	Performance characteristics of some sail- and steel-bladed windrotors. By Th. A.H. Dekker, 60 p., December 1977	5,–	10,–
SWD 78-1	Feasibility-study of windmills for water supply in Mara Region, Tanzania. By H.J.M. Beurskens, 89 p., March 1978	7,–	14,–
SWD 78-2	Savoniusrotors for waterpumping. By E.H. Lysen, H.G. Bos and E.H. Cordes, 42 p., June 1978	4,–	8,–
SWD 78-3	Matching of wind rotors to low power electrical generators. By H.J. Hengeveld, E.H. Lysen and L.M.M. Paulissen, 85 p., December 1978	7,–	14,–
SWD 79-1	Catalogue of windmachines By L.E.R. van der Stelt and R. Wanders, 41 p., September 1979	4,–	8,–
SWD 80-1	Conception des pales des éoliennes à axe horizontal. (French version of SWD 77-1) Par W.A.M. Jansen et P.T. Smulders, 52 p., Décembre 1980	4,–	8,–
SWD 81-1	Windmills for water pumping in Cape Verde By H.J.M. Beurskens, 150 p., February 1981	10,–	20,–
SWD 81-2	Wind energy in Sudan. By Dr. Yahia H. Hamid and W.A.M. Jansen, 75 p., July 1980	6,–	12,–
SWD 81-3	Energia eólica para bombagem de água em Cabo Verde (versao portuguesa de SWD 81-1). Por H.J.M. Beurskens, 150 p., Fevereiro de 1981	10,–	20,–
SWD 81-4	Aspects of irrigation with windmills. By A.E.M. van Vilsteren, 100 p., January 1981	8,–	16,–

SWD 82-1	Introduction to wind energy (basics + advanced). By E.H. Lysen, 220 p., January 1982	15,–	30,–
SWD 82-2	The economics of small-scale irrigation with windmills in Sri Lanka By J.A.C. Vel and L.R. Veldhuizen, 120 p., October 1981	9,–	18,–

Research institutes in third world countries may ask for one copy free of charge max. 3 titles, writing directly to:

SWD,
c/o DHV Consulting Engineers,
P.O. Box 85,
3800 AB Amersfoort, The Netherlands

SWD publications can only be ordered by letter to SWD c/o DHV Consulting Engineers, P.O. Box 85, 3800 AB Amersfoort, The Netherlands

With a) your address in printing characters
b) requested titles

Payment: by cheque enclosed with your letter, or by remittance directly to DHV Consulting Engineers with Bank Mees en Hope, P.O. Box 293, 1000 AG Amsterdam, The Netherlands, acc. nr. 25.00.72.009 stating your name and address.

SWD STEERING COMMITTEE WIND ENERGY DEVELOPING COUNTRIES

A brief introduction to the Netherlands programme for assistance to developing countries in the utilization of wind energy.

February 1982

The basis for a sound economic development of many countries in the Third World is the development of agriculture. The so-called oil crisis in 1973 once again stressed the vital role of energy in this development process and thus caused a world-wide revival of the interest in the utilization of renewable energy sources. In the Netherlands wind energy still appeals to many people and in 1974 a study was made to analyse the possibilities of utilizing wind energy in developing countries. It came out that in many countries wind energy could play an important role to satisfy the energy need for water pumping, particulary for irrigation purposes.

In July 1975 the Steering Committee Wind Energy Developing Countries (SWD) was establised by the Netherlands' Minister for Development Co-operation. SWD promotes the interest for wind energy in developing countries and aims at helping governments, institutions and private parties in the Third World with their efforts to utilize wind energy.

The SWD pursues this aim in three ways:

1. assistance to wind energy projects in developing countries
2. wind energy research, mainly undertaken in the Netherlands
3. transfer of knowledge on wind energy use.

The parties that currently participate in SWD are:

Eindhoven University of technology (Wind Energy Group)
Twente University of Technology (Windmill Group)
DHV Consulting Engineers.

Each participant has its own, more or less well defined, field of research and the co-ordination is in the hands of DHV Consulting Engineers.

In the field of agriculture SWD closely collaborates with the Institute of Land Reclamation and Improvement (ILRI)

SWD has regular contacts with the Working Group on Development Technology (WOT) at Twente University.

The installation of a ⌀ 5 m windmill in Colombo, Sri Lanka; at the background the ⌀ 3 m WEU-I windmill.

RESEARCH ACTIVITIES

The research activities are undertaken with the following purposes:

- to develop windmill components as well as complete prototypes
- to support the country projects
- *to train future experts for country projects*

Rotors

A large number of rotors have been designed and tested, both at open air test stands and in a large windtunnel. Good results have been achieved with horizontal axis curved metal plate rotors, as predicted by theory. For low Reynolds numbers (< 100,000) curved plate profiles turn out to be better than airfoils.

Designing with higher tip speed ratios (λ>1) results in lighter rotors and thus lighter and cheaper windmills.

Pumps

The optimum matching of a pump to the quadratic torque-speed characteristic of a wind rotor has been pursued by the development of variable torque reciprocating pumps and the application of centrifugal pumps. This optimum matching results in much higher overall outputs than with the traditional (constant torque) piston pumps. The closing of valves and the operation of air chambers has been analyzed.

Generators

For deep wells electrically driven pumps are considered as a serious alternative to direct mechanically driven pumps. Two types of generators have been tested to drive these pumps:

- a self excited induction generator
- an induction generator equipped with a permanent magnet rotor

Also two control systems for alternators have been developed.

Safety Systems

A reliable safety system has been developed and tested for wind speeds up to 30 m/s. The system operates by means of a small auxiliary vane that pushes the rotor out of the wind against the normal directional vane that is hinged on a leaning axis.

A complete theoretical model is being studied.

Wind measurement

An electrical counter with extremely low energy consumption was developed for contact-anemometers.

Theory

Of the following subjects theoretical models have been developed or refined:

- rotor performance
- forces on rotor blades
- output in different wind regimes
- matching of rotor with generator or pump
- dynamic behaviour of pumps

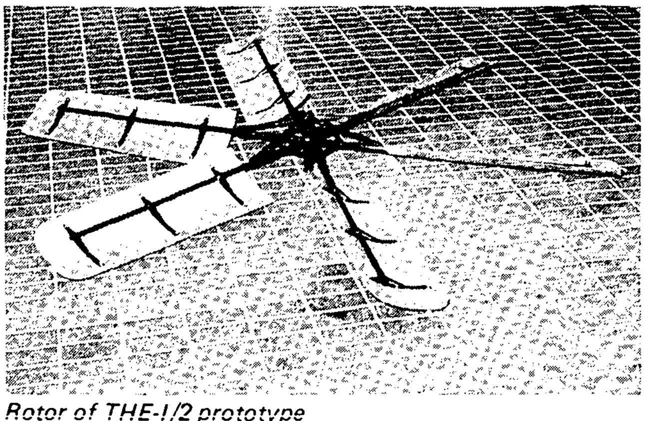
Windmill prototypes

The following prototypes have been developed:

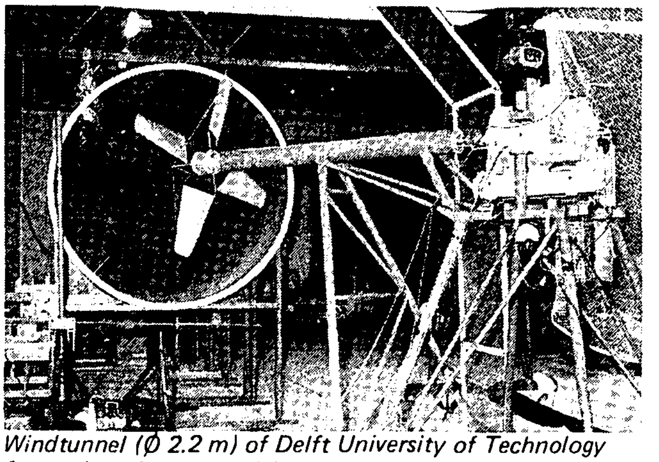
	diameter	number of blades	tip speed ratio	pump
THE-I/1	2.7 m	4	2.5	membrane
THE-I/2	2.7 m	6	2	piston
THT-I	4 m	8	2	piston
TNO-I	5 m	4	5	centrifugal
WEU-I/3	3 m	6	2	piston
* Cretan	6 m	8	1	piston
**WEU-II/1	5 m	12	2	piston
WEU-II/4	5 m	8	2	piston
Under development are:				
THE II	5 m	8	2	piston
THT II	8 m	2	8	electrical centrifugal

* developed by WOT with financial aid from SWD

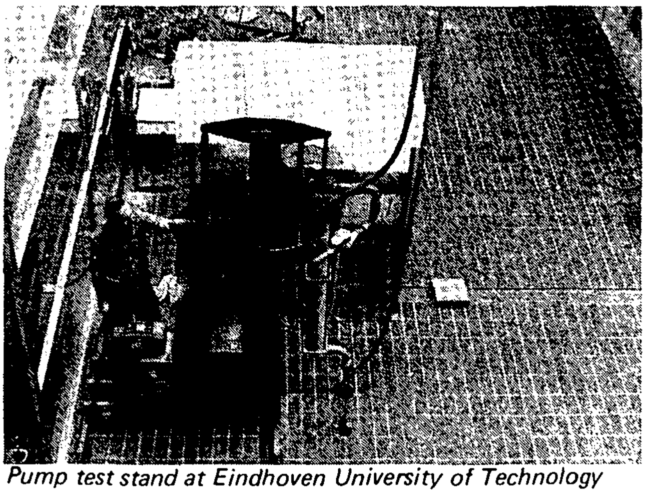
** developed by WOT



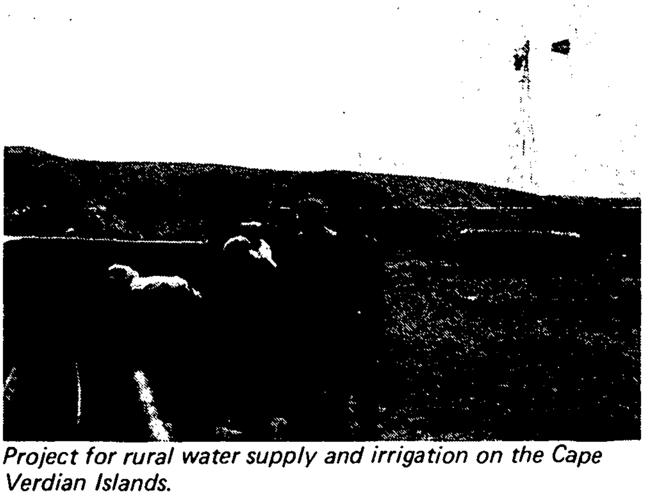
Rotor of THE-I/2 prototype



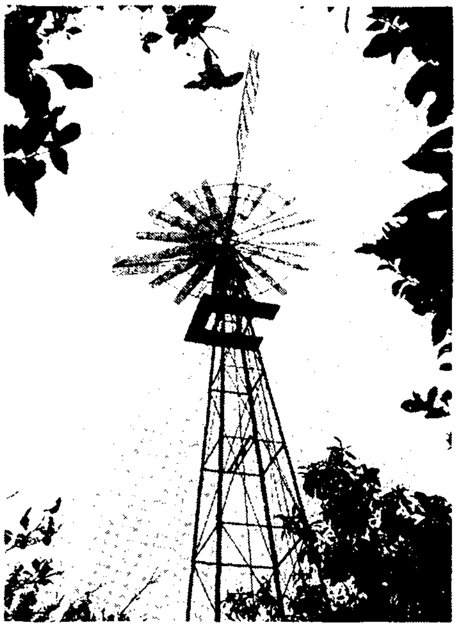
Windtunnel (Ø 2.2 m) of Delft University of Technology for testing of rotor models.



Pump test stand at Eindhoven University of Technology



Project for rural water supply and irrigation on the Cape Verdian Islands.



Prototype THT-I installed in Hammamet, Tunisia, irrigating an orchard.

WEU - I prototype irrigating in Sri Lanka.

Explaining the particulars of windmill testing at the Asian Institute of Technology Bangkok

COUNTRY PROJECTS

SWD gives assistance in the execution of wind energy programmes in close co-operation with interested ministries, institutions or private parties. The country projects encompass assistance in a number of fields:
- measurement and analysis of wind data
- selection of favourable areas
- selection and construction of prototype windmills
- training and education in the field of wind energy
- selection of application purposes
- organisation of pilot projects

The guiding principles for the country projects are:
- water pumping has the highest priority
- local production of as many components as possible
- construction methods and materials must be appropriate to the local technical level.

SWD is involved in projects in the following countries:

Sri Lanka
In March 1977 the Wind Energy Utilization Project was started with financial support from the governments of Sri Lanka and the Netherlands. The execution is in the hands of the Wind Energy Unit of the Water Resources Board. The project is staffed by Sri Lankan engineers, technicians, workers, and two SWD experts (wind engineering and agriculture). In 1981 50 WEU-I prototypes have been installed in pilot projects and private farms.

Republic of Cape Verde
Since 1981 SWD supplies two wind experts in a large renewable energy project with emphasis on wind power, executed by the Ministry of Rural Development.

Pakistan
Stimulating contacts with Merin Ltd. in Karachi led to SWD's consultancy to start series production of windmills. The WEU-I prototype developed in Sri Lanka has been selected and in 1980 a SWD expert paid a three-month visit for technical assistance.

Tanzania
The Ujuzi Leo Industries in Arusha has been supported in improving their windmill design via a two-month course in the Netherlands and an expert visit in 1981.

Tunesia
In support of the ASDEAR (Association pour le développement et l'animation rurale) SWD supervised in 1980 the construction of three THT-I prototypes as a start of a series production by a local entrepreneur.

Peru
As a part of an agricultural project, set up by the Netherlands Ministry of Development Cooperation, a THE I/2 prototype has been built. Since 1981 technical backstopping to a Dutch expert in a bilateral university cooperation programme is given.

Feasibility Studies
SWD has carried out feasibility studies on the use of wind energy in the following countries or areas:
Sri Lanka (1976), Cape Verde (1980), Tanzania (1977), the Sahel (1976), Djibouti (for GTZ, 1981), Yemen Arab Republic (1980), Sudan (1980), Maldives (for ADB, 1980).

TRANSFER OF KNOWLEDGE

Knowledge in wind energy technology and related fields is transferred by SWD to developing countries by:
- publications (see back page)
- drawings and construction manuals of prototypes
- visits and consultancies
- education and training

SWD also functions as a clearing-house for information and experience with wind energy systems: the experience with the WEU I/3 windmill in Sri Lanka has been transferred rapidly to Pakistan for example.

Another facet is the supply of experts for lecturing purposes such as for the six-month U.N. ESCAP Roving Seminar on Rural Energy Development in 1977. Summer 1980 and 1981 SWD has sent an expert to the Asian Institute of Technology, Bangkok, to give introductory and advanced courses on wind energy and to supervise MSc students.

PUBLICATIONS

		Price (incl. mail) US $	Dfl
SWD 76-2	Literature survey; horizontal axis fast running windturbines for developing countries. By W.A.M. Jansen, 43 p., March 1976	3.–	6.–
SWD 76-3	Horizontal axis fast running windturbines for developing countries. By W.A.M. Jansen, 91 p., June 1976	7.–	14.–
SWD 76-4	L'énergie éolienne au Cabo Verde, une étude préparatoire des besoins et des possibilités de l'utilisation de l'énergie éolienne. Par J.C. van Doorn et L.M.M. Paulissen, 54 p., Août 1976.	3.–	6.–
SWD 77-1	Rotor design for horizontal axis windmills. By W.A.M. Jansen and P.T. Smulders, 52 p., May 1977	4.–	8.–
SWD 77-2	Cost comparison of windmill and engine pumps. By L. Marchesini and S.F. Postma, 49 p., December 1978	4.–	8.–
SWD 77-3	Static and dynamic loadings on the tower of a windmill. By E.C. Klaver, 39 p., August 1977	4.–	8.–
SWD 77-4	Construction manual for a Cretan Windmill. By N. van de Ven, 59 p., October 1977	5.–	10.–
SWD 77-5	Performance characteristics of some sail- and steel-bladed windrotors. By Th.A.H. Dekker, 60 p., December 1977	5.–	10.–
SWD 78-1	Feasibility study of windmills for Water Supply in Mara Region, Tanzania By H.J.M. Beurskens, 89 p., March 1978	7.–	14.–
SWD 78-2	Savoniusrotors for waterpumping. By E.H. Lysen, H.G. Bos and E.H. Cordes, 42 p., June 1978	4.–	8.–
SWD 78-3	Matching of wind rotors to low power electrical generators. By H.J. Hengeveld, E.H. Lysen and L.M.M. Paulissen, 85 p., December 1978	7.–	14.–
SWD 79-1	Catalogue of Windmachines. By L.E.R. van der Stelt, R. Wanders, 41 p., September 1979	4.–	8.–
SWD 80-1	Conception des pales des éoliennes à axe horizontal.(French version of SWD 77-1) Par W.A.M. Jansen et P.T. Smulders, 52 p., Décembre 1980	4.–	8.–
SWD 81-1	Wind energy for water pumping in Cape Verde. By H.J.M. Beurskens, 150 p., February 1981	10.–	20.–
SWD 81-2	Wind energy in Sudan. By Dr. Yahia H. Hamid and W.A.M. Jansen, 75 p., July 1980	6.–	12.–
SWD 81-3	Energia Eólica para bombagem de água em Cabo Verde (versão portuguesa de SWD 81-1). Por H.J.M. Beurskens, 150 p., Fevereiro de 1981	10.–	20.–
SWD 81-4	Aspects of irrigation with windmills. By A.E.M. van Vilsteren, 100 p., January 1981	8.–	16.–
SWD 82-1	Introduction to wind energy (basics + advanced). By E.H. Lysen, 220p., January 1982	15.–	30.–

SWD publications can only be ordered by letter to:
SWD
c/o DHV Consulting Engineers
P.O. Box 85
3800 AB Amersfoort
The Netherlands

with:
a) your address in printing characters
b) requested titles

Payment: by cheque enclosed with your letter, or by remittance directly to DHV Consulting Engineers with Bank Mees en Hope, P.O. Box 293, Amsterdam, The Netherlands.
Acc. nr. 25.00.72.009 stating your name and address.
Research institutes in Third World countries may ask for three publications (one copy each) free of charge.

ADDRESSES

General address SWD:
DHV Consulting Engineers — P.O. Box 85, 3800 AB Amersfoort — The Netherlands, Ph: 033 - 689111/682366

Addresses of the other participants:
Eindhoven University of Technology
Wind Energy Group — Department of Physics, Building W & S, P.O. Box 513, 5600 MB Eindhoven — The Netherlands, Ph: 040 - 472160

Twente University of Technology
Windmill Group — Department of Mechanical Engineering, P.O. Box 217, 7500 AE Enschede — The Netherlands, Ph: 053 - 894098

Address of ILRI:
International Institute for Land Reclamation and Improvement — P.O. Box 45, 6700 AA Wageningen — The Netherlands, Ph: 08370 - 19100

Address of WOT:
Working Group on Development Technology (WOT) — Twente University of Technology, Vrijhof 152, P.O. Box 217, 7500 AE Enschede — The Netherlands, Ph: 053 - 893870